THE HOPI TRIBE

PRELIMINARY SUBMIT
TO REVIEW

Progress Report on The Characteristics of the Little Colorado River Basin Of Northeastern Arizona and Northwestern New Mexico

Statistical and Trend Analyses of the Hydrology, Climatology, Sedimentation, and Geochemistry From Existing Historical Records and Reconstructed Data

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by: Ron Morgan, Water Rights Hydrologist
Hopi Water Resources Program

Bureau of Reclamation
Glen Canyon Environmental Studies
Contract No. 1-FC-40-10560

May, 1995

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Acknowledgements

First of all, I would like to express my appreciation for the patience of my wife, Loretta, in allowing me to spend hundreds of hours at night and on weekends at home reading project-related literature, analyzing data, producing illustrations, and typing the text. In addition, Loretta has assisted me in proof reading, data management, and producing CAD illustrations for this manuscript.

Next, I would like to acknowledge the assistance and encouragement of Nat Nutongla, Director of the Water Resources Program; Rose Polivema, Administrative Assistant of the Water Resources Program; Gayl Honani, former Water Resources Technician; Arnold Taylor, Manager of the Department of Natural Resources; Water Rights Team Members Philip Quotswytewa, Clifton Ami, Robert Makewa, Robert Charley, Owen Numkena; former Tribal Chairman Vernon Maseyesva; present Tribal Chairman Ferrell Secakuku; and the the Tribal Council, all of the Hopi Tribe.

No project of this magnitude can be accomplished without collaborators. The firm of D. B. Stephens is assisting in the production of missing data from computer modeling of surface water flows and sediment discharges, under the understanding and kindly direction of Joanne Hilton, and the able and competent technical execution of hydrologists Robert Marley and Neil Blandford; their interim report is appended to this volume. Providing technical consultation to their effort is Dr. Timothy Ward, of New Mexico State University. Management of the firm is provided by Dr. Daniel B. Stephens.

Notes on Computer Resources and Techniques

The mathematical, statistical, and graphical analyses of available data for the sparsely collected but voluminous data set for the Little Colorado River Basin hydrology, geology, and climatology requires extensive computational power to analyze, digest, assemble, and publish. The activities of the Hopi Tribe Water Resources Program Staff and the contracted consultant, D. B. Stephens and Associates have utilized numerous computer programs on high-end personal computers.

The hardware requirements have been met by Intel 80486 class personal computers running at 33 Mhz with significant core memory and mass storage capacity, HP Laserjet class printers, various digitizers, and HP plotters. The programs and data sets presently occupy over 400 Mb of mass storage capacity, and the extended memory programs require as much as 16 Mb of internal memory.

Statistical analyses have been conducted with StatGraphics, Version 7, Jandel TableCurve for Windows, Lotus 1-2-3, version 2.4, and Cohort Software CoStat. Geostatistics by kriging are performed by the public domain EPA Geoeas program and Golden Software Surfer. Trilinear plots, Piper diagrams, and graphical well logs are produced by the modular RockWare program. Log Pearson Type III analyses are performed by Haestead Methods HECWRC program.

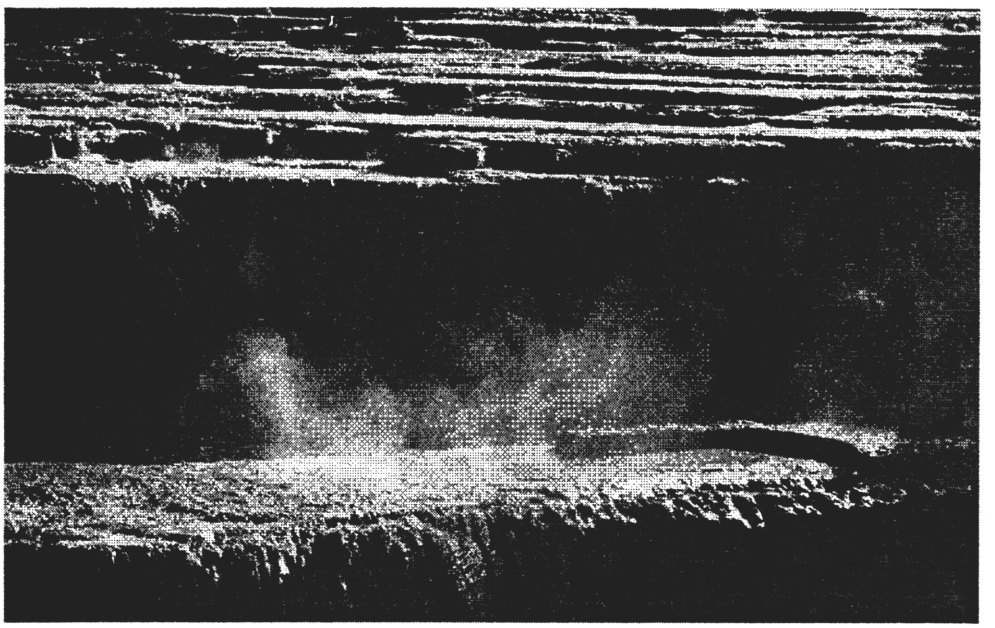
Presentation and publication-quality graphics are produced primarily by Lotus International Freelance Graphics for DOS and Statgraphics. Conversions between graphics file formats for inclusion into the document processor are provided by Inset Systems Hijaak, Version 2. Scientific graphics are produced by StatGraphics, Axum Graphics for DOS, Version 2, CoHort CoPlot, and Jandel SigmaPlot.

Database management is provided by dBASE IV, version 2, Lotus 1-2-3, version 2.4, and Borland Reflex. D. B. Stephens is presently contracted to generate an integrated water resources, geological, and climatological database in dBASE IV, which can be utilized by various Geographical Information Systems, spreadsheet, statistical, hydrological, and geological programs for input data sets.

Geographical Information Systems requirements are met by use of Atlas GIS and Rockware to produce maps of spatially distributed data. The mapping and attribute data can be exported from these programs to the widely used ArcInfo format.

Magellan GPS units are in use to locate unsurveyed data locations and verify previously surveyed locations.

Document processing in structured MILSPEC outline format is accomplished utilizing Lotus Manuscript.



Frontispiece

Grand Falls on the Little Colorado River, Arizona

Executive Summary

The previously missing discharge records of the Little Colorado River near Cameron and the Little Colorado River at Grand Falls gages have been reconstructed by statistical modeling. The discharges at Blue Spring have been reconstructed. The reconstruction of these flow records enables the evaluation of discharge and water quality information within that portion of the lower Little Colorado River environment which has been designated as critical habitat of the endangered fish species, the humpback chub.

The precipitation records for 55 Little Colorado River Basin and adjacent areas climate stations have been reconstructed and statistically analyzed. These records enable a characterization of climate for the WY 1939-90 study period. The climate is best described as an arid mediterranean climate, with a mean precipitation of approximately 12 inches.

The sediment transport mechanism has been extensively analyzed. It has been determined that the origin of the sediment in the lower Little Colorado River is in the Puerco River drainage and the northern washes which flow through the Hopi and Navajo Indian Reservations. It is not certain that sediment is a necessary ingredient to endangered species management, but the transport of sand to the main stem Colorado River by the Little Colorado River may assist in the replenishmentof eroding beaches in the Grand Canyon.

It has been determined that the critical flow essential to the survival of the humpback chub is the base flow discharge from Blue Spring.

It has been suggested that the temperature variations in the lower Little Colorado River may trigger the reproductive cycle of the humpback chub. Water supply developments on the southern snowmelt-fed tributaries may modify these temperature fluctuations and negatively impact the propogation of the humpback chub.

It is probable that the use of piscides in the 1950's at Lyman reservoir and the introduction of predator fish, such as rainbow trout, in the southern LCR tributaries have depleted the numbers of Little Colorado spinedace. Prohibition of predator species plantings and reintroduction of spinedace from a captive breeding program may be required to repopulate the species in its critical habitat areas.

Accordingly, it is estimated that a modest additional diversion of water to beneficial use by the human inhabitants of the Little Colorado River Basin from the northern LCR tributaries may be tolerated without disruption of the life cycle of endangered species, depending upon the location of the point of diversion.

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Characteristics of the Little Colorado River Basin

by Ron Morgan, Water Rights Hydrologist,
Water Resources Program, The Hopi Tribe

1 Introduction

The Little Colorado River Basin consists of the 27,760 square mile drainage area of the intermittent stream, the Little Colorado River. Within this area, the Hopi Tribe has resided since at least 900 A. D., when the village of Oraibi was established. The Navajo Tribe began to arrive from Canada in the early 1500's. Spanish settlements in the area were minimal, limited largely to missions and trading centers. A larger influx of Anglo-American cattlemen, railroad workers, and traders began to populate the region in the latter half of the 19th century. The meager rainfall of the region, along with wells dug into shallow, perched aquifers were sufficient to sustain the slowly growing population. Increasing demand for water in Southern California led to the construction of a series of dams on the lower Colorado River in the 1920's and 1930's. The demand for electrical power and water in the southern Arizona area led to the implementation of the Central Arizona Project and Glen Canyon Dam in the 1960's. The retention of suspended sediments and bed load in the Colorado River by Glen Canyon Dam has coincided with the depletion of beaches in Grand Canyon National Park along the Colorado River and the reduction in the numbers of native Colorado River fish species.

It is important to note that the dams on the Colorado River primarily serve the water and electrical power supply demands of the Anglo-American population in Phoenix, the Los Angeles metropolitan area, and Las Vegas. Only limited supplies of power and water are provided to native American populations within the Little Colorado River Basin by these massive public works and natural resources developments.

Approximately 70,000 members of the Hopi, Navajo, and San Juan Southern Paiute tribes reside within the Little Colorado River Basin. An additional 100,000 non-Indian people inhabit that region, in communities such as Gallup, NM, and Flagstaff, Winslow, Holbrook, St Johns, and Springerville, AZ. The primary sources of water -- for drinking, agriculture, and industry -- are the fossil waters of the deep groundwater basins recharged principally by widely varied precipitation. It was once considered that the groundwater basins were an inexhaustible source of water. However, declining groundwater levels indicate that the aquifers are a finite resource. The only renewable source of water in the vicinity is the intermittent Little Colorado River and its tributaries. Already, significant stream depletions are induced by the several small dams on the main stem of the river and several of its tributaries. Further water supply developments could reduce the Little Colorado to a trickle.

Central to the future of the Little Colorado River is the General Stream Adjudication now before the Arizona Supreme Court to quantify water rights claimed by various Indian and non-Indian parties. As a part of the settlement negotiations in the adjudication process, significant water supply development projects have been proposed: groundwater withdrawals, stream diversions, surface water reservoirs, import of water from Lake Powell, and even additional out-of-basin transfers. Any and all of these proposals will impact the water supply and quality at the mouth of the Little Colorado. Although several technical studies dealing with water resources in the Little Colorado River Basin have commenced

or have been completed as a part of the adjudication, these documents are considered confidential by the parties involved until the case is litigated or settled.

Several remnant native Colorado River fish species inhabit the lower reaches of the Little Colorado River: the humpback chub and the spinedace. The last 18km of the river have been designated as critical habitat by U.S. Fish and Wildlife (1993). The requirement of maintaining adequate flow of water, sediment, and dissolved minerals in that habitat may preclude the implementation of new water supply projects on the river system.

It is apparent that neither the environmental nor the water supply interests are served by the lack of hydrologic information in the public domain. Accordingly, the present study contracted by the Glen Canyon Environmental Studies Group through the Hopi Tribe will serve to derive from the historical data record sufficient interpretive information to characterize the flows, water quality, climate, and water use/demand parameters apart from confidential information produced by federal and private legal/technical experts as a component of the adjudication evidentiary record.

It is the purpose of this study to provide sufficient data and analytical information to enable an ovjective debate on the competing environmental and demographic demands for the water supplies of the Little Colorado River Basin.

2 Project Scope of Work

The project scope of work is defined by the terms of Cooperative Agreement No. 1-FC-40-10560 entitled "Cooperative Agreement for Hopi Tribe with the Glen Canyon Environmental Studies and the Glen Canyon Environmental Impact Statement." This agreement, executed in FY1991 by the Hopi Tribe and the U.S. Bureau of Reclamation, sets out goals and objectives, a work program, and a schedule of deliverables for studies involving Hopi cultural interests in the Grand Canyon and the Little Colorado River Basin, as well as hydrologic studies related to Hopi and other interests in the Glen Canyon EIS and the Little Colorado River General Stream Adjudication. This document discusses exclusively the results of the hydrologic study portion of that contract.

Excerpts from Cooperative Agreement No. 1-FC-40-10560, Program Narrative:

"COOPERATIVE AGREEMENT NO. 1-FC-40-10560
FOR HOPI TRIBE COORDINATION WITH THE GLEN CANYON ENVIRONMENTAL STUDIES
AND THE GLEN CANYON DAM ENVIRONMENTAL IMPACT STATEMENT

PROGRAM NARRATIVE

"1. BACKGROUND. The Bureau of Reclamation (Reclamation) manages the operations of Glen Canyon Dam and the releases of water for the Colorado River through the Grand Canyon. The Glen Canyon Environmental Studies (GCES) were initiated by the Department of the Interior (Department) on December 6, 1982, with the directive to scientifically quantify the impacts to the resources of the Grand Canyon caused by the operations of Glen Canyon Dam and to determine if the means existed, within the existing Colorado River water law, to minimize the defined impacts. The first phase of the GCES program was completed in 1988, and resulted in a directive from the Department for additional scientific and technical work. On July 27, 1989, the Secretary of the Interior directed that the Glen Canyon Dam Environmental Impact Statement (GCDEIS) be initiated.

"Under the initial phase of the GCES program the specific areas of study included sediment transport, aquatic biology, endangered fish studies, and recreation. No specific work was associated with the cultural resources of the Grand Canyon. The GCES is designed to support the technical requirements of the GCDEIS, and to provide the technical data base required for analysis of the EIS alternatives. A large portion of the GCES Phase II work effort includes the study of the cultural resource impacts in the Grand Canyon. A large portion of the study area includes resources of the Hopi Tribe.

"The Hopi Tribe concerns also include the impacts of operations as associated with the endangered fish in the mainstem Colorado River and in the Little Colorado River (LCR). The endangered fish issues are also included in the GCES program under the umbrella of the conservation measures being completed under the requirements of the Glen Canyon Dam Biological Opinion effort. The concerns of the Hopi Tribe include not only the endangered fish, but also any potential impacts on the water resources of the LCR.

"The Hopi Tribe is a full cooperating member of the GCDEIS, and as such participates on the GCDEIS Cooperating Committee and the GCDEIS Writing Team.

"The work identified in this Agreement is designed to allow the Hopi Tribe to fully participate in all GCES and GCDEIS activities, and to provide both groups with their expertise and concerns as related to the operation of Glen Canyon Dam. The GCES Flagstaff Office will coordinate all of the technical activities with the Hopi Tribe and provide support in their activities with the GCDEIS group.

"2. OBJECTIVES. The objectives of this Agreement are to: ...

"(e) Assist the GCES in identification of significant hydrologic and environmental concerns associated with the endangered fish and environmental studies in the LCR and the mainstem Colorado River.

"3. AUTHORIZATION. The GCES were authorized by the Department in a letter dated December 6, 1982. The Department, through a directive by the Secretary, directed the initiation of the GCDEIS on July 27, 1989.

"The Hopi Tribe has been granted cooperator status on the GCDEIS and was asked, by a September 17, 1990, letter, to formalize their input through this Agreement.

"4. OVERVIEW. This Agreement *will* establish the mechanism for Reclamation to provide funds to the Hopi Tribe to complete the objectives stated above. The expected results from this work effort will be utilized by the GCES researchers in the development and analysis of the cultural resource and endangered species data. In addition, the input of the Hopi Tribe will ensure that the GCDEIS include the concerns of importance to the Hopi Tribe.

"The information *will* be collected, collated, and developed as input to the individual study efforts. A copy of all Hopi Tribe technical recommendations for the GCES work effort *will* be retained at the GCES office in Flagstaff, Arizona. Additional copies of selected information, as required by the other GCES researchers, will be provided by the GCES office.

"The results from this work will be of benefit to the GCES Phase II Integrated Scientific Program and the GCDEIS effort.

"5. GENERAL AGREEMENT RESPONSIBILITIES.

"5.1 Bureau of Reclamation Responsibilities. Under this Agreement, Reclamation *will* provide the primary funding, overall study , objectives, necessary coordination of the other GCES study documents, and utilization of the results in the GCES Phase II program reports and technical recommendations.

"The primary coordination of this Agreement will be through the GCES Program Manager and the GCES Field Station Office in Flagstaff, Arizona. Overall coordination will include assistance in the acquisition of required information, budget assistance, defining product due dates, coordination of review protocol, providing the developed information to the other interested researchers, and integration of the results into the GCES technical reports and cultural resource activities.

"Additional responsibilities of Reclamation include: ...

"(c) Provide information and guidance on the development of a computerized data base that *will* interface with the GCES program data bases, and with the GCES Geographic Information System being developed for the long-term monitoring program for the Grand Canyon.

"(d) Provide a technical review, through the GCES Office, for the review and utilization of the technical information generated from the work efforts.

"(e) Provide staff support in the development of the data bases necessary for integration of the GCES related information.

"(f) Provide office support for two Hopi representatives in the GCES Flagtaff Office. The space will be provided within the existing GCES office.

"5.2 Hopi Tribe Responsibilities. Under this Agreement, the Hopi Tribe will provide the primary technical expertise and guidance on the review of the GCES archaeological program activities in the areas of Hopi Tribe concerns. In addition, the Hopi Tribe will provide technical expertise on the hydrological issues in the LCR basin as related to the GCES endangered species studies. Specifically, the Hopi Tribe responsibilities include: ...

"(f) Development of procedural review to prevent conflict between the GCES results and results being done in support of the LCR water rights adjudication by the U.S. Department of Justice and Hopi Tribe experts.

"(g) Review work plans, spot check field work, and review draft and final reports to prevent conflicts described in points a through f.

"The Hopi Tribe will work primarily through the Cultural Preservation Office, the Department of Natural Resources, and through the Water Resources Program. The complete Hopi Tribe study plan is enclosed in this Agreement as Enclosure No. 1.

"7. STUDY APPROACH. The approach that will be used in this study will include literature review, field survey, technical guidance and development of specific technical and cultural resource recommendations. A large amount of effort will be required in the coordination and collation of the information from tribal, State, and Federal sources. ...

"The Hopi Tribe water rights specialist will work with the GCES office to ensure that any potential conflicts with the current adjudication efforts on the LCR and the GCES program can be avoided. The Hopi Tribal water rights specialist will also assist the GCES in identification of specific water quality and quantity studies that may be required on the LCR to support the endangered species studies."

"Proposal for Involvement of the Hopi Tribe in GCES Projects in the Colorado River Corridor and Little Colorado River

"Introduction

"The Colorado and Little Colorado Rivers have long been important to the Hopi Tribe. Today, much of the length of both drainages is controlled by federal agencies or private landowners; other stretches are within areas of dispute between the Hopi and Navajo. Nevertheless, traditional Hopi uses of and concerns for both areas continue to the present. Hopi concerns regarding the two drainages focus on the protection of cultural resources.

"The Little Colorado River is also important to the Hopi Tribe because of the water rights adjudication of the basin now in progress. Moreover, the portion of the Little Colorado River between Leupp and its junction with the Colorado mainstem is part of the Bennett Freeze Order Area land dispute. Since 1934, restrictions require that construction in this area must be approved by both tribes pending the court decision which will establish jurisdiction. In the past the Navajo have used occupancy and evidence of management plans to establish claim to land, so the Hopi Tribe is particularly sensitive about any arrangements the Navajo Tribe may be currently pursuing along these lines. Any such arrangements require consultation with tribal attorneys for both the land and the water cases and concurrence by the Hopi Tribe. ...

"Hopi concerns for cultural resources in the Grand canyon relate mainly to the adverse affects of erosion and increased visitation on sacred areas. Erosion resulting from dam releases exposes burials to looting and has the potential to destroy ancestral sites and shrines. Visitation of shrines by outsiders, including researchers, constitutes desecration, and any erosion that accompanies such visitation could cause additional physical deterioration of sites. Erosion also affects areas of native plant habitat important to the proper enactment of rituals associated with Hopi cultural sites.

"Little Colorado River

"The LCR has figured prominently in Hopi prehistory and history. The river extends through nearly the entire width of Hopi ancestral lands, and one of the eight aboriginal land markers/shrines is located along its course. A major portion of the sacred Salt Pilgrimage route from third Mesa is located within the LCR. The pilgrimage to Sipapuni and the Salt Caves is conducted following initiation into the highly secret Wuwutsim Society. As noted above, the shrines along the route are very sacred and highly susceptible to desecration by the uninitiated.

"In addition to the Salt Pilgrimage route, a variety of other sacred areas occur in the LCR. These include eagle shrines in the collecting areas along the LCR Gorge, and springs along the LCR. Springs are considered to be gifts from the katchinas, and most continue to be tended and utilized by one or another clan. These curatorial activities are marked by shrines. The LCR is also one of the most important traditional sources of cottonwood root, the material required for carving the katchina dolls used in certain traditional ceremonies.

"The Hopi Tribe wishes to prevent damage and disturbance along the Salt Pilgrimage route and at other shrines and sites along the lower LCR. It is believed that such damage may occur in the context of environmental research activities and there is also concern that the management of water resources for the development of humpback chub habitat may affect the existing natural springs.

"Scope of Hopi Involvement ...

"The following natural resource concerns will be addressed by Hopi involvement in the Glen Canyon Dam EIS and LCR studies:

"1) Development of procedural review to prevent conflict between GCES results and results of work being done in support of the Little Colorado River Water Rights adjudication by USDOJ and Hopi Tribe experts.

"2) Review work plans, spot check field work, and review draft reports to prevent conflicts described above.

"Proposed approaches to be used in addressing these concerns are outlined below. ...

"Natural Resources Oversight and Review

"Because the LCR lies in the Bennett Freeze Order area and IS a part of the adjudication of which the Hopi Tribe is a party, Hopi tribal staff involvement will be designed to prevent and reduce development of conflicting data which could impact legal issues of concern to the Tribe. This will include but not be limited to attendance at meetings, participation in field work, and review of documents.

"The staff hydrologist/litigation specialist will review work plans, and other documents to assist in avoiding areas which could be damaging to the legal position of the Hopi Tribe. Of importance in the cases are any water resources investigations, both quantity and quality; soil studies, cultural and archaeological studies, and biological studies.

"Staff will be available to review cultural and natural resources sections of the EIS and supporting documents. Staff will also assist researchers by identifying and coordinating for information exchange of use in their work.

"MODIFICATION NO. 005
COOPERATIVE AGREEMENT NO. 1-FC-40-10560

"1. TITLE. Cooperative Agreement for Hopi Tribe Coordination with the Glen Canyon Environmental Studies and the Glen Canyon Environmental Impact Statement.

"2. PURPOSE. The purpose of Modification No. 005 is to identify specific work items and dollar values for fiscal year 1994 that the Hopi Tribe will accomplish as related to the Glen Canyon Environmental Studies (GCES), the Glen Canyon Dam Environmental Impact Statement (GCDEIS), the Programmatic Agreement and the Glen Canyon Dam Interim Flow Program. The following specific work objectives will be covered by Modification No. 005: ...

"(f) Coordination of the Hopi Tribe's hydrology concerns into the GCDEIS and the GCES technical programs. This will include the development of the technical water volume, sediment quantity and water quality in the lower Little Colorado River. (Hydrology Office)

"ATTACHMENT 01

"MODIFICATION NO. 005
COOPERATIVE AGREEMENT NO. 1-FC-40-10560

"1. BACKGROUND. The Glen Canyon Environmental Studies (GCES)

"Phase II Integrated Research Plan identified the inclusion of the Native American concerns into the overall study program. The need for this stems from the legal requirements of the National Environmental Policy Act (NEPA), the coordination needs of the Glen Canyon Dam Environmental Impact Statement (GCDEIS), the Programmatic Agreement and the implementation of the Glen Canyon Dam Interim Flow and Long-Term Monitoring programs.

"In 1991 the Bureau of Reclamation (Reclamation) and the Hopi Tribe entered into Cooperative Agreement No. 1FC4010560, entitled Cooperative Agreement for Hopi Tribe Coordination with the Glen Canyon Environmental Studies and the Glen Canyon Environmental Impact Statement as a means to allow for Hopi Tribe involvement in the technical programs. The Agreement focuses on the technical areas of archaeological resource studies, culture resource coordination, ethnography, hydrology, and GCDEIS coordination. The Hopi Tribe is a full cooperating member of the Cooperating Committee directing the overall GCDEIS program.

"The Hopi Tribe has historically used the Grand Canyon and Little Colorado River canyons and water resources. The use has been for spiritual, cultural and habitation. The work identified in Modification No. OO5 reflects the specific work items that the Hopi Tribe will be responsible for during fiscal year 1994. These work items support the technical programs of the GCES, the GCDEIS, and the interim flow and long-term monitoring programs.

"2. OBJECTIVES. The objectives of Modification No. 005 are to support the completion of selected technical studies and the continued coordination of the Hopi Tribe in the development of the GCDEIS product, the Programmatic Agreement and the interim flow monitoring efforts. Six (6) specific objectives have been identified: ...

"(f) Coordination of the Hopi Tribe's hydrology concerns into the GCDEIS and the GCES technical programs. This will include the development of the technical water volumes, sediment quantity and water quality in the lower Little Colorado River. (Hydrology Office)

"3. FUNDING LEVELS. The specific work items identified as necessary to complete the defined objective will be described in Attachment No. 02 to this Modification. For clarity the objectives can be separated into the following work elements:

	"Work Elements	Fiscal Year 1994 Amounts		
		FY 93 Carryover	Total Required	Actual Need
1.	Cultural Preservation	$ 70,000	$461,267	$391,267
3.	Hopi Hydrologist Survey	0	$194,350	$194,350
4.	TOTAL	$ 70,000	$989,444	$585,617

"The figures presented above represent those dollar values available for Modification No. 005. Carryover fiscal year 1993 dollars in the amount of $ 70,000 for the Cultural Preservation Office will be used to provide additional support to the fiscal year 1994 effort and has resulted in a reduced fiscal year 1994 requirement.

"4. STATEMENT OF WORK. The specific work tasks associated with this Modification will be discussed as related to the six study objectives. ...

"4.6 Coordination of the Hopi Tribe's hydrology concerns into the GCDEIS and the GCES technical programs. This will include the development of the technical water volume, sediment quantity, and water quality in the lower Little Colorado River. (Hydrology Office)

"(a) Compile and assess the historical technical information on the hydrology and sediment history of the Little Colorado River.

"(b) Characterize the hydrologic and sedimentologic environment of the portion of the Little Colorado River from Cameron to the mouth. This will include frequency charts and other statistical representations.

"c) Identify the controls on the hydrologic attributes that define the habitat for the endangered fish species and the sediment attributes that control the delivery of sediment to the mainstem Colorado River.

"(d) Develop a hydrologic data base for the Little Colorado River section from Cameron to the mouth of the mainstem which will integrate with the GCES long-term data bases. Provide technical data bases and reports on this project including elements a through d.

"(e) Coordinate the integration of the EPA 106 and other federal, state and privately funded water quality research on the Little Colorado River into the GCES long-term data base.

"5.6 Coordination of the Hopi Tribe's hydrology concerns into the GCDEIS and the GCES technical programs. This will include the development of the technical water volume, sediment quantity and water quality in the lower Little Colorado River. (Hydrology Office)

"(a) Quarterly progress reports

"(b) Annual reports on all pertinent activities

"(c) Final completion report with data for the GCES long-term data base development.

"(d) Consultants report(s) on the LCR data base.

"(e) Report on the location of springs, gages, other water resources, sediment sampling locations, and water quality sampling sites on the Hopi Reservation that are within the Little Colorado River basin.

2.1 Study Area

The general study area for the Little Colorado River Basin Hydrology Report is defined as that area of the states of Arizona and New Mexico which constitutes the drainage area of the Little Colorado River.

Except for several small depressions which have no drainage outlet, the entire basin contributes to the discharge of the Little Colorado River at Blue Spring. Together with this massive groundwater discharge source (the spring), the Little Colorado empties into the main stem Colorado River at the east end of Grand Canyon National Park. It is this combined surface and groundwater discharge within the study area - the quantity, quality, and sediment content - which is the subject matter of this report.

The Little Colorado Basin is some 27,000 square miles in surface area. The elevation ranges from 3,000 to 12,600 feet amsl. The vegetation ranges from desert scrub to mountainous woodlands and even arctic tundra. Sedimentary layers and igneous deposits constitute the bulk of the surficial geology. Violent meteorological events, from heavy winter storms to summer monsoon flash floods, occur with annual regularity. The sparse amount of water precipitated from the usually dry atmosphere runs sinuously through the vegetation and mineral deposits, acquiring its distinctive chemical and sedimentary signature on its way to the Colorado River, and ultimately, the Pacific Ocean.

Each aspect of the natural history of the water supply to the Little Colorado has unique features - climatological, geological, erosional, chemical - and encourages individual analysis in painting the complete picture. For this reason, the present report is arranged into disparate sections in order to build a gradual wholistic perception on the part of the reader for the purpose of illustrating the facets which make up the whole of the subject.

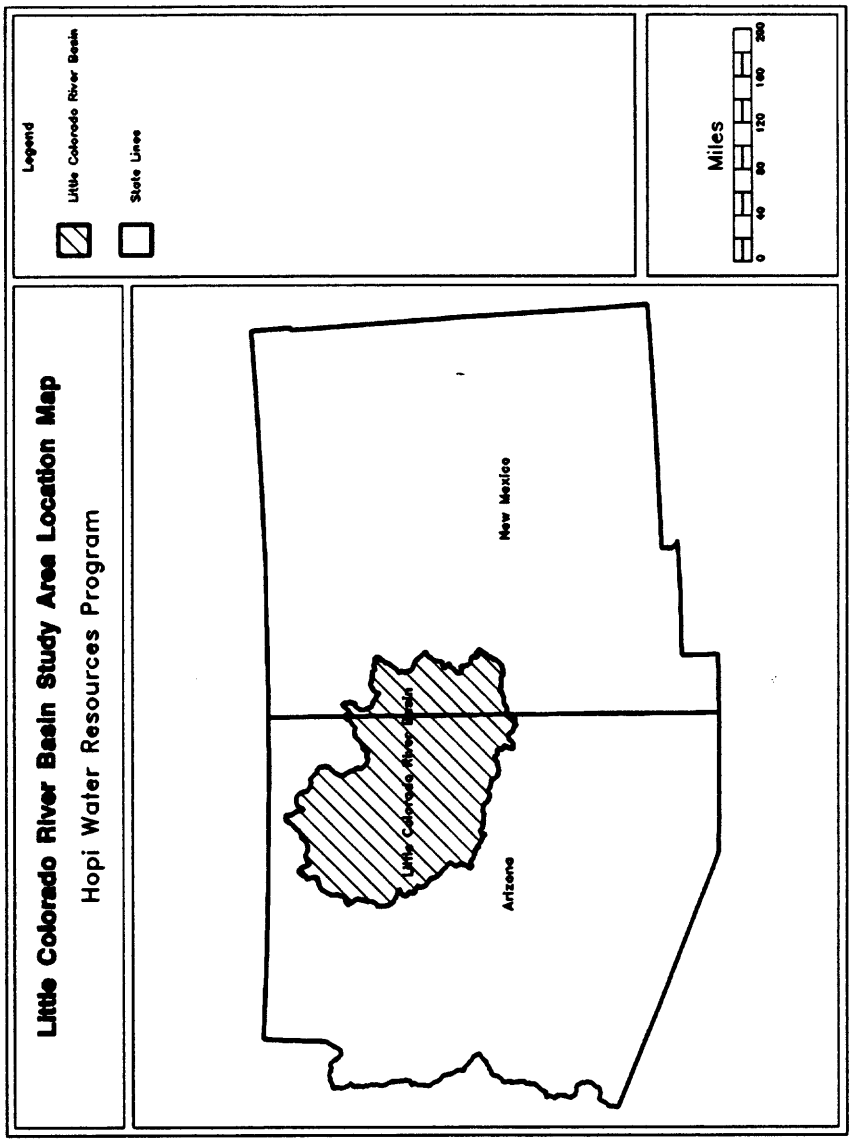


Figure 1. Map of Study Area

3 Basin Geography and Physiography

The Little Colorado River Basin is bounded on the west by the San Francisco volcanic field (San Francisco Mountains or Peaks), on the south by the Mogollon Rim, on the east by the Continental Divide, and on the north by the rim of Black Mesa. The approximate geographic extent is from 111 to 106 degrees west in longitude and from 34 to 36 degrees north in latitude. The 27,000 square mile area lies entirely within the Colorado Plateau Physiographic Province, and lies entirely within northeastern Arizona and northwestern New Mexico.

3.1 Geographic Description of Study Area

3.2 Topography of Study Area

TO BE COMPLETED IN FINAL REPORT, 9/30/95

3.3 Physiography of the Little Colorado River Basin

TO BE COMPLETED IN FINAL REPORT, 9/30/95

4 Environmental Requirements and Human Resources Developments

Any natural ecosystem, such as the Little Colorado River and its basin, contains native species of plants and animals which are adapted to the natural conditions. Among these species are fish, aquatic plants, and migratory birds. The natural environment of the Grand Canyon, known world-wide as a natural wonder, has been seriously altered by the construction and operation of Glen Canyon Dam. The natural water and sediment flows, the water temperature, and physical and chemical water parameters have been affected. The Little Colorado River is essentially a wild and uncontrolled stream, despite several reservoirs located in tributary drainages. The Little Colorado River preserves its original habitat values and provides refuge for species endangered by the interruption of Colorado River flows by Glen Canyon Dam.

The importance of the Little Colorado River to the Glen Canyon Environmental Studies lies in its capability of preserving a remnant of the once widespread Colorado Plateau environment. It may be that the management of endangered species may succeed based upon preserving the Little Colorado River system, and that replenishment of Colorado River beaches within Grand Canyon may still ensue as a result of these preserved flows. On the other hand, the Little Colorado River is an important renewable water supply source which can be utilized for the steadily increasing native American and non-Indian population in the basin. It is realistic to expect that increased political pressures will arise for additional water supply developments to serve a growing population. One of the difficulties to be explored in this investigation is whether the delicate balance of the environment in the LCR Basin can accomodate any major expansion of water use in the area.

It is important to assess the factors in the Little Colorado River for those conditions which are necessary for endangered species survival and continued sediment contribution to the main stem Colorado River. Critical to an understanding of the environmental requirements of endangered species management are preference studies and life cycle studies which determine the chemical and physical environmental factors conducive to preservation of the life cycle of the species. It is also critical to evaluate historical environmental data taken within the hydrological system to determine the sensitive controls which give rise to those environmental requirements of the native species.

A river system is dynamic in that the input of one event into the system has consequences in other parts of the system. The data collected is generally time series data, through which seasonality and trends can be determined. Much of the data collected within the Little Colorado River Basin is sporadic and inconsistent with respect to the periods of record for the data collection points. For this reason, computer modeling must be utilized to reconstruct the missing records from these data points.

Although there are numerous native species of wildlife and plants in the Little Colorado River Basin, this study concentrates upon those species which are totally reliant on Little Colorado River flows for their survival.

The purpose of this portion of the study is to identify sensitive environmental parameters for nurture of endangered species to compare with historical data available for the designated habitat areas of the Little Colorado River Basin. This will lead to an assessment of the compatibility of human consumptive use of LCR Basin water supplies with these environmental requirements.

4.1 Endangered Aquatic Species within the Little Colorado Basin

The following aquatic species have been listed as endangered by the federal government and inhabit the wetlands and stream environments of the Little Colorado River and its tributaries.

4.1.1 Humpback Chub, Gila cypha

The humpback chub was first identified as a distinct species by Robert R. Miller (Miller, 1946) from the collection of fish specimens at Grand Canyon National Park. Evidently, the chub, now called Gila cypha, was misidentified as Gila elegans by investigators prior to that time (1942). One of the distinguishing characteristics of the fish is the large nuchal hump located just behind its head.

Miller states that the humpback chub is "of unusual interest in possessing remarkable adaptations for life in torrential waters.." An examination of the water velocity and the swimming capability of the chub are discussed in detail in subsequent sections of this report.

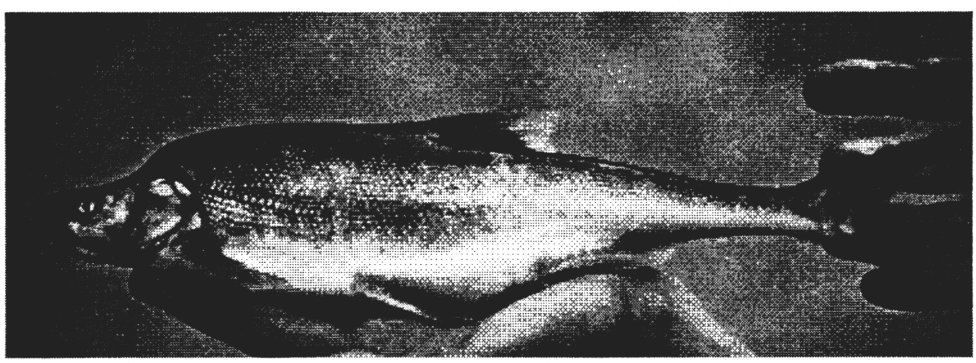


Figure 2. Adult Humpback Chub (Gila cypha)

Although the humpback chub has been recognized as as distinct species only recently, it's ancient existence in the chasm below Hoover Dam has been verified. Miller (1955) reports that unmistakable remains of the Gila cypha were excavated by a group from the University of Arizona Anthropology Department in Catclaw Cave on the east bank of the

Colorado River 15 miles below the dam. Cultural remains deposited with the chub skeleton in the cave were dated from 750 to 1100 A.D. According to Miller (1971) the humpback chub was also found in the 4,000 year old riverine deposits of Stanton's Cave.

The life cycle of the humpback chub begins in May through June of each year when the female begins to show signs of expressible gametes (Kaeding, *et al*, 1990, Fig. 2, p. 138). This event apparently follows shortly after spring snowmelt flows. Spawning occurs from May through July, when the water temperature reaches 16-19° C (Valdez and Clemmer, 1982). A frequency diagram of 1977-78 humpback chub captures, printed in Carothers and Minckley (1981, p. 132), suggests the young fish far outnumber the older members. This factor indicates a relatively high mortality for young of the year. The growth rate of the fry averages about 86 mm in the first year to only 18.6 mm in the ninth year (Carothers and Minkley, 1981, Table 6-8, p. 131). The humpback chub is considered mature when it reaches a length of 250 mm, or about 5 years old (Kaeding, et al, 1990, p.136).

The humpback chub is presumably negatively phototrophic in a portion of its lifetime. For this reason, it is assumed that it requires a significant suspended sediment load at that time (Wegner, 1992). The seasonal load and sediment concentration requirements have not yet been published, however (Yard, M., 1994).

The young appear to ingest midge larvae, biting midge larvae, and long-legged fly larvae. Specimens captured in the main stem Colorado River below Glen Canyon Dam appear to feed on planktonic crustaceans which are discharged from Lake Powell. Adults appear to actively feed on Cladophora as well as organic detritus (Carothers and Minkley, 1981, p. 134).

The humpback chub range minimally within their habitat when compared to other native Colorado River fish, such as the roundtail chub, with which it is frequently confused (Kaeding, *et al*, 1990). According to Valdez and Clemmer (1982), tagged humpback chub rarely range more than 1.6 km from where they are tagged. By comparison, the roundtail chub may range as far as 33.9 km from where they are originally captured (Kaeding, *et al*, 1990). A radio-tagged humpback chub male was observed periodically for 67 days near Black Rock, Colorado by Valdez and Nilson (1982). This fish was released about 2 km upstream of its capture site. After spending 26 days near the release site, it made a two day journey to its capture site, where it settled for the remaining 39 days of monitoring. This incident implies that the humpback chub may have a homing behavior which closely ties an individual to a specific reach of the habitat river.

The humpback chub prefers a habitat of swift, deep flows with a rocky or sandy substrate with quiet water microhabitats (Valdez and Nilson, 1982). Although the fish perform well at velocities of up to 2.2 fps, they are most frequently found in quiet areas where the velocity is near zero. They evidently utilize the placid microhabitats for resting and feeding (Valdez and Nilson, 1982). The ability of the humpback chub to outswim

not only other native Colorado River fish species (Bulkley, et al, 1981, Table 16, p. 232), but also the introduced species, may be a key to its survival. The table is reproduced here for review:

Table 1. Sustained swimming speeds of various species of fish (28-120 mm in length) compared to swimming speeds of juveniles of three rare Colorado River species of fish

Species	Sustained Speeds ft/sec	m/sec	Reference
Colorado River fish			
Humpback chub	2.20	0.66	This study
Colorado squawfish	1.60	0.51	This study
Razorback sucker	1.47	0.45	This study
Bonytail chub	1.90	0.57	This study
Other species (small fish or fingerlings)			
Striped bass (12 cm)	2.75	0.83	Bell 1973
Striped mullet (2.8 cm)	0.70	0.21	Hettler 1977
Atlantic menhaden (6 cm)	0.80	0.24	Hettler 1977
Fathead minnow (5 cm)	0.60	0.18	MacLeod 1967
Largemouth bass fingerlings	0.75	0.23	MacLeod 1967
Rainbow trout (6 cm)	1.77	0.54	Fry and Cox
Emerald shiner (6.5 cm)	1.70	0.52	1970 Jones et al 1974
Other species (adults)			
White suckers	5.20	1.58	Bell 1973
Carp	4.00	1.22	Bell 1973
Whitefish	4.40	1.34	Bell 1973
Brown trout	6.20	1.89	Bell 1973
Coho salmon	10.80	3.29	Bell 1973
Squawfish	3.50	1.06	This study

1/ Sustained speed is that speed which the fish can maintain for a matter of minutes.

2/ Sustained speed at 20 C.

There is an interesting diurnal and nocturnal pattern to humback chub movements. The fish generally occupied river depths of less than 5 m near dawn (0600-0800 hrs) and evening (1700-1800 hrs). At noon and at midnight, they prefer waters deeper than 7 m. This pattern takes the fish between the swiftly-flowing bedrock channel to the submerged cobble terraces and the sandy river banks, and back again, during a 24 hr period. There is an interesting diagram on p. 35 of Valdez and Nilson (1982) which illustrates this pattern of movement.

4.1.1.1 Humpback Chub Critical Habitat Area in the LCR Basin

In Federal Register Vol. 50, No. 54, March 21, 1994, the final rule on the designation of critical habitats for four Colorado River Endangered Fishes was published. That portion of the designation for the humpback chub within the Little Colorado River Basin is described as follows:

"Arizona: Coconino County. The Little Colorado River from river mile 8 in T.32N., R.6.E., section 12 (Salt and Gila River Meridian) to the confluence with the Colorado River in T.32N., R.5.E., section 1 (Salt and Gila River Meridian).

"Known constituent elements include water, physical habitat, and biological environment as required for each particular life stage for each species."

In the following subsections of this report are enumerated several known water quality chemical and physical preferences and tolerances of the humpback chub which would be included in any assessment of environmental impacts on the life cycle of the chub by proposed developments involving water supply within the Little Colorado River Basin. By designating the last eight miles of the LCR, any river reach upstream of the critical habitat would be included in an Environmental Impact Statement for such proposed development.

In designating the critical habitat, U.S. Fish and Wildlife (USF&W) investigated the chub's former range in the main stem Colorado River and its tributaries. USF&W declared 379 miles of river reaches in the designation and estimates that this habitat is 28 percent of the fish's former range. That portion of the critical habitat within the Little Colordo River Basin amounts to the final eight miles of the Little Colorado before its confluence with the main stem Colorado River.

In later sections of this report, and in the conclusion, existing water quality and physical paramenters in the LCR at the Mouth are evaluated for sensitivity to upstream inputs into the hydrologic system.

Due to the ongoing settlement negotiations and trial relative to the Little Colorado River General Stream Adjudication now pending before the Arizona Supreme Court, both the Hopi and Navajo Tribes and the Bureau of Indian Affairs protested this designation on the grounds of unquantified economic impacts on the Tribes, should the chub be found by USF&W to require all the water presently flowing in the Little Colorado River and its tributaries for maintenance of its habitat. The protest is unanswered.

The humpback chub was first listed as an endangered species on March 11, 1967 (32 FR 4001). Critical habitat was not designated at that time, due to the lack of information available on the subject. On December 6, 1991, the USF&W held a meeting in which it concluded that designation of critical habitat for the razorback sucker was prudent and determinable, and that it could designate critical habitat for the Colorado squawfish, the humpback chub, and the bonytail chub as well. UDF&W published the proposed rule to designate critical habitat on January 29, 1993 (68 FR 6578). This led to the publication of the final rule, as cited above.

4.1.1.2 Preference Study

Of particular importance for this report is the consideration of the various hydrologic conditions which could impact the survival potential of the humpback chub. A preference study was published by Bulkley (1981) which discusses the results of an interesting experiment utilizing an isolation chamber to determine the tolerance levels and preferences of the chub to varying temperatures, total dissolved solids, and stream velocities with respect to swimming ability. It is one of the purposes of this report to examine various environmental requirements of endangered species and to relate existing conditions in the Little Colorado River to compare actual LCR conditions to these requirements. Further, it is desirable to identify specific hydrologic controls which affect the sensitive water quality and physical parameters necessary for favorable endangered species management options.

Because the preference study just mentioned is so enlightening as to the environmental requirements of the humpback chub as it relates to water quality and hydraulic conditions, extensive relevant excerpts are quoted from the preference study in the following subsections of this report to enable the reader to understand the experimental conditions and the variability of the results.

In Section 12.3, the means, the variability and seasonality of the sensitive parameters are developed for that portion of the lower LCR which has been designated as critical habitat for the humpback chub.

4.1.1.2.1 Temperature Preference

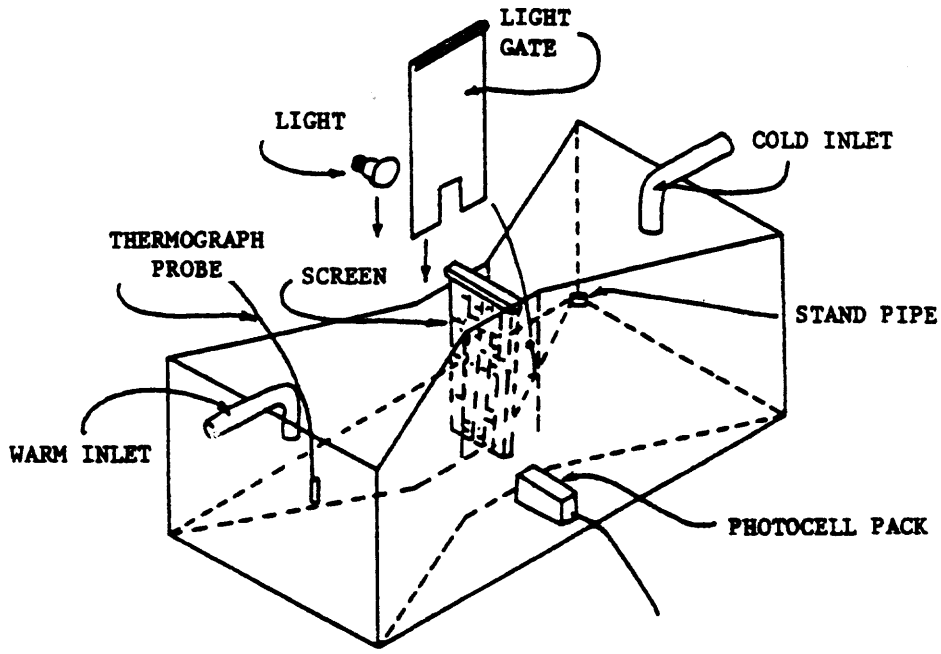
Water temperature is normally taken with every sample of water taken to the laboratory for analysis. For this reason, it is possible to reconstruct the temperature history of the LCR at mouth, given the flow rate of the LCR at Cameron, the flow rate of Blue Spring (approximately at river mile 8), and the seasonal (or monthly) temperatures of the waters.

Evidently, the temperature of the water is related to the tubuculation and spawning of the female chub. Valdez and Clemmer report that when the flow in the Colorado River was unusually low in 1981, tuburculate fish were found at Black Rock as early as April 10, when the temperature of the water was 14.0° C (Valdez and Clemmer, 1982). Normally, the chub spawn in the Little Colordo in May through July, when the water temperature is from 16-19° C.

The temperature preference study by Bulkley (1982) is supportive of field findings, and excerpts from the preference study are reproduced here:

METHOD

"The final temperature preferendum is defined by Fry (1947) as that temperature toward which a fish will finally gravitate regardless of previous thermal history and at which acclimation and preferred temperature are equal. Final preferendum has been generally assumed to be an innate and speciesspecific measure of thenmal behavior (Reynolds and Casterlin 1976, Magnuson and BeitinRer 1978). Final preferendum for razorback suckers acclimated to four temperatures (8°, 14°, 20°, and 26° C) was determined using an electronic shuttle box adapted from Neill et al. (1972). This device is basically a plexiglass chamber in which individual fish were allowed to regulate water temperatures by triggering photocells controlling warm and cold water flow (Figure a). The shuttle box was filled with water from tanks in which the fish were being held and an individual fish was placed in the device. After a 1 hour acclimation period, the photocells were activated and water temperature was recorded (Honeywell Thermographs) for the next 47 hours. The final preferendum during light and dark hours was determined with data from 15-minute intervals of the last 24 hours of testing for 20-23 specimens. The mode, instead of the mean or median, was used to describe the final preferendum of individual fish because it best corresponds to the definition of (modal) preferendum as that temperature occupied most frequently by a fish (Pitt et al. 1976, Richards et al. 1977). In addition to individual modes, a mean of the individual modes, a pooled mode and mean, and Pearson's coefficient of skewness were calculated for day and night for fish of each acclimination temperature. Data were collected in degrees Fahrenheit but were not converted to degrees Centigrade for statistical analysis.



Electronic shuttlebox for thermal preference studies (after Neill et al. 1972)

Figure a. Electronic Shuttlebox

"Because of their small size, humpback, bonytail, and hybrid chubs were unable to operate the shuttle box and no final preferendum could be directly determined. Acute preferendum (measured in the first 3 hours and affected by prior thermal history) was measured for humpback and bonytail chubs acclimated to 14°, 20°, and 26° C and hybrid acclimated to 20° C using a horizontal gradient trough (234 cm x 33 cm). The range of temperature in the gradient was ca. 14-34° C but varied slightly with each fish. The range was maintained by adjusting the flow of hot and cold water at opposite ends of the trough. Temperature probes (YSI tele-thermometer) recorded temperatures in degrees Fahrenheit at 26 cm intervals along the trough bottom. The device was supplied with aeration by five air stones 40 cm apart and was enclosed by a curtain. Fish were observed through a small aperture in the side of the curtain. A fish was placed in the gradient device at a position that approximated its acclimation temperature and was allowed to explore the trough for lhour before observations began. Temperature and location of the fish were observed at 1-minute intervals for 2 hours. During the second hour hot water was turned off to alter the gradient and check for positional effects (Stauffer et al. 1975). An additional test for positional effects (i.e. as a control) was done by placing a fish in the trough with a uniform temperature (14° C) and observing it in the same manner as above. Twenty to 30 fish for each acclimation temperature were tested and 10 additional fish, acclimated to 14° C, were tested in the control experiment. All temperature data were converted to degrees Centrigrade before statistical analysis. Data were analyzed similarly to that recorded for the razorback sucker.

"Preliminary tests were conducted for juvenile souawfish. At least 10 fish from three acclimation temperatures (14°, 20°, and 26° C) were tested in the horizontal thermal gradient (234 cm x 33 cm) used for humpback chubs to determine acute temperature preference. Several squawfish were left in the gradient overnight to estimate final temperature preferendum.

"Additional juvenile squawfish (10-18 cm in length) were tested in a horizontal trough, 5 m x 25 cm with variable depth (510 cm). Seven air stones and 13 thermistor probes were attached at uniform intervals along the bottom of the trough. Air stones used to prevent gas supersaturation and vertical temperature stratification helped to maintain an even temperature gradient. The thenmistor probes were attached to a telethenmometer on the observation platform. Unifonm, lowlevel lighting (1 lux) was provided, and the area surrounding the trough was covered in black plastic with a small opening for observation.

"Twenty squawfish from each acclimation temperature (14°, 20°, and 26° C) were tested in the larger gradient trough. Range of temperatures in the gradient was varied according to the acclimation temperature of the fish; 13-33° C for 14° C fish, 16-35° C for 20° C fish, and 14-34° C for 26° C fish. A single fish was placed in the trough at a point where the temperature corresponded to the fish's acclimation temperature (Richards and Ibara 1978, Hall *et al.* 1979). Observations of fish position and temperature at that position were recorded at lminute intervals for 3 hours, beginning as soon as the fish was placed in the trough. Only the last hour was used in the analysis of temperature preference. At the end of 3 hours, either the hot or cold water was turned off to shift the gradient. The fish was observed in a similar manner for 30 minutes to see if it remained in a particular preferred area of the trough (e.g., corner or end), or if it followed its selected temperature down the trough (Richards and Ibara 1978, Erlicl *et al.* 1979, Hesthagen 1979).

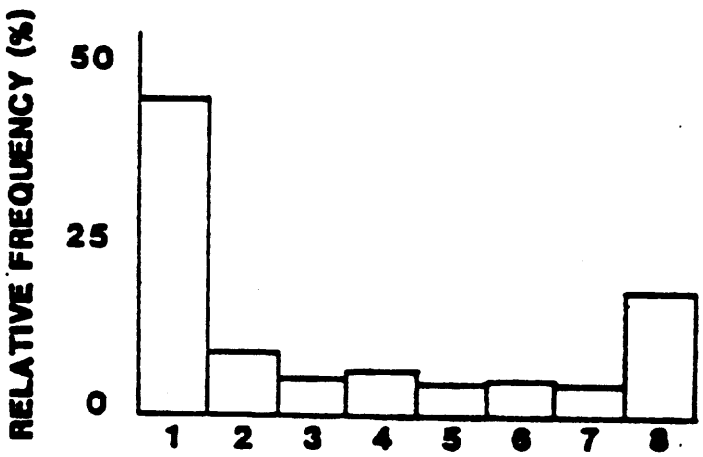
"Frequently the gradient did not shift significantly, particularly near the end of the trough where the water remained on, therefore additional criteria were used to determine if those fish were actually selecting temperature over other physical factors of the trough. Five fish from each acclimation temperature were individually tested in the trough with the water held at a uniform temperature equal to their respective acclimation temperature (Richards and Ibara 1978, Hesthagen 1979). Fish position was recorded at lminute intervals for 3 hours; only the last hour was used in data analysis.

"Testing procedures of adult squawfish were essentially identical to those of the juveniles, though an even larger gradient trough (5.3 m long x 61 cm wide x 13 cm deep) was constructed after testing 10 of the smaller adults (38-42 cm in length). The large gradient provided ample room for the larger adults (42-50 cm in length). Two air stones were added and slightly higher flows were required; otherwise conditions were the same. Ten adults per acclimation temperature (14°, 20°, and 26° C) were tested with a thermal gradient. Fish acclimated to 20° C and 26° C were offered a range of 16-32° C, those acclimated to 14° C were offered 13-26° C. Five fish per acclimation temperature were tested at a uniform temperature equal to their acclimation temperature. The 10 smaller adults were tested in April 1981, the remaining adults were tested in April 1981, the remaining adults were tested in August and early September 1981.

"Individual modes, a mean of individual modes, a pooled mean and mode, and Pearson's coefficient of skewness were calculated for juvenile and adult squawfish at each acclimation temperature. Effects of acclimation temperature and age on selected temperature were tested by analysis of variance. If differences were significant, means were further compared with Fisher's (protected) least significant difference test (Steel and Torrie 1960)."

RESULTS

"Testing thermal preference in a horizontal gradient device tends to produce more variable data than that obtained from the shuttlebox but gives comparable results (Magnuson and Beitinger 1978, Huggins 1978). There is also the problem of fish selecting for a particular position in the trough rather than the temperature associated with that position. Ten 14° C acclimated humpback chubs were tested in the horizontal gradient with a uniform temperature (14° ± 1° C) to detect preferred positions. The results indicated that the ends of the chambers were the most preferred positions (Figure b). (Future horizontal gradients should be constructed long enough to insure thermal avoidance temperatures at each end of the gradient to eliminate this problem.) As an additional test for positional effects, hot water was shut off to the gradient during the second hour of observation. This change allowed the gradient to shift and eventually be eliminated (Stauffer et al. 1975, Cherry *et al.* 1975, Richards et al. 1977). Use of these two tests effectively screened fish for positional effects and allowed us to eliminate those fish that were influenced by the chamber. Data of fish were rejected for analysis if location modes of an individual were the same during the first and the second hour of observation, or if their location mode during the first hour was at one end of the gradient and at the other end during the second hour. Humpback chubs acclimated to 20° C selected higher temperatures (x modes = 24.4° C) than did chubs acclimated to 14° C (x modes = 21° C). Chubs acclimated to 26° C, however, selected temperatures lower (x modes = 23.5° C) than those of 20° C chubs and much lower than would be predicted from data of other researchers (Stauffer et al. 1975, Mathur et al. 1981). Similar results were also seen in spotfin shiner, (Notropis spilopterus), (Stauffer et al. 1975) and in bluegill sunfish (Beitinger 1974). Differences in temperatures selected by humpbacks acclimated to the three temperatures were not statistically significant, however.



Humpback chub relative frequency distribution in 8 locations within a horizontal thermal gradient chamber. (Fish were acclimated to 14°C and placed in chamber with a uniform water temperature of 14°C). Data on 10 fish pooled for first hour, one observation/minute.

Figure a. Humpback Chub Relative Frequency Distribution

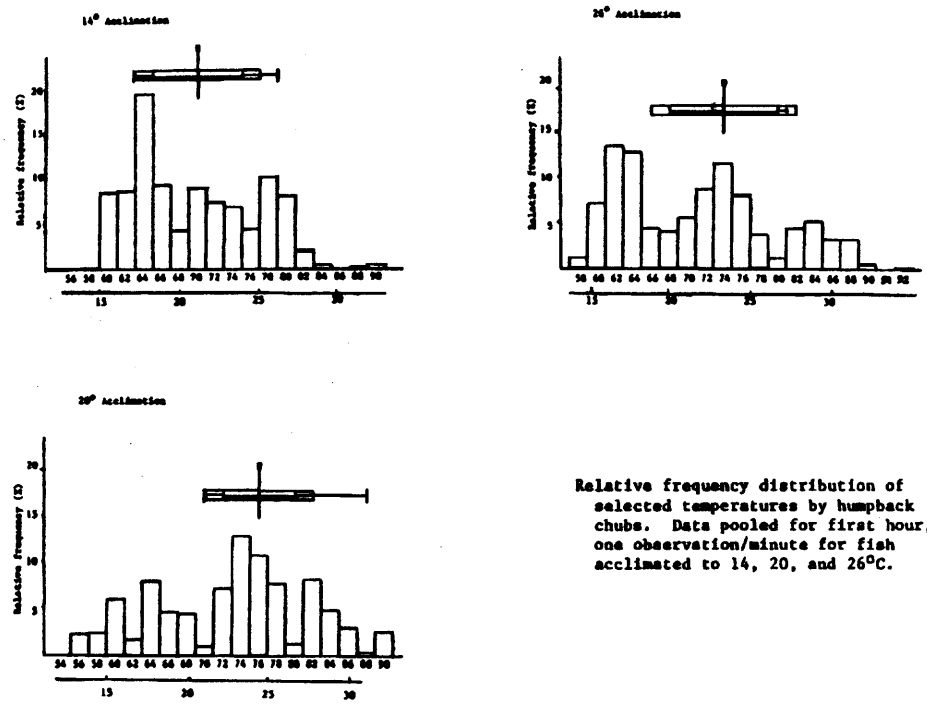
"Further testing of humpbacks is needed to determine if our lack of relation of acclimation temperature to acute preferenda was the result of a negative energy balance. Energy intake from food must at least equal energy expended in metabolism, or fish seek lower temperature to balance their energy budget. Stuntz and Magnuson (1976) found that insufficient energy stores in bluegills acclimated to high temperatures caused them to select a lower than expected temperature. Another possibility is that photoperiod should have reflected time of year when low and high temperatures were found in the field (Cherry *et al.* 1975).

Table a. Temperature selection of four Colorado River fishes

Species	Acclimation Temperature deg. C	Number	Range of Individual Modes	Mean of Modes (x) modes	Mode	Mean	Standard Deviation	Skewness(2)
Razorback Sucker	8	4	22 - 27	25.0 +/- 0.96	26	24.8	3.42	-0.4
	14	10	27 - 31	29.0 +/- 0.52	28	28.3	2.47	0.6
	20	20	12 - 28	22.7 +/- 1.07	24	22.5	2.87	-0.6
	26	20	13 - 29	23.1 +/- 0.90	26	23.0	2.60	-1.2
Humpback chub	14	9	17 - 26	21.0 +/- 1.26	18	20.3	3.88	0.6
	20	8	21 - 31	24.4 +/- 1.20	23	23.1	3.78	0.03
	26	7	21 - 27	23.5 +/- 1.72	17	21.3	4.37	1.0
Bonytails	14	6	15 - 21	17.9 +/- 0.92	17	17.9	3.31	0.3
	20	8	15 - 30	22.5 +/- 1.94	27	22.5	4.81	-0.9
	26	8	21 - 31	25.1 +/- 1.71	24	25.1	4.67	0.2
Hybrid	20	8	18 - 28	23.8 +/- 1.48	26	22.3	4.26	-0.8
Squawfish								
Juveniles	14	18	17 - 27	21.9 +/- 0.74	21	22.1	2.97	0.4
Adults	14	4	24 - 27	21.5 +/- 3.07	26	20.9	6.28	-1.0
Juveniles	20	20	24 - 32	27.6 +/- 0.44	28	27.4	2.46	-0.3
Adults	20	2	20 - 25	22.5 +/- 2.50	20	22.1	3.68	0.6
Juveniles	26	19	21 - 31	23.7 +/- 0.64	23	24.1	3.46	0.3
Adults	26	6	24 - 27	25.7 +/- 0.50	27	24.7	3.53	-0.7

(1) +/- standard error of mean.

(2) Pearson's skewness coefficient = (mean-mode)/standard deviation. A negative value indicates a longer tail on the low temperature side of the distribution curve.



Relative frequency distribution of selected temperatures by humpback chubs. Data pooled for first hour, one observation/minute for fish acclimated to 14, 20, and 26°C.

Figure b. Relative Frequency Distribution of Humpback Chubs

"It is interesting to note that pooled distributions of humpback chub were skewed in the opposite direction from those of razorback suckers and that the distribution for 26° C humpback chubs was bimodal. The 17° C peak is the mode by definition, but the mean of the individual modes and the pooled mean line up with the peak on the right (23° C). Perhaps this bimodality is an artifact of the shuttling behavior of fishes described by Reynolds (1978). Reynolds noted that fish tend to "shuttle back and forth within a range of temperatures above and below the preferendum" rather than staying at the preferred temperature.

"Bonytail chubs acclimated to 14°, 20°, and 26° C were also tested in the horizontal gradient and screened in the same manner as the humpback chubs. They showed a trend of increasing preferred temperature with increasing acclimation temperature which was similar to data of other researchers (Stauffer et al. 1975, Mathur et al. 1981). Fish acclimated to 14° C had a thermal preference of 17.9° C (x mode) whereas 20° C fish preferred 22.5° C and 26° C fish preferred 25.1° C. Pooled distributions, however, showed the same pattern as that of the humpback chubs. The pooled mode for 20° C acclimated fish (27° C) was higher than the pooled mode for the 26° C fish (24° C) (Figure c). The final preferendum was estimated for the bonytail chubs in same manner as for the humpback chubs. The point of intersection with the 45 degree line was 24.2° C.

"Hybrid chubs (humpback x bonytail) acclimated to 20° C were tested in the horizontal gradient and screened in the same manner as were the humpback and bonytail chubs. The mean of the individual modes (23.8° C) was intermediate to that of the 20° C acclimated humpbacks (24.4° C) and bonytails (22.5° C). The pooled distribution showed a higher mode (26° C vs. 23° C) than that of the humpbacks but was similar to that of the bonytails (27° C) (Figure x). The distribution was also bimodal as with the 26° C humpback chubs.

"Razorback suckers, humpback chubs, and bonytail chubs had almost identical final preferenda (23°-24° C vs. 24° C vs. 24.2° C). Final preferendum for hybrid chubs could not be determined, but their acute preferendum of 23.8° C when acclimated to 20° C was very close to the final preferendum of razorbacks, humpbacks, and bonytails. Final preferendum of both juvenile and adult squawfish was only one degree higher from that of the other species. Considering the amount of variation in the estimates, all four species had essentially the same final preferendum.

"Stauffer et al. (1975) found that they could predict the distribution of different species of fish in a heated powerplant effluent based on laboratory thermal preference of the fish. Conversely, razorback suckers, humpback chubs, bonytail chubs, and Colorado squawfish based on their laboratory preferences would avoid cold tailwaters of a reservoir. This avoidance probably explains at least in part the disappearance of native species from the Green River below Flaming Gorge Reservoir. For years after construction of the reservoir, native Colorsdo River fishes have not been found from the dam downstream to the confluence of the warmer Yampa River (McAda and Wydoski 1980, Holden 1978)."

4.1.1.2.2 Total Dissolved Solids Preference

One of the most usual measures of water quality, for which an analysis is performed on nearly every water quality sample is taken from whatever source (stream, spring, well), is total dissolved solids (TDS). For the samples taken at Blue Spring and the lower LCR, TDS is analyzed in almost every case.

There are two methods of TDS analysis, TDS by evaporation and TDS by summation. In the TDS by evaporation, a measured quantity of water is evaporated in an evaporation dish. The weight of the residue is calculated per unit volume of water, usually one liter. The results are reported in mg/l. In TDS by summation, all the major ion concentrations reported by weight, in mg/l are added together. In some cases, minor ionic weights are not analyzed or reported which, taken together, may affect the accuracy of the results of TDS by summation. On the other hand, there may be dissolved material in the water which is not of interest in terms of water quality, in which case, the TDS by summation may be more accurate.

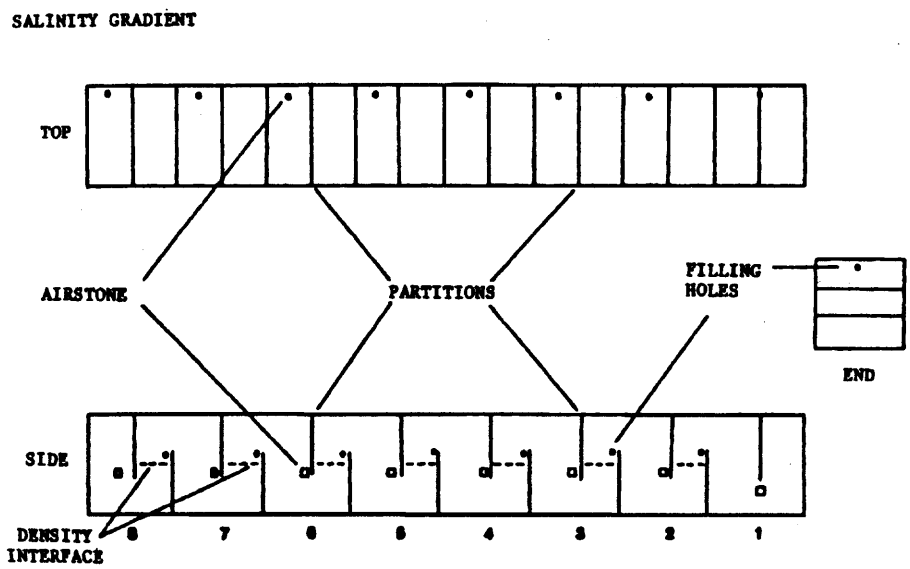
TDS is an approximate measure of the salinity of water. Although some ions are not considered to be "saline," the majority of inorganic chemical constituents of natural water are considered to be saline, in terms of, i.e., agricultural tolerances.

Although it may be possible to conduct preference and tolerance studies on the basis of individual ionic concentrations, the results may not be any more informative for environmental management purposes than the TDS preference experiment described below. Therefore, the TDS study is adequate for the purposes of determining the desirable water quality for the propogation and survival of the humpback chub.

The following excerpts are from Bulkley (1982):

METHOD

"The preference of Colorado squawfish, humpback chub, and bonytail chub to various levels of total dissolved solids (TDS) was tested in an enlarged version of a salinity gradient device designed by Staaland (1960). The apparatus was designed to test marine snails and later modified by Reynolds and Thomson (1974) for use with fish. The device consisted of a long trough (243 cm x 30 cm x 45 cm) with series of staggered partitions 20 cm high that enable the establishment of salinity gradient by using the difference in densities of water at different levels of TDS to keep them from mixing. Chamber 1 contained dechlorinated Logan city water to which the fish were acclimated and chamber 2 contained the major ions found in the Colorado River at Moab, Utah, (U.S. Geological Survey 1978, mean of 1978 water year August-March). Chambers 3-8 contained the same ions as chamber 2 except levels of Mg^{++}, SNa^{+},$S04^{-}$ were raised a combined total of 1 g/L/chamber. These three ions are considered to be the major constituents of the saline input from oil shale processing (Wagenet *el al.* 1980). A group of fish (30 squawfish, 20 humpbacks, or 40 bonytails) were placed in chamber 1 at the start of the experiment and allowed to migrate throughout the trough for 24 hours. Positions were recorded every 0.5 hours for the first 7 hours (to insure that all chambers were sampled by the fish) and again at 24 hours for the distribution used as data. TDS was measured (YSI conductivity meter) before and after the experiment because the concentration in each chamber would slowly change over time, but only the last measurement was used for data. Three treatments and three controls (all chambers filled with city water) were performed for each species. Because of the schooling tendency of these fish, independence could not be assumed for their distributions and no statistics could be performed. Pooled distributions, however, were made for comparisons between controls and treatments, and between species.



The TDS gradient device with positions of density/TDS interfaces and location of airstones. Length = 2.4 m, width = 45.7 cm, height = 30.5 cm.

Figure c. TDS Gradient Device

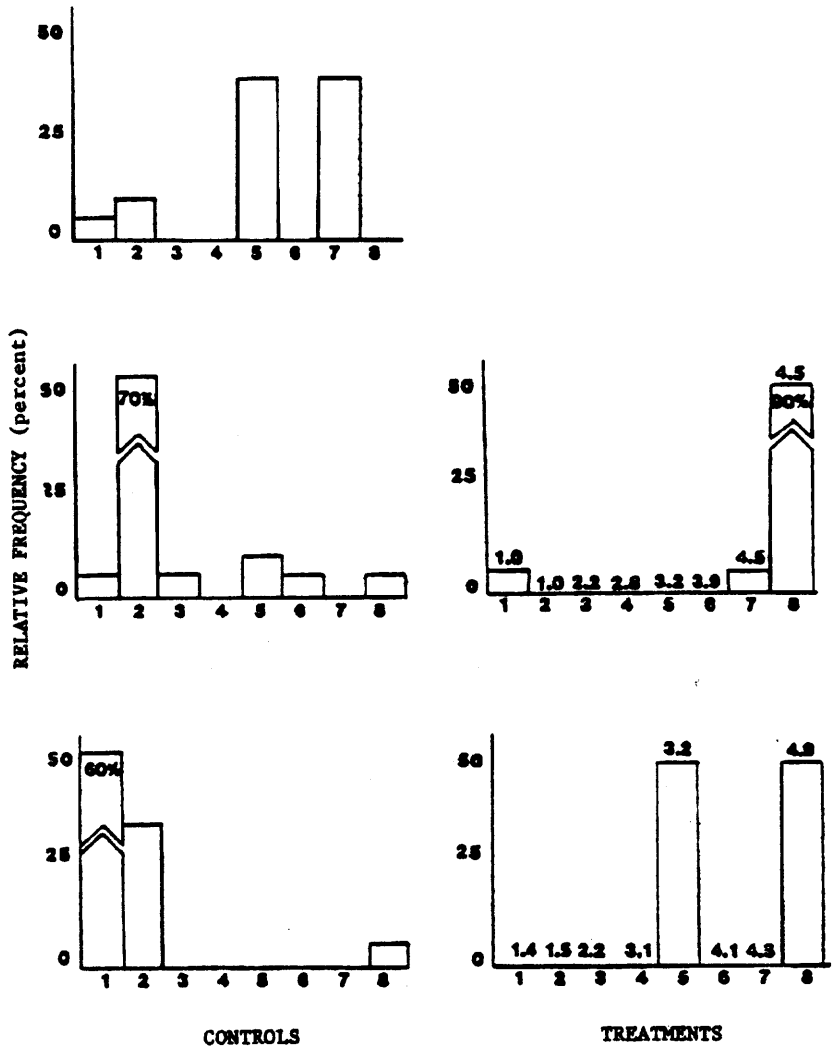
"Black plastic was used to shieid the apparatus from light and to minimize external disturbance. Photoperiod was maintained at ambient (14L x lOD). Temperature of the gradient was 16-18° C. Water was changed after each experiment. Dissolved oxygen and NH_3 (first controls only) were measured before and after each experiment and were never found to be a problem (D.O. > 7.2 mg/L, NH_3 < 0.2 mg/L).

RESULTS

"Colorado River fishes tested in the TDS gradient device showed varying degrees of schooling behavior, therefore, no independence could be assumed for their distributions and no analyses were performed. Pooled distributions, however, were made for comparisons between controls and treatments, and between species.

"Colorado squawfish were the most mobile species in the gradient of the species tested evidentially because of their tendency to swim in the upper level of the water column and because of their relatively loose schooling behavior. Comparison of the control histograms showed that while the distributions were not uniform, the compartment modes were random between replicates (Figure c). Conversely, the distributions of the treatments appeared to have

very consistent modes with a range of 1.0-2.7 mmhos of conductivity. The pooled distributions of the three replicates indicated a fairly uniform control distribution with an unexplainable peak at compartment 3. The treatments, however, indicated a definite preference for lower TDS (mode = 1.0-1.4 mmhos); 97 percent of the 90 fish tested avoided TDS > 3.6 mmhos. Note that because the water was changed with each replicate, no two gradients were identical, and the concentrations of TDS for pooled distributions are given as the range of TDS in that compartment over the three replicates. Note also that the gradients had the same conductivity in more than one compartment. This condition was the result of a "gradient drift," i.e. the gradient started out with a different and discrete increment of TDS concentration in each compartment, but during the 24-hour period of the test some mixing caused by aeration and the fish swimming through the density interface occurred. This shift in gradient may explain why fish were not found in adjacent compartments even though they had equal conductivity (i.e. compartments drifted to same conductivity after the fish had made their final compartment selection).



Relative frequency distribution of juvenile humpback chubs in 8 compartments to TDS gradient device (Figure 2) with and without gradient established. Numbers I, II, and III are replicates for controls and treatments. Number over vertical bars is conductivity in mmhos. Data on location and conductivity are values 24 hours after start of experiment. N = 20 8-12-cm fish/replicate.

Figure d. Relative Frequency Distribution of Juvenile Chubs

"Pooled controls histograms indicated a relatively uniform distribution while the pooled treatment histogram had a strong peak in compartment 5 which had a TDS of 3.4-3.8 mmhos of conductivity.

"Humpback chubs had the strongest schooling tendency of the fish tested and were bottom oriented like the bonytail chubs. Because of their larger size (8-12 cm), only 20 fish/replicate could be tested in the gradient. An initial two test replicates suggested that distribution of the fish was affected by the schooling tendency of this species so that fish tended to be either abundant or absent in a compartment (Figure d). Fish also appeared to be selecting the highest TDS concentration in the gradient. Hence, concentrations in each compartment except compartment 1 (Logan city water) were doubled so that conductivity up to 9.8 mmhos was present. Distribution of fish in three treatment replicates at these higher concentrations was just as random as for the controls (Figure x). The mode of treatment 1 was in compartment 5 (6.8 mmhos); treatment 2 was bimodal (compartment 1 = 2.4 mmhos, compartment 7 = 8.5 mmhos); mode of treatment 3 was in compartment 2 (3.0 mmhos). Hence, it did not appear that humpbacks were consistently selecting a particular concentration of TDS within the available range. Part of the apparent random distribution of humpback chubs in the TDS gradient was attributed to the small sample size per replicate. A sample of 20 fish 8-12 cm in length was the maximum that could be held in the chamber and maintain dissolved oxygen level over the 24-hour period. Fish from a later spawning and of suitable length (ca. 4.0 cm) to test 40 individuals/replicate were eventually obtained. Water temperature which could not be controlled in the gradient had decreased, however, from the 16-18° C level used in all previous tests to 12° C. Temperature is a factor that must be considered in TDS preference determinations because low temperature hinders osmoregulation and thus influences tolerance to salinity. Controls and three test replicates were run with the smaller fish, cooler water temperature, and the original TDS concentrations used for the other species. Fish in the first control run with the new conditions were rather uniformly distributed over the gradient. Succeeding control runs were less uniform, but distribution was more widespread than when 20 fish/replicate were used. In contrast, fish in test runs were consistently more abundant in compartment 3 where conductivity was either 1.3 or 2.3 mmhos. Conductivity in specific compartments is not constant during replicates because of gradient drift described earlier.

"Pooled treatment results from humpbacks of both body sizes tested at 12° and 18° C indicated that most fish selected water with a conductivity of 1.3 to 3.0 mmhos. About 60 percent of the 220 fish tested were found after 24 hours in this conductivity range. No fish selected water with TDS above 9.4 mmhos, and only 5 percent was found in conductivity of 8.5-9.4 mmhos.

"Pooled distribution of Colorado squawfish, bonytail chubs, and small humpback chubs agreed well in overall shape with those of the Gulf of California grunion (Leuresthes sardina) (Reynolds and Thomson 1974), and the common welk (Buccinum undatum) (Staaland 1969), while distribution of the larger humpback did not. Both Reynolds and Thomson, and Staaland found good agreement with salinity preference in laboratory and salinities occupied in the field. McInerney (1964) also found good agreement between laboratory and field salinity preferences for five species of juvenile Pacific salmon, using a different type of preference chamber. Comparison of our experiments indicated that the Colorado squawfish has the lowest TDS preference (1.0-1.4 mmhos - 0.6-1.1 mg/ml) of the species tested but has a similar TDS avoidance (ca. 5.0 mmhos) to that of the bonytail chub (ca. 5.1 mmhos). TDS preference of the squawfish is similar to TDS levels found in the Green and Upper Colorado Rivers today but the bonytail chub preference (3.4-3.8 mmhos - 4.1-4.7 mg/ml) is much higher. Humpback chub TDS preference (1.3-3.0 mmhos = 1.0-3.5 mg/ml) appears to be intenmetiate to squawfish and bonytails, however, their TDS avoidance level (>8.5 mmhos) may be much higher. From the results of these experiments, one would predict that of the species tested,

the Colorado squawfish woult be the most affected by increases in TDS caused from evaporative loss in reservoirs and any salt release from oil shale development. TDS preference of the bonytail and humpback chubs is also low enough that habitat could be lost to them by TDS increases."

4.1.1.2.3 Egg Temperature Tolerance

It is important to know the range of temperatures of water in which humpback chub eggs will hatch. If the water temperature is too cold or too warm, the eggs will not hatch. As will be seen in Section 12.3.2, the temperature of the natural flow of the Little Colorado River varies widely with the season. After mixture with the discharges of Blue Spring, the temperatures moderate in their fluctuation. Knowing the spawning season and the temperature of water in that season, the viability of the eggs can be understood.

The following excerpts are from Bulkley (1982):

METHOD

"Eggs were initially held at the water temperature of spawning or if shipped, at the water temperature of the water in which they arrived. They were gradually tempered to test temperatures. Eggs were placed in water in plastic cups supported by styrofoam, ten eggs per cup and three or four replicates per temperature. The eggs were initially checked with a dissecting scope to see if they were viable and if in the same stage of development (usually fourcelled). They were then checked for viability every 24 hours."

RESULTS

"Two lots of Colorado squawfish eggs received from the Fisheries Experiment Station of the Utah Division of Wildlife Resources, Logan, Utah, did not develop. A third lot developed only at 20° C (test incubation temperatures ranged from 5-35° C) with a 50 percent normal hatch and a 5-day incubation time. A fourth lot was incubated at test temperatures of 5°, 10°, 14°, 20°, and 26° C in the holding tanks, and 16°, 18°, 22°, and 26° C in the gradient trough. Water temperatures in the trough varied and increased as much as 3° C throughout the duration of the experiment. The only group that had a hatch higher than 50 percent was those held at 20° C. They had a 60 percent normal hatch and a 10-day incubation time. No hatching occurred among eggs held at 5°, 10°, or 14° C.

"One lot of humpback chub eggs was received on June 4, 1981, approximately 30 hours after fertilization. They were incubated at 5°, 10°, 14°, 20°, and 26° C with four replications per temperature. There was no hatch at 5° C, 30 percent at 10° C (after 19 days); 50 percent hatch at 14° C with a 16-day incubation time; 100 percent hatch into replicates at 20° C with a 4-day incubation time, and 90-100 percent hatch in two replicates at 26° C with a 3-day incubation time."

The results of the Bulkley (1981) preference study are confirmed by Marsh (1985). Marsh conducted experiments to determine the hatching efficiency of native Colorado River fish under various conditions. The eggs were placed in aquaria under temperature-controlled conditions for incubation. It is notable that the humpback chub had the lowest hatching efficiency of all the fish. The humpback chub hatching efficiency peaked at 20° C, while the bonytail chub hatching efficiency peaked at 15° C. The following graph summarizes the Marsh results:

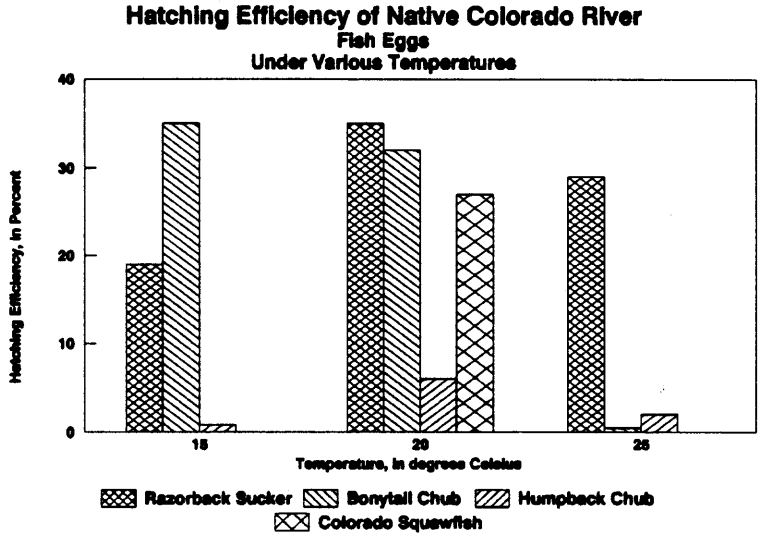


Figure 3. Hatching Efficiency of Colorado River Fish Eggs (Marsh, 1985)

A summary of LCR at Mouth temperatures reconstructed for the WY 1939-90 study period appears in Section 12.3.2. These temperatures can be compared to various species requirements on a monthly basis. Fish counts can be compared to mean LCR temperatures for the month and year of the count.

4.1.1.2.4 Swimming Ability

The adult humpback chub tends to favor deep, swift water with a rocky substrate (Valdez and Clemmer, 1982). The young and juveniles show a preference for firm silt substrates in water 0.6 m deep and 0-0.15 meters per second (mps) velocity. Juveniles in Black Rock are found over sand-silt and boulder-bedrock substrates in water 0.4-10.7 m deep and velocities of 0.06-0.60 mps velocity. On the other hand, adult humpback chub were found in depths of 0.7-12.2 m and velocities of 0.03-1.16 mps.

The seasonal velocities of the waters of the LCR at Mouth are easily calculated from velocity curves drawn from calibrating measurements by USGS taken during the brief operation of that gage.

In Section 9.4.1, the issue of water flow velocity at various gaging stations is discussed, also with the chub preferences in mind.

The following excerpt from Bulkley (1982) confirms the field observations:

METHOD

"Swimming ability was determined in a stamina tunnel (Thomas et al., 1964). Fish were tested at temperatures of 14°, 20°, and 26° C, at various water velocities. A standard testing protocol was used. Fish were acclimated for at least 1 week to the temperature at which they were tested. Acclimated fish were netted and introduced in pairs into the stamina tunnel. Fish were allowed to swim for 5 minutes in a water velocity of 0.15 m/sec, and were then immediately subjected to the test velocity. Swimming fish which retreated to the rear of the tunnel were subjected to mild electric shock (5-10 volts). Time of fatigue was defined as the time at which a fish could no longer avoid the electric field. Fatigued fish were removed from the tunnel, measured for length, and returned to holding tanks for post-test observation. Data were analyzed by analysis of variance with temperature and velocity as main effects, and fish length as a covariate."

RESULTS

"Swimming speeds of fish are usually defined as (1) burst speed (darting for a few seconds at 8-12 body lengths/sec), (2) sustained speed (swimming for several minutes at 47 body lengths/sec), and (3) cruising speed (swimming for hours at 24 body lengths/sec). Great variability exists in swimming data collected in the artificial conditions of a stamina tunnel (Bell 1973, Hettler 1977). We also noted such variability especially at water velocities between the extremes tested at each temperature. For example, one fish in a pair would occasionally tire in a few minutes while the remaining fish swam for 2 hours. We compared the swimming ability of fish tested singly and in pairs and found no difference. We felt, therefore, that the behavior of the fish that we tested probably represented different levels of motivation and ability within each species.

"Several cursory studies were conducted to determine testing protocol. Fish conditioned to the tunnel for 10 minutes at no current and for 5 and 20 minutes at 0.15 m/sec. did not perform differently when tested at 0.45 m/sec. Retesting individual fish four times at 48 hour intervals did not affect performance. Occasionally a fish did not learn to swim in the tunnel in the 5 minute conditioning time, and was not tested further.

"Humpback chub swimming stamina was similar to that of the squawfish and razorback. Humpbacks could swim for about 2 hours at 0.32 m/sec but only for a few minutes at 0.78 m/sec (Table b). Their ability was positively and significantly related to temperature. Larger fish (134 mm maximum length) performed significantly ($p < 0.05$) better than did smaller fish (73 mm minimum length).

"The results of our studies compare well (considering differences in test conditions) with data collected for similar sized fish of other species (Table a). The fish used in our work were reared under culture conditions in low velocity waters since hatching. Lack of conditioning to test velocities may have resulted in reduced time-to-fatigue values compared to wild or exercised fish. Wild fish can swim at a rate of about 30 percent higher than cultured fish (Green 1964, Thomas et al.). Exercized fish usually have greater swimming ability than unexercized fish (Brett et al. 1958, Hammond and Heckman 1966).

"A direct relationship between fish length and swimming speed and stamina is fairly well established (Bainbridge 1958). However, small fish usually show greater speed as measured in body lengths per second than larger fish. We also noted the positive relationship between length and stamina in our studies. We expect that adult fish of each species have significantly greater stamina than do juveniles of the same species. Preliminary data on stamina of adult squawfish support this expectation. The average sustained speed at 14° C of adult squawfish (373-416 mm in length) was 0.76-1.0 m/sec, about twice that of juveniles at 14° C. One might expect the difference to be greater, however, temperature effects have a relatively greater effect on large fish than on juveniles (Brett 1967, Jones et al. 1974).

"Temperature influences the swimming ability of most fish (Brett et al. 1958). The typical pattern of influence is that of an adverse effect on either side of the optimum temperature range. Our data generally indicated that 20-26° C was in the range of the optimum temperature for species. All fish performed more poorly at 14° C than at 20° C or 26° C. We did not examine swimming performance at temperature above 26° C where performance might have been adversely affected.

"Brett and Glass (1973) in summarizing swimming literature on the Pacific salmon presented temperature fish size response surfaces for critical swimming speed. Uniform isopleths were evident, i.e. temperature effects on the speed of large and small fish were similar. Our data indicate otherwise. The swimming ability of the juvenile, small (73-142 mm in length) squawfish, bonytail chubs, and humpback chubs was significantly and directly related to water temperature. On the other hand, swimming ability of the older, larger (132-497 mm in length) razorback suckers and squawfish was not significantly affectcd by water temperature. The difference between the generalizations made from salmonid literature and our data may be due to the oligothermal nature of salmonids and the eurythermal nature of the rare fish of the Colorado. Little information is available on teperature-fish size-effects on swimming speeds of warm water fish. There is one indication (Glova and McInerney 1977) that the relative change in critical swimming speed with temperature is less in large (12 cm) than in all (3 cm) salmon. Brett and Glass (1973) also concluded that optimum temperature produces a more pronounced maximum metabolic rate for small fish than for large. This may be another indication that the swimming ability of small fish may be more responsive to temperature change than that of large fish.

"Swimming performance of fish has been investigated in various ways. Some investigators have measured "burst speed" at low water velocity. Others have determined the water velocity at which fatigue occurs using continual incremental increases in water speed. Still others have determined the time required to fatigue at a fixed water velocity. We employed the latter technique to determine the range of water velocities each species could tolerate up to 2 hours swimming time. We feel that these data are more meaningful to workers who must predict the impact of various alterations in water flow regimes on fish behavior. And, this information can be readily employed in planning and designing man made alterations to the stream or riverine environment."

Table a. Swimming performance (minutes to fatigue) of humpback chubs (73-134 mm in length) at different water temperatures and velocities (A test was discontinued if a fish swam for 120 minutes)

Temperature	14 deg. C			20 deg. C			26 deg. C		
Velocity (m/sec)	Number	Mean	Standard deviation	Number	Mean	Standard deviation	Number	Mean	Standard deviation
0.27	10	116.27	11.8						
0.30	10	117.05	9.3						
0.33	10	95.18	47.8						
0.36	10	96.47	49.6						
0.39	10	74.15	59.2						
0.42	10	44.82	52.4						
0.45	10	28.05	48.6	10	74.38	58.9	8	120.00	0
0.48	10	4.68	2.8	-	-	-	10	108.07	37.8
0.51	10	2.22	1.4	10	85.22	56.0	10	60.65	62.6
0.54				-	-	-	10	60.62	62.6
0.57				10	39.8	56.5	-	-	-
0.60				10	2.03	1.3	14	61.75	60.4
0.63				11	23.77	47.6			
0.66				-	-	-	14	61.45	60.8
0.69				10	13.43	37.4	-	-	-
0.72				10	4.00	4.8	10	2.32	3.8
0.75							-	-	-
0.78							9	2.08	1.8

"The construction of highways requires the installation of culverts at river crossing. Faulty culvert design which allows excessive water flow rates can create barriers to upstream fish migration. The ability of fish to swim through culverts has been investigated by Wales (1950), Metsker (1970) and Blahm (1963). Watts (1974) and MacPhee and Watts (1976) discussed means of incorporating fish swimming speeds into culvert design. A simple way to use the data we have collected is to determine the distance a fish can swim at a certain flow through a proposed culvert using the following formula

$$D = 60VT$$

"where D = distance in meters a fish can travel before becoming fatigued, V = velocity of water through the proposed culvert in m/sec, and T = fatigue time at V (T is found in the accompanying data tables for fatigue times of each species tested). For example, if at a water temperature of 20° C, the flow through a 100 m culvert to be 1.2 m/sec, then most adult Colorado squawfish of the size tested in our experiment could travel only 96 m before becoming fatigued. Hence, most might not pass through the 100 m-long culvert. However, if the projected water velocity was about 1.0 m/sec then the fish would be able to travel 234 m and easily pass through the 10 m-long culvert.

$$(60)\ (1.0)\ (3.9) = 234 \text{ m}$$

"Hydroelectric plants and other industrial complexes usually remove water from a river at a water intake structure. When water flow rates at these structures are excessive, fish become impinged on intake screens (Barnes 1976). Knowledge of swimming abilities of resident fishes has been employed in estimating the risk in some cases (Hettler 1977, Barnes 1976). Bozeman (1977) summarized that 0.15 m/sec would be the maximum acceptable velocity for protecting small fish. Assuming average approach velocities of 0.3 m/sec at the trashrack of a powerplant, all species tested on our study should be able to avoid being overcome by the current.

"Dams constitute a physical barrier which fish cannot overcome without the aid of a fish ladder or fishway. Swimming speeds of fish (in most cases salmonids) have been employed in designing fishways (Collins et al. 1961, Conner at al. 1963, Slatick 1970). Also of concern are effects of periodic releases of water on stream flows below dam sites. For example, large quantities of released water may create such excessive instream flows that the habitat below the dam would be unsuited for fish! Adults frequently seek higher velocities at obstructions and this behavior could be used to attract adult fish to fishway entrances (Bell 1973). However, attractant velocites should be well under the darting speed but may exceed the cruising speed for species and sizes involved.

"When guiding or directing fish with water velocity, smooth transitions and accelerations are required to prevent the fish from hesitating or refusing to enter an area. In summary, data attained in this study on swimming ability of Colorado River fishes are of value in the design of many structures which alter or control river flow rate."

It is not clear from the above evaluations whether the humpback chub can survive the Little Colorado River flows within the critical habitat during peak flow events without protection by overhangs, boulders, and aquatic plants. It is equally unclear whether the humpback chub can outswim introduced species of predator fish or whether it exhibits a predator avoidance behavior.

4.1.2 Little Colorado River Spinedace, Lepidomeda vittata

The Little Colorado River spinedace is a small cyprinid minnow fish whose habitat is restricted to the trubutaries of the Little Colorado River which flow northward from the Mogollon Rim to the main stem. The fish was first described by Cope (1874) from specimens collected in 1871-1874 by members of the Wheeler expedition (Wheeler 1889).

The following description is summarized from Cope (1874), Miller and Hubbs (1960), and Minckley (1973): Mouth moderately oblique; second "spine" or dorsal fin strong; dorsal fin moderately high and acute; anal fin rays eight; scales in lateral line, usually more than 90; pharyngeal teeth in two rows; vertebrae number 41 to 43. The spinedace is usually less than 100 mm in total length.

Life color is described by Miller (1963): "The sides of the body below the base of the fine, nearly vertical dark lines (that extend dorsally from the midside) shine like polished silver and the venter is white. The upper sides are olivaceous, and the back is olivaceous to bluish or dark grey. Except for pigmentation along the fin rays and on the interradial membranes near the bases of the fins, both paired and unpaired fins are largely clear. Irregularly distributed, fine black puncticulations (giving a pepper-like effect) overlie the silvery sides from the bases of the dark vertical lines to about halfway between the lateral line and the midline of the abdomen. When the lived fish are viewed from directly above, a conspicuous, cream-colored spot is seen at both the origin of the dorsal fin and near the bases of the terminal rays of this fin.

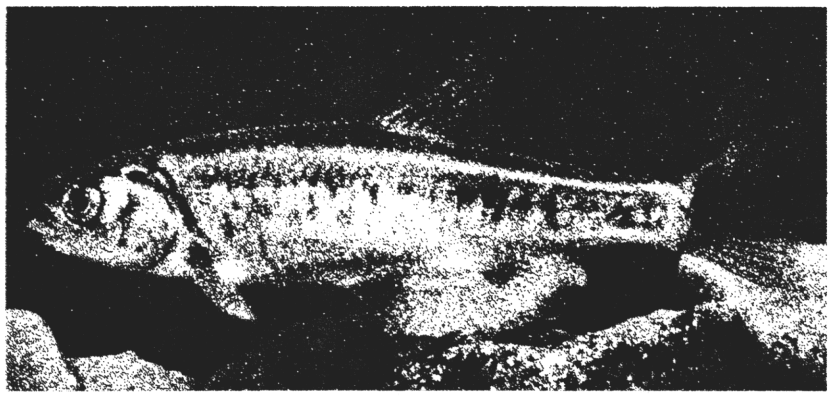


Figure 4. Little Colorado River Spinedace

4.1.2.1 Little Colorado River Spinedace Critical Habitat in the LCR

The Little Colorado River spinedace was listed in the U.S. Fish and Wildlife "Review of Vertebrate Wildlife for Listing as Endangered or Threatened Species" (USF&WS 1982). The spinedace was considered as a category 1 species, reflecting the fact that the USF&WS had sufficient information at hand to merit a proposal to list the fish as threatened or endangered.

A petition delivered on April 12, 1983, to USF&WS by the Desert Fishes Council contained significant scientific information on the LCR spinedace. A notice of finding was published by USF&WS on June 14, 1983 (USF&WS 1983). Subsequently, the spinedace was listed as threatened on May 22, 1985 (USF&WS 1984, 1985). The critical habitat areas within the Little Colorado River basin are described as follows (50 CFR, Ch1, Sect. 17.95):

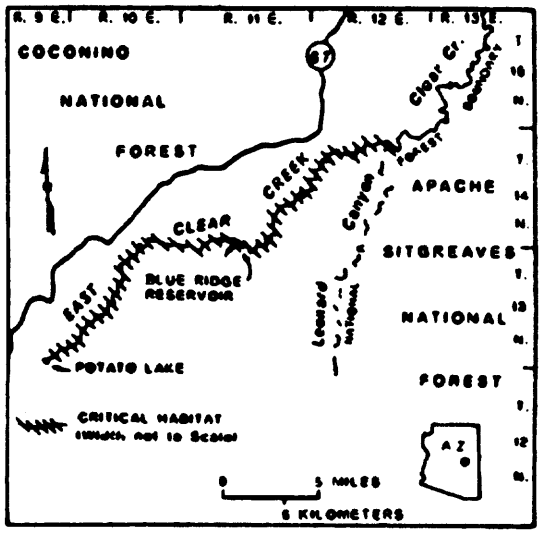


Figure 5. Clear Creek Spinedace Habitat

"(1.) Coconino County. East Clear Creek; approximately 18 miles of stream extending from the confluence with Leonard Canyon (NE 1/4 Sec. 11 T14N R12E) upstream to the Blue Ridge Resservoir Dam (SE 1/4 Sec. 33 T14N R12E), and approximately 13 miles of stream extending from the upper end of Blue Ridge Reservoir (east boundary SE 1/4 Sec. 36 T14N R10E) upstream to Potato Lake (NE 1/4 Sec. 1 T12N R9E)."

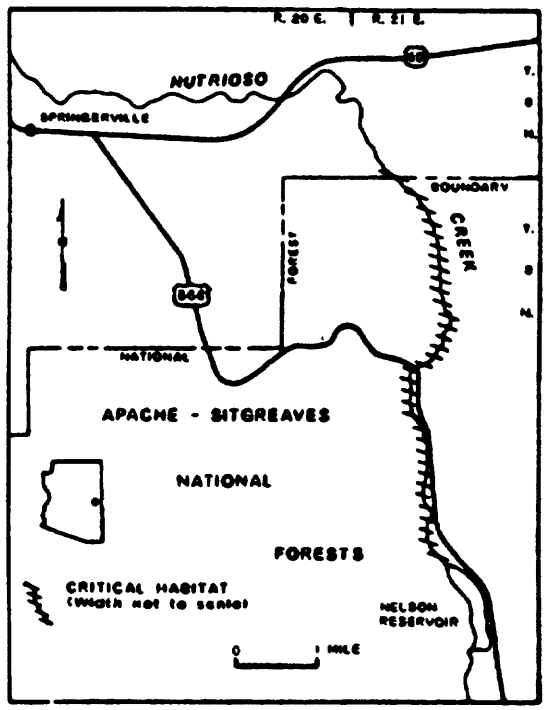


Figure 6. Nutrioso Creek Spinedace Habitat

"(2.) Navajo County. Chevelon Creek; approximately 8 miles of stream extending from the confluence with the Little Colorado River (NW 1/4 Sec. 23 T18N R17E) upstream to Bell Cow Canyon (SE 1/4 of the SW 1/4 Sec. 23 T17N R17E)."

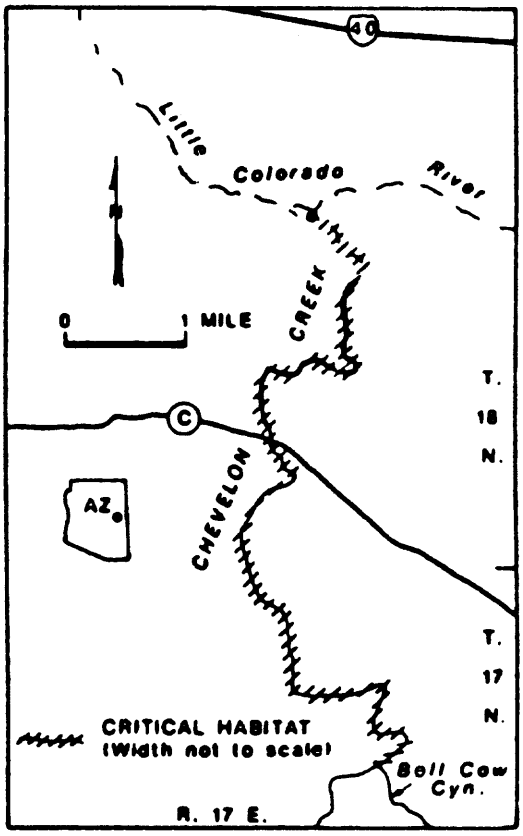


Figure 7. Chevelon Creek Spinedace Habitat

"(3.) Apache Creek. Nutrioso Creek; approximately 5 miles of stream extending from the Apache-Sitgreaves National Forest boundary (north boundary Sec. 9 T8N R30E) upstrean to the Nelson Reservoir (SE 1/4 Sec. 29 T8N R30E)."

4.1.2.2 Habitat Preferences of the Little Colorado River Spinedace

The Little Colorado River spinedace once occupied most of the southern tributaries of the Little Colorado River, including certain portions of the main stem (Minckley, C. O., 1994). Miller and Hubbs (1960) reviewed the historical literature and placed its type locality to "the Little Colorado [River] somewhere between the mouth of the Zuni River and Sierra Balnca (White Mountains). It has been collected in the main stem downstream of Woodruff (Minckley, W. L. and Carufel, 1967). Today, the species appears to be restricted to the critical habitat areas described above and the pond at the Flagstaff Arboretum. Unfortunately a recent survey (Denova and Abarca, 1992) revealed few spinedace in the designated critical habitat areas.

The fish appears to prefer clear, flowing pools of medium depth (<3m) over fine gravel to cobble and boulder substrates (Minckley, W. L. and Carufel, 1967, and Nisselson and Blinn, 1991).

Spinedace survives a broad range of physical and chemical parameters. They have been found in waters ranging in temperatures from 8.0 to 25.0°C (Nisselson, and Blinn, 1991). They may survive to near zero (°C) temperatures in deeper pools, such as the pond at Flagstaff Arboretum (Blinn, *et al*, 1994) and Dinnes Tank (Denova, and Abarca, 1992) in Leonard Canyon. The range of dissolved oxygen 4.1 to 13.4 ppm appears to be acceptable (Nisselson and Blinn , 1991, and Blinn, *et al*, 1994). Spinedace have been noted in waters of pH range 6.1 to 8.5 (Nisselson and Blinn, 1991). The alkalinity range of 12.0 to 168 mg/l as $CaCO_3$ and the specific conductance range of 33.2 to 319.4 mmS/cm have been reported (Nisselson and Blinn, 1991).

These physical and chemical parameters are very different from the main stem Little Colorado River, the Puerco River, and the northern washes on the Hopi and Navajo Reservations (see Section 12.4). The LCR main stem and the northern tributaries tend to be higher in dissolved solids (i.e., conductance) and alkalinity than the southern tributaries favored by the spinedace. Undoubtedly, physical and chemical factors are among the reasons why the spinedace is restricted to mountain stream and pond habitats.

The spinedace tend to avoid deeper, shaded pools and shallow open areas (Minckley, W. L. and Carufel, 1967); undercut banks, boulders, and aquatic vegetation also attract the species due to the cover they provide. Turbid and stagnant waters do not affect the spinedace; they have been found in water which is "yellowish, brownish-white, and murky" (Miller and Hubbs, 1960). In fact, the increase in turbidity and temperature during spring snowmelt flows may induce spawning. According to Blinn, *et al* (1994): "Therefore reduced water transparency likely serves as a proximate cue to spinedace for optimum spawning conditions, i.e., increased water levels and

hydrologic continuity of the main channel, increased water temperatures, elevated dissolved oxygen, removal of bottom sediments, increased invertebrate food as drift, and overall predator visibility."

4.1.2.3 Predator Impacts on the Little Colorado River Spinedace

Rapid fluctuations of spinedace numbers from year to year in the designated critical ahbitat areas and the high mortality of spinedace young led to the proposition that predation may deplete the numbers of spinedace after hatching. A predataion experiment with rainbow trout was conducted by Blinn and Runck (1992) utilizing captive trout and spinedace under laboratory conditions. The indicated results of the experiment were that the spinedace does not exhibit avoidance behavior in the presence of rainbow trout, "which suggests limited interaction with large non-native predators through evolutionary time. Habitats with high turbidity apperar to be one of the last habitats where L. vittata can co-occur with rainbow trout in arid southwestern lotic ecosystems. Our results suggest that rainbow trout have a significant influence on the distribution and behavior of L. vittata, and may be responsible for the disjunct distribution of this native fish species in Arizona, U.S.A."

The body of opinion that rainbow trout predation has had a major effect on the decline of the spinedace is steadily growing, with Minckley (1994), Meffe (1985), and Renne and Minckley (1991) joining Blinn, *et al*, (1994) in this conclusion. Blinn, *et al*, conclude: "We propose that rainbow trout may be instrumental in delimiting both the intra- (habitat) and inter-stream (geographic) distribution and ultimate survival of spinedace."

Other introduced species of fish are attributed to predation on the spinedace. In Minckley, W. L. and Carufel (1967), the red shiner and golden shiner have been reported in Concho Reservoir and in the Chevelon Creek drainage. Both are known to have extirpated the spikedace and the loach minnow from their native habitats.

4.1.2.4 Use of Piscides in the Little Colorado River Spinedace Habitat

Hemphill (1954) reported the repeated use and subsequent release of toxaphene in Lyman Lake in 1951. This is felt by Minckley, W. L. and Carufel (1967) to have contributed to the decline of native fish in the upper Little Colorado River reaches. It is noted that such piscides are now "judiciously administered, with consideration for indigenous fishes." Unfortunately, the damage has already done.

4.1.2.5 Life Cycle of the Little Colorado River Spinedace

Spawning of the spinedace was first meticulously observed by Blinn, *et al*, (1994) utilizing transplanted fish in the Flagstaff Arboretum pond. Spawning occurs largely in late May, with later spawning periods also possible. The fish school, with one female attended by several males, migrates upstream to the inlet stream of the pond. The warmer waters, up to 20°C, are ideal for incubation. The female makes a small depression in the fine gravel and lays her eggs, after which the male fertilizes the eggs.

Up to 9,000 young were observed initially in the pond. The numbers rapidly decreased during the season, with cannibalism by adult spinedace a possible reason. The fish grow from a length of about 6mm to 50% of their adult length within two months, growing nearly 4.2mm per week. The rapid decline in the numbers of young are detailed in size frequency distribution graphs in Blinn, *et al*, (1994). In this report, disappearance of the original transplated fish after 3.3 years may mark the upper limit of the lifespan of the spinedace.

4.1.2.6 Population Counts of the Little Colorado River Spinedace

The relative abundance of spinedace have been reported periodically since 1960 (Miller, 1963). Miller reports that in that year, the spinedace had been extirpated throughout its known range, with one specimen being taken from Clear Creek. In 1961, a sizeable population had been found in East Clear Creek (Miller, 1963) and the fish was concluded to have been restricted to that drainage. Between 1963 and 1966, the spinedace re-invaded most of its former range, and occurred in most north-flowing tributaries of the Little Colorado River (Minckley, W.L. and Carufel, 1967). Populations again declined and the spinedace was again considered endangered in 1973 (Minckley, 1973). A new population was discovered in 1977 (Blinn, *et al*, 1977) in lower Chevelon Creek. Spinedace were again found in large numbers in 1983 (Minckley, 1984) in East Clear Creek. In 1990, no species of any fish were found in that habitat (Denova and Abarca, 1992); in that year, spinedace in Dines Tank declined from 51% of total catch in 1983 (Minckley, 1984) to less than 10% of the total catch in 1990 (Denova and Abarca, 1992).

The reasons for the up and down populations have not been satisfactorily explained. Minckley and Carufel (1967) suggested predation by shiners, and it has more recently been suggested that competition by the introduced fathead minnow, with which it shares habitat preferences, has led to the demise of the spinedace (Blinn and Runck, 1990, and Sublette, *et al*, 1990). Denova and Abarca (1992), notes that fathead minnow increased in Dines Tank from less than 5% of total in 1983 to 12 to 70% of catch in 1990.

4.1.2.7 Flagstaff Arboretum Pond Alternate Spinedace Habitat

On September, 1992, 44 Little Colorado River spinedace were collected at Rudd Creek, a tributary of Nutrioso Creek, for transplanting into a small stream/pond system at the Arboretum at Flagstaff, Arizona (Blinn and Runck, 1993). The pond contained only salamanders at the time of transplant, with no previous record of fish. All of the fish were placed in the 115 foot long stream of recirculation water from pumps submerged in the pond. A wire mesh screen (<5mm) was placed upstream of the pond to increase efficiency of observation.

A heavy inflow during spring snowmelt of January and February of 1993 removed the wire screen. The fish were presumably flushed into the pond. On May 10, 1993, the pond was seined and five fish, four males and a gravid female, were captured. On May 16, 1993, four gravel substrate beds were placed in the margins of the pond. On May 24, 1993, several hundred spinedace juveniles were observed in the pond, along with 15-20 adults.

During 1994, up to 9,000 spinedace were hatched in the pond from eggs deposited in the inlet stream. Although infant mortality was high, a significant number of the animals persevered through the fall (Blinn, *et al*, 1994).

For this reason, the surrogate habitat success at the Arboretum Pond suggests that a captive breeding program may succeed, and that restocking the natural habitat in East Clear Creek may be achieved if predator fish are removed.

4.1.3 Parish Alkali Grass, Puccinellia parishii

The Parish alkali grass is a small, blue-green, annual grass known to inhabit the marshy area surrounding the Pasture Canyon Spring source near Tuba City and Moenkopi Arizona. Another small area of its habitat is known near Shonto Arizona. All known populations exist where the soil is moist and saline.

Figure 8. Parish Alkali Grass, Nature Print

The blades of the grass are flat and subinvolute, less than one millimeter wide. The flowering stems are 1-8 inches tall, and the very narrow leaves are 0.5-1.5 inches long and upright. The plants are short-lived, mostly in April and May.

Threats to the survival of this species include cattle grazing, farming, water diversions, and especially, groundwater pumping. It will be shown in a later section that the largest habitat, Pasture Canyon Spring area, is expected to decline in discharge by the year 2012, due to excessive groundwater overdraft from the pumping of drinking water wells at Tuba City and Moenkopi.

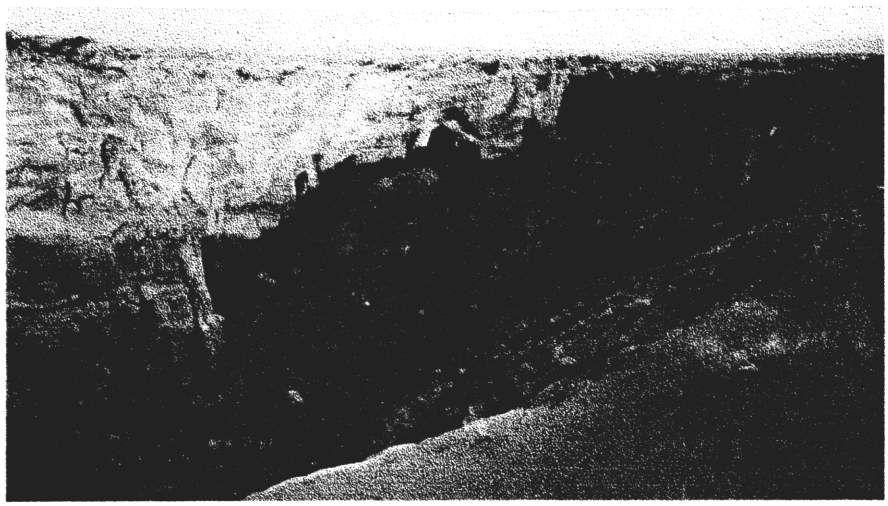


Figure 9. Parish Alkali Grass habitat, Pasture Canyon

4.2 Wild and Scenic Rivers Act

TO BE COMPLETED IN FINAL REPORT, 9/30/95

4.3 Stream Depletions

TO BE COMPLETED IN FINAL REPORT, 9/30/95

4.4 Present Community Consumptive Water Uses

4.5 Agricultural Irrigation Uses

TO BE COMPLETED IN FINAL REPORT, 9/30/95

4.6 Industrial Uses

TO BE COMPLETED IN FINAL REPORT, 9/30/95

4.7 Native American Water Rights

TO BE COMPLETED IN FINAL REPORT, 9/30/95

4.8 Impacts of Future Community Development and Growth

TO BE COMPLETED IN FINAL REPORT, 9/30/95

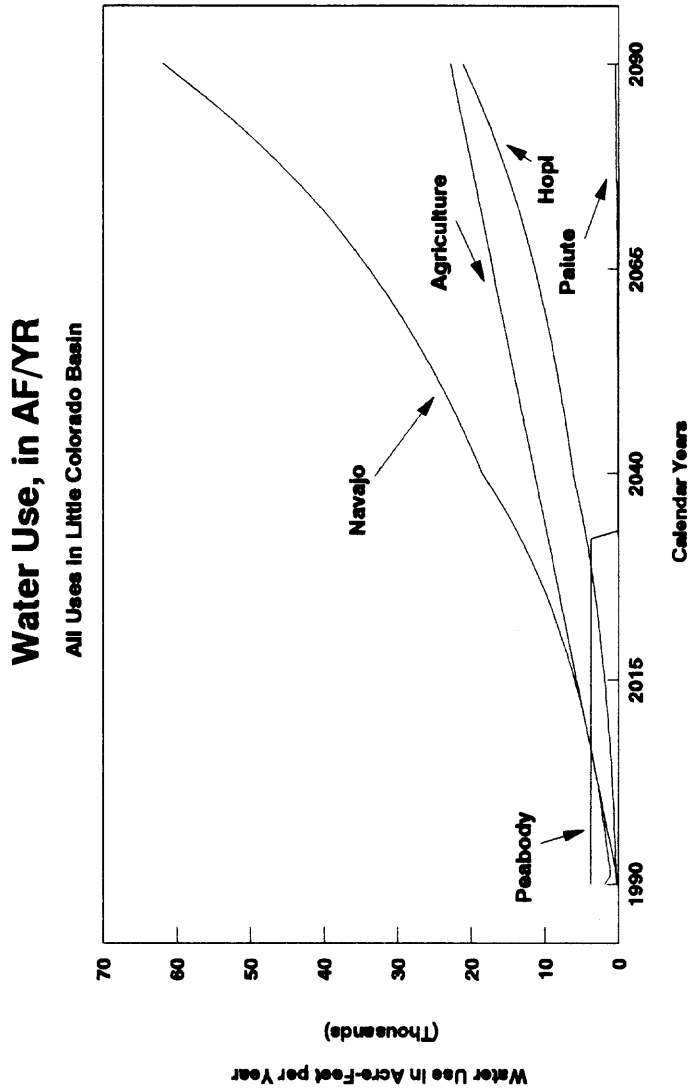


Figure 10. LCR Basin, Projected Water Use

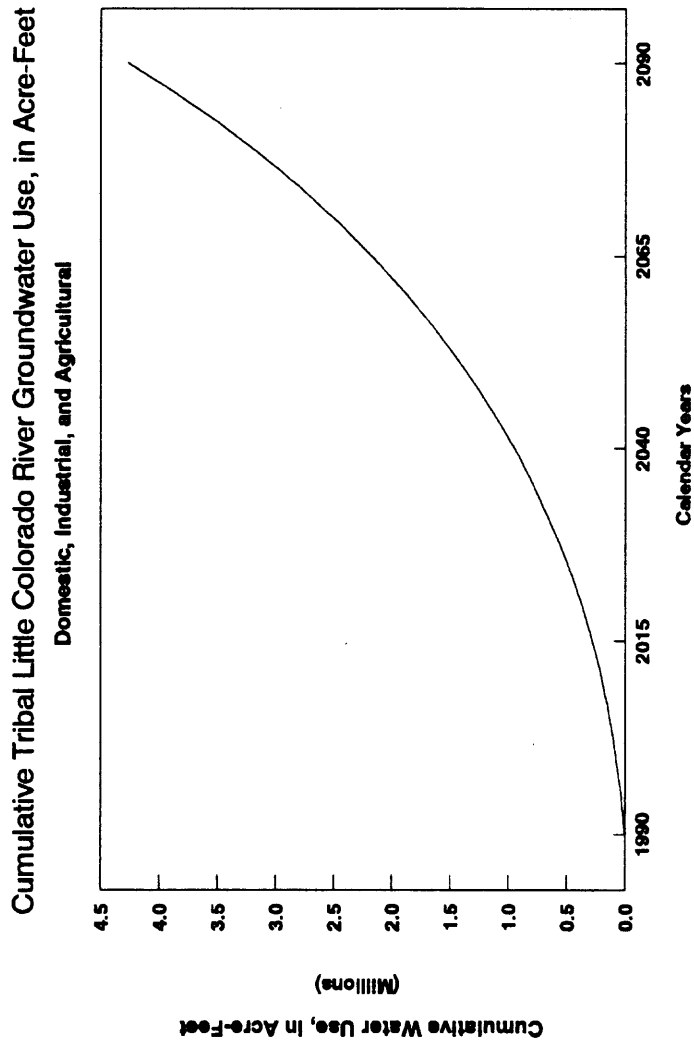


Figure 11. Cumulative Tribal Groundwater Use

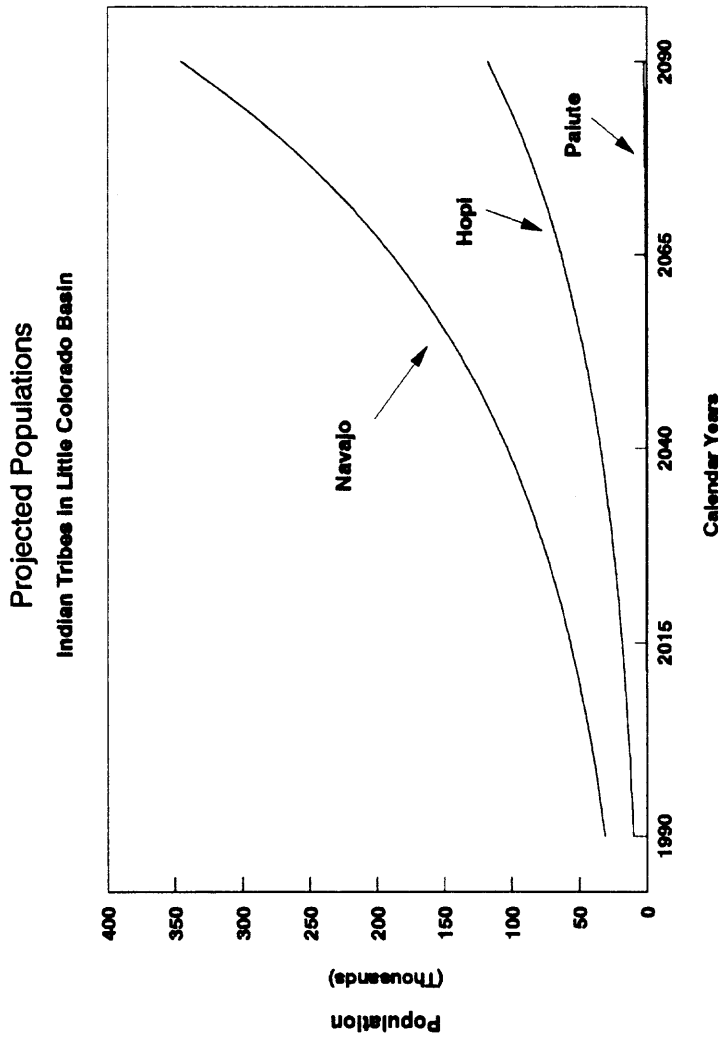


Figure 12. Projected Tribal Populations

Table 1.

Population and Water Use Projections
Indian Tribes, Little Colorado River Basin
1990-2090 A.D.

Year	Population			Water Use in AF/YR					
	Hopi	Navajo	Paiute	Hopi	Navajo	Paiute	Peabody	Agri	Total
1990	10,000	31,075	215	291	1,100	31	3,800	26	5,248
1991	10,250	31,833	220	329	1,128	32	3,800	254	5,544
1992	10,506	32,609	226	369	1,252	33	3,800	482	5,936
1993	10,769	33,404	232	411	1,380	34	3,800	710	6,335
1994	11,038	34,218	237	454	1,514	35	3,800	939	6,742
1995	11,314	35,052	243	499	1,654	36	3,800	1,167	7,156
1996	11,597	35,907	249	547	1,800	37	3,800	1,395	7,578
1997	11,887	36,782	256	596	1,951	38	3,800	1,623	8,008
1998	12,184	37,679	262	647	2,110	39	3,800	1,851	8,447
1999	12,489	38,598	269	701	2,274	40	3,800	2,079	8,895
2000	12,801	39,539	275	757	2,446	42	3,800	2,307	9,352
2001	13,121	40,503	282	815	2,624	43	3,800	2,536	9,818
2002	13,449	41,490	289	876	2,810	44	3,800	2,764	10,294
2003	13,785	42,502	296	939	3,003	45	3,800	2,992	10,780
2004	14,130	43,538	304	1,005	3,204	47	3,800	3,220	11,276
2005	14,483	44,599	311	1,074	3,413	48	3,800	3,448	11,783
2006	14,845	45,687	319	1,145	3,630	50	3,800	3,676	12,302
2007	15,216	46,800	327	1,220	3,856	51	3,800	3,904	12,831
2008	15,597	47,941	335	1,297	4,091	53	3,800	4,133	13,373
2009	15,987	49,110	344	1,377	4,335	54	3,800	4,361	13,927
2010	16,386	50,308	352	1,461	4,588	56	3,800	4,589	14,494
2011	16,796	51,534	361	1,548	4,851	57	3,800	4,817	15,074
2012	17,216	52,790	370	1,638	5,125	59	3,800	5,045	15,667
2013	17,646	54,077	379	1,732	5,408	61	3,800	5,273	16,275
2014	18,087	55,396	389	1,830	5,703	63	3,800	5,501	16,896
2015	18,539	56,746	399	1,931	6,008	64	3,800	5,729	17,533
2016	19,003	58,130	409	2,037	6,325	66	3,800	5,958	18,186
2017	19,478	59,547	419	2,146	6,654	68	3,800	6,186	18,854
2018	19,965	60,999	429	2,260	6,995	70	3,800	6,414	19,539
2019	20,464	62,486	440	2,378	7,349	72	3,800	6,642	20,241
2020	20,976	64,009	451	2,500	7,716	75	3,800	6,870	20,961
2021	21,500	65,570	462	2,627	8,097	77	3,800	7,098	21,699
2022	22,038	67,169	474	2,759	8,491	79	3,800	7,326	22,456
2023	22,589	68,806	486	2,896	8,900	81	3,800	7,555	23,232
2024	23,153	70,484	498	3,038	9,324	84	3,800	7,783	24,028
2025	23,732	72,202	510	3,185	9,763	86	3,800	8,011	24,845
2026	24,325	73,962	523	3,338	10,218	89	3,800	8,239	25,684
2027	24,933	75,766	536	3,496	10,690	91	3,800	8,467	26,544
2028	25,557	77,613	549	3,660	11,178	94	3,800	8,695	27,427
2029	26,196	79,505	563	3,830	11,684	97	3,800	8,923	28,334
2030	26,851	81,443	577	4,007	12,208	99	3,800	9,152	29,266
2031	27,522	83,429	592	4,189	12,750	102	3,800	9,380	30,222
2032	28,210	85,463	607	4,379	13,312	105	3,800	9,608	31,204
2033	28,915	87,546	622	4,575	13,894	108	0	9,836	28,413
2034	29,638	89,681	637	4,778	14,495	112	0	10,064	29,450
2035	30,379	91,867	653	4,989	15,118	115	0	10,292	30,515
2036	31,139	94,107	669	5,207	15,763	118	0	10,520	31,609
2037	31,917	96,401	686	5,433	16,430	122	0	10,749	32,734
2038	32,715	98,751	703	5,667	17,121	125	0	10,977	33,890
2039	33,533	101,159	721	5,910	17,835	129	0	11,205	35,078
2040	34,371	103,625	739	6,160	18,573	132	0	11,433	36,299

Table 2.

Population and Water Use Projections
Indian Tribes, Little Colorado River Basin
1990-2090 A.D.

Year	Population			Water Use in AF/YR					
	Hopi	Navajo	Paiute	Hopi	Navajo	Paiute	Peabody	Agri	Total
2041	35,230	106,152	757	6,314	19,026	136	0	11,661	37,137
2042	36,111	108,740	776	6,472	19,489	139	0	11,889	37,990
2043	37,014	111,391	796	6,634	19,965	143	0	12,117	38,859
2044	37,939	114,106	816	6,800	20,451	146	0	12,346	39,743
2045	38,888	116,888	836	6,970	20,950	150	0	12,574	40,643
2046	39,860	119,738	857	7,144	21,461	154	0	12,802	41,560
2047	40,856	122,657	878	7,323	21,984	157	0	13,030	42,494
2048	41,878	125,648	900	7,506	22,520	161	0	13,258	43,445
2049	42,925	128,711	923	7,693	23,069	165	0	13,486	44,414
2050	43,998	131,849	946	7,886	23,631	170	0	13,714	45,401
2051	45,098	135,063	970	8,083	24,207	174	0	13,943	46,407
2052	46,225	138,356	994	8,285	24,798	178	0	14,171	47,431
2053	47,381	141,729	1,019	8,492	25,402	183	0	14,399	48,476
2054	48,565	145,185	1,044	8,704	26,021	187	0	14,627	49,540
2055	49,780	148,724	1,070	8,922	26,656	192	0	14,855	50,625
2056	51,024	152,350	1,097	9,145	27,306	197	0	15,083	51,731
2057	52,300	156,065	1,124	9,374	27,971	202	0	15,311	52,858
2058	53,607	159,869	1,153	9,608	28,653	207	0	15,540	54,007
2059	54,947	163,767	1,181	9,848	29,352	212	0	15,768	55,180
2060	56,321	167,760	1,211	10,094	30,068	217	0	15,996	56,375
2061	57,729	171,850	1,241	10,347	30,801	222	0	16,224	57,594
2062	59,172	176,039	1,272	10,605	31,552	228	0	16,452	58,837
2063	60,652	180,331	1,304	10,871	32,321	234	0	16,680	60,105
2064	62,168	184,728	1,337	11,142	33,109	240	0	16,908	61,399
2065	63,722	189,231	1,370	11,421	33,916	246	0	17,136	62,719
2066	65,315	193,845	1,404	11,706	34,743	252	0	17,365	64,066
2067	66,948	198,571	1,439	11,999	35,590	258	0	17,593	65,440
2068	68,622	203,412	1,475	12,299	36,458	264	0	17,821	66,842
2069	70,337	208,371	1,512	12,607	37,346	271	0	18,049	68,273
2070	72,096	213,451	1,550	12,922	38,257	278	0	18,277	69,734
2071	73,898	218,655	1,589	13,245	39,190	285	0	18,505	71,224
2072	75,746	223,986	1,629	13,576	40,145	292	0	18,733	72,746
2073	77,639	229,447	1,669	13,915	41,124	299	0	18,962	74,300
2074	79,580	235,041	1,711	14,263	42,126	307	0	19,190	75,886
2075	81,570	240,771	1,754	14,620	43,153	314	0	19,418	77,505
2076	83,609	246,641	1,798	14,985	44,205	322	0	19,646	79,159
2077	85,699	252,654	1,843	15,360	45,283	330	0	19,874	80,847
2078	87,842	258,814	1,889	15,744	46,387	338	0	20,102	82,572
2079	90,038	265,123	1,936	16,137	47,518	347	0	20,330	84,333
2080	92,289	271,587	1,984	16,541	48,677	356	0	20,559	86,132
2081	94,596	278,208	2,034	16,954	49,863	365	0	20,787	87,969
2082	96,961	284,991	2,085	17,378	51,079	374	0	21,015	89,846
2083	99,385	291,939	2,137	17,813	52,324	383	0	21,243	91,763
2084	101,869	299,057	2,190	18,258	53,600	393	0	21,471	93,722
2085	104,416	306,348	2,245	18,714	54,907	402	0	21,699	95,723
2086	107,026	313,817	2,301	19,182	56,245	412	0	21,927	97,768
2087	109,702	321,467	2,359	19,662	57,617	423	0	22,156	99,857
2088	112,445	329,305	2,418	20,153	59,021	433	0	22,384	101,992
2089	115,256	337,333	2,478	20,657	60,460	444	0	22,612	104,174
2090	118,137	345,557	2,540	21,174	61,934	455	0	22,840	106,403

Table 3.

Population and Cumulative Water Use Projections
Indian Tribes, Little Colorado River Basin
1990-2090 A.D.

Year	Population			Cumulative Water Use in AF/YR					
	Hopi	Navajo	Paiute	Hopi	Navajo	Paiute	Peabody	Agri	Total
1990	10,000	31,075	215	291	1,100	31	3,800	26	5,248
1991	10,250	31,833	220	620	2,228	63	7,600	280	10,792
1992	10,506	32,609	226	989	3,480	96	11,400	762	16,727
1993	10,769	33,404	232	1,400	4,860	130	15,200	1,473	23,062
1994	11,038	34,218	237	1,854	6,374	165	19,000	2,411	29,804
1995	11,314	35,052	243	2,353	8,028	201	22,800	3,578	36,959
1996	11,597	35,907	249	2,899	9,828	238	26,600	4,973	44,537
1997	11,887	36,782	256	3,495	11,779	276	30,400	6,596	52,546
1998	12,184	37,679	262	4,143	13,889	315	34,200	8,447	60,993
1999	12,489	38,598	269	4,844	16,163	355	38,000	10,526	69,888
2000	12,801	39,539	275	5,601	18,609	397	41,800	12,834	79,240
2001	13,121	40,503	282	6,416	21,233	440	45,600	15,369	89,058
2002	13,449	41,490	289	7,292	24,043	484	49,400	18,133	99,352
2003	13,785	42,502	296	8,231	27,046	529	53,200	21,125	110,132
2004	14,130	43,538	304	9,237	30,250	576	57,000	24,345	121,408
2005	14,483	44,599	311	10,311	33,664	624	60,800	27,793	133,191
2006	14,845	45,687	319	11,456	37,294	674	64,600	31,469	145,493
2007	15,216	46,800	327	12,676	41,151	725	68,400	35,373	158,325
2008	15,597	47,941	335	13,973	45,242	777	72,200	39,506	171,698
2009	15,987	49,110	344	15,350	49,576	832	76,000	43,867	185,625
2010	16,386	50,308	352	16,811	54,165	887	79,800	48,455	200,119
2011	16,796	51,534	361	18,359	59,016	945	83,600	53,272	215,192
2012	17,216	52,790	370	19,998	64,141	1,004	87,400	58,317	230,859
2013	17,646	54,077	379	21,730	69,549	1,065	91,200	63,591	247,134
2014	18,087	55,396	389	23,560	75,251	1,127	95,000	69,092	264,030
2015	18,539	56,746	399	25,491	81,259	1,192	98,800	74,821	281,564
2016	19,003	58,130	409	27,528	87,585	1,258	102,600	80,779	299,750
2017	19,478	59,547	419	29,674	94,239	1,326	106,400	86,965	318,604
2018	19,965	60,999	429	31,934	101,234	1,397	110,200	93,379	338,143
2019	20,464	62,486	440	34,311	108,583	1,469	114,000	100,021	358,385
2020	20,976	64,009	451	36,812	116,300	1,544	117,800	106,891	379,346
2021	21,500	65,570	462	39,439	124,397	1,620	121,600	113,989	401,045
2022	22,038	67,169	474	42,198	132,888	1,699	125,400	121,316	423,501
2023	22,589	68,806	486	45,093	141,788	1,780	129,200	128,871	446,733
2024	23,153	70,484	498	48,131	151,112	1,864	133,000	136,653	470,761
2025	23,732	72,202	510	51,316	160,876	1,950	136,800	144,664	495,606
2026	24,325	73,962	523	54,654	171,094	2,039	140,600	152,903	521,290
2027	24,933	75,766	536	58,149	181,784	2,130	144,400	161,370	547,834
2028	25,557	77,613	549	61,810	192,962	2,224	148,200	170,066	575,261
2029	26,196	79,505	563	65,640	204,646	2,320	152,000	178,989	603,596
2030	26,851	81,443	577	69,646	216,854	2,420	155,800	188,141	632,861
2031	27,522	83,429	592	73,836	229,605	2,522	159,600	197,521	663,083
2032	28,210	85,463	607	78,214	242,917	2,628	163,400	207,128	694,287
2033	28,915	87,546	622	82,789	256,811	2,736	163,400	216,964	722,700
2034	29,638	89,681	637	87,568	271,306	2,847	163,400	227,029	752,150
2035	30,379	91,867	653	92,557	286,424	2,962	163,400	237,321	782,664
2036	31,139	94,107	669	97,764	302,188	3,080	163,400	247,841	814,274
2037	31,917	96,401	686	103,198	318,618	3,202	163,400	258,590	847,007
2038	32,715	98,751	703	108,865	335,739	3,327	163,400	269,567	880,897
2039	33,533	101,159	721	114,775	353,574	3,456	163,400	280,771	915,976
2040	34,371	103,625	739	120,935	372,147	3,588	163,400	292,204	952,274

Table 4.

Population and Cumulative Water Use Projections
Indian Tribes, Little Colorado River Basin
1990-2090 A.D.

Year	Population			Cumulative Water Use in AF/YR					
	Hopi	Navajo	Paiute	Hopi	Navajo	Paiute	Peabody	Agri	Total
2041	35,230	106,152	757	127,249	391,172	3,724	163,400	303,866	989,411
2042	36,111	108,740	776	133,722	410,662	3,863	163,400	315,755	1,027,401
2043	37,014	111,391	796	140,356	430,626	4,006	163,400	327,872	1,066,260
2044	37,939	114,106	816	147,156	451,077	4,152	163,400	340,218	1,106,003
2045	38,888	116,888	836	154,125	472,027	4,302	163,400	352,792	1,146,646
2046	39,860	119,738	857	161,269	493,488	4,455	163,400	365,593	1,188,206
2047	40,856	122,657	878	168,592	515,472	4,613	163,400	378,623	1,230,700
2048	41,878	125,648	900	176,098	537,992	4,774	163,400	391,882	1,274,145
2049	42,925	128,711	923	183,791	561,061	4,939	163,400	405,368	1,318,559
2050	43,998	131,849	946	191,677	584,692	5,109	163,400	419,082	1,363,960
2051	45,098	135,063	970	199,760	608,899	5,283	163,400	433,025	1,410,367
2052	46,225	138,356	994	208,045	633,697	5,461	163,400	447,195	1,457,798
2053	47,381	141,729	1,019	216,537	659,099	5,644	163,400	461,594	1,506,274
2054	48,565	145,185	1,044	225,241	685,120	5,831	163,400	476,221	1,555,814
2055	49,780	148,724	1,070	234,163	711,776	6,022	163,400	491,076	1,606,438
2056	51,024	152,350	1,097	243,308	739,082	6,219	163,400	506,160	1,658,169
2057	52,300	156,065	1,124	252,682	767,054	6,421	163,400	521,471	1,711,027
2058	53,607	159,869	1,153	262,290	795,707	6,627	163,400	537,010	1,765,035
2059	54,947	163,767	1,181	272,138	825,059	6,839	163,400	552,778	1,820,214
2060	56,321	167,760	1,211	282,233	855,126	7,056	163,400	568,774	1,876,589
2061	57,729	171,850	1,241	292,580	885,927	7,278	163,400	584,998	1,934,183
2062	59,172	176,039	1,272	303,185	917,479	7,506	163,400	601,450	1,993,020
2063	60,652	180,331	1,304	314,056	949,799	7,740	163,400	618,130	2,053,125
2064	62,168	184,728	1,337	325,198	982,908	7,980	163,400	635,038	2,114,524
2065	63,722	189,231	1,370	336,619	1,016,824	8,225	163,400	652,175	2,177,243
2066	65,315	193,845	1,404	348,325	1,051,567	8,477	163,400	669,540	2,241,309
2067	66,948	198,571	1,439	360,324	1,087,157	8,735	163,400	687,132	2,306,748
2068	68,622	203,412	1,475	372,623	1,123,614	8,999	163,400	704,953	2,373,590
2069	70,337	208,371	1,512	385,230	1,160,960	9,270	163,400	723,002	2,441,863
2070	72,096	213,451	1,550	398,152	1,199,217	9,548	163,400	741,280	2,511,597
2071	73,898	218,655	1,589	411,396	1,238,407	9,833	163,400	759,785	2,582,821
2072	75,746	223,986	1,629	424,972	1,278,552	10,125	163,400	778,518	2,655,567
2073	77,639	229,447	1,669	438,888	1,319,676	10,424	163,400	797,480	2,729,867
2074	79,580	235,041	1,711	453,151	1,361,802	10,731	163,400	816,670	2,805,753
2075	81,570	240,771	1,754	467,770	1,404,955	11,045	163,400	836,088	2,883,258
2076	83,609	246,641	1,798	482,756	1,449,161	11,367	163,400	855,734	2,962,417
2077	85,699	252,654	1,843	498,115	1,494,444	11,697	163,400	875,608	3,043,265
2078	87,842	258,814	1,889	513,859	1,540,831	12,036	163,400	895,710	3,125,836
2079	90,038	265,123	1,936	529,997	1,588,349	12,383	163,400	916,041	3,210,169
2080	92,289	271,587	1,984	546,538	1,637,026	12,739	163,400	936,599	3,296,301
2081	94,596	278,208	2,034	563,492	1,686,889	13,103	163,400	957,386	3,384,270
2082	96,961	284,991	2,085	580,870	1,737,968	13,477	163,400	978,401	3,474,116
2083	99,385	291,939	2,137	598,683	1,790,292	13,860	163,400	999,644	3,565,879
2084	101,869	299,057	2,190	616,941	1,843,892	14,252	163,400	1,021,115	3,659,600
2085	104,416	306,348	2,245	635,656	1,898,799	14,655	163,400	1,042,814	3,755,323
2086	107,026	313,817	2,301	654,838	1,955,044	15,067	163,400	1,064,742	3,853,091
2087	109,702	321,467	2,359	674,500	2,012,661	15,490	163,400	1,086,897	3,952,948
2088	112,445	329,305	2,418	694,653	2,071,682	15,923	163,400	1,109,281	4,054,939
2089	115,256	337,333	2,478	715,311	2,132,142	16,367	163,400	1,131,893	4,159,113
2090	118,137	345,557	2,540	736,484	2,194,077	16,822	163,400	1,154,733	4,265,516

5 Demographics and Economic Considerations

TO BE COMPLETED IN FINAL REPORT, 9/30/95

5.1 Population

5.1.1 Native American Population

5.1.2 Non-Indian Population

5.1.3 Population Projections

5.2 Basin Economic Statistics

5.2.1 Native American Economics

5.2.2 Non-Indian Economics

5.2.3 Economic Impacts of Environmental Protection

6 Climatology of the Little Colorado River Basin

Climatology is study of the composite weather conditions and atmospheric variables over an extended period of time (Trewartha, 1968). By comparison, weather represents the current, recent, or immediate future of atmospheric conditions. Although concerned with averages and other descriptive statistics for a given period of record, climate is also concerned with elements of change over time. In the following subsections, the climate, as an aggregate of daily or monthly weather conditions, is defined for the WY 1939-90 study period.

6.1 General Climatic Characteristics of the Little Colorado River Basin

The Little Colorado River Basin is classed as an arid, Mediterranean climate. The climate of the American southwest has much in common with regions such as the inland portion of Spain, in which warm southwesterly winds drive moist air against coastal mountains and the resulting precipitation depletes the air of moisture and leaves a "rain shadow" on the downwind inland slopes. This results in a dry, subtropical environment with a generally biannual precipitation maximum. According to Trewartha (1968), "A distinctive feature of the dry intermontane region of the United States is its biannual rainfall maximum. One maximum consistently occurs in winter. The second is more variable in its occurrence; ... it is a feature of mid- or late summer."

As the examination of the study period climatic variables unfolds, it will become

more obvious how this appropriate description evolves.

6.2 Precipitation

This section details the methodology which has been utilized to reconstruct the precipitation records from 55 climate stations within or surrounding the Little Colorado River Basin. Of these stations, only Flagstaff, AZ has a complete record for the 1939-90 study period.

The precipitation reconstruction effort was initially intended to develop area weighted basin precipitation values to correlate with the gaged basin outflows of Little Colorado River near Cameron plus (+) Moenkopi Wash at Moenkopi. An additional use was to correlate with tree ring indices to reconstruct long-term precipitation and flow data. It quickly became apparent to the DBS&A modeler (Bob Marley) and to Timothy Ward (project consultant) that the available precipitation records were insufficient and too sparsely distributed with respect to time and space to enable accurate modeling of minor Little Colorado tributaries. For this reason, a reliable and practical method had to be employed to provide input of adequate precipitation data into the model. Another factor was time -- the modeling team has deadlines and milestones which have to be met to justify continued funding by GCES. What follows is a discussion of the method employed.

6.2.1 Study Period Precipitation Statistics, WY 1939-90

The purpose of this section is to present precipitation values and statistics which have been reconstructed during the course of this project. The precipitation amounts and variability account for most of the Little Colorado River discharge and flow variability. Although other climate parameters, such as evaporation and temperature certainly have an influence on the losses in the system, the major factor remains precipitation. The following sections are intended to enable a less technical person to evaluate the system input parameters.

6.2.1.1 Descriptive Statistics

Given a series of numbers which represent the measurement of the same variable, either of a different member of a species or of the same member at a different time, the summary statistics of the mean (average), mode, standard deviation, etc. are among the statistics which describe the measurements. First, let us consider the time series, of which most hydrologic and meteorologic variables are composed.

6.2.1.1.1 Time Series Variables, Population, and Sample Variables

Given several measurements of a variable, taken in a sequence of different dates or times, the series, taken in order of the measurement, is called a time series. This series, or any other non-temporal series, consists either of a sequence of measurements or continuous measurements. A sequence of measurements is considered discretized in accordance with the increment in date or time between measurements. If the measurements are taken in a sequence of equal times, such as days, the series is regularly discretized. If the measurements are taken at disparate intervals, the series is irregularly discretized.

In any aggregate of data, the entire collection of the members of a species is called the population. The members of the population which are measured are called the sample. In general, the sample is smaller than the population. Statistical tests exist to estimate the degree to which the sample is representative of the population.

6.2.1.1.1.1 Time Domain

If one plots the values of the measured variables against the dates or times at which they are taken, the resulting graph is called a time series graph.

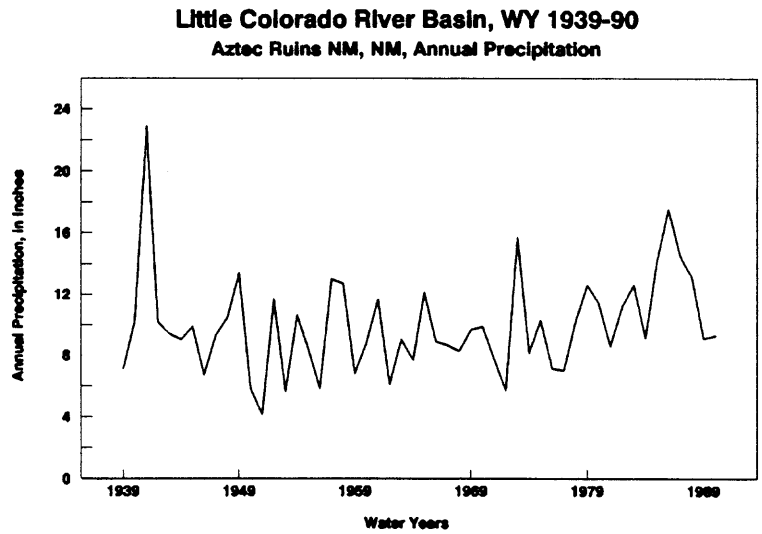


Figure 13. Example of a Time Domain Graph, Annual Precipitation

In this graphical example, the annual precipitation of Aztec NM, New Mexico, is plotted from WY 1939 to 1990. The water year (WY) is plotted on the horizontal axis (x-axis) and the annual precipitation is plotted on the vertical axis (y-axis). As the independent variable (date) varies, the dependent variable (annual precipitation) varies. With such a graph, it is possible to note wet and dry years, the range, or the maximum and minimum of the series.

6.2.1.1.1.2 Frequency Domain

It is generally useful to know how many times in a given time interval that an event of a given magnitude occurs. One example is the need to know the magnitude of a peak flow of a stream for culvert and bridge design purposes. The data is ordered in ascending fashion and divided into equal intervals of the quantity measured. The number of instances of a measurement between intervals is counted. The numbers of instances is plotted against the centers of the intervals. A frequency domain graph, known as a histogram, results. This procedure transforms the representation of the data from the time domain to the frequency domain.

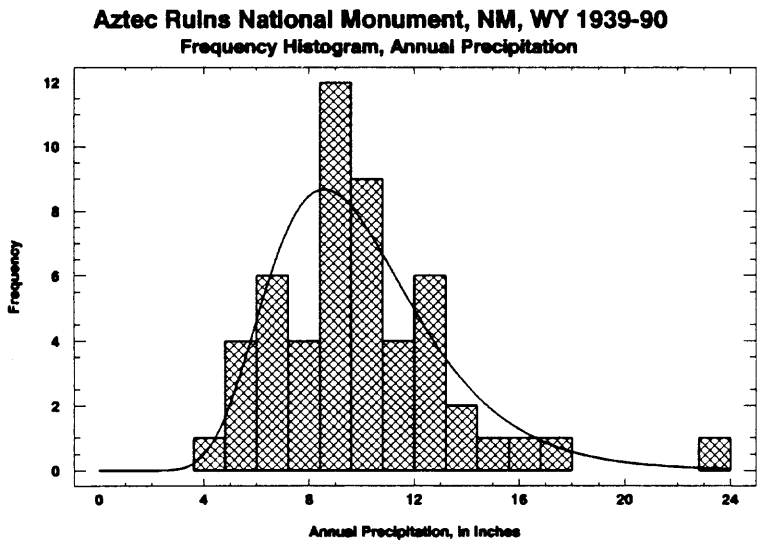


Figure 14. Example of a Frequency Domain Graph, Histogram of Annual Precipitation

6.2.1.1.2 Mean, Mode, and Median - Measurements of Central Tendency

Three statistics of the data series relate to the position of the data (for example, on the x-axis) relative to the central position of the measurements. These measures are typically used to illustrate where on the scale the data is located.

The most familiar of these is the mean, or average. Given n data points,

$$Mean = \frac{1}{n}\sum_{i=1}^{n} x_n$$

Where x_i = the ith measurement of x

n = the number of measurements of x

The mode of the data Value of X for the most frequent occurrence of x in the frequency domain.

The median of the data is the midpoint between the extremes of the measurements of the data.

$$Median = \frac{X_{max} - X_{min}}{2}$$

Where X_{max} = Maximum value of X, and

X_{min} = Minimum value of X.

The following graph illustrates the relationship between the mean, mode, and median for an symmetrical (about the center) and an unsymmetrical data set, the mode being the peak of the curve.

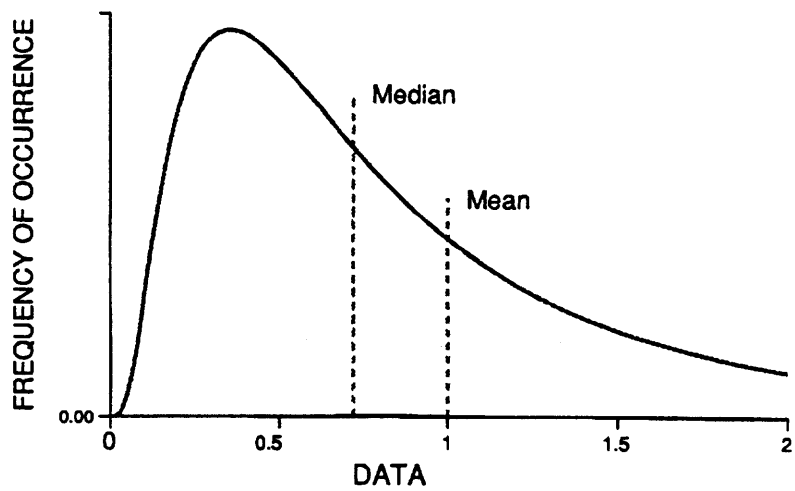


Figure 15. Mean and Mode compared

6.2.1.1.3 Standard Deviation and Variance

Given a distribution of the measurements of a variable from members of a population, a normal sample will possess a shape called the normal distribution. The shape of a distribution of a normal sample of a population is called a "bell curve," due to the shape of the distribution curve. The spread of the curve can be mathematically described by a property called the standard deviation. The square of this measure is called the variance. The population variance is given by:

$$\sigma^2 = \frac{\sum_{i=1}^{n} (X_i - \mu)^2}{n}$$

Where σ = the population variance,

X_i = the ith instance of X,

μ = the population mean, and

n = the number of instances of X.

The standard deviation is the square root of the variance. The units of the standard deviation are the same as those of X, and the units of the variance are the square of the units of X.

If the sample is normally distributed, then the sample mean of the sample means is equal to the population mean:

$$\overline{X}_{\overline{X}} = \mu$$

If the sample is normally distributed, then the sample standard deviation is given by:

$$s_{\overline{X}}^2 = \frac{\sigma^2}{n}$$

Where s = the sample standard deviation,

σ = the population standard deviation,

$\overline{X}$ = the sample mean, and

n = the sample size.

Thus, the population and sample standard deviations are a measure of the spread of the measurements of the variable.

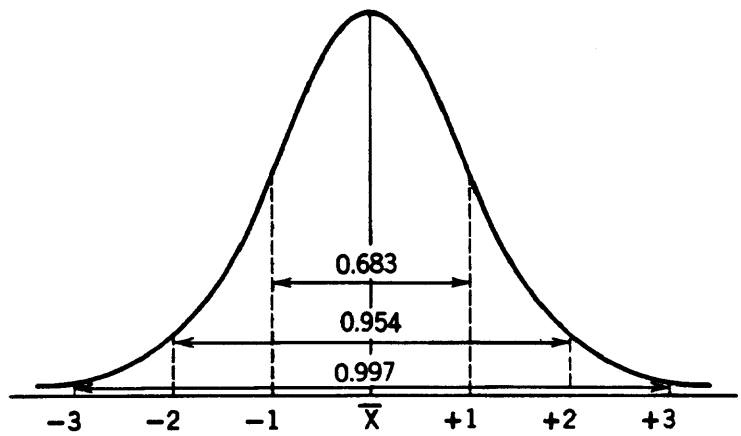


Figure 16. Areas enclosed by successive standard deviations of the standard normal distribution

6.2.1.1.4 Skewness and Kurtosis

Given an symmetrical or unsymmetrical data distribution, the data may not be a standard distribution. In the following graphs, the standard distribution is symmetrical and the unsymmetrical distribution is skewed to the left (positive) or to the right (negative). The formula for the skewness statistic is given as:

$$Skewness = \frac{n * M^3}{(n-1)*(n-2)*\sigma^3}$$

where n = the number of measurements

M^3 = the third moment of the mean $(\sum(x_i - Mean_x)^3$

and σ = the standard deviation.

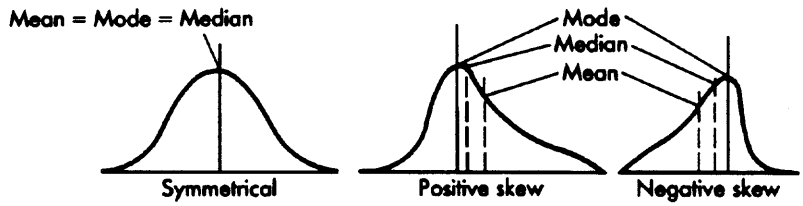


Figure 17. Mean, Mode, and Median for Symetrical and Unsymmetrical Data

Kurtosis is a measure of how "wide" or "skinny" ("broad" or "sharp") the distribution of the variable is, relative to the standard normal distribution (for which the kurtosis is equal to 0). The equation for kurtosis is:

$$Kurtosis = \frac{(n*(n+1)*M^4)-(3*M^2*M^2*(n-1))}{(n-1)*(n-2)*(n-3)*\sigma^4}$$

where M^4 = the fourth moment of the mean: $\sum(x_i - Mean_x)^4$

σ^4 = the fourth power of the standard deviation, and

n = the valid number of cases

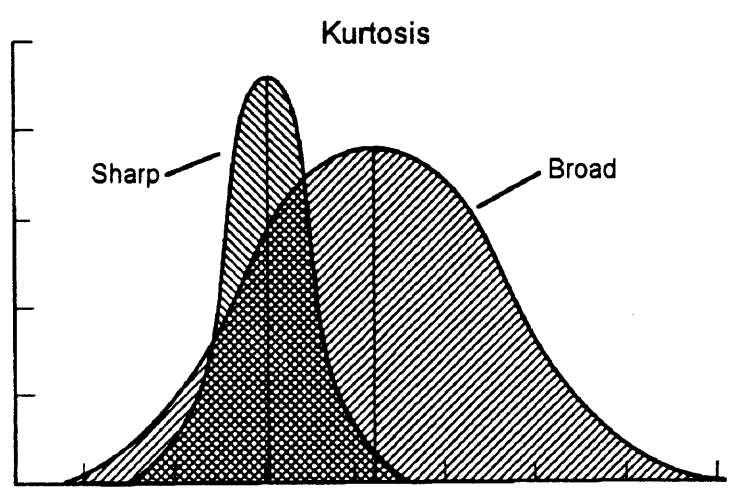


Figure 18. Diagram of Kurtosis

6.2.2 Reconstruction of Missing Climate Data

An initial idea proposed by Ward was to develop a statistical model based upon the Box-Jenkins ARIMA time series method. Unfortunately, the temporal and spatial variability of precipitation in the Little Colorado Basin is too intermittent and irregular to utilize an essentially predictive methodology. Instead, a more usual interpolative method was applied.

6.2.2.1 Techniques of Climatological Data Estimation

Several techniques are well known in reconstructing precipitation values from adjacent known values: (a.) arithmetic averaging (Bedient and Huber, 1988, p.27, Fig. 1.9a) of known precipitation values in the watershed; (b.) isohyetal method, in which an isohyetal map is constructed (Bedient and Huber, 1988, p.27, Fig. 1.9c) and the value between the contours at the unknown station is estimated; (c.) the Thiessen Polygon Method, in which perpendicular bisectors of lines between rain gage stations are constructed and projected to form irregular polygons (Bedient and Huber, 1988, p.27, Fig. 1.9b); the measured data are weighted by area of the polygons and averaged to reconstruct the missing data, and (d.) climatic modeling, in which upper atmosphere parameters are input to an orographic model to predict precipitation amounts at ungaged locations (Hay, Battaglin, *et al*, 1993).

Unfortunately, there are only one or two stations in each sub-watershed of the Little Colorado River Basin. Averaging values on either side of the unknown station may invite errors from orographic effects (elevation differences) or from differences between watershed air flow patterns. For this reason, the enormous Little Colorado Basin watershed, having too few stations in the sub-watersheds, is not a good candidate for arithmetic averaging of the precipitation records.

The isohyetal method, while taking into account spatial distributions of the data, still does not adequately account for differences in elevation or storm track effects. The resolution of the results depends upon the spatial distribution and density of the existing data points.

The Thiessen Polygon Method accurately weights the precipitation falling on the polygon areas to make the interpolation; however, this method still does not account for elevation differences. There is a rarely used method, namely, three dimensional Thiessen Polygons; unfortunately, this method is too complex for repetitive calculations in which the station records are discontinuous from month to month. In addition, there is no user-friendly computer program which will construct the polygons and calculate the weighted interpolations.

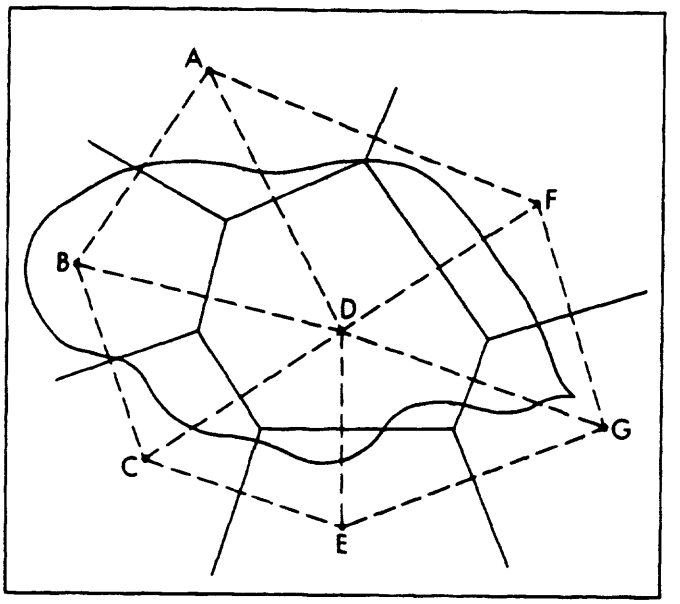


Figure 19. Thiessen Polygons

The necessary parameters for orographic climate modeling (pressure, height, temperature, relative humidity, wind direction, and wind speed) are not available for the Little Colorado River Basin. For this reason, the orographic model is not possible to apply in the case of the LCR.

6.2.2.2 Two-Dimensional and Three-Dimensional Kriging

Kriging is a well-known technique of environmental statistics. The method is employed in several readily available computer codes: GEOEAS by EPA (see Englund, 1991); GRIDZO by Rockware; Surfer for Windows by Golden Software; and GEOPACK, also by EPA. All that is required for two-dimensional Kriging is a data file containing columnar data for latitude, longitude, and known precipitation values. The computer supposedly does the rest. GRIDZO and Surfer both utilize proprietary data output files which cannot be read by an editor program. It is necessary to search through the output files to identify and tabulate the data element which most closely corresponds to the longitude and latitude of the missing value. GEOPACK would not run without crashing on the available computer

system. Therefore, GEOEAS was selected as the code of choice. An easily read mathematical treatment of kriging and its applications is contained in Hoeksema (1992).

The use of the geostatistical method of kriging for climate modeling and reconstruction of missing records is well documented. Cressie (1991) mentions diverse applications of kriging to rainfall, precipitation, atmospheric science, acid deposition, and groundwater flow. Ord and Rees (1979) delineate the advantages of geostatistical methods in precipitation and surface water modeling. Guttorp (1991) discusses the interaction between deterministic and stochastic processes involved in precipitation modeling. For an interesting treatment of acid deposition data, see Cressie (1991, p.259ff) and Rhodes and Myers (1993). Rhodes and Myers utilizes the GEOEAS program for an application similar to the present study.

Initially, two-dimensional kriging was attempted for the LCR Basin precipitation reconstruction, utilizing only latitude, longitude, and known precipitation data. After going through over 500 data output files and tabulating the results, it became apparent the low altitude stations under the influence of high altitude stations gave results which were too large; conversely, high altitude stations under the influence of low altitude stations gave results which were too small. Clearly, another method had to be found.

Upon the suggestion of Evan J. Englund of EPA Las Vegas, and the author of the GEOEAS code (also see Englund, 1993), it was decided to conduct a trend removal preprocessing of the data prior to kriging. The method suggested was to calculate a linear regression, month to month in the record, of precipitation vs. elevation of the stations. The regression residuals were calculated by subtracting the values predicted from the regression from the values from the known stations. The residuals were then kriged. The missing residual values were then added to the regression predicted values to obtain the actual precipitation. Although mathematically precise in concept, the methodology was extremely labor intensive.

Although the results are reasonable when compared to adjacent station records, it must be remembered that the methodology utilized reconstructs a probable value, rather than an actual value. There is no substitute for real data!

The kriging method used was ordinary block kriging on a 50X50 grid. This resulted in 2,500 data points, through which the operator had to search to locate and record the missing values. An examination of the reconstructed records illustrates how extensive the missing record was. An asterisk is placed beside the water year whenever one or more months or record were reconstructed for a given station. In some cases, decades of record were reconstructed for particular stations. Unfortunately, these stations (such as Copper Mine Trading Post, in the headwaters

of Moenkopi Wash) were frequently in ideal locations for modeling particular tributary watersheds. See the data supplement to this report for measured precipitation data.

The first step was to prepare data files from Lotus 1-2-3 spreadsheets by printing to an ASCII file which was of the appropriate format for GEOEAS. The spreadsheets were utilized to calculate the regression residuals. Next, a variogram model had to be fitted for each month's data. The models available in GEOEAS are spherical, gaussian, exponential, and linear. It is assumed that the theory of kriging does not need to be explained here, since it is thoroughly explained in most geostatistics texts.

The second step involved searching through the 500 output data files, each containing 2,500 points on the grid, for the missing residual values. The third step involved adding the missing residuals to the predicted values to obtain the estimated actual data. It is to be noted that residuals were not added to predicted values for stations for which the measured precipitation data is known, since it is of little use to estimate a measured value. Finally, the reconstructed data was transferred to Lotus spreadsheets by month and year, and by station. All-station averages were also calculated month by month to compare with basin outflow.

The following graphs illustrate the raw data isohyetal map and the linear regression and residual plots for the month of October, 1938. Note in the residual contour plot that the residuals are roughly continuous in their spatial distribution.

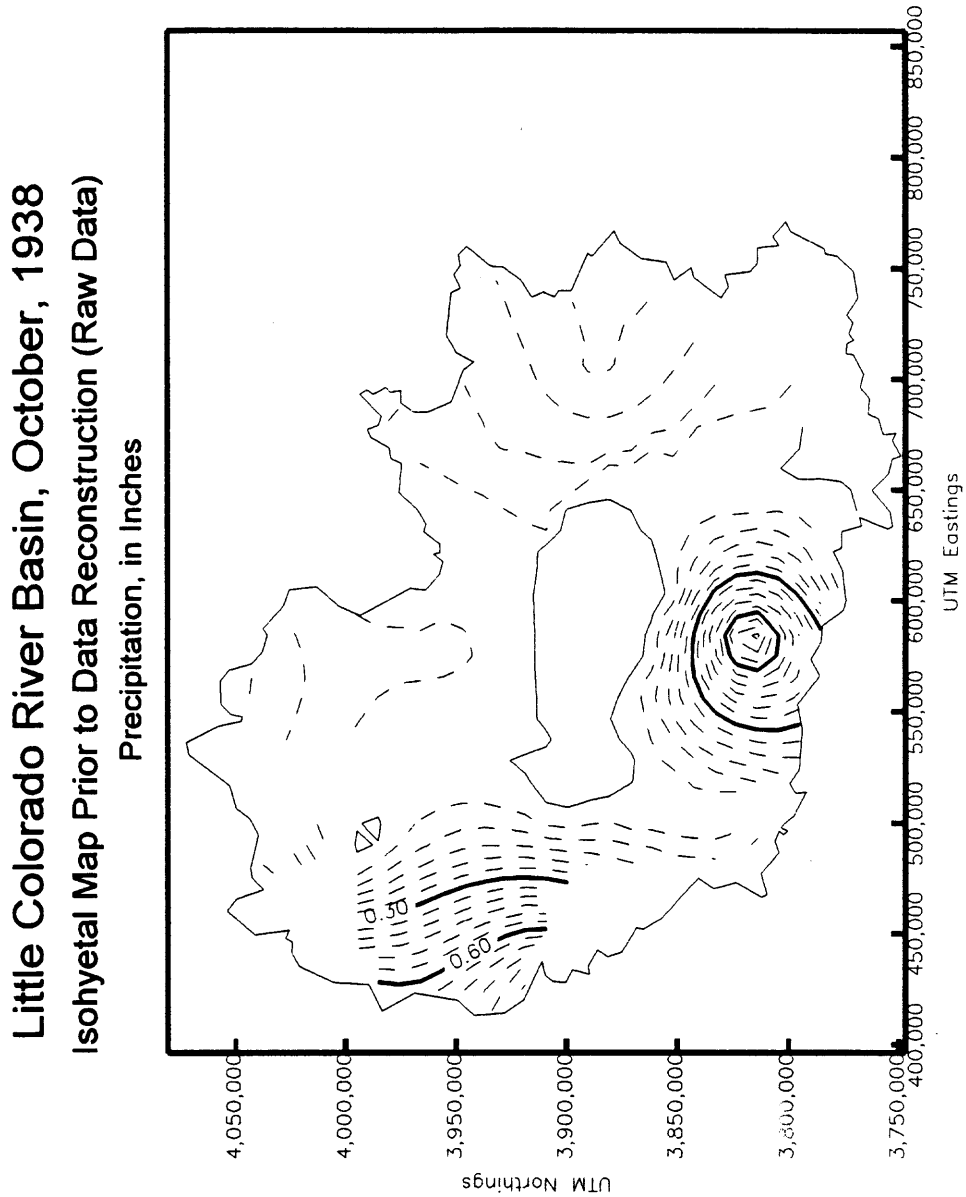


Figure 20. LCR Basin Isohyetal Map from Raw Data, October, 1938

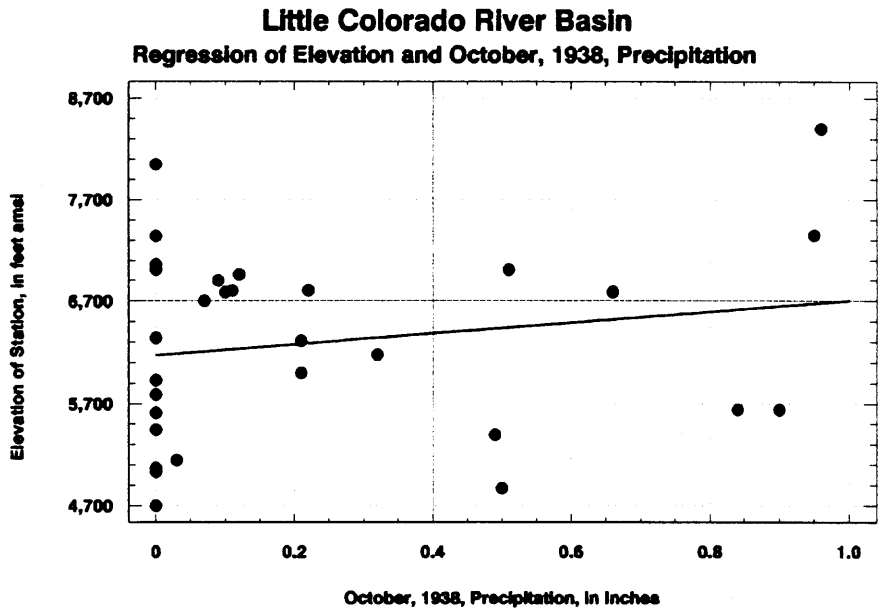


Figure 21. Linear Regression Graph, Precip vs. Elev, Oct, 1938

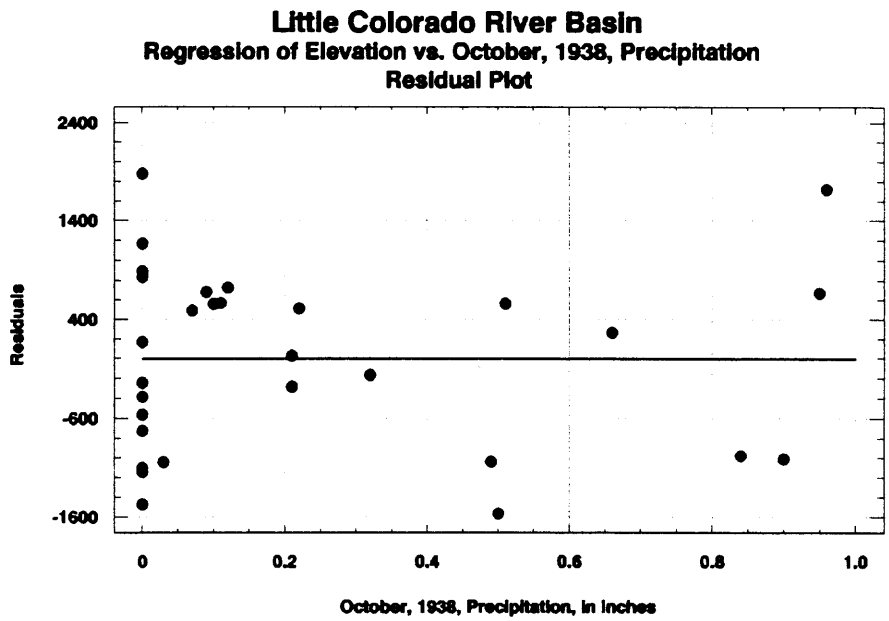


Figure 22. Residual Graph, Precip vs. Elev, Oct, 1938

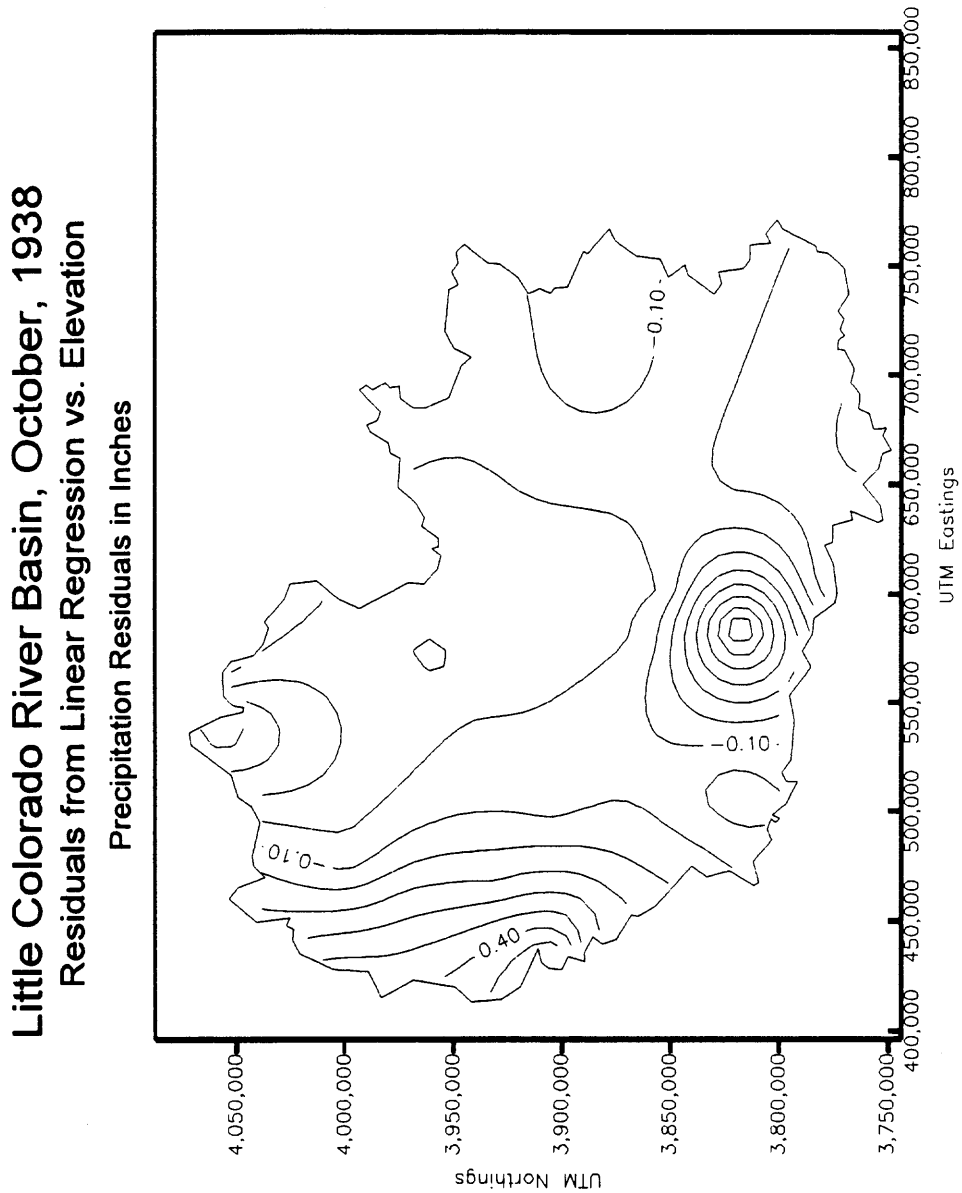


Figure 23. Contour map of Residuals for October 1938

The fitting of the variogram model has a great influence on the accuracy of the kriged results. After certain preprocessing by the program to obtain pair comparison files, a variogram display is printed to screen (monitor).

Variogram of Calcium

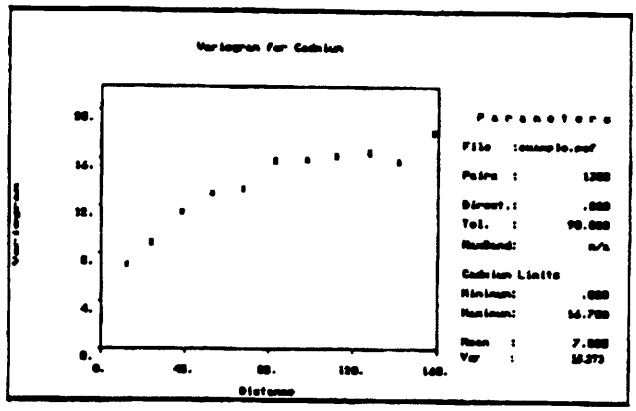


Figure 24. Unfitted Variogram

From this image, it is possible to estimate an approximate model, which will then be refined. In this example from the GEOEAS manual, a spherical model with a Nugget Value of 5, a Sill value of 11, and a Range of 80 is attempted. The results on the monitor show a slight skew to the left when compared to the original pair comparison variogram data.

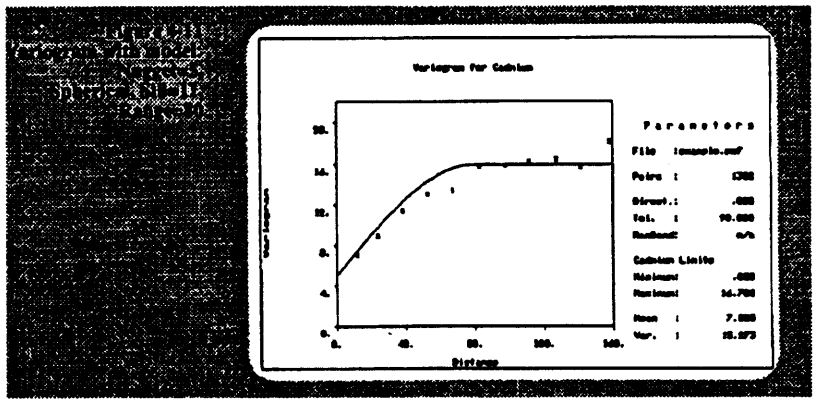


Figure 25. Unfitted Spherical Model Variogram

The range of the model is increased to 100, which shifts to curve to the right.

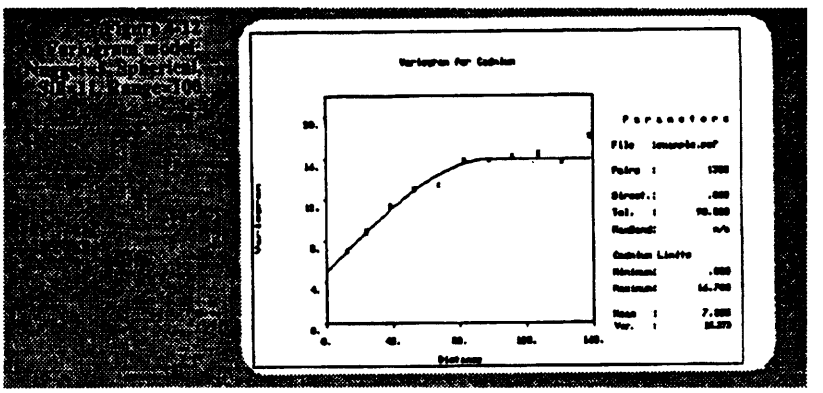


Figure 26. Fitted Spherical Model Variogram

After a suitable model has been selected from the interactive display, a cross-validtion program (XVALID within GEOEAS) is employed to calculate the goodness of fit.

The initial image is of a color-coded low resolution kriged contour map.

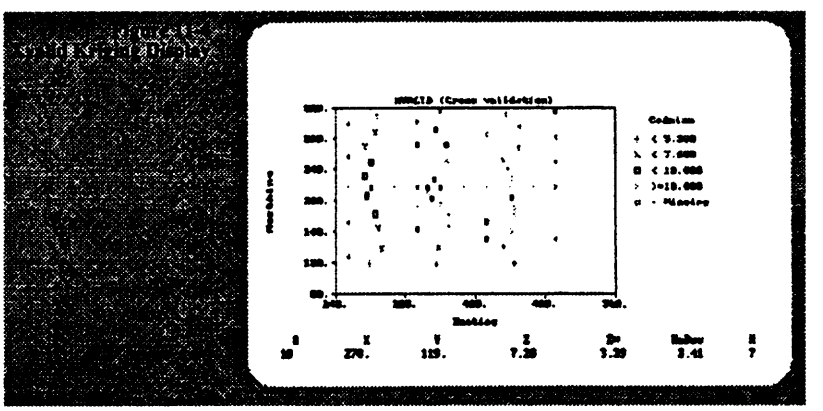


Figure 27. Xvalid Plot of Fitted Variogram

One useful measure of fit is the ZSCORE in the right hand column of the following screen. This value should be approximately 2.5 or less.

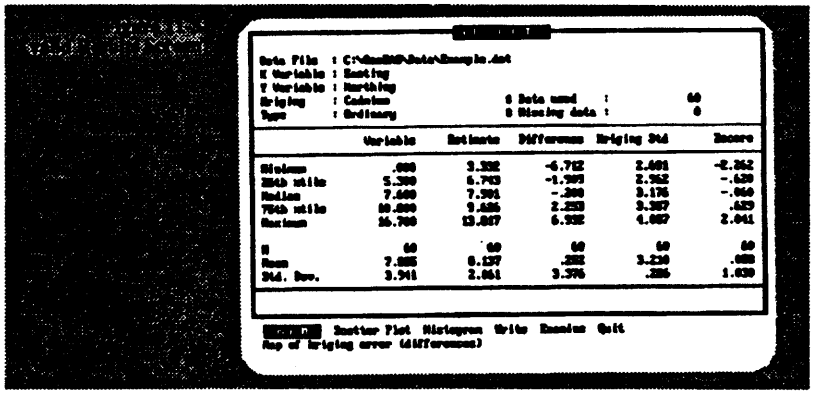


Figure 28. Zscore Table of Fitted Variogram

An error map is displayed in which crosses and x's of varying sizes denote the size of the kriging error. It will be noted that the errors are spatially distributed.

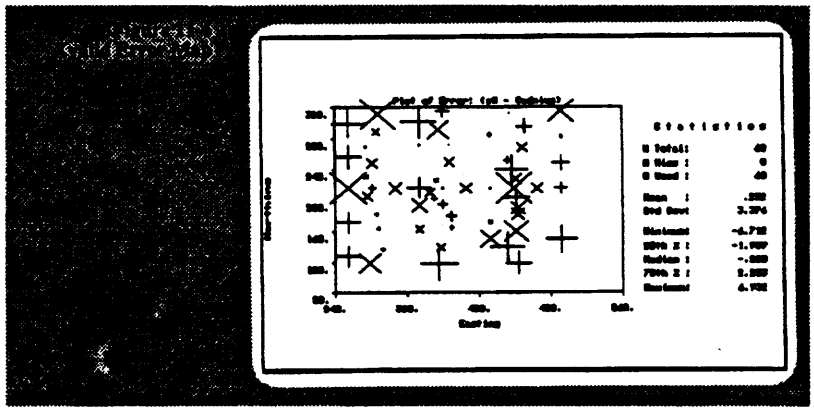


Figure 29. Error Map of Fitted Variogram

A scatter plot of predicted vs. actual values is displayed next from the code results. This enables the operator to look at the scatter and error magnitudes when compared to actual data.

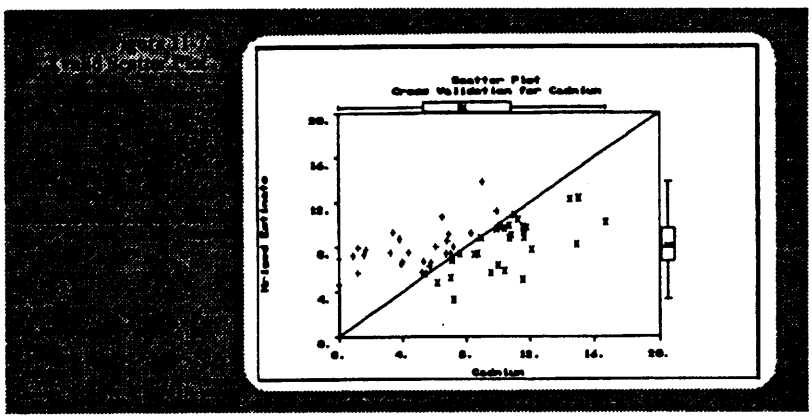


Figure 30. Xvalid Scatter Plot of Fitted Variogram

A histogram further demonstrates the goodness of fit in the frequency domain. The histogram maximum should closely center about the zero (0) error value.

These displays are extremely useful for exploring the mathematical fit of visually equal alternative models for the month's data.

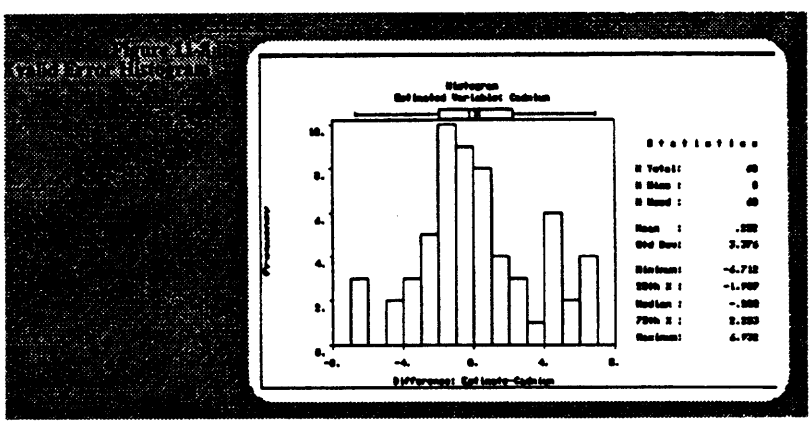


Figure 31. Xvalid Error Histogram of Fitted Variogram

The actual kriging program within GEOEAS is called KRIGE. After the model, grid, and search parameters are input, the results of the kriging are displayed in a color coded hatch map to enable the operator to compare actual and predicted values visually.

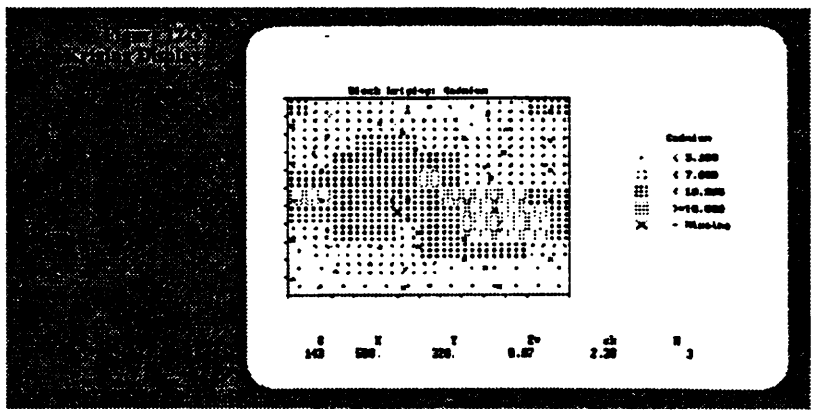


Figure 32. Kriging Display of Fitted Variogram

Finally, the results of the kriging estimates are added to the predicted values from the linear regression to obtain a mixture of actual and probable values for the grid. The following isohyetal map demonstrates the results.

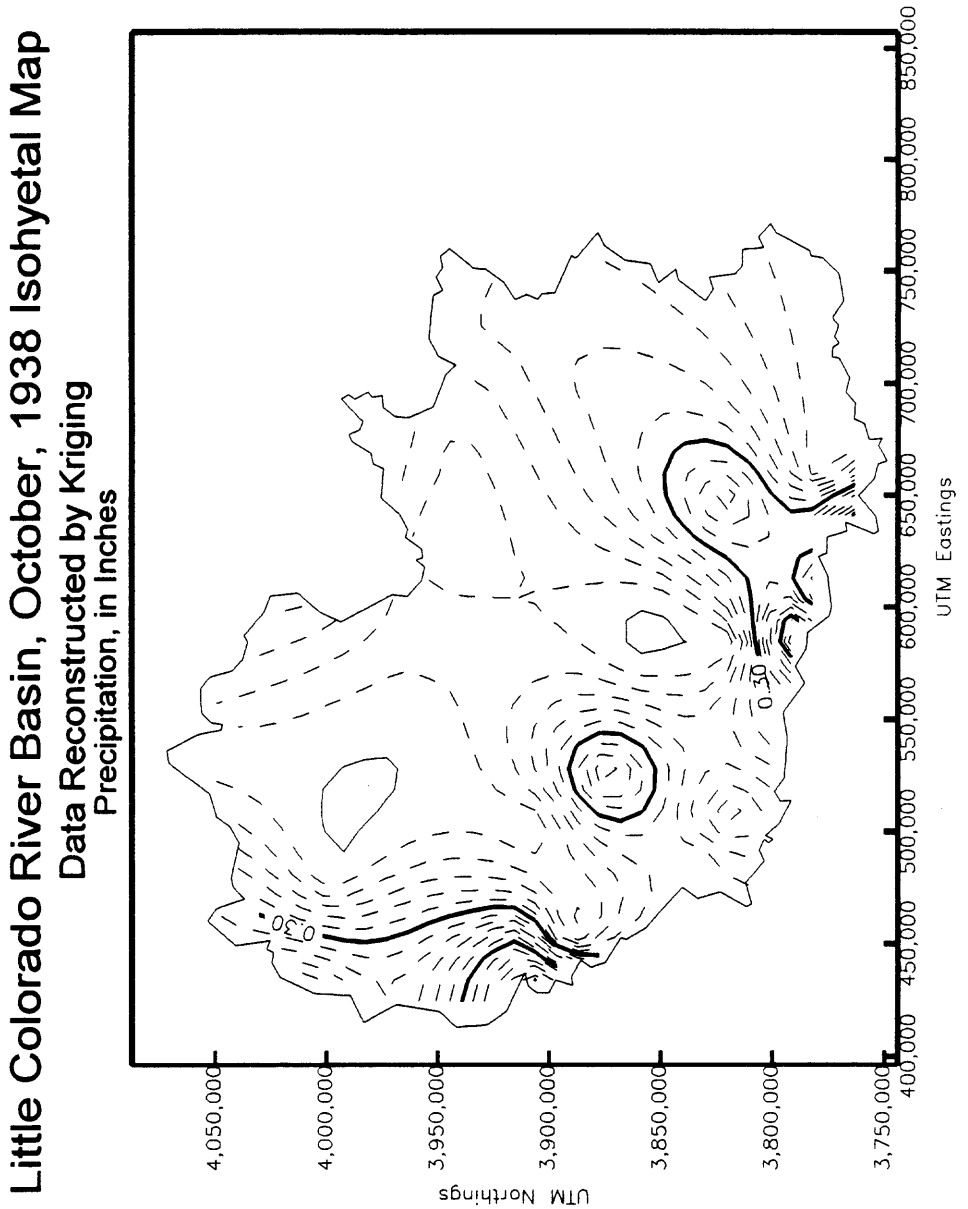


Figure 33. Isohyetal Map from Fitted Variogram Grid

6.2.3 Statistics for Project Model Period 1939-90

The following map locates the available precipitation data with respect to the tributary watersheds of the Little Colorado River Basin. Several watersheds have no precipitation records. Stations outside of the basin are included to compensate for the lack of LCR data and to insure that the calculations are spatially interpolative, rather than extrapolative. This data distribution insures a grid with internal integrity.

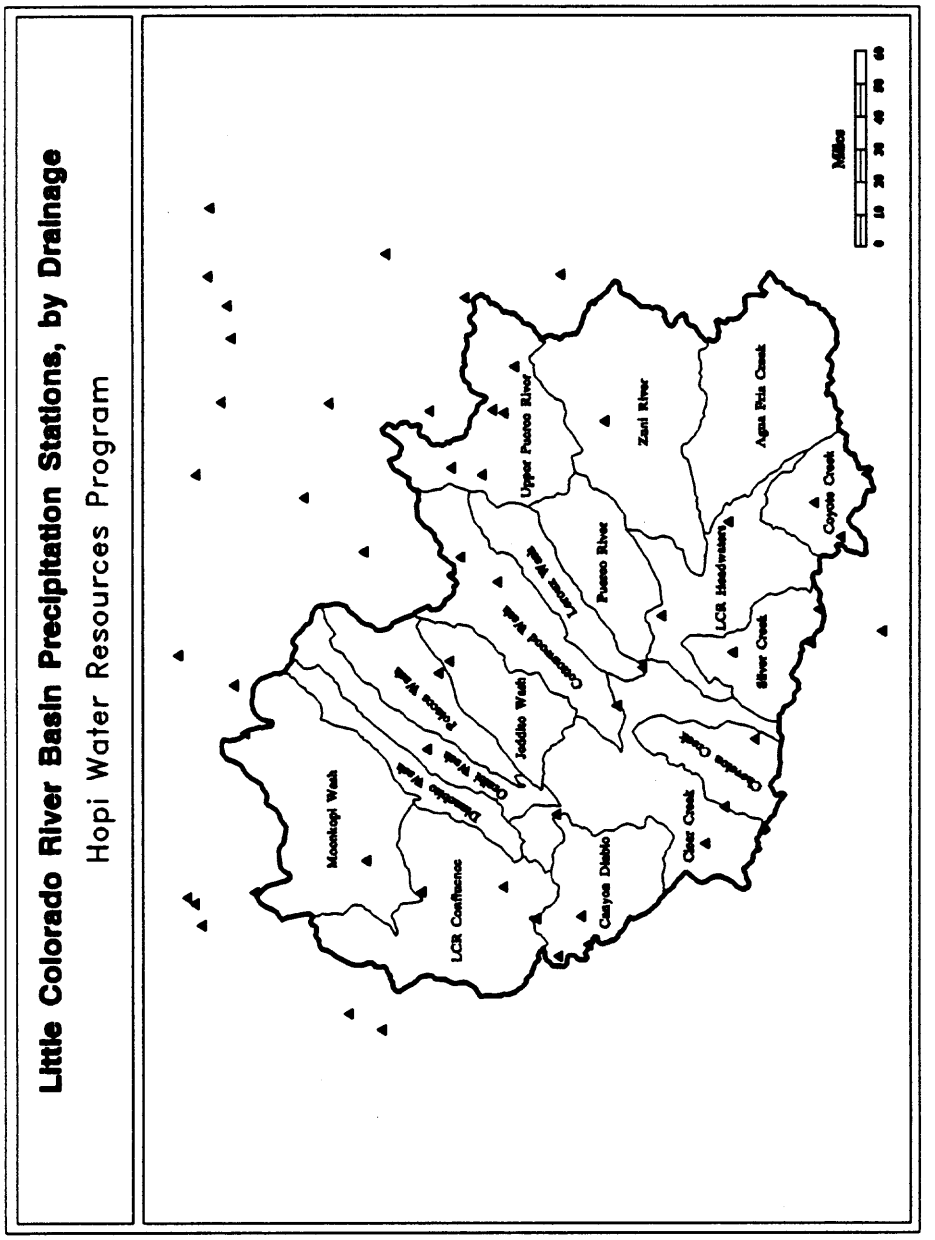


Figure 34. Precipitation Station Location Map and LCR Subdrainages

The following map identifies each climate station by name.

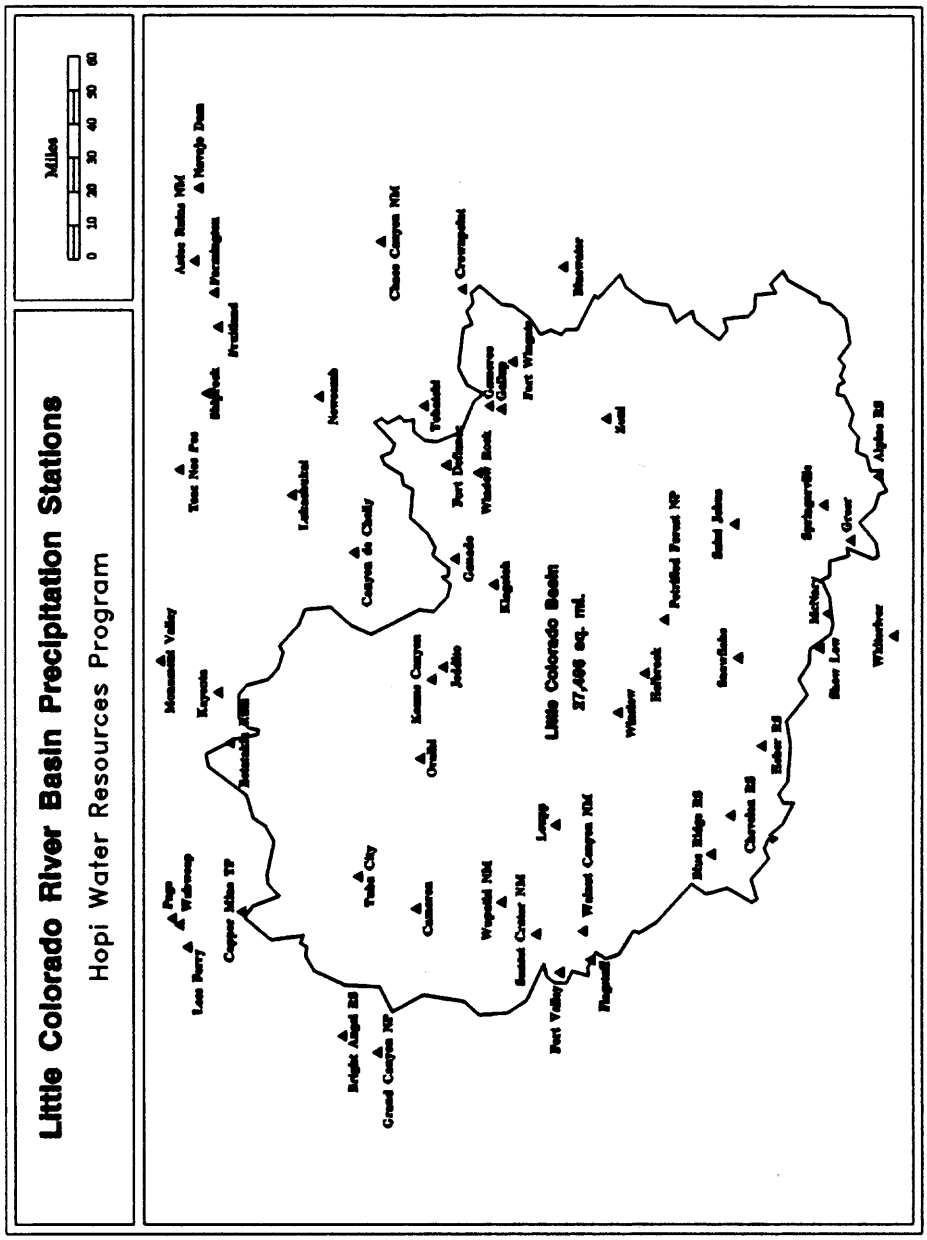


Figure 35. Precipitation Station Location Map

The following thematic map illustrates the annual average precipitation throughout the basin based upon actual periods of record for each station. For further detail, see the data supplement to this report.

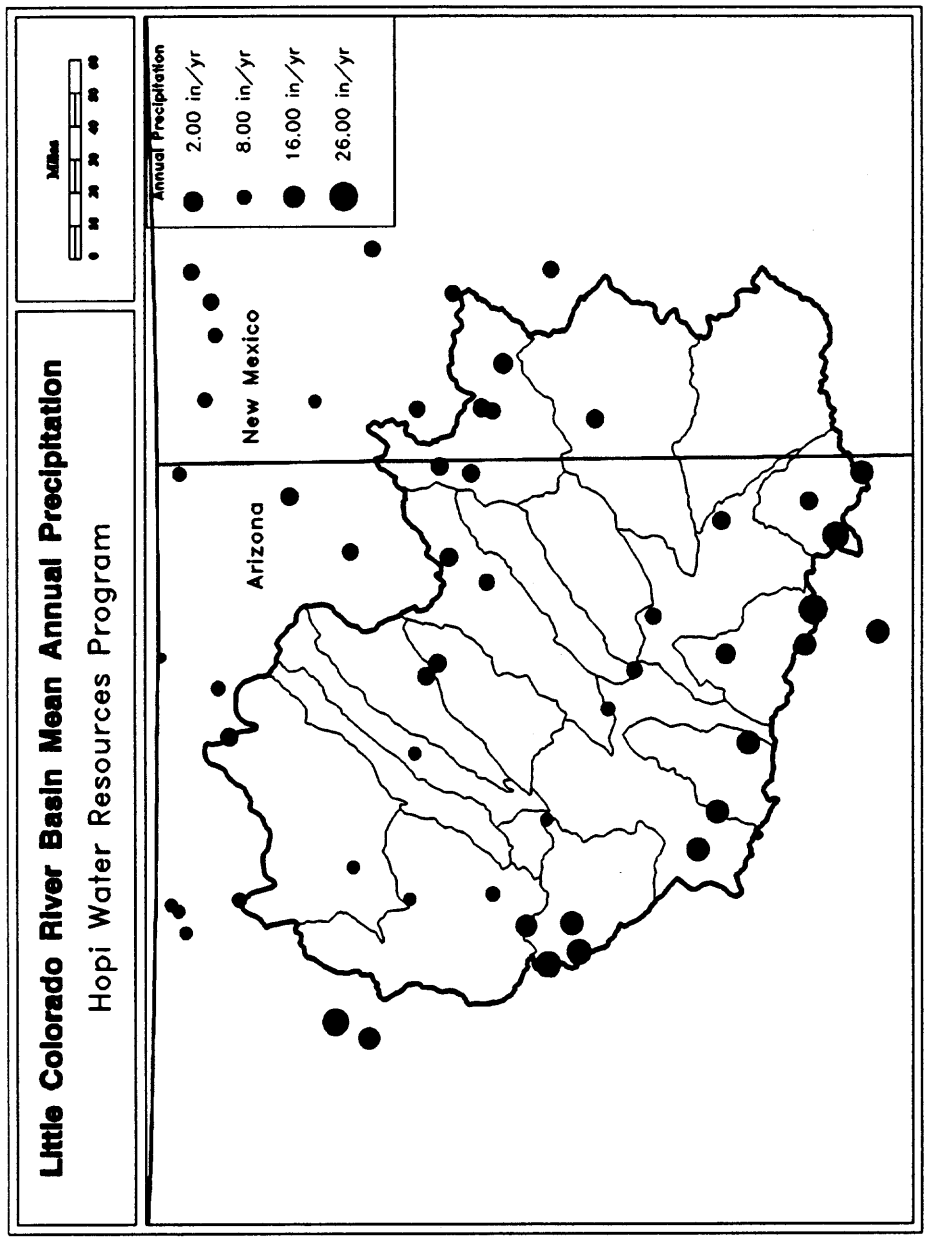


Figure 36. LCR Basin Average Annual Precipitation Map

The following tabulations and graphs show the reconstructed precipitation record for the period 1939-90. Asterisks beside the water year indicate a year in which one or more months of record have been reconstructed. Extensive quotations from Sellars and Hill (1974) are made in the following sections for the purposes of illustrating the climatic conditions for each station.

The general trend for the period shows a decrease from 1939 to 1950, followed by a drought in the 1950's. The recent period shows a gradual increase in precipitation. The long-term records and the tree ring analyses show a cyclic variation with a period of approximately of 90-100 years. Evidently, what is represented in the analysis is a portion of the period in which the values decrease and then increase for most stations.

Several low altitude stations, such as Copper Mine, Leupp, Tuba City, Page, and Wahweap appear to rapidly crest at about 1988. There may be an increase in moisture carrying over from the mountainous regions by unusual storm tracks. Generally, the high altitude stations demonstrate more annual and seasonal variability than the low altitude data points.

The final report will analyze these effects in more detail, as additional long-term data is deduced from tree ring indices.

Table 5. The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Hydrology Study
Precipitation, Reconstructed Averages for All Stations, WY 1939-90

All Station Average Precipitation, in Inches

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.23	0.22	1.10	1.17	0.88	0.88	0.76	0.14	0.04	0.70	1.32	2.20	9.66
1940	0.30	0.76	0.34	0.86	1.28	0.40	0.94	0.47	0.56	0.92	1.93	2.93	11.68
1941	1.39	1.00	2.23	1.52	1.55	2.04	2.13	1.44	0.79	1.29	1.93	2.65	19.96
1942	2.60	0.71	1.26	0.43	0.92	0.53	1.05	0.02	0.01	0.91	1.34	0.74	10.53
1943	1.49	0.12	1.25	1.30	0.51	1.33	0.32	0.39	0.32	0.90	2.56	1.03	11.51
1944	0.92	0.14	1.21	0.73	1.27	1.07	0.98	0.66	0.07	0.98	1.17	1.44	10.63
1945	0.45	1.19	0.97	0.84	0.48	1.64	0.49	0.05	0.13	2.16	1.97	0.27	10.65
1946	0.88	0.03	1.29	0.69	0.27	0.73	0.91	0.22	0.06	2.01	2.95	1.62	11.65
1947	0.74	1.31	0.54	0.42	0.21	0.15	0.08	1.31	0.17	1.02	3.68	0.87	10.49
1948	2.11	0.83	0.93	0.35	1.46	1.06	0.25	0.23	0.76	1.33	1.90	0.93	12.14
1949	1.62	0.09	1.38	2.20	0.69	0.59	0.36	0.68	1.31	2.10	1.37	1.43	13.82
1950	1.18	0.24	0.77	0.45	0.79	0.52	0.06	0.12	0.29	2.10	0.79	0.91	8.23
1951	0.04	0.17	0.07	0.97	0.48	0.44	0.93	0.42	0.00	1.20	2.76	0.57	8.06
1952	1.08	0.77	1.91	1.98	0.44	1.33	1.71	0.14	0.65	1.75	1.74	1.63	15.14
1953	0.00	1.72	0.66	0.31	0.36	0.72	0.76	0.15	0.23	2.67	1.82	0.05	9.46
1954	0.52	0.60	0.50	0.64	0.36	2.12	0.12	0.64	0.47	2.72	1.31	1.92	11.93
1955	0.60	0.15	0.47	0.95	0.78	0.09	0.26	0.40	1.39	1.90	2.81	0.08	9.88
1956	0.19	0.60	0.61	1.33	0.76	0.15	0.51	0.32	0.34	1.71	1.25	0.07	7.83
1957	0.57	0.10	0.22	2.52	0.61	0.92	0.84	1.44	0.67	2.30	2.87	0.08	13.14
1958	2.36	1.18	0.34	0.35	1.11	1.79	0.80	0.42	0.37	0.87	2.09	2.56	14.24
1959	0.89	0.60	0.11	0.26	0.99	0.04	0.81	0.18	0.57	1.30	2.50	0.43	8.69
1960	2.50	0.53	1.87	0.92	0.78	0.55	0.37	0.46	0.38	0.59	1.00	0.67	10.63
1961	2.64	0.38	0.95	0.44	0.30	1.64	0.31	0.12	0.12	1.43	2.52	1.25	12.08
1962	1.66	0.81	1.41	1.13	1.13	0.58	0.10	0.26	0.38	0.74	0.63	1.94	10.77
1963	1.82	1.14	0.50	0.67	0.80	0.49	0.37	0.02	0.05	0.80	4.09	1.21	11.96
1964	0.92	0.70	0.26	0.40	0.33	1.17	0.96	0.25	0.17	2.20	2.49	1.76	11.60
1965	0.07	0.96	1.07	1.41	1.10	0.89	1.39	1.01	0.81	2.53	1.07	1.57	13.88
1966	0.76	1.48	2.73	0.50	0.67	0.33	0.32	0.18	0.40	1.95	1.79	1.22	12.33
1967	0.57	0.76	1.69	0.30	0.04	0.52	0.31	0.49	0.99	2.68	2.32	1.41	12.09
1968	0.16	0.44	3.06	0.40	0.52	0.92	0.82	0.31	0.16	1.88	2.02	0.20	10.89
1969	0.84	0.90	1.15	1.24	0.99	1.09	0.25	0.94	0.32	2.00	1.88	1.03	12.63
1970	1.78	0.81	0.47	0.29	0.25	2.08	0.71	0.07	0.33	1.40	1.73	1.85	11.76
1971	0.68	0.43	0.60	0.27	0.51	0.19	0.34	0.27	0.02	1.08	2.89	1.84	9.12
1972	2.13	0.57	1.46	0.03	0.02	0.02	0.13	0.16	1.56	1.08	1.58	0.72	9.47
1973	6.12	1.01	1.47	0.89	1.47	2.44	0.72	1.03	0.59	1.32	0.99	0.40	18.45
1974	0.12	0.82	0.13	1.86	0.24	0.44	0.28	0.02	0.06	1.82	0.97	0.88	7.65
1975	2.69	0.50	0.42	0.79	1.07	1.50	0.85	0.40	0.04	2.14	0.77	2.03	13.19
1976	0.13	0.93	0.76	0.15	1.25	0.61	0.66	1.25	0.10	2.30	0.99	1.66	10.79
1977	0.55	0.25	0.18	0.99	0.36	0.41	0.47	0.32	0.40	2.25	2.20	1.20	9.56
1978	0.78	0.54	0.49	1.89	1.72	2.25	0.49	0.83	0.09	0.82	1.13	0.89	11.93
1979	1.31	3.31	2.45	2.26	0.68	1.48	0.28	1.66	0.42	0.58	1.37	0.16	15.96
1980	0.97	1.07	0.99	2.60	2.88	1.42	0.70	0.34	0.06	1.15	1.62	1.08	14.88
1981	0.68	0.08	0.47	0.44	0.57	1.91	0.60	0.73	0.58	2.36	1.79	1.28	11.49
1982	1.30	1.12	0.12	1.50	1.60	1.57	0.30	1.07	0.07	1.52	3.07	1.52	14.75
1983	0.24	1.73	1.99	1.37	0.99	1.96	0.70	0.25	0.24	2.27	1.98	2.54	16.25
1984	1.12	1.11	1.38	0.24	0.12	0.88	0.72	0.12	0.37	2.08	2.92	1.75	12.81
1985	1.74	0.50	2.31	1.45	0.66	1.60	1.84	0.30	0.19	2.04	0.97	1.83	15.42
1986	1.49	1.98	0.28	0.10	1.12	1.29	0.82	0.51	0.69	2.47	2.59	1.74	15.08
1987	1.33	2.05	1.12	1.18	1.51	0.85	0.32	0.82	0.52	1.77	2.39	0.51	14.36
1988	1.51	1.87	1.19	1.00	1.01	0.08	1.99	0.28	1.29	1.21	3.44	0.71	15.59
1989	0.48	0.89	0.52	1.00	0.69	0.62	0.04	0.23	0.06	1.53	1.82	0.37	8.25
1990	0.74	0.12	0.35	0.59	1.03	0.66	0.83	0.60	0.22	2.19	1.82	2.36	11.50
1939-90 Average	1.15	0.81	1.00	0.93	0.82	0.98	0.66	0.48	0.40	1.64	1.94	1.23	12.05

Table 6. The Hopi Tribe
Glen Canyon Environmental Studies Little Colorado River Hydrology
All Station Average Monthly Precipitation, WY 1939-90

Month:	Oct	Nov	Dec
Sample size	52	52	52
Average	1.153541	0.813386	0.999892
Median	0.905162	0.756462	0.939552
Mode	0.876097	0.714141	0.769599
Geometric mean	0.685509	0.568332	0.730901
Variance	1.037706	0.389800	0.520804
Standard deviation	1.018679	0.624340	0.721668
Standard error	0.141265	0.086580	0.100077
Minimum	0.000182	0.027727	0.070466
Maximum	6.116375	3.314470	3.056424
Range	6.116193	3.286743	2.985958
Lower quartile	0.535656	0.405741	0.468563
Upper quartile	1.567794	1.090915	1.380489
Interquartile range	1.032139	0.685174	0.911926
Skewness	2.442964	1.540065	0.938337
Standardized skewness	7.191891	4.533828	2.762388
Kurtosis	9.948279	3.923040	0.421449
Standardized kurtosis	14.643471	5.774559	0.620357
Coeff. of variation	88.308833	76.758114	72.174570
Sum	59.984132	42.296080	51.994381

Table 7. The Hopi Tribe
Glen Canyon Environmental Studies Little Colorado River Hydrology
All Station Average Monthly Precipitation, WY 1939-90

Month:	Jan	Feb	Mar
Sample size	52	52	52
Average	0.934217	0.819492	0.980369
Median	0.851726	0.768569	0.882559
Mode	0.785827	0.692817	0.852025
Geometric mean	0.700095	0.632570	0.690022
Variance	0.416515	0.270004	0.422954
Standard deviation	0.645380	0.519619	0.650349
Standard error	0.089498	0.072058	0.090187
Minimum	0.032476	0.024315	0.017508
Maximum	2.603938	2.880726	2.444900
Range	2.571462	2.856411	2.427392
Lower quartile	0.410074	0.460762	0.504311
Upper quartile	1.312229	1.104898	1.491576
Interquartile range	0.902155	0.644136	0.987265
Skewness	0.888213	1.272448	0.471790
Standardized skewness	2.614829	3.745985	1.388912
Kurtosis	0.176492	3.437416	-0.753374
Standardized kurtosis	0.259789	5.059739	-1.108936
Coeff. of variation	69.082441	63.407525	66.337163
Sum	48.579290	42.613573	50.979175

Table 8. The Hopi Tribe
Glen Canyon Environmental Studies Little Colorado River Hydrology
All Station Average Monthly Precipitation, WY 1939-90

Month:	Apr	May	Jun
Sample size	52	52	52
Average	0.655187	0.483825	0.401342
Median	0.632393	0.328608	0.321620
Mode	0.508461	0.316276	0.316083
Geometric mean	0.486303	0.319243	0.221768
Variance	0.230052	0.169871	0.143112
Standard deviation	0.479637	0.412154	0.378302
Standard error	0.066514	0.057156	0.052461
Minimum	0.040316	0.021081	0.001880
Maximum	2.134759	1.663796	1.559360
Range	2.094443	1.642716	1.557480
Lower quartile	0.305951	0.180578	0.095539
Upper quartile	0.835522	0.669815	0.576384
Interquartile range	0.529571	0.489237	0.480845
Skewness	1.350410	1.223083	1.399543
Standardized skewness	3.975498	3.600659	4.120143
Kurtosis	1.989192	0.739453	1.678659
Standardized kurtosis	2.928011	1.088445	2.470920
Coeff. of variation	73.206134	85.186644	94.259207
Sum	34.069726	25.158904	20.869785

Table 9. The Hopi Tribe
Glen Canyon Environmental Studies Little Colorado River Hydrology
All Station Average Monthly Precipitation, WY 1939-90

Month:	Jul	Aug	Sep
Sample size	52	52	52
Average	1.635215	1.940628	1.229961
Median	1.732433	1.854145	1.214297
Mode	1.531594	1.817065	1.200592
Geometric mean	1.506187	1.778190	0.893751
Variance	0.383423	0.631383	0.553426
Standard deviation	0.619212	0.794596	0.743926
Standard error	0.085869	0.110192	0.103164
Minimum	0.575882	0.630183	0.045404
Maximum	2.719063	4.086494	2.930279
Range	2.143181	3.456311	2.884875
Lower quartile	1.077271	1.315552	0.691411
Upper quartile	2.152015	2.507958	1.756620
Interquartile range	1.074744	1.192406	1.065209
Skewness	-0.036221	0.530090	0.228445
Standardized skewness	-0.106631	1.560543	0.672523
Kurtosis	-1.226120	-0.128109	-0.635974
Standardized kurtosis	-1.804799	-0.188572	-0.936129
Coeff. of variation	37.867287	40.945311	60.483714
Sum	85.031186	100.912657	63.957988

The following partial correlation matrix tables examines the possibility of interseasonal correlations. One often hears an "old timer" state something to the effect that if there is a wet July, there will be a dry winter. In the case of the Little Colorado River Basin, the only significant correlation is between March and October, with a correlation of 0.507. The intermonthly correlations are otherwise weak, indicating a random relation between precipitation events for various months.

Table 10. The Hopi Tribe
Glen Canyon Environmental Studies Little Colorado River Hydrology
Basin Mean Monthly Precipitation, All Precipitation Stations, 1939-90

Partial Correlation Matrix

Correlation
(Sample Size)

Month	Oct	Nov	Dec	Jan
Oct	-1.00000 (52)	-0.06373 (52)	0.05246 (52)	-0.35627 (52)
Nov	-0.06373 (52)	-1.00000 (52)	0.31254 (52)	-0.10378 (52)
Dec	0.05246 (52)	0.31254 (52)	-1.00000 (52)	0.08732 (52)
Jan	-0.35627 (52)	-0.10378 (52)	0.08732 (52)	-1.00000 (52)
Feb	0.11863 (52)	0.21083 (52)	-0.26104 (52)	0.25842 (52)
Mar	0.50675 (52)	0.11943 (52)	0.03857 (52)	0.26096 (52)
Apr	0.00863 (52)	-0.07011 (52)	0.25637 (52)	0.13630 (52)
May	-0.06645 (52)	0.16194 (52)	-0.02094 (52)	0.22632 (52)
Jun	0.36169 (52)	0.01915 (52)	0.13407 (52)	0.13416 (52)
Jul	-0.45888 (52)	-0.01545 (52)	-0.14831 (52)	-0.22564 (52)
Aug	-0.10245 (52)	0.22906 (52)	-0.32492 (52)	-0.13330 (52)
Sep	-0.21672 (52)	-0.13596 (52)	-0.03003 (52)	-0.29128 (52)

Table 11. The Hopi Tribe
Glen Canyon Environmental Studies Little Colorado River Hydrology
Basin Mean Monthly Precipitation, All Precipitation Stations, 1939-90

Partial Correlation Matrix

Correlation
(Sample Size)

Month	Feb	Mar	Apr	May
Oct	0.11863 (52)	0.50675 (52)	0.00863 (52)	-0.06645 (52)
Nov	0.21083 (52)	0.11943 (52)	-0.07011 (52)	0.16194 (52)
Dec	-0.26104 (52)	0.03857 (52)	0.25637 (52)	-0.02094 (52)
Jan	0.25842 (52)	0.26096 (52)	0.13630 (52)	0.22632 (52)
Feb	-1.00000 (52)	0.03100 (52)	0.16432 (52)	0.16487 (52)
Mar	0.03100 (52)	-1.00000 (52)	0.05167 (52)	0.20421 (52)
Apr	0.16432 (52)	0.05167 (52)	-1.00000 (52)	-0.06180 (52)
May	0.16487 (52)	0.20421 (52)	-0.06180 (52)	-1.00000 (52)
Jun	-0.05818 (52)	-0.38679 (52)	0.09272 (52)	0.19327 (52)
Jul	-0.22788 (52)	0.35163 (52)	0.11448 (52)	0.03011 (52)
Aug	-0.23171 (52)	-0.08509 (52)	0.18469 (52)	0.07671 (52)
Sep	0.12159 (52)	0.32069 (52)	0.28612 (52)	-0.03673 (52)

Table 12. The Hopi Tribe
Glen Canyon Environmental Studies Little Colorado River Hydrology
Basin Mean Monthly Precipitation, All Precipitation Stations, 1939-90

Partial Correlation Matrix

Correlation
(Sample Size)

Months	Jun	Jul	Aug	Sep
Oct	0.36169 (52)	-0.45888 (52)	-0.10245 (52)	-0.21672 (52)
Nov	0.01915 (52)	-0.01545 (52)	0.22906 (52)	-0.13596 (52)
Dec	0.13407 (52)	-0.14831 (52)	-0.32492 (52)	-0.03003 (52)
Jan	0.13416 (52)	-0.22564 (52)	-0.13330 (52)	-0.29128 (52)
Feb	-0.05816 (52)	-0.22788 (52)	0.23171 (52)	0.12159 (52)
Mar	-0.38679 (52)	0.35163 (52)	-0.08509 (52)	0.32069 (52)
Apr	0.09272 (52)	0.11448 (52)	0.18469 (52)	0.28612 (52)
May	0.19327 (52)	0.03011 (52)	0.07671 (52)	-0.03673 (52)
Jun	-1.00000 (52)	0.30553 (52)	0.07673 (52)	0.03284 (52)
Jul	0.30553 (52)	-1.00000 (52)	-0.17898 (52)	-0.10963 (52)
Aug	0.07673 (52)	-0.17898 (52)	-1.00000 (52)	-0.06214 (52)
Sep	0.03284 (52)	-0.10963 (52)	-0.06214 (52)	-1.00000 (52)

6.2.3.1 Alpine Ranger Station, AZ

As summarized in Sellars and Hill (1974, p. 66):

"Alpine is located at an elevation of 8050 feet in the Apache National Forest of extreme east-central Arizona. It lies in a narrow valley near the headwaters of the San Francisco River, which at this point flows eastward into New Mexico. Escudilla Mountain, at an elevation of 10955 feet, towers over the town eight miles to the north, while the ... White Mountains rise to 11490 feet on Baldy Peak, twenty-five miles to the west-northwest, and to 10115 feet on Greens Peak, thirty miles to the west. Elevations above 9000 feet are also found to the southwest of Alpinein the Blue Mountains of the Gila National Forest and to the distant southeast in the Mogollon Mountains of New Mexico. Between Alpine and the Mogollon Mountains the terrain slopes downward into the valleys of the southward-flowing Blue and San Franciso Rivers. The eastern boundaries of the [White Mountain] and San Carlos [Apache] Indian Reservations are located a short distance to west and southwest, respectively. The vegetation in the area is quite luxuriant, consisting mainly of dense ponderosa pine and Douglas fir forests, although beautiful mountain meadows may also be found. In the river valleys to the south and east, chaparral, oak woodland, and mesquite grass are common.

"Alpine is one of the few towns in Arizona that receives enough precipitation during a normal year to support a dense vegetation growth. Almost half of its average annual total of slightly less than twenty inches usually falls between the first week in July and the middle of September. During this period afternoon thundershowers form almost daily over the mountains in moist, tropical air that flows into Arizona from the south, generally from the Gulf of Mexico. Although these showers are numerous at Alpine, they are only rarely of more than moderate intensity, primarily because of the town's high elevation and correspondingly low temperatures. It is partly as a result of these persistent late afternoon showers that Alpine has early morning relative humidities of about 90 percent in midsummer. In some years during the warmer months moderately heavy rain showers may persist for two or three days in a row. These are practically always associated with the remnants of tropical disturbances moving northward from the Pacific Ocean. They usually bring the heaviest summer precipitation to Arizona.

"Most of the rest of Alpine's precipitation falls during the winter months when middle latitude storms move eastward from the Pacific Ocean. Despite the fact that some of the moisture associated with these storms is lost on the windward sides of the mountains to the west of Alpine, they are still capable of giving the town about seven inches of precipitation during an average winter. Most of this falls as snow, usually in gentle to moderate showers which may continue for several days. Snow accumulation may reach a depth of several feet during the colder winters, particularly on the northern slopes."

During the study period of 1939-90, the precipitation at Alpine showed a gradual increase, as do many stations in the LCR Basin. (See the Brown's exponential smoothing graph.) An explanation for this increase is contained in the section on paleoclimatology (Section 6.2.7). Mean monthly precipitation for the period is concentrated in the months of July through October, the monsoon season. Another peak from December through February represents winter storms. The histogram shows an approximately normal distribution, with flat kurtosis and little skewness. This station is located in the extreme southeast corner of the LCR Basin, and receives its storm tracks from the southwesterly direction from the desert regions of southwestern Arizona.

Table 13. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Alpine Ranger Station, AZ
Station No. 0174
Elevation 8050
Latitude 33d 54m, Longitude 109d 08m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.10	2.28	2.14	1.50	1.41	2.20	0.00	0.00	1.72	3.94	2.11	17.40
1940	0.57	1.66	1.65	0.70	2.21	0.54	1.10	1.56	0.67	2.40	3.43	4.50	20.99
*1941	0.86	1.78	2.31	1.44	2.07	2.08	1.68	1.50	0.65	2.10	3.48	4.62	24.57
1942	2.79	1.64	2.01	1.98	0.87	0.76	0.72	0.00	0.10	1.14	3.08	1.63	16.72
1943	1.66	0.00	1.88	1.92	1.03	0.94	0.20	0.58	1.59	1.89	5.66	2.70	20.05
*1944	2.37	0.00	1.49	0.60	1.20	1.08	0.34	0.39	0.69	2.43	2.51	3.83	16.93
1945	1.87	1.80	1.27	1.68	0.10	2.38	0.20	0.17	0.20	2.44	2.83	1.01	15.95
1946	1.59	0.01	1.36	1.25	0.18	0.98	0.65	0.24	0.84	2.86	4.23	2.86	17.05
1947	1.01	1.49	0.92	0.60	0.24	0.07	0.10	1.07	0.27	3.57	4.73	2.95	17.02
1948	2.19	1.09	1.33	0.86	2.70	2.01	0.03	0.25	0.78	2.51	3.78	1.82	19.35
1949	1.95	0.12	3.00	6.99	0.84	0.91	0.78	0.27	1.18	4.02	3.41	1.30	24.77
1950	1.45	0.12	1.76	0.71	0.94	0.80	0.02	0.06	0.41	5.78	1.02	2.17	15.24
1951	0.30	0.12	0.04	1.38	0.57	0.58	1.06	0.30	0.00	2.04	6.31	0.75	13.45
1952	3.12	0.82	2.62	3.93	0.49	1.37	1.74	0.19	1.63	2.91	2.89	2.93	24.64
1953	0.00	1.57	0.88	0.03	0.65	2.50	0.89	0.35	0.67	4.49	1.58	0.07	13.68
1954	0.41	0.65	0.65	0.70	0.06	3.91	0.03	0.74	0.54	7.32	4.94	2.34	22.29
1955	1.08	0.06	0.29	2.40	0.37	0.29	0.47	0.96	1.18	2.68	4.29	0.31	14.38
1956	0.93	0.35	0.56	1.03	1.77	0.05	0.59	0.30	1.06	2.54	2.50	0.48	12.16
1957	0.79	0.00	0.12	3.02	0.82	1.46	0.90	1.60	2.17	5.40	8.79	0.19	25.26
1958	3.88	0.72	0.23	0.90	2.10	3.08	1.47	0.61	1.26	2.77	4.10	3.61	24.73
1959	3.50	0.84	0.06	0.34	1.23	0.03	0.74	0.00	1.19	3.24	3.37	0.37	14.91
1960	4.47	1.02	2.62	1.55	0.91	0.73	0.23	0.55	0.49	1.61	3.78	1.78	19.74
1961	4.71	0.19	1.98	0.67	0.41	1.39	0.15	0.07	0.75	2.65	4.09	2.29	19.35
1962	3.87	2.77	2.62	2.09	0.80	0.74	0.40	0.01	0.74	1.63	0.95	2.86	19.48
1963	3.40	1.74	1.70	2.50	1.20	0.20	0.50	0.07	0.75	2.06	6.34	2.59	23.05
1964	2.76	1.58	0.15	0.61	1.12	0.63	0.92	0.11	0.65	6.54	4.81	4.62	24.50
1965	0.26	2.11	1.38	2.41	1.87	0.49	0.77	0.19	1.34	5.72	1.73	2.55	20.82
1966	0.75	1.57	4.42	0.73	1.14	0.40	0.28	0.03	0.41	4.03	3.35	2.68	19.79
1967	0.47	2.21	1.45	0.43	0.65	0.98	0.28	0.85	1.06	5.91	5.79	3.86	23.94
1968	0.47	0.95	7.07	0.85	1.16	0.99	0.34	0.12	0.44	4.43	3.94	0.54	21.30
1969	0.57	0.76	2.20	0.99	0.55	0.72	0.28	0.91	0.00	3.22	6.78	3.37	20.35
1970	2.08	0.89	1.14	0.00	0.71	1.32	0.60	0.17	0.23	2.94	3.01	2.58	15.67
1971	2.52	0.19	0.26	0.58	0.09	0.20	0.74	0.00	0.17	2.35	4.98	3.26	15.34
1972	5.06	1.07	2.16	0.00	0.00	0.00	0.01	0.48	3.73	2.65	3.95	1.62	20.73
1973	10.08	0.58	1.46	0.90	2.89	2.25	0.69	1.56	1.21	2.92	3.11	0.16	27.81
1974	0.00	0.48	0.11	2.18	0.03	1.12	0.38	0.32	0.00	4.11	3.55	2.53	14.81
1975	4.75	0.20	0.54	2.74	0.86	1.71	0.48	0.67	0.07	2.98	2.41	5.21	22.62
1976	0.27	1.18	0.64	0.20	2.79	0.99	0.32	1.44	0.20	5.13	2.45	3.72	19.33
1977	0.75	0.42	0.02	0.98	0.39	1.07	1.01	0.00	0.89	4.23	4.17	1.64	15.57
1978	1.49	0.73	0.33	1.72	1.64	2.60	0.06	0.70	0.41	2.42	6.11	1.27	19.48
1979	1.98	7.69	4.34	3.58	0.70	1.11	0.25	1.32	0.57	2.43	2.75	1.84	28.56
1980	0.41	1.34	1.55	4.05	4.22	1.08	0.88	0.58	0.00	2.69	3.52	1.60	21.92
1981	0.82	0.29	0.52	0.45	0.48	2.81	1.02	0.86	0.54	4.57	4.76	2.96	20.08
1982	1.64	0.65	0.02	1.51	1.58	2.02	0.49	0.94	0.35	2.45	4.86	2.20	18.71
1983	0.00	2.40	2.59	1.90	1.84	2.47	0.58	0.05	0.32	2.73	4.56	6.81	26.25
*1984	3.79	1.30	0.97	0.71	0.00	0.45	1.05	0.26	1.51	2.50	5.42	3.00	20.96
1985	3.08	0.69	5.42	1.45	1.15	2.06	2.14	0.34	0.96	3.38	2.98	3.80	27.45
1986	2.27	1.26	0.38	0.11	2.29	1.15	1.17	0.51	2.99	4.06	4.00	1.52	21.71
1987	3.20	3.55	1.35	0.85	3.31	1.01	0.55	1.30	1.46	4.26	5.62	1.16	27.62
1988	1.74	2.07	2.10	0.77	1.42	0.02	2.94	0.14	1.29	4.75	6.32	1.40	24.96
1989	1.30	0.48	0.59	0.73	0.05	0.86	0.01	0.35	0.00	4.34	1.32	1.31	11.34
1990	3.13	0.24	0.27	0.85	1.08	0.54	0.61	1.09	0.48	6.25	4.99	4.48	24.01
1939-90 Average	1.95	1.10	1.52	1.40	1.12	1.17	0.68	0.50	0.78	3.31	3.89	2.29	19.71

* Denotes year in which one or more monthly records are reconstructed.

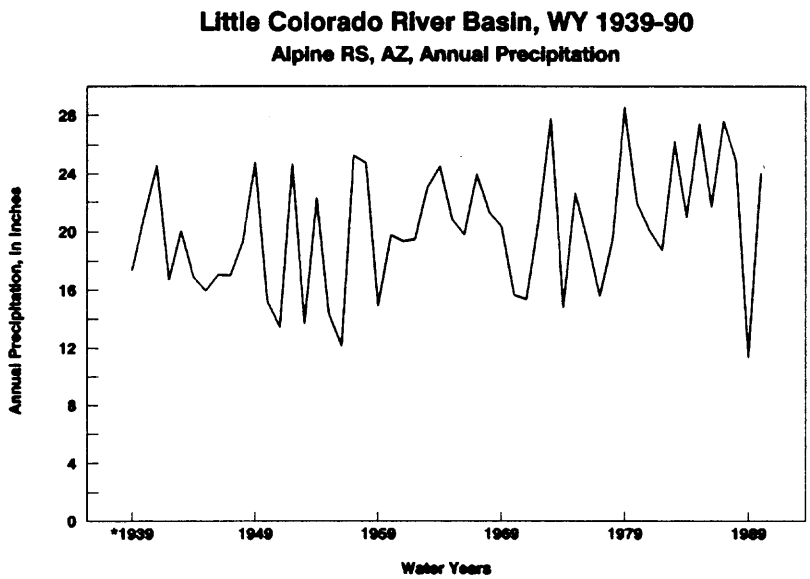


Figure 37. Alpine RS, AZ, Annual Precipitation, WY 1939-90

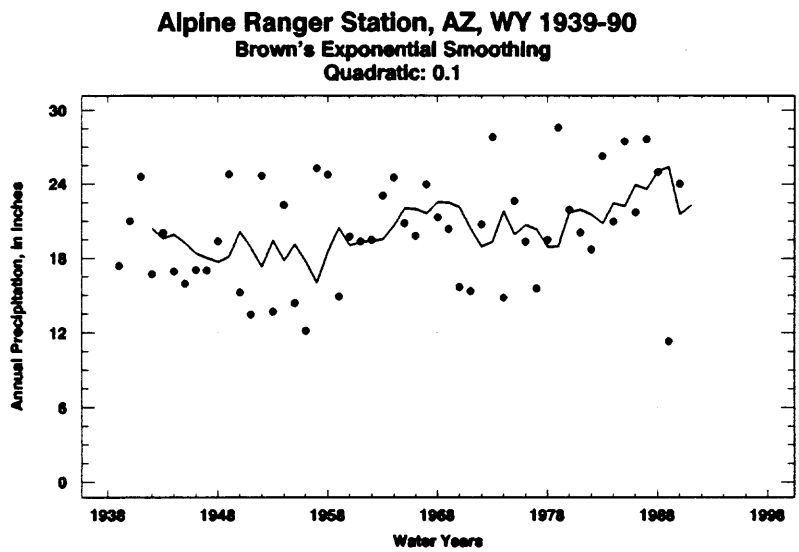


Figure 38. Alpine AZ, Smoothed Annual Precipitation, WY 1939-90

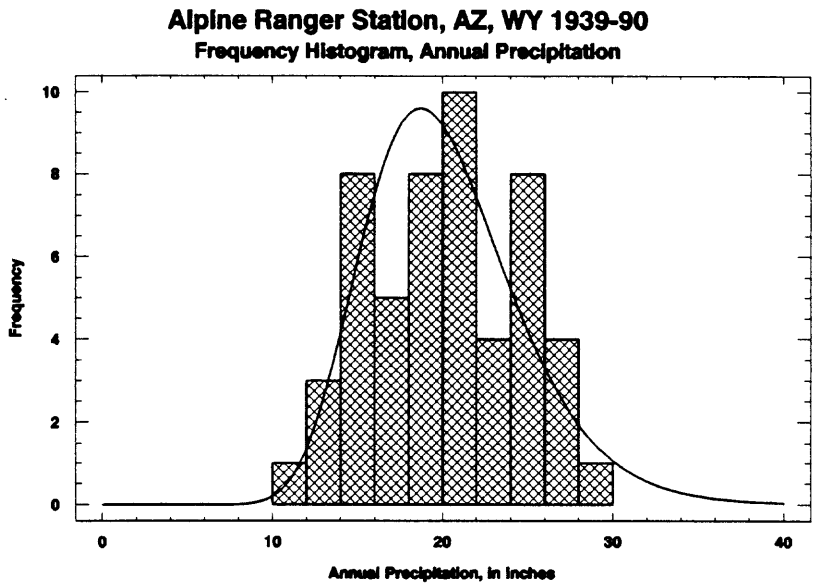


Figure 39. Histogram of Annual Precipitation, WY 1939-90

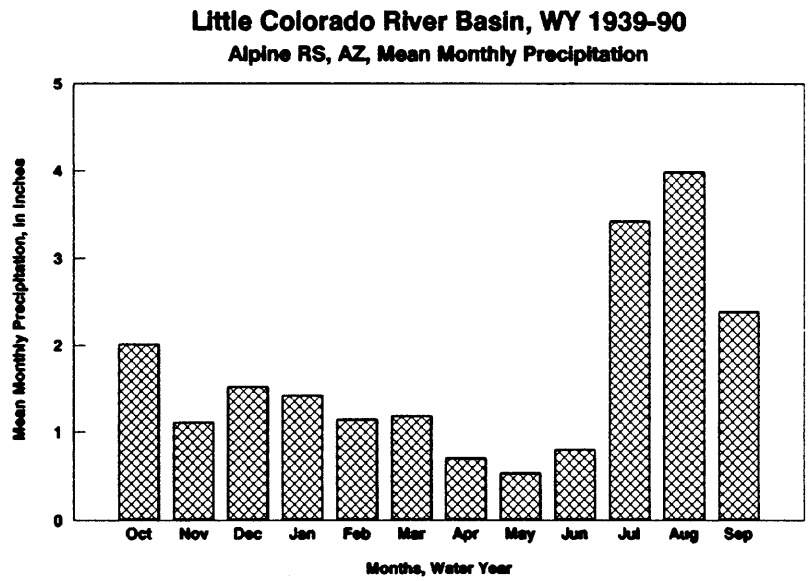


Figure 40. Monthly Distribution of Precipitation, WY 1939-90

6.2.3.2 Aztec National Monument, NM

This station is located at an elevation of 5640 feet amsl in northeastern New Mexico. It has been operated by the National Park Service since 1895-1902 and continuously since 1911. Although this station is located outside the LCR Basin, its inclusion was necessary to insure interpolation, rather than extrapolation, of missing records from stations near Aztec Ruins within the Basin.

The trend during the study period shows a gradual decrease in precipitation from 1939 to 1969, and an increase from 1969 to 1988, after which there is a sharp decrease again. As will be apparent from the section on long-term trends (Section 6.2.4) and paleoclimatology (Section 6.2.7), these trends are related to one cycle of the cyclic tends noted from tree-ring retrodictions.

The mean monthly precipitation distribution peaks from July through October, with a slight winter peak from December through January. It is to be noted that the seasonal variation at desert stations is not as extreme as the variation at high altitude stations. The histogram for the period shows a relatively normal distribution with flat kurtosis and little skewness.

Table 14. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Aztec Ruins National Mon., NM
Station No.: 0692
Elevation: 5640
Latitude: 36d 50m
Longitude: 108d 00m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.90	0.16	0.72	0.69	0.76	0.94	0.38	0.01	0.00	0.02	0.55	1.98	7.11
1940	0.60	0.46	0.86	1.63	1.57	0.36	0.50	0.53	0.30	0.35	1.12	1.91	10.19
1941	0.71	0.94	3.09	1.56	1.45	1.74	2.77	3.82	1.09	0.41	1.11	4.22	22.91
1942	3.83	0.49	1.25	0.25	0.50	0.62	1.85	0.20	0.00	0.31	0.49	0.37	10.16
1943	0.82	0.10	1.15	0.61	0.68	1.39	0.19	0.94	1.41	0.44	0.97	0.67	9.37
1944	0.79	0.37	0.99	0.80	1.32	0.53	1.00	0.66	0.16	1.05	0.45	0.89	9.01
1945	0.85	1.07	1.23	1.16	0.44	1.68	0.73	0.01	0.00	1.19	0.80	0.70	9.86
1946	0.47	0.09	0.92	0.09	0.36	0.63	0.13	0.40	0.27	1.36	1.17	0.80	6.69
1947	0.64	0.48	0.41	0.30	0.59	0.26	0.17	1.98	0.05	0.47	3.32	0.62	9.29
1948	1.73	0.88	0.77	0.12	1.06	1.07	0.15	0.62	1.89	0.07	1.13	0.96	10.45
1949	1.81	0.00	0.97	2.17	0.91	0.53	0.09	1.56	1.77	0.63	2.77	0.18	13.39
1950	0.69	0.00	0.21	0.48	1.17	0.36	0.03	0.03	0.34	0.73	0.26	1.50	5.80
1951	0.00	0.35	0.10	0.83	0.38	0.11	0.09	0.10	0.00	0.07	1.98	0.12	4.13
1952	0.89	0.47	2.15	1.41	0.67	0.46	2.21	0.19	0.57	0.99	0.79	0.87	11.67
1953	0.00	1.03	0.64	0.98	0.00	0.94	0.80	0.00	0.01	0.55	0.66	0.00	5.61
1954	2.17	0.58	0.78	0.29	0.00	1.07	0.05	0.46	0.15	3.02	0.93	1.12	10.62
1955	0.72	0.26	0.29	0.62	1.03	0.05	0.65	0.86	0.19	0.81	2.77	0.16	8.41
1956	0.00	0.21	0.81	1.75	0.43	0.12	0.17	0.05	0.09	1.04	1.07	0.08	5.82
1957	0.68	0.24	0.25	1.97	0.59	1.16	1.26	1.85	0.42	2.46	2.01	0.09	12.98
1958	3.05	1.58	0.50	0.60	0.69	1.56	0.48	0.11	0.45	0.32	1.46	1.88	12.68
1959	1.06	0.29	0.30	0.10	0.35	0.14	1.34	0.00	0.09	0.47	1.69	0.93	6.76
1960	2.36	0.48	1.50	0.80	0.92	0.64	0.45	0.68	0.43	0.13	0.12	0.27	8.78
1961	2.16	0.13	1.29	0.61	0.64	1.48	0.61	0.00	0.00	1.11	2.39	1.24	11.66
1962	1.31	0.33	0.49	0.98	0.84	0.08	0.10	0.36	0.05	0.24	0.01	1.30	6.09
1963	2.41	1.16	0.55	0.25	0.58	0.54	0.46	0.02	0.06	0.79	1.45	0.74	9.01
1964	1.13	0.64	0.19	0.14	0.22	0.43	1.22	0.11	0.00	0.46	1.91	1.20	7.65
1965	0.00	0.80	1.66	0.75	1.39	0.34	1.44	0.84	1.04	1.47	1.20	1.19	12.12
1966	1.29	1.28	1.90	0.23	0.22	0.20	0.33	0.22	0.21	0.30	2.40	0.30	8.88
1967	0.22	0.27	2.86	0.31	0.04	0.31	0.01	0.17	1.10	1.33	1.28	0.72	8.62
1968	0.05	0.25	0.98	0.37	0.70	0.64	1.47	1.25	0.15	1.75	0.56	0.07	8.24
1969	0.70	1.17	0.24	1.76	0.73	0.80	0.17	0.58	1.15	0.46	0.94	0.96	9.66
1970	2.40	0.56	0.74	0.23	0.24	1.16	0.37	0.00	1.15	0.37	0.57	2.08	9.87
1971	0.90	0.48	0.43	0.94	0.28	0.08	0.44	0.68	0.02	0.43	1.83	1.21	7.72
1972	1.46	1.04	0.86	0.07	0.00	0.13	0.09	0.00	0.57	0.08	1.18	0.21	5.69
1973	5.19	0.65	1.16	0.73	0.40	2.69	0.72	1.28	0.71	0.78	0.25	1.16	15.72
1974	0.49	0.18	0.07	2.76	0.35	0.17	0.58	0.03	0.00	1.40	0.29	1.80	8.12
1975	3.89	0.58	0.33	0.54	1.07	0.47	1.24	0.24	0.00	0.55	0.07	1.31	10.29
1976	0.00	0.70	0.38	0.03	1.21	0.01	0.42	0.61	0.00	1.21	0.31	2.21	7.09
1977	0.10	0.05	0.05	2.20	0.03	0.11	0.03	0.68	0.00	1.69	1.53	0.52	6.99
1978	0.27	0.00	0.47	2.23	2.19	1.46	0.81	1.70	0.02	0.06	0.28	0.72	10.21
1979	1.39	2.80	1.76	1.47	0.81	1.46	0.34	1.29	0.12	0.66	0.50	0.00	12.60
1980	1.16	0.99	0.98	2.52	1.02	1.14	0.43	0.52	0.00	0.32	0.64	1.66	11.38
1981	0.87	0.39	0.11	0.14	0.34	1.30	0.88	1.18	0.19	2.66	0.32	0.17	8.55
1982	1.50	0.68	0.07	0.81	1.21	1.89	0.33	0.92	0.03	0.65	1.45	1.62	11.16
1983	0.26	0.96	1.49	1.00	1.07	2.41	0.68	0.43	0.44	1.19	1.48	1.20	12.61
1984	0.47	0.98	2.06	0.21	0.20	0.62	1.10	0.12	0.41	0.57	1.18	1.16	9.08
1985	1.99	0.88	1.36	0.62	0.44	2.64	2.48	0.80	0.21	0.39	0.26	2.01	14.08
1986	1.26	1.32	0.45	0.30	1.37	1.08	1.44	0.32	1.08	3.02	2.97	2.96	17.57
1987	1.26	3.37	1.10	0.74	2.91	1.11	0.20	1.30	0.31	0.56	1.62	0.01	14.49
1988	1.09	1.91	0.78	1.11	0.91	0.16	0.79	0.91	1.56	1.42	2.15	0.33	13.12
1989	0.31	1.12	1.25	1.38	1.51	0.58	0.00	0.06	0.00	1.46	0.95	0.45	9.07
1990	0.79	0.00	0.01	0.72	0.50	0.70	0.93	1.34	0.22	0.79	2.12	1.15	9.27
1939-90 Average	1.17	0.70	0.89	0.87	0.76	0.86	0.68	0.61	0.43	0.87	1.16	1.04	10.03

* Denotes year in which one or more monthly records are reconstructed.

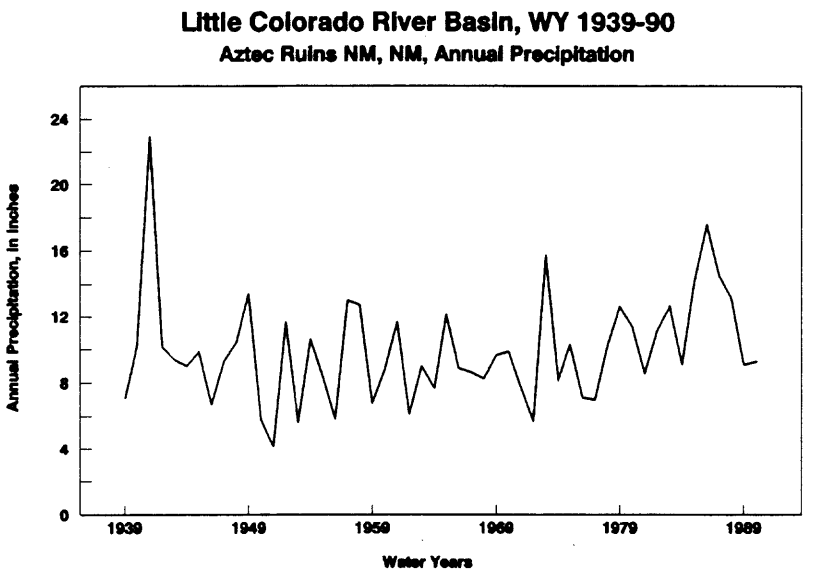


Figure 41. Aztec Ruins NM, NM, Annual Precipitation, WY 1939-90

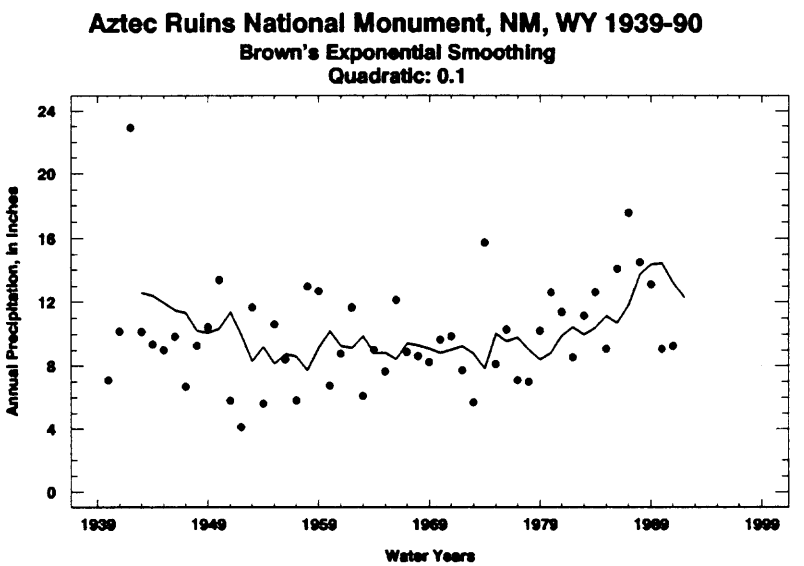


Figure 42. Aztec Ruins NM, NM, Smoothed Annual Precipitation, WY 1939-90

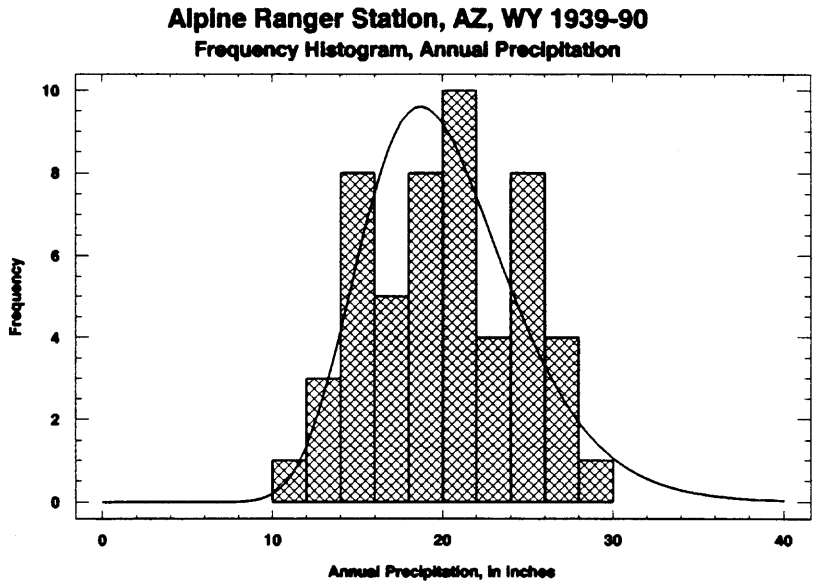


Figure 43. Aztec Ruins NM, NM, Histogram of Annual Precipitation, WY 1939-90

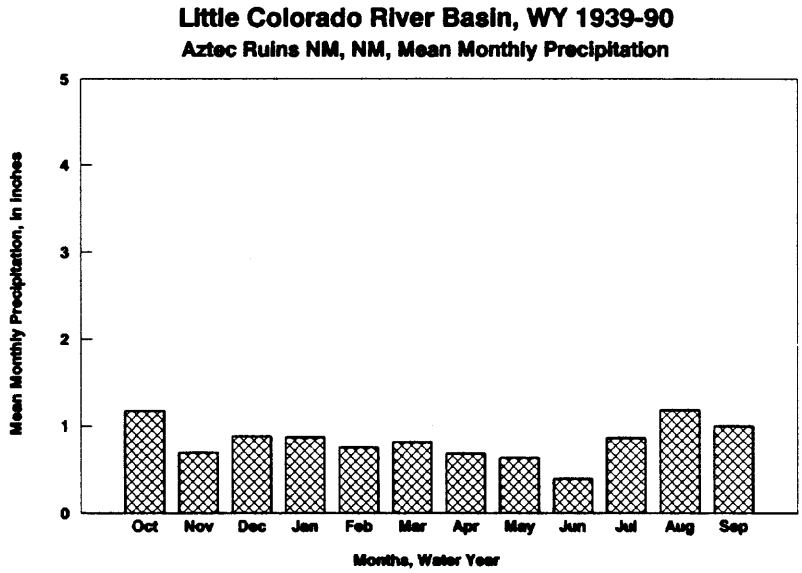


Figure 44. Aztec Ruins NM, NM, Monthly Distribution of Precipitation, WY 1939-90

6.2.3.3 Betatakin Ruins National Monument, AZ

Betatakin is one of three ancient Anasazi Indian ruins within the Navajo National Monument administered by the National Park Service. The period of record for this station is from 1939 to the present. It is located at the extreme northern tip of the LCR Basin.

As summarized in Sellars and Hill (1974, p.102):

"Betatakin is located in the wind-swept northeastern corner of Arizona at a relatively high altitude of 7286 feet. It lies on the southern fringes of Skeleton Mesa, just northwest of narrow Laguna Canyon which separates Skeleton Mesa to the west from Black Mesa on the south. The mean elevation at the forested tops of both of these flat mesas exceeds 7,500 feet. Numerous mesas within 20 miles rise to considerable heights, including Zilnez, 9 miles to the west-northwest, Piute, 20 miles to the north-northwest, and Tyende, 13 miles to the northeast. The terrain gradually slopes downward toward the south-southwestand the north-northeast into the Klethla and Chinle Valleys, respectively. Thirty-five miles to the north the San Juan River of southern Utah follows a westward course, with elevations reaching only 3,500 feet. The highest peak within thirty miles of Betatakin is found to the north-northwest on Navajo Mountain which soars to a majestic 10,416 feet. Scenic Monument Valley to the northeast, a region of towering, isolated, red-rock formations and spires, is a splendid example of some of the unique beauty of Arizona. The famous Rainbow Bridge National Monument in the northwestern section of the Navajo Indian Reservation lies 40 miles to the northwest. A few miles to the north, thousands of tourists are annually attracted to the fascinating caves and Indian cliff-dwellings in the Navajo National Monument. Undoubtedly, the entire northeastern corner of the state is permeated by an enormity of historically and aesthetically interesting features. The vegetation is largely dominated by pinyon and juniper on the mesas to the north and south, while to the east sparse quantities of sage brush and plains grass prevail.

"Betatakin has an essentially dry climate, receiving less than twelve inches of precipitation in most years. Maximum amounts are normally recorded during the warm summer months when local thunderstorm activity predominates associated with strong heating over the mesas. Gusty winds are often associated with these storms, most of the moisture being ultimately obtained from the Gulf of Mexico. The severest warm season rains, often persisting for over twenty-four hours, concide with the rare passage over the state of weakened tropical disturbances from the Pacific Ocean.

"Small amounts of rain are recorded at Betatakin the rest of the year, usually in association with the eastward movement of storm systems from the Northern Pacific Ocean. Occasionally, great quantities of moisture are brought into the area when these storms follow a southerly track. Owing to its high elevation and cold temperatures, most of the winter precipitation falls in the form of snow. In an average year, over fifty-five inches of snow are measured and in December, 1967, a record of 64 inches of snow accumulated."

The precipitation trend from 1939 to 1975 shows a gradual decline, from 1975 to 1988 a sharper increase with greater variability, and from 1988 to 1990, an abrupt decrease. As will be apparent from the section on long-term trends (Section 6.2.4) and paleoclimatology (Section 6.2.7), these trends are related to one cycle of the cyclic trends noted from tree-ring retrodictions.

The mean monthly precipitation distribution peaks dramatically from July through October, with a gradual winter and spring decline from December through April. The histogram for the period shows a lognormal distribution with flat kurtosis and positive skewness.

Table 15. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Betatakin Ruins National Monument, AZ
Station No. 0750
Elevation: 7286
Latitude: 36d 41m
Longitude: 110d 32m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.26	1.96	2.64	1.20	1.45	0.60	0.23	0.00	2.12	0.62	3.25	11.08
1940	0.20	0.38	0.20	0.89	2.00	0.46	1.07	0.35	0.30	0.58	1.80	3.04	8.23
*1941	2.00	0.95	2.51	1.36	1.85	2.49	1.90	0.83	0.79	0.39	1.45	1.78	18.31
*1942	3.98	0.65	1.59	0.27	1.12	0.59	0.98	0.11	0.00	0.77	1.07	0.82	11.13
1943	1.48	0.20	1.95	1.61	1.05	1.26	0.39	0.57	0.03	1.12	1.40	0.76	11.06
1944	1.05	0.62	1.50	1.49	1.77	1.20	1.66	0.79	0.15	0.66	0.89	1.04	11.78
*1945	0.34	1.46	0.96	0.78	0.48	2.13	0.75	0.09	0.17	4.14	2.28	0.08	13.67
*1946	1.12	0.10	1.06	0.50	0.27	0.96	3.21	0.16	0.01	2.42	3.74	0.43	13.98
1947	0.55	1.94	0.55	0.45	0.01	0.05	0.09	0.84	0.25	0.72	3.49	0.53	8.94
1948	3.21	0.58	1.03	0.23	1.92	1.20	0.23	0.00	1.06	0.59	0.82	1.13	10.87
*1949	1.82	0.15	1.84	3.71	1.17	0.70	0.35	0.63	1.20	1.35	0.78	0.71	14.42
*1950	2.11	0.52	0.87	0.63	1.31	0.76	0.18	0.48	0.57	1.83	0.84	0.43	10.54
*1951	0.00	0.18	0.10	0.83	0.52	0.48	1.15	0.65	0.00	0.92	2.61	0.23	7.67
1952	0.98	1.19	3.13	2.42	0.40	1.27	1.05	0.20	1.09	1.50	1.44	3.00	14.67
1953	0.00	1.28	0.56	0.15	0.31	0.40	0.87	0.03	0.08	3.44	3.27	0.74	10.39
1954	0.02	1.11	0.58	0.97	0.59	1.36	0.11	0.87	2.07	2.85	0.14	2.20	10.67
1955	0.51	0.44	0.66	0.97	1.07	0.04	0.18	0.16	0.59	1.59	2.39	0.01	8.60
1956	0.00	0.87	0.30	1.54	0.21	0.33	0.67	0.45	0.10	1.42	1.26	0.04	7.15
1957	0.41	0.07	0.34	3.30	0.67	0.94	1.66	1.83	1.38	1.31	1.82	0.00	13.73
1958	1.74	2.76	0.46	0.40	0.34	1.41	0.74	0.18	0.15	0.40	2.36	2.22	10.94
1959	0.51	0.62	0.11	0.35	1.38	0.06	0.61	0.08	1.33	0.73	1.29	0.07	7.07
1960	1.61	0.58	2.67	0.56	1.62	0.40	0.68	0.21	0.09	0.84	0.49	1.60	9.75
1961	2.40	0.66	1.58	0.83	0.21	2.43	0.61	0.16	0.04	2.28	1.48	1.16	12.68
1962	1.23	1.09	1.34	0.89	1.70	0.66	0.03	0.05	0.45	0.05	0.59	1.43	8.08
1963	1.09	1.06	0.33	0.50	0.92	0.47	0.80	0.05	0.08	0.45	3.62	0.54	9.37
1964	0.56	0.45	0.19	0.53	0.20	2.32	0.81	0.40	0.15	1.64	1.70	0.83	8.95
1965	0.00	0.89	1.41	1.25	1.57	1.52	1.83	0.68	0.68	1.95	1.27	2.49	13.05
1966	1.18	1.91	2.46	1.11	1.16	0.05	0.80	0.47	0.14	1.96	1.10	1.70	12.34
1967	0.73	0.66	1.41	0.51	0.00	0.41	0.32	0.90	1.12	2.67	2.73	1.19	11.46
1968	0.01	0.16	2.05	0.14	0.31	0.52	0.31	0.39	0.16	2.05	1.73	0.19	7.83
1969	1.07	0.81	1.09	1.45	1.31	0.64	0.11	1.04	0.33	1.01	0.85	0.32	9.71
1970	1.87	0.82	0.33	0.54	0.20	1.86	0.65	0.00	0.47	0.78	2.10	0.48	9.62
1971	0.48	0.29	0.99	0.18	0.62	0.16	0.31	0.18	0.08	1.22	2.13	0.28	6.64
1972	2.57	0.91	1.69	0.00	0.00	0.01	0.15	0.00	1.42	0.08	1.85	0.78	8.68
1973	9.01	0.65	2.43	0.45	0.61	2.70	0.49	0.39	0.58	1.25	0.57	0.43	19.13
*1974	0.17	1.27	0.82	1.44	0.37	0.17	0.00	0.00	1.26	0.27	0.55	0.87	7.19
1975	2.41	0.64	0.46	0.48	2.52	1.61	1.01	0.47	0.20	4.27	0.19	1.09	14.26
1976	0.09	2.98	0.66	0.05	1.96	0.37	0.73	1.35	0.08	4.35	1.61	2.58	14.23
1977	0.06	0.29	0.09	0.79	0.13	0.12	0.10	0.20	0.02	1.52	2.19	0.63	5.51
1978	0.09	0.17	0.76	2.33	1.06	1.24	1.04	0.31	0.12	0.15	0.01	0.46	7.28
1979	0.49	3.58	2.81	2.24	0.76	0.96	0.12	1.15	0.67	0.05	1.42	0.04	14.25
1980	1.68	1.72	0.94	1.76	2.40	1.65	0.69	0.74	0.00	0.46	0.92	1.78	12.96
1981	0.82	0.23	0.91	0.14	0.39	1.87	0.99	2.29	1.00	1.49	1.05	0.86	11.18
1982	1.29	0.79	0.20	1.10	1.56	1.46	0.35	1.85	0.00	0.99	4.94	2.29	14.53
1983	1.00	1.88	2.83	1.08	1.22	3.04	1.05	0.07	0.26	2.29	1.69	2.60	16.41
1984	0.40	2.19	1.19	0.32	0.21	0.24	1.08	0.00	0.26	2.51	2.54	0.53	10.94
1985	2.32	0.42	3.21	1.85	0.68	1.63	2.65	0.11	0.04	1.86	0.09	1.94	14.86
1986	1.27	2.80	0.19	0.04	0.74	1.19	0.76	0.48	0.00	2.11	1.19	2.14	10.77
1987	0.90	1.61	0.57	1.31	1.34	1.50	0.27	0.37	0.39	1.21	3.81	0.21	13.28
1988	2.20	2.35	0.77	1.09	1.02	0.56	2.08	0.33	1.82	0.55	3.26	1.78	16.03
1989	0.44	2.71	0.52	0.90	0.95	0.66	0.00	0.24	0.15	1.06	2.07	0.04	9.70
1990	1.04	0.00	0.00	0.71	1.33	0.68	0.69	0.35	0.31	1.35	1.71	2.72	8.17
1939-90 Average	1.20	1.02	1.14	1.00	0.94	1.01	0.77	0.48	0.46	1.45	1.68	1.12	11.23

* Denotes year in which one or more monthly records are reconstructed.

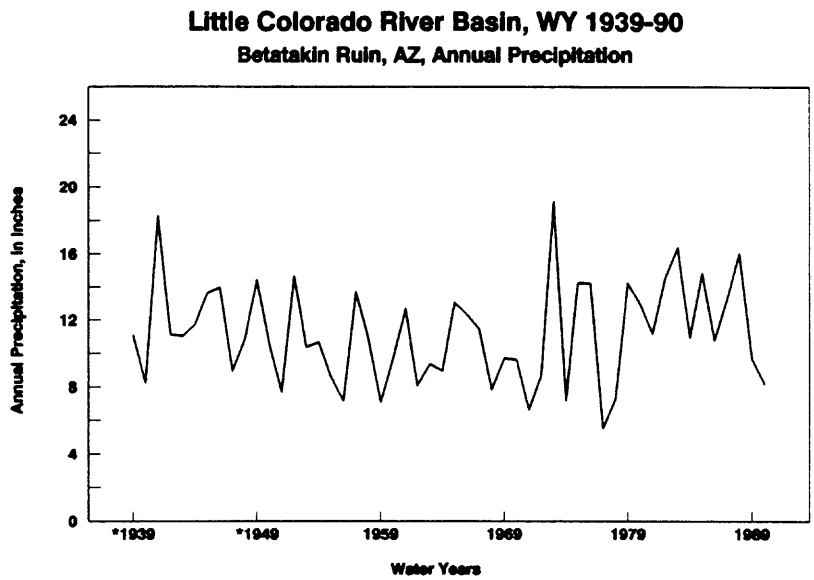


Figure 45. Betatakin Ruins, AZ, Annual Precipitation, WY 1939-90

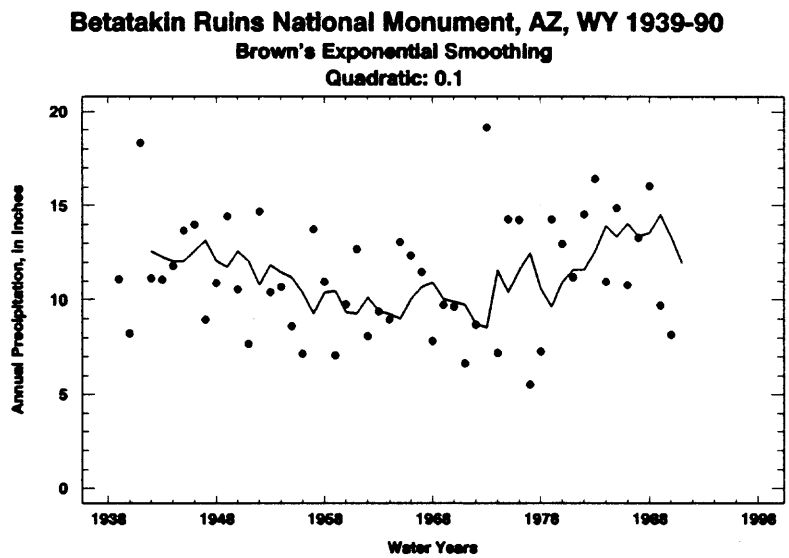


Figure 46. Betatakin Ruins, AZ, Smoothed Annual Precipitation

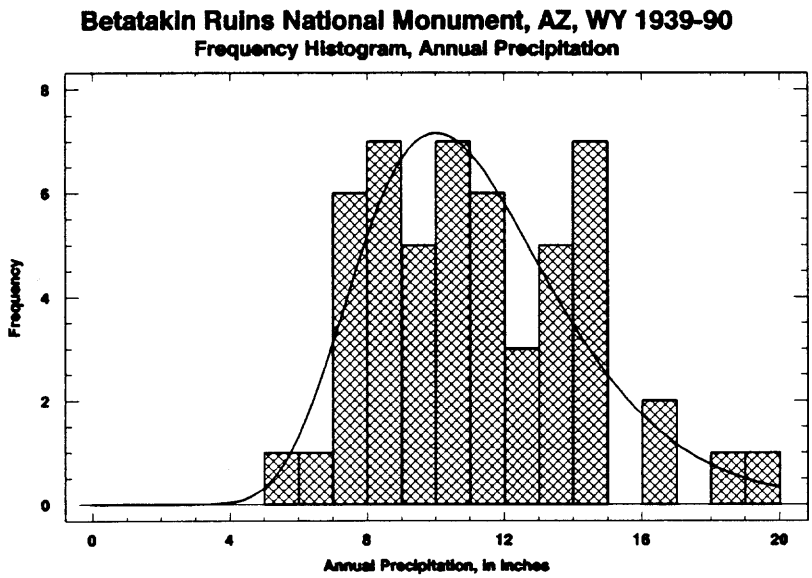


Figure 47. Betatakin Ruins, AZ, Histogram of Annual Precipitation

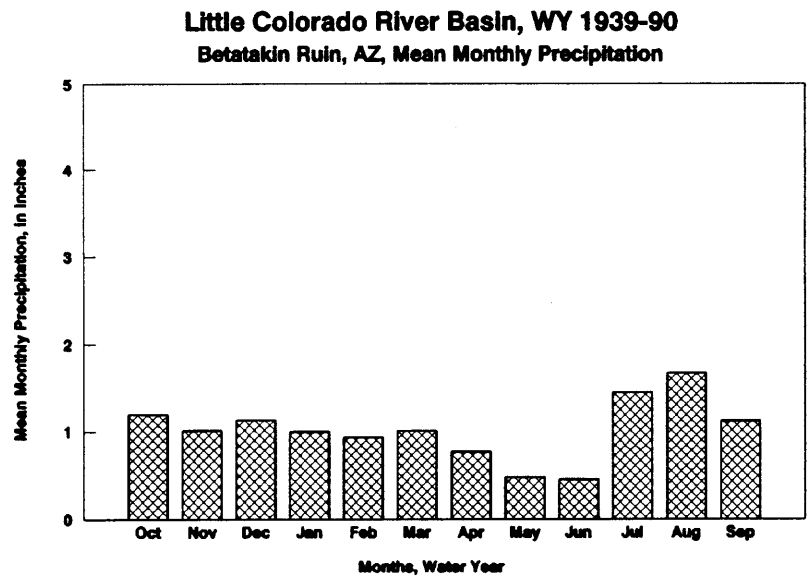


Figure 48. Betatakin Ruins, AZ, Monthly Distribution of Precipitation

6.2.3.4 Bluewater, NM

Bluewater, New Mexico is located at an elevation of 6,800 feet amsl in the northwest corner of the state, some 42 miles east-southeast of Gallup. It is a New Mexico state park. The location is somewhat to the east of the LCR Basin, and is included to provide interpolation of missing data from nearby LCR stations. The period of record is from 1896 to 1903, from 1909 through 1919, and from 1925 to 1960. The missing record from years 1960 to 1990 have been reconstructed.

The precipitation trend shows a decrease from 1939-1957, a peak centered on 1957-79, and an increase from 1979-88, followed by the basin-wide decline from 1988-90. The mean monthly precipitation distribution peaks dramatically from July through October, with a gradual winter and spring decline from December through April. The histogram for the period shows a relatively normal distribution with flat kurtosis and little skewness.

Table 16. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Bluewater, NM
Station No.: 1080
Elevation: 6800
Latitude: 35d 15m N
Longitude: 108d 02m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.22	0.01	0.21	1.14	0.40	0.44	0.44	0.17	0.33	0.72	1.66	1.98	7.72
1940	0.06	0.72	0.06	0.68	0.62	0.49	0.23	0.41	0.16	1.45	1.76	2.02	8.66
1941	0.78	0.95	1.37	0.51	0.37	1.08	1.22	1.80	1.83	1.73	1.33	2.69	15.66
1942	1.08	1.19	0.55	0.30	0.12	0.14	0.04	0.18	0.22	0.94	2.77	0.46	7.99
1943	1.22	0.04	1.17	0.71	0.00	0.73	0.12	0.19	0.84	0.76	2.76	0.45	8.99
1944	0.53	0.39	0.82	0.10	0.24	0.17	0.08	0.45	0.35	1.21	1.83	0.80	6.97
1945	0.79	0.64	0.41	0.56	0.06	0.59	0.61	0.02	0.00	1.77	3.04	0.52	9.01
1946	0.38	0.00	1.27	0.56	0.07	0.36	0.02	0.12	0.02	2.01	4.40	1.04	10.25
*1947	0.11	1.05	0.00	0.51	0.00	0.00	0.03	1.55	0.17	0.32	4.71	0.44	8.89
1948	0.24	0.47	0.73	0.20	1.14	0.18	0.02	0.79	2.04	0.73	1.44	1.01	8.99
1949	1.29	0.09	0.43	0.36	0.40	0.00	0.66	0.69	1.28	4.10	2.21	0.87	12.38
*1950	0.39	0.00	0.09	0.14	0.18	0.47	0.11	0.00	0.00	2.76	1.11	1.14	6.39
*1951	0.00	0.00	0.00	0.31	0.14	0.11	0.31	0.00	0.00	1.04	1.82	0.11	3.84
1952	0.30	0.86	0.56	0.61	0.27	0.15	1.65	0.24	0.50	1.15	2.09	0.39	8.77
1953	0.00	0.53	0.13	0.00	0.55	0.52	0.47	0.02	0.13	1.44	1.56	0.00	5.35
1954	0.45	0.03	0.24	0.11	0.07	0.57	0.00	0.10	0.53	2.15	1.20	2.65	8.10
1955	0.73	0.04	0.28	0.11	0.17	0.02	0.00	0.27	0.54	1.40	4.49	0.00	8.05
1956	0.00	0.06	0.28	0.92	0.36	0.03	0.02	0.57	0.09	0.88	0.11	0.07	3.39
1957	0.25	0.00	0.00	0.94	0.25	0.86	0.83	1.45	0.25	3.20	2.55	0.00	10.58
*1958	1.03	0.64	0.00	0.01	0.14	1.25	0.82	0.29	0.28	2.21	2.20	2.05	10.90
*1959	1.27	0.65	0.06	0.18	0.44	0.00	0.54	0.85	1.37	0.71	4.41	0.05	10.53
*1960	2.03	0.14	1.54	0.64	0.58	0.41	0.29	0.56	0.46	0.53	0.65	0.60	8.45
*1961	2.62	0.25	0.67	0.36	0.40	1.45	0.37	0.16	0.23	1.56	2.74	0.94	11.75
*1962	1.90	0.59	1.61	1.00	1.05	0.65	0.24	0.09	0.42	0.93	0.68	2.10	11.26
*1963	2.65	1.25	0.42	0.67	0.66	0.30	0.08	0.16	0.04	1.17	3.43	1.41	12.24
*1964	0.78	0.79	0.16	0.37	0.20	0.50	0.72	0.32	0.05	2.44	3.73	1.47	11.53
*1965	0.06	1.10	0.90	1.14	0.56	0.45	0.79	0.74	1.48	3.31	1.18	0.89	12.59
*1966	0.45	1.12	1.49	0.31	0.41	0.45	0.49	0.17	0.61	2.13	2.50	1.95	12.09
*1967	0.31	0.52	1.22	0.20	0.04	0.38	0.11	0.28	1.39	3.29	2.46	1.42	11.64
*1968	0.18	0.26	2.09	0.37	0.53	1.59	0.81	0.33	0.14	1.49	2.19	0.21	10.18
*1969	0.48	0.86	1.10	0.85	0.70	1.37	0.46	0.70	0.52	2.21	1.70	1.67	12.61
*1970	2.18	0.71	0.39	0.24	0.23	1.50	0.46	0.22	0.78	2.01	1.36	1.92	12.00
*1971	0.87	0.36	0.60	0.28	0.49	0.28	0.18	0.07	0.03	1.20	2.87	2.85	10.07
*1972	1.40	0.23	0.89	0.04	0.03	0.01	0.12	0.30	0.99	0.83	1.19	0.83	6.85
*1973	6.13	0.95	0.85	0.46	0.86	1.51	0.34	1.47	0.50	1.68	0.69	0.68	16.13
*1974	0.03	0.29	0.14	1.20	0.12	0.12	0.14	0.01	0.01	1.68	1.31	0.76	5.81
*1975	2.87	0.31	0.27	0.66	0.78	0.89	0.59	0.38	0.02	1.69	0.69	2.48	11.62
*1976	0.08	0.28	0.36	0.09	0.53	0.45	0.24	0.73	0.16	1.80	1.45	0.98	7.14
*1977	0.64	0.38	0.27	0.70	0.37	0.13	0.22	0.34	0.29	2.28	2.82	0.92	9.36
*1978	0.65	0.65	0.29	1.42	1.01	1.43	0.39	1.17	0.07	0.54	1.05	1.26	9.94
*1979	1.37	2.68	1.23	1.77	0.47	1.08	0.13	1.76	0.51	0.73	1.47	0.07	13.28
*1980	0.94	1.57	0.80	2.07	2.65	0.80	0.20	0.25	0.02	0.42	1.20	0.73	11.63
*1981	0.51	0.04	0.62	0.30	0.50	2.12	0.50	0.46	0.54	2.70	1.38	1.20	10.86
*1982	0.96	0.33	0.04	0.76	1.51	1.38	0.13	1.17	0.06	1.69	3.30	1.82	13.16
*1983	0.16	1.22	1.29	1.23	0.70	1.45	0.74	0.44	0.57	2.27	1.74	1.24	13.06
*1984	1.18	0.94	1.46	0.19	0.07	1.04	0.81	0.17	0.38	1.40	2.29	2.60	12.53
*1985	1.82	0.37	1.51	1.17	0.44	1.20	0.70	0.32	0.32	2.52	1.07	1.24	12.68
*1986	1.05	1.33	0.29	0.03	1.02	1.09	1.16	0.51	1.13	2.37	2.57	1.77	14.32
*1987	1.35	2.84	1.14	0.89	1.13	0.51	0.38	1.04	0.99	2.19	1.84	0.44	14.73
*1988	1.02	1.87	1.12	1.04	0.61	0.16	2.02	0.34	1.23	1.04	4.25	1.20	15.90
*1989	0.28	0.92	0.24	1.13	0.85	0.19	0.01	0.14	0.03	2.13	1.02	0.24	7.17
*1990	0.87	0.07	0.14	0.29	0.75	0.75	1.26	0.80	0.44	1.76	1.60	1.92	10.65
1939-90 Average	0.94	0.65	0.65	0.59	0.50	0.65	0.45	0.50	0.49	1.67	2.07	1.13	10.28

* Denotes year in which one or more monthly records are reconstructed.

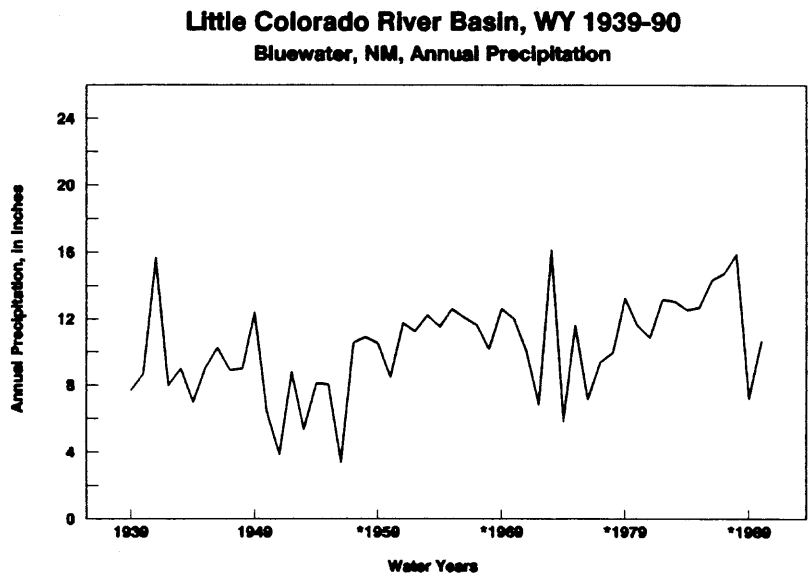


Figure 49. Bluewater, NM, Annual Precipitation, WY 1939-90

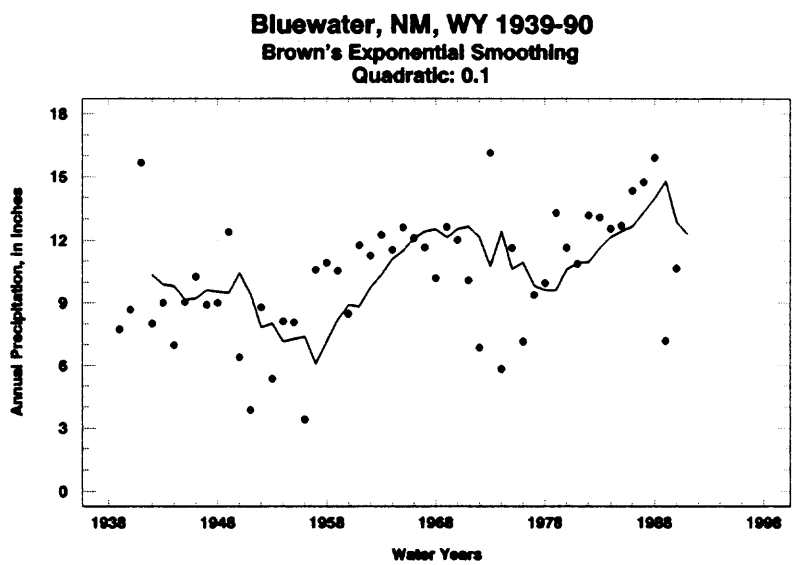


Figure 50. Bluewater, NM, Smoothed Annual Precipittion, WY 1939-90

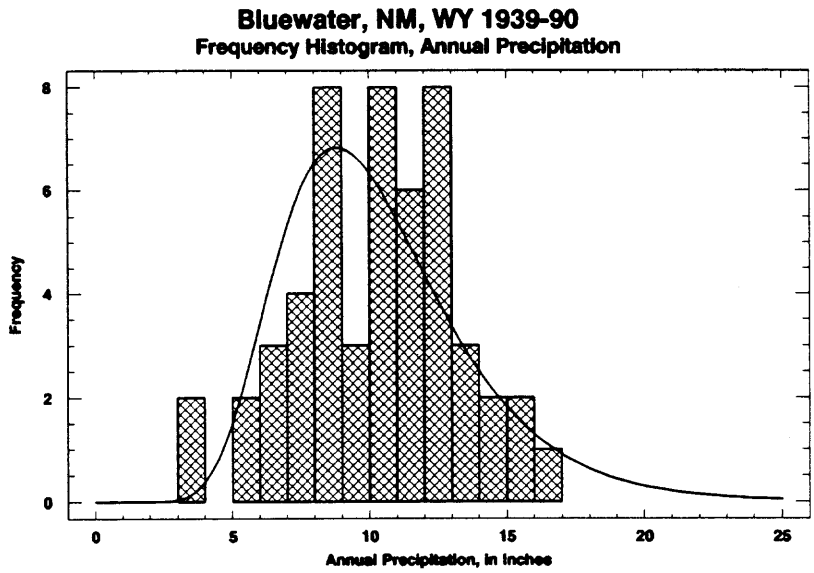


Figure 51. Bluewater, NM, Histogram of Annual Precipitation

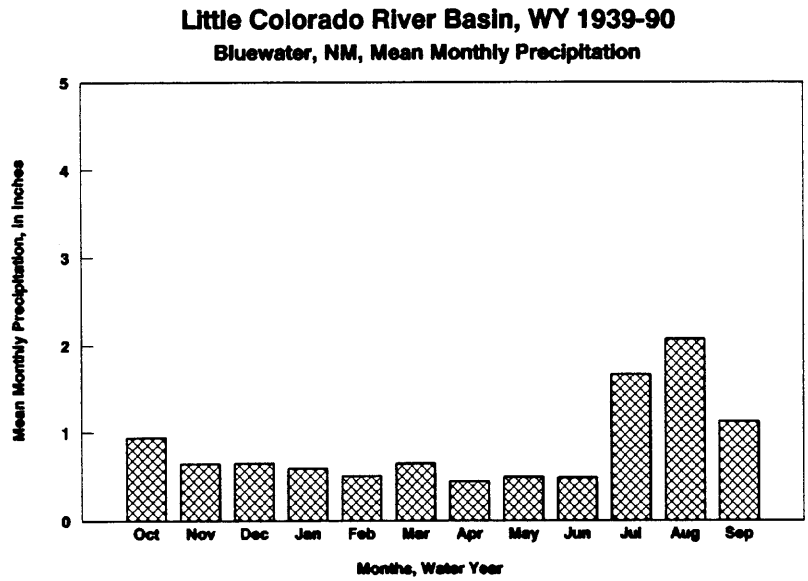


Figure 52. Bluewater, NM, Monthly Distribution of Precipitation

6.2.3.5 Blue Ridge Ranger Station, AZ

Blue Ridge Ranger Station is located at an elevation of 6,860 feet amsl in the Coconino National Forest near the Mogollon Rim. Approximately 32 miles to the south is the community of Payson, Az. Nearby is the Blue Ridge Reservoir on East Clear Creek, a tributary of the Little Colorado. It lies within a dense ponderosa pine forest along steep canyons and sharp crested ridges. To the north at a distance of some 60 miles is the City of Flagstaff, at approximately the same elevation. At that location on the southwestern ridge of the Mogollon Rim, Blue Ridge is on the windward side of the southwesterly storm tracks. For this reason, the area receives nearly 19 inches of precipitation in an average year. This station has been operated continuously by the US Forest Service since 1965. The years between 1939 and 1965 have been reconstructed.

The precipitation trends from 1939 to 1968 show a barely perceptible decrease, with a slight increase from 1969 to 1988. From 1988 to 1990, there has been a sharp decline.

The histogram for the period shows a strong lognormal distribution with sharp kurtosis and a positive skewness. Mean monthly values show a dramatic peak from July to October, with an essentially even monthly distribution of winter storms from December through March.

Table 17. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Blue Ridge Ranger Station, AZ
Station No.: 0871
Elevation: 6880
Latitude: 34d 36m
Longitude: 111d 07m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.15	0.29	2.23	1.60	1.27	0.79	0.99	0.09	0.00	0.79	2.61	3.31	14.10
*1940	0.55	1.20	0.50	1.27	2.07	0.49	1.63	0.51	1.94	1.47	3.19	3.42	18.24
*1941	3.04	1.23	2.61	1.22	1.70	2.54	2.52	0.99	1.04	1.98	3.60	3.20	25.66
*1942	3.01	1.70	2.17	0.85	1.79	0.68	1.37	0.01	0.01	1.59	2.98	1.21	17.36
*1943	1.87	0.30	1.39	2.07	0.94	1.34	0.66	0.09	0.05	1.15	2.37	1.76	14.00
*1944	1.61	0.07	2.25	1.30	3.27	2.02	1.74	0.78	0.04	1.49	1.87	2.14	18.58
*1945	0.33	1.37	1.79	1.90	0.48	4.10	0.54	0.00	0.04	3.17	2.50	0.37	16.58
*1946	0.87	0.07	1.98	0.84	0.56	1.00	2.06	0.23	0.05	4.07	3.41	1.49	16.63
*1947	1.25	1.46	0.88	0.70	0.15	0.34	0.10	1.14	0.00	1.91	4.54	1.14	13.61
*1948	2.28	1.90	1.83	0.83	1.71	1.43	0.20	0.21	0.27	1.06	3.83	0.98	16.53
*1949	1.17	0.01	2.71	4.88	1.22	0.54	0.38	0.55	1.78	2.59	1.53	2.79	20.16
*1950	2.53	0.41	1.55	0.62	0.77	0.80	0.05	0.25	0.25	3.49	1.40	1.37	13.48
*1951	0.02	0.49	0.11	1.81	1.28	1.07	1.72	0.70	0.00	2.76	5.15	0.79	15.92
*1952	1.74	1.03	2.77	3.54	0.22	3.13	1.74	0.09	0.22	2.90	3.21	2.47	23.07
*1953	0.00	3.11	0.84	0.58	0.54	1.07	0.91	0.22	0.11	4.13	2.72	0.08	14.31
*1954	0.15	1.07	0.72	1.29	0.73	3.18	0.38	0.58	0.71	3.47	1.86	2.48	16.61
*1955	0.70	0.23	0.48	1.57	0.91	0.09	0.59	0.33	3.00	3.48	4.14	0.08	15.59
*1956	0.32	1.22	0.81	1.20	1.50	0.17	1.12	0.28	0.75	2.87	1.91	0.04	12.18
*1957	1.08	0.17	0.28	5.73	0.63	1.26	0.94	1.46	1.04	2.66	2.59	0.00	17.84
*1958	3.13	1.87	0.30	0.42	2.31	2.30	1.38	0.44	0.47	1.09	3.18	6.26	23.15
*1959	0.94	1.19	0.10	0.41	2.13	0.05	0.88	0.48	0.82	2.20	4.06	3.52	16.80
*1960	4.17	0.60	3.52	1.56	1.26	0.92	0.61	0.62	0.27	0.85	2.32	1.05	17.76
*1961	3.46	0.85	0.98	0.52	0.45	2.20	0.27	0.14	0.20	2.17	3.95	2.13	17.30
*1962	1.56	1.32	2.06	2.39	2.37	1.08	0.07	0.42	0.52	1.63	0.84	2.95	17.22
*1963	1.54	1.27	0.65	0.88	0.79	0.84	0.87	0.01	0.02	1.16	6.35	1.96	16.33
*1964	1.34	1.13	0.58	0.80	0.59	1.89	1.10	0.25	0.33	4.58	2.80	1.74	17.12
*1965	0.05	1.15	1.81	2.42	1.42	1.38	2.84	1.09	0.22	3.43	1.12	2.10	19.04
1966	0.81	3.56	5.83	1.50	0.68	1.19	0.24	0.12	0.64	4.62	1.53	1.06	21.78
1967	1.42	2.10	2.67	0.65	0.00	1.43	1.55	0.50	2.67	3.74	3.03	1.69	21.45
*1968	0.17	1.20	7.28	2.03	0.87	1.27	1.31	0.38	0.23	2.88	2.44	0.08	20.14
1969	1.57	1.26	0.88	2.64	2.20	1.39	0.67	1.84	0.00	4.23	4.38	1.62	22.68
1970	1.48	1.77	0.68	0.28	0.17	3.39	1.34	0.08	0.07	2.47	2.03	3.73	17.49
1971	0.91	1.03	1.50	0.47	1.24	0.43	0.72	0.49	0.00	1.26	5.23	2.36	15.64
1972	4.12	0.37	3.59	0.00	0.05	0.00	0.31	0.53	2.93	0.95	3.88	0.87	17.60
1973	9.55	2.12	2.30	0.83	2.77	4.52	1.14	0.81	0.17	3.15	0.87	0.01	28.24
1974	0.07	1.86	0.20	3.39	0.38	0.82	0.32	0.00	0.14	2.01	1.41	1.81	12.41
1975	2.44	0.45	1.34	0.68	1.27	2.85	2.47	0.42	0.00	3.48	0.25	2.21	17.86
1976	0.32	1.94	1.10	0.20	3.02	1.36	1.90	1.84	0.01	2.85	1.03	2.54	18.11
1977	1.35	0.17	0.03	1.18	0.61	0.23	1.51	0.44	1.03	2.32	4.72	3.17	16.76
1978	1.19	0.62	0.80	3.02	2.91	4.82	0.84	1.17	0.00	1.86	1.63	0.34	19.20
1979	1.78	1.49	7.35	4.69	0.95	1.25	0.64	1.66	0.59	0.70	2.89	0.15	24.14
1980	0.09	0.92	1.13	4.44	6.35	2.64	1.74	0.81	0.00	2.05	2.04	0.76	22.97
1981	1.06	0.00	0.18	0.90	1.02	2.40	1.19	0.73	0.59	4.70	3.99	1.08	17.84
1982	3.00	2.47	0.04	3.55	2.29	3.70	0.32	2.17	0.04	1.66	2.98	1.57	23.79
1983	0.35	3.52	5.19	1.18	1.84	3.33	2.33	0.29	0.00	1.85	3.85	3.93	27.66
1984	1.55	2.80	2.66	0.44	0.20	0.83	0.62	0.52	1.19	2.46	4.07	3.96	21.30
1985	3.46	1.20	4.28	1.80	1.11	3.03	1.45	0.10	0.15	4.50	2.94	2.94	26.96
1986	1.86	4.55	0.68	0.12	2.08	1.60	0.81	0.51	0.46	2.40	5.17	2.95	23.19
1987	2.23	2.33	1.34	2.86	2.62	1.83	0.17	0.63	0.32	1.45	3.64	1.50	20.92
1988	2.12	4.05	1.66	2.22	1.46	0.06	1.91	0.02	1.94	1.55	3.38	0.97	21.34
1989	1.60	1.01	0.98	0.83	2.08	1.01	1.37	0.93	0.19	2.99	2.43	2.29	17.71
*1990	0.26	1.80	2.26	0.96	1.97	1.11	1.03	0.52	0.12	3.61	3.00	4.05	20.69
1939-90 Average	1.61	1.37	1.80	1.62	1.41	1.60	1.07	0.57	0.53	2.50	2.94	1.89	18.91

* Denotes year in which one or more monthly records are reconstructed.

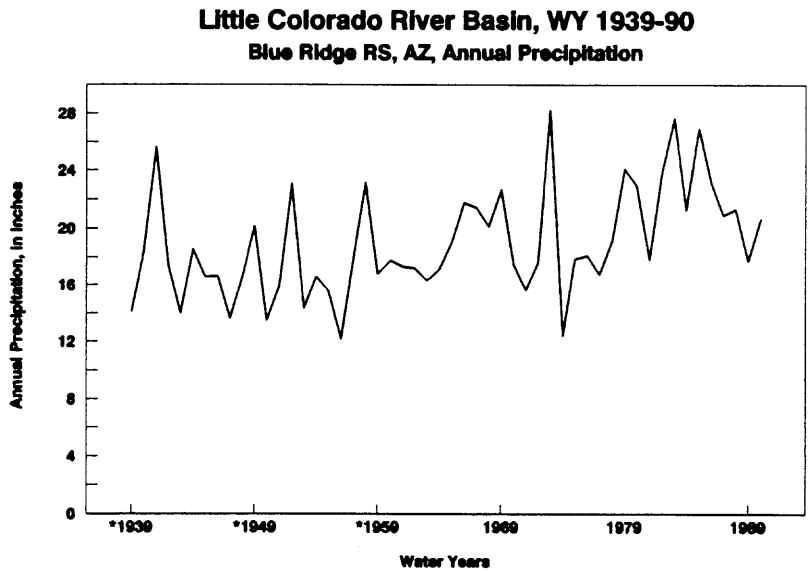


Figure 53. Blueridge RS, AZ, Annual Precipitation, WY 1939-90

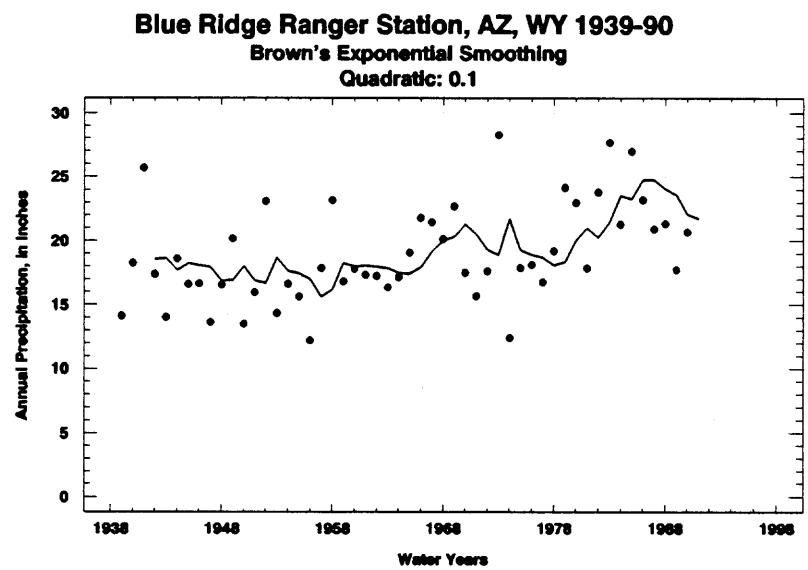


Figure 54. Blueridge RS, AZ, Smoothed Annual Precipitation, WY 1939-90

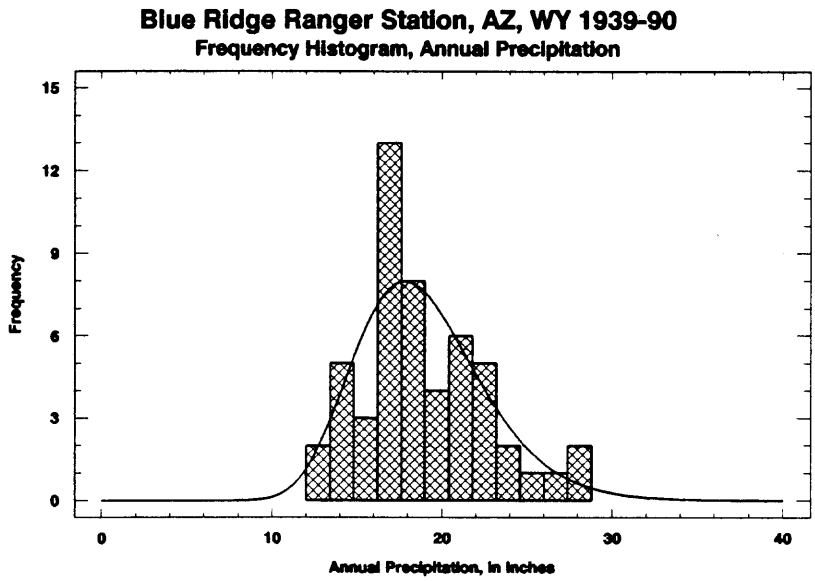


Figure 55. Blueridge RS, AZ, Histogram of Annual Precipitation

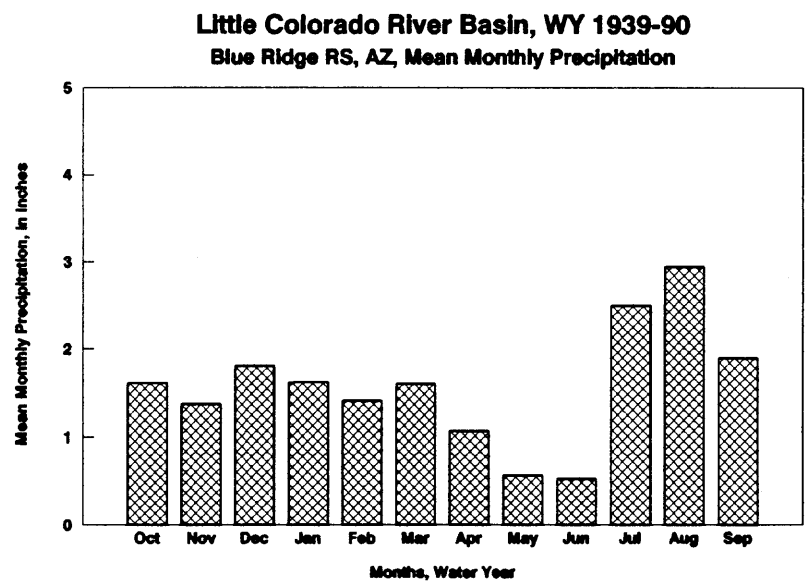


Figure 56. Blueridge RS, AZ, Monthly Distribution of Precipitation

6.2.3.6 Bright Angel Ranger Station, Grand Canyon National Park, AZ

Bright Angel Ranger Station is located within the North Rim area of Grand Canyon National Park. The period of record is from 1925-1958 for the entire year, from 1959-1973 excepting the winter months, and from 1974-90 for the entire year. The winter months from 1959-73 have been reconstructed. The station lies northwest of the LCR Basin. It is included to provide interpolation of missing data from nearby LCR stations.

As summarized in Sellars and Hill (1974, p. 120):

"The Bright Angel Ranger Station lies at an elevation of 8,400 feet in the Grand Canyon National Park, 1.2 miles north of the northern rim of the Grand Canyon in the Kaibab [National] Forest. One of the most awe-inspiring and spectacular sights in the world, The Grand Canyon was carved out by the erosive forces of the rapidly moving Colorado River which follows an irregular course to the west. Depths exceeding one mile and widths of more than ten miles are found at sundry locations along the canyon rim, the Colorado River itself being barely discernable at these points. The Kaibab Plateau to the north of the canyon is forested with a splendid, homogeneous stand of ponderosa pine while to the south in the broad, flat Coconino Plateau, forests of pinyon and juniper dominate the vegetation. Elevations above 9,000 feet are reached only 20 miles north of the Colorado River in the central Kaibab Plateau. The south rim of the Canyon averages aproximately 1,500 feet lower than the north rim. Eighteen miles to the north-northeast beautiful Marble Canyon is found while 13 miles almost due east, the Colorado and Little Colorado Rivers merge. The magnificence of this entire northern Arizona region is perhaps unsurpassed anywhere in the world for sheer beauty and unique rock formations. In contrast to the green forests and meadows that prevail north and south of the Grand Canyon, to the east barren desert wastelands dominate along the valley of the Little Colorado River.

"The average annual precipitation at the Bright Angel Ranger Station is slightly under 23 inches, with greatest amounts being received in winter. Most of the moderate summer rains are associated with an influx of moist, tropical air from the Gulf of Mexico and ensuing thunderstorm buildup over the strongly heated canyon walls. These storms form almost daily from early in July to Late in August, typically lasting for less than an hour and rarely extending beyond sunset. The greatest summer precipitation occurs when dissipating tropical disturbances penetrate into the area from the Pacific Ocean. Consistent with nearly all stations in Arizona, May and June are the driest months of the year.

"Most of the winter precipitation occurs as snow, in conjunction with eastward-moving middle latitude storms that originate in the Pacific. When these storms intensify of the southern California coast during the cold season, particularly abundant quantities of snow can fall. In an average year about 130 inches of snow are recorded and in January, 1949, a record eighty-five inches fell."

Precipitation trends for the study period show a moderate to slight decline from 1939 to 1970, with a sharp increase from 1970 to 1985. From 1985 to 1990 was a period of modest decline.

The histogram shows a near-perfect lognormal distribution with a sharp peak at 20-22 inches. The kurtosis is moderate, and the skewness is noticeably positive.

Table 18. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Bright Angel Ranger Station, Grand Canyon National Park, AZ
Station No.: 1001
Elevation: 8400
Latitude: 36d 12m
Longitude: 112d 04m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.96	0.47	4.47	4.13	2.25	3.08	1.36	0.22	0.00	0.46	0.29	12.31	30.00
1940	0.37	1.47	0.71	2.88	4.26	1.07	2.70	1.37	0.08	0.49	4.15	5.32	24.87
1941	2.36	1.51	4.15	3.91	5.40	4.50	6.16	0.94	1.21	1.10	2.26	1.96	35.46
1942	4.10	0.88	4.33	0.63	3.94	2.38	1.91	0.23	0.00	1.42	1.52	0.86	22.20
*1943	1.49	0.46	2.51	6.16	1.92	4.61	0.79	0.00	0.06	0.68	4.01	1.43	24.12
1944	1.19	0.26	1.24	2.50	4.56	3.28	1.97	0.75	0.02	0.40	0.34	0.21	16.72
1945	0.01	2.60	1.97	1.15	3.37	7.07	1.22	0.12	0.11	2.02	2.77	0.04	22.45
*1946	2.26	0.21	3.69	1.75	0.91	1.46	2.69	0.18	0.00	3.14	1.91	1.04	19.24
1947	2.74	4.45	3.06	0.93	0.69	0.50	0.45	1.80	0.26	0.70	2.24	0.20	18.02
1948	1.93	1.35	2.87	0.67	2.62	2.42	0.40	0.30	1.06	1.08	3.04	1.27	19.01
1949	1.69	0.02	2.98	6.67	2.84	1.03	0.48	0.99	3.13	0.17	1.59	3.54	25.13
1950	1.31	0.86	2.97	3.46	3.63	1.53	0.08	0.76	0.26	3.14	3.13	1.60	22.73
*1951	0.00	0.33	0.87	2.36	1.53	1.72	2.83	0.58	0.00	1.09	8.34	1.20	20.85
1952	1.97	0.93	8.84	6.88	0.95	7.16	3.15	0.20	0.55	1.84	1.40	2.92	36.79
1953	0.00	1.92	1.95	1.87	0.82	1.30	2.57	0.52	0.96	4.16	3.95	0.00	20.02
1954	1.24	0.76	1.15	1.87	2.08	5.46	0.15	0.55	1.67	3.21	0.39	1.88	20.41
1955	0.53	0.17	1.38	2.56	3.13	0.22	0.30	0.07	3.15	1.07	4.05	0.02	16.65
1956	0.00	3.86	2.38	4.63	0.62	0.27	0.60	0.78	0.24	2.30	2.53	0.00	18.21
1957	1.57	0.00	1.64	7.73	2.36	1.24	2.33	4.67	1.37	3.14	3.96	0.00	30.01
1958	3.35	3.29	2.95	1.64	3.00	5.81	2.70	1.53	0.00	0.54	3.31	4.17	32.29
*1959	1.42	1.12	0.18	0.67	2.78	0.06	1.33	0.32	1.04	1.75	2.99	0.36	14.02
*1960	2.55	0.91	4.15	1.65	2.14	0.68	0.98	0.41	0.91	1.03	2.06	2.08	19.56
*1961	5.68	1.38	1.49	0.81	0.54	2.81	0.54	0.16	0.27	2.70	4.03	1.80	22.22
*1962	1.56	1.55	3.08	2.82	2.53	1.30	0.12	2.45	0.97	0.63	2.45	1.32	20.78
*1963	0.95	1.13	1.12	1.17	1.42	0.76	1.05	0.00	0.00	0.09	8.16	1.96	17.81
*1964	1.20	1.21	0.25	1.03	0.65	2.25	1.80	1.22	0.57	2.29	1.92	1.06	15.45
*1965	0.02	1.63	1.62	1.98	1.96	1.72	3.19	1.76	1.25	2.59	1.05	2.85	21.62
*1966	1.02	2.97	4.60	0.88	1.44	0.82	0.51	0.70	0.95	3.96	2.10	0.87	20.82
*1967	1.40	1.79	4.59	0.54	0.02	0.24	0.27	1.71	1.52	2.63	1.89	3.39	19.99
*1968	0.45	0.66	2.00	0.96	0.65	1.37	1.46	0.26	0.54	3.29	2.61	0.17	14.41
*1969	0.84	0.92	2.30	3.73	2.87	1.74	0.39	0.54	0.49	3.32	1.42	1.66	20.22
*1970	1.31	1.51	0.62	0.38	0.14	5.54	1.06	0.00	0.20	1.77	1.94	0.94	15.41
*1971	0.44	0.86	1.17	0.29	1.24	0.36	0.53	1.05	0.00	1.08	1.49	0.00	8.50
*1972	3.18	0.67	2.25	0.03	0.04	0.00	1.16	0.00	1.25	0.60	0.91	1.41	11.50
*1973	9.04	1.58	2.50	1.95	2.62	4.40	2.69	1.60	0.97	0.52	0.64	0.59	29.09
1974	0.18	1.64	0.53	5.81	0.76	1.21	0.63	0.00	0.00	1.75	0.06	0.67	13.24
1975	3.74	1.37	1.75	4.70	4.32	5.55	2.55	1.01	0.21	3.04	0.84	1.31	30.39
1976	0.17	2.22	2.56	0.09	5.87	2.03	2.14	1.52	0.07	1.59	0.43	2.55	21.24
1977	0.57	0.19	0.80	2.50	0.04	1.02	0.79	2.11	0.56	2.73	1.83	0.85	13.99
1978	1.75	0.76	2.43	9.79	5.62	8.92	1.79	0.63	0.00	0.36	0.68	2.29	35.02
1979	1.48	4.95	8.52	8.61	4.17	7.56	0.90	1.91	0.71	0.64	1.92	0.02	41.39
1980	2.60	1.34	1.98	9.59	10.01	4.85	0.67	0.54	0.25	2.83	1.79	2.15	38.60
1981	2.03	0.09	1.38	0.91	1.05	4.40	1.57	1.73	0.34	2.61	3.09	3.09	22.29
*1982	1.23	2.17	0.55	5.30	2.54	3.76	0.98	1.17	0.58	1.53	3.42	1.57	24.81
*1983	0.82	4.41	5.76	3.16	4.48	5.89	2.50	0.17	0.16	4.49	1.79	3.15	36.78
*1984	2.48	3.52	4.93	0.51	1.61	1.12	1.21	0.16	0.08	3.76	2.63	0.74	22.75
1985	2.33	1.89	6.67	4.70	1.82	2.98	1.62	0.96	0.18	3.77	0.26	1.93	29.11
1986	0.92	6.84	0.64	0.51	3.89	4.14	1.92	1.51	0.21	1.59	1.04	2.24	25.45
1987	2.08	1.80	1.45	2.42	1.98	2.41	0.10	0.79	0.78	1.87	4.45	0.19	20.32
*1988	4.26	3.01	1.81	2.97	2.54	0.30	1.86	0.77	2.41	0.44	5.89	0.44	26.70
1989	0.25	2.14	2.31	3.17	2.63	1.48	0.00	0.38	0.02	2.36	2.92	0.02	17.68
1990	0.74	0.00	0.47	2.26	3.28	1.48	0.52	0.30	0.20	1.40	2.95	2.66	16.26
1939-90 Average	1.69	1.62	2.55	2.89	2.47	2.68	1.42	0.85	0.61	1.87	2.44	1.66	22.74

* Denotes year in which one or more monthly records are reconstructed.

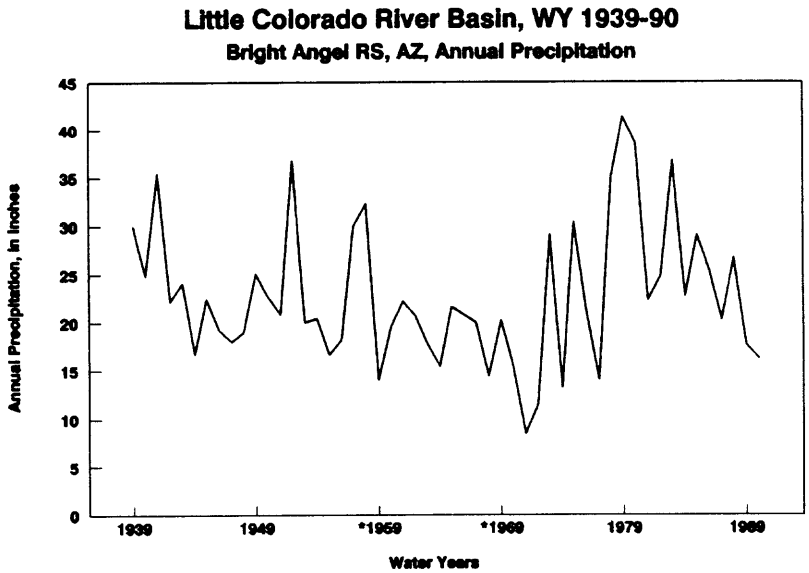


Figure 57. Bright Angel RS, AZ, Annual Precipitation, WY 1939-90

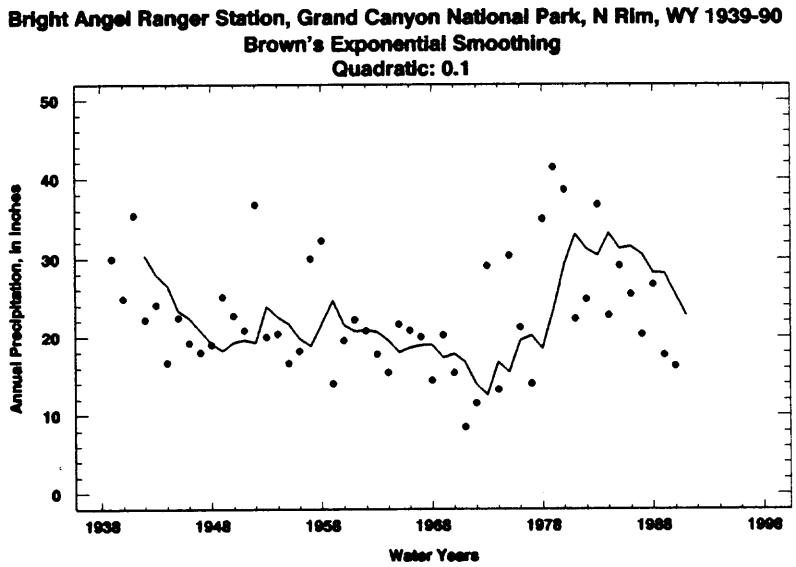


Figure 58. Bright Angel RS, AZ, Smoothed Annual Precipitation

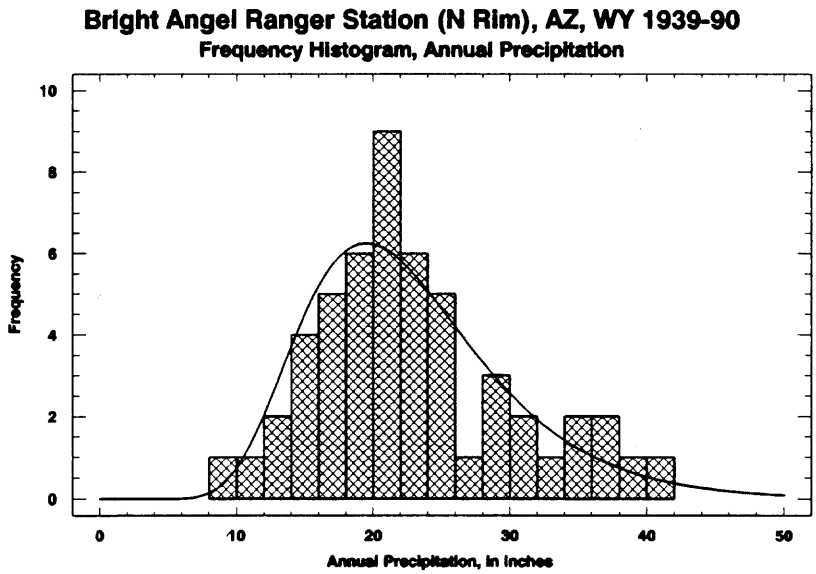


Figure 59. Bright Angel RS, AZ, Smoothed Annual Precipitation

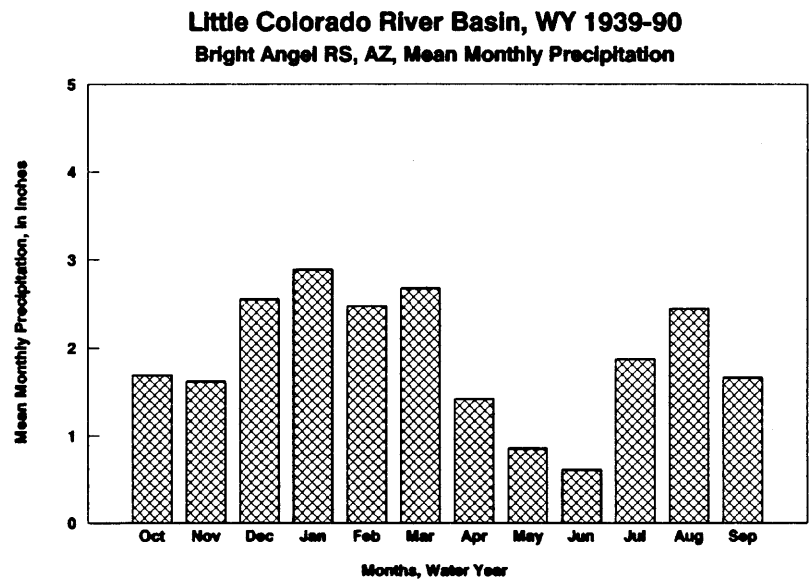


Figure 60. Bright Angel RS, AZ, Monthly Distribution of Precipitation

6.2.3.7 Cameron, AZ

The village of Cameron lies at an elevation of 4,165 feet at the crossing of the Little Colorado River by US Highway 89 from Flagstaff to Page, Arizona. The historic Cameron Trading Post was established in the 1880's to serve the Navajo and Hopi Indians living in the region. The sandstone and shale surface formations in the vicinity are cut by deep, narrow canyons. Extreme desert flora and fauna prevail, with tamarisk and cottonwoods occasionally lining the gorge of the Little Colorado.

The period of record for this station is from 1962 to the present. The missing record from 1939 to 1961 has been reconstructed.

Cameron lies in a "rain shadow" of the San Francisco Mountains near Flagstaff, 70 miles to the south-southeast and of the Coconino and Kaibab Plateaus to the west. Due to the highly orographic nature of its physiographic setting, the annual precipitation at Cameron is only slightly more than 5.6 inches, among the lowest of LCR Basin stations.

Annual precipitation trends for Cameron are essentially flat, with a slight decline from 1939-66, and a slight increase from 1967 to 1990. As with many low altitude desert stations, the annual variability is minimal, with occasional sharp peaks. The histogram shows a pronounced lognormal distribution, with a sharp peak at 6-7 inches and a definite positive skew due to the rare wet years. Seasonal and monthly differences are slight, with somewhat greater precipitation occurring from July through October during the monsoon season.

Table 19. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Cameron 1 NNE, NM
Station No.: 1169
Elevation: 4165
Latitude: 35d 53m
Longitude: 111d 24m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.22	0.05	0.22	0.12	0.58	0.32	0.00	0.15	0.06	0.00	0.94	2.53	5.19
*1940	0.00	0.46	0.00	0.43	0.54	0.12	0.84	0.00	0.39	0.33	0.72	1.82	5.66
*1941	1.24	0.62	1.30	1.54	0.82	1.59	1.54	2.20	0.26	0.77	0.74	1.11	13.73
*1942	1.70	0.23	0.63	0.17	0.19	0.23	0.54	0.00	0.00	0.94	0.37	0.00	5.00
*1943	0.30	0.09	0.97	0.66	0.34	1.22	0.23	0.07	0.00	0.27	1.12	0.83	6.08
*1944	0.23	0.03	0.72	0.36	0.65	0.90	0.96	0.46	0.00	0.00	0.20	0.00	4.51
*1945	0.00	0.74	0.30	0.28	0.46	0.74	0.47	0.02	0.03	0.99	0.31	0.00	4.35
*1946	0.44	0.01	0.59	0.57	0.05	0.55	0.88	0.20	0.00	1.06	1.70	0.13	6.19
*1947	0.52	0.63	0.13	0.00	0.06	0.03	0.05	0.74	0.02	0.04	1.24	0.00	3.44
*1948	1.79	0.22	0.54	0.01	0.35	0.35	0.09	0.13	0.24	0.14	1.38	0.14	5.39
*1949	0.51	0.00	0.45	0.44	0.32	0.42	0.00	0.49	1.37	0.46	0.72	0.85	6.02
*1950	0.80	0.34	0.03	0.05	0.78	0.36	0.04	0.07	0.00	1.44	1.22	0.35	5.50
*1951	0.00	0.00	0.01	0.23	0.02	0.00	0.46	0.58	0.00	0.02	1.64	0.39	3.35
*1952	0.50	0.51	0.71	0.52	0.40	0.53	1.23	0.16	0.18	0.82	1.30	2.70	9.55
*1953	0.00	1.04	0.61	0.16	0.00	0.00	0.63	0.00	0.03	1.70	2.04	0.00	6.22
*1954	0.38	0.25	0.05	0.25	0.20	0.35	0.00	0.33	0.59	2.55	0.73	1.33	6.99
*1955	0.19	0.16	0.26	0.24	0.52	0.16	0.09	0.00	2.06	0.00	1.28	0.00	4.96
*1956	0.00	0.19	0.00	0.77	0.00	0.16	0.14	0.24	0.03	0.51	0.44	0.00	2.49
*1957	0.01	0.04	0.11	0.51	0.29	0.53	0.30	1.30	0.24	1.28	1.06	0.06	5.72
*1958	1.57	1.04	0.27	0.03	0.18	1.32	0.13	0.57	0.00	0.11	0.29	1.61	7.12
*1959	0.02	0.05	0.01	0.00	0.68	0.00	0.68	0.38	0.00	0.30	0.08	0.61	2.81
*1960	0.56	0.44	0.50	0.18	0.38	0.29	0.46	0.37	0.21	0.15	0.16	0.59	4.31
*1961	1.74	0.47	0.53	0.17	0.00	1.22	0.15	0.13	0.00	0.05	1.63	0.73	6.82
*1962	0.00	0.00	0.03	0.00	0.25	0.00	0.00	0.30	0.04	0.19	0.95	1.23	2.99
1963	1.22	0.42	0.14	0.13	0.53	0.21	0.01	0.00	0.02	0.01	2.39	0.14	5.22
1964	0.82	0.19	0.00	0.10	0.00	0.23	0.45	0.09	0.44	0.45	0.39	0.45	3.61
1965	0.00	0.13	0.13	0.91	0.54	0.42	0.51	0.86	0.08	0.49	0.20	2.55	6.82
1966	0.30	0.29	1.21	0.03	0.64	0.32	0.03	0.16	0.18	0.05	0.78	0.34	4.33
1967	0.42	0.29	0.24	0.10	0.00	0.00	0.03	0.15	0.59	0.21	2.18	1.37	5.58
1968	0.01	0.02	1.58	0.02	0.10	0.24	0.69	0.11	0.18	1.40	0.83	0.07	5.25
1969	0.37	0.51	0.44	0.77	0.25	0.49	0.00	0.42	0.36	0.39	0.42	1.19	5.61
1970	1.03	0.30	0.03	0.00	0.08	2.22	0.01	0.00	0.01	0.55	0.96	0.13	5.32
1971	0.25	0.04	0.11	0.00	0.23	0.00	0.28	0.08	0.00	0.53	1.52	0.98	4.02
1972	0.56	0.15	0.28	0.00	0.00	0.00	0.01	0.00	0.20	1.55	0.52	0.34	3.61
1973	6.83	0.16	0.48	0.29	1.21	1.25	0.13	1.15	0.14	0.49	0.39	0.11	12.63
1974	0.03	0.49	0.00	0.97	0.11	0.29	0.21	0.00	0.00	0.45	0.40	0.58	3.53
1975	0.78	0.33	0.00	0.28	0.34	0.79	0.11	0.10	0.04	1.61	0.15	2.16	6.69
1976	0.00	0.19	0.57	0.00	0.29	0.07	0.96	1.33	0.00	0.97	0.14	1.56	6.08
1977	0.17	0.00	0.12	0.27	0.00	0.02	0.26	0.05	0.18	0.19	0.67	0.11	2.04
1978	0.01	0.26	0.54	1.32	0.92	0.63	0.03	0.13	0.22	0.10	0.27	0.98	5.41
1979	0.70	2.30	0.52	0.90	0.09	0.77	0.00	0.83	0.06	0.00	1.55	0.00	7.72
1980	0.15	0.55	0.60	2.21	0.97	0.43	1.29	0.00	0.00	0.30	1.66	0.07	8.23
1981	0.09	0.00	0.00	0.40	0.07	0.43	0.15	0.83	0.05	0.01	1.95	0.25	4.23
1982	0.10	0.51	0.02	0.41	0.68	0.12	0.27	0.85	0.00	0.37	0.59	0.69	4.61
1983	0.00	0.08	3.43	0.17	0.16	0.21	0.25	0.03	0.00	0.19	0.25	2.24	7.01
1984	0.44	0.37	0.09	0.30	0.05	0.28	0.01	0.00	0.00	1.22	0.88	0.78	4.42
1985	0.20	0.37	1.17	1.57	0.19	0.68	1.23	0.02	0.00	0.22	0.22	0.92	6.79
1986	0.20	1.70	0.05	0.00	0.24	0.55	0.36	0.80	0.00	0.42	0.98	0.85	6.15
1987	0.72	0.75	1.47	0.34	0.38	0.19	0.00	0.99	0.30	0.59	1.94	0.07	7.74
1988	0.84	0.21	0.21	0.29	0.92	0.00	1.08	0.00	0.45	0.22	1.61	0.29	6.12
1989	0.12	0.38	0.01	0.54	0.10	0.06	0.00	0.01	0.04	0.22	1.33	0.00	2.81
1990	0.29	0.00	0.19	0.53	0.60	0.75	0.46	0.09	0.00	1.99	0.40	0.92	6.22
1939-90 Average	0.57	0.36	0.43	0.40	0.34	0.44	0.36	0.35	0.18	0.56	0.92	0.71	5.62

* Denotes year in which one or more monthly records are reconstructed.

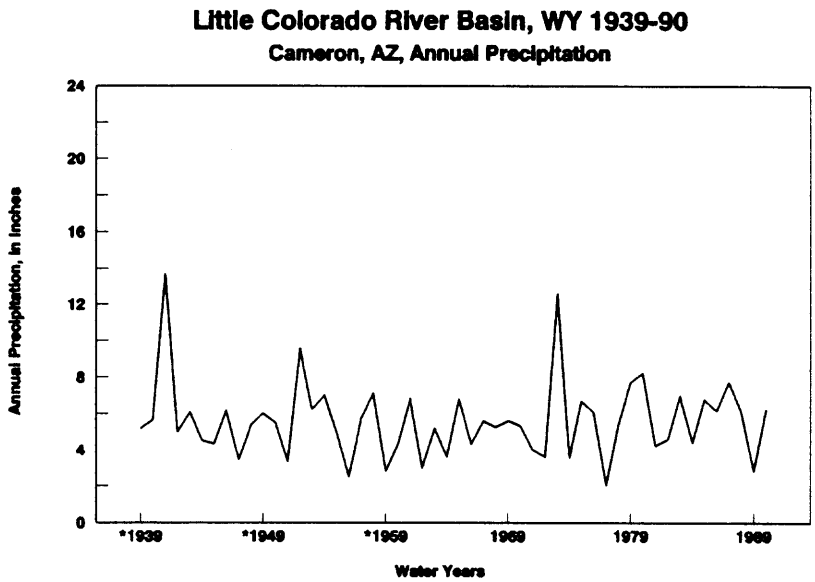


Figure 61. Cameron, AZ, Annual Precipitation, WY 1939-90

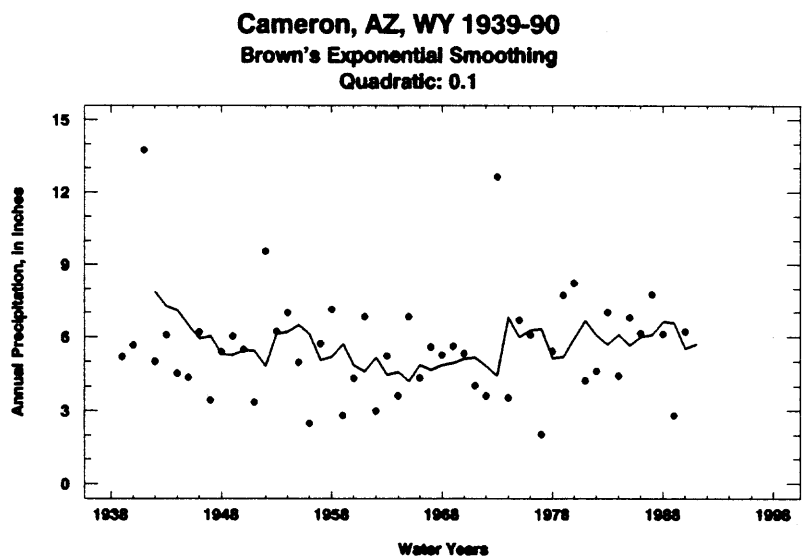


Figure 62. Cameron, AZ, Smoothed Annual Precipitation, WY 1939-90

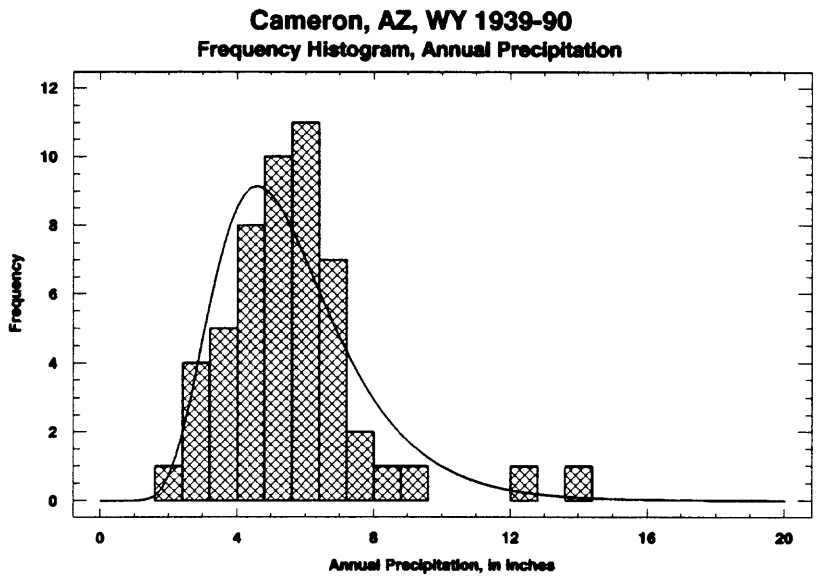


Figure 63. Cameron, AZ, Histogram of Annual Precipitation

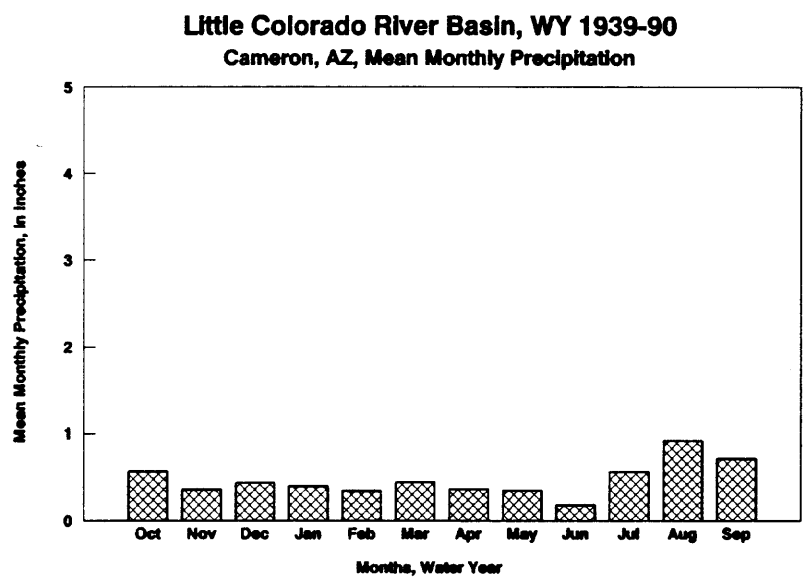


Figure 64. Cameron, AZ, Monthly Distribution of Precipitation

6.2.3.8 Chaco Canyon National Monument, NM

Chaco Canyon National Monument lies well to the east of the LCR Basin in northwestern New Mexico. It is included in the study to provide interpolation of missing record from stations on the eastern border of the basin. Its period of record extends from 1910-1913, 1922-1925, and 1932-present, excepting 1972. The record from 1972 is reconstructed.

Chaco Canyon National Monument contains a series of large Anasazi Indian ruins which lie along the valley floor and overlooking cliffs of the Chaco River. The valley vegetation consists of desert scrub and grasses, as well as occasional cottonwood. The highlands above the deep Chaco River canyon are vegetated by sage and pinyon, and deep sand beds overlie the sandstone.

The precipitation trends follow that of the LCR Basin in that there is a decline from 1939 to 1958, followed by an increase from 1959 to 1988, with a slight, broad peak centered on 1969. From 1988 to 1990, a sharp decline seems to be developing.

The histogram shows a tendency toward an irregular lognormal distribution, with flat kurtosis and a slight positive skew. As with other desert stations, the seasonal variation is only slightly pronounced from July to October, with little in the way of winter storm tendency.

Table 20. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Chaco Canyon National Monument, NM
Station No.: 1647
Elevation: 6175
Latitude: 36d 02m
Longitude: 107d 54m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.32	0.80	0.57	0.25	0.35	1.50	0.70	0.22	0.25	0.68	0.36	1.38	7.38
1940	0.06	0.68	0.47	0.06	0.64	0.00	0.00	0.42	0.43	2.42	1.83	1.72	8.73
*1941	1.04	1.13	2.49	1.25	1.76	1.81	1.79	3.03	0.82	0.21	1.27	4.15	20.75
*1942	2.22	0.14	1.36	0.12	0.34	0.73	0.83	0.02	0.00	0.39	0.28	1.26	7.69
*1943	1.40	0.00	0.67	0.23	0.05	1.50	0.00	0.71	0.39	0.95	1.27	0.39	7.57
1944	0.67	0.11	0.97	0.72	0.55	0.73	0.32	0.42	0.02	0.59	1.44	1.17	7.71
*1945	0.67	1.41	0.82	0.80	0.54	1.04	1.17	0.18	0.05	1.22	2.39	0.35	10.63
1946	0.38	0.00	1.48	0.39	0.10	0.88	0.64	0.50	0.00	0.96	1.69	1.19	8.21
1947	1.62	0.97	0.15	1.33	0.33	0.20	0.05	2.24	0.14	1.06	3.35	0.53	11.97
1948	1.73	0.28	0.69	0.52	1.17	0.99	0.51	1.04	1.10	0.95	1.49	0.83	11.30
*1949	1.70	0.24	0.58	0.61	0.47	0.14	1.00	0.91	0.89	1.38	0.61	0.52	9.04
1950	0.26	0.02	0.05	0.00	0.00	0.60	0.44	0.00	0.19	0.77	0.06	1.21	3.60
1951	0.03	0.05	0.00	0.60	0.63	0.10	0.48	0.14	0.00	0.30	1.97	0.24	4.54
1952	0.83	0.41	0.44	0.68	0.16	0.22	1.61	0.23	0.49	1.18	0.59	0.38	7.22
1953	0.00	1.55	0.40	0.16	0.61	0.37	0.28	0.60	0.09	1.00	0.33	0.00	5.39
1954	1.04	0.63	0.28	0.20	0.03	1.10	0.12	1.02	0.65	1.90	1.51	2.41	10.89
1955	0.39	0.09	0.81	0.26	0.43	0.02	0.32	1.16	0.26	1.15	1.59	0.03	6.51
1956	0.01	0.19	0.63	0.70	0.30	0.04	0.00	0.35	0.17	0.57	0.29	0.08	3.33
1957	0.43	0.33	0.11	0.50	0.49	0.65	0.56	1.42	0.54	2.12	2.73	0.08	9.96
1958	2.80	0.83	0.31	0.73	0.46	1.25	0.58	0.15	0.24	0.66	1.59	2.69	12.29
1959	1.06	0.53	0.26	0.00	0.06	0.07	1.13	0.00	0.21	1.04	2.75	0.31	7.42
*1960	1.47	0.03	0.33	0.33	0.67	0.33	0.25	0.33	0.75	0.57	0.29	0.29	5.64
1961	2.58	0.16	1.20	0.11	0.14	1.86	0.28	0.22	0.00	1.12	2.15	1.35	11.17
1962	1.39	0.64	3.90	0.53	0.30	0.42	0.23	0.05	0.00	0.25	0.44	2.43	10.58
1963	2.08	1.55	0.34	0.21	0.71	0.28	0.01	0.10	0.11	0.39	2.16	1.78	9.72
1964	0.52	0.50	0.10	0.10	0.63	0.27	0.48	0.30	0.01	0.97	1.37	1.14	6.39
1965	0.00	0.95	0.58	0.49	0.32	0.26	0.83	0.72	1.14	1.85	1.34	1.47	9.95
1966	1.14	0.91	1.18	0.21	0.28	0.08	0.22	0.45	0.94	0.90	0.80	1.79	8.90
1967	0.02	0.24	1.12	0.07	0.00	0.23	0.00	0.26	1.39	3.16	1.50	1.44	9.43
1968	0.14	0.10	0.57	0.11	1.17	0.91	0.39	0.41	0.18	2.01	1.58	0.05	7.62
1969	0.63	0.64	0.46	0.47	0.60	0.68	0.72	0.87	1.49	1.41	2.23	1.24	11.44
1970	2.46	0.45	0.46	0.15	0.00	0.94	0.17	0.43	0.78	1.49	0.54	1.30	9.17
1971	0.52	0.35	0.29	0.07	0.44	0.27	0.03	0.03	0.08	1.25	2.14	2.34	7.81
1972	0.96	0.67	0.33	0.02	0.10	0.02	0.00	0.10	0.61	0.10	1.33	1.13	5.37
1973	5.88	0.25	0.62	0.44	0.71	1.49	0.45	1.16	0.11	1.15	0.63	0.93	13.82
1974	0.11	0.04	0.33	0.67	0.07	0.08	0.00	0.02	0.00	2.06	0.77	0.50	4.65
1975	2.93	0.17	0.24	0.42	0.34	0.49	0.38	0.76	0.05	0.93	0.40	1.55	8.66
1976	0.06	0.29	0.07	0.17	0.13	0.05	0.24	0.47	0.24	0.88	1.40	0.79	4.79
1977	0.31	0.42	0.12	1.14	0.60	0.00	0.20	0.48	0.29	1.46	1.21	0.62	6.85
1978	0.41	0.55	0.39	1.03	0.88	0.82	0.90	2.50	0.07	0.15	0.98	2.52	11.20
1979	1.31	2.19	0.73	1.19	0.02	0.77	0.13	1.84	0.62	0.50	2.47	0.01	11.78
1980	1.14	1.65	0.35	0.71	1.52	0.41	0.15	0.48	0.00	0.17	1.34	0.66	8.58
1981	0.56	0.00	0.51	0.25	0.37	1.45	0.50	0.65	0.59	1.86	0.45	0.65	7.84
1982	1.58	0.07	0.00	0.12	1.92	1.51	0.27	2.81	0.00	1.35	1.23	3.66	14.52
1983	0.00	0.83	0.86	1.32	0.61	1.32	0.40	0.62	0.82	0.73	0.80	1.01	9.32
1984	1.09	0.96	1.38	0.30	0.00	1.02	0.60	0.26	0.72	0.70	1.93	1.46	10.42
1985	1.73	0.14	0.71	0.83	0.07	0.63	2.36	0.34	0.21	2.88	1.27	1.35	12.52
1986	0.81	0.63	0.42	0.00	1.46	0.80	0.82	0.22	0.97	2.03	1.19	2.19	11.54
1987	1.19	3.29	0.96	1.13	1.05	0.47	0.08	0.65	0.04	1.29	0.64	0.24	11.03
1988	0.60	1.24	0.77	0.70	0.49	0.05	0.70	0.62	1.58	0.34	2.53	1.42	11.04
1989	0.50	0.75	0.01	1.87	0.58	0.10	0.00	0.23	0.02	1.88	0.68	0.13	6.75
1990	0.58	0.00	0.01	0.39	0.75	0.90	1.95	0.42	0.66	1.14	0.20	1.19	8.19
1939-90 Average	1.03	0.60	0.63	0.49	0.51	0.63	0.51	0.65	0.41	1.12	1.30	1.15	9.02

* Denotes year in which one or more monthly records are reconstructed.

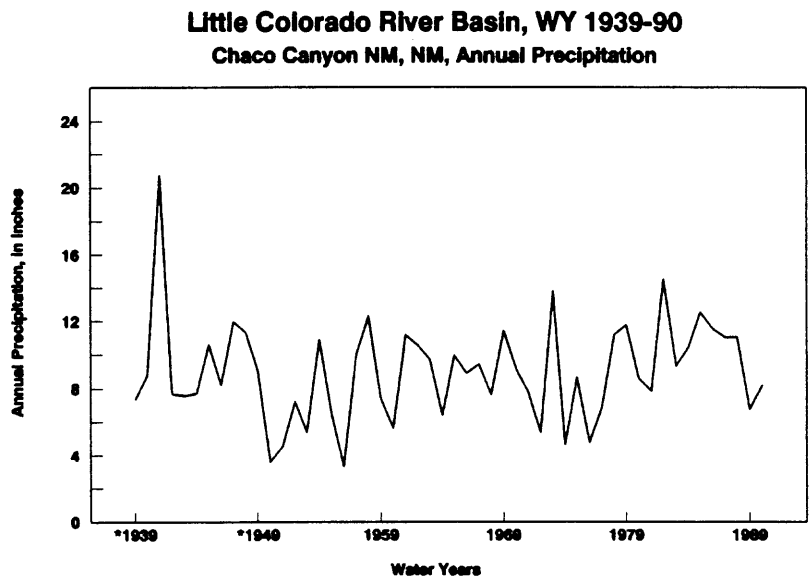


Figure 65. Chaco Canyon NM, NM, Annual Precipitation, WY 1939-90

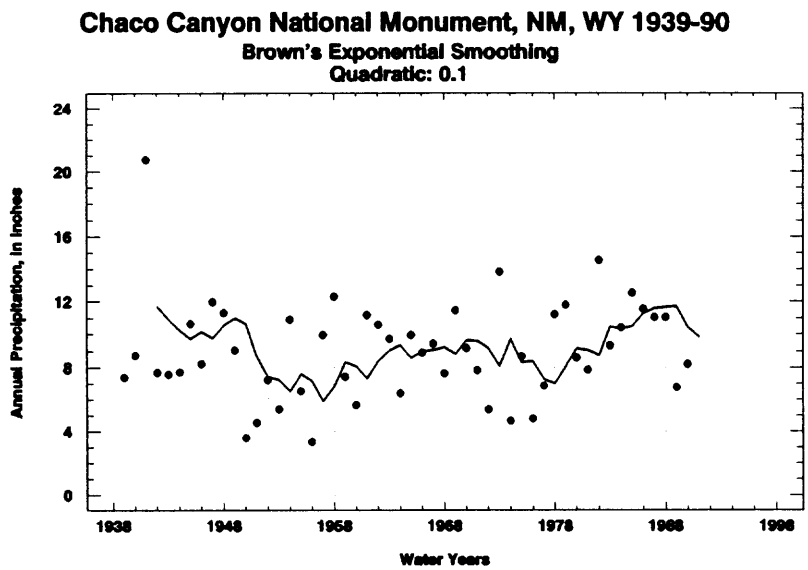


Figure 66. Chaco Canyon NM, NM, Smoothed Annual Precipitation, WY 1939-90

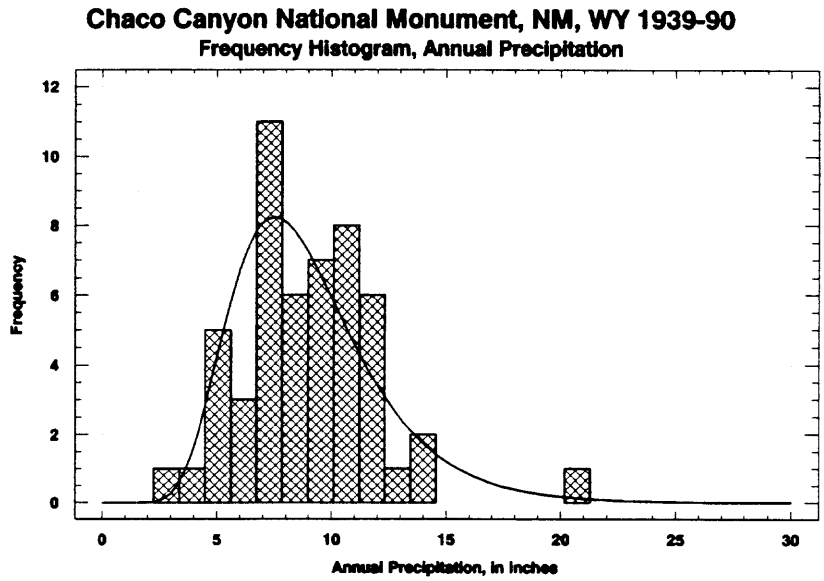


Figure 67. Chaco Canyon NM, NM, Histogram of Annual Precipitation

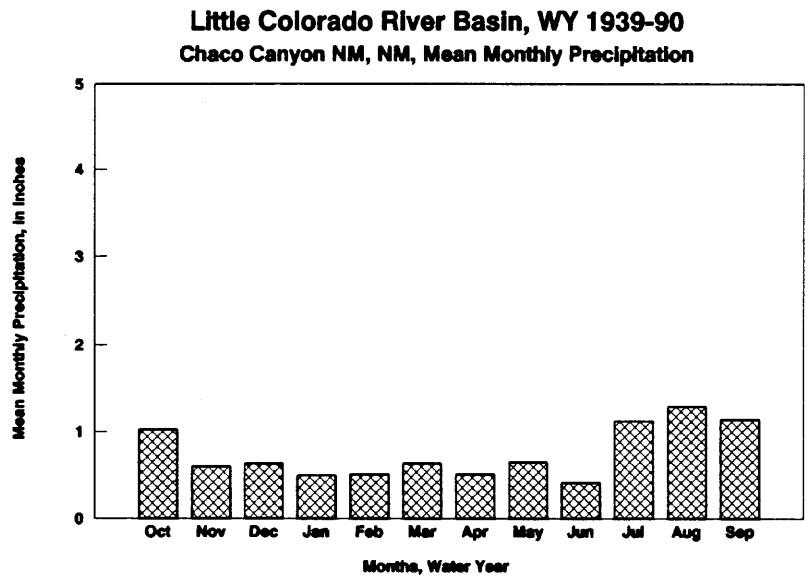


Figure 68. Chaco Canyon NM, NM, Monthly Distribution of Precipitation

6.2.3.9 Chevelon Ranger Station, (formerly Wallace RS), AZ

As summarized in Sellars and Hill (1974, p.150):

"Chevelon Ranger Station is located at an elevation of about 7,000 feet in Sitgreaves National Forest in central Arizona. It lies on the north-sloping incline of the Mogollon Plateau in rather flat timbered country cut by several canyons and creeks which drain into the Little Colorado River, thirty-five miles to the northeast. Beyond the river stretch the vast expanses of the colorful Painted Desert. Lake-studded Coconino National Forest is centered forty miles to the northwest. Highest elevations are found to the west and south of Chevelon Ranger Station. Hutch Mountain, thirty miles to the northwest, rises to 8,650 feet while the rim of the Mogollon Plateau, stretching from east to west fifteen miles to the south, has an average height of about 7,500 feet. Further to the south the terrain slopes irregularly downward into the valleys of Tonto Creek and the Salt River, which flow southward and westward, respectively, into Roosevelt Lake, sixty miles from the Ranger Station. The prevailing vegetation type in the area varies from ponderosa pine south of the Station to juniper and pinyon to the north. Sagebrush and short grass are common on the desert plains along the Little Colorado River while chaparral and oak woodland, as well as juniper and pinyon, may be found south of the Mogollon Rim.

"Chevelon Ranger Station has a semi-arid climate. Annual precipitation amounts are not as great as those received in the mountains to the west and along the Mogollon Rim to the south, nor are they as small as those received on the desert plateaus to the northeast. More than thirty percent of the annual precipitation falls in July and August. During these two months afternoon thundershowers develop readily over the strongly heated terrain in moist tropical air that moves into the state from the Gulf of Mexico. These showers rarely last for more than a few hours and are replaced shortly after sunset by nearly clear skies. In some years the remnants of a tropical disturbance may pass over Arizona from the Gulf of California or the adjacent parts of the Pacific Ocean, producing several days of heavy precipitation accompanied by occasionally strong winds. These storms may occur at any time between early June and late September.

"Chevelon Ranger Station receives much of the remainder of its annual precipitation during the winter when moisture-laden storms from the Pacific Ocean occasionally move far enough south on their eastward journey across the country to affect central Arizona. Precipitation from these storms is generally light, although it is widespread and may continue for several days. The heaviest amounts normally fall from storms that either advance unusually far south or develop or intensify off the coast of southern California moving into the state from the southwest. Because of its 7,000 foot altitude, almost ninety percent of the winter precipitation at Chevelon Ranger Station falls as snow. This often accumulates to a depth of several feet, particularly in the nearby forested areas."

Precipitation trends at this station for the study period are essentially flat, with a minimum at 1948-52 and a maximum at 1987-88. From 1988 to 1990, there is a decline.

The histogram shows a nominally lognormal distribution, with flat kurtosis and a slight positive skewness. The seasonal distribution shows a marked peak from July through October, with a flat distribution for the winter months. From April to June, there is a gradual decline to the summer minimum.

Table 21.22. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Chevelon Ranger Station (formerly Wallace RS), AZ
Station No.: 1574
Elevation: 7006
Latitude: 34d 32m
Longitude: 110d 55m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.14	2.20	2.13	2.11	1.12	1.06	0.06	0.00	0.81	3.06	3.39	16.08
*1940	0.81	1.12	0.70	1.20	1.83	0.63	1.61	1.14	2.65	2.28	3.74	3.53	21.25
*1941	3.25	1.40	2.36	1.58	1.74	3.28	2.56	1.40	2.13	2.51	4.43	2.79	29.43
*1942	2.71	1.93	2.37	1.03	2.02	0.62	1.69	0.00	0.00	2.43	3.34	1.93	20.07
1943	2.64	0.40	1.51	1.70	0.90	1.15	0.32	0.05	0.01	0.90	2.49	1.84	13.91
1944	1.72	0.03	2.34	1.10	3.53	2.10	1.70	0.59	0.00	1.42	2.49	2.49	19.51
*1945	0.37	0.98	1.13	0.97	0.57	1.74	0.29	0.08	0.12	3.02	2.60	0.32	12.20
*1946	0.84	0.05	1.65	1.13	0.39	0.66	1.04	0.04	0.09	3.30	3.46	3.39	16.04
*1947	0.52	1.60	0.64	0.65	0.13	0.32	0.10	1.19	0.00	2.62	4.87	1.50	14.14
1948	3.43	3.05	2.15	0.92	1.90	1.49	0.19	0.06	0.25	1.26	4.72	1.48	20.90
1949	1.08	0.00	3.27	4.90	1.17	0.55	0.31	0.36	1.83	2.33	1.60	2.01	19.41
1950	2.55	0.40	1.58	0.48	0.50	0.92	0.00	0.25	0.29	3.69	1.73	1.69	14.08
1951	0.00	0.71	0.06	2.30	1.48	1.26	1.79	0.63	0.00	2.33	5.01	0.48	16.05
1952	1.68	1.29	4.46	4.12	0.33	3.62	2.24	0.26	0.08	4.46	4.60	2.85	29.99
1953	0.00	3.54	0.71	0.18	0.71	0.98	0.58	0.29	0.16	4.31	2.71	0.17	14.34
1954	0.09	1.01	0.83	1.07	0.45	3.02	0.39	0.36	0.57	4.09	2.45	2.62	16.95
1955	0.29	0.35	0.36	1.39	0.96	0.02	0.94	0.29	3.59	4.83	5.29	0.08	18.39
1956	0.48	1.06	0.63	0.83	2.20	0.18	1.34	0.29	0.10	4.59	3.14	0.02	14.86
1957	1.75	0.07	0.25	6.38	0.28	1.26	0.27	1.25	0.82	3.04	2.68	0.00	18.05
1958	3.32	1.52	0.00	0.35	2.89	2.02	1.31	0.48	0.29	1.47	4.41	6.93	24.99
1959	0.97	1.43	0.20	0.33	1.75	0.08	1.03	0.26	0.42	1.77	4.18	1.15	13.57
1960	4.83	0.75	4.18	1.77	1.04	0.85	0.15	0.67	0.05	0.61	2.75	0.94	18.59
1961	3.79	1.10	1.08	0.22	0.70	2.14	0.27	0.09	0.00	1.80	5.66	2.18	19.03
1962	1.59	1.55	1.90	1.90	2.19	0.58	0.13	0.09	0.88	2.38	0.97	2.48	16.64
1963	1.29	1.50	0.57	0.66	0.68	0.94	0.55	0.00	0.00	1.48	6.97	2.74	17.38
1964	1.34	1.32	0.37	0.84	0.95	1.83	0.67	0.12	0.43	5.86	2.54	1.45	17.72
1965	0.00	1.33	2.23	2.53	1.61	0.61	2.62	1.11	0.40	3.40	1.42	1.15	18.41
1966	0.72	2.34	5.24	0.93	0.31	0.49	0.06	0.00	0.18	4.49	3.54	2.04	20.34
1967	1.58	1.32	2.22	0.31	0.01	0.98	0.33	1.26	1.08	4.00	3.01	1.75	17.85
1968	0.06	1.25	7.44	0.80	0.50	1.03	0.68	0.29	0.00	2.53	3.22	0.22	18.02
1969	1.46	1.87	1.14	1.70	1.18	0.75	0.38	2.15	0.00	4.50	2.63	0.00	17.76
1970	0.26	1.52	0.75	0.30	0.38	2.01	0.44	0.00	0.07	2.40	2.19	2.73	13.05
1971	0.00	0.46	0.85	0.14	0.41	0.17	0.61	0.43	0.00	2.30	9.50	3.19	18.06
1972	4.69	0.11	2.63	0.00	0.00	0.00	0.00	0.08	1.91	2.55	2.06	1.09	15.12
1973	6.30	2.68	2.45	1.07	3.44	4.69	1.15	1.26	0.00	2.13	0.54	0.00	25.71
1974	0.00	1.92	0.00	3.68	0.08	0.66	0.00	0.00	0.00	3.06	1.90	1.58	12.88
*1975	3.47	0.54	0.79	0.65	1.27	1.62	1.44	0.35	0.00	3.27	1.55	2.95	17.90
*1976	0.25	1.60	1.10	0.15	2.62	1.31	1.28	1.94	0.03	4.95	1.74	2.37	19.34
1977	1.22	0.79	0.05	1.21	0.78	0.57	1.12	0.30	0.41	3.18	3.71	3.71	17.05
1978	0.63	0.47	0.48	1.87	2.84	3.88	0.94	0.62	0.00	1.34	1.27	0.11	14.45
1979	1.53	5.79	4.31	3.50	0.84	2.31	0.47	2.14	0.42	0.96	0.73	0.35	23.35
1980	0.59	0.73	1.24	3.96	4.73	2.55	1.10	0.77	0.10	1.08	1.12	0.90	18.87
1981	0.80	0.00	0.52	1.07	0.37	2.31	0.58	2.91	0.89	3.32	6.27	2.22	21.26
*1982	2.02	1.87	0.00	3.13	1.82	2.54	0.26	1.63	0.03	3.83	1.64	1.12	19.89
1983	0.21	3.24	3.82	1.04	1.08	2.08	1.23	0.49	0.58	1.62	2.75	3.78	21.92
1984	2.20	2.06	1.34	0.18	0.07	0.89	0.35	0.18	0.44	4.90	5.62	3.03	21.26
*1985	1.60	0.96	3.49	1.62	0.85	1.99	1.30	0.33	0.08	5.61	1.01	3.40	22.24
1986	2.14	4.03	0.66	0.13	1.49	1.55	0.65	1.39	0.28	3.04	4.21	1.54	21.11
1987	1.96	2.06	0.81	2.78	2.01	1.15	0.33	1.34	0.30	2.04	2.32	0.34	17.44
1988	1.61	2.63	1.48	1.83	1.80	0.18	2.04	0.03	2.62	1.66	3.97	0.51	20.36
1989	1.48	1.27	1.75	1.21	0.74	1.79	0.03	0.49	0.15	1.84	3.63	1.12	15.50
1990	0.99	0.17	0.41	0.40	1.52	1.17	0.94	0.42	0.03	3.43	2.62	3.43	15.53
1939-90 Average	1.52	1.37	1.63	1.47	1.27	1.40	0.82	0.62	0.48	2.83	3.19	1.83	18.43

* Denotes year in which one or more monthly records are reconstructed.

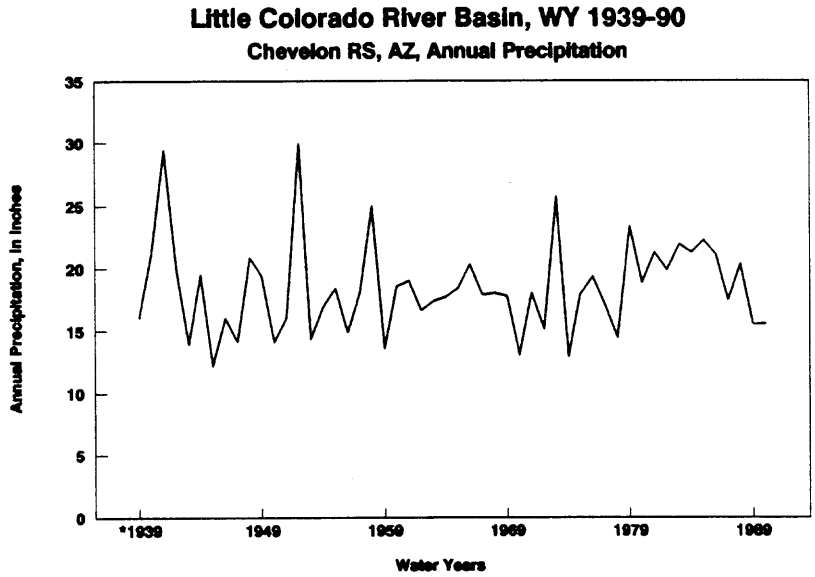


Figure 69. Chevelon RS, AZ, Annual Precipitation, WY 1939-90

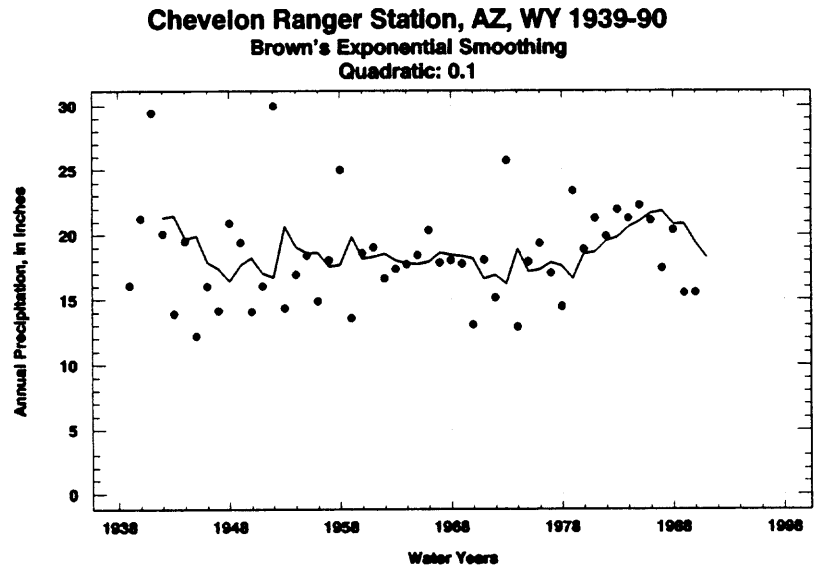


Figure 70. Chevelon RS, AZ, Smoothed Annual Precipitation, WY 1939-90

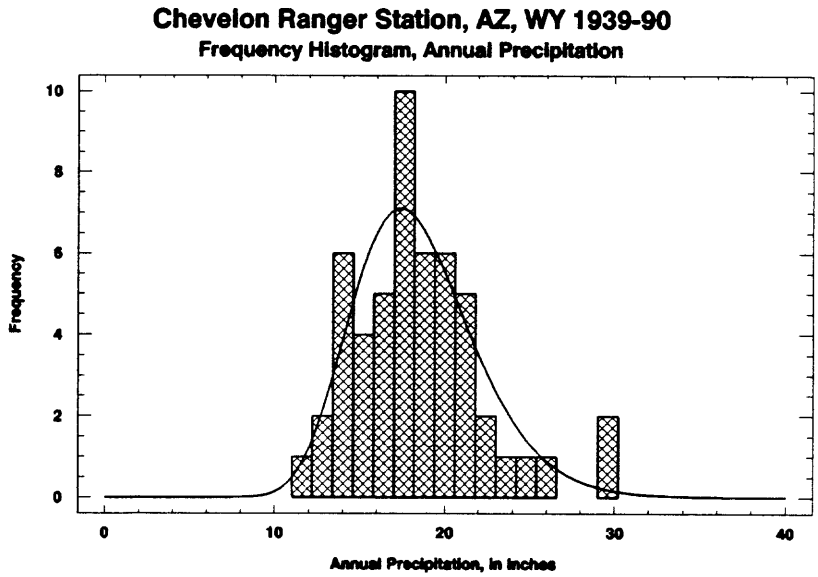


Figure 71. Chevelon RS, AZ, Histogram of Annual Precipitation

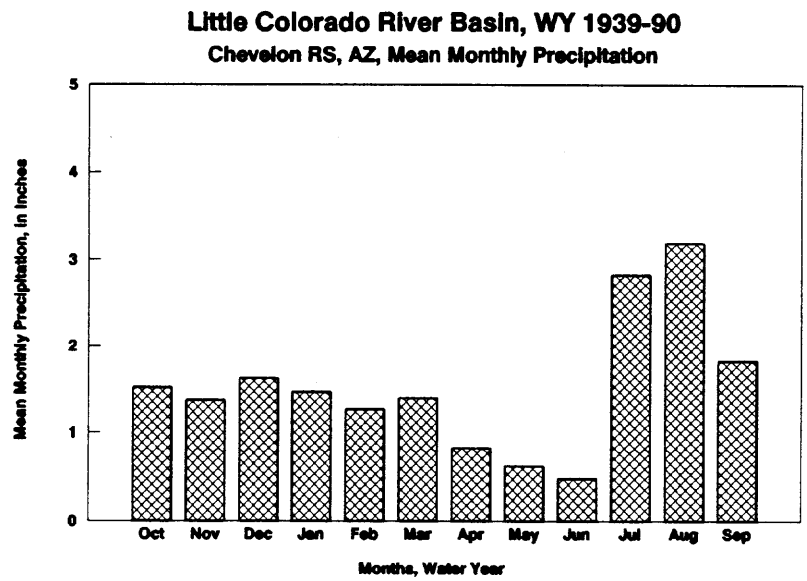


Figure 72. Chevelon RS, AZ, Monthly Distribution of Precipitation

6.2.3.10 Copper Mine Trading Post, AZ

This station is located just outside the LCR Basin in the extreme northwest corner. It is an outlying station with a period of record of 1939-1970, and is located in such a region that few stations of a longer period exist within a small radius. Therefore, reconstruction of the 1971-90 period is somewhat problematical. However, the trends of the reconstructed data match that of Page and Wahweap. It was included to obtain resolution for the isohyetal maps which follow this section (See Section 6.2.5). It was hoped that a correlation between this station and Moenkopi Wash could be developed in the flow and sediment modeling activities of DBS&A for 1994. This hope proved optimistic.

As summarized in Sellars and Hill (1974, p. 166):

"The Copper Mine Trading Post is located at an elevation of 6,380 feet in the semi-forested Kaibito Plateau of north-central Arizona, just west of the Navajo Indian Reservation. It lies eighteen miles to the southeast of the confluence of the Paria and Colorado Rivers which merge less than a mile below Lees Ferry. The northern end of Marble Canyon, carved out by the erosive forces of the Colorado River, is also found in the vicinity of Lees Ferry. Glen Canyon is situated in the extreme northern section of the state, 20 miles to the north-northwest. The highest elevations within fifty miles of the post are found on Kaibab Plateau, rising above 9,000 feet, fifty miles to the west and on Navajo Mountain in southern Utah, forty miles to the northeast. The steep Vermillion Cliffs form the southern and eastern borders of the Paria Plateau, twenty miles to the northwest. Among the numerous interesting sites near the Copper Mine Trading Post are the magnificent Grand Canyon National Park, forty miles to the southwest, the fascinating Navajo Bridge, 17 miles to the northwest, and the Navajo National Monument, 43 miles to the east-northeast. The vegetation in the area is dominated by forests of pinyon and juniper, with sagebrush and plains grass prevailing at the lower elevations to the north, south, and west. Stands of ponderosa pine are found at heights exceeding 8,000 feet on Navajo Mountain and on the Kaibab Plateau.

"The Copper Mine Trading Post has an extremely arid climate, receiving less than seven and one-half inches of precipitation during an average year [including reconstructed record 1971-90, ten inches]. Significant rainfall occurs only in July and August when late afternoon thunderstorms develop over the high plateau country. These storms are typically preceeded by blowing dust and strong dusty winds as they traverse the plateau region and usually produce only light showers. Dissipating tropical disturbances tend to give the most intense summer rains in the state, but by the time they reach northern Arizona, they are usually too weak to augment significantly the precipitation at the Copper Mine Trading Post.

"During the rest of the year at the Copper Mine Trading Post dry conditions generally prevail. Winter rains are associated with middle latitude storms that originate in the Pacific Ocean and travel eastward. However, such storm systems rarely have a significant effect upon this northern region of the state. Excluding July and August, each of the remaining ten months receives less than an inch of precipitation, ranging from .31 inches in June to .71 inches in October. Only small quantities of snow are measured in an average year and the little that does fall usually melts upon striking the ground."

Precipitation trends show a dramatic decline from 1939 to 1949 (note that this span of time is measured precipitation), followed by a flat period from 1949 through 1979. From 1979 to 1987, there is a dramatic increase in precipitation (reconstructed data) followed by a decline from 1988 to 1990. See nearby Page, Wahweap and Lees Ferry for comparison. Although these trends may be an artifact of the reconstruction, based upon records from nearby stations, there is reason to believe that the reconstruction reflects actual trends in the region.

As is the case in the measured period of record from 1939-70, the entire study period distribution follows a strongly lognormal shape, with moderate kurtosis and strong positive skewness. The seasonal distribution shows a strong peak in July and August, followed by a gradual decline for the rest of the year to June, the summer minimum.

Table 23. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Copper Mine Trading Post, AZ
Station No.: 2099
Elevation: 6380
Latitude: 36d 38m
Longitude: 111d 25m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.37	0.32	2.15	1.79	1.36	1.20	0.37	0.02	0.00	0.55	1.80	4.77	14.68
1940	0.00	0.80	0.00	0.51	0.43	0.34	0.36	0.11	0.07	0.28	1.72	2.86	7.48
1941	1.74	0.43	1.57	0.78	1.02	1.23	2.05	1.08	0.47	0.88	2.08	0.87	14.20
1942	2.38	0.39	1.06	0.00	0.71	0.39	0.67	0.00	0.00	1.63	0.72	0.27	8.22
1943	0.74	0.08	1.27	0.45	0.22	0.84	0.35	0.08	0.05	0.34	1.28	0.44	6.14
1944	0.51	0.06	1.23	0.32	0.58	1.20	0.73	0.03	0.03	0.11	0.06	0.04	4.90
1945	0.18	0.73	0.23	0.37	0.29	0.82	1.22	0.00	0.04	2.05	1.01	0.01	6.95
1946	0.58	0.02	0.04	0.53	0.13	0.61	0.76	0.08	0.00	1.43	1.43	0.61	6.22
1947	1.43	0.75	0.17	0.59	0.07	0.00	0.13	0.25	0.19	0.61	2.73	0.07	6.99
1948	1.68	0.41	0.44	0.26	1.49	0.58	0.26	0.02	1.36	1.00	0.95	0.49	8.94
1949	0.55	0.12	0.68	1.44	0.55	0.89	0.03	0.02	1.27	0.26	0.52	1.26	7.59
1950	0.68	0.09	0.15	0.30	0.62	0.49	0.08	0.02	0.16	1.29	0.79	0.50	5.17
*1951	0.07	0.18	0.02	0.87	0.27	0.11	0.24	0.66	0.00	1.30	2.30	0.23	6.25
*1952	0.84	0.33	0.88	1.12	0.33	0.67	1.35	0.16	0.54	1.66	2.70	2.47	13.05
1953	0.00	0.90	0.97	0.16	0.13	0.40	0.89	0.04	0.41	4.02	2.52	0.16	10.60
1954	0.23	0.94	0.00	0.66	0.26	0.93	0.02	0.40	0.38	1.72	0.77	0.95	7.26
1955	0.25	0.63	0.37	0.34	0.41	0.17	0.08	0.01	1.40	0.88	3.97	0.23	8.74
1956	0.00	1.30	0.40	0.55	0.14	0.05	0.35	0.42	0.02	1.98	1.66	0.00	6.87
1957	0.04	0.00	0.00	1.67	0.23	0.53	0.52	0.95	0.65	1.46	3.15	0.00	9.20
1958	0.89	1.22	0.00	0.00	0.26	2.57	0.35	0.75	0.00	1.75	2.03	1.03	10.85
1959	0.20	0.20	0.00	0.00	0.40	0.00	1.65	0.35	0.13	0.39	1.73	0.00	5.05
1960	2.63	0.62	1.45	0.92	0.40	0.47	0.10	0.00	0.23	0.00	0.29	0.23	7.34
1961	2.28	0.32	0.71	0.20	0.00	0.96	0.00	0.05	0.00	0.65	1.61	1.54	8.32
1962	0.00	0.54	0.75	0.39	0.10	0.20	0.00	0.45	0.31	0.00	0.76	0.93	4.43
1963	1.52	0.97	0.20	0.80	0.25	0.44	0.00	0.00	0.00	0.40	2.58	1.22	8.38
1964	1.01	0.00	0.00	0.05	0.00	0.73	0.53	0.57	0.15	1.84	1.95	0.00	6.83
1965	0.00	0.45	0.05	0.32	0.65	0.65	0.57	1.56	0.58	0.15	0.60	0.85	6.43
1966	0.68	0.66	0.91	0.00	0.50	0.15	0.38	0.53	0.00	1.48	0.92	0.79	7.00
1967	0.14	0.60	0.47	0.00	0.00	0.00	0.00	1.01	0.26	1.25	1.25	1.10	6.08
1968	0.00	0.00	0.91	0.00	0.05	0.30	0.77	0.15	0.00	1.89	1.10	0.05	5.22
1969	0.20	0.30	0.00	0.43	0.79	0.30	0.00	0.61	0.51	0.85	1.35	0.25	5.59
1970	1.07	0.68	0.00	0.23	0.28	0.44	0.20	0.15	0.10	0.81	1.35	0.23	5.54
1971	0.00	0.40	0.23	0.10	0.69	0.25	0.02	0.17	0.15	0.38	1.75	0.27	4.41
1972	1.92	0.50	0.60	0.00	0.00	0.00	0.05	0.16	1.21	0.27	1.35	0.91	6.97
1973	6.35	0.61	0.56	0.60	0.31	1.44	0.20	0.35	0.46	0.94	1.04	0.10	12.96
1974	0.00	0.35	0.00	0.93	0.11	0.40	0.10	0.00	0.00	1.23	0.00	0.15	3.27
1975	1.05	0.56	0.50	0.23	0.63	0.41	0.82	0.02	0.23	0.19	0.43	0.30	5.37
1976	0.00	0.10	1.33	0.00	2.30	0.53	0.81	1.95	0.00	0.60	0.00	1.38	9.00
*1977	0.20	0.00	0.00	1.10	0.26	0.64	0.53	0.64	0.52	2.10	1.73	0.70	8.44
*1978	0.81	0.64	0.86	3.64	2.52	3.59	0.91	0.43	0.05	0.88	1.10	1.08	16.52
*1979	1.12	4.46	4.56	4.13	1.57	3.04	0.41	1.58	0.50	0.51	1.50	0.18	23.57
*1980	1.05	1.29	1.29	4.48	4.66	2.41	1.04	0.46	0.08	1.83	1.64	1.38	21.61
*1981	1.03	0.07	0.62	0.54	0.71	2.57	0.85	1.17	0.45	2.28	2.74	2.17	15.18
*1982	1.65	1.50	0.26	2.51	2.42	2.18	0.61	0.78	0.16	1.58	2.65	1.25	17.56
*1983	0.49	2.76	3.18	1.49	1.91	2.54	1.20	0.16	0.18	3.31	2.34	3.16	22.71
*1984	1.38	1.83	1.87	0.38	0.35	0.57	0.73	0.11	0.34	2.68	2.71	1.38	14.32
*1985	1.46	0.78	3.66	2.47	0.92	2.00	1.51	0.37	0.23	2.41	0.94	1.79	18.53
*1986	1.13	3.10	0.29	0.18	1.67	1.93	1.17	0.91	0.67	1.83	2.34	1.64	16.86
*1987	1.68	1.53	1.19	1.38	1.46	1.32	0.24	0.89	0.77	1.83	3.11	0.56	15.98
*1988	2.32	1.89	1.00	1.37	1.39	0.12	2.45	0.24	1.60	1.02	3.34	0.59	17.31
*1989	0.55	1.01	0.88	1.51	0.86	0.75	0.05	0.50	0.05	1.49	2.08	0.39	10.14
*1990	0.64	0.18	0.48	1.19	1.75	0.84	1.00	0.46	0.25	2.52	1.92	2.92	14.15
1939-90 Average	0.92	0.74	0.78	0.85	0.76	0.89	0.57	0.42	0.33	1.25	1.62	0.90	10.03

* Denotes year in which one or more monthly records are reconstructed.

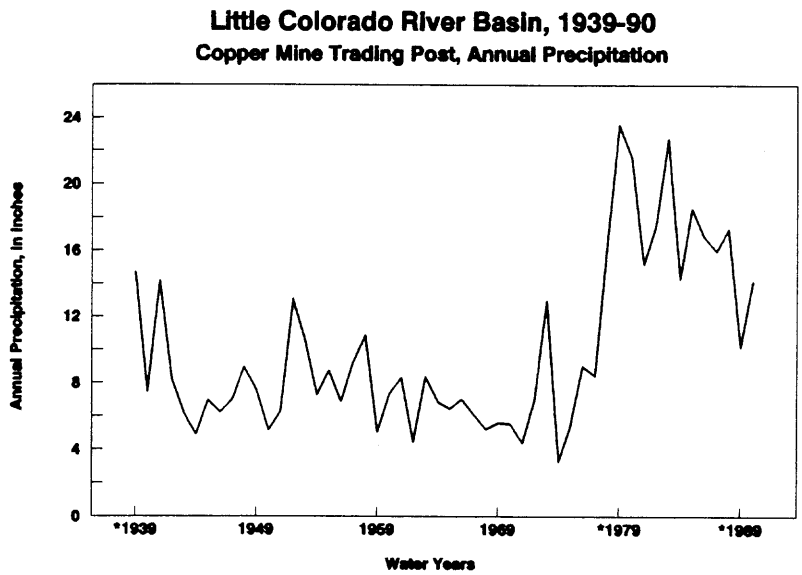


Figure 73. Copper Mine TP, Annual Precipitation, WY 1939-90

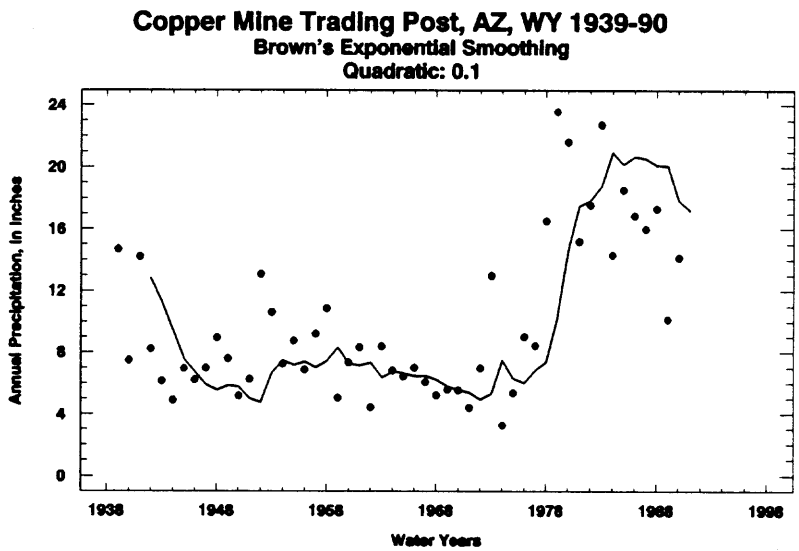


Figure 74. Copper Mine TP, AZ, Smoothed Annual Precipitation, WY 1939-90

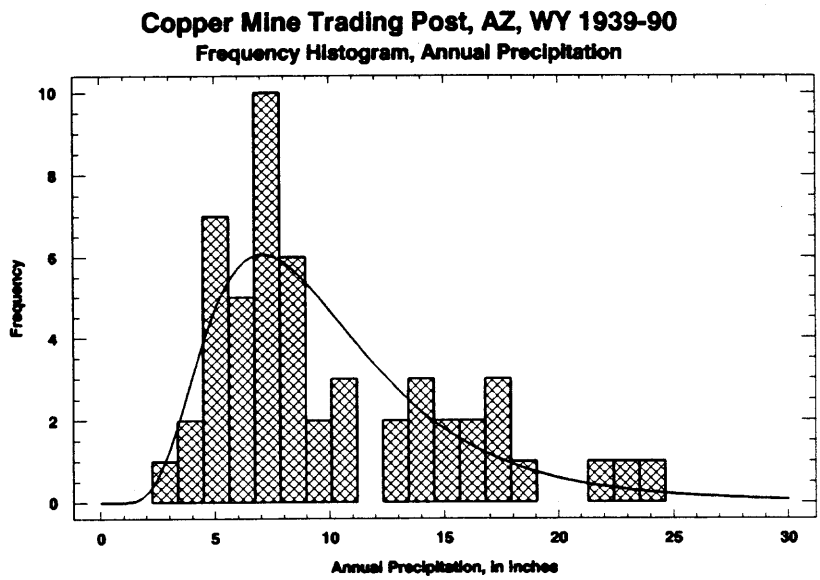


Figure 75. Copper Mine TP, AZ, Histogram of Annual Precipitation

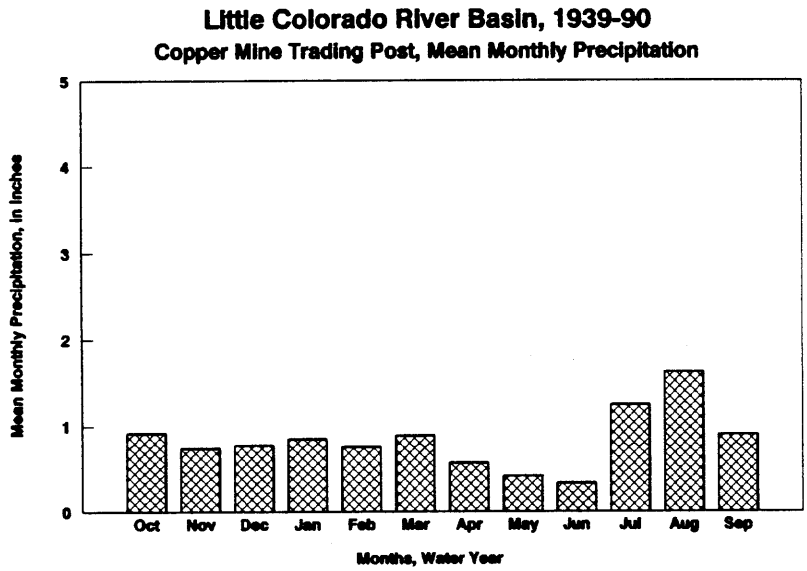


Figure 76. Copper Mine TP, AZ, Monthly Distribution of Precipitation

6.2.3.11 Crownpoint, NM

This station is located at an elevation of 6,960 feet, some 35 miles east-northeast of Gallup. The station lies about four miles east of the extreme southeast corner of the Navajo Indian Reservation, just outside the LCR Basin. This station is included to provide interpolation of neaby LCR stations with missing record. The period of record for Crownpoint is from 1914 to 1970, with some months missing in the 1920-24 period and during 1955-56. The missing record is reconstructed for the missing months from 1939-90.

The precipitation trends show a slight decline from 1939 to 1959, and a gradual increase from 1960 to 1988. From 1988 to 1990, there is an indication of a decline.

The histogram shows a slight lognormal trend, with the median annual of about ten inches conspicuously missing. There is a slight positive skewness, although the negative direction of skew is also present. The monthly distribution shows a strong peak in July through September, with a gradual decline from October to the summer minimum in June.

Table 24. The Hopi Tribe
Little Colorado River Study - Precipitation,
Reconstructed Data
Station Name: Crownpoint, NM
Station No.: 2219
Elevation: 6960
Latitude: 35d 41m
Longitude: 108d 09m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.12	0.69	0.30	0.93	0.55	0.67	1.09	0.24	0.03	0.79	0.73	1.06	7.20
1940	0.37	0.60	0.42	0.40	0.52	0.31	0.35	1.32	1.38	1.35	0.87	1.32	9.21
1941	0.77	0.88	1.56	0.57	0.78	1.19	0.91	2.64	1.09	2.36	1.39	2.77	16.91
1942	1.46	0.12	0.54	0.23	0.78	0.33	0.55	0.00	0.00	0.09	1.19	1.38	6.67
1943	0.86	0.05	0.97	0.57	0.26	0.55	0.10	0.77	0.41	0.72	3.03	0.12	8.41
1944	1.01	0.16	1.06	0.42	0.78	0.81	0.27	0.51	0.17	1.05	1.93	2.25	10.42
1945	1.08	0.59	0.41	0.66	0.37	0.60	0.94	0.04	0.03	1.84	1.92	0.12	8.60
1946	0.90	0.03	1.09	0.40	0.09	0.35	0.10	0.10	0.03	1.65	5.20	1.21	11.15
1947	0.17	1.21	0.10	0.75	0.20	0.20	0.09	1.17	0.25	1.16	4.43	1.33	11.06
1948	1.56	0.64	0.56	0.52	1.11	0.83	0.36	0.54	2.26	1.97	1.54	0.36	12.25
1949	1.74	0.30	0.39	0.50	0.56	0.17	0.83	0.30	0.40	2.59	0.78	0.34	8.90
1950	0.23	0.00	0.45	0.38	0.58	0.42	0.03	0.07	0.31	0.97	0.37	0.90	4.71
1951	0.00	0.39	0.00	0.81	0.23	0.33	0.75	0.05	0.00	1.08	2.08	0.21	5.93
1952	0.04	0.70	1.27	1.19	0.20	0.72	1.77	0.00	0.74	1.72	2.35	1.01	11.71
1953	0.00	1.28	0.25	0.08	0.51	0.35	0.38	0.22	0.42	2.21	0.26	0.02	5.98
*1954	0.41	0.23	0.95	0.41	0.05	1.07	0.45	1.12	0.38	2.67	1.13	3.57	12.44
1955	0.23	0.02	0.37	0.21	0.43	0.00	0.10	0.60	0.49	4.04	2.31	0.03	8.83
1956	0.14	0.33	0.37	0.89	0.50	0.07	0.17	0.58	0.65	0.67	1.20	0.00	5.57
1957	0.52	0.16	0.07	1.47	0.43	0.51	0.19	1.31	0.57	4.56	2.11	0.03	11.93
1958	2.47	0.38	0.18	0.30	0.50	1.21	1.08	0.23	0.35	1.18	2.78	0.96	11.62
1959	1.30	0.76	0.18	0.33	0.33	0.03	0.49	0.00	0.97	0.44	4.80	0.19	9.82
1960	1.68	0.10	0.87	0.46	0.52	0.25	0.36	0.76	1.39	0.19	0.89	0.81	8.28
1961	2.71	0.27	0.74	0.15	0.62	1.30	0.41	0.12	0.67	1.25	2.61	0.44	11.29
1962	1.71	0.39	0.71	0.94	0.72	0.45	0.17	0.11	0.53	0.91	0.49	1.75	8.88
1963	2.06	0.54	0.38	0.71	0.05	0.09	0.04	0.00	0.00	1.97	1.92	1.70	9.46
1964	0.17	0.68	0.13	0.16	0.77	0.30	0.63	0.52	0.00	2.61	6.28	1.64	13.89
1965	0.00	1.06	0.97	1.14	0.42	0.36	0.77	0.74	1.53	3.97	1.24	0.40	12.60
1966	0.13	0.72	0.89	0.22	0.49	0.24	0.71	0.21	1.29	2.86	2.54	1.05	11.35
1967	0.04	0.49	0.64	0.10	0.05	0.29	0.07	0.14	1.37	3.15	2.01	0.73	9.08
1968	0.11	0.22	2.42	0.12	0.00	1.97	0.75	0.19	0.00	1.28	2.11	0.00	9.17
1969	0.26	0.52	0.83	0.46	0.51	0.83	0.25	0.24	0.21	3.20	0.46	1.57	9.34
*1970	2.26	0.56	0.43	0.09	0.05	1.42	0.52	0.22	0.62	1.58	1.38	2.03	11.16
*1971	0.83	0.39	0.54	0.31	0.40	0.24	0.12	0.11	0.03	1.28	2.55	2.69	9.48
*1972	1.32	0.59	0.90	0.04	0.06	0.02	0.08	0.25	0.80	0.80	1.30	0.87	7.04
*1973	7.99	0.83	0.73	0.50	0.90	1.64	0.46	1.51	0.48	1.11	0.73	0.62	17.49
*1974	0.20	0.34	0.15	1.24	0.13	0.14	0.15	0.02	0.02	1.77	1.39	0.81	6.35
*1975	2.97	0.33	0.31	0.75	0.64	1.00	0.46	0.43	0.03	1.54	0.54	2.38	11.39
*1976	0.04	0.33	0.25	0.07	0.50	0.19	0.24	0.84	0.20	1.20	1.56	1.06	6.50
*1977	0.60	0.47	0.08	1.24	0.45	0.14	0.24	0.38	0.32	2.48	2.38	0.80	9.59
*1978	0.69	0.59	0.22	1.18	0.85	1.08	0.48	1.42	0.10	0.34	1.19	1.62	9.78
*1979	1.66	3.22	1.13	1.63	0.35	1.13	0.13	1.70	0.64	0.54	1.48	0.08	13.69
*1980	0.94	1.71	0.65	1.88	2.60	0.88	0.21	0.25	0.01	0.32	1.26	0.81	11.53
*1981	0.57	0.06	0.48	0.24	0.41	1.74	0.42	0.46	0.59	2.60	0.98	1.04	9.57
*1982	0.96	0.40	0.06	0.72	1.58	1.58	0.18	1.32	0.09	1.49	2.66	1.79	12.83
*1983	0.09	1.23	1.22	1.24	0.68	1.40	0.50	0.44	0.60	1.83	1.39	1.24	11.85
*1984	1.18	0.94	1.50	0.25	0.08	1.03	0.72	0.20	0.48	1.17	2.43	1.70	11.67
*1985	1.70	0.32	1.40	1.11	0.41	1.07	2.03	0.39	0.17	2.60	1.36	1.24	13.80
*1986	1.18	1.09	0.36	0.05	1.11	0.99	1.35	0.69	1.29	2.24	2.30	1.90	14.55
*1987	1.23	2.86	0.88	0.83	1.04	0.57	0.28	1.16	0.77	1.91	1.81	0.50	13.84
*1988	0.96	1.79	1.21	1.12	0.59	0.06	1.87	0.34	1.24	1.00	3.69	1.14	15.00
*1989	0.35	1.05	0.30	1.13	1.02	0.24	0.02	0.13	0.04	1.86	1.09	0.28	7.50
*1990	0.73	0.07	0.17	0.29	0.84	0.80	1.51	0.61	0.50	2.22	1.34	1.71	10.80
1939-90 Average	1.01	0.65	0.64	0.62	0.55	0.66	0.52	0.53	0.52	1.70	1.88	1.07	10.35

* Denotes year in which one or more monthly records are reconstructed.

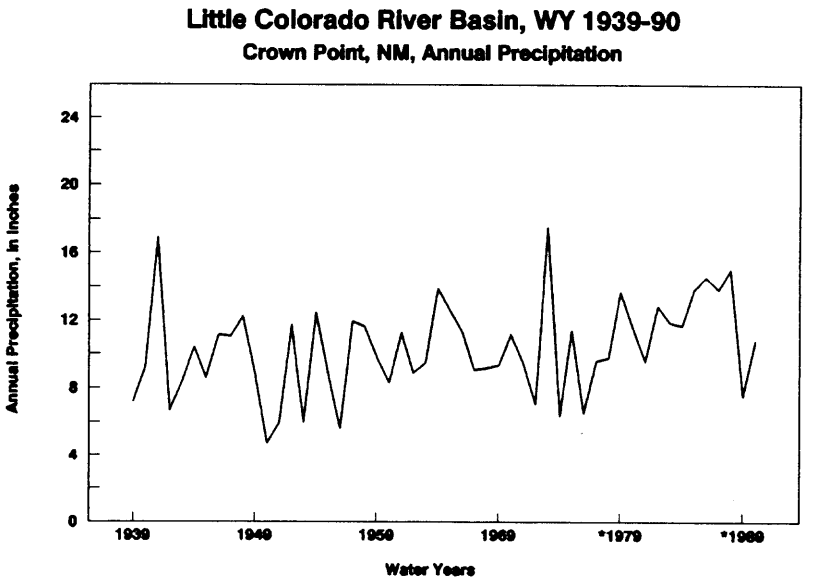


Figure 77. Crownpoint, NM, Annual Precipitation, WY 1939-90

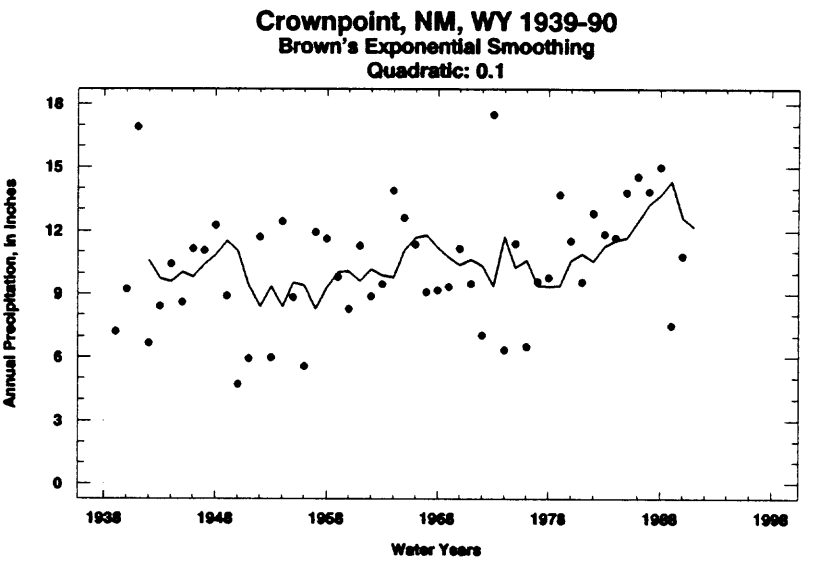


Figure 78. Crownpoint, NM, Smoothed Annual Precipitation, WY 1939-90

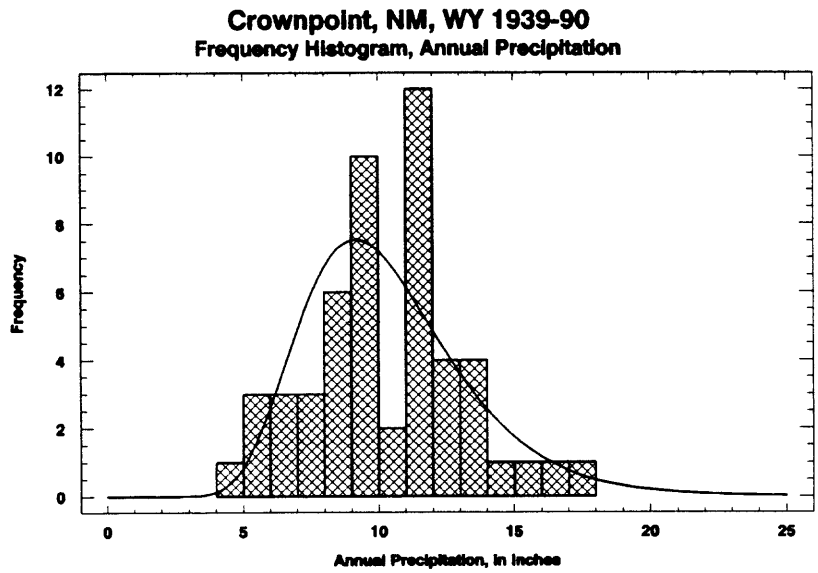


Figure 79. Crownpoint, NM, Histogram of Annual Precipitation

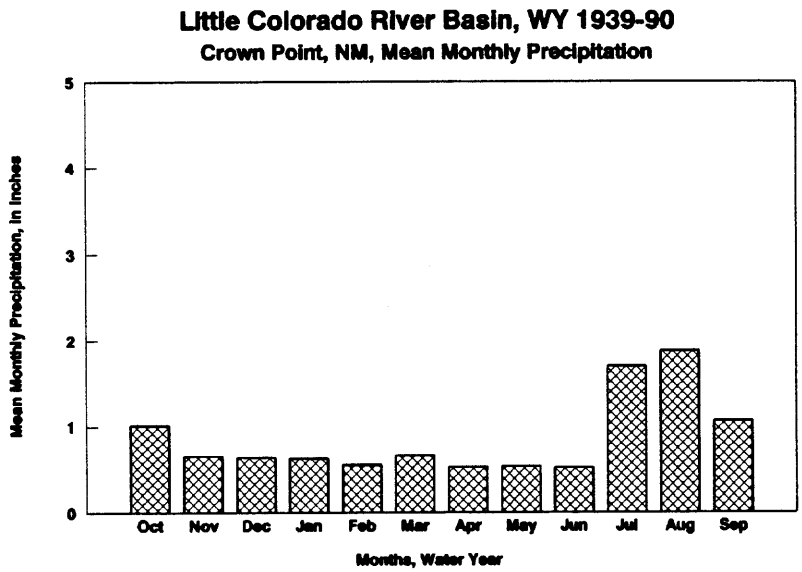


Figure 80. Crownpoint, NM, Montly Distribution of Precipitation

6.2.3.12 Farmington, NM

This station lies at an elevation of 5,395 feet in the northeast corner of New Mexico, just east of the Navajo Indian Reservation and somewhat outside the LCR Basin. It is included to provide interpolation of missing record from nearby LCR stations. The period of record is from 1914 to the present, with the 1931-32, 1955-56, and 1972-73 years missing. The missing record has been reconstructed.

This is a farming community along the Animas River valley, just upstream of the confluence with the La Plata River. The vegetation includes cottonwood and tamarisk along the river banks. The native vegetation in the broad alluvial valleys is now obscured by numerous farms.

The precipitation trends are typical of eastern LCR Basin desert stations. From 1939 to 1968, there is a slight, gradual decline. From 1969 to 1988, there is a slight, gradual increase. From 1989 to 1990, there are the beginnings of a slight decline.

The histogram shows a strong lognormal distribution, with a flat kurtosis and a positive skewness. The monthly distribution shows a barely noticeable July to October peak, with a gradual decline from November to the June minimum. Another slight peak occurs in March.

Table 25. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Farmington 4NE, NM
Station No.: 3134
Elevation: 5395
Latitude: 36d 45m
Longitude: 108d 10m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.49	0.05	0.71	0.64	0.53	0.99	0.29	0.05	0.00	0.15	1.47	2.36	7.73
1940	0.34	0.47	0.56	1.30	0.88	0.13	0.25	1.07	0.12	0.65	0.61	1.37	7.75
1941	0.29	0.63	2.52	1.42	0.77	0.80	2.81	2.25	1.20	0.40	1.03	2.93	17.05
1942	3.71	0.44	0.68	0.07	0.46	0.50	1.04	0.12	0.00	0.20	0.34	0.57	8.13
1943	0.93	0.03	0.82	0.26	0.61	1.36	0.11	0.90	0.53	0.40	0.78	0.39	7.12
1944	0.40	0.18	1.31	0.65	0.74	0.34	0.62	0.72	0.04	0.78	0.84	0.71	7.33
1945	0.25	0.81	0.86	0.75	0.54	0.96	0.86	0.00	0.17	0.85	0.79	0.59	7.43
1946	0.99	0.02	0.57	0.02	0.13	0.52	0.11	0.38	0.08	1.09	1.67	0.86	6.44
1947	0.53	0.78	0.30	0.22	0.28	0.26	0.08	1.37	0.00	0.40	2.56	0.39	7.17
1948	1.94	0.44	0.41	0.02	1.01	0.66	0.26	0.24	1.63	0.11	1.34	0.72	8.78
1949	2.39	0.00	0.84	0.92	0.19	0.98	0.17	0.98	1.49	0.41	1.11	0.37	9.85
1950	0.70	0.17	0.03	0.26	0.43	0.24	0.10	0.02	0.59	0.65	0.10	1.50	4.79
1951	0.00	0.13	0.05	0.76	0.43	0.08	0.46	0.25	0.00	0.05	1.02	0.16	3.39
1952	0.73	0.57	0.84	1.13	0.46	0.24	1.53	0.25	0.53	1.06	0.50	0.95	8.79
1953	0.00	0.96	0.83	0.30	0.11	0.28	0.96	0.05	0.07	0.63	1.03	0.00	5.22
1954	1.07	0.30	0.81	0.25	0.00	7.00	0.00	0.33	0.16	2.81	1.18	1.34	15.25
1955	0.37	0.17	0.81	0.61	0.88	0.05	0.42	0.62	0.44	1.19	0.83	0.17	6.56
1956	0.19	0.34	0.62	1.23	0.47	0.09	0.06	0.03	0.09	1.16	0.51	0.07	4.86
1957	0.27	0.33	0.13	1.32	0.50	1.05	1.37	1.30	0.26	2.02	1.87	0.05	10.47
1958	2.61	1.44	0.43	0.60	0.51	1.47	0.59	0.18	0.55	0.07	1.20	1.30	10.95
1959	1.00	0.31	0.23	0.14	0.50	0.09	0.84	0.00	0.36	0.72	1.66	0.91	6.76
1960	1.92	0.42	1.17	0.67	0.80	0.73	0.35	0.80	0.46	0.47	0.15	0.22	8.16
1961	1.91	0.14	1.12	0.61	0.42	1.51	0.49	0.08	0.00	0.40	3.65	0.54	10.87
1962	0.99	0.19	1.20	0.37	0.98	0.02	0.33	0.22	0.07	0.08	0.00	1.12	5.57
1963	2.71	0.76	0.51	0.40	0.58	0.29	0.36	0.00	0.10	0.17	1.17	1.33	8.38
1964	0.95	0.44	0.20	0.00	0.12	0.53	1.62	0.11	0.00	0.29	1.28	1.48	7.02
1965	0.00	1.00	1.38	0.56	1.12	0.35	0.95	0.61	1.24	2.37	1.89	1.46	12.93
1966	1.13	1.20	1.42	0.50	0.00	0.00	0.30	0.70	0.00	0.62	0.52	0.68	7.07
1967	0.32	0.15	0.34	0.31	0.00	0.05	0.00	0.24	0.56	0.29	2.24	0.46	4.96
1968	0.17	0.39	0.82	0.19	0.14	0.11	0.56	0.52	0.03	1.52	1.84	0.05	6.34
1969	0.63	1.22	0.31	1.18	0.60	0.50	0.25	0.71	1.60	1.40	1.73	1.33	11.46
1970	3.11	0.36	0.60	0.38	0.10	0.72	0.46	0.02	1.45	0.49	0.48	2.52	10.69
1971	0.62	0.55	0.25	0.26	0.10	0.25	0.33	0.19	0.00	0.29	0.94	1.17	4.95
1972	0.95	0.58	0.45	0.00	0.00	0.03	0.05	0.00	0.74	0.15	0.97	0.50	4.42
1973	4.93	0.41	1.30	0.59	0.37	2.02	0.61	0.89	0.99	0.48	0.67	1.36	14.62
1974	0.51	0.26	0.26	1.40	0.48	0.12	0.57	0.06	0.04	0.99	0.31	0.41	5.41
1975	2.51	0.46	0.46	0.79	0.99	1.72	1.45	0.24	0.07	1.06	0.33	0.79	10.87
1976	0.65	0.87	0.45	0.16	0.53	0.08	0.14	0.72	0.35	1.19	0.57	1.67	7.38
1977	0.06	0.04	0.02	0.95	0.06	0.09	0.07	0.56	0.14	1.02	1.43	0.34	4.78
*1978	0.34	0.75	0.98	1.44	2.90	2.39	0.58	0.96	0.00	0.07	0.18	1.35	11.94
1979	1.46	2.24	0.59	0.88	0.19	0.96	0.28	0.58	0.43	1.40	0.49	0.06	9.56
1980	1.37	0.97	0.73	1.45	0.70	0.63	0.29	0.25	0.07	0.08	0.89	1.05	8.48
1981	0.84	0.02	0.00	0.00	0.30	1.76	0.21	1.05	0.16	1.34	0.35	0.69	6.72
1982	0.89	0.36	0.03	0.32	0.77	1.18	0.67	0.82	0.00	1.27	2.78	1.50	10.59
1983	0.16	0.92	0.76	0.94	0.69	1.84	0.31	0.13	0.35	1.67	0.72	0.53	9.02
*1984	0.52	0.91	0.67	0.06	0.12	0.87	1.00	0.00	0.67	0.62	1.64	0.45	7.53
1985	1.13	0.23	0.87	0.39	0.13	1.74	1.76	0.29	0.01	1.38	0.43	1.31	9.67
1986	1.21	0.52	0.22	0.11	0.77	0.51	0.97	0.13	0.74	4.10	0.93	2.18	12.39
1987	0.65	2.73	0.76	0.10	1.75	0.66	0.00	0.68	0.02	0.28	1.17	0.27	9.07
1988	1.07	1.65	0.59	0.63	0.82	0.02	0.72	1.11	0.33	0.58	2.34	0.27	10.13
1989	0.22	0.78	0.19	1.19	0.56	0.06	0.00	0.00	0.00	1.24	1.62	0.14	6.00
1990	0.51	0.00	0.00	0.53	0.53	0.74	0.85	1.07	0.07	0.35	1.32	1.97	7.94
1939-90 Average	1.03	0.58	0.63	0.58	0.54	0.78	0.57	0.48	0.37	0.84	1.11	0.90	8.40

* Denotes year in which one or more monthly records are reconstructed.

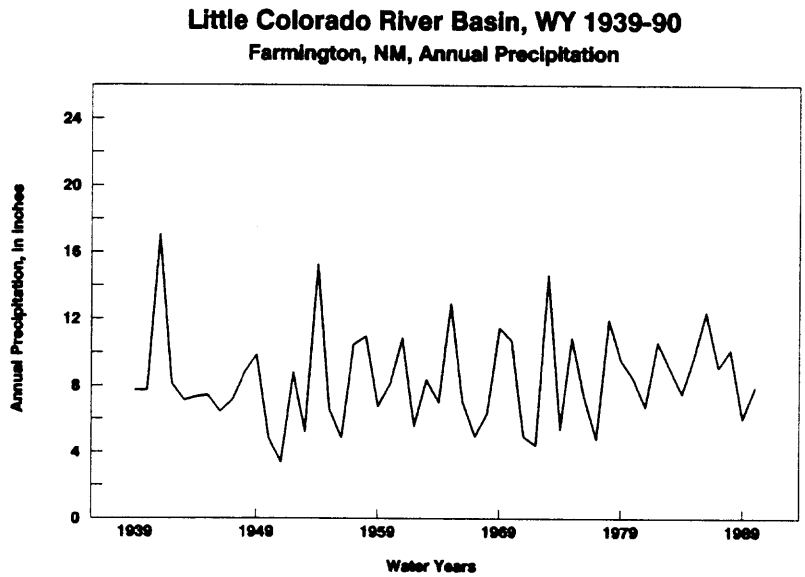


Figure 81. Farmington, NM, Annual Precipitation, WY 1939-90

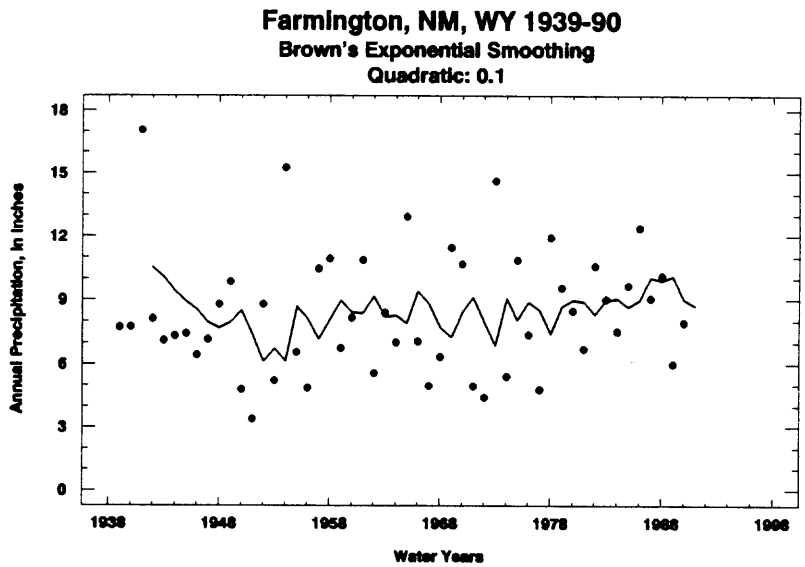


Figure 82. Farmington, NM, Smoothed Annual Precipitation, WY 1939-90

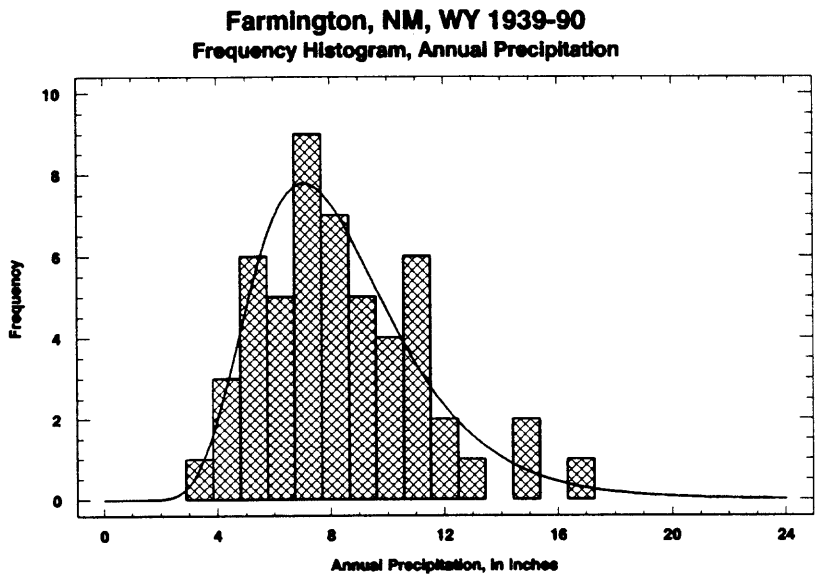


Figure 83. Farmington, NM, Histogram of Annual Precipitation

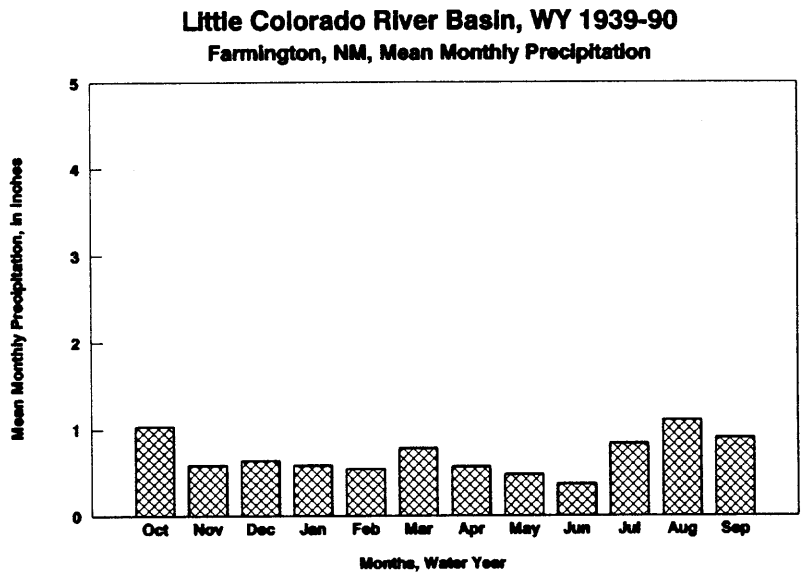


Figure 84. FArmington, NM, Monthly Distribution of Precipitation

6.2.3.13 Flagstaff, AZ

This station has been moved several times during the period of record from 1888 to the present. The station has remained within the City of Flagstaff, or somewhat to the south, for the entire period. No adjustment for these moves have been attempted, and would probably be unnecessary. The present location is at the Pulliam Airport, four miles to the south of the city. The year of 1891 is missing. Since 1898 the record is continuous for all months. No reconstruction for the study period was necessary. This station is very important to long-term trend analysis, not only because of the lengthy uninterrupted period of record, but also because of the long tree ring record from ponderosa pine samples.

As summarized in Sellars and Hill (1974, p. 208):

"Flagstaff is located at an elevation of about 7,000 feet on a volcanic plateau in north-central Arizona. It lies in the center of the largest standing forest of ponderosa pine in the United States. Spectacular scenery and prime recreational areas surround the town on all sides. Ten miles to the north lie the towering San Francisco Mountains, which include majestic Humphreys Peak, the highest point in the state at an elevation of over 12,600 feet. Further to the north, sixty miles from Falgstaff, is the incomparable Grand Canyon National Park. The terrain slopes gently downward for thirty miles to the east and northeast into the sagebrush covered valley of the Little Colorado River. On the east side of this valley lies the famous multi-colored Painted Desert. To the southeast of Flagstaff may be found the lake-studded high plateau country of Coconino National Forest. Hutch Mountain in this forest rises to an elevation of 8,650 feet. Oak Creek Canyon, second only to Grand Canyon in beauty and marvelous coloring, is located fifteen miles to the south-southwest. It lies about halfway between Flagstaff and the broad Verde River Valley which is oriented in a general northwest to southeast direction, paralleling the Little Colorado River Valley to the northeast of Flagstaff. Thirty miles or so to the west, in Kaibab National Forest, Bill Williams Mountain rises to an elevation of 9,264 feet.

"Unlike the desert towns to northeast and southwest, Flagstaff receives enough precipitation during an average year to support a lush growth of vegetation. The most consistently wet period occurs during the summer months. From early July until early September afternoon thunderstorms develop almost daily over the rugged terrain surrounding Flagstaff. These storms, which are normally associated with moist, tropical air that flows into Arizona from the Gulf of Mexico, rarely last longer than 30 minutes. However, several may occur in a single afternoon, producing two or three hours with almost continuous precipitation. The sky usually clears rapidly after sunset. Some of the more prolonged and steady rains of summer are associated with weak tropical disturbances that move northward from the Pacific Ocean. These storms occur very infrequently and are absent in most summers.

"Flagstaff also receives abundant precipitation during the winter, although amounts are quite variable from one year to the next. The most severe weather is associated with middle latitude storms that enter the state from the west after picking up considerable moisture from the Pacific Ocean. These storms are capable of producing gentle to moderate precipitation which may continue intermittently for several days. About 75 percent of Flagstaff's winter precipitation falls as snow. Amounts in the mountains to the north are great enough to provide good skiing conditions from November through March."

Precipitation trends for the study period show a gradual incline from 1939 to 1988. A slight decline appears to be developing from 1988 to 1990. An examination of trends for the 1888-1990 period indicates a decline from 1888 to 1939, and an increase from 1939-90, as if one cycle of a cyclic variation has been produced. (See Section 6.2.7).

The histogram shows a moderately lognormal distribution, with a noticeable peak at eighteen inches. Flat kurtosis and slight positive skewness are noted. Seasonal variations indicate a strong peak during July and August, and a broad peak in the winter from December through March. Although the individual monthly averages are greater in July and August, the sustained high precipitation in the winter indicates that most of the precipitation occurs during the winter.

Table 26. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Flagstaff WSO AP, AZ
Station No.: 3010
Elevation: 7004
Latitude: 35d 08m
Longitude: 111d 40m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.51	0.28	2.84	1.26	1.52	0.84	0.57	0.08	0.00	0.90	2.45	3.47	14.72
1940	0.34	1.45	0.03	1.56	2.43	0.27	1.71	0.15	1.18	0.52	2.26	3.63	15.53
1941	3.45	0.92	3.14	1.19	1.77	2.31	3.12	0.70	0.55	1.71	1.31	4.54	24.71
1942	4.90	0.81	2.11	0.54	1.40	0.58	0.96	0.00	0.00	1.07	2.08	0.65	15.10
1943	1.00	0.24	1.38	3.26	1.24	1.66	1.18	0.18	0.15	1.72	2.45	1.67	16.13
1944	1.57	0.19	2.51	1.72	2.98	2.00	1.84	0.99	0.10	1.74	0.67	1.33	17.64
1945	0.35	1.96	1.82	1.94	0.51	4.21	0.55	0.00	0.06	4.14	2.91	0.18	18.63
1946	0.76	0.08	2.27	0.98	0.77	1.46	3.45	0.46	0.00	4.78	3.46	1.53	20.00
1947	2.10	1.60	1.15	0.85	0.18	0.59	0.14	0.98	0.00	1.21	4.25	0.64	13.69
1948	1.39	0.88	2.02	0.82	2.33	2.10	0.38	0.13	0.46	0.73	2.10	1.05	14.39
1949	1.87	0.00	3.38	6.91	1.64	0.75	0.31	1.03	2.19	2.74	1.26	3.47	25.55
1950	3.84	0.86	1.49	1.07	1.29	1.01	0.28	0.35	0.37	3.42	1.47	0.89	16.34
1951	0.00	0.45	0.16	1.61	0.99	0.91	1.74	1.00	0.00	4.47	5.50	0.60	17.43
1952	2.26	1.26	5.45	3.48	0.82	3.03	1.63	0.00	0.09	2.10	2.92	2.09	25.13
1953	0.00	2.84	1.06	0.45	0.38	0.87	1.16	0.27	0.00	2.50	4.21	0.12	13.86
1954	0.49	1.83	0.53	1.97	1.27	3.90	0.80	0.44	1.17	3.51	1.53	3.14	20.58
1955	0.89	0.32	0.61	2.67	1.56	0.17	0.51	0.21	2.92	3.49	3.73	0.00	17.08
1956	0.05	1.78	0.88	1.62	1.06	0.12	0.86	0.17	2.79	1.19	1.42	0.02	11.96
1957	0.68	0.05	0.39	6.46	0.85	0.92	1.04	2.02	1.59	1.57	1.65	0.00	17.22
1958	3.66	4.24	0.59	0.22	3.04	2.98	1.23	0.45	0.70	0.75	3.02	6.60	27.48
1959	0.86	1.39	0.00	0.34	3.63	0.08	1.49	0.64	0.77	2.93	4.96	0.28	17.37
1960	2.35	0.31	3.68	1.03	1.82	0.66	1.34	0.71	0.39	0.96	3.28	1.18	17.71
1961	3.57	1.27	0.39	1.15	0.12	2.89	0.35	0.28	0.37	2.03	3.37	1.92	17.71
1962	1.89	1.43	3.15	2.65	4.15	1.30	0.09	0.99	0.52	2.36	0.26	2.48	21.27
1963	1.23	1.23	0.85	0.96	1.28	1.03	2.13	0.05	0.00	0.32	4.96	0.79	14.83
1964	1.25	1.39	0.36	1.07	0.14	3.08	2.17	0.84	0.17	5.23	1.32	0.99	18.01
1965	0.02	1.27	2.74	3.05	2.34	3.33	5.62	1.88	0.30	2.34	1.01	4.85	28.75
1966	0.27	4.97	6.63	1.10	1.06	0.95	0.27	0.00	0.21	1.62	3.55	2.03	22.66
1967	0.99	2.33	6.17	0.93	0.00	1.11	1.90	0.41	1.05	3.80	2.68	2.25	23.62
1968	0.30	0.54	7.30	1.55	1.29	1.15	2.09	0.55	0.16	3.61	1.13	0.04	19.71
1969	1.38	0.87	2.71	4.63	3.91	3.00	0.11	1.06	0.01	3.81	1.90	1.34	24.73
1970	1.14	2.04	0.46	0.51	0.41	6.75	1.16	0.00	0.07	2.58	5.15	3.79	24.06
1971	0.11	1.37	2.12	0.08	1.48	0.25	0.55	1.23	0.00	1.97	4.48	2.02	15.66
1972	4.37	0.40	4.18	0.00	0.02	0.00	0.72	0.14	1.93	1.90	2.82	0.81	17.29
1973	9.86	2.34	4.13	1.89	3.69	6.18	1.21	1.17	0.40	1.87	1.25	0.00	33.99
1974	0.03	1.90	0.12	3.63	0.26	1.01	0.57	0.00	0.00	3.00	2.16	0.93	13.61
1975	3.64	1.03	1.18	1.76	1.90	2.92	2.20	1.16	0.05	2.24	0.74	1.89	20.71
1976	0.33	2.96	1.95	0.17	5.96	2.06	3.09	1.65	0.00	3.82	0.58	1.16	23.73
1977	0.73	0.10	0.80	1.85	0.84	0.92	1.47	0.96	0.91	3.60	3.72	1.52	17.42
1978	1.04	0.76	1.18	4.09	4.67	5.58	1.60	0.27	0.09	1.17	0.68	0.46	21.59
1979	0.56	6.16	5.39	5.54	1.73	2.52	0.31	2.16	0.18	0.79	2.38	0.13	27.85
1980	1.30	1.14	1.50	6.52	7.81	4.16	1.21	1.79	0.25	2.49	2.19	0.65	31.01
1981	1.08	0.00	1.15	1.31	1.16	4.04	1.50	0.72	1.09	2.87	3.73	2.54	21.19
1982	1.81	2.43	0.17	4.62	2.55	5.69	0.25	0.86	0.00	1.89	2.32	3.17	25.76
1983	0.71	5.36	3.67	1.61	3.04	4.36	2.18	0.06	0.28	2.86	3.53	6.75	34.41
1984	0.75	1.53	2.52	0.36	0.13	0.89	0.73	0.21	0.13	4.20	3.86	1.75	17.06
1985	1.43	1.40	5.00	2.38	1.67	2.54	3.39	0.26	0.09	2.36	1.07	3.68	25.27
1986	2.44	6.64	0.15	0.31	1.76	2.60	1.23	0.72	1.16	6.62	8.06	4.80	36.49
1987	2.02	1.68	1.43	2.51	2.54	1.69	0.21	0.70	0.25	1.93	3.74	1.49	20.19
1988	4.64	2.91	1.37	1.64	2.30	0.14	3.83	0.14	1.86	3.48	4.77	0.15	27.23
1989	1.23	1.14	1.00	1.84	1.35	2.08	0.01	0.62	0.23	2.28	3.40	0.30	15.48
1990	1.28	0.00	1.05	1.54	3.20	2.17	2.32	0.73	0.24	4.32	1.71	6.18	24.74
1939-90 Average	1.63	1.58	2.08	1.98	1.85	2.07	1.36	0.63	0.53	2.53	2.72	1.88	20.85

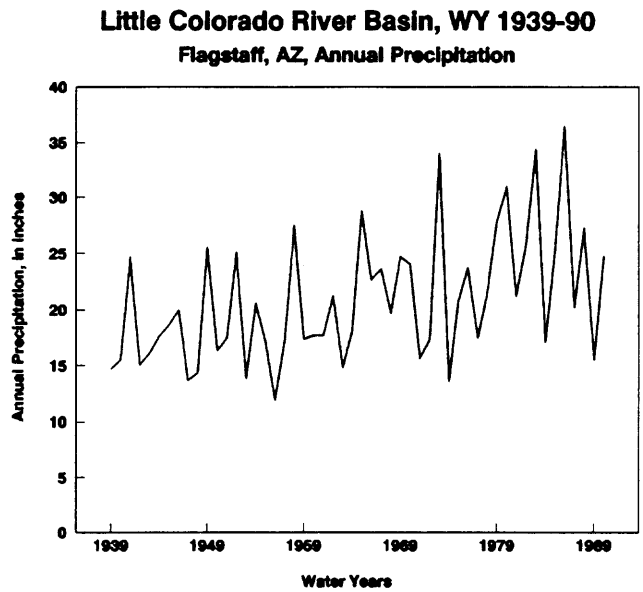


Figure 85. Flagstaff, AZ, Annual Precipitation, WY 1939-90

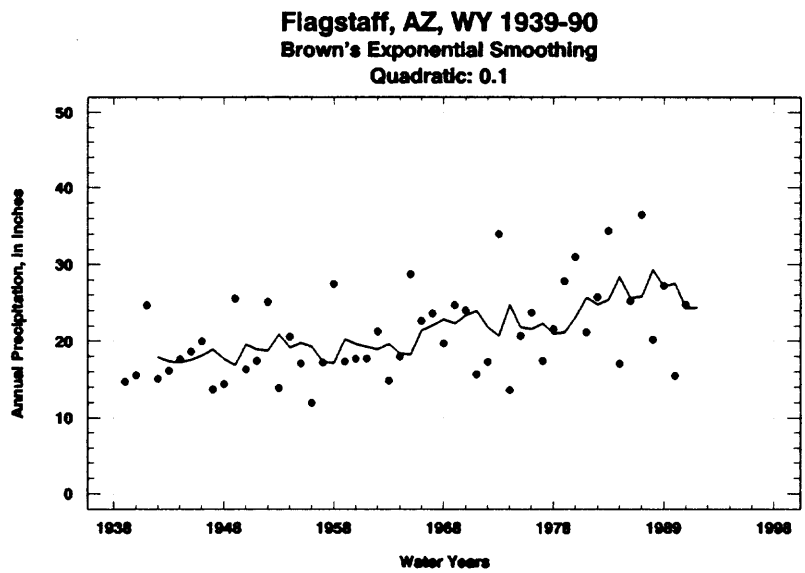


Figure 86. Flagstaff, AZ, Smoothed Annual Precipitation, WY 1939-90

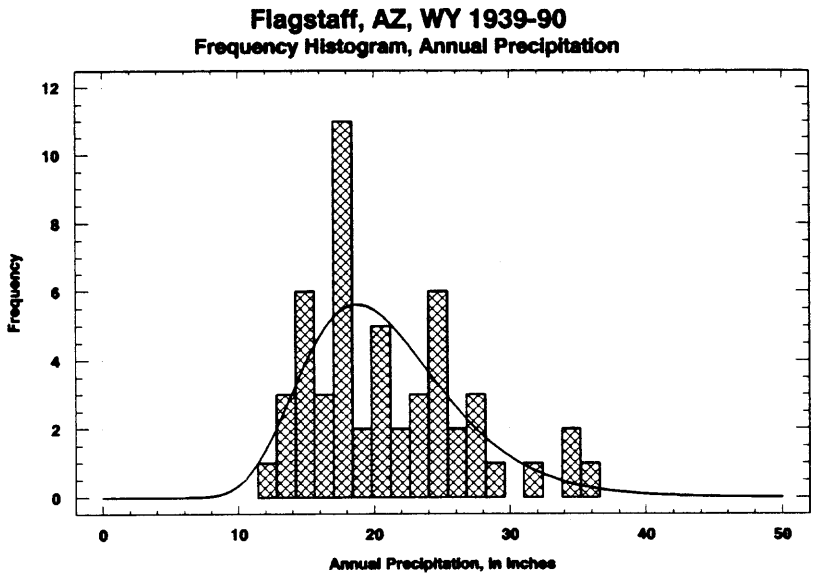


Figure 87. Flagstaff, AZ, Histogram of Annual Precipitation

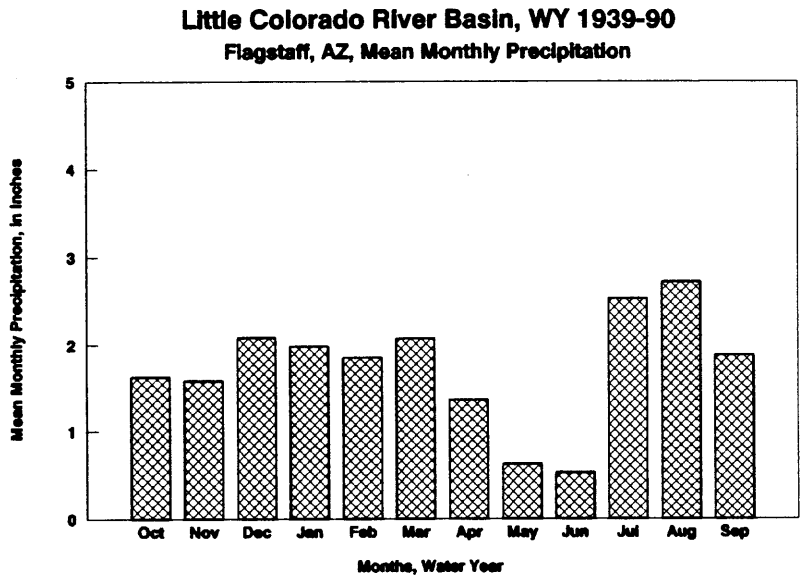


Figure 88. Flagstaff, AZ, Monthly Distribution of Precipitation

6.2.3.14 Fort Defiance, AZ

This station was operated by the Bureau of Indian Affairs from 1897 to 1906 and from 1930 to 1932. When combined with Window Rock (1931-present) it provides a long-term record for trend analysis. The period from 1906-31 is missing and has not been reconstructed. The station lies about fifteen miles north of Window Rock, at an approximate elevation of 6,950 feet amsl, estimated from USGS topographic map. The trends and means of the 1939-90 study period, all of which is reconstructed, varies only slightly from Window Rock. The difference in annual means between Fort Defiance and Window Rock is only 0.10 inch.

The precipitation trends for this station is similar to several in this area of the LCR Basin, with a gradual decline from 1939 through 1959, and a gradual rise from 1960 through 1988. A broad peak centered around 1965 to 1979 is interposed on the gradual rise. From 1988 to 1990, there is an indication of a decline.

The histogram shows a lognormal distribution for the study period, with an interesting gap at ten to eleven inches. This differs somewhat with Window Rock, but is probably due to slight differences in discretization of the frequency domain.

Table 27. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Fort Defiance, AZ
Elevation: 6950

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.10	0.28	0.96	1.23	1.36	0.99	0.93	0.19	0.00	1.04	1.05	1.26	9.37
*1940	0.46	0.65	0.42	0.65	1.13	0.60	0.66	0.80	0.45	0.93	2.44	3.16	12.35
*1941	1.14	0.94	2.35	1.08	1.36	1.92	2.23	2.02	1.23	1.25	2.77	3.39	21.69
*1942	3.92	0.51	1.18	0.22	1.24	0.54	1.26	0.00	0.00	0.97	1.14	1.07	12.06
*1943	1.73	0.11	1.18	1.11	0.22	1.36	0.42	0.30	0.42	1.15	3.74	0.87	12.63
*1944	1.16	0.20	1.12	0.82	1.07	1.10	0.83	0.87	0.09	1.21	1.26	2.01	11.74
*1945	1.05	1.13	1.29	0.96	0.31	1.35	0.38	0.05	0.17	3.46	2.81	0.32	13.26
*1946	1.04	0.02	1.46	0.43	0.27	0.58	0.55	0.21	0.07	2.18	3.38	2.34	12.51
*1947	0.58	1.32	0.44	0.55	0.24	0.21	0.03	1.47	0.27	1.15	4.89	1.21	12.37
*1948	1.90	0.94	0.94	0.37	1.19	1.32	0.34	0.44	0.85	2.50	1.47	1.46	13.72
*1949	2.30	0.09	1.33	1.47	0.57	0.70	0.54	1.16	1.13	2.64	1.05	1.27	14.25
*1950	0.83	0.10	0.97	0.46	0.90	0.37	0.03	0.06	0.29	2.08	0.33	0.91	7.33
*1951	0.02	0.23	0.12	0.92	0.50	0.34	0.88	0.32	0.03	1.14	2.06	0.53	7.10
*1952	1.10	0.72	1.35	1.73	0.32	0.94	2.03	0.09	0.99	1.79	1.70	0.91	13.68
*1953	0.00	1.60	0.59	0.36	0.45	0.58	0.49	0.27	0.28	2.08	1.17	0.04	7.91
*1954	0.82	0.45	0.59	0.61	0.28	2.17	0.18	0.99	0.14	2.83	1.17	1.81	12.05
*1955	0.84	0.05	0.46	0.76	0.80	0.06	0.37	0.72	0.76	1.95	2.50	0.08	9.35
*1956	0.12	0.48	0.83	1.08	0.49	0.07	0.26	0.34	0.22	1.74	1.26	0.02	6.90
*1957	0.75	0.07	0.15	2.23	0.88	0.88	1.12	1.68	0.41	2.87	2.56	0.00	13.60
*1958	2.16	1.02	0.41	0.32	0.79	1.31	1.49	0.54	0.23	1.01	2.16	1.44	12.88
*1959	0.79	0.49	0.22	0.31	0.79	0.48	0.78	0.00	0.80	2.19	2.82	0.00	9.67
*1960	1.86	0.52	1.65	0.90	0.90	0.57	0.16	0.44	0.45	0.42	0.90	0.40	9.18
*1961	2.58	0.24	0.68	0.41	0.50	1.40	0.37	0.14	0.10	1.93	2.54	1.18	12.08
*1962	2.48	0.84	1.37	0.99	1.29	0.73	0.10	0.20	0.40	0.84	0.75	2.28	12.29
*1963	2.88	1.29	0.48	0.72	1.04	0.39	0.20	0.01	0.04	1.06	4.56	1.11	13.78
*1964	0.75	0.65	0.34	0.36	0.52	0.69	0.98	0.14	0.12	2.67	4.09	2.66	13.96
*1965	0.03	1.09	0.98	1.48	0.81	0.58	0.88	0.90	1.32	3.40	1.32	1.32	14.12
*1966	0.76	1.38	2.56	0.36	0.53	0.54	0.32	0.05	0.30	2.42	1.95	1.45	12.62
*1967	0.63	0.46	1.66	0.27	0.02	0.46	0.15	0.43	1.32	2.90	2.22	1.04	11.56
*1968	0.09	0.31	2.38	0.26	0.41	0.92	0.76	0.29	0.21	1.42	2.61	0.18	9.84
*1969	0.71	1.14	1.27	0.66	0.77	1.27	0.66	0.60	0.23	1.85	2.12	0.97	12.23
*1970	2.17	0.49	0.27	0.24	0.11	1.61	0.82	0.07	0.42	1.19	2.01	2.24	11.66
*1971	0.81	0.38	0.57	0.31	0.48	0.25	0.22	0.23	0.00	1.18	2.62	2.32	9.35
*1972	1.80	0.63	1.38	0.06	0.04	0.02	0.10	0.22	1.14	0.98	1.26	0.80	8.44
*1973	8.45	1.04	1.10	0.73	1.03	2.15	0.50	1.31	0.71	1.02	1.01	0.39	19.43
*1974	0.21	0.50	0.15	1.42	0.32	0.26	0.33	0.00	0.09	2.31	0.94	1.12	7.66
*1975	3.17	0.40	0.37	0.93	0.83	1.48	0.51	0.25	0.01	2.30	0.59	2.32	13.17
*1976	0.11	0.60	0.50	0.06	0.65	0.17	0.37	1.10	0.16	1.91	1.17	1.11	7.91
*1977	0.60	0.36	0.06	0.56	0.40	0.33	0.30	0.26	0.36	2.44	2.85	1.15	9.68
*1978	0.67	0.76	0.23	1.23	1.19	1.36	0.39	1.21	0.02	0.54	1.07	0.82	9.50
*1979	1.63	3.55	1.78	1.74	0.51	1.47	0.27	1.37	0.61	0.32	0.94	0.08	14.26
*1980	1.04	1.16	0.95	2.21	2.55	1.02	0.56	0.25	0.02	0.41	1.34	1.38	12.90
*1981	0.60	0.09	0.34	0.22	0.50	1.39	0.35	0.37	0.54	2.85	1.17	0.86	9.27
*1982	1.11	2.10	0.12	0.84	1.75	1.44	0.22	0.96	0.05	1.69	4.15	1.35	15.76
*1983	0.26	1.41	1.52	2.08	0.77	1.27	0.39	0.33	0.12	2.31	1.45	1.45	13.37
*1984	1.04	0.80	1.63	0.18	0.05	1.24	0.83	0.13	0.24	1.33	2.27	1.48	11.21
*1985	2.06	0.23	1.66	1.13	0.33	1.37	2.47	0.37	0.20	1.96	1.17	1.84	14.79
*1986	1.77	1.25	0.27	0.05	0.96	1.24	1.26	0.76	0.91	2.46	2.19	2.18	15.28
*1987	0.89	2.42	0.84	0.95	1.00	0.58	0.54	0.86	0.64	2.39	1.89	0.45	13.45
*1988	1.22	1.97	1.24	0.90	1.02	0.05	2.60	0.23	1.30	1.66	3.53	0.62	16.33
*1989	0.22	1.06	0.27	0.67	0.89	0.35	0.01	0.07	0.08	1.15	1.32	0.26	6.36
*1990	0.93	0.11	0.17	0.40	0.97	0.66	0.43	0.89	0.50	2.70	1.75	1.62	11.15
1939-90 Average	1.28	0.78	0.91	0.79	0.74	0.87	0.65	0.52	0.41	1.77	1.99	1.20	11.90

* Denotes year in which one or more monthly records are reconstructed.

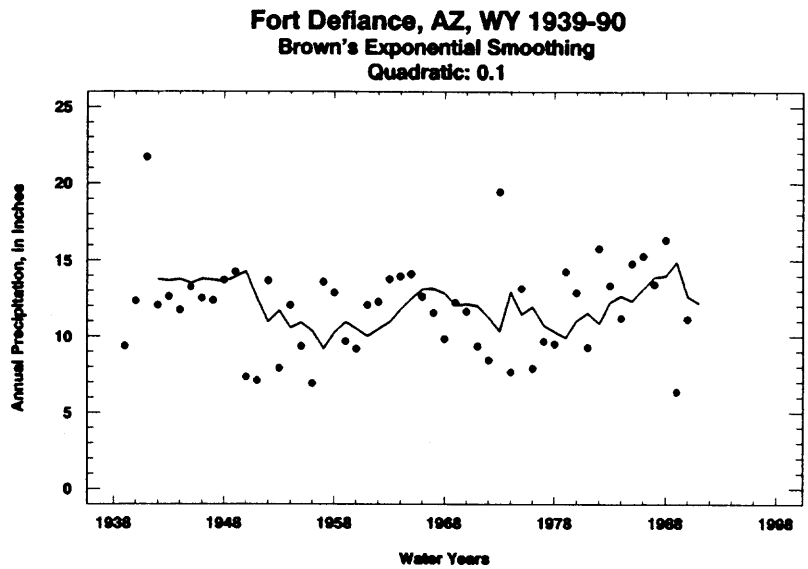


Figure 89. Fort Defiance, AZ, Smoothed Annual Precipitation, WY 1939-90

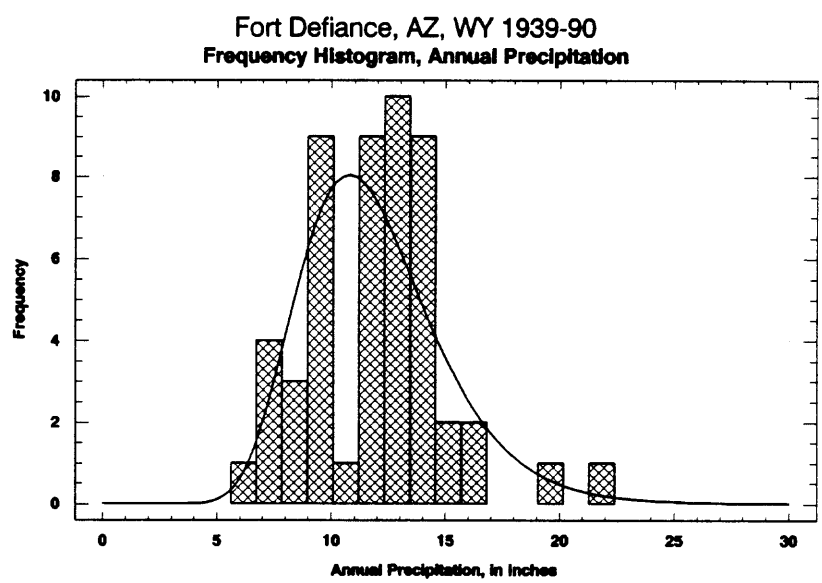


Figure 90. Fort Defiance, AZ, Histogram of Annual Precipitation

6.2.3.15 Fort Valley Ranger Station, AZ

This station lies just inside the LCR Basin in the extreme western portion, and within eleven miles of the Flagstaff Pulliam Airport station. However, Fort Valley is on the windward side of the San Francisco Mountains, while the Sunset Crater and Walnut Canyon stations are on the leeward side. The Flagstaff station to the south invites comparison to the Fort Valley station due to their proximity, comparable elevation, and similar period of record. The Fort Valley station record is continuous from 1909 to the present.

As summarized in Sellars and Hill (1974, p. 222):

> "Fort Valley is located at an elevation of 7,350 feet seven miles northwest of Flagstaff in north-central Arizona. Dominating the terrain in the area are the towering peaks of the San Francisco Mountains, which include Humphreys Peak, the highest point in the state, rising to an elevation in excess of 12,600 feet seven miles north of Fort Valley. To the west and south, respectively, lie the scenic Kaibab and Coconino National Forests. In contrast to the verdant, pine-covered country in the immediate vicinity of Fort Valley is the multi-colored Painted Desert, a scant 45 miles to the northeast on the east side of the southeastward (sic) flowing Little Colorado River. The incomparable Grand Canyon borders the Colorado River 55 miles to the north. Finally, to establish Fort Valley's position in the center of some of the most impressive scenery in the United States, stretching to the southeast is the rugged Mogollon Plateau, separating the high desert country in the northeastern part of the state from the low desert country to the southwest. Although yellow pine and Douglas fir make up the dominant vegetation types in the gently rolling country immediately surrounding Fort Valley, at higher elevations in the San Francisco Mountains, above about 10,000 feet, spruce becomes more common. On Humphreys Peak the timber line lies at roughly 11,500 feet.
>
> "Fort Valley is one of the few points in Arizona which receives an abundance of precipitation. Only in the late spring are drought conditions common. The summer rains normally fall from moist, unstable air which works its way northwestward along the Mogollon Plateau from its source region in the Gulf of Mexico. Thunderstorms are quite common, perhaps more so than in any other section of the state. However, they are not usually as intense, in terms of the amount of rainfall produced, as the storms that occasionally deluge the desert regions.
>
> "In winter, from December through mid-April, most of Fort Valley's precipitation falls as snow from storms that move into Arizona from the Pacific Ocean. These storms often produce several successive days of cloudy, cool weather with intermittent snow and rain showers, usually of only moderate intensity. On the average, about 97 inches of snow are recorded at Fort Valley during the winter. However, as much as 94 inches have fallen in a single month."

Precipitation trends mirror those of Flagstaff, with a gradual increase during the study period from 1939 to 1990. There is a minimum at 1980, however.

The histogram shows a distinct lognormal distribution, with low kurtosis (a sharp peak at the means), and a slight positive skewness. The seasonal distribution is similar to Flagstaff, but with an even more pronounced peak in July and August. However, the winter precipitation totals are greater than late summer, producing a large spring snowmelt runoff.

Table 28. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Fort Valley Ranger Station, AZ
Station No.: 3160
Elevation: 7347
Latitude: 35d 16m
Longitude: 111d 44m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.95	0.72	3.38	2.08	2.09	1.34	1.05	0.06	0.04	0.63	3.97	3.66	19.97
1940	0.55	1.47	0.14	2.90	3.37	0.41	2.98	0.30	1.37	0.13	2.30	5.47	21.39
1941	3.67	1.59	4.35	2.56	2.74	3.09	4.48	0.64	0.98	1.87	1.87	3.30	31.14
1942	4.93	1.08	3.72	1.67	2.48	1.19	2.19	0.00	0.00	1.89	1.29	0.88	21.32
1943	1.14	0.29	2.25	4.38	1.84	2.61	1.18	0.25	0.38	1.45	5.34	1.52	22.63
1944	1.96	0.27	2.23	1.96	3.88	2.26	2.62	1.33	0.00	1.22	1.90	1.17	20.80
1945	0.97	2.48	1.99	2.59	0.75	5.06	1.07	0.04	0.06	2.18	3.42	0.34	20.95
1946	1.12	0.16	3.57	1.27	0.95	1.55	4.56	0.41	0.00	2.63	5.02	0.91	22.15
1947	1.49	2.91	1.73	0.84	0.41	0.25	0.12	1.30	0.01	0.81	4.41	0.89	15.17
1948	1.31	0.80	2.24	0.52	2.13	2.51	0.52	0.06	0.38	1.68	3.59	1.34	17.08
1949	2.16	0.00	2.60	6.96	1.69	1.19	0.53	1.35	1.85	4.10	2.40	2.57	27.40
1950	3.64	0.92	1.63	1.76	1.96	1.39	0.21	0.36	0.16	5.31	1.07	1.07	19.48
1951	0.00	0.25	0.12	1.74	1.57	0.65	2.47	0.61	0.00	3.68	6.38	0.73	18.20
1952	1.78	1.53	6.56	3.52	1.03	3.75	2.52	0.07	0.30	4.25	4.38	2.50	32.19
1953	0.00	2.79	1.89	1.24	0.12	1.06	1.36	0.35	0.00	5.12	3.19	0.00	17.12
1954	0.60	1.27	0.54	2.22	1.79	4.89	0.09	1.10	1.01	3.55	1.81	2.27	21.14
1955	0.78	0.31	0.86	3.23	2.34	0.30	0.74	0.43	3.69	3.24	7.05	0.00	22.97
1956	0.09	1.32	1.15	2.50	1.00	0.47	1.12	0.17	1.89	2.61	1.80	0.00	14.12
1957	0.82	0.05	0.54	6.17	1.06	1.31	1.02	2.12	1.34	2.85	2.42	0.00	19.70
1958	3.96	3.81	0.85	0.42	2.63	4.10	1.73	0.85	0.38	0.92	4.09	8.35	32.09
1959	0.77	1.38	0.05	0.41	4.49	0.00	1.05	0.65	0.80	4.55	3.36	1.18	18.69
1960	1.80	0.35	3.44	1.67	1.27	1.15	1.91	1.02	0.74	1.58	3.12	3.22	21.27
1961	3.42	1.19	0.69	1.13	0.19	3.26	0.42	0.60	0.28	1.99	5.54	1.68	20.39
1962	1.56	0.92	2.56	2.86	3.20	1.16	0.19	1.16	0.69	2.39	1.50	1.60	19.79
1963	1.20	1.15	0.89	0.96	1.26	0.91	1.61	0.05	0.02	0.50	6.56	2.03	17.14
1964	1.67	1.89	0.26	1.67	0.20	3.08	2.66	0.56	0.26	3.46	3.84	1.81	21.36
1965	0.01	1.07	2.38	2.46	2.12	2.59	5.59	2.43	0.32	5.48	2.01	4.42	30.88
1966	0.13	3.92	5.82	0.90	1.46	1.48	0.40	0.09	2.06	3.37	2.66	1.03	23.32
1967	0.86	2.01	5.65	1.21	0.00	1.05	1.68	0.78	1.26	7.41	4.45	1.81	28.17
1968	0.84	0.98	6.52	1.11	0.77	0.88	2.71	0.78	0.26	2.60	3.08	0.03	20.56
1969	1.81	1.17	2.09	4.73	4.21	3.34	0.15	1.22	0.12	2.92	2.57	1.68	26.01
1970	1.20	1.85	0.54	0.76	0.31	7.14	0.97	0.00	0.05	3.45	3.58	2.26	22.11
1971	0.59	1.74	1.59	0.24	1.13	0.32	0.89	0.83	0.00	2.33	4.90	1.85	16.41
1972	3.45	0.24	2.47	0.00	0.01	0.00	1.19	0.12	3.25	2.84	3.52	0.63	17.72
1973	9.55	1.71	3.10	1.87	3.20	6.57	1.46	0.80	1.04	2.97	1.29	0.00	33.56
1974	0.38	2.07	0.30	2.84	0.27	0.77	0.54	0.05	0.00	1.94	1.74	0.48	11.38
1975	2.85	0.75	0.63	0.98	1.98	2.38	1.69	0.89	0.00	5.49	1.21	1.23	20.08
1976	0.26	2.00	0.94	0.21	3.91	1.59	2.30	2.37	0.01	3.30	1.76	1.97	20.62
1977	0.52	0.10	1.00	1.61	0.70	0.83	1.38	0.80	1.21	1.99	1.89	1.30	13.33
1978	1.11	0.58	1.40	2.88	3.77	3.48	1.11	0.31	0.00	2.04	2.24	0.82	19.74
1979	0.72	3.91	3.62	3.81	2.14	2.68	0.31	2.21	0.07	0.40	2.57	0.03	22.47
1980	1.88	1.18	1.03	5.86	6.44	2.94	1.52	0.94	0.00	2.70	1.18	0.38	26.05
1981	0.80	0.00	0.88	1.04	0.90	3.70	1.09	1.03	0.66	2.47	3.91	4.70	21.18
1982	1.70	1.93	2.00	4.74	2.64	4.75	0.18	0.64	0.00	1.53	2.36	3.02	25.49
1983	0.45	4.95	3.11	1.86	2.52	4.16	1.28	0.06	0.14	1.37	3.36	6.57	29.83
1984	0.66	1.12	2.71	0.72	0.13	1.39	0.48	0.19	0.19	3.34	6.91	1.65	19.49
1985	1.02	1.41	4.61	2.85	1.47	2.15	2.43	0.38	0.02	3.92	1.37	2.54	24.17
1986	1.85	6.55	0.00	0.20	2.26	3.18	1.32	0.62	0.97	2.40	3.59	3.52	26.46
1987	1.90	1.19	1.46	2.58	3.05	2.50	0.28	1.52	0.26	3.79	4.01	1.40	23.94
*1988	3.05	3.75	1.20	2.11	2.23	0.19	4.56	0.25	0.40	2.63	4.43	2.60	27.40
1989	0.32	1.77	1.22	1.87	1.03	1.89	0.00	0.79	0.03	3.60	3.10	0.18	15.80
1990	0.15	0.00	1.07	1.64	3.31	1.78	2.17	0.65	0.60	6.01	2.40	5.96	25.74
1939-90 Average	1.55	1.52	2.07	2.12	1.89	2.17	1.50	0.70	0.57	2.82	3.23	1.93	22.07

* Denotes year in which one or more monthly records are reconstructed.

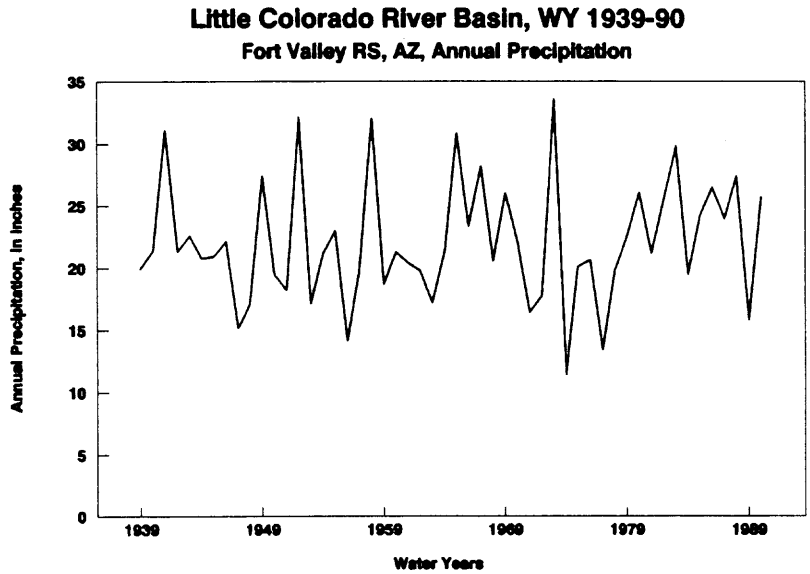


Figure 91. Fort Valley RS, AZ, Annual Precipitation, WY 1939-90

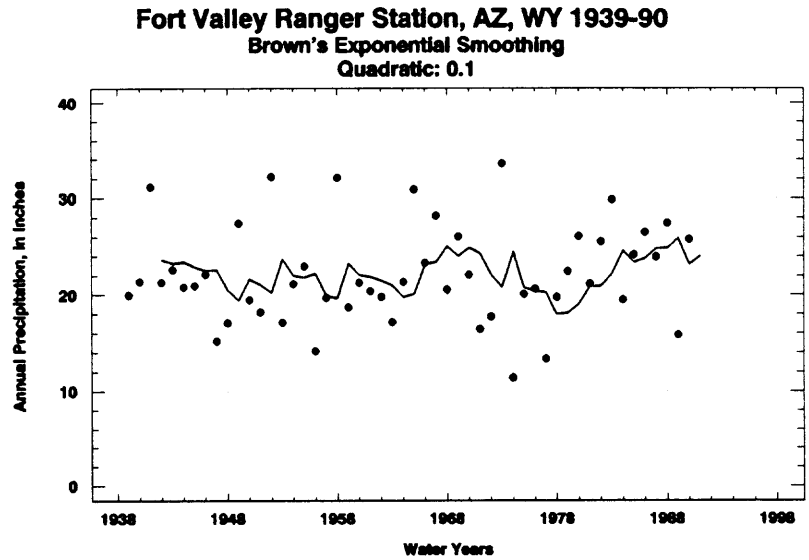


Figure 92. Fort Valley RS, AZ, Smoothed Annual Precipitation, WY 1939-90

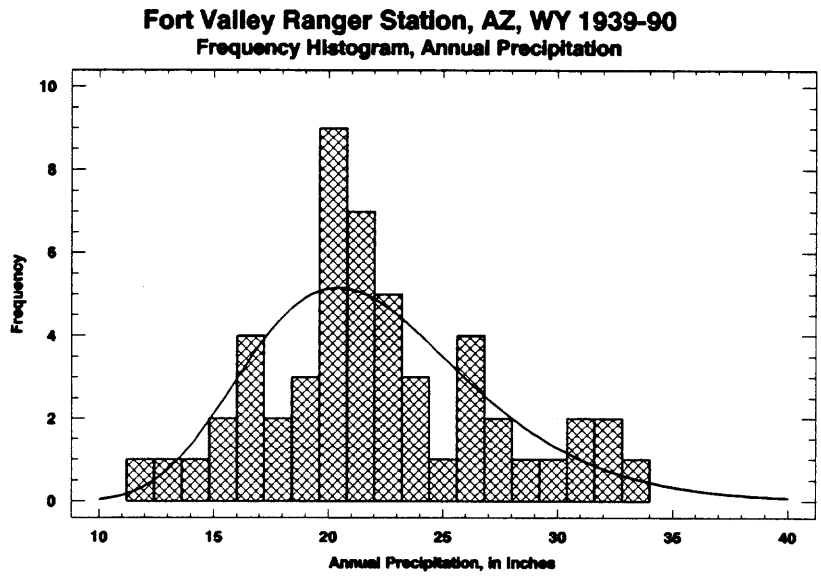


Figure 93. Fort Valley, AZ, Histogram of Annual Precipitation

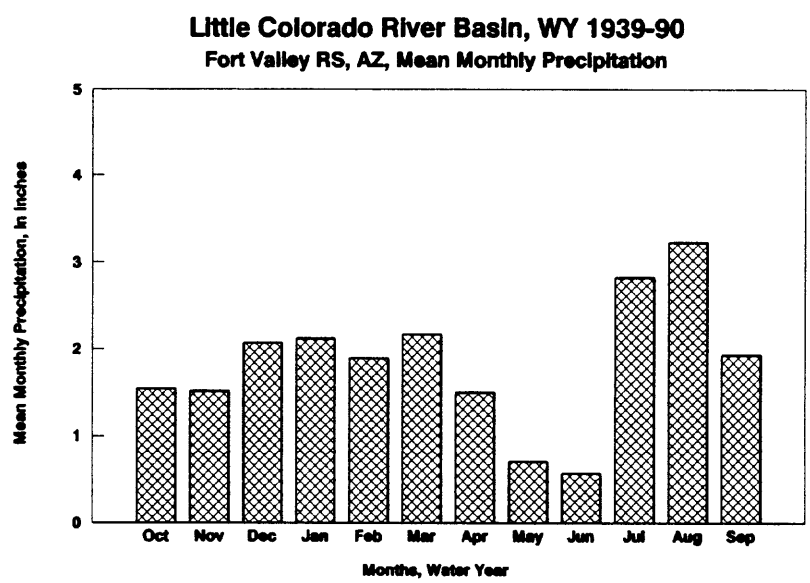


Figure 94. Fort Valley, AZ, Monthly Distribution of Precipitation

6.2.3.16 Fort Wingate, NM

The record from this long-term station begins in the 1860's. The record from 1888 to 1911 is continuous, as well as from 1940 to 1966, except for 1955-56. For this reason, it is an important station to assess long-term trends. The 1939-40 and 1955-56 years have been reconstructed, as well as the period 1966 to the present to enable long-term analysis. (See Section 6.2.4). Gallup is only 15 miles to the west, and its period overlaps the missing dates for Fort Wingate. It lies at an elevation of about 7,000 feet amsl along the descent of the Puerco River from the continental divide.

Percipitation trends for the study period show a decline from 1939 to 1979, with a slight peak centered on 1970. From 1980 to 1988 there is a period of rapid increase, with indications of a decrease from 1988-90. This trend is similar to many eastern LCR stations.

The histogram shows an irregular normal to lognormal distribution, with a sharp peak at about fourteen inches.

The monthly distribution shows a pronounced peak in July through September, with a gradual decline from October to the annual minimum in June.

Table 29. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Fort Wingate, NM
Station No.: 3305
Elevation: 7000
Latitude: 35d 28m
Longitude: 108d 32m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.16	0.26	0.78	1.24	0.74	0.79	1.01	0.26	0.05	1.12	1.01	1.44	8.85
*1940	0.40	0.87	0.45	0.76	1.02	0.96	0.64	0.43	1.04	0.54	1.62	2.77	11.50
1941	1.72	1.06	2.23	0.98	1.47	2.11	2.03	1.99	1.43	1.26	1.59	4.18	22.05
1942	2.50	0.74	1.25	0.27	1.13	0.72	0.97	0.00	0.00	0.57	1.96	1.23	11.34
1943	1.19	0.16	1.00	0.58	0.43	1.61	0.38	0.35	0.48	2.00	3.47	0.45	12.10
1944	1.33	0.11	0.70	0.61	0.67	1.09	0.01	1.20	0.12	1.33	1.95	2.28	11.40
*1945	0.93	0.97	0.89	0.84	0.36	1.11	0.49	0.07	0.12	3.03	2.63	0.19	11.63
1946	1.48	0.08	1.14	0.56	0.27	0.31	0.66	0.08	0.09	2.38	4.94	1.44	13.43
1947	0.62	1.36	0.52	0.44	0.72	0.14	0.01	1.58	0.38	1.89	4.87	0.57	13.10
1948	1.16	0.68	0.69	0.38	1.37	1.72	0.33	0.53	1.29	2.68	1.98	0.89	13.70
1949	1.86	0.31	0.94	1.23	0.38	0.87	0.72	0.59	1.06	2.47	1.56	1.54	13.53
1950	0.79	0.05	0.45	0.57	0.73	0.46	0.02	0.05	0.20	2.06	0.18	1.54	7.10
1951	0.12	0.43	0.08	1.21	0.54	0.20	0.56	0.49	0.00	1.48	1.81	0.67	7.59
1952	1.01	0.89	1.31	2.08	0.25	0.91	1.19	0.05	1.12	1.89	1.75	1.00	13.45
1953	0.00	2.44	0.64	0.21	0.36	0.55	0.32	0.12	0.14	1.89	0.85	0.00	7.52
1954	1.20	0.62	1.20	0.49	0.40	3.22	0.37	1.39	0.04	2.90	1.02	1.57	14.42
1955	0.80	0.03	0.43	0.90	0.96	0.06	0.18	0.75	0.46	2.07	2.70	0.04	9.38
1956	0.01	0.35	0.95	1.34	0.76	0.04	0.46	0.52	0.29	2.72	0.95	0.00	8.39
1957	0.75	0.21	0.46	2.60	1.01	0.52	0.78	0.81	0.45	5.16	2.29	0.00	15.04
1958	1.59	0.94	0.40	0.53	0.56	1.15	0.86	0.48	0.06	0.87	2.02	2.26	11.72
1959	1.50	0.52	0.10	0.28	0.80	0.12	1.00	0.00	1.28	0.57	2.29	0.38	8.84
1960	2.62	0.28	1.51	1.01	0.43	0.49	0.18	0.65	0.54	1.03	0.44	0.45	9.63
1961	2.05	0.20	0.24	0.37	0.51	1.49	0.61	0.00	0.13	1.44	2.73	0.95	10.72
1962	2.44	0.53	0.73	1.13	1.15	1.04	0.20	0.01	1.23	1.91	1.23	1.57	13.17
1963	3.51	1.44	0.47	1.26	0.70	0.35	0.06	0.00	0.00	1.12	3.89	0.82	13.62
1964	0.46	0.89	0.13	0.55	0.90	0.69	0.92	0.25	0.19	2.33	3.36	1.53	12.20
1965	0.17	1.30	1.04	1.33	0.75	0.43	0.64	1.00	1.51	1.41	0.66	0.78	11.02
*1966	0.37	1.39	2.05	0.45	0.40	0.81	0.34	0.11	0.21	2.41	2.70	1.88	13.11
*1967	0.41	0.53	1.46	0.26	0.05	0.44	0.13	0.30	1.41	3.20	2.83	1.37	12.39
*1968	0.17	0.32	2.48	0.40	0.41	1.71	1.02	0.28	0.15	1.34	2.86	0.24	11.36
*1969	0.47	0.97	1.27	0.84	0.64	1.53	0.30	0.71	0.16	2.37	1.90	1.54	12.71
*1970	2.06	0.65	0.38	0.26	0.29	1.57	0.58	0.10	0.58	1.39	1.92	2.25	12.04
*1971	0.99	0.37	0.70	0.36	0.51	0.27	0.24	0.14	0.00	1.21	2.92	2.89	10.59
*1972	1.62	0.61	1.16	0.05	0.04	0.01	0.14	0.35	1.25	1.02	1.31	0.93	8.47
*1973	6.00	1.17	0.96	0.50	0.88	1.64	0.36	1.39	0.72	1.73	0.91	0.32	16.58
*1974	0.29	0.48	0.05	1.41	0.22	0.14	0.28	0.01	0.07	1.93	1.10	1.14	7.12
*1975	3.10	0.38	0.26	0.84	1.02	1.22	0.63	0.13	0.01	2.62	0.75	2.84	13.80
*1976	0.07	0.42	0.53	0.08	0.54	0.44	0.33	0.81	0.14	2.25	1.40	0.97	7.96
*1977	0.65	0.29	0.24	0.52	0.12	0.37	0.25	0.22	0.31	2.22	3.27	1.06	9.52
*1978	0.67	0.78	0.22	1.25	1.04	1.47	0.25	0.90	0.07	0.86	1.12	0.68	9.31
*1979	1.51	2.84	1.52	1.72	0.54	1.21	0.17	1.52	0.57	0.62	1.07	0.07	13.37
*1980	0.87	1.39	0.86	2.43	2.85	1.03	0.25	0.27	0.01	0.44	1.02	1.04	12.47
*1981	0.46	0.07	0.57	0.17	0.52	2.12	0.49	0.36	0.54	2.86	1.50	1.25	10.91
*1982	0.95	0.89	0.05	0.93	1.34	1.27	0.09	0.57	0.08	1.97	4.01	1.39	13.53
*1983	0.23	1.33	1.30	0.99	0.68	1.42	0.68	0.33	0.18	2.41	1.70	1.41	12.66
*1984	1.23	1.01	1.65	0.21	0.11	1.13	0.90	0.12	0.17	1.53	2.62	2.55	13.23
*1985	1.79	0.42	1.63	1.23	0.59	1.34	2.11	0.37	0.26	2.21	0.98	1.54	14.48
*1986	1.11	1.16	0.30	0.04	0.96	1.22	1.34	0.83	1.15	2.91	2.97	1.58	15.57
*1987	1.16	2.60	1.02	0.92	1.09	0.54	0.47	0.90	1.08	2.65	2.16	0.47	15.07
*1988	1.10	1.89	1.26	1.02	0.67	0.04	2.47	0.22	1.18	1.40	4.38	0.94	16.57
*1989	0.21	0.97	0.37	1.04	0.96	0.26	0.02	0.09	0.09	2.07	1.26	0.32	7.66
*1990	0.00	0.14	0.16	0.31	0.69	0.77	0.66	1.05	0.29	2.35	2.09	2.01	11.48
1939-90 Average	1.15	0.78	0.83	0.81	0.70	0.91	0.58	0.49	0.47	1.89	2.05	1.22	11.89

* Denotes year in which one or more monthly records are reconstructed.

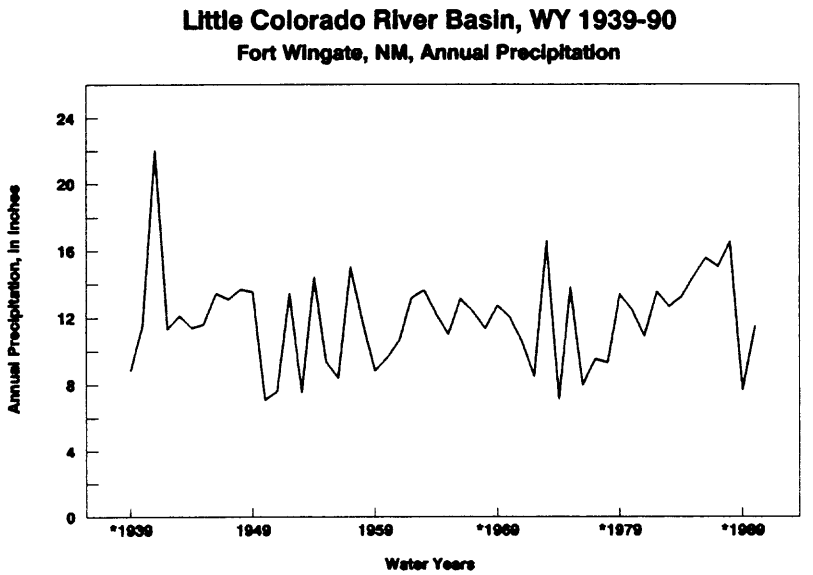


Figure 95. Fort Wingate, NM, Annual Precipitation, WY 1939-90

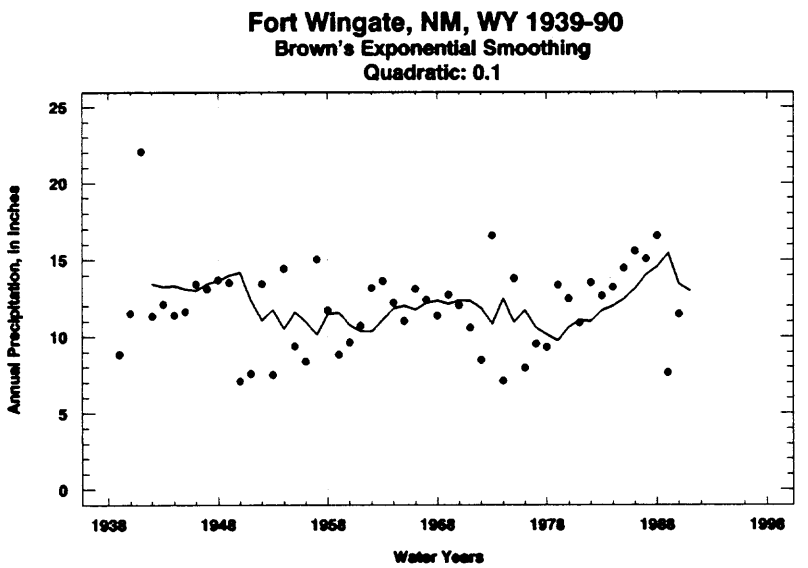


Figure 96. Fort Wingate, NM, Smoothed Annual Precipitation, WY 1939-90

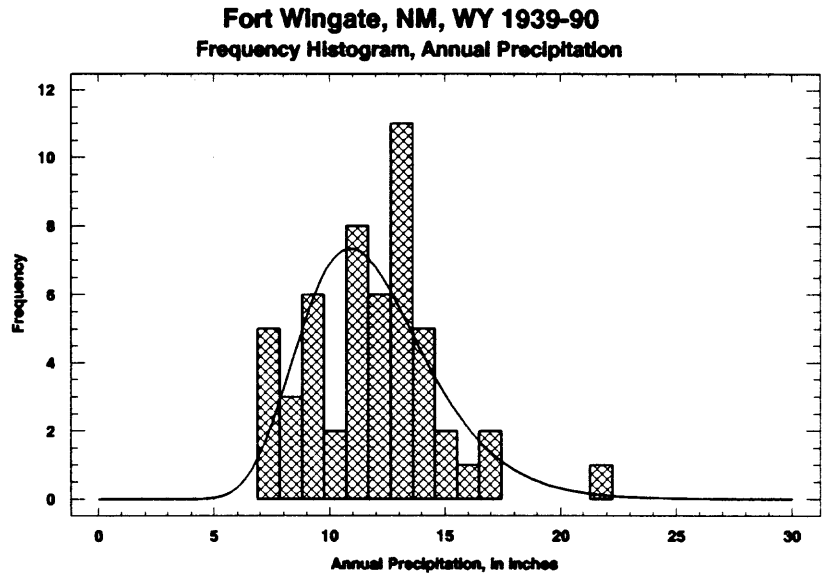


Figure 97. Fort Wingate, NM, Histogram of Annual Precipitation

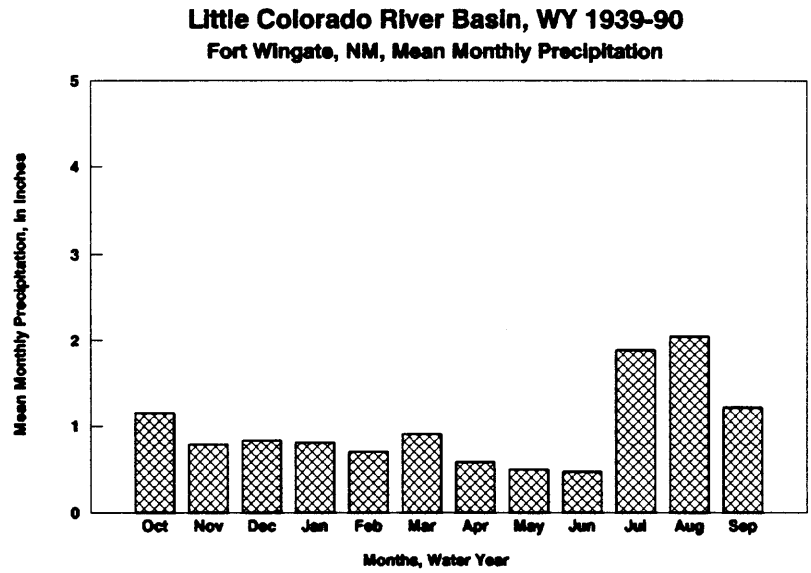


Figure 98. Fort Wingate, NM, Monthly Distribution of Precipitation

6.2.3.17 Fruitland, NM

This station is located at an elevation of 5,145 feet amsl approximately fifteen miles west of Farmington, along the San Juan River valley, well northeast of the LCR Basin. Its period of record extends from 1891 sporadically until 1904 and continuously from 1905 to 1925 and from 1939 until the present. Its long period makes this station valuable for reconstruction of missing records from relatively nearby LCR Basin stations. As its name implies, numerous orchards lie along the valley.

The precipitation trends for the study period exhibits the typical slight decline from 1939 through 1968 and a slight increase from 1969 to 1988. From 1988 to 1990 there appears to be a decline developing. There is a slight peak around 1960 which does not effect the overall 1939-68 decline.

The histogram shows a lognormal distribution with a sharp peak at seven to eight inches. The monthly averages peak somewhat in July through October and gradually decline towards the minimum in June.

Table 30. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Fruitland, NM
Station No.: 3340
Elevation: 5145
Latitude: 36d 44m
Longitude: 108d 21m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.03	0.23	0.51	0.56	0.43	1.69	0.18	0.05	0.00	0.15	1.02	1.90	6.75
1940	0.23	0.52	0.42	0.86	1.31	0.17	0.62	0.46	0.00	0.42	0.72	1.25	6.98
*1941	0.23	1.10	1.96	1.51	1.29	0.88	3.67	2.03	1.18	0.65	0.74	3.16	18.40
*1942	3.31	0.36	0.55	0.00	0.03	0.58	0.85	0.00	0.00	0.29	0.46	0.40	6.83
1943	0.89	0.05	0.76	0.12	0.18	0.96	0.00	0.78	0.11	0.18	0.88	0.67	5.58
*1944	0.54	0.03	1.11	0.51	0.57	0.32	0.56	0.56	0.00	0.81	0.60	1.13	6.75
1945	0.02	0.67	0.90	0.47	0.51	1.15	0.73	0.00	0.05	0.03	0.41	0.23	5.17
1946	1.04	0.00	0.63	0.11	0.22	0.58	0.20	0.45	0.01	0.87	1.41	0.68	6.20
1947	0.57	0.81	0.28	0.21	0.15	0.17	0.13	1.23	0.12	0.98	3.07	0.45	8.17
1948	2.17	0.47	0.27	0.00	1.25	0.61	0.31	0.23	1.36	0.30	2.45	0.68	10.10
*1949	2.03	0.77	0.61	1.22	0.26	0.61	0.31	0.90	2.22	1.14	0.38	0.49	10.94
1950	0.43	0.13	0.00	0.08	0.53	0.11	0.03	0.00	0.49	0.47	0.19	0.95	3.41
1951	0.00	0.08	0.12	0.79	0.34	0.00	0.13	0.41	0.00	0.21	1.18	0.18	3.44
*1952	0.64	0.56	0.62	1.05	0.33	0.20	1.31	0.54	0.48	0.85	0.19	0.95	7.72
1953	0.00	0.64	0.70	0.11	0.28	0.14	0.92	0.07	0.00	0.90	1.24	0.00	5.00
1954	1.16	0.50	1.37	0.31	0.00	0.45	0.13	0.67	0.52	2.49	1.15	1.45	10.20
1955	0.36	0.10	0.72	0.99	1.03	0.02	0.36	0.39	0.17	0.84	1.15	0.17	6.30
1956	0.00	0.36	0.35	2.22	0.13	0.17	0.07	0.32	0.06	0.61	0.87	0.00	5.16
1957	0.17	0.15	0.06	1.33	0.40	1.06	1.55	1.29	0.40	2.47	2.82	0.00	11.70
1958	2.38	0.01	0.18	0.64	0.51	1.17	0.33	0.18	0.24	0.16	1.39	1.32	8.51
1959	1.00	0.18	0.22	0.05	0.34	0.02	1.03	0.00	0.14	0.15	1.74	0.44	5.31
1960	1.39	0.54	0.95	0.42	0.44	0.40	0.27	0.60	0.19	1.29	0.14	0.58	7.21
1961	2.17	0.06	1.39	0.40	0.00	1.11	0.30	0.00	0.00	0.00	2.51	0.41	8.35
*1962	0.97	0.44	0.69	0.33	0.78	0.19	0.00	0.03	0.00	0.00	0.02	1.32	4.77
*1963	2.21	1.15	0.26	0.63	0.58	0.28	0.33	0.01	0.00	0.40	0.94	1.08	7.87
1964	0.71	0.36	0.31	0.00	0.00	0.60	1.02	0.17	0.00	0.00	0.00	1.98	5.15
1965	0.00	1.05	1.10	0.73	0.46	0.46	0.99	1.11	0.93	1.42	0.57	0.95	9.77
1966	1.44	1.04	1.21	0.26	0.27	0.10	0.28	0.26	0.16	0.54	0.27	0.62	6.45
1967	0.13	0.12	1.51	0.24	0.00	0.25	0.07	0.16	0.56	0.79	1.90	1.19	6.92
1968	0.08	0.11	1.34	0.23	0.50	0.67	0.67	0.34	0.11	1.57	1.63	0.08	7.33
1969	0.89	1.38	0.46	0.75	0.57	0.98	0.51	0.75	0.47	1.44	0.50	2.53	11.23
1970	2.96	0.48	0.37	0.24	0.16	0.72	0.55	0.00	0.80	0.79	0.14	2.19	9.40
1971	0.44	0.55	0.47	0.20	0.40	0.00	0.12	0.46	0.00	0.55	2.41	1.23	6.83
1972	1.14	1.12	0.61	0.02	0.00	0.06	0.00	0.00	0.24	0.00	1.26	0.73	5.18
1973	4.89	0.50	1.06	0.89	0.69	1.93	1.27	0.88	0.79	0.48	0.80	1.62	15.80
1974	0.49	0.32	0.12	1.71	0.22	0.02	0.21	0.16	0.16	0.99	0.23	0.30	4.93
1975	2.74	1.02	0.42	0.73	1.22	1.52	0.84	0.40	0.00	1.21	0.34	1.28	11.72
1976	0.06	0.30	0.51	0.25	0.27	0.07	0.11	0.16	0.23	1.43	0.67	0.97	5.03
1977	0.08	0.03	0.03	0.72	0.07	0.07	0.14	0.27	0.04	1.45	0.37	0.32	3.59
1978	0.41	0.54	0.69	1.92	1.00	1.69	0.73	1.13	0.00	0.05	0.05	1.72	9.93
1979	0.89	2.19	1.24	1.60	0.51	0.57	0.42	0.66	0.04	0.47	0.12	0.00	8.71
1980	1.24	0.62	0.88	1.14	1.15	0.63	0.20	0.17	0.00	0.00	0.84	0.89	7.76
1981	1.03	0.04	0.03	0.08	0.38	1.43	0.32	0.66	0.12	1.25	0.53	0.35	6.22
1982	0.84	0.51	0.07	0.48	1.27	1.38	0.23	0.72	0.00	0.70	1.62	0.92	8.74
1983	0.17	0.79	1.38	1.45	0.94	1.58	0.41	0.27	0.29	0.36	1.18	0.74	9.56
1984	0.41	0.92	1.12	0.16	0.27	0.89	1.42	0.00	0.75	0.44	1.07	0.44	7.89
1985	1.17	0.44	1.19	0.76	0.22	1.89	1.78	0.74	0.02	0.61	0.24	1.47	10.53
1986	0.96	0.92	0.41	0.15	1.01	0.79	1.25	0.05	0.08	4.17	0.60	2.01	12.40
1987	1.03	2.64	0.85	0.23	2.22	0.98	0.12	1.09	0.05	0.27	1.69	0.32	11.49
1988	0.94	2.13	1.11	0.71	0.88	0.12	0.86	0.69	0.49	0.06	1.54	0.29	9.82
1989	0.23	0.64	0.18	1.12	0.70	0.25	0.00	0.00	0.00	0.17	0.89	0.34	4.52
1990	0.77	0.00	0.00	0.73	1.39	0.38	1.29	0.84	0.15	0.43	2.27	1.44	9.69
1939-90 Average	0.96	0.59	0.66	0.62	0.55	0.64	0.58	0.45	0.27	0.74	0.99	0.90	7.95

* Denotes year in which one or more monthly records are reconstructed.

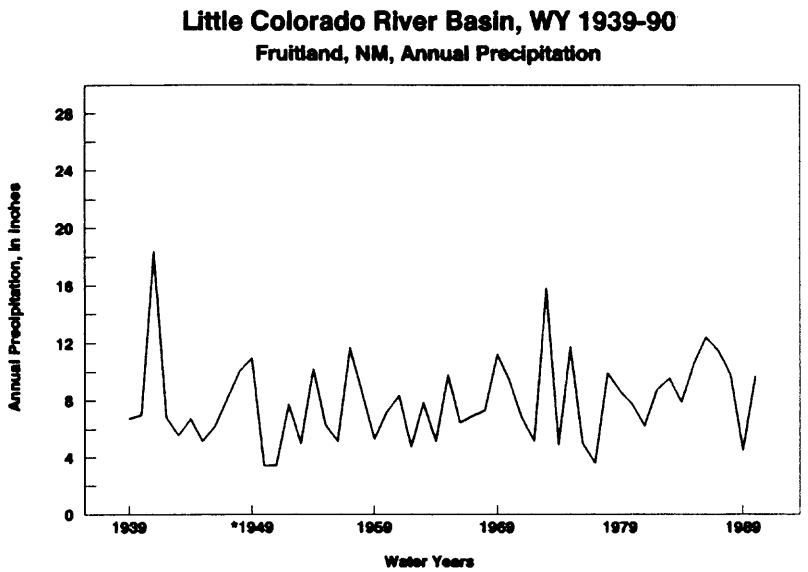


Figure 99. Fruitland, NM, Annual Precipitation, WY 1939-90

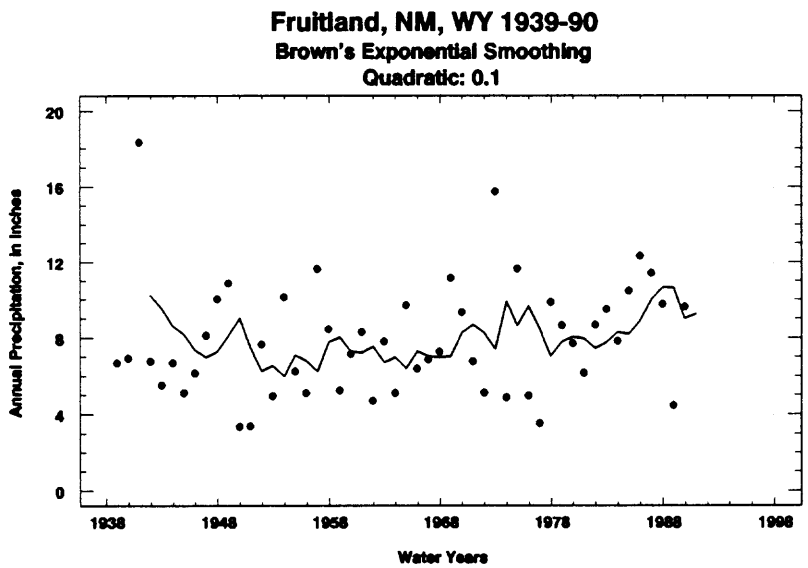


Figure 100. Fruitland, NM, Smoothed Annual Precipitation, WY 1939-90

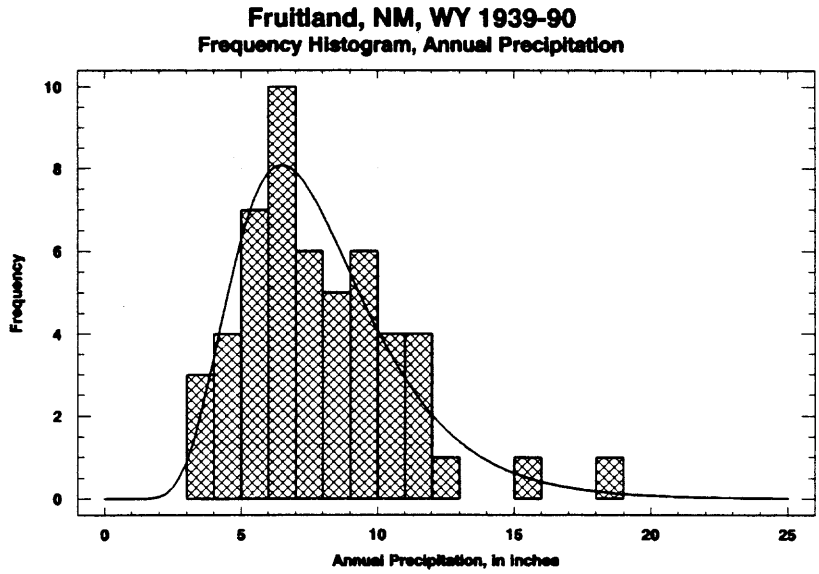


Figure 101. Fruitland, NM, Histogram of Annual Precipitation

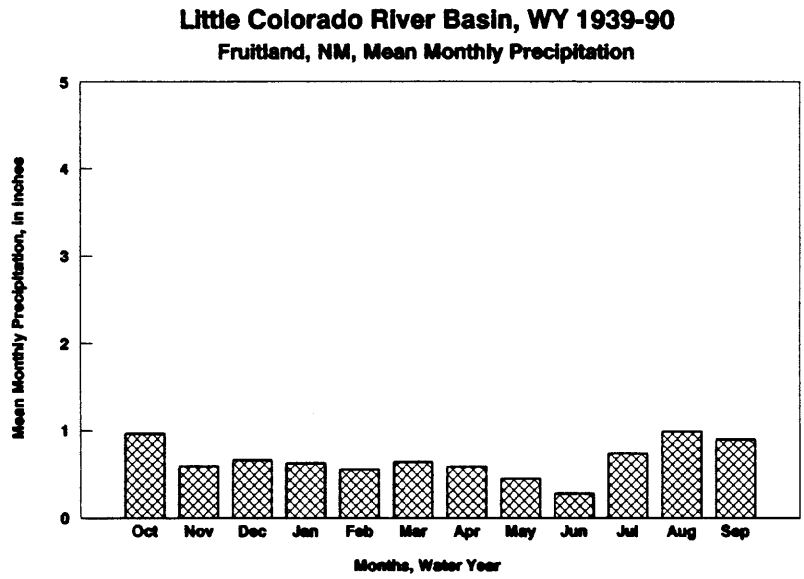


Figure 102. Fruitland, NM, Monthly Distribution of Precipitation

6.2.3.18 Gallup, NM

This station is about 20 miles east of the now defunct Fort Wingate station, which it replaces. It lies at an elevation of 6,468 feet amsl. The period of record for Gallup is from 1919 to 1924 and from 1948 to the present, with 1956 and 1972 missing. This station overlaps with Fort Wingate from 1940 to 1966 and enables the reconstruction of Fort Wingate data for long-term trend analysis. (See Section 6.2.4).

The long-term precipitation trends at Gallup indicate a gradual decline from 1939 to 1967 and a gradual increase from 1968 to 1988, with a slight peak around 1966-67. The period from 1988 to 1990 may reflect the start of a decline.

The histogram is similar to Fort Wingate, with a slight lognormal aspect to the frequency distribution, with flat kurtosis and a slight positive skewness. There is a sharp peak at about seven to eight inches. The mean monthly distribution shows a slight peak from July through October, with a gradual decline to the annual minimum in June.

Table 31. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Gallup, NM
Station No.: 3422
Elevation: 6468
Latitude: 35d 31m
Longitude: 108d 47m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.09	0.25	0.41	0.90	0.64	0.75	0.92	0.30	0.00	1.13	0.75	0.71	6.84
*1940	0.40	0.71	0.32	0.62	0.80	1.03	0.73	0.96	0.67	1.34	1.87	2.22	11.67
*1941	0.39	0.85	2.07	1.04	1.28	2.06	1.63	2.10	0.72	1.29	2.20	3.12	18.74
*1942	2.87	0.47	0.75	0.20	0.87	0.40	0.87	0.00	0.00	0.70	1.36	1.10	9.59
*1943	1.28	0.08	0.89	0.45	0.20	0.82	0.33	0.48	0.57	1.05	2.46	0.72	9.33
*1944	0.95	0.09	1.07	0.36	0.68	0.62	0.42	0.55	0.16	1.12	1.44	1.83	9.29
*1945	0.80	0.86	1.27	0.71	0.18	0.81	0.36	0.04	0.09	2.87	2.48	0.20	10.66
*1946	1.00	0.01	1.25	0.59	0.18	0.39	0.22	0.32	0.09	1.52	3.61	1.52	10.70
*1947	0.36	1.03	0.41	0.54	0.25	0.14	0.03	1.59	0.29	1.36	5.02	0.90	11.93
*1948	1.61	0.71	0.55	0.24	1.57	1.13	0.24	0.29	1.27	3.26	2.20	1.56	14.64
1949	2.11	0.10	0.88	0.73	0.14	0.45	0.52	1.17	1.09	2.92	1.28	0.81	12.20
1950	0.49	0.06	0.30	0.24	0.80	0.24	0.01	0.02	0.06	2.37	0.09	0.61	5.29
*1951	0.00	0.50	0.00	0.53	0.13	0.18	0.37	0.40	0.00	1.27	1.69	0.79	5.86
1952	1.02	0.81	0.59	1.47	0.30	0.67	2.36	0.12	1.14	0.95	2.45	0.85	12.73
1953	0.00	2.36	0.23	0.10	0.27	0.39	0.80	0.27	0.11	1.54	0.77	0.03	6.87
1954	0.50	0.33	0.57	0.29	0.29	2.39	0.19	1.46	0.14	3.73	0.95	1.37	12.21
1955	0.48	0.00	0.42	0.78	0.74	0.00	0.33	0.49	0.77	4.41	0.77	0.05	9.24
1956	0.00	0.43	0.89	1.11	0.68	0.03	0.39	0.00	0.00	0.46	1.12	0.00	5.11
1957	0.47	0.02	0.11	1.65	1.10	0.87	1.65	1.08	0.26	2.58	1.98	0.00	11.77
*1958	2.02	0.85	0.51	0.24	0.43	1.00	0.57	0.43	0.24	1.67	1.83	1.37	11.15
1959	1.41	0.45	0.66	0.03	0.35	0.14	0.74	0.00	0.81	0.58	2.14	0.12	7.43
1960	1.78	0.34	1.03	0.92	0.89	0.39	0.22	0.52	0.57	0.00	0.95	0.05	7.66
1961	1.88	0.01	0.48	0.06	0.29	0.15	0.25	0.18	0.01	2.15	2.56	1.20	9.22
1962	2.90	0.65	1.13	1.08	2.26	0.89	0.12	0.18	0.35	0.59	0.55	1.72	12.42
1963	3.02	1.33	0.25	0.94	1.05	0.33	0.00	0.01	0.00	0.95	3.18	1.52	12.58
*1964	0.62	0.47	0.23	0.63	0.64	0.87	0.17	0.15	0.02	2.40	3.85	1.01	11.07
1965	0.00	0.84	0.03	1.31	0.04	0.49	0.00	0.68	1.40	4.24	0.22	0.49	9.74
1966	0.87	1.12	2.47	0.17	0.13	0.41	0.58	0.00	0.22	2.14	2.53	0.99	11.63
1967	1.02	0.37	1.31	0.00	0.00	0.22	0.00	0.37	1.54	2.19	2.79	1.00	10.81
*1968	0.00	0.10	1.90	0.16	0.39	1.56	0.96	0.00	0.12	0.00	1.36	0.28	6.85
1969	0.33	1.17	1.40	0.32	0.13	1.34	0.00	0.14	0.05	2.08	1.40	1.34	9.70
1970	2.08	0.43	0.26	0.09	0.01	1.20	0.34	0.14	0.72	0.50	1.60	2.00	9.37
1971	1.29	0.38	0.24	0.18	0.35	0.19	0.06	0.14	0.00	1.42	3.12	3.35	10.72
1972	1.01	0.51	0.79	0.03	0.00	0.01	0.08	0.26	1.14	1.30	1.16	0.70	6.99
1973	5.75	0.89	0.63	0.35	0.72	1.13	0.37	1.44	0.54	0.94	0.56	0.43	13.75
1974	0.39	0.17	0.04	1.39	0.17	0.06	0.32	0.00	0.00	1.26	1.73	1.01	6.54
1975	4.55	0.61	0.12	0.46	0.45	0.86	0.22	0.14	0.05	1.32	0.34	1.78	10.90
1976	0.00	0.03	0.04	0.00	0.00	0.00	0.00	0.78	0.32	1.13	1.39	1.75	5.44
1977	0.93	0.40	0.00	0.36	0.08	0.05	0.20	0.25	0.25	2.76	2.24	1.25	8.77
1978	1.05	0.00	0.00	0.63	0.41	0.30	0.00	0.28	0.14	0.12	0.54	0.78	4.25
1979	2.18	3.12	0.60	0.73	0.20	0.69	0.00	1.41	0.50	0.01	0.74	0.00	10.18
1980	1.23	1.45	0.93	2.41	2.22	1.38	0.45	0.13	0.00	0.14	1.01	0.82	12.17
1981	0.72	0.11	0.51	0.08	0.31	1.82	0.35	0.53	0.83	3.59	1.05	1.34	11.24
1982	0.73	0.36	0.06	0.90	0.82	1.49	0.18	1.09	0.05	1.08	4.59	0.75	12.10
1983	0.21	1.25	1.29	1.02	0.50	1.43	0.37	0.42	0.13	3.13	1.44	0.98	12.17
1984	1.01	1.08	1.54	0.16	0.11	1.01	0.55	0.13	0.02	1.82	2.91	1.79	12.13
1985	1.63	0.30	1.41	0.94	0.40	1.37	2.00	0.58	0.60	1.90	1.57	1.29	13.99
1986	1.13	0.71	0.16	0.09	0.82	1.00	0.72	1.21	1.06	2.28	2.07	1.59	12.84
1987	1.11	2.04	0.79	0.75	1.25	0.66	0.65	0.92	0.36	2.40	2.19	0.15	13.27
1988	1.16	1.74	0.82	1.87	0.28	0.07	3.18	0.20	1.33	0.68	2.97	1.07	15.37
1989	0.08	1.01	0.34	0.76	1.05	0.11	0.00	0.06	0.07	1.42	1.06	0.05	6.01
1990	0.79	0.02	0.05	0.06	0.42	0.67	0.68	0.83	0.73	2.32	2.08	1.62	10.27
1939-90 Average	1.15	0.65	0.67	0.61	0.54	0.71	0.51	0.49	0.42	1.66	1.81	1.04	10.26

* Denotes year in which one or more monthly records are reconstructed.

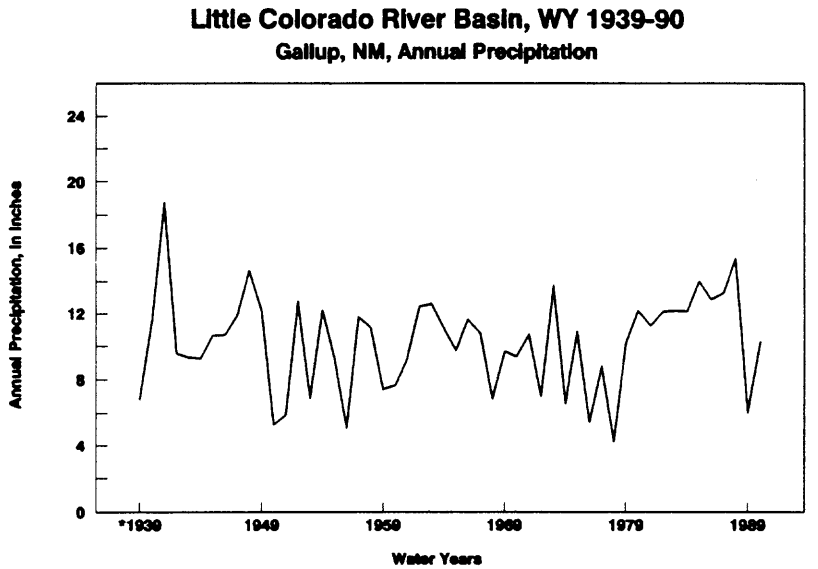


Figure 103. Gallup, NM, Annual Precipitation, WY 1939-90

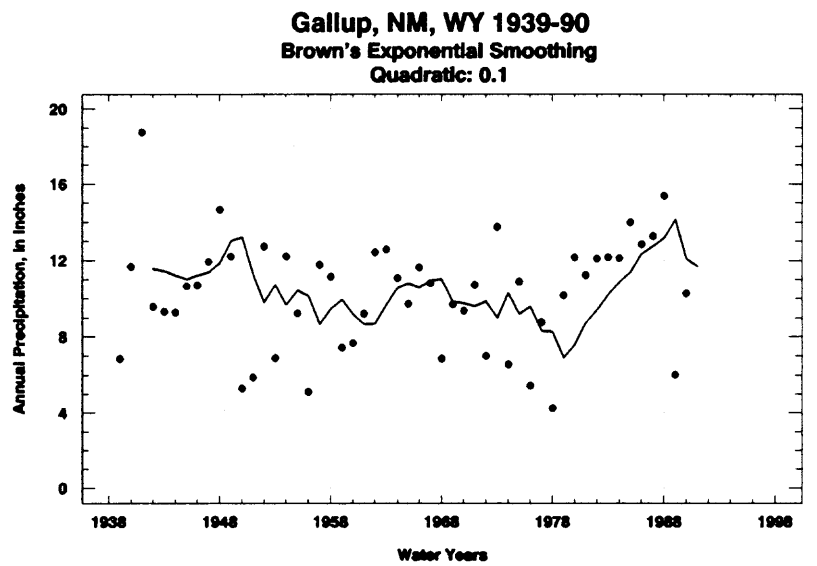


Figure 104. Gallup, NM, Smoothed Annual Precipitation, WY 1939-90

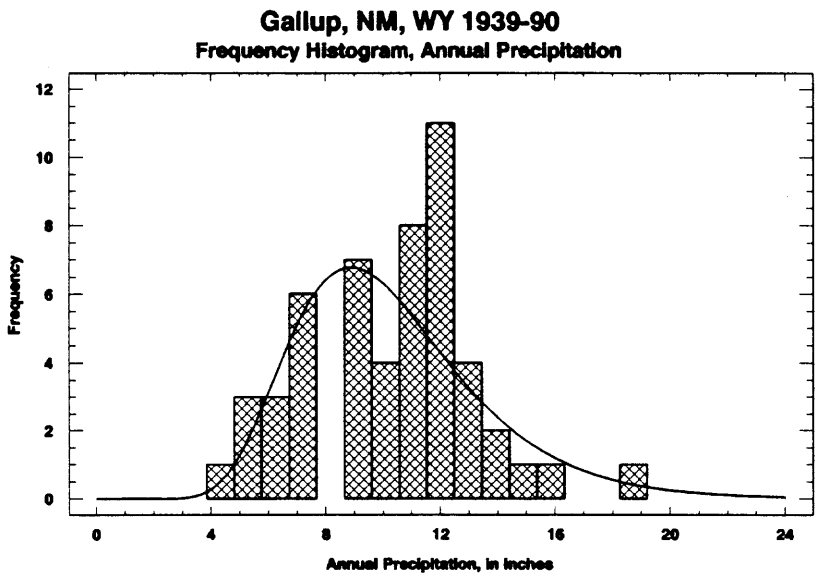


Figure 105. Gallup, NM, Histogram of Annual Precipitation

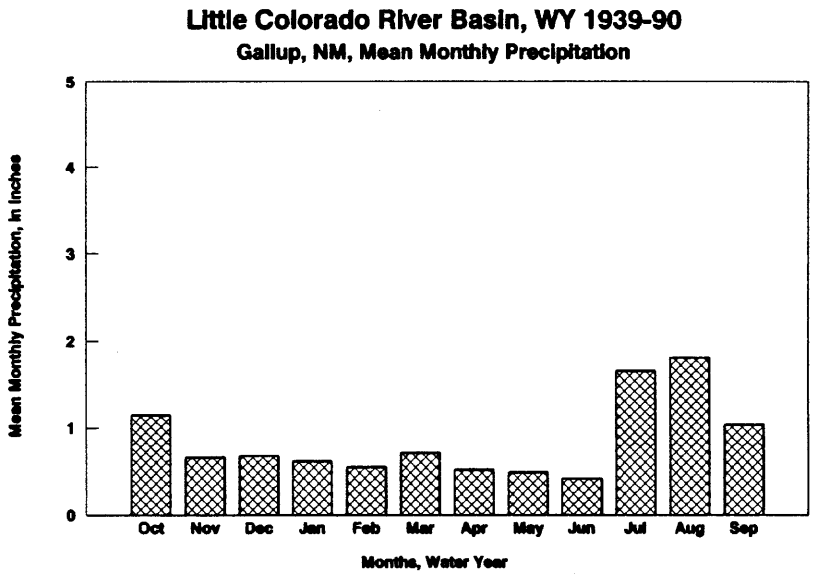


Figure 106. Gallup, NM, Monthly Distribution of Precipitation

6.2.3.19 Gamerco, NM

Gamerco is located about five miles north of Gallup at an elevation of 6,785 feet amsl. The period of record is from 1922 to 1951, and fills in missing record from Gallup and Fort Wingate for the purposes of long-term trend analysis. The period from 1952 to the present has been reconstructed for comparison to other nearby stations.

The precipitation trends for the study period 1939-90 indicate a decline from 1939 to 1960, a peak from 1961 to 1980 centered on 1969, and a sharp increase from 1980 to 1988, and indications of a decline beginning in 1988.

The histogram is mixed normal/lognormal, with flat kurtosis, and a sharp peak at about fifteen inches. The difference in precipitation between the Gamerco station and the neighboring Gallup station may be due to a somewhat higher elevation at Gemerco.

The mean monthly distribution shows a moderate peak from July through October, followed by a gradual decline from November through the annual June minimum.

Table 32. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Gamerco, NM
Station No.: 3431
Elevation: 6785
Latitude: 35d 36m
Longitude: 108d 46m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.10	0.15	0.79	0.97	0.66	0.88	1.01	0.35	0.00	1.29	0.94	0.93	8.07
1940	0.28	0.85	0.56	0.71	0.75	0.47	0.50	0.92	0.45	0.64	0.75	3.11	9.99
1941	1.11	0.74	2.13	0.80	1.37	2.52	1.81	1.73	0.54	1.88	1.76	4.40	20.79
1942	2.90	0.51	1.20	0.18	1.11	0.63	0.97	0.00	0.00	0.74	1.55	1.58	11.37
1943	1.72	0.09	1.02	0.63	0.41	1.13	0.40	0.66	0.69	0.89	3.43	1.12	12.19
1944	0.54	0.05	1.28	0.44	0.95	0.59	0.34	0.00	0.01	1.03	1.54	1.91	8.68
1945	1.06	0.88	1.33	0.95	0.20	1.32	0.47	0.04	0.04	2.81	1.96	0.37	11.43
1946	1.04	0.00	1.72	0.71	0.29	0.56	0.48	0.38	0.27	1.32	2.00	1.43	10.20
1947	0.38	1.24	0.51	0.51	0.28	0.30	0.00	1.98	0.29	1.87	6.53	0.56	14.45
1948	1.81	0.91	0.57	0.23	2.30	0.98	0.23	0.28	0.86	2.22	2.26	1.76	14.41
1949	2.22	0.03	1.05	1.25	0.60	0.93	0.38	1.26	0.69	3.04	0.83	1.03	13.31
1950	0.69	0.10	0.53	0.55	1.03	0.32	0.00	0.06	0.21	1.57	0.20	0.86	6.12
*1951	0.00	0.51	0.01	0.94	0.14	0.25	0.77	0.28	0.00	1.16	1.93	0.58	6.57
*1952	0.76	0.70	1.18	1.57	0.34	0.71	2.01	0.09	1.03	1.47	2.01	0.84	12.71
*1953	0.00	2.06	0.40	0.24	0.36	0.58	0.53	0.25	0.32	1.75	0.83	0.02	7.34
*1954	0.57	0.40	0.66	0.52	0.25	2.24	0.23	1.13	0.13	2.96	1.00	1.95	12.04
*1955	0.60	0.05	0.46	0.82	0.75	0.03	0.33	0.69	0.43	2.63	2.21	0.05	9.05
*1956	0.09	0.33	0.77	1.20	0.53	0.05	0.32	0.30	0.18	1.79	1.16	0.01	6.73
*1957	0.59	0.09	0.20	1.95	0.90	0.82	1.00	1.31	0.49	2.82	2.25	0.00	12.43
*1958	2.14	0.92	0.40	0.31	0.59	1.19	0.69	0.49	0.28	1.16	2.21	1.80	12.19
*1959	1.16	0.50	0.24	0.28	0.59	0.00	0.68	0.16	0.75	0.89	2.78	0.00	8.02
*1960	2.13	0.40	1.44	0.94	0.69	0.53	0.19	0.52	0.62	0.43	0.77	0.52	9.18
*1961	2.52	0.21	0.57	0.42	0.51	1.28	0.52	0.12	0.17	1.86	2.80	1.06	12.02
*1962	2.81	0.64	1.11	0.98	1.18	0.61	0.19	0.10	0.39	0.85	0.76	2.26	11.89
*1963	3.09	1.14	0.42	0.70	1.04	0.39	0.13	0.01	0.03	1.04	4.12	1.28	13.39
*1964	0.83	0.73	0.18	0.40	0.68	0.88	0.76	0.18	0.04	2.67	4.15	1.80	13.31
*1965	0.05	1.11	0.90	1.30	0.65	0.52	0.59	0.72	1.40	3.54	1.31	0.81	12.91
*1966	0.85	1.12	2.47	0.29	0.42	0.49	0.50	0.07	0.46	2.21	2.60	1.79	13.29
*1967	0.39	0.42	1.49	0.23	0.03	0.38	0.09	0.28	1.39	2.87	2.70	1.26	11.54
*1968	0.15	0.28	2.21	0.34	0.41	1.65	0.99	0.25	0.14	1.23	2.70	0.23	10.59
*1969	0.42	0.94	1.15	0.60	0.54	1.46	0.19	0.69	0.21	2.20	1.89	1.48	11.76
*1970	2.09	0.51	0.35	0.25	0.26	1.46	0.52	0.09	0.55	1.06	1.87	2.16	11.18
*1971	0.94	0.36	0.64	0.32	0.48	0.25	0.20	0.14	0.00	1.14	2.70	2.80	9.98
*1972	1.43	0.57	1.04	0.05	0.01	0.01	0.10	0.33	1.19	0.92	1.18	0.88	7.72
*1973	5.76	1.10	0.86	0.45	0.85	1.46	0.36	1.35	0.70	1.55	0.88	0.33	15.65
*1974	0.28	0.41	0.04	1.30	0.21	0.09	0.29	0.00	0.06	1.81	0.99	1.16	6.65
*1975	2.96	0.35	0.22	0.75	0.92	1.15	0.53	0.10	0.01	2.51	0.69	2.75	12.93
*1976	0.05	0.33	0.49	0.07	0.38	0.30	0.27	0.75	0.14	2.07	1.29	0.90	7.06
*1977	0.62	0.27	0.21	0.46	0.18	0.32	0.21	0.20	0.30	2.11	3.13	0.99	8.99
*1978	0.61	0.76	0.20	1.07	0.89	1.21	0.21	0.88	0.11	0.79	1.01	0.75	8.50
*1979	1.49	2.66	1.31	1.43	0.43	1.09	0.15	1.45	0.54	0.57	0.98	0.04	12.14
*1980	0.85	1.39	0.82	2.21	2.53	1.06	0.26	0.24	0.01	0.34	0.96	1.02	11.68
*1981	0.41	0.06	0.53	0.14	0.49	1.90	0.44	0.33	0.51	2.70	1.26	1.07	9.85
*1982	0.94	0.70	0.03	0.78	1.31	1.16	0.11	0.56	0.06	1.85	3.90	1.31	12.72
*1983	0.25	1.24	1.15	0.93	0.58	1.29	0.54	0.31	0.13	2.26	1.58	1.24	11.50
*1984	1.11	1.05	1.62	0.18	0.12	1.07	0.85	0.11	0.14	1.38	2.87	1.85	12.35
*1985	1.80	0.33	1.42	1.12	0.46	1.31	2.05	0.36	0.25	2.01	0.92	1.39	13.41
*1986	1.24	0.98	0.28	0.03	0.87	1.13	1.30	0.83	1.06	2.82	2.75	1.49	14.79
*1987	1.08	2.53	0.98	0.84	1.02	0.48	0.45	0.88	1.02	2.49	1.92	0.39	14.10
*1988	1.01	1.79	1.19	0.92	0.62	0.03	2.40	0.22	1.08	1.28	4.15	0.89	15.57
*1989	0.19	0.91	0.32	0.92	0.93	0.20	0.01	0.08	0.09	1.94	1.19	0.26	7.03
*1990	0.91	0.11	0.10	0.27	0.59	0.70	0.66	1.02	0.28	2.30	1.94	1.77	10.66
1939-90 Average	1.14	0.70	0.82	0.70	0.67	0.82	0.56	0.49	0.40	1.75	1.96	1.20	11.20

* Denotes year in which one or more monthly records are reconstructed.

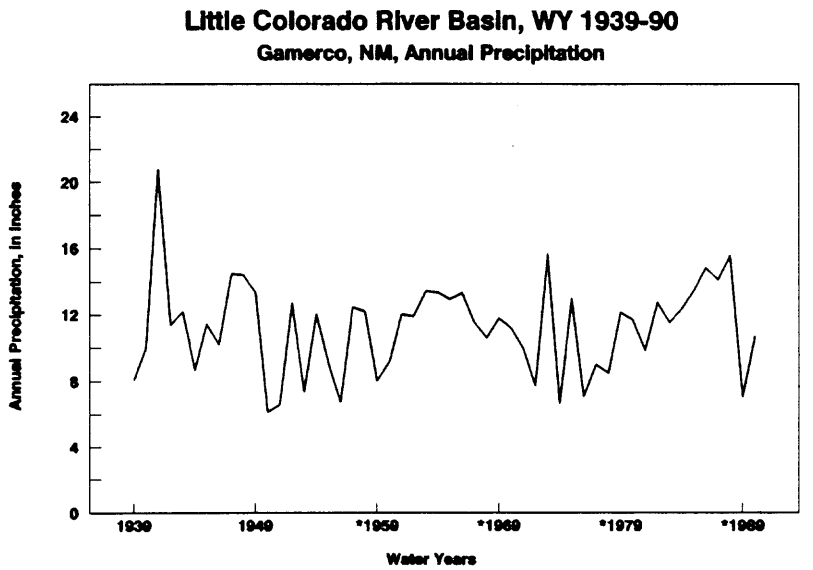


Figure 107. Gamerco, NM, Annual Precipitation, WY 1939-90

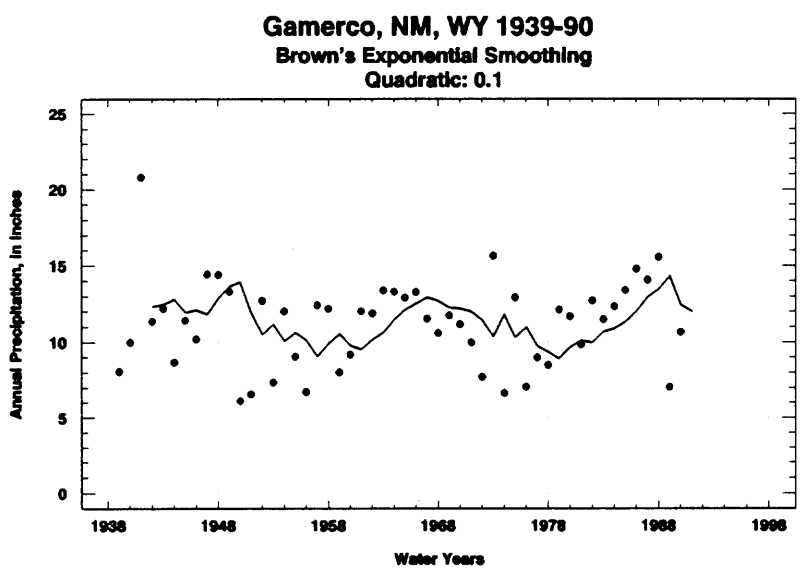


Figure 108. Gamerco, NM, Smoothed Annual Precipitation, WY 1939-90

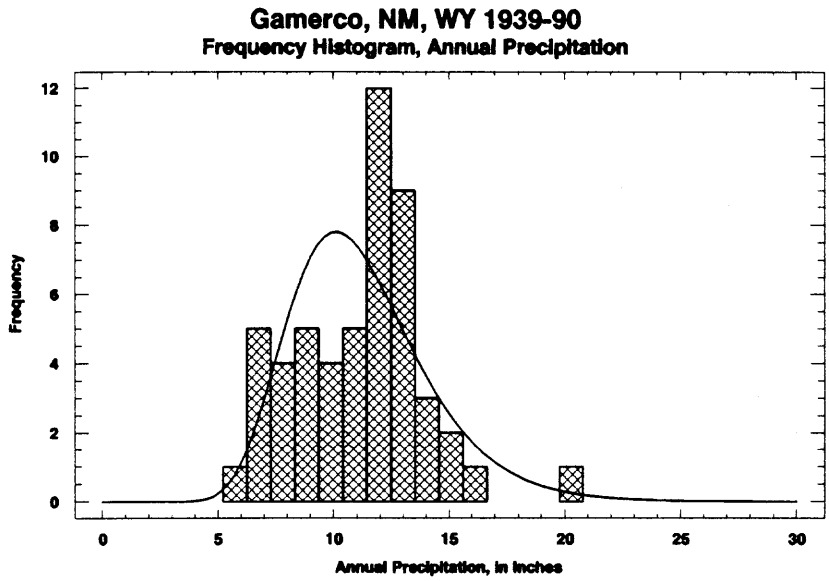


Figure 109. Gamerco, NM, Histogram of Annual Precipitation

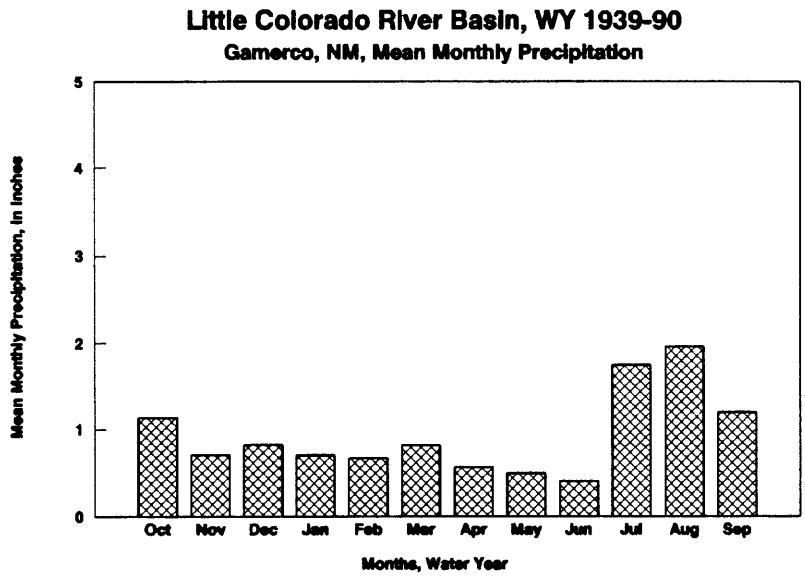


Figure 110. Gamerco, NM, Monthly Distribution of Precipitation

6.2.3.20 Ganado, AZ

The period of record for Ganado is from 1931 to the present, with occasional missing months. The missing record has been reconstructed. The station lies some thirty miles west of Window Rock and Fort Defiance, near the northeast Arizona border of the LCR Basin.

As summarized in Sellars and Hill (1974, p. 230):

"Ganado lies at an elevation of 6,340 feet just to the south of Ganado Mesa in northeastern Arizona. The terrain slopes upward to the northeast onto Defiance Plateau which rises to 7,500 feet, fourteen miles away. Beautiful Valley, located sixteen miles to the north and having a general north-south orientation, is intersected by a considerable number of washes that emanate from the higher elevations to the east and west. Numerous mesas are found in the area, some of the more prominent ones including Sastanha Mesa, 44 miles to the northwest, Carson Mesa, 40 miles to the north-northwest, Ventana Mesa, 31 miles to the north-northwest and Rock Mesa, 22 miles to the north-northeast. The imposing Canyon de Chelly National Monument lies thirty miles to the north-northeast in the heart of the Navajo Indian Reservation and features two deep canyons consisting of towering red-rock walls that have undergone wind erosion for thousands of years. The exquisite beauty and natural brilliant red coloring annually attract tens of thousands of tourists to the monument. The prevalent form of vegetation to the east of Ganado consists of sagebrush, while to the south in the Apache Indian Reservation sections of pinyon and juniper are common. Northern plains grass is found, mixed with sagebrush, to the west.

"Ganado has an arid climate with an average of less than eleven inches of precipitation falling annually. [Note 11.47 inches of measured precipitation for the 1939-90 study period]. During the forty year period for which annual totals have been recorded amounts have ranged from almost twenty five inches in [calendar year] 1941 to a sparse 5.79 inches in [calendar year] 1950. About sixty percent of the annual precipitation is normally measured between early July and the end of October. These warm season rains are associated with northward-moving tropical air that flows from the Gulf of Mexico and rises over the surrounding high plateau regions, forming thunderstorms. The most severe summer precipitation at Ganado may occur when tropical storm systems, considerably weakened, enter the state from the Pacific Ocean and affect parts of northeastern Arizona. The driest months, May and June, each average in excess of four-tenths of rain not unusual (sic) for a semi-desert climate.

"The minimal amounts of precipitation that fall in the winter are associated with cyclonic storms that originate in the Pacific Ocean and follow an eastward track. These storms usually remain too far north to produce little more than cloudy skies and strong gusty winds. However, on the infrequent occasions when they move southward, precipitation can be intermittent for several days, covering a widespread area. Almost all the winter precipitation falls as snow, only a fraction of which melts immediately owing to the rather cold temperatures."

The histogram shows a normal to lognormal distribution, with a moderate kurtosis and a slight positive skew. The monthly distribution shows a definite peak in July through October, declining from that point to the annual minimum in June.

Table 33. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Ganado, AZ
Station No.: 3303
Elevation: 6340
Latitude: 35d 31m
Longitude: 108d 47m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.34	0.82	0.87	0.70	0.45	0.78	0.15	0.00	0.09	1.09	1.36	6.65
1940	0.53	1.55	0.31	1.04	1.24	0.67	1.41	0.48	0.26	0.56	4.26	4.70	17.01
1941	1.98	1.12	2.45	0.87	1.77	1.70	3.46	1.62	3.19	0.39	2.07	4.60	25.22
1942	3.32	0.79	1.14	0.05	1.36	0.57	1.60	0.00	0.00	1.29	1.90	1.10	13.12
1943	1.89	0.15	1.52	1.23	0.28	1.29	0.22	0.38	0.18	0.41	2.58	0.93	11.06
1944	1.27	0.00	0.62	1.60	1.65	1.61	0.62	0.80	0.00	1.32	0.41	2.14	12.04
1945	0.00	0.86	2.11	1.06	0.74	1.79	0.26	0.04	0.23	3.11	2.35	0.58	13.13
1946	0.63	0.00	1.22	0.10	0.18	0.41	0.10	0.44	0.00	1.59	3.27	1.81	9.75
1947	0.63	1.42	0.62	0.55	0.04	0.25	0.03	1.34	0.24	0.26	4.07	0.38	9.83
1948	2.73	1.08	1.02	0.17	1.58	1.61	0.38	0.14	0.24	1.30	2.14	1.50	13.89
1949	2.81	0.00	1.44	1.69	0.78	1.05	0.47	0.56	1.79	1.52	0.20	1.40	13.71
1950	1.50	0.26	0.47	0.42	0.43	0.14	0.00	0.05	0.43	2.61	0.52	0.70	7.53
1951	0.00	0.25	0.24	0.62	0.16	0.32	1.07	0.30	0.00	0.46	1.63	0.16	5.21
1952	1.22	0.65	0.74	1.34	0.33	0.87	1.92	0.07	0.85	2.40	1.46	1.30	13.15
1953	0.00	1.56	0.77	0.33	0.38	0.16	0.37	0.28	0.02	2.03	0.64	0.00	6.54
1954	0.66	0.53	0.66	0.28	0.16	1.91	0.22	0.59	0.10	2.24	2.28	1.25	10.88
1955	1.11	0.06	0.46	0.43	0.60	0.21	0.26	0.37	1.09	1.57	2.61	0.14	8.91
1956	0.00	0.36	0.60	0.98	0.18	0.05	0.07	0.37	0.28	1.82	0.82	0.00	5.53
1957	0.93	0.18	0.23	2.57	0.57	1.03	0.96	1.88	0.17	1.66	2.41	0.00	12.59
1958	2.40	0.74	0.28	0.25	0.98	0.95	0.61	0.25	0.16	0.69	2.49	1.55	11.35
1959	0.73	0.65	0.15	0.21	0.67	0.00	0.60	0.00	0.82	0.70	2.46	0.43	7.42
1960	1.97	0.35	1.64	0.59	1.03	0.62	0.21	0.36	0.43	0.18	1.06	0.12	8.56
1961	2.92	0.30	0.59	0.25	0.49	0.98	0.29	0.01	0.00	2.05	1.87	0.90	10.65
1962	2.05	0.52	1.19	0.76	1.02	0.61	0.05	0.24	0.25	0.53	0.22	2.32	9.76
1963	2.43	1.53	0.13	0.32	0.66	0.27	0.24	0.00	0.01	0.51	3.67	0.80	10.57
1964	0.57	0.42	0.50	0.17	0.14	0.93	1.28	0.00	0.09	2.81	3.82	3.02	13.75
1965	0.00	1.09	1.05	1.65	0.96	0.68	0.88	1.33	0.85	3.18	1.20	2.03	14.90
1966	1.16	1.83	1.84	0.39	0.59	0.54	0.16	0.05	0.02	1.89	0.66	1.00	10.13
1967	0.20	0.74	1.63	0.33	0.00	0.41	0.38	0.21	0.78	2.39	1.79	0.81	9.67
1968	0.21	0.25	2.07	0.06	0.21	0.36	0.74	0.41	0.20	2.56	1.41	0.00	8.48
1969	1.91	1.38	1.55	0.84	0.77	1.12	0.49	0.28	0.20	1.88	1.59	0.33	12.34
1970	2.16	0.70	0.10	0.39	0.00	1.55	1.86	0.07	0.43	1.32	1.21	1.70	11.49
1971	0.66	0.42	0.65	0.10	0.53	0.23	0.32	0.23	0.00	1.49	3.22	1.92	9.77
1972	2.31	0.95	2.74	0.10	0.23	0.05	0.06	0.14	1.07	0.92	0.63	0.34	9.54
*1973	3.87	0.91	1.41	1.34	1.01	2.78	0.85	1.18	0.69	0.63	0.92	0.43	16.02
*1974	0.06	0.70	0.25	1.50	0.80	0.41	0.73	0.00	0.18	3.27	0.23	0.57	8.70
1975	3.18	0.36	0.65	1.12	0.74	1.52	0.57	0.33	0.00	2.14	0.51	1.72	12.84
1976	0.18	0.83	0.51	0.00	0.99	0.18	0.46	0.70	0.25	2.73	1.49	0.82	9.14
1977	0.61	0.44	0.07	1.07	0.60	0.06	0.65	0.41	0.35	3.23	1.99	2.05	11.53
1978	0.60	0.85	0.30	2.01	2.05	1.70	0.76	1.08	0.00	0.10	0.87	0.50	10.82
1979	1.40	4.33	2.96	2.16	0.46	1.80	0.45	1.17	0.73	0.00	1.17	0.00	16.63
1980	1.06	0.63	1.37	1.76	2.28	0.76	0.54	0.10	0.00	0.44	1.45	2.75	13.14
1981	0.57	0.22	0.28	0.56	0.83	2.66	0.36	0.45	0.38	2.21	2.02	1.15	11.69
1982	1.30	1.18	0.20	0.44	2.94	1.53	0.15	1.98	0.00	1.05	4.83	1.38	16.98
*1983	0.00	1.25	1.20	2.55	0.00	0.67	0.28	0.26	0.44	2.49	2.46	0.96	12.56
1984	0.66	1.04	0.97	0.00	0.00	0.89	0.73	0.13	0.42	1.41	3.27	1.57	11.09
*1985	2.40	0.00	1.34	1.19	0.05	1.47	3.25	0.19	0.02	2.00	1.55	2.96	16.42
*1986	2.70	0.63	0.03	0.00	0.55	1.87	1.26	0.50	0.35	2.24	1.21	4.13	15.47
*1987	0.70	2.19	1.29	1.09	0.92	0.22	0.62	0.46	0.07	2.43	1.34	0.37	11.70
*1988	1.04	1.68	1.11	0.87	1.30	0.01	2.56	0.02	0.67	0.12	3.45	0.22	13.05
1989	0.10	0.61	0.04	0.18	0.00	0.45	0.00	0.13	0.00	0.08	2.52	0.00	4.11
1990	1.14	0.00	0.00	0.45	1.95	1.00	0.57	0.72	1.51	1.76	1.10	0.09	10.29
1939-90 Average	1.24	0.79	0.91	0.79	0.75	0.87	0.71	0.45	0.39	1.50	1.85	1.21	11.47

* Denotes year in which one or more monthly records are reconstructed.

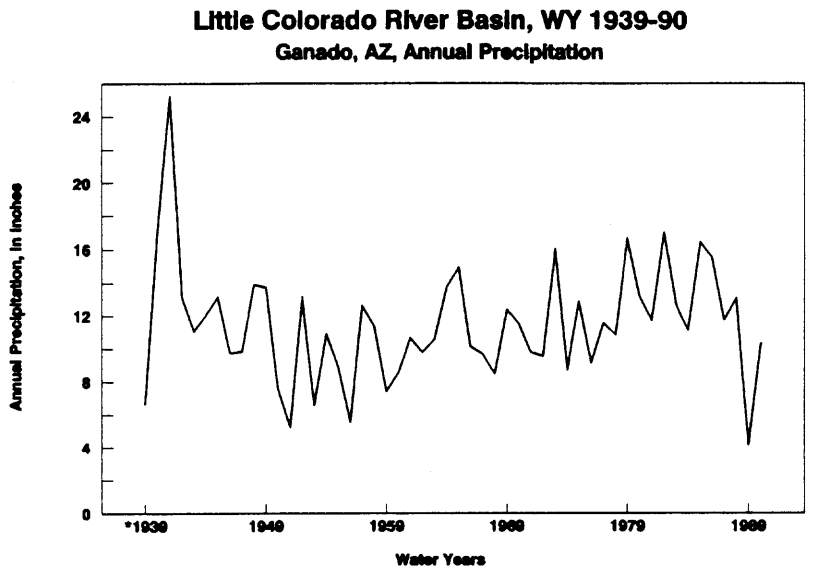


Figure 111. Ganado, AZ, Annual Precipitation, WY 1939-90

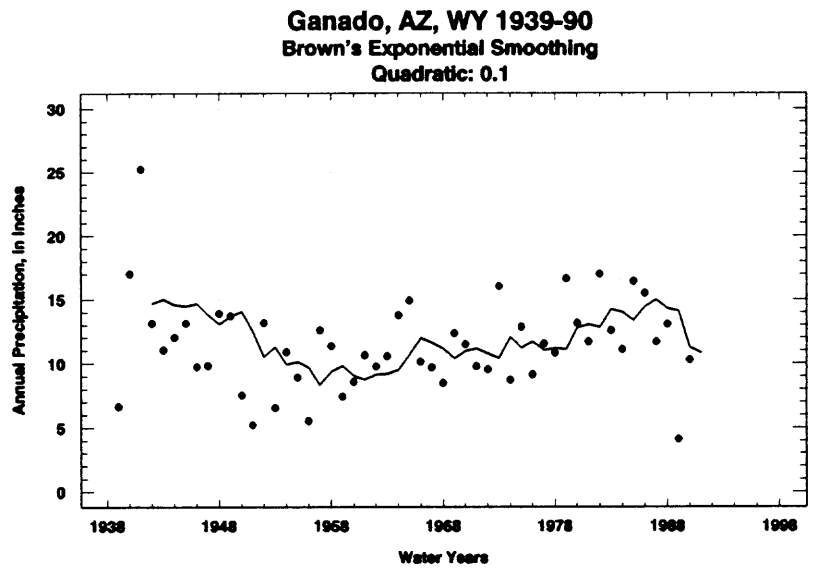


Figure 112. Ganado, AZ, Smoothed Annual Precipitation, WY 1939-90

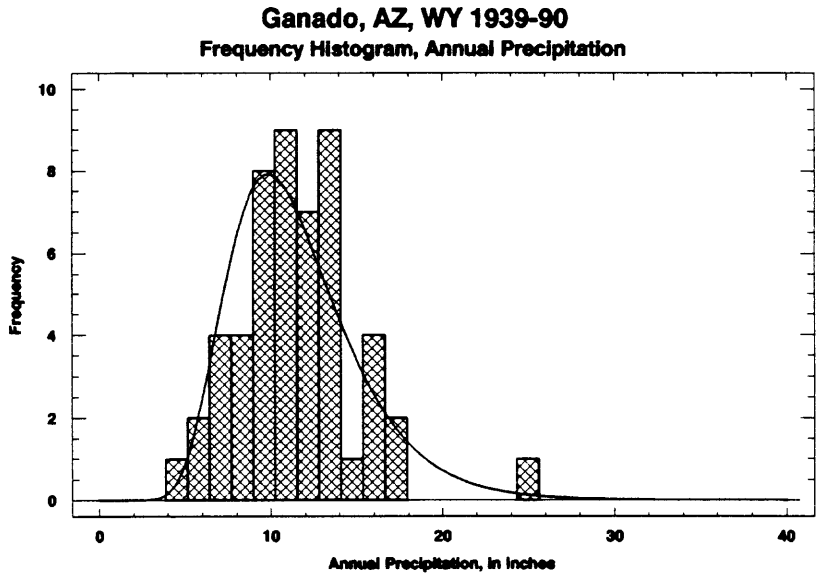


Figure 113. Ganado, AZ, Histogram of Annual Precipitation

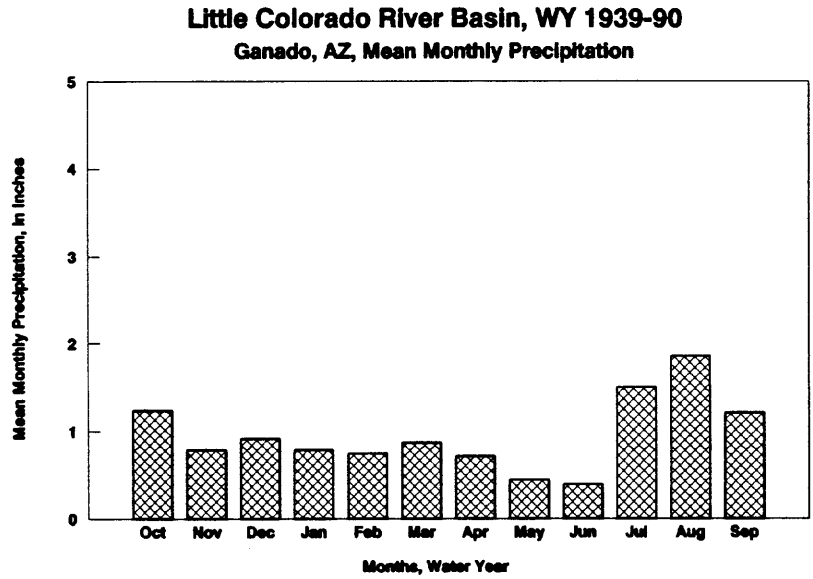


Figure 114. Ganado, AZ, Monthly Distribution of Precipitation

6.2.3.21 Grand Canyon National Park, South Rim, AZ

This station is located at an elevation of 6,785 feet about 20 miles west of the western boundary of the LCR Basin. It is situated near Grand Canyon Village in the south rim US Park Service complex, and is maintained by Park Service personnel. The station record is included in this study to provide interpolation of missing records from nearby LCR stations and to enable accurate isohyetal maps. The period of record is almost continuous since 1904, with 1909 to 1912 mostly missing except for one or two months per year.

As summarized in Sellars and Hill (1974, p. 240):

"The Grand Canyon National Park is located in northern Arizona about 55 miles north of Williams. Formed by erosive action of the waters of the swift flowing Colorado River, it contains some of the most spectacular scenery to be found in the world. At many points along its 200 mile length the canyon reaches a depth of more than one mile and a width of more than ten miles. The Colorado River, following an irregular course through the Park at an average elevation of about 2,500 feet, is barely discernable from the canyon rim 5,000 feet above. The Grand Canyon separates the broad, flat Coconino Plateauto the south from the unspoiled wilderness of the Kaibab Plateau to the north. Both plateaus are forested, the Kaibab containing one of the most magnificent and homogeneous stands of ponderosa pines in the United States. In general, the north rim of the Grand Canyon is about 20 miles north of the Colorado River. While verdant forests and meadows bound the Grand Canyon to the north and south, and to a lesser extent to the west, the country to the east, in the valley of the Little Colorado River consists of little more than barren desert wastelands. But even here a hint of grandeur is added by the colorful Painted Desert.

"The Grand Canyon has many climates, depending mainly on the elevation. Average annual precipitation varies from more than 25 inches along the forested north rim (8,400 feet) to less than 10 inches on the desert-like canyon floor (2,500 feet). Intermediate amounts of about 14 inches per year are recorded along the south rim (6,900 feet). While the north rim normally receives quite a bit more precipitation in winter than in summer, the south rim and the canyon floor obtain about equal amounts during the two seasons. The spring and fall are relatively dry at all three locations. The summer precipitation usually falls from thunderstorms that form over the strongly heated canyon walls almost every afternoon from early July until the end of August. Although these storms are capable of producing locally heavy downpours, they rarely last longer than 30 minutes and usually cease completely shortly after sunset. In some years one or two days of almost continuous precipitation may occur during the summer when a weak tropical disturbance moves northward from the Pacific Ocean.

"Winter precipitation at the Grand Canyon is not as consistent as that of summer, varying greatly from one year to the next in both amount and frequency of occurrence. It is associated with middle latitude storms moving eastward from the Pacific Ocean and normally falls in gentle to moderate showers which may persist for several days. The most severe weather and abundant precipitation occur when these storms move directly into Arizona from the west after intensifying off the California coast. Practically all of the winter precipitation on the north and south rim of the Grand Canyon occurs as snow. An average annual accumulation of more than 125 inches on the Kaibab Plateau is sufficient to keep the road to the north rim blocked from early November until mid-May. Snowfall is rare on the canyon floor, averaging less than one inch per year."

Precipitation trends for the study period show a marked decrease from 1939 to 1946 and a slight decrease from 1947 to 1957. From 1958 to 1980, there is a modest increase, followed by a sharp increase from 1981 to 1988. From 1988 to 1990 there is an indication of the beginnings of a decrease in precipitation.

The histogram shows a slight lognormal distribution with flat kurtosis and a slight positive skewness. The monthly distribution shows a peak from July to October, with a broad secondary peak from December through March. May and June are the driest months.

Table 34. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Grand Canyon Ranger Station, Grand Canyon National Park, AZ
Station No.: 3596
Elevation: 6785
Latitude: 36d 03m
Longitude: 112d 09m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.66	0.34	1.67	1.64	1.22	1.30	0.97	0.43	0.00	1.55	0.49	8.64	18.91
1940	0.45	0.72	0.31	2.60	2.86	0.58	2.25	0.28	0.84	0.27	3.57	3.92	18.65
1941	1.58	1.05	2.89	2.34	3.67	2.75	3.11	0.89	0.89	0.96	2.11	1.76	24.00
1942	3.24	0.42	2.49	0.19	1.39	0.75	0.84	0.01	0.00	1.80	1.21	0.70	13.04
1943	0.34	0.49	1.96	2.14	0.85	1.52	0.58	0.00	0.00	1.24	2.43	1.03	12.58
1944	0.98	0.27	1.22	0.85	2.27	1.87	1.47	0.66	0.09	0.85	0.36	0.03	10.92
1945	0.45	1.31	0.70	0.68	1.36	2.56	0.46	0.06	0.03	1.10	2.19	0.19	11.09
1946	1.07	0.02	2.93	1.33	0.39	1.74	2.37	0.37	0.00	3.78	2.92	1.62	18.54
1947	1.52	1.91	0.75	0.34	0.25	0.30	0.33	0.77	0.21	1.22	3.22	0.14	10.96
1948	1.78	1.14	2.10	0.70	1.17	1.26	0.24	0.00	0.52	1.98	2.64	0.90	14.43
1949	1.72	0.05	2.33	4.14	1.17	0.80	0.06	0.70	0.99	1.27	1.78	3.65	18.66
1950	1.25	0.45	1.62	1.24	2.09	1.49	0.00	0.35	0.02	2.22	0.80	1.75	13.28
1951	0.12	0.11	0.08	1.02	0.92	0.87	0.86	0.55	0.00	0.67	3.84	1.25	10.29
1952	2.50	0.56	4.21	2.39	0.71	2.64	2.36	0.00	0.53	2.17	2.00	2.52	22.59
1953	0.00	1.46	1.04	0.87	0.31	0.76	0.91	0.03	0.40	2.81	3.56	0.00	12.15
1954	0.39	0.53	0.33	1.05	0.69	3.09	0.00	0.48	1.13	1.43	0.66	2.75	12.53
1955	0.36	0.17	0.70	1.72	1.60	0.31	0.38	0.12	2.54	1.38	2.09	0.05	11.42
1956	0.00	0.99	0.69	1.63	0.53	0.10	0.25	0.32	0.33	1.94	0.35	0.00	7.13
*1957	1.09	0.00	1.05	3.74	0.77	0.81	0.92	2.42	0.50	1.67	2.93	0.04	15.94
1958	3.33	2.46	1.02	0.60	1.97	3.28	0.86	1.30	0.00	0.17	2.93	3.85	21.77
*1959	0.70	0.80	0.23	0.29	2.29	0.00	1.81	0.16	0.81	0.58	1.54	1.13	10.34
1960	1.34	0.92	3.77	1.34	2.73	0.41	1.26	0.40	0.50	0.37	1.20	2.26	16.50
1961	3.74	0.58	1.37	0.76	0.30	2.70	0.63	0.14	0.00	1.64	4.18	1.44	17.48
1962	0.20	0.77	1.62	1.51	2.28	0.95	0.00	0.52	1.16	0.90	0.92	0.58	11.41
1963	1.36	0.39	0.86	0.42	1.58	0.74	1.09	0.16	0.00	0.41	5.96	1.79	14.76
1964	0.84	0.74	0.14	0.94	0.07	1.99	2.24	0.71	0.68	1.11	1.13	0.28	10.87
1965	0.00	0.79	1.52	1.62	1.55	1.91	3.23	3.00	0.61	0.74	0.40	1.99	17.36
1966	0.45	2.71	2.49	0.30	1.85	0.44	0.69	0.38	0.16	2.78	2.20	0.54	14.99
1967	1.42	1.31	5.40	1.05	0.00	0.40	0.44	0.78	0.74	2.00	1.51	2.68	17.73
1968	0.20	0.23	2.52	0.92	0.50	1.25	1.88	0.10	0.95	3.02	2.25	0.00	13.82
1969	0.50	0.84	1.27	3.83	2.70	0.88	0.28	0.80	0.33	1.95	1.71	1.74	16.83
1970	1.06	1.15	0.38	0.63	0.32	5.38	0.43	0.00	0.25	0.93	3.20	0.73	14.46
1971	0.26	1.02	0.86	0.02	1.48	0.19	0.18	0.55	0.10	1.08	3.21	0.00	8.95
1972	2.61	0.13	0.82	0.00	0.00	0.00	0.29	0.00	2.42	0.51	2.44	1.17	10.39
1973	6.09	1.36	2.36	2.26	1.93	3.37	1.49	0.50	1.33	0.82	0.71	0.27	22.49
1974	0.16	1.39	0.23	3.18	0.30	0.52	0.71	0.00	0.00	3.40	1.69	0.65	12.23
1975	2.15	0.80	1.09	1.25	1.01	3.06	1.13	0.16	0.02	2.61	0.87	0.81	14.96
1976	0.18	1.10	1.65	0.00	0.95	0.65	0.72	1.13	0.21	0.95	0.22	2.19	9.95
1977	0.12	0.00	0.00	1.03	0.00	0.67	0.47	0.91	1.09	2.34	1.40	0.48	8.51
1978	0.62	0.95	0.32	4.10	2.85	4.51	1.00	0.44	0.00	0.90	0.49	0.76	16.94
1979	1.11	5.26	3.87	2.96	1.70	3.55	0.26	1.82	0.60	0.66	1.38	0.00	23.17
1980	1.32	0.79	1.08	3.17	3.77	2.82	0.96	0.54	0.00	2.75	1.73	0.91	19.84
1981	1.96	0.03	0.68	0.52	0.85	2.73	1.07	1.07	0.73	3.76	3.25	3.16	19.81
1982	1.59	1.14	0.30	2.76	2.30	3.30	1.81	1.11	0.00	2.21	2.78	1.69	20.99
1983	0.96	3.77	2.82	1.40	2.52	2.87	1.15	0.16	0.00	4.58	1.78	2.69	24.70
*1984	0.92	2.08	1.87	0.24	0.40	1.02	0.61	0.03	0.84	3.26	3.52	0.46	15.25
1985	0.72	1.01	2.74	2.65	1.07	2.26	1.34	0.47	0.25	1.14	0.29	1.28	15.22
1986	0.81	4.03	0.37	0.24	1.64	1.96	1.79	0.79	0.40	0.57	1.58	1.28	15.46
1987	1.95	1.43	1.52	0.96	1.61	1.80	0.57	1.14	1.41	1.84	3.01	0.65	17.89
1988	2.45	1.74	1.34	1.78	1.67	0.14	3.19	0.42	2.25	0.47	2.89	0.22	18.56
*1989	0.56	2.00	0.78	1.65	0.67	0.98	0.03	0.47	0.00	0.34	4.37	0.10	11.95
*1990	0.50	0.00	0.08	1.46	2.48	1.04	2.28	0.43	0.22	1.00	2.33	3.16	14.98
1939-90 Average	1.19	1.07	1.47	1.47	1.38	1.60	1.04	0.56	0.52	1.58	2.08	1.38	15.34

* Denotes year in which one or more monthly records are reconstructed.

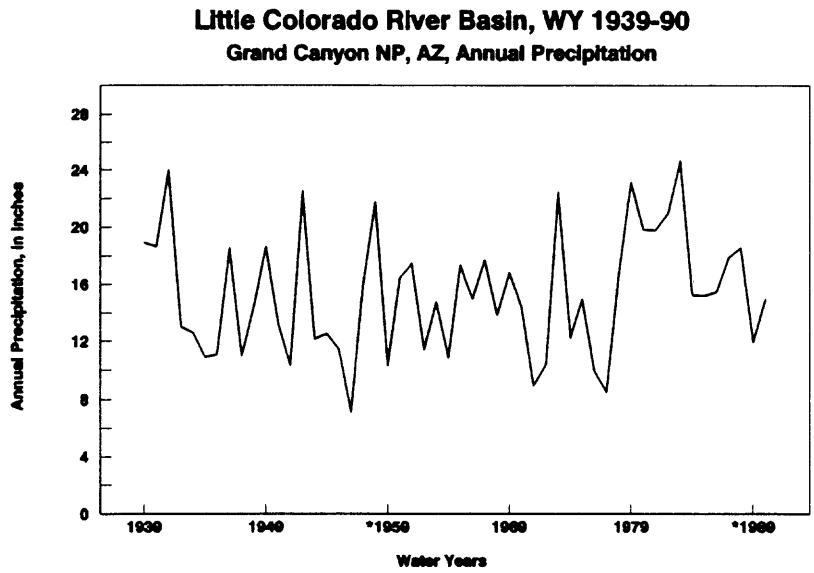


Figure 115. Grand Canyon RS, AZ, Annual Precipitation, WY 1939-90

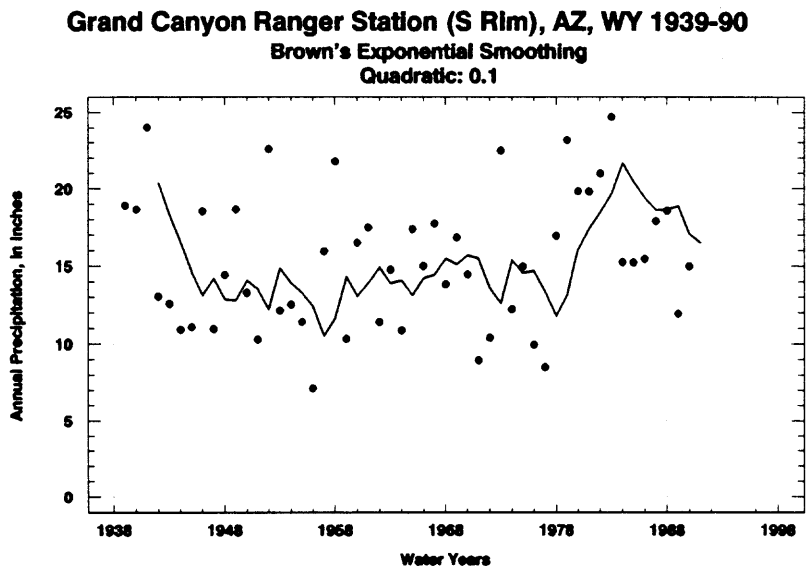


Figure 116. Grand Canyon RS, AZ, Smoothed Annual Precipitation, WY 1939-90

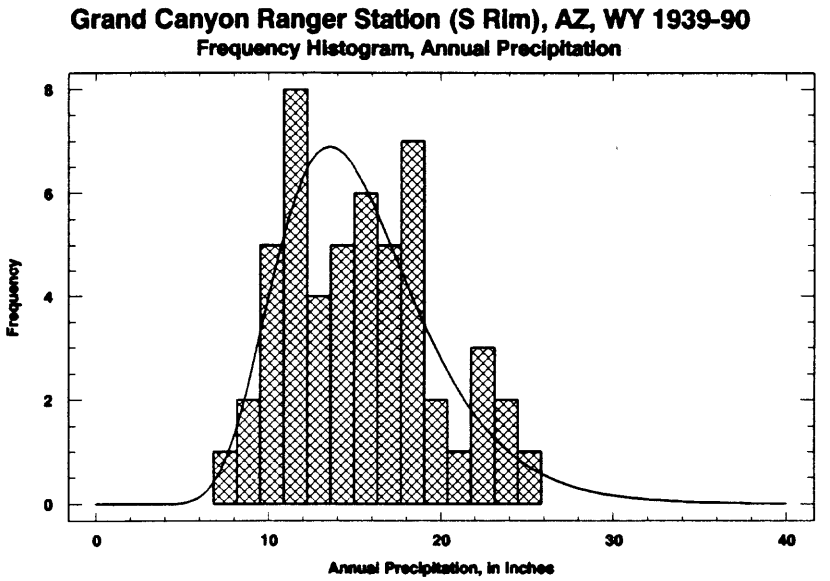


Figure 117. Grand Canyon RS, AZ, Histogram of Annual Precipitation

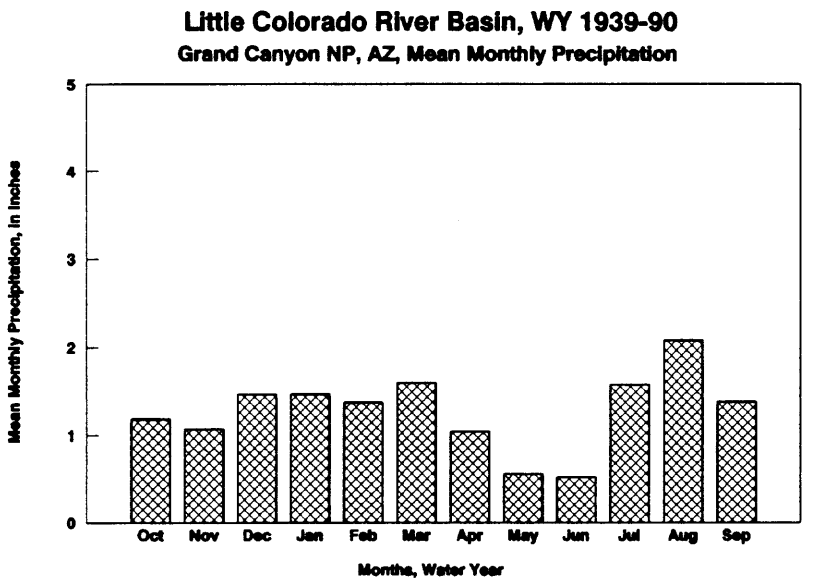


Figure 118. Grand Canyon RS, AZ, Monthly Distribution of Precipitation

6.2.3.22 Greer, AZ

Greer is located at an elevation of 8,491 feet about 25 miles southwest of Springerville, near the southernmost extent of the LCR Basin. It is situated in a heavily forested area, with ponderosa pine and spruce predominating. The period of record for the station is from 1904 to 1910, 1913 to 1927, and 1947 to the present. Winter data is mostly missing from 1947 to 1956. The record for the study period is largely reconstructed for the winter.

The precipitation trends for the study period indicate a slight decline from 1939 to 1959, a sharp increase from 1960 to 1965, and a gradual decline from 1966 to 1986. There is a sharp increase from 1987 to 1989, followed by what may be a decline from 1989 to 1990.

The histogram shows an irregular lognormal distribution with narrow kurtosis and an elongated positive skewness. The monthly distribution indicates a sharp peak from July through September, with a secondary peak from December through March. May and June are relatively dry. However, this cool high altitude station at nearly 24 inches average annual precipitation is one of the wettest in the LCR Basin. Most, if not all, of the winter precipitation falls as snow. Snowmelt from this region of the Basin accounts for much of the spring peak of Little Colorado River flows.

Table 35. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Greer, AZ
Station No.: 3683
Elevation: 8491
Latitude: 34d 01m
Longitude: 109d 28m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.11	0.17	2.81	2.79	1.58	1.36	2.03	0.07	0.01	1.78	3.11	3.64	19.44
*1940	0.69	1.21	0.98	0.99	2.55	0.69	1.14	1.04	0.74	2.06	4.00	5.39	21.46
*1941	1.57	1.78	2.65	2.18	2.81	3.64	2.62	1.00	0.97	2.67	3.49	3.99	29.37
*1942	2.19	1.89	2.63	1.49	2.03	1.13	1.29	0.03	0.02	1.88	2.61	1.55	18.73
*1943	3.04	0.12	2.76	3.10	1.16	2.13	0.56	0.66	0.81	1.74	5.49	2.04	23.60
*1944	1.87	0.07	1.55	0.97	2.30	1.77	1.09	0.53	0.23	2.66	3.02	3.37	19.42
*1945	1.26	2.07	1.66	1.45	0.80	3.29	0.46	0.09	0.23	3.11	4.32	0.73	19.47
*1946	1.89	0.07	2.74	1.99	0.59	1.14	1.46	0.07	0.31	3.67	5.26	4.70	23.90
*1947	1.29	2.14	1.59	0.83	0.57	0.28	0.25	1.34	0.44	2.84	5.22	2.41	19.21
*1948	2.52	1.48	1.61	0.66	3.15	0.15	0.15	0.00	0.78	4.53	3.07	1.01	19.12
*1949	1.55	0.61	2.47	4.17	0.99	0.99	0.70	0.43	0.46	3.09	3.79	3.42	22.66
*1950	1.98	0.16	2.34	1.18	1.10	1.21	0.00	0.18	0.62	7.08	1.72	1.54	19.11
*1951	0.54	0.11	0.11	1.95	1.08	1.36	2.00	0.00	0.00	4.27	5.15	0.79	17.37
*1952	2.33	0.84	4.45	4.93	0.73	3.43	2.60	0.18	1.13	2.95	3.14	1.05	27.78
*1953	0.00	2.53	1.21	0.62	0.87	2.43	0.71	0.30	0.90	6.45	2.80	0.14	18.97
*1954	0.53	1.00	0.94	1.48	0.65	5.37	0.00	1.03	0.25	3.60	1.28	2.40	18.54
*1955	0.99	0.20	0.78	2.70	1.23	0.15	0.28	0.66	1.09	7.80	5.60	0.53	22.01
*1956	1.81	1.37	1.64	1.96	2.96	0.09	1.68	0.57	1.02	5.72	2.73	0.32	21.87
1957	1.50	0.10	0.20	4.73	0.87	2.33	1.60	1.29	1.88	3.21	8.90	0.28	26.89
1958	3.70	1.47	0.30	1.03	4.54	3.30	2.66	0.55	1.49	3.00	5.91	4.41	32.36
1959	1.78	1.07	0.26	1.33	2.37	0.17	1.32	0.00	1.50	5.24	5.98	0.33	21.35
1960	5.93	0.68	5.60	3.83	1.94	0.81	0.80	0.85	0.68	1.92	2.40	1.60	27.04
1961	3.43	0.28	3.24	0.79	1.19	2.50	1.20	0.04	0.59	3.09	3.23	1.91	21.49
1962	4.48	2.61	6.78	5.68	3.63	3.82	0.19	0.28	1.00	3.08	0.94	4.39	36.88
1963	2.55	1.69	1.68	2.81	0.25	1.17	0.59	0.00	0.06	2.67	7.24	3.48	24.19
1964	2.39	1.48	0.25	0.93	0.75	1.09	1.15	0.30	0.60	6.39	5.29	5.71	26.33
1965	0.48	2.30	1.68	3.24	1.67	0.65	0.91	0.31	1.59	6.58	3.36	2.17	24.94
1966	0.63	1.92	6.16	1.06	1.60	0.95	0.59	0.00	1.43	4.38	3.80	2.07	24.59
1967	0.33	1.49	1.45	0.46	0.28	1.76	0.40	0.50	1.89	6.78	4.68	3.42	23.44
1968	0.53	1.00	7.07	0.49	0.85	1.12	0.68	0.43	0.22	3.58	6.74	0.51	23.22
1969	0.35	1.14	3.45	1.79	1.44	2.16	0.37	1.13	0.24	6.65	6.57	2.29	27.58
1970	2.11	1.09	0.74	0.27	1.06	2.98	1.10	0.55	1.01	3.40	2.82	2.41	19.54
1971	2.24	0.12	0.85	0.66	1.10	0.43	0.82	0.25	0.00	1.71	5.35	4.69	18.22
1972	4.64	1.41	3.11	0.07	0.13	0.00	0.17	0.55	3.68	3.73	3.99	1.98	23.46
1973	7.20	1.34	2.28	2.08	2.28	3.61	1.13	2.77	1.10	4.80	1.49	0.16	30.24
1974	0.04	1.35	0.28	4.84	0.53	1.78	0.48	0.07	0.00	4.85	3.14	1.82	19.18
1975	4.95	2.10	0.61	2.22	1.59	2.59	1.66	0.79	0.03	3.73	2.94	5.05	28.26
1976	0.08	1.77	1.64	0.26	2.53	2.13	0.81	2.13	0.13	6.17	1.98	1.49	21.12
1977	0.98	0.62	0.04	1.27	0.75	1.79	0.86	0.12	0.86	4.69	3.77	2.00	17.75
1978	2.15	0.95	0.48	1.14	1.96	2.12	0.53	1.60	0.00	2.23	3.95	1.38	18.49
1979	1.54	5.51	3.96	4.49	1.77	2.75	1.13	2.51	0.75	1.95	3.69	0.84	30.89
1980	0.75	0.36	1.30	2.93	3.87	1.79	1.00	0.01	0.18	3.58	1.72	1.73	19.22
1981	0.86	0.23	0.67	0.35	0.81	3.64	0.56	1.41	1.37	3.24	2.72	3.20	19.06
1982	1.31	0.95	0.08	2.97	1.69	2.01	0.07	0.27	0.25	5.17	3.79	1.00	19.56
*1983	0.06	3.02	3.58	1.97	1.80	3.34	1.58	0.80	0.77	6.09	7.43	6.26	36.70
1984	3.94	1.23	1.65	0.76	0.07	0.84	1.37	0.40	1.51	2.20	5.14	4.76	23.87
1985	3.14	0.71	5.89	2.05	1.44	1.83	2.34	0.76	1.02	5.07	5.01	5.00	34.26
*1986	2.80	2.80	0.56	0.28	2.03	0.95	1.76	0.67	3.26	6.04	6.61	3.19	30.95
1987	3.60	4.22	1.48	1.86	2.09	1.14	1.28	1.56	2.97	4.36	10.76	1.89	37.21
*1988	3.25	2.93	2.81	1.17	0.92	0.12	2.79	0.10	2.92	3.36	6.04	1.38	27.79
1989	1.82	0.81	1.59	0.24	0.80	0.77	0.35	0.87	0.48	4.33	1.89	4.22	18.17
*1990	0.59	2.43	3.81	0.79	1.58	1.10	0.89	0.94	0.24	4.70	4.30	4.73	26.10
1939-90 Average	1.97	1.37	2.12	1.85	1.53	1.73	1.04	0.63	0.88	4.04	4.22	2.51	23.89

* Denotes year in which one or more monthly records are reconstructed.

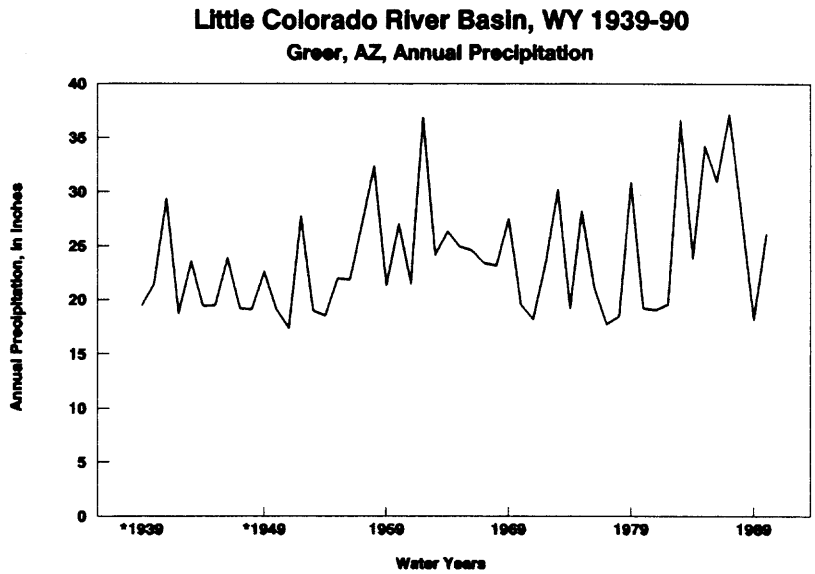


Figure 119. Greer, AZ, Annual Precipitation, WY 1939-90

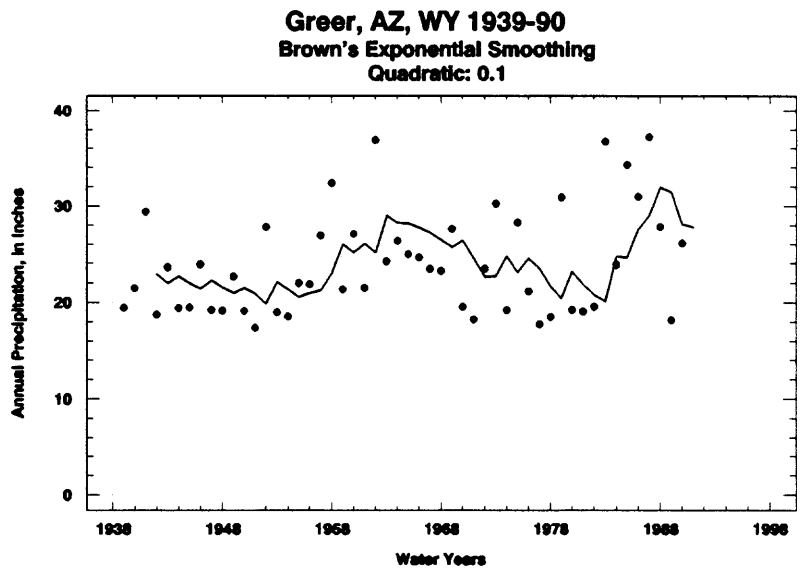


Figure 120. Greer, AZ, Smoothed Annual Precipitation, WY 1939-90

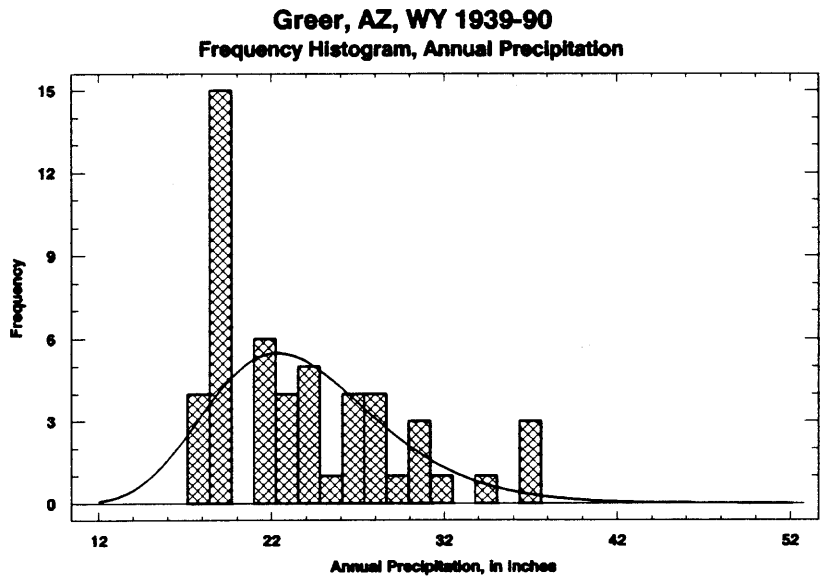


Figure 121. Greer, AZ, Histogram of Annual Precipitation

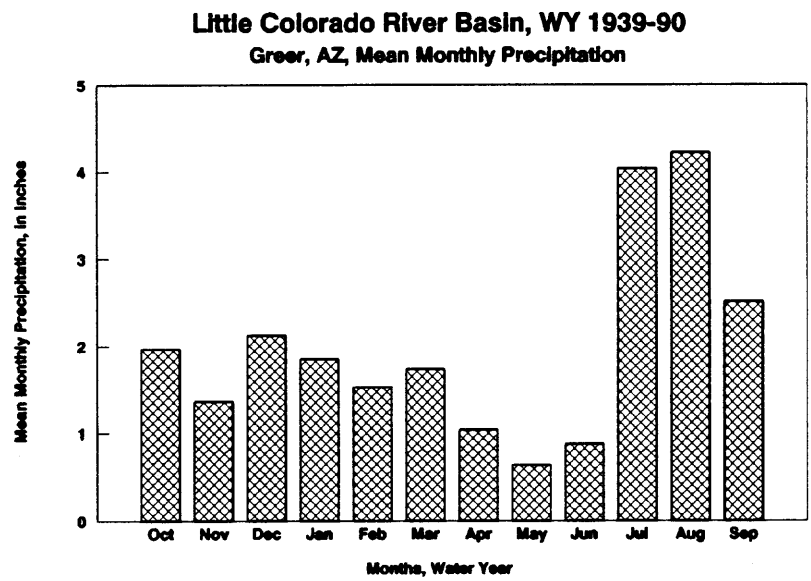


Figure 122. Greer, AZ, Monthly Distribution of Precipitation

6.2.3.23 Heber Ranger Station, AZ

Heber Ranger station is located about 35 miles west-southwest of the town of Snowflake near the southwest edge of the LCR Basin. The period of record is from 1915 to 1922, from 1925 to 1931, and from 1948 to the present. The period of 1939 to 1948 is reconstructed.

As summarized in Sellars and Hill (1974, p. 256):

"The Heber Ranger Station, at an elevation of 6,590 feet, is located three and one-half miles southeast of [the community of] Heber in east-central Arizona. It lies in the Sitgreaves National Forest which beautifies the Mogollon Plateau with dense stands of ponderosa pine. The generally flat terrain slopes very gradually downward to the Little Colorado River which follows a winding westward course, 38 miles to the northeast. Numerous creeks and washes are located in the Sitgreaves National Forest, originating in the higher elevations of extensive Mogollon Mesa to the west. Elevations along this generally east-west oriented mesa are about 7,500 feet, with Promintory Butte rising to 7,915 feet, 28 miles to the west-southwest. The Mogollon Rim concides with the northern boundary of the Fort Apache [White Mountain Apache] Indian Reservation. Before emptying into Roosevelt Lake at a point 58 miles to the southwest, the Salt River flows through the Reservation at about 5,000 feet. The vegetation at lower elevations to the north is dominated first by juniper and pinyon between 6,100 and 5,800 feet and then by plains grass at 5,100 feet, with sagebrush prevailing in the valley of the Little Colorado River. To the south the pine forests yield to juniper and mesquite at lower elevations, while cacti and palo verde are found in the river valleys.

"Although less precipitation falls at the Heber Ranger Station than in more rugged areas on the Mogollon Plateau to the south and west, an average of slightly more than seventeen inches are measured annually. About forty-five percent of this falls during the summer monsoon season, largely associated with thunderstorms that form in the northward flow of moist tropical air from the Gulf of Mexico. These storms often produce several showers in a single day, usually in the late afternoons and early evenings. Some of the heaviest summer precipitation at the Heber Ranger Station results from tropical disturbances that produce widespread rains. This was the case on August 28, 1951 when 4.35 inches fell from a dissipating hurricane that entered the Pacific Ocean and moved northward after traversing the Mexican mainland.

"Winter precipitation at the Heber Ranger Station is normally not as intense, although of longer duration, than that of the warm season. The wettest month on record, however, was December 1967 with 91.5 inches of snow. The major storm systems contributing most of the precipitation originate in the north Pacific Ocean adn follow an eastward track. Unfortunately, much of the moisture associated with these cold storms is lost on the windward slope of the Mogollon Plateau, curtailing the potential winter precipitation at Heber Ranger Station. Most of this precipitation falls in the form of snow, with considerable amounts accumulating on the plateau ground until the spring thaw."

The precipitation trends for the 1939-90 study period show a gradual increase throughout the period with no dramatic peaks.

The histogram shows a lognormal distribution with sharp kurtosis centered about 17 and 19 inches. There is a noticeable positive skewness to the distribution. The monthly distribution shows a sharp peak in July and August, with a broad secondary winter crest from September through March. The dry period is in April through June.

Table 36. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Heber Ranger Station, AZ
Station No.: 3961
Elevation: 6590
Latitude: 34d 24m
Longitude: 110d 33m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.25	0.09	1.86	2.20	1.15	1.24	1.13	0.03	0.14	0.76	2.27	2.81	13.94
*1940	0.56	1.07	0.62	0.78	1.59	0.46	1.31	0.40	1.46	1.75	3.15	3.81	16.97
*1941	2.51	1.29	2.16	1.73	1.51	2.72	2.24	1.09	0.93	2.53	3.38	2.76	24.83
*1942	2.01	1.54	1.90	0.99	1.63	0.51	1.54	0.00	0.01	1.24	2.16	1.17	14.69
*1943	2.94	0.20	1.70	1.60	0.72	1.52	0.38	0.26	0.15	0.81	2.90	1.88	15.06
*1944	1.17	0.02	1.79	0.72	2.54	1.74	1.56	0.51	0.01	1.41	2.47	2.14	16.09
*1945	0.44	1.28	1.40	1.02	0.58	2.06	0.36	0.08	0.22	3.02	2.95	0.44	13.84
*1946	1.05	0.04	1.90	1.42	0.52	1.04	1.20	0.01	0.03	3.03	3.67	3.81	17.72
*1947	0.85	1.91	1.25	0.54	0.37	0.16	0.09	1.83	0.08	1.71	5.19	1.66	15.64
*1948	3.36	1.88	1.43	0.58	0.60	1.10	0.09	0.72	0.00	0.61	2.35	0.88	13.60
1949	1.12	0.00	2.27	3.54	1.18	0.23	0.53	0.28	2.19	4.14	2.03	3.05	20.56
1950	1.08	0.00	2.17	0.23	0.88	0.74	0.00	0.30	0.25	3.00	0.82	1.43	10.90
*1951	0.00	0.38	0.05	1.88	1.18	0.88	1.28	0.81	0.00	2.46	7.87	1.52	18.31
1952	1.75	1.11	3.71	3.69	0.28	2.89	2.09	0.03	0.54	1.55	2.78	1.95	22.37
1953	0.00	3.23	0.84	0.42	0.97	1.48	1.05	0.12	0.02	6.22	1.40	0.00	15.75
1954	0.06	0.64	1.13	1.10	0.48	3.05	0.00	1.46	0.61	3.54	1.98	2.07	16.12
1955	0.45	0.03	0.56	1.07	0.24	0.04	0.35	0.17	2.15	2.87	3.80	0.18	11.91
1956	0.38	1.08	0.78	1.14	2.06	0.04	1.26	0.60	0.27	4.20	1.24	0.00	13.05
1957	1.09	0.81	0.18	5.48	0.28	1.01	0.40	1.23	1.16	1.64	2.51	0.02	15.81
1958	2.38	0.77	0.29	0.68	1.75	2.24	1.61	0.31	0.57	0.99	2.10	5.32	19.01
*1959	1.17	1.05	0.12	0.62	1.84	0.00	0.81	0.08	1.05	2.57	5.67	0.70	15.68
1960	6.82	0.69	3.37	1.78	0.84	1.16	0.27	0.50	0.03	0.09	1.54	1.00	18.09
1961	3.45	0.36	1.40	0.23	0.48	1.87	0.11	0.04	0.39	3.42	3.31	2.11	17.17
1962	2.13	0.91	1.14	2.19	1.43	1.15	0.05	0.23	0.23	1.48	0.90	4.58	16.42
1963	1.96	1.21	0.60	0.73	0.63	0.67	0.53	0.01	0.01	1.98	8.06	2.49	18.88
1964	1.54	1.18	1.39	0.85	0.88	1.38	1.11	0.00	0.25	2.90	2.87	4.28	18.63
1965	0.15	1.34	1.64	2.35	1.13	0.53	1.67	0.43	0.40	2.66	2.24	1.33	15.87
1966	0.88	2.16	5.99	1.68	1.20	0.38	0.20	0.00	0.92	4.31	2.07	1.55	21.34
1967	1.27	1.40	2.49	0.43	0.00	1.31	0.55	0.45	0.45	6.80	3.05	1.25	19.45
1968	0.15	1.03	9.04	0.83	0.85	1.18	1.19	0.34	0.11	3.13	1.50	0.16	19.51
1969	1.27	0.95	1.86	1.21	1.26	1.02	0.17	2.37	0.00	3.39	2.42	1.64	17.56
1970	1.70	1.85	1.47	0.18	0.83	1.27	1.07	0.12	0.03	1.63	3.17	4.06	17.38
1971	1.13	0.30	1.05	0.32	0.42	0.38	0.44	0.08	0.00	3.39	6.11	3.60	17.22
1972	3.80	0.61	2.97	0.06	0.00	0.00	0.00	0.58	2.14	3.50	1.99	1.28	16.93
1973	7.42	1.84	2.13	0.60	3.94	3.79	1.29	1.97	0.24	2.03	1.93	0.00	27.18
1974	0.01	1.70	0.00	3.64	0.20	0.79	0.30	0.00	0.00	1.66	1.47	2.33	12.10
1975	3.41	0.48	0.74	0.75	2.63	2.42	1.51	0.15	0.00	2.91	1.13	2.51	18.64
1976	0.30	2.05	1.27	0.13	2.80	1.49	1.19	1.77	0.14	2.94	0.81	3.51	18.40
1977	1.08	0.60	0.10	1.37	0.90	0.99	1.67	0.46	0.65	2.62	2.59	4.07	17.10
1978	1.62	0.39	0.40	2.13	2.52	4.26	0.54	0.97	0.00	4.19	3.44	1.31	21.77
1979	1.64	4.96	3.64	3.01	0.56	2.52	0.15	3.11	0.71	1.59	1.67	0.47	24.03
1980	1.15	0.57	1.14	3.83	3.65	2.90	0.45	0.30	0.06	3.73	3.53	1.75	23.06
1981	0.90	0.00	0.99	0.86	0.62	2.13	0.87	0.89	0.76	2.40	3.56	0.45	14.43
1982	2.00	1.99	0.00	2.57	3.85	1.75	0.02	1.49	0.02	1.78	2.46	1.42	19.35
1983	0.12	3.03	3.83	0.77	1.09	1.92	0.78	0.42	0.01	3.20	1.33	5.31	21.81
1984	1.48	2.71	1.22	0.36	0.00	1.07	0.61	0.05	0.33	4.21	3.01	2.23	17.28
1985	2.61	0.63	3.59	1.60	0.80	1.36	1.35	0.17	0.14	1.39	1.96	3.53	19.13
1986	1.98	3.02	0.75	0.07	2.05	1.23	0.04	0.21	0.53	3.31	5.32	1.47	19.98
1987	0.83	2.75	1.20	1.36	2.30	0.73	0.00	0.86	0.21	4.25	2.38	0.23	17.10
1988	1.55	2.43	1.04	2.78	1.39	0.00	1.26	0.09	2.67	5.27	6.23	1.34	26.05
1989	0.11	0.00	1.80	1.46	0.28	2.42	0.02	0.06	0.00	3.52	3.67	0.30	13.64
1990	1.55	0.05	0.23	0.46	1.64	0.52	0.57	0.41	0.00	4.03	6.73	2.51	18.70
1939-90 Average	1.55	1.18	1.67	1.39	1.22	1.34	0.76	0.55	0.45	2.76	2.98	1.96	17.81

* Denotes year in which one or more monthly records are reconstructed.

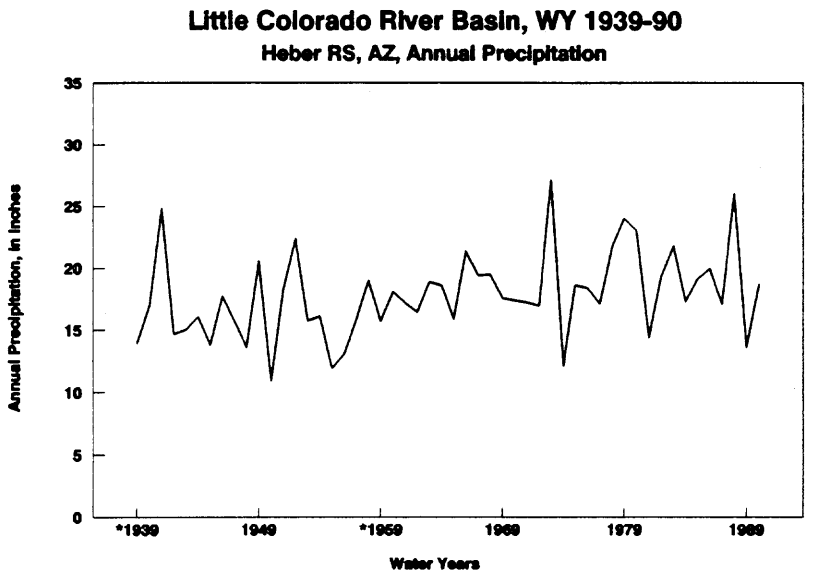


Figure 123. Heber RS, AZ, Annual Precipitation, WY 1939-90

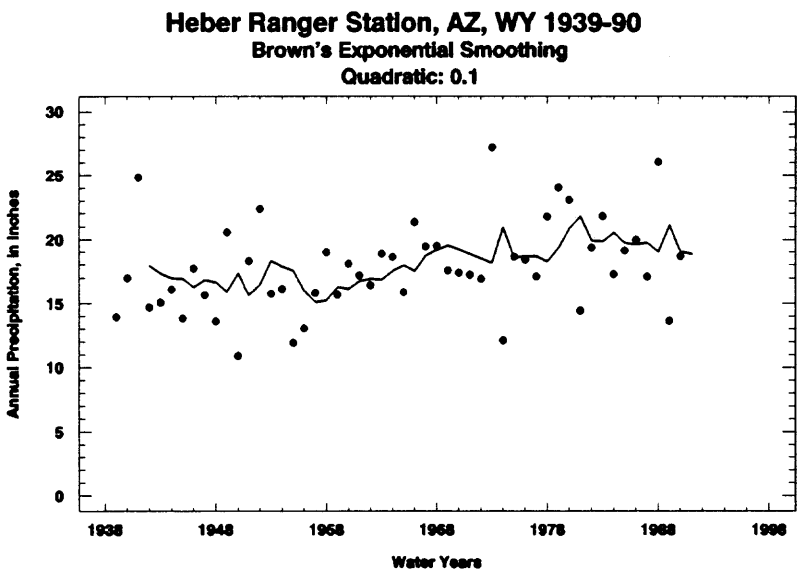


Figure 124. Heber RS, AZ, Smoothed Annual Precipitation, WY 1939-90

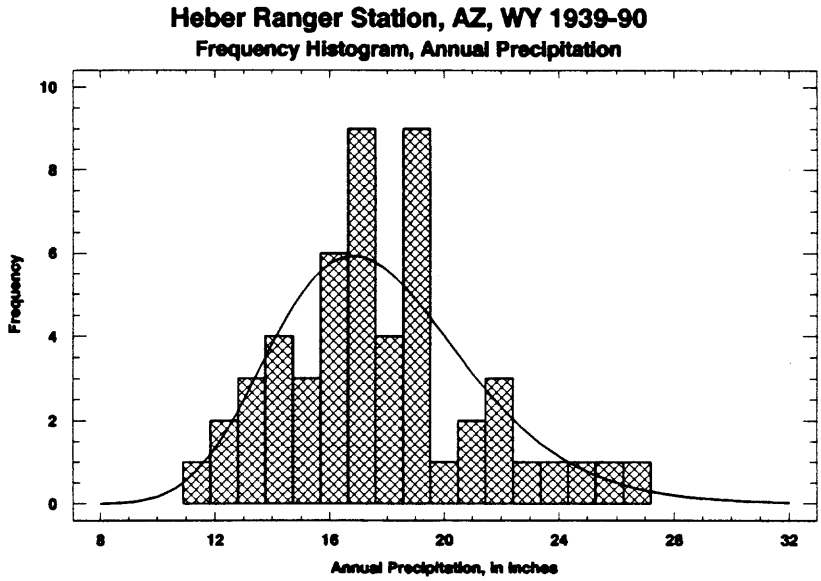


Figure 125. Heber RS, AZ, Histogram of Annual Precipitation

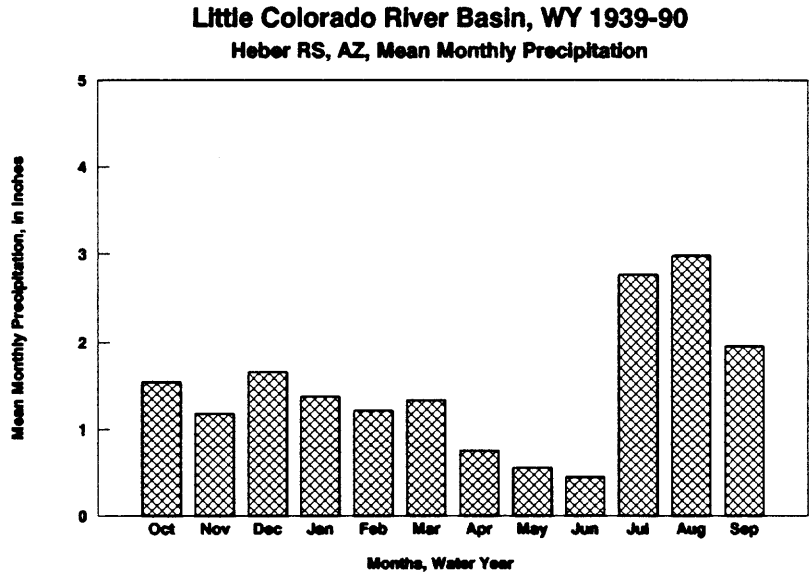


Figure 126. Heber RS, AZ, Monthly Distribution of Precipitation

6.2.3.24 Holbrook, AZ

The City of Holbrook is located about 90 miles east of Flagstaff along Interstate Highway 40. Its period of record spans from 1888 to 1900 and from 1904 to the present. Thus, Holbrook is one of the longer-term stations in the LCR Basin.

As summarized in Sellars and Hill (1974, p. 264):

> "Holbrook is located on the Little Colorado River in east-central Arizona at an elevation of about 5,100 feet. The river valley is flanked by bluffs and mesas so that the surrounding terrain is about 200 to 300 feet higher than the town in all directions except along the river, which follows an east-west course in the vicinity of the town. One of the most colorful sections of the Painted Desert lies along U.S. 66 [Interstate 40] about twenty miles to the northeast of town. The famous Petrified Forest National Monument [Park] is located about twenty miles east of Holbrook. The White Mountain area about 75 miles to the south-southwest reaches elevations of better than 11,000 feet. About the same distance to the southwest, The Mogollon Rim averages close to 7,000 feet, while about ninety miles to the west-northwest, the San Francisco Peaks rise to 12,655 feet.
>
> "The high terrain to the west and south has considerable effect on the climate in the Holbrook area, making it dry and relatively mild for the latitude and elevation. Holbrook receives about the same amount of annual precipitation as the flat desert areas of south-central Arizona. Nearly one-half of this precipitation occurs during the thunderstorm season in July, August, and September, when moist air moves northwestward over the state from the Gulf of Mexico. The winter precipitation maximum, which is quite evident over much of the rest of the state, is almost entirely lacking at Holbrook, because winter storms from the Pacific Ocean lose much of their moisture over the high mountainous terrain to the south and west.
>
> "Because winter precipitation is light, the average annual snowfall is only about five inches, and snow seldom stays on the ground for long because of the normally warm daytime temperatures. The heaviest fall, 21.5 inches, occurred during a prolonged winter storm in December, 1967."

The precipitation trends indicate an essentially flat tendency from 1939 until 1986. From 1986 to 1988 there was a sharp increase, followed by what may be a decline to 1990.

The histogram shows an irregular lognormal distribution, with peaks at 6, 9, and 10 inches and a dip at 7 and 8 inches. There is a definite positive skewness. The monthly distribution shows a peak in July through October, with a sustained dry period from November through June.

Table 37. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Holbrook
Station No.: 4089
Elevation: 5070
Latitude: 34d 54m
Longitude: 110d 10m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.00	0.00	0.23	0.76	0.28	0.82	0.70	0.00	0.00	0.22	0.50	0.87	4.38
1940	0.10	0.69	0.33	0.22	0.23	0.01	0.58	0.00	1.46	1.45	1.43	3.66	10.16
1941	0.70	0.54	1.49	1.24	0.63	1.59	1.02	0.87	0.23	1.19	2.04	1.68	13.22
1942	1.61	0.35	0.62	0.45	0.53	0.00	0.45	0.00	0.00	0.00	0.34	0.55	4.90
1943	0.27	0.22	0.26	0.60	0.45	0.87	0.00	0.22	0.00	0.00	1.49	1.61	5.99
1944	0.06	0.00	0.33	0.19	0.66	0.99	1.02	0.31	0.00	0.56	0.64	0.99	5.75
1945	0.08	0.46	0.60	0.45	0.22	0.51	0.05	0.06	0.06	1.95	0.50	0.09	5.03
1946	0.22	0.00	0.78	0.61	0.11	0.48	0.45	0.00	0.00	1.67	1.86	2.16	8.34
1947	0.00	0.45	0.14	0.14	0.00	0.00	0.00	0.75	0.03	0.31	4.37	0.57	6.76
1948	2.73	0.41	0.41	0.15	0.53	0.75	0.03	0.06	0.16	1.58	1.77	0.53	9.11
1949	0.84	0.00	0.47	0.51	0.53	0.29	0.17	0.90	0.91	2.01	1.11	1.27	9.01
1950	0.48	0.20	0.37	0.22	1.02	0.10	0.00	0.00	0.31	0.81	0.52	0.40	4.43
1951	0.00	0.00	0.08	0.78	0.26	0.25	0.81	0.10	0.00	0.24	2.39	0.46	5.37
1952	0.67	0.83	0.31	0.83	0.46	0.69	1.84	0.00	0.87	1.51	0.30	1.10	9.41
1953	0.00	2.13	0.08	0.00	0.06	0.38	0.83	0.05	0.23	3.08	1.16	0.00	8.00
1954	0.00	0.39	0.30	0.10	0.30	0.68	0.01	0.22	0.00	4.28	1.86	2.73	10.87
1955	0.37	0.17	0.55	0.30	0.26	0.21	0.03	0.19	1.84	0.81	1.42	0.40	6.55
1956	0.04	0.03	0.61	0.91	1.07	0.00	0.28	0.13	0.09	0.30	1.33	0.30	5.09
1957	0.17	0.21	0.00	0.75	0.25	0.51	0.20	0.56	0.45	0.82	4.70	0.02	8.64
1958	2.42	0.16	0.12	0.22	0.71	0.64	0.55	0.70	0.41	0.43	1.03	1.55	8.94
1959	0.14	0.18	0.05	0.15	0.31	0.00	0.57	0.03	0.41	1.63	1.31	0.39	5.17
1960	3.16	0.65	1.18	0.42	0.15	0.42	0.07	0.23	0.29	0.30	0.91	0.13	7.91
1961	2.14	0.03	0.79	0.17	0.14	0.74	0.00	0.10	0.01	0.49	1.17	0.76	6.54
1962	1.26	0.40	0.42	0.53	0.51	0.14	0.09	0.08	0.00	0.02	0.48	1.47	5.40
1963	0.51	1.04	0.16	0.52	1.06	0.10	0.28	0.00	0.00	0.06	4.40	0.88	9.01
1964	0.51	0.64	0.27	0.00	0.02	0.18	1.05	0.00	0.12	0.74	2.86	3.07	9.46
1965	0.00	0.56	0.54	1.03	0.14	0.66	0.12	0.44	0.47	2.08	1.14	0.89	8.07
1966	0.36	0.21	1.22	0.41	0.10	0.13	0.00	0.00	0.12	1.60	1.52	0.51	6.18
1967	0.96	0.37	0.27	0.00	0.00	0.06	0.03	0.45	0.41	1.85	4.19	0.81	9.40
1968	0.11	0.92	1.90	0.33	0.52	1.07	0.32	0.00	0.00	0.80	1.58	0.03	7.58
1969	1.38	0.43	0.62	0.20	0.19	0.94	0.00	1.22	0.00	1.35	1.28	0.35	7.96
1970	1.28	1.00	0.55	0.28	0.19	0.28	0.22	0.00	0.04	0.00	1.40	0.15	5.39
1971	0.04	0.00	0.00	0.05	0.20	0.00	0.04	0.04	0.00	0.00	1.28	2.10	3.75
1972	0.86	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.98	0.88	0.20	0.00	3.35
*1973	5.05	1.00	0.84	0.00	1.84	1.12	1.40	0.65	0.70	0.00	1.64	0.06	14.30
1974	0.00	0.87	0.00	1.04	0.04	0.13	0.00	0.00	0.00	1.76	0.42	0.77	5.03
1975	2.58	0.20	0.11	0.53	0.77	0.60	0.81	0.83	0.02	2.04	0.25	2.66	11.40
1976	0.00	0.65	0.79	0.12	0.44	0.20	0.19	1.47	0.06	3.67	0.24	1.51	9.34
1977	0.54	0.27	0.35	1.29	0.41	0.27	0.82	0.07	0.10	0.90	1.95	1.18	8.15
1978	0.92	0.34	0.15	1.12	0.82	1.64	0.00	0.85	0.05	0.49	0.36	0.60	7.34
*1979	1.63	1.59	0.72	0.98	0.00	0.27	0.17	2.20	0.00	0.00	1.24	0.04	8.84
*1980	0.75	0.84	0.97	1.72	2.66	0.96	0.46	0.03	0.00	0.17	1.20	0.90	10.66
1981	0.37	0.00	0.53	0.73	0.51	0.64	0.93	0.31	0.43	2.25	0.60	1.02	8.32
1982	0.51	1.70	0.00	0.35	0.43	0.27	0.28	0.37	0.00	0.17	3.09	1.22	8.39
1983	0.00	0.00	0.57	1.47	0.10	0.47	0.00	0.00	0.12	1.35	1.27	1.63	6.98
1984	0.91	0.44	1.60	0.00	0.00	1.38	0.00	0.02	0.15	3.40	4.15	3.93	15.98
1985	1.28	0.10	0.91	1.42	0.47	1.61	1.10	0.27	0.10	0.97	0.45	1.31	9.99
1986	1.97	0.91	0.23	0.19	1.08	1.27	0.09	0.14	0.35	1.16	0.66	1.12	9.17
1987	1.47	2.02	0.83	1.84	3.77	1.34	0.79	1.48	0.06	1.35	1.71	1.03	17.69
*1988	1.75	1.44	3.50	0.10	0.96	0.00	0.79	0.00	0.00	1.20	2.63	0.85	13.22
1989	0.44	0.68	0.22	0.68	0.31	0.87	0.00	0.06	0.22	0.86	2.45	0.13	6.92
1990	0.47	0.02	0.30	0.05	0.58	0.23	0.25	0.26	0.00	1.85	1.55	2.25	7.81
1939-90 Average	0.85	0.51	0.56	0.52	0.52	0.53	0.38	0.32	0.24	1.13	1.54	1.05	8.17

* Denotes year in which one or more monthly records are reconstructed.

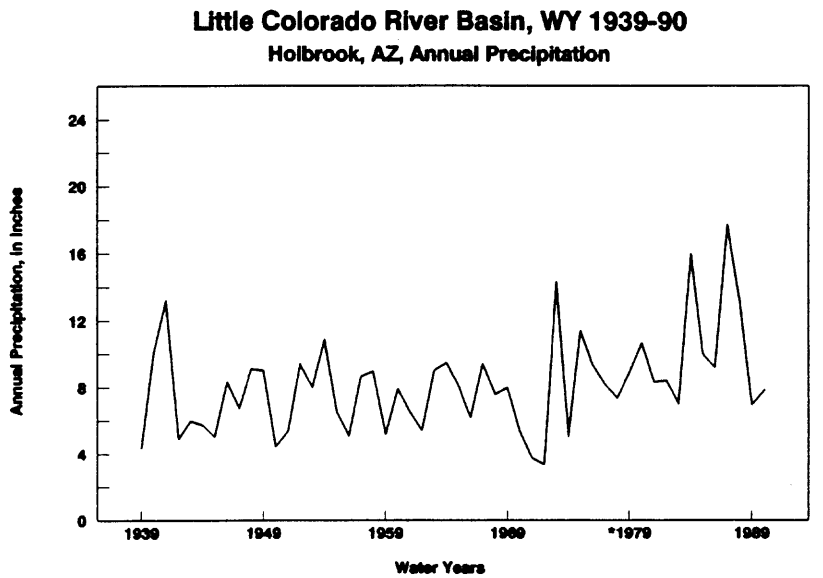


Figure 127. Holbrook, AZ, Annual Precipitation, WY 1939-90

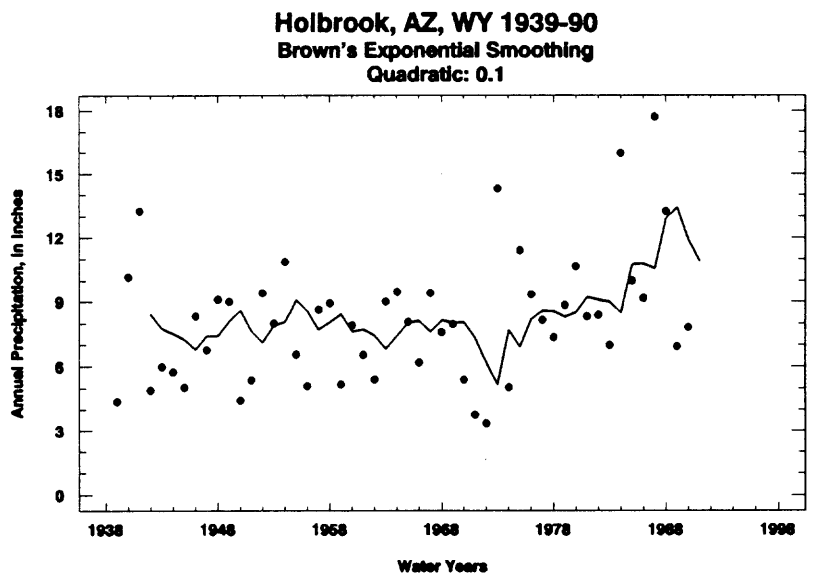


Figure 128. Holbrook, AZ, Smoothed Annual Precipitation, WY 1939-90

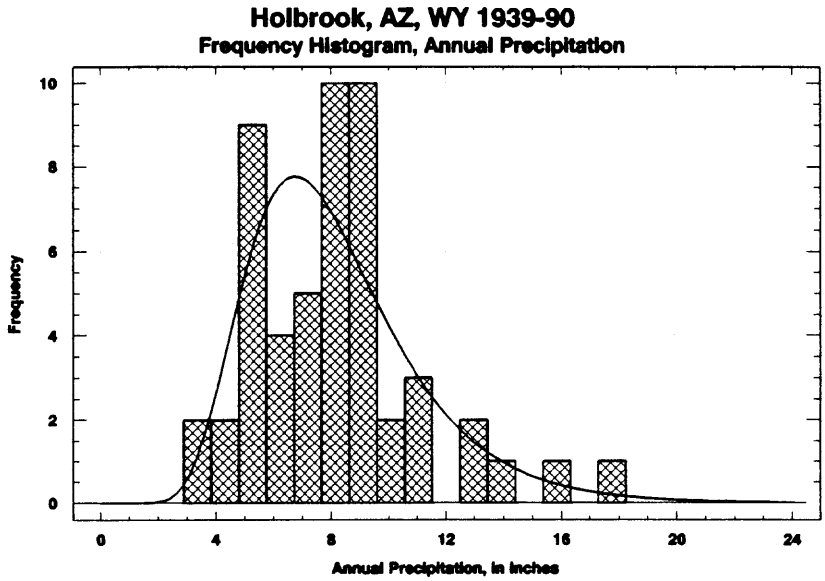


Figure 129. Holbrook, AZ, Histogram of Annual Precipitation

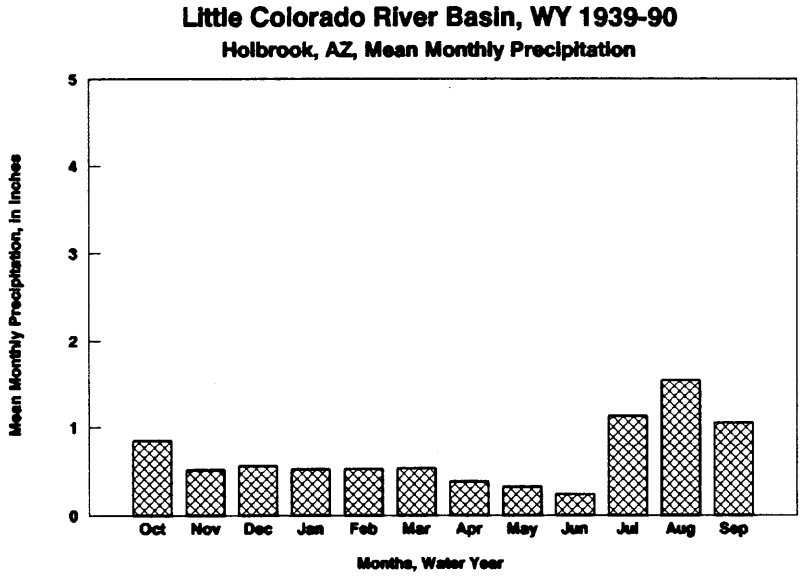


Figure 130. Holbrook, AZ, Monthly Distribution of Precipitation

6.2.3.25 Jeddito, AZ

Jeddito is located in a Navajo Indian Reservation enclave within the eastern portion of Hopi Partitioned Lands known as "Jeddito Island." The period of record is short, beginning in 1932 and ending in 1956. The missing record is reconstructed for the 1956-90 years in the 1939-90 study period.

As summarized in Sellars and Hill (1974, p. 272):

> "Jeddito lies at an elevation of 6,700 feet in northeastern Arizona just north of the Navajo Indian Reservation (sic). It is located less than a mile west of Jeddito Wash which originates at slightly higher elelvations to the northwest. The terrain slopes very gently downward toward the west-northwest for fifty miles onto the Moenkopi Plateau. Southwest of this plateau lies the famous Painted Desert, containing a portion of the most spectacular display of petrified wood in the world. Sixty miles to the southwest the Little Colorado River changes its course from west to north and is located only four miles southeast of Winslow at that point. Included among the numerous mesas in the area are Salahki Mesa at an elevation of 7,000 feet, eighteen miles to the northeast, Carson Mesa at 6,000 feet, forty miles to the north-northeast and Rock Mesa at 6,500 feet, forty miles to the northeast. The most famous sites in the area are the Petrified Forest National Monument [now Park], 50 miles to the south-southeast and Canyon de Chelly National Monument, featuring two brilliantly red-colored rock canyons, 52 miles to the northeast. The vegetation in the area is quite sparse, consisting mostly of plains grass. To the west and south the desert-like valley of the Little Colorado River is dominated by sagebrush. Quantities of pinyon and juniper dot a few northern sections of the Navajo Indian Reservation to the southwest.
>
> "Almost forty percent of Jeddito's annual precipitation of just under eleven inches [12.39 inches for the study period] is recorded during the summer months when moist, tropical air from the Gulf of Mexico rises over the high plateau regions of northeastern Arizona and widespread thunderstorms occur. The most intense warm season rains are associated with the occasional passage over northeastern Arizona of a weak tropical strom system that enters the state from the southwest. May and June are the driest months of the year receiving, respectively, .52 and .39 inches of rain [0.50 and 0.39 inches for the study period]. Relative to many of the locations in the south and southwestern sections of the state, these amounts are not especially low.
>
> "Eastward-moving middle latitude storms that originate in the north Pacific Ocean provide Jeddito with most of its winter precipitation, although amounts falling during these cold months are rather small. Normally, these cyclonic storms remain too far north to significantly affect the Jeddito region. However, when they follow a more southerly track and build up in the Pacific off the southern California coast, widespread precipitation may occur, intermittent for several days. The average 2.63 inches of cold season precipitation falls almost entirely in the form of snow."

Precipitation trends for the study period indicate a gradual decline from 1939 to 1968 and a gradual increase from 1968 to 1988. From 1989 to 1990 there are indications of a sharp decline.

The histogram shows a largely normal distribution with flat kurtosis and a slight positive skewness. The monthly distribution shows a sharp peak in July and August, followed by a gentle decline to the annual minimum in June.

Table 38. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Jeddito, AZ
Station No.: 4438
Elevation: 6700
Latitude: 35d 46m
Longitude: 110d 08m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.07	0.34	1.23	0.80	0.47	0.32	0.58	0.06	0.00	0.18	0.73	1.43	6.21
1940	0.30	0.79	0.39	1.31	1.64	0.77	1.05	0.38	0.07	0.47	2.10	2.91	12.18
1941	1.25	1.17	2.65	2.85	2.32	1.80	2.52	0.97	0.39	0.76	2.51	2.39	21.58
1942	2.75	0.78	1.47	0.26	1.10	0.74	1.90	0.00	0.00	0.46	2.44	0.81	12.71
1943	1.84	0.19	1.69	1.32	0.45	0.84	0.10	0.61	0.13	1.77	2.49	1.10	12.53
1944	0.93	0.12	1.24	0.90	1.39	0.75	1.32	1.26	0.06	0.48	0.50	2.25	11.20
1945	0.22	1.46	1.32	1.01	0.43	1.42	0.54	0.02	0.34	1.87	1.20	0.02	9.85
1946	0.82	0.00	2.13	0.52	0.22	1.27	0.35	0.54	0.03	0.44	2.61	1.23	10.16
1947	0.38	1.77	0.63	0.42	0.10	0.08	0.09	1.80	0.37	0.33	3.05	0.27	9.29
1948	2.65	1.36	1.03	0.32	1.60	1.90	0.53	0.12	1.07	0.10	0.56	1.10	12.34
1949	1.83	0.00	1.46	2.26	0.72	0.67	0.35	0.62	0.95	3.81	1.05	1.28	15.00
1950	1.17	0.30	0.69	0.54	0.89	0.36	0.00	0.14	0.40	1.25	0.23	0.55	6.52
1951	0.00	0.10	0.00	0.72	0.16	0.50	0.81	0.59	0.00	0.87	1.45	0.24	5.44
1952	0.87	0.87	1.22	1.36	0.55	1.46	2.08	0.00	0.62	1.97	1.97	1.60	14.57
1953	0.00	1.16	0.37	0.28	0.69	0.24	0.48	0.11	0.00	2.77	1.61	0.00	7.71
1954	0.26	0.31	0.30	0.23	0.37	1.58	0.05	0.61	0.00	2.79	0.95	0.38	7.83
*1955	1.14	0.00	0.03	1.14	0.92	0.05	0.19	0.39	1.44	1.97	3.46	0.00	10.74
*1956	0.00	0.69	0.86	1.40	0.73	0.10	0.62	0.45	0.24	2.05	1.56	0.14	8.83
*1957	0.73	0.06	0.23	3.19	0.85	0.96	0.79	1.70	0.84	1.50	3.54	0.00	14.39
*1958	2.34	1.09	0.35	0.34	1.44	1.70	0.94	0.42	0.25	0.69	2.39	1.69	13.63
*1959	1.14	0.00	0.03	1.14	0.92	0.05	0.19	0.39	1.44	1.97	3.46	0.00	10.74
*1960	2.04	0.61	2.30	0.66	0.95	0.39	0.25	0.46	0.44	0.57	1.05	0.48	10.20
*1961	2.90	0.41	0.96	0.59	0.35	1.63	0.27	0.13	0.07	1.57	2.75	1.26	12.89
*1962	1.79	0.89	1.47	1.21	1.16	0.70	0.08	0.19	0.48	0.59	0.50	1.95	11.02
*1963	1.69	1.41	0.37	0.55	0.66	0.21	0.44	0.00	0.03	0.52	5.78	1.34	12.99
*1964	0.74	0.63	0.45	0.25	0.26	1.35	1.35	0.08	0.17	2.55	2.85	1.92	12.60
*1965	0.02	1.09	1.30	1.55	1.19	0.92	1.17	1.17	0.70	2.71	1.15	1.99	14.95
*1966	1.23	1.61	3.02	0.00	0.82	0.38	0.19	0.01	0.24	2.38	1.30	1.41	12.57
*1967	0.68	1.17	1.82	0.26	0.03	0.55	0.33	0.42	1.06	3.53	2.36	1.15	13.37
*1968	0.23	0.62	3.53	0.28	0.53	0.93	0.77	0.49	0.18	1.73	2.03	0.08	11.38
*1969	1.33	1.42	1.90	1.23	1.02	1.22	0.31	0.94	0.06	2.27	1.71	0.68	14.09
*1970	1.56	0.68	0.46	0.40	0.16	2.71	1.23	0.08	0.19	1.18	1.86	2.23	12.73
*1971	0.63	0.46	0.62	0.17	0.52	0.17	0.41	0.28	0.00	0.73	2.61	2.09	8.70
*1972	2.38	0.73	1.56	0.03	0.03	0.01	0.13	0.10	1.57	1.02	1.71	0.46	9.72
*1973	5.66	1.14	1.48	0.87	1.43	2.85	0.91	0.84	0.51	0.79	1.38	0.34	18.19
*1974	0.06	0.97	0.20	1.90	0.33	0.50	0.40	0.01	0.06	2.65	0.78	1.02	8.90
*1975	3.50	0.40	0.55	0.92	0.88	1.53	0.70	0.47	0.01	2.16	0.78	2.20	14.10
*1976	0.15	0.97	0.74	0.09	1.36	0.35	0.52	1.59	0.11	2.87	0.85	1.59	11.18
*1977	0.62	0.31	0.27	1.07	0.65	0.38	0.74	0.24	0.40	2.45	2.74	1.54	11.43
*1978	0.91	0.59	0.35	2.17	2.02	2.21	0.40	1.00	0.23	0.59	1.02	0.84	12.32
*1979	1.61	3.25	2.54	2.62	0.78	1.63	0.41	1.74	0.55	0.32	1.27	0.16	16.88
*1980	1.18	0.73	1.20	2.83	3.10	1.20	1.00	0.29	0.06	1.02	1.86	1.14	15.60
*1981	0.76	0.08	0.44	0.64	0.72	2.02	0.59	0.57	0.65	2.85	1.54	1.07	11.92
*1982	1.32	1.12	0.15	1.65	1.75	1.58	0.20	1.31	0.05	1.64	3.95	1.53	16.26
*1983	0.12	1.36	2.68	3.02	1.14	1.83	0.56	0.36	0.03	2.24	1.94	2.52	17.78
*1984	1.17	0.86	1.45	0.13	0.09	1.22	0.68	0.13	0.28	3.20	4.28	1.09	14.58
*1985	2.38	0.46	2.50	1.31	0.67	1.60	2.63	0.32	0.12	2.58	1.11	2.29	17.97
*1986	2.70	1.96	0.30	0.07	1.14	1.50	0.60	0.27	0.51	2.06	2.04	2.19	15.35
*1987	1.47	1.81	0.99	1.30	1.46	0.74	0.45	0.81	0.41	2.02	2.68	0.45	14.58
*1988	1.90	1.95	2.08	0.87	1.47	0.08	1.97	0.14	1.36	1.66	3.45	0.49	17.40
*1989	0.37	1.18	0.47	0.53	0.52	0.57	0.04	0.13	0.06	1.12	2.10	0.34	7.42
*1990	0.96	0.13	0.45	0.44	1.23	0.80	0.67	0.42	0.30	2.22	1.63	2.38	11.62
1939-90 Average	1.24	0.84	1.11	1.00	0.89	0.99	0.69	0.50	0.38	1.62	1.98	1.15	12.39

* Denotes year in which one or more monthly records are reconstructed.

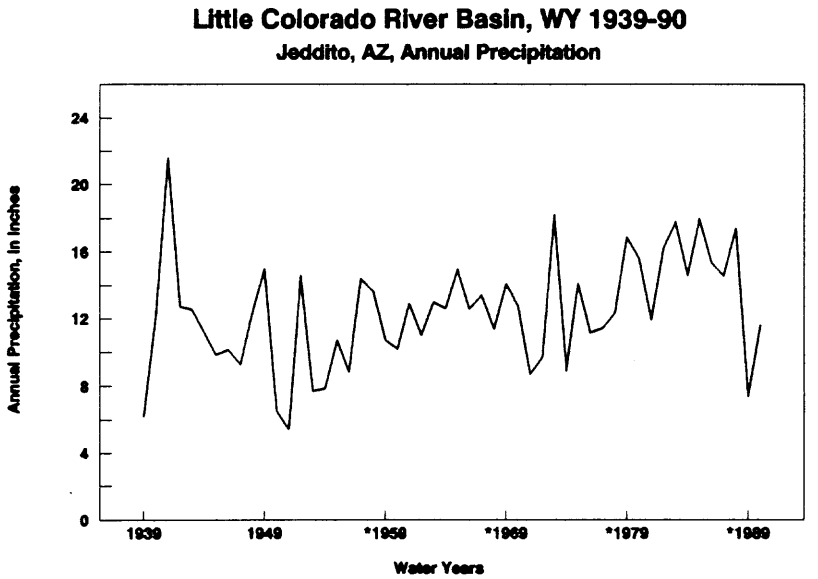


Figure 131. Jeddito, AZ, Annual Precipitation, WY 1939-90

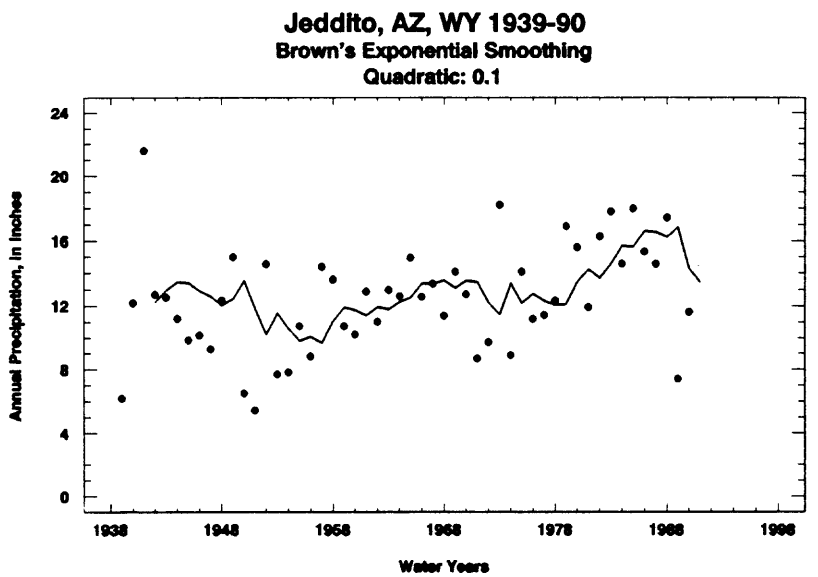


Figure 132. Jeddito, AZ, Smoothed Annual Precipitation, WY 1939-90

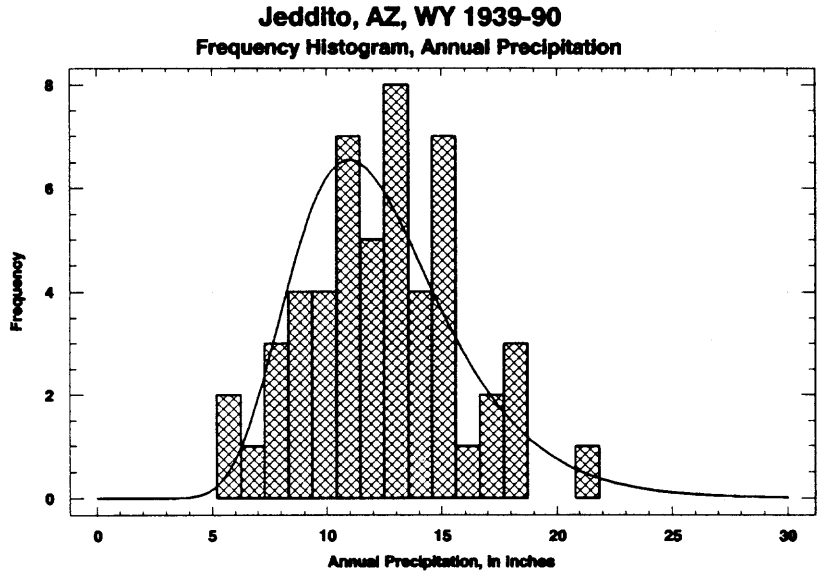


Figure 133. Jeddito, AZ, Histogram of Annual Precipitation

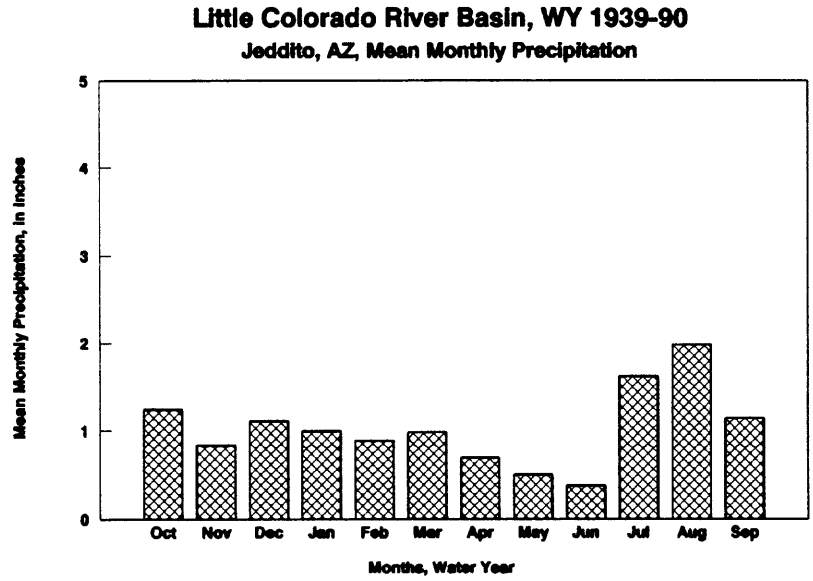


Figure 134. Jeddito, AZ, Monthly Distribution of Precipitation

6.2.3.26 Kayenta, AZ

This station has a long period of record from 1915 to 1940 and from 1945 to 1976. The period of 1976 to 1990 is reconstructed. This station lies 20 miles east of the northernmost tip of the LCR Basin and is included in the study to provide interpolation of missing data from nearby LCR Basin stations and to improve resolution of the isohyetal maps.

As summarized in Sellars and Hill (1974, p. 280):

> "Kayenta is located at an elevation of 5,660 feet on a rolling desert plateau in northeastern Arizona. It lies on the south side of Laguna Creek near the mouth of a narrow canyon which separates the Black Mesa to the south from the Skeleton Mesa to the west. The flat tops of both of these forested mesas are at an average elevation of better than 7,500 feet. In general, the terrain slopes gently downward toward the north and northeast into the San Juan and Chinle Valleys. Lowest elevations, about 3,500 feet, are reached 35 miles to the north along the westward San Juan River of southern Utah. Between the river and Kayenta lie the isolated mesas and rock spires of Monument Valley. These impressive 1,000 foot "monuments" rise like lonely sentinels from the flat desert floor. The highest point near Kayenta is found on Navajo Mountain, at an elevation of 10,416 feet, 37 miles to the northwest. This compact isolated peak rises more than a mile above Rainbow Bridge National Monument and the broad Colorado River, a short distance further to the northwest. Navajo National Monument, one of the most interesting features of the Navajo Indian Reservation, which covers most of the northeastern corner of Arizona, is located about 15 miles west of Kayenta. This [Navajo National] Monument contains many prehistoric Indian ruins, ancient caves, and cliff-dwellings. Except on the high mesas to the west and south, which are partially forested with pinyon and juniper, the sparse vegetation in the area consists mainly of sagebrush and plains grass.
>
> "Being located on a barren desert plateau, encircled by high mountain ranges, Kayenta has a dry climate, receiving less than seven inches [8.31 for the study period] of precipitation during an average year. Much of this falls during the warm summer months when afternoon thunderstorms form occasionally over the strongly heated desert mesas. These local storms, which obtain most of their moisture from the Gulf of Mexico, are usually accompanied by brief, heavy rain showers, often preceeded by strong gusty winds and blowing sand. In some years, late summer precipitation may be increased by a dissipating tropical disturbance moving northward from the Gulf of California and the adjacent sections of the Pacific Ocean. These rare storms produce unusually heavy rains, which may persist for more than 24 hours.
>
> "Kayenta normally receives very little precipitation in the fall, winter, and spring. Only occasionally does a storm from the Pacific Ocean release enough moisture to more than dampen the parched surface. Most of the winter and early spring storms that affect Kayenta are dry, advancing from the north or northeast. They are often accompanied by strong winds blowing unhindered over the flat desert floor, first from the south and then from the north. About seventy percent of the winter precipitation at Kayenta falls as snow. Although amounts are unusually small and melt after a few days, accumulations of a depth of more than two feet have been known to occur during the colder and wetter winters."

The precipitation trends show a gradual decline from 1939 to 1980 with a sharp peak from 1967 to 1969. From 1981 to 1986 there is a sharp increase. From 1987 to 1990 there may be the beginnings of a decline.

The histogram shows a strongly lognormal distribution with flat kurtosis and a pronounced positive skewness. The driest years are generally more frequent than wetter years. The seasonal distribution shows a strong peak from July through October, followed by a gradual decline from November through the annual minimum in June.

Table 39. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Kayenta, AZ
Station No.: 4578
Elevation: 5660
Latitude: 36d 44m
Longitude: 110d 16m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.21	0.28	0.65	1.26	0.46	0.84	0.32	0.23	0.00	1.33	0.39	1.53	7.50
*1940	0.07	0.25	0.00	0.15	0.90	0.46	0.38	0.29	0.36	1.28	1.21	2.49	7.84
*1941	1.26	0.89	2.26	1.43	1.79	1.55	1.69	1.14	0.49	0.73	1.49	1.76	16.49
*1942	3.17	0.64	0.95	0.06	0.59	0.69	1.13	0.05	0.00	0.46	0.90	0.43	9.08
1943	1.31	0.01	0.54	0.36	0.02	0.51	0.00	0.04	0.58	0.21	1.30	0.00	4.88
*1944	0.11	0.03	0.47	1.05	0.18	0.47	0.88	0.75	0.06	0.90	0.68	0.87	6.45
*1945	0.12	1.37	0.70	0.71	0.29	1.08	0.89	0.28	0.34	1.26	2.76	0.06	9.86
*1946	0.40	0.00	0.20	0.04	0.07	0.98	1.76	0.20	0.00	1.77	0.86	0.44	6.72
1947	0.51	0.66	0.00	0.54	0.00	0.00	0.00	0.35	0.05	0.87	2.95	0.45	6.38
1948	2.80	0.25	1.08	0.30	1.79	1.14	0.29	0.16	0.62	0.82	1.92	0.58	11.75
1949	1.08	0.07	1.22	2.79	1.07	0.54	0.41	0.72	1.03	0.81	0.40	0.50	10.64
1950	1.61	0.47	0.29	0.10	0.43	0.44	0.03	0.28	0.65	1.41	0.37	0.69	6.77
1951	0.00	0.13	0.00	1.09	0.10	0.19	0.52	0.95	0.00	0.63	0.94	0.95	5.50
1952	0.55	1.05	1.40	1.62	0.35	0.90	1.08	0.12	0.77	1.67	1.29	1.92	12.72
1953	0.00	1.63	0.42	0.05	0.05	0.20	0.59	0.04	0.00	3.61	1.46	0.02	8.07
1954	0.18	0.62	0.16	0.54	0.17	0.56	0.11	0.83	0.06	1.72	0.90	0.81	6.66
1955	0.63	0.24	0.13	0.21	0.45	0.00	0.13	0.16	1.32	0.88	2.24	0.00	6.39
1956	0.00	0.48	0.18	1.14	0.27	0.43	0.31	0.47	0.14	1.21	1.65	0.09	6.37
1957	0.26	0.08	0.14	1.85	0.25	0.66	0.74	1.28	0.45	1.32	2.86	0.00	9.89
1958	1.89	1.05	0.29	0.20	0.64	1.14	0.15	0.29	0.20	0.56	0.52	0.56	7.49
1959	0.54	0.27	0.00	0.00	0.48	0.00	1.01	0.00	0.10	1.25	1.83	0.00	5.48
1960	1.65	0.45	0.66	0.39	0.45	0.14	0.47	0.17	0.24	0.45	0.31	0.98	6.36
1961	4.23	0.13	1.49	0.08	0.10	1.14	0.09	0.07	0.07	1.77	1.55	0.74	11.46
1962	1.60	0.32	1.12	0.32	0.44	0.21	0.00	0.13	0.30	0.51	0.32	0.77	6.04
*1963	1.74	1.36	0.28	0.31	0.41	0.28	0.55	0.00	0.00	0.00	4.28	0.69	9.90
*1964	0.53	0.00	0.00	0.15	0.10	1.08	0.89	0.20	0.07	0.95	0.29	0.62	4.88
*1965	0.00	0.60	1.11	1.06	3.87	1.39	1.08	0.66	0.27	2.28	1.04	2.21	15.57
1966	0.45	1.05	1.35	0.14	0.92	0.00	0.46	0.54	0.06	1.52	1.87	0.95	9.31
1967	1.49	0.33	0.77	0.13	0.00	0.15	0.04	0.50	0.77	0.43	1.32	0.88	6.81
1968	0.19	0.04	1.00	0.05	0.13	0.21	0.24	0.16	0.08	0.33	0.96	0.05	3.44
1969	0.75	0.37	0.28	0.07	0.10	0.34	0.00	0.57	0.09	0.91	0.99	0.12	4.59
*1970	3.28	0.43	0.26	0.08	0.30	1.31	0.62	0.00	0.06	0.51	1.18	1.33	9.36
*1971	0.27	0.48	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.04	3.87	0.45	5.26
1972	1.60	0.90	1.24	0.00	0.00	0.00	0.01	0.00	0.00	0.35	0.45	0.61	5.16
*1973	4.94	0.23	1.14	1.42	0.38	2.30	0.38	0.34	0.32	0.48	0.67	0.69	13.28
*1974	0.11	0.80	0.34	0.82	0.57	0.05	0.05	0.00	0.00	1.07	0.10	0.91	4.82
*1975	0.24	0.35	0.23	0.72	0.82	0.95	0.43	0.33	0.00	1.93	0.05	1.23	7.27
*1976	0.10	1.21	0.66	0.32	0.77	0.02	0.29	1.48	0.00	2.17	0.00	3.03	10.06
*1977	0.53	0.18	0.00	0.70	0.13	0.00	0.23	0.00	0.03	1.59	1.94	0.35	5.68
*1978	0.15	0.16	0.14	1.20	0.64	1.22	0.38	0.79	0.12	0.01	0.14	0.44	5.38
*1979	0.93	2.50	1.60	1.32	0.51	0.64	0.15	1.50	0.63	0.12	0.66	0.00	10.53
*1980	1.31	1.24	1.04	1.55	1.36	1.05	0.90	0.31	0.00	0.45	1.40	1.05	11.66
*1981	0.81	0.09	0.16	0.08	0.40	1.58	0.44	0.99	0.49	1.66	0.59	0.59	7.88
*1982	1.30	1.03	0.17	0.86	1.03	0.83	0.25	1.06	0.00	0.81	3.28	1.44	12.07
*1983	0.43	0.89	1.26	1.68	0.72	1.55	0.44	0.27	0.14	2.25	1.08	1.61	12.32
*1984	0.53	0.87	0.68	0.06	0.08	0.50	0.62	0.01	0.27	1.61	1.96	0.22	7.41
*1985	1.52	0.16	1.52	1.23	0.29	1.02	1.66	0.11	0.01	1.94	0.20	1.18	10.84
*1986	1.15	1.25	0.13	0.00	0.80	0.86	0.39	0.32	0.00	1.41	1.25	1.20	8.75
*1987	0.84	1.18	0.38	0.64	0.53	0.37	0.35	0.56	0.26	1.27	2.00	0.08	8.47
*1988	1.68	1.92	0.79	0.83	0.77	0.15	1.83	0.56	1.25	0.90	2.31	0.83	13.82
*1989	0.08	1.29	0.16	0.32	0.54	0.15	0.00	0.04	0.03	0.51	1.40	0.00	4.54
*1990	0.47	0.00	0.01	0.27	0.55	0.27	0.35	0.25	0.10	1.19	1.04	2.06	6.54
1939-90 Average	0.99	0.62	0.60	0.62	0.54	0.63	0.50	0.40	0.25	1.08	1.30	0.80	8.31

* Denotes year in which one or more monthly records are reconstructed.

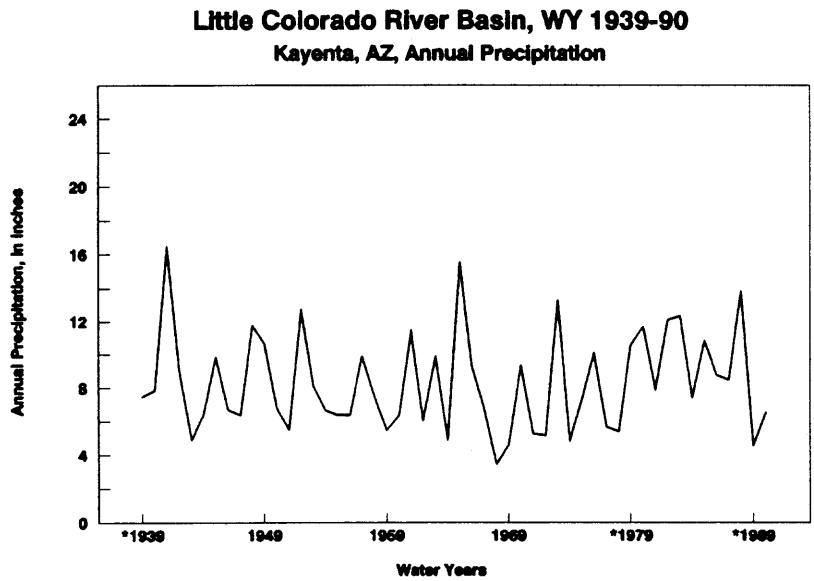


Figure 135. Kayenta, AZ, Annual Precipitation, WY 1939-90

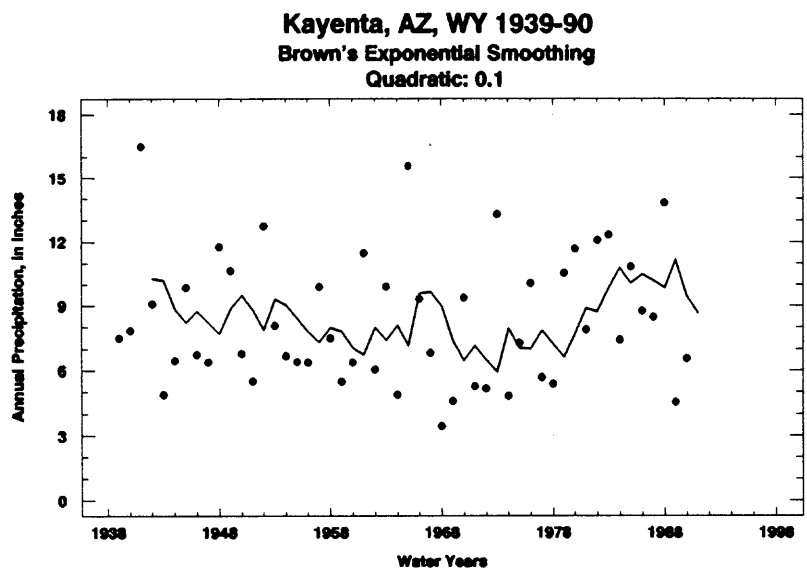


Figure 136. Kayenta, AZ, Smoothed Annual Precipitation, WY 1939-90

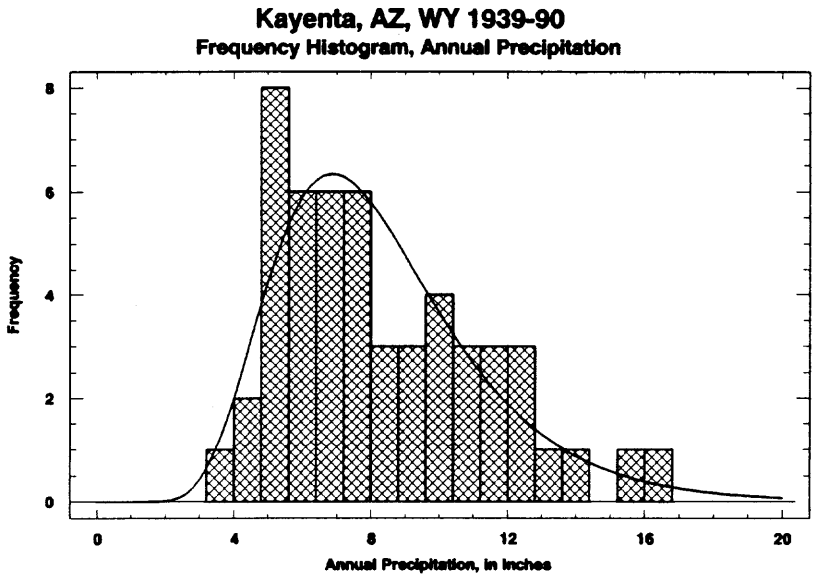


Figure 137. Kayenta, AZ, Histogram of Annual Precipitation

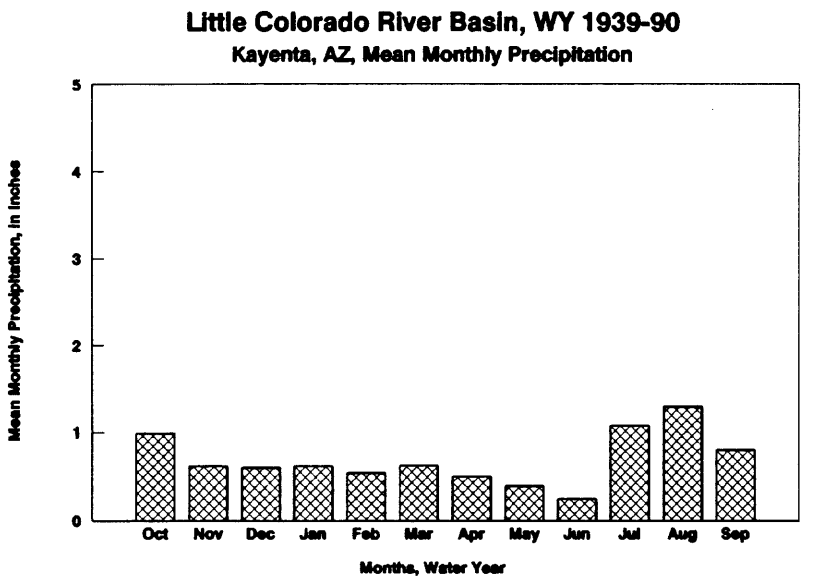


Figure 138. Kayenta, AZ, Monthly Distribution of Precipitation

6.2.3.27 Keams Canyon, AZ

This long-term station is located at the Bureau of Indian Affairs Hopi Reservation Headquarters. Its period of record dates from 1906 through 1921, 1929 and 1930, and 1949 to the present with many missing months. The missing record for the 1939-90 study periods have been reconstructed.

As summarized in Sellars and Hill (1974, p. 282):

"Keams Canyon lies at an elevation of 6,215 feet in the mesa country of northeastern Arizona. It is located, respectively, six and eighteen miles west of Jeddito and Steamboat Washes, both of which descend from Salahkai Mesa, sixteen miles to the northeast. Some of the more prominent mesas in the area include Black Mesa, 52 miles to the north, Carson Mesa, 40 miles to the northeast, Rock Mesa, 40 miles to the east-northeast, and Ganado Mesa, 35 miles to the east. The highest of these is Black Mesa which is found just south of the Navajo Indian Reservation and reaches elevations exceeding 7,500 feet. To the west and south the terrain slopes very gently into the valley of the Little Colorado River which changes its direction from generally westward to northward at a point 62 miles to the south-southwest. Sixty-five miles to the west the colorful Painted Desert, on the eastern slopes of the valley of the Little Colorado River, parallels the river southward to Winslow. Sixty-five miles to the south-southeast stands the Petrified Forest National Monument [Park]. The red-rocked Canyon de Chelly National Monument lies fifty miles to the northeast. The sparse vegetation in the area is dominated by plains grass, with sagebrush prevailing in the valley of the Little Colorado River.

"Keams Canyon has a semi-desert climate, receiving an average of just over ten inches of precipitation a year. The wettest season occurs during summer at which time moist, tropical air from the Gulf of Mexico enters northeastern Arizona and thunderstorms develop over the high plateau regions. Some of the heavier warm season rains at Keams Canyon are associated with weakened tropical storms that enter the continent from the Pacific Ocean during late summer and early fall. Drought conditions are prevalent during the period extending from the beginning of April through the end of June when the precipitation averages only 1.4 inches.

"Keams Canyon receives only slight amounts of precipitation in winter, largely in conjunction with cyclonic storms that develop in the north Pacific Ocean and follow an eastward track across the United States. Occasionally, these storms move farther south than normal, often intensifying off the Southern California coast. On such occasions, considerable amounts of precipitation may accumulate over a period of several days. Only about one-third of the winter precipitation, a relatively small fraction for this cold climate, falls in the form of snow. By far the heaviest fall, 46.5 inches occurred in December, 1968."

Precipitation trends show a decline from 1939 to 1969, a brief increase from 1969 to 1972, a decline from 1973 to 1979, a sharp increase from 1980 to 1988, followed by what may be the beginnings of a decline from 1988 to 1990.

The histogram is very slightly skewed in the positive direction, but not so much as to be lognormal. The kurtosis is flat, and the graph shows a sharp maximum frequency at about ten inches. The monthly distribution peaks from July through October, with a gradual decline from November to the annual minimum in June.

Table 40. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Keams Canyon, AZ
Station No.: 4586
Elevation: 6205
Latitude: 35d 49m
Longitude: 112d 12m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.05	0.19	0.85	1.24	0.39	0.34	0.53	0.10	0.01	0.13	0.82	1.06	5.71
*1940	0.27	0.63	0.24	1.08	1.32	0.56	1.57	0.46	0.14	0.44	2.13	3.05	11.90
*1941	1.18	1.02	2.16	1.97	1.99	1.47	2.34	1.14	1.13	1.00	2.36	2.72	20.49
*1942	2.52	0.68	1.29	0.26	0.94	0.63	1.37	0.01	0.00	0.72	1.87	0.59	10.88
*1943	1.90	0.12	1.35	1.33	0.34	1.53	0.20	0.56	0.11	1.24	3.69	0.98	13.36
*1944	0.99	0.13	1.24	0.76	0.88	1.07	1.21	1.03	0.01	0.55	0.37	1.86	10.13
*1945	0.13	1.31	1.09	0.80	0.32	1.48	0.26	0.03	0.18	2.00	1.28	0.25	9.12
*1946	0.67	0.01	1.19	0.42	0.22	0.73	0.41	0.47	0.02	2.03	2.39	1.05	9.62
*1947	0.40	1.78	0.37	0.31	0.07	0.15	0.05	1.56	0.30	0.45	3.14	0.67	9.24
*1948	2.39	1.06	1.01	0.29	1.77	1.86	0.58	0.02	0.85	0.66	0.60	0.94	12.03
*1949	1.79	0.03	1.36	1.71	0.71	0.98	0.10	0.52	1.71	2.23	0.86	1.26	13.27
*1950	1.39	0.23	0.56	0.47	1.10	0.27	0.00	0.24	1.10	2.21	0.95	0.30	8.82
*1951	0.00	0.17	0.04	0.59	0.23	0.26	0.88	0.56	0.00	0.00	2.12	0.80	5.65
*1952	0.94	0.67	1.25	1.53	0.38	1.19	1.80	0.06	0.60	1.81	1.75	1.64	13.60
*1953	0.00	1.22	0.39	0.30	0.43	0.42	0.53	0.14	0.14	2.85	1.79	0.00	8.22
1954	0.09	0.55	0.28	0.49	0.50	1.54	0.00	0.55	0.00	2.51	0.95	0.38	7.84
1955	1.33	0.00	0.35	1.23	1.31	0.16	0.34	0.29	1.29	0.73	3.48	0.02	10.53
1956	0.00	0.65	0.59	1.39	0.33	0.09	0.72	0.52	0.00	1.57	1.84	0.19	7.89
1957	0.36	0.00	0.13	2.88	0.57	0.52	0.25	1.60	0.94	1.14	3.16	0.00	11.55
1958	1.75	0.93	0.22	0.37	1.37	1.61	0.67	0.19	0.02	0.29	1.12	0.85	9.39
1959	0.89	0.88	0.10	0.16	0.70	0.00	0.77	0.14	0.25	0.27	2.64	0.13	6.93
1960	1.49	0.67	2.28	0.36	0.82	0.29	0.12	0.46	0.69	0.19	0.66	0.11	8.14
1961	2.80	0.39	0.99	0.81	0.12	1.87	0.27	0.11	0.01	1.05	1.73	0.99	11.14
1962	1.36	0.55	1.54	0.67	0.66	0.48	0.00	0.00	0.05	0.26	0.19	2.63	8.39
1963	1.21	1.31	0.18	0.23	1.10	0.23	0.56	0.00	0.00	0.08	4.85	1.54	11.29
1964	0.72	0.45	0.46	0.16	0.19	1.31	1.69	0.05	0.05	1.29	1.48	1.50	9.35
1965	0.00	0.76	2.09	0.33	1.44	0.98	1.18	1.69	0.77	2.35	0.51	2.16	14.26
1966	1.30	1.70	2.79	0.27	0.83	0.08	0.00	0.08	0.00	1.20	1.50	1.03	10.78
1967	0.17	1.33	1.68	0.20	0.00	0.43	0.20	0.27	1.10	2.54	1.78	0.77	10.47
1968	0.00	0.42	3.29	0.02	0.60	0.72	1.18	0.74	0.04	1.13	0.82	0.00	8.96
1969	1.23	1.53	3.37	1.26	0.78	1.13	0.21	0.85	0.00	2.90	0.92	0.81	14.99
1970	1.48	0.43	0.39	0.43	0.05	2.97	1.48	0.00	0.25	0.97	1.08	2.31	11.84
1971	0.54	0.59	0.73	0.01	0.41	0.24	0.33	0.39	0.00	0.35	1.01	0.94	5.54
1972	1.56	0.84	1.21	0.00	0.00	0.00	0.07	0.00	0.99	0.13	3.88	0.20	8.88
1973	4.67	1.13	0.67	1.13	0.97	3.71	0.50	0.28	0.27	0.45	0.91	0.45	15.14
*1974	0.14	0.69	0.20	1.57	0.25	0.45	0.54	0.01	0.09	1.80	0.00	0.58	6.32
1975	2.96	0.27	0.46	0.36	0.51	1.18	0.41	0.20	0.06	1.21	0.48	1.12	9.22
1976	0.17	0.95	0.48	0.11	0.93	0.07	0.30	1.07	0.05	2.72	0.39	1.44	8.68
1977	0.30	0.04	0.28	0.89	0.54	0.04	0.92	0.06	0.45	2.75	1.21	0.70	8.18
1978	0.44	0.04	0.29	2.01	2.22	2.07	0.01	0.66	0.32	0.20	1.11	0.91	10.28
1979	1.64	2.73	2.23	2.56	0.88	1.34	0.32	1.83	1.40	0.04	1.08	0.00	16.05
1980	1.64	1.06	0.96	2.59	2.70	1.06	1.22	0.39	0.00	0.94	1.60	0.79	14.95
*1981	1.15	0.05	0.12	0.55	0.90	1.79	0.52	0.57	0.33	1.71	1.05	0.87	9.61
*1982	2.06	0.86	0.11	1.26	2.00	1.28	0.16	1.19	0.00	1.48	2.97	1.25	14.62
1983	0.13	0.46	0.46	1.15	1.19	1.67	0.36	0.70	0.00	1.94	2.16	2.73	12.95
1984	0.58	0.77	1.09	0.00	0.21	1.16	0.99	0.03	0.15	3.95	4.46	0.60	13.99
1985	1.42	0.37	1.82	0.78	0.60	1.62	2.73	0.27	0.10	2.27	0.10	1.78	13.86
1986	1.64	1.33	0.48	0.02	0.60	1.65	0.21	0.10	0.29	1.60	3.28	0.75	11.95
1987	1.42	0.63	0.17	0.36	0.22	0.06	0.00	0.53	0.10	1.13	1.02	0.00	5.64
1988	1.67	1.68	1.84	1.24	1.32	0.12	1.92	0.02	1.18	0.63	3.39	0.00	15.01
1989	0.04	1.32	0.38	0.37	0.43	0.05	0.00	0.05	0.00	1.02	2.06	0.27	5.99
*1990	0.28	0.00	0.36	0.31	0.88	0.73	0.77	0.36	0.04	1.53	1.03	2.47	8.76
1939-90 Average	1.06	0.72	0.95	0.80	0.77	0.92	0.65	0.45	0.34	1.28	1.69	0.97	10.60

* Denotes year in which one or more monthly records are reconstructed.

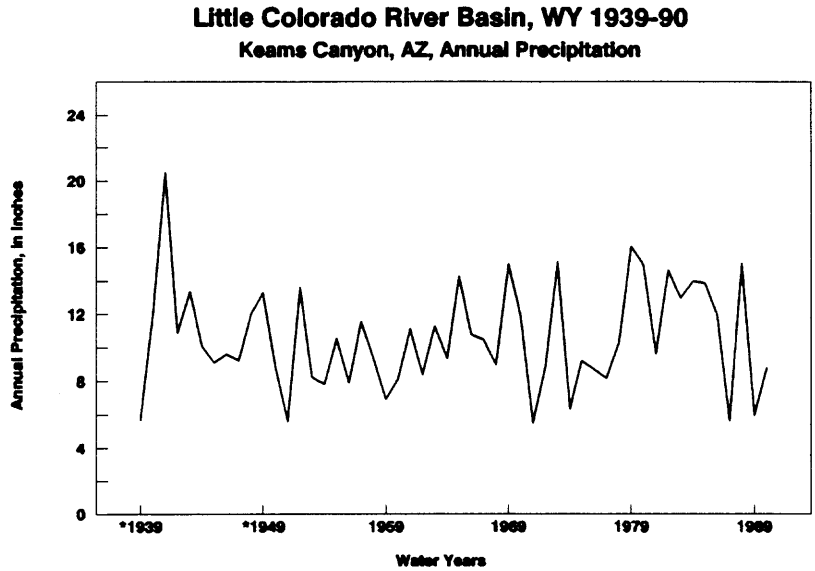


Figure 139. Keams Canyon, AZ, Annual Precipitation, WY 1939-90

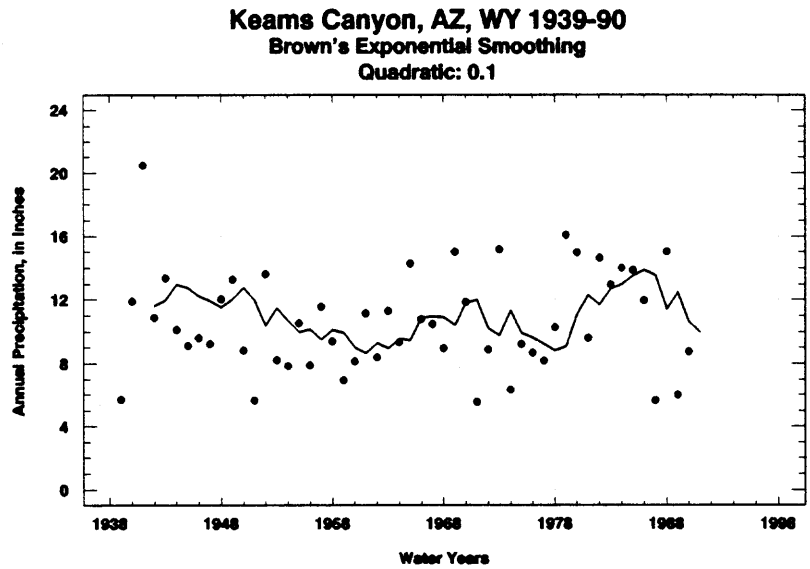


Figure 140. Keams Canyon, AZ, Smoothed Annual Precipitation

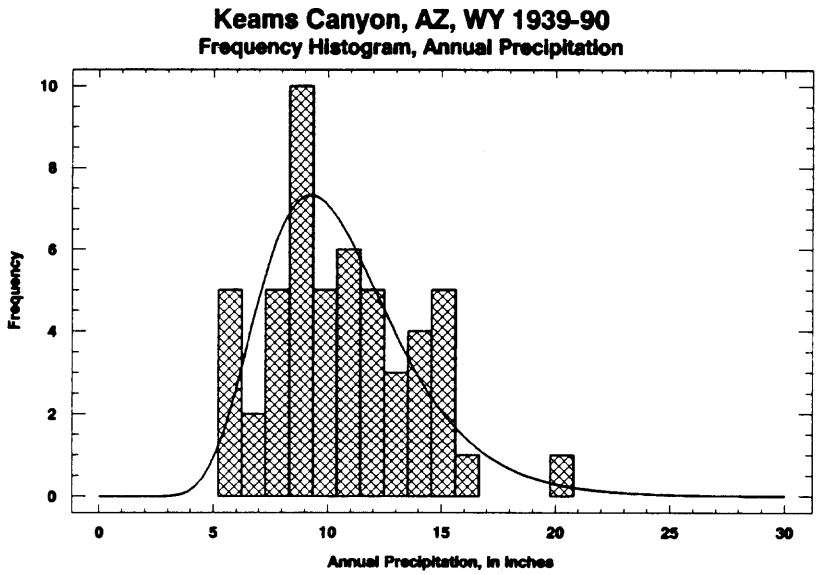


Figure 141. Keams Canyon, AZ, Histogram of Annual Precipitation

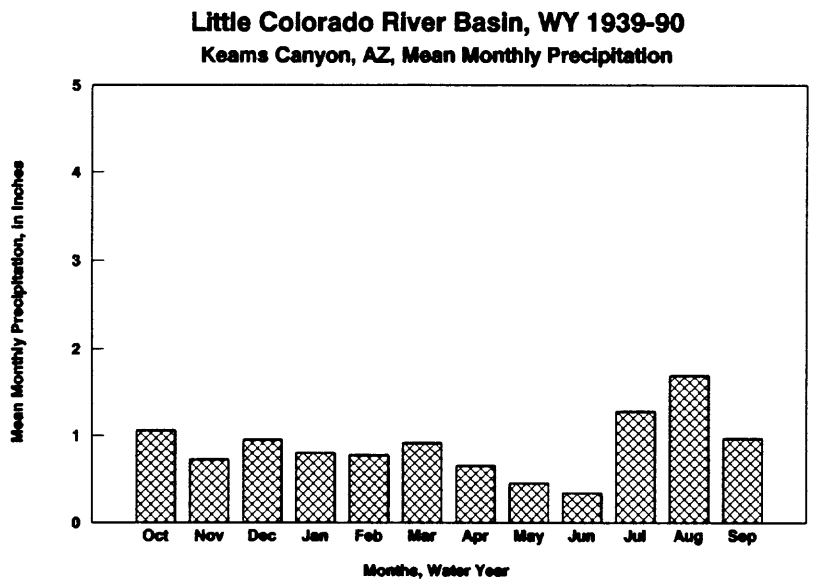


Figure 142. Keams Canyon, AZ, Monthly Distribution of Precipitation

6.2.3.28 Klagetoh, AZ

This station has a short period of record from 1950 to the present. The period of from 1939 to 1950 had been reconstructed. The station lies at an elevation of about 6,500 feet about 25 miles southwest of Ganado.

The precipitation trends show a decline from 1939 to 1968, an increase from 1968 to 1987, and a sharp decline from 1988 to 1990.

The histogram shows a ragged normal distribution with a flat kurtosis. Two wet years slightly skew the distribution in a positive direction. The monthly distribution shows a strong peak from July through October, followed by a gradual decline from November through the annual minimum in June.

Table 41. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Klagetoh, AZ
Station No.: 4686
Elevation: 6500
Latitude: 35d 33m
Longitude: 109d 42m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.05	0.30	1.06	0.94	1.08	0.70	0.88	0.11	0.00	0.30	1.22	1.38	8.01
*1940	0.38	1.18	0.36	1.03	1.29	0.51	1.34	0.55	0.30	0.80	3.11	3.51	14.36
*1941	1.47	1.09	2.44	1.62	1.88	2.01	2.59	1.67	1.05	1.38	2.21	2.94	22.35
*1942	3.09	0.76	1.20	0.26	1.19	0.52	1.44	0.01	0.00	0.81	1.90	0.79	11.98
*1943	1.92	0.19	1.42	1.30	0.40	1.34	0.30	0.41	0.26	1.10	3.30	1.05	12.97
*1944	1.13	0.12	1.12	0.96	1.26	1.04	1.15	0.98	0.16	1.04	0.79	2.10	11.84
*1945	0.39	1.22	1.19	0.87	0.64	1.46	0.36	0.04	0.25	3.33	2.33	0.23	12.29
*1946	0.75	0.01	1.48	0.26	0.22	0.70	0.38	0.38	0.03	1.78	2.73	1.94	10.66
*1947	0.56	1.45	0.61	0.49	0.13	0.16	0.04	1.36	0.29	0.57	3.66	0.85	10.16
*1948	2.23	1.04	0.99	0.28	1.48	1.44	0.37	0.25	0.51	1.51	1.73	1.17	13.00
*1949	2.42	0.03	1.40	1.77	0.64	0.72	0.41	0.61	1.22	2.35	1.50	1.43	14.50
*1950	1.23	0.20	0.68	0.44	0.69	0.31	0.00	0.06	0.45	1.94	0.57	0.28	6.85
1951	0.00	0.00	0.09	0.11	0.06	0.03	0.11	0.06	0.00	0.94	2.57	0.53	4.50
1952	1.37	0.71	1.43	1.92	0.34	0.80	2.91	0.00	1.08	3.21	1.28	1.07	16.12
1953	0.01	2.67	0.57	1.05	0.13	0.89	0.55	0.03	0.58	2.59	1.54	0.00	10.61
1954	0.65	0.61	0.48	0.55	0.33	2.09	0.18	0.20	0.00	2.86	1.03	1.82	10.80
1955	0.26	0.02	0.65	0.72	0.80	0.15	0.43	0.31	1.20	2.49	3.13	0.00	10.16
1956	0.00	0.25	1.18	1.08	0.10	0.10	0.24	0.61	0.03	2.89	0.55	0.19	7.22
1957	0.98	0.23	0.35	2.98	0.96	0.87	1.34	1.18	1.51	0.94	3.80	0.00	15.14
1958	2.22	1.57	0.36	0.05	1.04	1.10	0.33	0.30	0.36	0.66	2.73	2.18	12.90
*1959	0.59	0.64	0.00	0.33	0.76	0.00	0.70	0.03	0.50	0.94	2.74	0.00	7.23
*1960	2.27	0.49	1.34	0.61	0.54	0.56	0.06	0.42	0.22	0.48	0.93	0.09	8.01
1961	2.88	0.17	0.40	0.81	0.28	1.07	0.00	0.07	0.00	1.63	1.36	1.33	10.00
1962	2.00	0.91	0.73	0.45	0.83	0.33	0.00	0.00	1.71	0.29	0.03	1.19	8.47
1963	2.26	1.53	0.14	0.03	0.70	0.00	0.00	0.00	0.00	0.09	4.44	1.39	10.58
1964	0.00	0.13	0.40	0.00	0.00	0.80	0.70	0.00	0.00	2.09	2.33	1.10	7.55
1965	0.00	1.10	0.53	2.06	0.88	0.35	0.50	1.25	0.42	0.89	0.18	1.26	9.42
1966	1.28	1.38	1.81	0.70	0.90	0.22	0.25	0.00	0.00	1.93	0.20	1.97	10.64
1967	0.30	0.50	2.35	0.02	0.00	0.19	0.45	0.08	0.85	3.48	1.03	1.42	10.67
1968	0.54	0.40	1.73	0.08	0.12	0.80	0.28	0.76	0.06	0.74	1.89	0.01	7.41
1969	1.46	2.28	1.76	0.53	1.11	1.09	0.70	0.67	0.26	0.78	1.46	0.48	12.58
1970	2.05	0.93	0.50	0.39	0.14	2.01	1.56	0.17	0.12	0.71	1.90	3.15	13.63
1971	0.36	0.45	0.44	0.40	0.46	0.03	0.45	0.12	0.00	0.15	2.49	2.28	7.63
1972	2.40	0.78	0.86	0.00	0.17	0.02	0.01	0.00	0.92	0.24	0.59	0.07	6.06
1973	5.98	1.18	1.31	0.44	0.92	0.63	1.52	0.77	0.81	0.35	1.92	0.32	16.15
*1974	0.02	0.66	0.12	1.55	0.33	0.44	0.67	0.00	0.00	3.55	0.11	0.91	8.36
1975	2.65	0.42	0.37	0.35	0.53	1.35	0.86	0.04	0.00	2.39	1.00	1.72	11.68
1976	0.00	0.31	0.29	0.00	1.02	0.03	0.27	1.86	0.00	1.18	0.86	1.53	7.35
1977	0.60	0.10	0.20	0.94	0.87	0.19	0.40	0.29	0.03	1.40	2.54	1.01	8.57
1978	0.87	0.90	0.17	3.52	1.66	1.19	0.32	0.90	0.01	0.00	0.14	0.92	10.60
1979	1.69	2.37	1.79	1.40	0.21	1.41	0.50	1.70	0.15	0.06	0.41	0.00	11.69
1980	0.87	0.83	1.34	2.49	1.80	0.58	1.41	0.34	0.04	0.05	1.97	0.65	12.37
1981	0.29	0.04	0.36	0.65	0.77	1.63	0.16	0.32	0.76	1.90	0.70	0.15	7.73
1982	1.43	1.13	0.00	1.59	1.73	1.07	0.12	1.58	0.16	0.57	2.64	1.06	13.08
1983	0.00	1.45	0.78	5.03	0.10	2.81	0.50	0.00	0.00	0.55	0.79	1.51	13.52
1984	0.67	0.26	1.22	0.00	0.07	1.12	0.40	0.09	0.19	1.78	3.04	1.15	9.99
1985	1.09	0.36	1.12	0.54	0.44	1.15	3.88	0.37	0.00	3.06	1.18	2.00	15.19
1986	5.43	0.94	0.00	0.00	0.32	0.57	0.30	0.25	0.02	1.81	0.39	2.63	12.66
1987	1.27	1.35	1.35	0.36	0.22	0.06	0.00	0.53	0.10	1.19	3.25	0.21	9.89
1988	1.78	0.75	2.19	0.30	1.33	0.00	0.70	0.00	0.30	1.29	1.72	0.08	10.44
1989	0.04	0.77	0.04	0.30	0.00	0.00	0.00	0.12	0.00	0.66	1.38	0.00	3.31
1990	1.48	0.00	0.00	0.15	0.36	0.84	0.01	0.00	0.00	1.26	0.23	1.02	5.35
1939-90 Average	1.26	0.75	0.86	0.86	0.66	0.76	0.63	0.42	0.32	1.36	1.68	1.08	10.66

* Denotes year in which one or more monthly records are reconstructed.

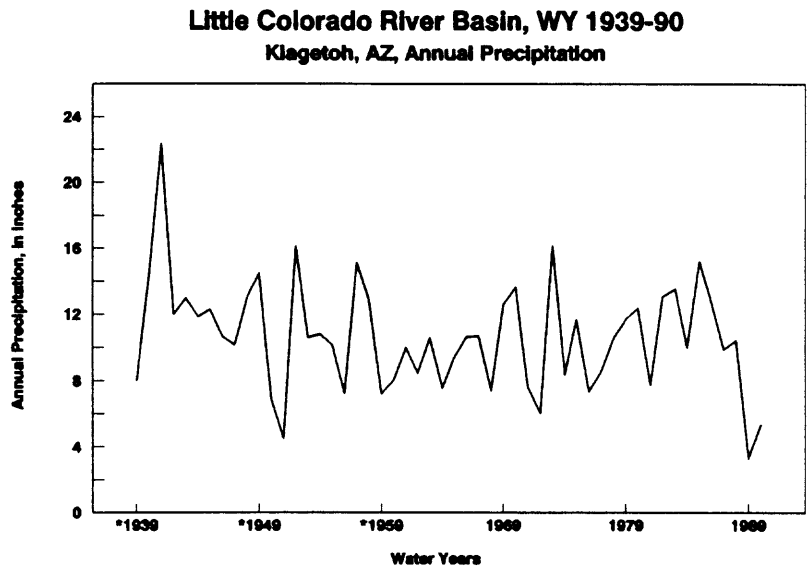


Figure 143. Klagetoh, AZ, Annual Precipitation, WY 1939-90

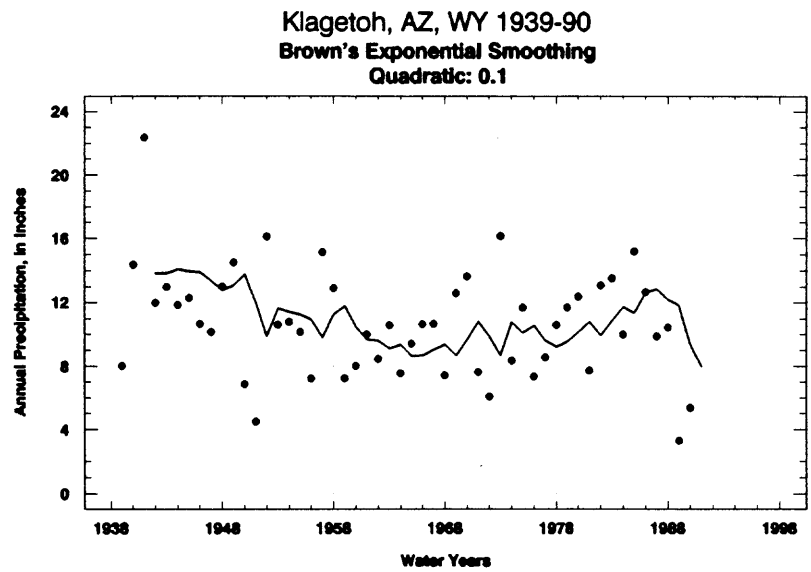


Figure 144. Klagetoh, AZ, Smoothed Annual Precipitation, WY 1939-90

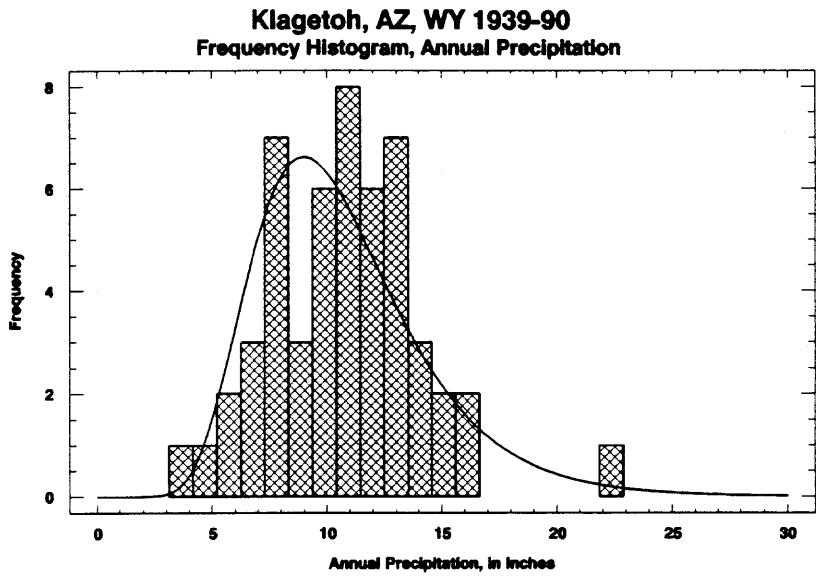


Figure 145. Klagetoh, AZ, Histogram of Annual Precipitation

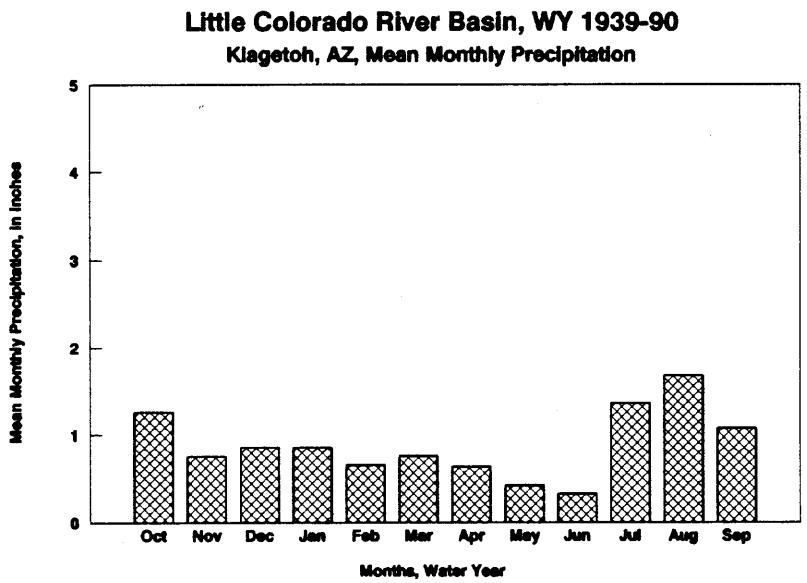


Figure 146. Klagetoh, AZ, Monthly Distribution of Precipitation

6.2.3.29 Lees Ferry, AZ

This is a long-term station with a period of record of 1916 to 1938 and from 1944 to the present. It is located just slightly northwest of the northwestern corner of the LCR Basin and is included in the study to provide interpolation of missing record for nearby LCR Basin stations and to enable higher resolution of isohyetal maps.

As summarized in Sellars and Hill (1974, p. 302):

"Lees Ferry is located at an elevation of about 3,200 feet eight miles southwest of Glen Canyon Dam on the Colorado River in extreme northern Arizona. It lies near the northern end of Marble Canyon less than a mile above the mouth of the Paria River, which enters the Colorado River from the northwest. The canyon is bounded on both sides by cliffs. The Vermillion Cliffs to the west rise 2,500 feet in less than two miles onto the barren Paria Plateau, while to the east the less steep Echo Cliffs slope upward onto the semi-forested Kaibito Plateau. Fifty miles south of Lees Ferry the Colorado River leaves Marble Canyon and enters the magnificent Grand Canyon. The highest elevations within fifty miles of the town are found on the verdant Kaibab Plateau, which rises above 9,000 feet 45 miles to the southwest, and on Navajo Mountain, 40 miles to the east-northeast in Utah. This compact isolated peak, at an elevation of 10,416 feet towers almost a mile and a half above the Colorado River, a short distance to the northwest. Points of interest near Lees Ferry, other than Glen Canyon Dam and the Grand Canyon, include the remarkable Navajo National Monument, fifty miles to the east on the Navajo Indian Reservation. The sparse vegetation in the area consists mainly of sagebrush and plains grass on the canyon floors and juniper and pinyon on the plateaus and mesas rising above 6,500 feet. Stands of ponderosa pine are common above 8,000 on Kaibab Plateau and on Navajo Mountain.

"Lees Ferry has an extremely dry climate, receiving less than six inches of precipitation during a normal year. Only in July and August do average monthly values exceed seven tenths of an inch. During this period an occasional late afternoon thunderstorm may pass over the town after forming over the high plateau country to the southwest. These storms rarely produce more than light rain showers and are often preceeded by strong gusty winds and blowing dust. The heaviest summer rains normally fall from weak tropical disturbances that move northward from the Pacific Ocean, bringing with them widespread cloudiness and precipitation, which may continue for more than 24 hours. Unfortunately, these beneficial storms do not occur every summer and are often almost dissipated by the time that they reach Lees Ferry.

"Normal precipitation amounts in the fall, winter, and spring at Lees Ferry are barely sufficient to settle the dust. However, once in a great while an unusually moist storm may move into the area from the Pacific Ocean, producing several days of cloudy, wet weather. These productive storms are few and far between and certainly much less numerous than dry storms accompanied by steady strong winds, which may persist for several days, blowing first unseasonably warm from the south and then bitterly cold from the north. Although clouds are often present during these windstorms, they are usually too high and too thin to produce more than a light drizzle. Less than 20 percent of the winter precipitation at Lees Ferry falls as snow, and this normally melts as soon as it strikes the ground. However, the high cliffs to the west and south may be white with snow for several weeks at a time during the coldest months."

The precipitation trends for the study period show a rapid rise from 1939 to 1956, followed by a gradual decline from 1957 to 1980. From 1981 to 1987 is a dramatic increase, with a declining trend from 1988 to 1990.

The histogram peaks at about five inches, with an irregular, broad maximum frequency from four to eight inches. Four years from nine to thirteen inches give the slight impression of a lognormal distribution with a positive skewness. The monthly distribution shows a slight peak from July through October, followed by a gradual decline from November through the annual minimum in June.

Table 42. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Lees Ferry, AZ
Station No.: 4849
Elevation: 3210
Latitude: 36d 52m
Longitude: 111d 36m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.08	0.00	0.00	0.02	0.32	0.00	0.10	0.06	0.00	0.00	0.91	1.49
*1940	0.00	0.16	0.00	0.00	0.00	0.04	0.03	0.00	0.00	0.00	0.05	1.02	1.30
*1941	0.51	0.23	0.89	1.18	0.00	1.05	1.16	1.01	0.04	0.02	0.66	0.34	7.09
*1942	0.82	0.00	0.00	0.00	0.00	0.03	0.29	0.00	0.00	0.48	0.00	0.00	1.62
*1943	0.03	0.06	0.31	0.00	0.00	0.90	0.00	0.13	0.00	0.09	0.34	0.31	2.17
1944	0.47	0.22	0.75	0.42	0.52	0.74	0.45	0.31	0.08	0.06	0.34	0.01	4.37
1945	0.00	0.43	0.09	0.29	0.60	0.99	0.19	0.13	0.09	0.86	1.16	0.02	4.85
1946	0.56	0.00	0.17	0.21	0.00	0.88	0.96	0.01	0.00	0.44	3.57	0.27	7.07
1947	1.70	0.60	0.21	0.03	0.02	0.00	0.04	0.33	0.15	0.65	1.70	0.02	5.45
1948	1.79	0.05	0.62	0.28	1.74	0.27	0.10	0.00	0.60	0.44	1.91	0.10	7.90
1949	0.44	0.00	0.52	1.02	0.30	0.98	0.06	0.00	0.79	0.16	0.33	1.16	5.76
1950	0.44	0.01	0.05	0.05	0.25	0.60	0.00	0.00	0.00	1.82	0.69	0.17	4.08
1951	0.00	0.00	0.01	0.94	0.10	0.42	0.42	0.33	0.00	0.35	1.92	1.00	5.49
1952	0.74	0.94	0.97	1.08	0.21	0.40	1.29	0.07	0.63	0.31	0.67	0.81	8.12
1953	0.00	0.72	0.95	0.12	0.06	0.16	0.50	0.00	0.48	3.13	1.86	0.00	7.98
1954	0.43	0.42	0.05	0.40	0.35	0.93	0.04	0.51	0.42	1.05	0.54	1.55	6.69
1955	0.27	0.19	0.37	0.22	0.09	0.05	0.10	0.09	0.61	1.06	0.21	0.00	3.26
1956	0.00	0.20	0.07	0.16	0.10	0.09	0.38	0.32	0.00	0.87	0.48	0.00	2.67
1957	0.21	0.10	0.04	1.30	0.17	0.17	0.37	1.47	0.77	1.07	2.65	0.00	8.32
1958	1.45	1.21	0.20	0.13	0.48	1.40	0.14	0.35	0.03	0.38	0.46	1.29	7.52
1959	0.30	0.41	0.00	0.00	0.42	0.00	0.83	0.48	0.10	0.13	0.60	0.11	3.38
1960	2.13	0.51	0.82	0.70	0.19	0.18	0.42	0.14	0.11	0.20	0.12	0.37	5.89
1961	2.30	0.43	0.70	0.12	0.20	1.12	0.21	0.08	0.00	0.32	2.00	0.96	8.44
1962	0.19	0.17	0.74	0.09	0.31	0.16	0.00	0.11	0.14	0.00	0.32	0.86	3.09
1963	1.05	0.55	0.17	0.50	0.24	1.04	0.02	0.12	0.00	0.32	1.75	0.34	6.10
1964	0.47	0.25	0.00	0.12	0.00	0.47	0.45	0.17	0.01	0.32	0.48	0.20	2.94
1965	0.00	0.67	0.62	0.47	0.72	0.42	1.22	2.30	0.35	0.19	0.57	0.40	7.93
1966	0.35	0.63	0.83	0.06	0.85	0.04	0.01	0.25	0.28	1.19	1.59	0.53	6.61
1967	0.74	0.47	0.89	0.05	0.00	0.04	0.21	0.84	0.28	0.60	2.10	2.06	8.28
1968	0.00	0.01	1.12	0.28	0.01	0.19	0.66	0.05	0.08	1.29	0.69	0.02	4.40
1969	0.08	0.47	0.31	0.45	0.77	0.42	0.25	0.17	0.16	1.55	0.65	0.26	5.54
1970	0.75	0.52	0.05	0.39	0.15	0.92	0.06	0.00	0.23	1.26	1.82	0.08	6.23
1971	0.10	0.57	0.12	0.00	0.49	0.11	0.04	0.28	0.00	0.24	1.07	0.29	3.31
1972	0.77	0.05	0.31	0.00	0.00	0.00	0.00	0.00	2.00	0.11	0.18	0.18	3.60
1973	3.15	0.78	0.56	0.35	0.59	1.61	0.23	0.11	0.15	2.89	0.31	0.03	10.76
1974	0.00	0.46	0.00	0.77	0.03	0.36	0.25	0.05	0.00	0.41	0.09	0.46	2.88
1975	0.83	0.05	0.00	0.02	0.91	0.58	0.73	0.00	0.00	1.40	0.35	0.58	5.45
1976	0.00	0.58	1.02	0.00	0.58	0.65	0.53	0.23	0.00	1.32	0.00	0.61	5.52
1977	0.15	0.00	0.00	0.22	0.03	0.00	0.00	0.16	0.02	1.36	0.47	0.15	2.56
1978	0.17	0.27	0.76	1.45	0.14	0.99	0.39	0.36	0.00	0.55	0.33	0.33	5.74
1979	0.82	2.79	1.05	1.30	0.33	1.06	0.10	0.50	0.07	0.00	0.27	0.00	8.29
1980	0.59	1.37	0.97	1.14	1.57	1.36	1.58	0.27	0.00	0.99	1.14	1.55	12.53
1981	0.00	0.02	0.03	0.17	0.37	0.80	0.33	0.83	0.07	0.11	1.55	1.30	5.58
1982	2.19	1.09	0.01	0.44	0.94	0.32	0.80	0.76	0.03	0.51	2.26	0.35	9.70
*1983	0.60	1.05	0.60	0.70	0.40	1.14	0.19	0.05	0.00	1.18	1.60	1.14	8.65
*1984	0.00	0.80	0.34	0.05	0.08	0.00	0.22	0.00	0.05	1.55	1.33	0.40	4.82
1985	0.11	0.00	1.12	0.59	0.00	1.24	0.87	0.00	0.10	1.35	0.47	0.52	6.37
1986	0.49	0.83	0.07	0.01	0.14	0.45	0.37	0.33	0.02	1.30	1.44	0.69	6.14
*1987	0.50	0.45	0.49	0.35	0.88	0.30	0.00	1.00	0.00	0.55	0.00	0.00	4.52
*1988	1.70	0.45	0.05	0.09	0.51	0.03	2.33	0.17	0.45	0.19	0.67	0.06	6.70
1989	0.81	0.16	0.00	1.15	0.31	0.02	0.00	0.45	0.02	0.46	1.22	0.03	4.63
*1990	0.00	0.00	0.00	0.45	0.00	0.00	0.82	0.15	0.29	1.49	0.17	0.71	4.08
1939-90 Average	0.60	0.43	0.39	0.39	0.33	0.51	0.40	0.30	0.19	0.74	0.91	0.47	5.65

* Denotes year in which one or more monthly records are reconstructed.

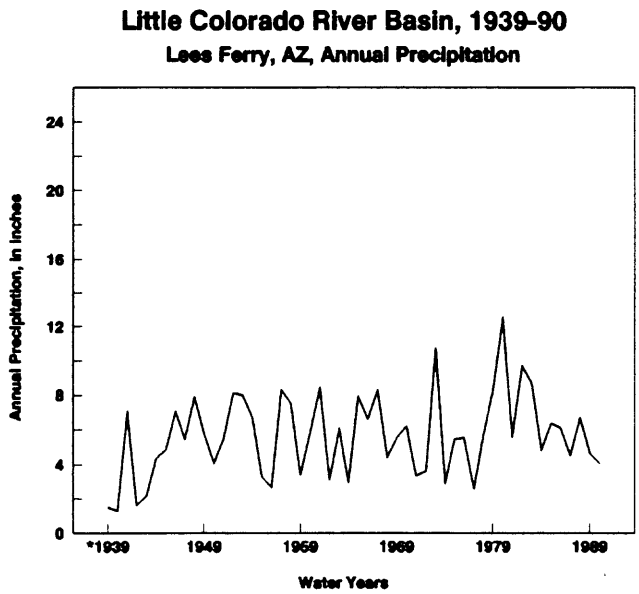


Figure 147. Lees Ferry, AZ, Annual Precipitation, WY 1939-90

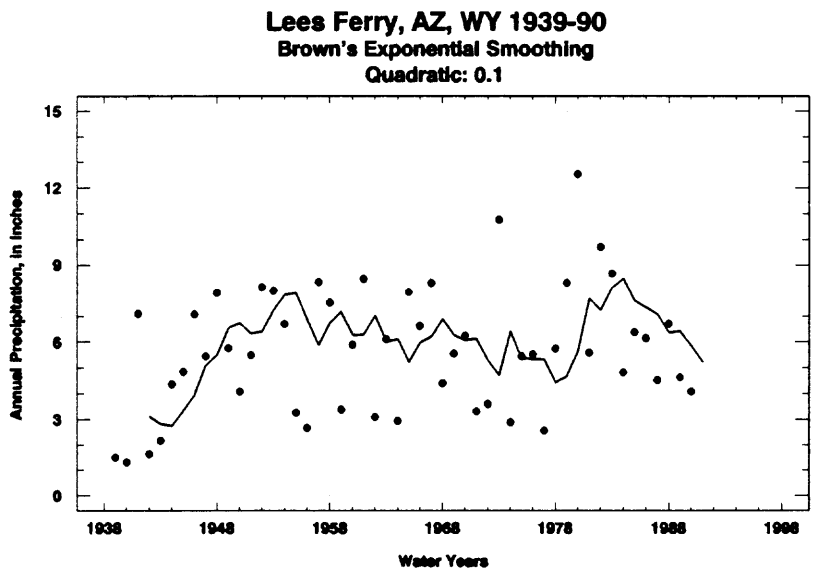


Figure 148. Lees Ferry, AZ, Smoothed Annual Precipitation WY 1939-90

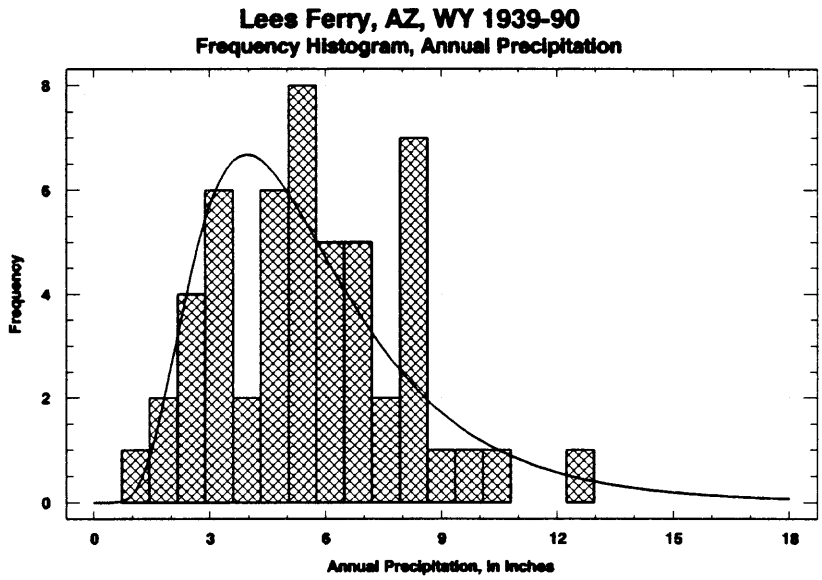


Figure 149. Lees Ferry, AZ, Histogram of Annual Precipitation

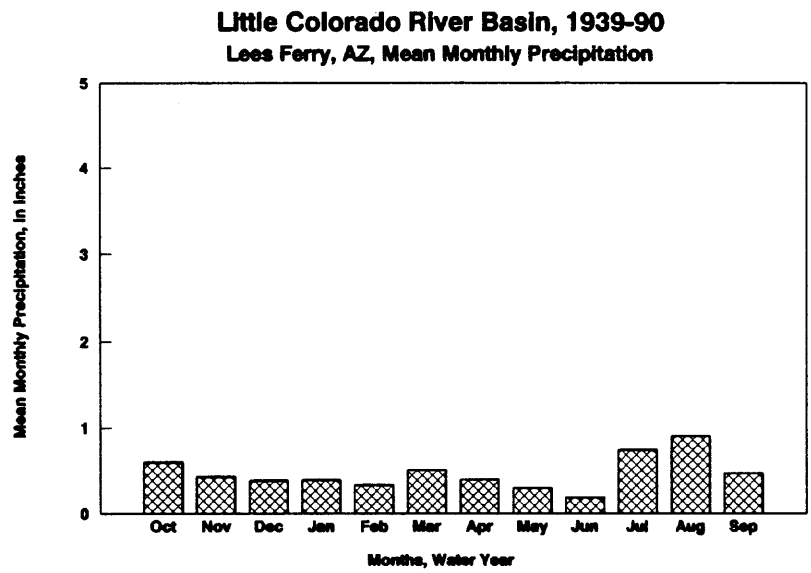


Figure 150. Lees Ferry, AZ, Monthly Distribution of Precipitation

6.2.3.30 Leupp, AZ

This is a long-term station with a period of record of from 1915 to 1922, 1926, from 1935 to 1943, and from 1946 to its abrupt end in 1981. The missing data from 1944-45 and from 1982-90 have been reconstructed. This is an important station to provide resolution to isohyetal maps. The reconstructed record may be too strongly influenced by high altitude stations to the west. However, the trend line for the study period resembles Holbrook and other low altitude stations in the northwestern portion of the LCR Basin. In addition, Leupp's proximity to high elevations in the San Francisco Mountains to the west may result in more easterly storm tracks in some seasons, resulting in higher than normal precipitation.

As summarized in Sellars and Hill (1974, p. 306):

"Leupp, at an elevation of 4,700 feet, lies in the valley of the Little Colorado River in northeastern Arizona, twenty-two miles northwest of Winslow. The river flows northwestward about one-half mile to the west, ultimately emptying into the Colorado River. The colorful Painted Desert is found just to the northwest, extending for over sixty miles in a general southeast to northwest direction. Forty miles to the west-northwest impressive Humphreys Peak in the San Francisco Mountains rises to 12,670 feet, the highest elevation in Arizona. Southward from these mountains lies the lake-studded Coconino National Forest and the forested Mogollon Plateau. The southern rim of this plateau, which has elevations exceeding 8,000 feet, coincides with the northern boundary of the Fort Apache [White Mountain Apache] Indian Reservation about sixty-five miles south of Leupp at its nearest point. The vegetation in the area is dominated sagebrush in the valleys, with plains grass prevailing on the desert plateaus to the northeast and south. Pinyon and juniper are found along the north side of the Mogollon Plateau, while forests of yellow [ponderosa] pine constitute the main vegetation type in the San Francisco Mountains.

"An extremely arid climate exists at Leupp, largely resulting from its position with respect to the Mogollon Plateau. Considerable quantities of moisture from the south and west are lost as air flowing from these directions passes over the high plateau. Thus, a mere 6.27 inches [7.39 inches for the study period] of precipitation falls in an average year, an amount comparable to that received in the very dry southwestern sections of Arizona. Nearly fifty percent of this small annual total falls during the months of July, August, and September when afternoon thunderstorms develop over the plateau regions in moist, tropical air from the Gulf of Mexico. However, these showers tend to be quite gentle and of short duration, rarely producing significant quantities of rain.

"In only two out of the thirty-two years for which annual precipitation totals were compiled [as of 1972] (1941 and 1972) have amounts exceeded ten inches. Oddly enough, the wettest month on record, October, 1972, with 6.94 inches, occurred during the normally dry fall. The total for this single month exceeded that normally received during the whole year.

"From January to June the mean monthly precipitation varies by only thirteen-hundredths of an inch, hovering around .30 inches per month. Most of the winter precipitation at Leupp is governed by eastward-moving storm systems that develop in the Pacific Ocean and manage to penetrate the mountain barriers to the west. About thirty percent of the winter precipitation falls in the form of snow and most of this soon melts under the warm mid-day sun."

The precipitation trends for Leupp show a gradual decline from 1939 to 1958, essentially flat from 1959 to 1976, followed by an increasingly upward trend from 1977 to 1987. From 1988 to 1990, there are indications of a declining trend.

The histogram shows a radically sharp peak for the seven inch precipitation frequency during the study period. There is some indication of a lognormal tendency, with several wet years present. The monthly distribution shows a definite peak from July through October, with a gradual decline from November through the annual minimum in June.

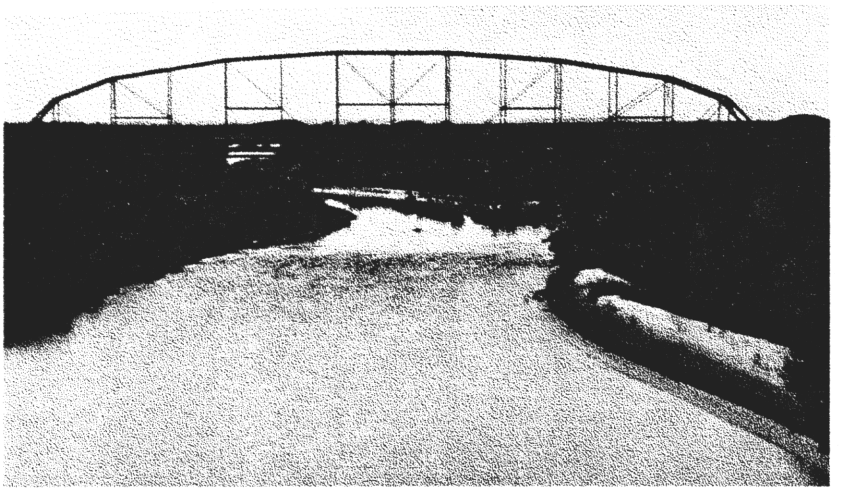


Figure 151. Little Colorado River at Leupp

Table 43. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Leupp , AZ
Station No.: 4872
Elevation: 4700
Latitude: 35d 17m
Longitude: 110d 58m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.00	0.09	0.06	0.43	0.21	0.10	0.78	0.20	0.00	0.05	0.78	1.07	3.77
1940	0.05	0.74	0.08	0.67	0.51	0.25	1.18	0.06	0.39	0.19	1.29	1.82	7.23
*1941	1.36	0.68	2.15	0.93	0.57	0.38	0.89	0.52	0.05	0.85	1.75	1.72	11.85
1942	1.65	0.46	0.79	0.36	0.32	0.20	0.97	0.00	0.00	0.52	1.86	0.25	7.38
*1943	1.54	0.13	0.33	0.75	0.30	0.94	0.37	0.09	0.00	1.08	1.47	1.32	8.31
*1944	0.50	0.02	1.47	0.42	0.53	0.94	1.03	0.63	0.00	0.52	0.00	0.82	6.89
*1945	0.00	1.17	0.71	0.64	0.03	1.48	0.54	0.00	0.00	1.25	0.75	0.38	6.96
*1946	0.50	0.00	0.50	0.20	0.10	0.20	0.00	0.00	0.00	2.39	2.54	0.50	6.93
*1947	0.00	0.31	0.00	0.21	0.00	0.00	0.00	0.92	0.00	0.43	2.01	0.20	4.08
1948	1.69	0.91	0.32	0.30	0.87	0.38	0.05	0.00	0.12	0.28	2.05	0.10	7.07
1949	0.49	0.00	0.60	0.82	0.13	0.33	0.06	0.87	0.72	0.76	0.45	1.74	6.97
1950	1.08	0.20	0.21	0.00	0.40	0.10	0.00	0.05	0.00	1.87	0.51	0.41	4.83
1951	0.00	0.00	0.00	0.16	0.05	0.08	0.60	0.39	0.00	3.03	1.70	0.85	6.86
1952	0.35	0.24	0.73	0.66	0.35	0.60	0.85	0.04	0.00	0.52	1.26	2.07	7.67
1953	0.00	0.81	0.09	0.00	0.21	0.43	0.30	0.04	0.00	2.86	1.74	0.00	6.48
1954	0.06	0.20	0.06	0.19	0.06	0.51	0.16	0.05	0.84	0.59	0.56	1.26	4.54
1955	0.88	0.01	0.06	0.32	0.11	0.02	0.02	0.13	2.98	0.51	1.12	0.00	6.16
1956	0.00	0.00	0.07	0.32	0.32	0.05	0.43	0.07	0.29	1.00	0.18	0.00	2.73
1957	0.31	0.01	0.00	0.72	0.65	0.84	0.25	0.21	0.25	1.82	2.04	0.00	7.10
1958	1.91	0.25	0.04	0.09	0.31	0.45	0.29	0.18	0.60	0.29	0.89	2.35	7.65
1959	0.19	0.21	0.02	0.00	0.18	0.00	0.75	0.18	0.41	1.32	0.65	0.17	4.08
1960	1.71	0.28	0.59	0.65	0.24	0.97	0.09	0.28	0.20	0.61	0.29	0.23	6.14
1961	1.75	0.48	0.52	0.02	0.28	0.90	0.02	0.00	0.19	0.89	1.94	1.31	8.30
1962	0.28	0.29	0.45	0.45	0.32	0.21	0.00	0.25	0.26	0.21	0.63	1.56	4.91
1963	1.58	0.78	0.15	0.90	0.33	0.02	0.24	0.00	0.00	0.16	1.94	0.50	6.60
1964	0.77	0.39	0.30	0.09	0.04	0.62	0.27	0.12	0.53	0.82	1.17	0.95	6.07
1965	0.00	0.29	0.27	0.50	0.24	0.48	0.53	0.56	0.32	1.98	0.43	1.33	6.93
1966	0.05	0.19	1.41	0.59	0.54	0.08	0.01	0.06	0.40	0.43	1.45	0.47	5.68
1967	0.41	0.32	0.78	0.11	0.00	0.15	0.13	0.06	1.63	1.73	1.14	1.69	8.15
1968	0.00	0.33	1.83	0.00	0.16	0.13	0.43	0.08	0.00	1.29	0.24	0.02	4.51
1969	0.51	0.55	0.16	1.02	0.40	0.51	0.06	1.11	0.00	0.95	0.86	1.03	7.16
1970	0.60	0.26	0.25	0.02	0.00	2.21	0.00	0.00	0.00	0.60	1.15	1.35	6.44
1971	0.16	0.00	0.20	0.00	0.66	0.00	0.52	0.17	0.00	2.33	0.93	1.51	6.48
1972	0.83	0.05	0.81	0.00	0.00	0.00	0.00	0.00	1.13	1.46	1.18	0.00	5.46
1973	6.94	0.25	0.90	0.06	2.02	2.00	0.45	0.07	0.35	0.98	0.61	0.17	14.80
1974	0.00	0.50	0.05	0.72	0.00	0.00	0.00	0.00	0.00	2.77	0.12	0.32	4.48
1975	1.20	0.37	0.10	0.20	0.02	0.56	0.52	0.14	0.00	1.24	0.25	2.72	7.32
1976	0.00	0.40	0.34	0.02	0.34	0.26	0.46	0.83	0.00	1.20	0.20	1.39	5.44
1977	0.61	0.19	0.30	0.46	0.72	0.03	0.40	0.00	0.19	2.10	1.07	2.49	8.56
1978	0.89	0.16	0.22	0.67	0.77	0.69	0.00	0.46	0.01	0.92	0.27	1.10	6.16
1979	1.24	1.04	0.87	1.11	0.11	0.61	0.03	0.97	0.02	0.15	0.68	0.00	6.83
1980	0.50	0.50	0.43	1.09	2.04	0.86	1.15	0.03	0.00	0.61	0.74	0.51	8.46
*1981	0.31	0.00	0.06	0.74	0.23	0.58	0.17	0.32	0.83	2.14	2.21	1.11	8.70
*1982	1.59	1.30	0.00	1.36	1.47	1.25	0.33	1.02	0.00	1.06	2.18	1.39	12.95
*1983	0.10	1.54	1.98	0.30	0.66	1.48	0.57	0.11	0.00	1.54	1.89	3.26	13.45
*1984	0.03	0.79	0.85	0.10	0.06	0.78	0.02	0.18	0.10	1.94	1.90	1.40	8.15
*1985	0.86	0.53	1.71	0.93	0.55	1.82	1.60	0.18	0.06	1.03	0.71	0.00	9.99
*1986	1.17	2.35	0.15	0.03	0.70	1.05	0.33	0.26	0.23	2.52	3.45	1.54	13.76
*1987	0.95	1.25	1.01	1.72	1.48	0.79	0.05	0.52	0.00	0.36	1.68	0.44	10.26
*1988	1.38	1.95	1.11	0.42	0.78	0.04	1.74	0.03	1.23	0.54	1.41	0.27	10.92
*1989	0.57	0.51	0.07	1.19	0.49	0.65	0.17	0.41	0.04	0.69	1.90	0.14	6.82
*1990	0.10	0.09	0.65	0.82	0.92	0.47	0.51	0.33	0.13	2.04	0.60	2.34	9.01
1939-90 Average	0.76	0.47	0.52	0.47	0.44	0.55	0.39	0.25	0.28	1.14	1.17	0.95	7.39

* Denotes year in which one or more monthly records are reconstructed.

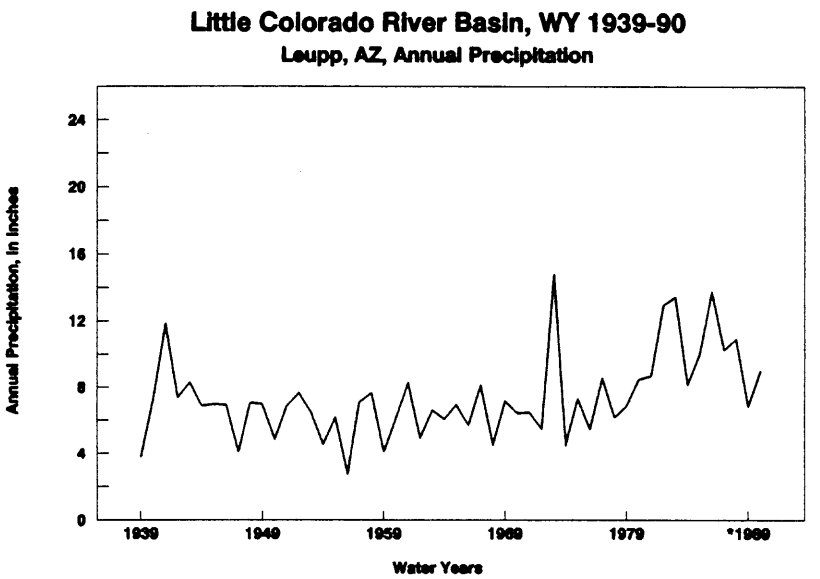


Figure 152. Leupp, AZ, Annual Precipitation, WY 1939-90

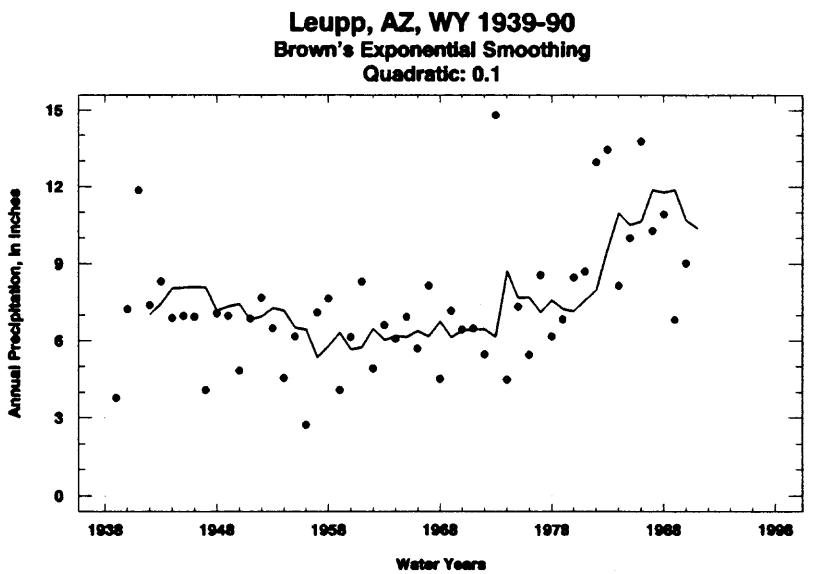


Figure 153. Leupp, AZ, Smoothed Annual Precipitation

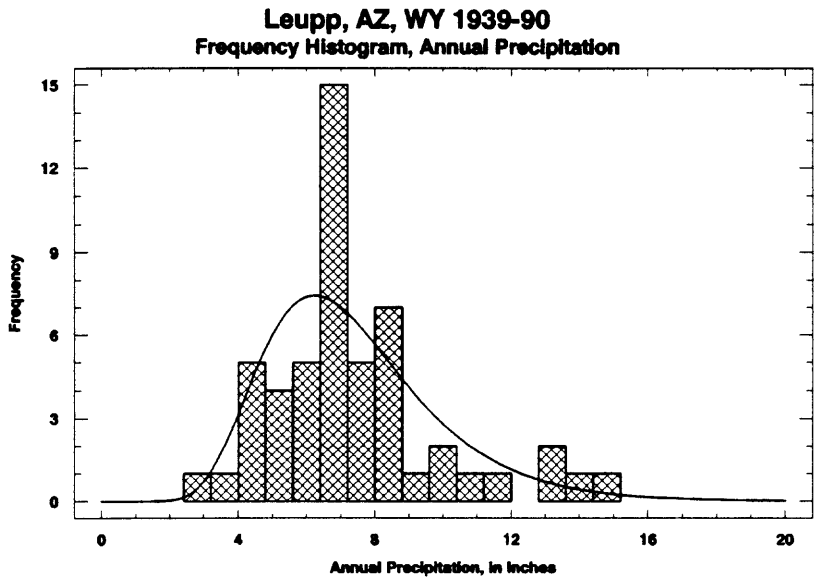


Figure 154. Leupp, AZ, Histogram of Annual Precipitation

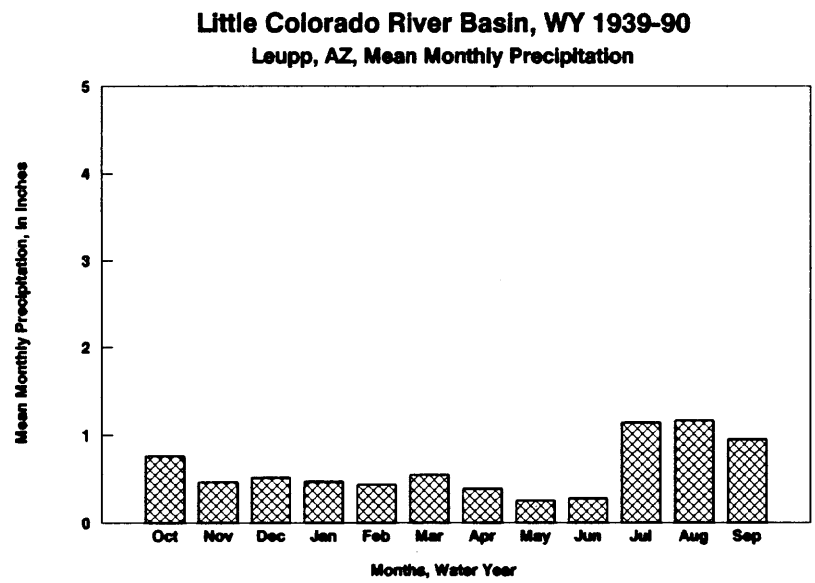


Figure 155. Leupp, AZ, Monthly Distribution of Precipitation

6.2.3.31 Lukachukai, AZ

This station is located about 45 miles northeast of the northeastern boundary of the LCR Basin within Arizona. It is included in the study to aid in interpolating missing data from LCR stations and to provide resolution to isohyetal maps. The period of record is from 1915 to 1919, from 1952 to 1965, and from 1967 to the present, with some months missing. Missing data from 1939 to 1990 is reconstructed.

As summarized in Sellars and Hill (1974, p. 312):

> "Lukachukai is a Navajo Indian town found in extreme northeastern Arizona at an elevation of 6,520 feet. Actual measurements are made two miles east of the town and from this point the Arizona-New Mexico border is only nine miles to the east. The terrain slopes gently downward to the northwest into the Chinle Valley, which lies within twenty-five miles of Lukachukai, while to the north and south higher elevations are reached in the Chuska Mountains and the Canyon de Chelly National Monument, respectively. About forty miles to the west lies the southeastern end of forested Black Mesa which is oriented in a southeast to northwest direction and averages better than 7,500 feet on its flat top. Thirty miles to the north-northeast Pastora Peak in the Carrizo Mountains rises to a height of 9,412 feet while eight miles to the northeast in the Chuska Mountains, Roof Butte ascends to an impressive 9,784 feet. In this particular region of the Navajo Indian Reservation the most famous attraction is undoubtedly the Canyon de Chelly National Monument, fourteen miles to the south, featuring two beautiful canyons consisting of red rock walls that have undergone considerable wind-erosion for thousands of years. The prevalent form of vegetation at higher elevations in the immediate area consists of yellow pine, although plains grass is found to the east. At intermediate elevations in the Carrizo and Chuska Mountains pinyon and juniper occur.
>
> "Lukachukai, being located on a desert plateau with much higher elevations to the east, has a dry climate, receiving an average of slightly under eleven inches of precipitation a year. Although annual totals have only been determined [as of 1972 and exclusive of 1915-1919], they have been remarkably constant from one year to the next, varying from 9.92 inches in 1955 to 14.06 inches in 1969. Over fifty percent of the yearly precipitation normally occurs during the four month period extending from July through October in association with moist, tropical air that enters northeastern Arizona from the Gulf of Mexico. Most of the heavy thundershowers that originate in this flow of moist air are confined to the higher elevations in the Chuska Mountains to the east. Occasionally, severe late summer rains may result from an influx of moisture from the Gulf of California in conjunction with weakened tropical storm systems.
>
> "During the remaining months of the year Lukachukai receives minimal amounts of precipitation. The eastward-moving storm systems that originate in the Pacific Ocean and provide Arizona with most of its winter precipitation rarely have a significant effect on the area, bringing with them more blowing dust from Chinle Valley than needed moisture. Almost all of the precipitation that falls during the cold months is in the form of snow, but unless unusually cold periods prevail, much of this melts after a few days."

The precipitation trends during the study period for Lukachukai indicate a gradual decline from 1939 to 1960 followed by a largely flat trend from 1961 to 1990.

The histogram shows a sharp peak around twelve and fourteen inches, with thirteen inches occuring less frequently. A barely noticeable positive skewness may be present. The monthly distribution of precipitation shows a peak from July through October, followed by a gradual decline to the annual minimum in June.

Table 44. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Lukachukai, AZ
Station No.: 5129
Elevation: 6520
Latitude: 36d 25m
Longitude: 109d 14m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.24	0.26	1.43	1.19	0.72	1.11	0.92	0.32	0.00	1.06	1.39	2.81	11.45
*1940	0.39	0.69	0.37	1.17	1.46	0.39	0.93	0.74	0.23	0.78	2.44	3.48	13.08
*1941	1.28	0.93	2.77	1.09	2.02	1.62	2.78	2.01	1.47	1.08	2.51	2.82	22.38
*1942	3.50	0.72	1.22	0.34	1.16	0.41	1.53	0.01	0.00	1.13	1.59	0.90	12.51
*1943	1.88	0.11	1.38	2.70	0.21	1.61	0.43	0.28	0.16	0.91	4.86	0.84	15.38
*1944	1.25	0.38	0.77	1.39	1.07	1.41	1.13	1.22	0.02	0.89	1.25	1.78	12.57
*1945	0.43	1.26	1.21	1.00	0.55	1.72	0.53	0.06	0.20	2.07	1.86	0.32	11.19
*1946	0.95	0.03	1.32	0.38	0.34	0.81	0.71	0.45	0.07	2.18	2.60	1.07	10.91
*1947	0.76	1.52	0.54	0.42	0.18	0.20	0.11	1.58	0.18	0.79	4.16	1.50	11.93
*1948	2.12	0.88	1.07	0.46	1.42	1.12	0.52	0.13	0.98	1.44	1.88	1.37	13.40
*1949	2.62	0.14	1.50	1.99	0.64	0.53	0.44	0.74	1.54	1.94	0.77	1.18	14.03
*1950	1.11	0.12	0.55	0.56	0.67	0.34	0.03	0.13	0.33	1.74	0.48	0.76	6.84
*1951	0.04	0.19	0.15	0.68	0.43	0.37	0.85	0.44	0.00	1.16	2.18	0.26	6.75
1952	1.17	1.16	1.95	2.69	0.65	1.22	1.57	0.35	0.42	1.35	0.88	1.27	14.68
1953	0.00	1.76	0.72	0.60	0.65	0.65	1.05	0.04	0.36	2.17	1.76	0.08	9.84
1954	1.44	0.85	0.42	0.44	0.28	1.95	0.24	0.79	0.09	3.65	0.55	2.10	12.80
1955	1.62	0.14	0.48	0.40	1.29	0.16	0.17	0.68	1.11	2.29	2.73	0.03	11.10
1956	0.10	0.78	0.18	2.36	1.52	0.55	0.68	0.54	0.32	1.95	1.88	0.00	10.86
1957	0.69	0.10	0.44	2.02	0.78	0.52	1.99	2.53	0.16	2.13	3.55	0.00	14.91
1958	2.44	0.81	0.14	0.58	0.97	2.03	0.63	0.23	0.33	0.34	0.30	2.22	11.02
*1959	0.87	0.76	0.11	0.26	0.67	0.01	1.60	0.01	0.71	0.66	2.74	0.47	8.87
*1960	1.65	0.31	1.42	0.75	0.93	0.25	0.00	0.22	0.72	0.82	0.70	0.00	7.77
*1961	1.65	0.26	1.00	1.00	0.51	3.37	0.63	0.49	0.00	1.08	0.16	0.70	10.85
1962	0.62	1.43	1.85	0.52	0.44	0.47	0.20	0.30	0.19	0.05	0.53	2.81	9.41
1963	2.58	1.98	0.55	1.40	0.52	0.10	0.00	0.00	0.23	0.94	5.32	0.15	13.77
1964	0.98	0.15	1.48	0.20	0.35	4.74	0.47	0.00	0.11	1.21	1.36	2.40	13.45
*1965	0.00	0.00	0.78	1.50	0.84	0.78	1.28	0.90	1.18	3.22	1.10	1.48	13.05
*1966	1.20	1.42	2.49	0.45	0.56	0.35	0.38	0.09	0.38	2.11	1.61	1.20	12.23
*1967	0.46	0.56	0.22	0.00	0.00	0.85	0.41	0.13	0.05	0.56	0.88	0.99	5.11
*1968	0.00	0.90	2.63	0.31	0.64	0.82	0.59	0.00	0.42	0.33	0.28	0.45	7.37
*1969	1.32	0.99	1.14	0.06	0.80	1.50	0.05	0.75	0.18	2.25	1.81	0.48	11.33
1970	4.27	0.91	1.00	1.25	0.10	2.15	3.50	0.00	0.16	0.79	0.52	2.62	17.27
1971	0.40	0.39	0.54	1.20	0.50	0.45	0.85	0.32	0.00	0.21	2.93	1.03	8.82
1972	2.50	0.61	1.30	0.10	0.00	0.25	0.00	0.01	1.56	0.52	0.80	0.47	8.12
1973	4.77	0.70	6.14	3.43	1.05	2.05	0.80	0.10	0.00	0.50	1.01	1.38	21.93
*1974	0.05	1.40	0.17	1.80	0.37	0.00	0.28	0.00	0.00	1.76	0.00	0.05	5.88
1975	0.84	0.33	0.06	0.75	0.13	0.94	0.09	0.24	0.00	1.97	0.00	1.50	6.85
1976	0.30	1.10	1.80	1.20	0.62	0.14	0.35	2.40	0.00	2.06	1.05	2.91	13.93
1977	0.29	0.25	0.25	1.20	0.30	0.05	0.00	0.00	0.00	1.53	2.43	0.00	6.30
1978	0.06	0.00	0.73	1.71	0.81	1.29	0.50	0.60	0.00	0.00	0.00	0.00	5.70
1979	0.60	2.90	2.13	1.40	0.80	1.08	0.20	2.00	0.61	0.37	0.44	0.00	12.53
*1980	0.48	1.50	1.42	2.20	1.09	1.02	0.20	0.00	0.00	0.94	1.56	1.41	11.82
*1981	0.78	0.00	0.00	0.17	0.50	2.34	0.20	0.62	0.59	2.44	0.73	1.78	10.15
*1982	0.62	2.15	0.50	0.44	0.00	1.45	0.38	0.00	0.00	0.70	3.29	1.39	10.92
*1983	0.00	1.49	0.70	0.70	0.00	1.96	0.40	0.00	0.68	5.03	1.40	0.30	12.66
*1984	1.69	0.00	1.31	0.00	0.30	0.30	0.89	0.00	0.35	1.50	4.96	2.80	14.10
1985	1.38	0.00	0.77	2.90	0.70	0.40	0.36	0.00	0.00	1.74	1.59	0.85	10.69
*1986	1.58	0.58	0.00	0.00	0.00	1.14	0.00	0.00	0.57	2.67	1.17	1.43	9.14
*1987	0.81	1.52	0.75	0.75	0.60	0.00	0.30	0.17	0.00	1.74	1.51	0.43	8.58
1988	1.32	1.75	0.20	1.92	0.12	0.01	3.53	1.94	1.77	0.61	3.93	1.40	18.50
1989	0.00	1.47	0.64	0.00	1.20	0.19	0.00	0.00	0.00	0.44	1.24	0.00	5.18
*1990	0.20	0.00	0.00	0.00	0.60	0.00	0.95	0.77	0.36	3.05	1.67	3.52	11.12
1939-90 Average	1.12	0.78	1.01	1.00	0.64	0.95	0.70	0.49	0.36	1.44	1.70	1.18	11.37

* Denotes year in which one or more monthly records are reconstructed.

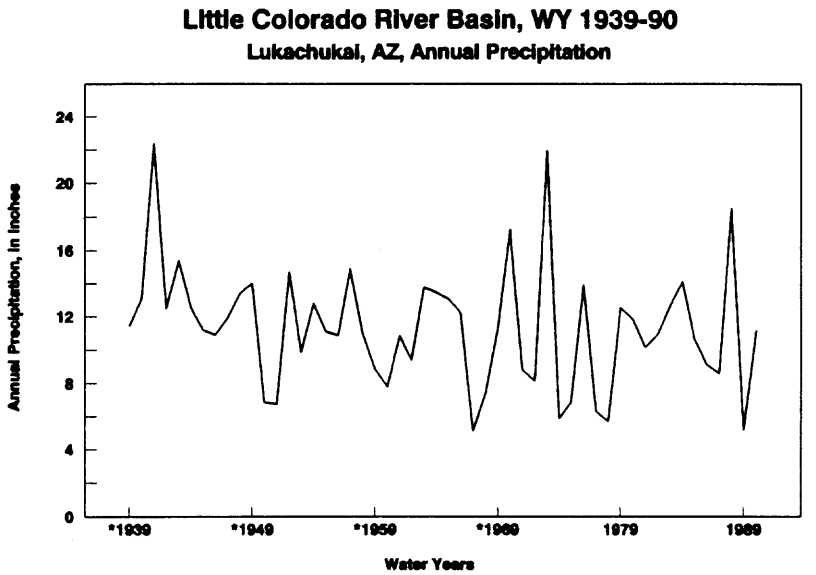


Figure 156. Lukachukai, AZ, Annual Precipitation, WY 1939-90

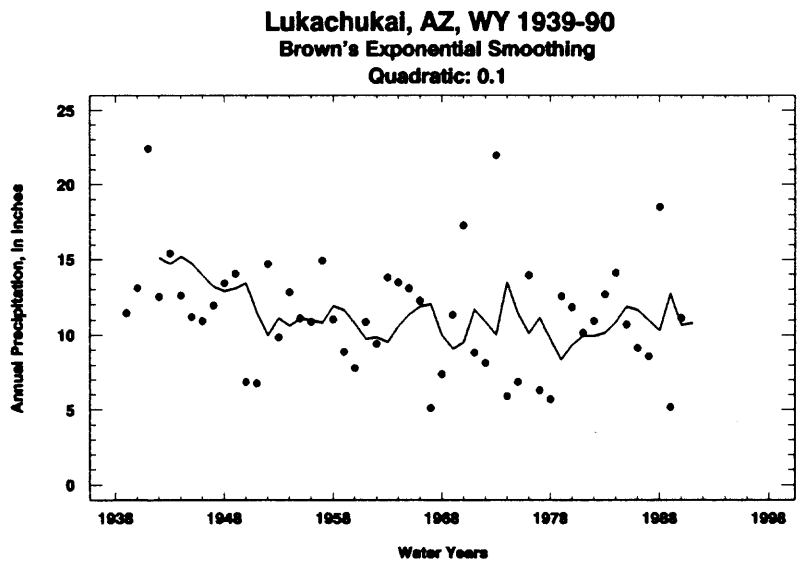


Figure 157. Lukachukai, AZ, Smoothed Annual Precipitation, WY 1939-90

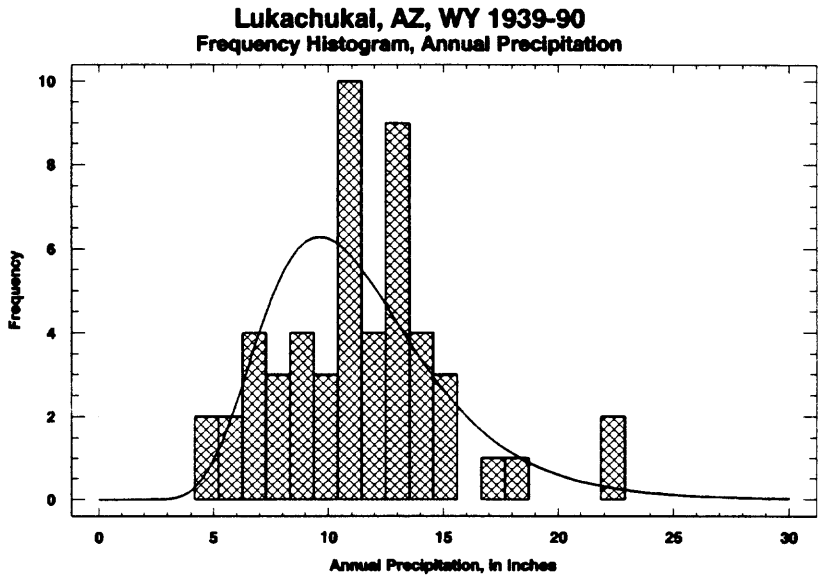


Figure 158. Lukachukai, AZ, Histogram of Annual Precipitation

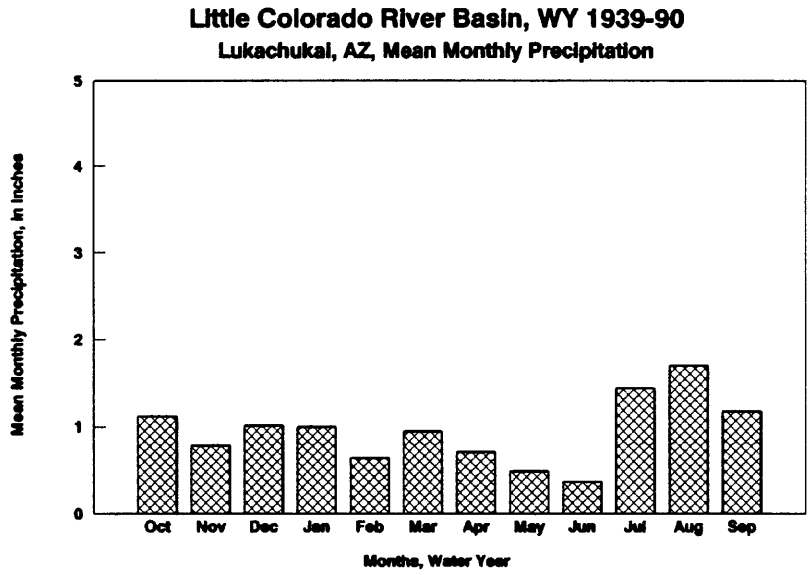


Figure 159. Lukachukai, AZ, Monthly Distribution of Precipitation

6.2.3.32 McNary, AZ

McNary is located along the southerly border of the LCR Basin, some 40 miles west of Springerville. The period of record extends from 1934 to the present with some months missing during World War II.

As summarized in Sellars and Hill (1974, p. 322):

"McNary is located at an elevation of about 7,300 feet in the forested mountain country of east-central Arizona. It lies on gently sloping ground two miles northwest of the North Fork of the White River, which flows out of the magnificent White Mountains a short distance to the east. Beyond McNary the river follows a southwestward course for about thirty miles until it merges with the Black River to form the westward flowing Salt River. In general, the terrain slopes downward toward the southwest into the spectacular steep-walled Salt River Canyon. Highest elevations near McNary are reached in the White Mountains, which rise to 10,115 feet on Green's Peak, sixteen miles to the east, and to 11,590 feet on Baldy Peak, 20 miles to the southeast. This lake-studded high mountain country of eastern Arizona attracts many summer visitors from the torrid desert sections of the state. To the west-northwest of the town lies the broad forested Mogollon Plateau which stretches northwestward for more than 100 miles, rising to an average elevation of more than 7,500 feet along its southern rim. The saddle connecting this plateau with the White Mountains dips to a minimum elevation of about 6,500 feet ten miles northwest of McNary. Further to the north of the town the terrain descends gradually into the semi-arid valley of the Little Colorado River. McNary is located in one of the most extensive ponderosa pine forests in the world. These forests are interspersed with beautiful open mountain meadows in the White Mountains. With decreasing elevation to the north and south of McNary the prevailing vegetation type changes first to juniper and pinyon and then to plains grass along the Little Colorado River and to chaparral and oak woodland in the Salt and Black River Canyons.

"McNary is one of the few towns in Arizona that receives enough precipitation during a normal year to support a luxuriant growth of vegetation. Drought conditions exist consistently only in May and June, which together receive less rain, on the average, than the next driest month (April). About 80 percent of the town's annual precipitation occurs in three summer months and four winter months. Most of the warm season precipitation falls from thunderstorms that form over the tall peaks of the White Mountains practically every afternoon from early July until early September. These storms, which feed on moist currents of tropical air from the Gulf of Mexico, produce moderate to heavy rain showers. However, these showers are very localized and rarely last longer than 30 minutes. The most continuous and productive summer rains on record at McNary have been associated with rare surges of extremely moist tropical air from the Gulf of California.

"Winter precipitation at McNary generally lasts longer and is much more widespread than that of summer. It is associated with middle latitude storms that move eastward from the Pacific Ocean. These storms are capable of producing unusually long periods of heavy precipitation, particularly when they move further south than normal or when they form or intensify off the coast of California. Such a storm, moving onto the continent near San Francisco, flooded McNary with a record 4.43 inches of precipitation on December 28, 1967. About 80 percent of the cool season precipitation at the town usually falls as snow. During the colder and wetter winters snow may accumulate to a depth of several feet, particularly in depressions and on the northern slopes."

Precipitation trends at McNary during the study period indicate a gradual increase from 1939 to 1980, followed by a possible decline from 1987 to 1990.

The histogram shows a largely lognormal distribution with a peak at 28 inches, with a positive skewness up to about 44 inches. This is the wettest gaged climate station within the Little Colorado River Basin. The monthly distribution shows a sharp peak in July and August, and a secondary peak from December through March. The precipitation dramatically declines in May and June, the annual minimum.

Table 45. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed data
Station Name: McNary, AZ
Station No.: 5412
Elevation: 7340
Latitude: 34d 07m
Longitude: 109d 51m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.00	0.00	3.92	3.30	1.74	1.40	1.64	0.00	0.00	1.54	2.64	2.96	19.14
*1940	0.50	1.01	0.57	0.87	2.50	0.50	1.20	0.00	0.00	0.50	3.38	5.31	16.33
*1941	2.40	1.90	3.13	2.70	3.05	4.10	3.12	1.07	0.42	3.97	4.10	3.74	33.70
*1942	1.84	2.69	2.46	1.38	2.47	0.97	2.07	0.00	0.00	1.49	2.63	1.27	19.27
1943	6.19	0.04	4.10	2.54	1.04	3.28	0.75	0.62	0.47	1.45	4.42	2.07	26.97
1944	2.04	0.06	1.73	0.80	3.49	2.18	1.90	0.62	0.00	2.23	4.10	3.27	22.42
1945	0.79	2.63	2.40	1.64	1.09	4.29	0.67	0.09	0.34	3.02	4.42	0.91	22.29
1946	2.06	0.07	3.72	2.02	1.10	2.05	2.16	0.00	0.00	3.54	4.80	5.32	26.84
1947	2.15	3.25	1.89	0.89	1.26	0.21	0.18	3.72	0.21	1.63	8.66	2.92	26.97
1948	3.53	1.94	1.39	0.32	3.23	2.64	0.15	0.00	0.46	3.83	2.27	1.67	21.43
1949	3.38	0.05	4.89	4.35	2.00	1.88	0.73	0.49	1.52	7.49	3.09	2.74	32.61
1950	2.25	0.25	2.23	1.26	0.80	1.50	0.26	0.20	0.77	1.92	1.50	1.74	14.68
1951	0.25	0.46	0.00	2.53	1.42	1.90	2.62	0.60	0.00	4.10	5.43	1.17	20.48
1952	3.30	1.95	4.58	6.53	1.11	5.11	3.72	0.00	1.03	2.56	2.93	2.63	35.45
1953	0.00	3.21	2.06	0.89	1.34	3.65	2.03	0.23	0.81	3.48	3.87	0.00	21.57
1954	0.32	1.51	1.15	2.25	0.72	8.29	0.00	0.75	0.53	4.80	4.80	2.35	27.47
1955	0.87	0.53	0.96	3.53	1.56	0.12	0.01	0.30	2.58	4.76	5.46	0.39	21.07
1956	1.44	2.05	3.24	3.27	2.42	0.11	2.05	0.00	0.24	3.31	1.89	0.56	20.58
1957	1.46	0.00	0.66	9.07	1.24	2.11	1.60	1.81	0.63	3.75	4.30	0.29	26.92
1958	3.55	1.89	0.53	0.27	4.16	5.99	2.30	0.31	1.18	1.43	4.96	3.41	29.98
1959	2.42	1.75	0.30	1.17	1.68	0.00	0.93	0.00	0.94	1.83	5.88	1.15	18.05
1960	5.63	1.98	4.76	3.14	0.81	1.76	0.60	1.30	0.37	0.87	1.73	1.23	24.18
1961	3.63	0.52	1.51	1.25	0.85	3.47	0.31	0.07	0.38	2.67	4.70	1.78	21.14
1962	4.52	1.16	3.77	3.09	2.28	1.14	0.06	0.37	0.74	2.87	1.41	4.42	25.83
1963	2.05	2.09	1.26	1.40	2.60	1.88	0.72	0.00	0.00	3.08	5.97	1.95	23.00
1964	1.50	2.42	0.28	1.12	0.53	1.96	1.44	0.00	0.04	5.16	4.87	4.75	24.07
1965	0.37	1.99	1.56	2.92	3.99	2.97	3.63	0.68	0.88	6.54	2.07	1.81	29.41
1966	1.08	4.76	9.26	1.49	1.70	0.51	0.27	0.28	0.53	2.88	1.82	2.90	27.48
1967	0.90	1.49	3.05	1.07	0.24	3.45	0.54	0.96	1.22	6.35	5.71	2.44	27.42
1968	0.17	1.76	10.73	2.16	1.10	3.62	1.55	0.21	0.55	5.01	3.72	0.53	31.11
1969	0.95	2.05	4.68	3.64	2.41	2.50	0.37	1.60	0.04	3.77	3.50	1.02	26.53
1970	1.54	2.04	1.12	0.31	0.43	3.88	2.23	0.51	0.41	3.64	3.61	4.05	23.77
1971	1.93	0.50	2.18	0.87	0.95	0.68	1.26	0.02	0.00	1.84	6.87	3.55	20.65
1972	7.51	2.14	4.55	0.09	0.12	0.00	0.07	0.60	5.26	2.01	2.67	1.69	26.71
1973	8.15	3.06	2.73	1.92	3.54	9.33	1.21	3.20	1.42	4.29	1.55	0.26	40.66
1974	0.11	3.06	0.26	5.35	0.61	2.13	0.40	0.15	0.00	2.46	3.88	2.52	20.93
1975	8.28	0.58	1.08	2.84	3.64	4.38	2.47	0.50	0.00	4.08	2.39	2.08	32.32
1976	0.34	2.64	1.61	0.86	3.56	3.08	2.84	1.58	0.55	7.62	3.57	3.13	31.38
1977	1.99	0.77	0.25	3.95	0.57	2.46	1.55	0.65	1.46	4.46	3.33	2.93	24.37
1978	2.63	1.33	0.95	4.04	6.26	7.57	1.21	1.23	0.41	2.34	2.72	1.49	32.18
1979	1.72	8.31	9.24	7.00	1.14	5.07	0.55	4.37	1.43	0.87	3.03	0.51	43.24
1980	0.78	1.55	1.63	9.46	8.08	3.37	1.08	0.00	0.00	2.38	4.70	2.16	35.19
1981	2.00	0.55	1.83	0.78	2.59	5.57	1.87	0.60	0.28	3.69	3.27	1.68	24.71
1982	1.01	2.17	0.14	5.22	3.49	4.48	0.30	2.02	0.05	3.01	5.69	3.12	30.70
1983	0.10	5.24	4.29	3.98	2.83	6.10	1.65	0.06	0.00	4.04	3.20	4.30	35.79
1984	4.02	2.14	3.51	1.59	0.00	0.89	2.45	0.25	0.61	4.68	4.93	4.50	29.57
1985	5.15	1.67	6.83	4.41	2.15	2.93	2.41	0.12	0.56	4.02	1.42	7.27	38.94
*1986	2.46	3.55	0.79	0.49	3.30	4.47	0.99	0.46	0.68	3.52	3.72	3.05	27.48
1987	2.96	3.91	4.09	3.20	4.55	2.94	0.90	0.98	1.14	4.55	3.18	1.51	33.91
*1988	1.77	3.13	1.74	3.71	1.68	0.00	2.54	0.46	2.89	3.00	7.61	1.45	29.98
1989	1.59	1.31	1.27	2.14	1.25	1.28	0.05	0.39	0.00	2.58	3.09	0.63	15.58
1990	1.55	0.06	0.50	1.00	2.19	1.46	1.06	0.60	0.05	3.81	3.37	3.82	19.47
1939-90 Average	2.29	1.87	2.64	2.62	2.09	2.84	1.32	0.67	0.66	3.36	3.82	2.39	26.58

* Denotes year in which one or more monthly records are reconstructed.

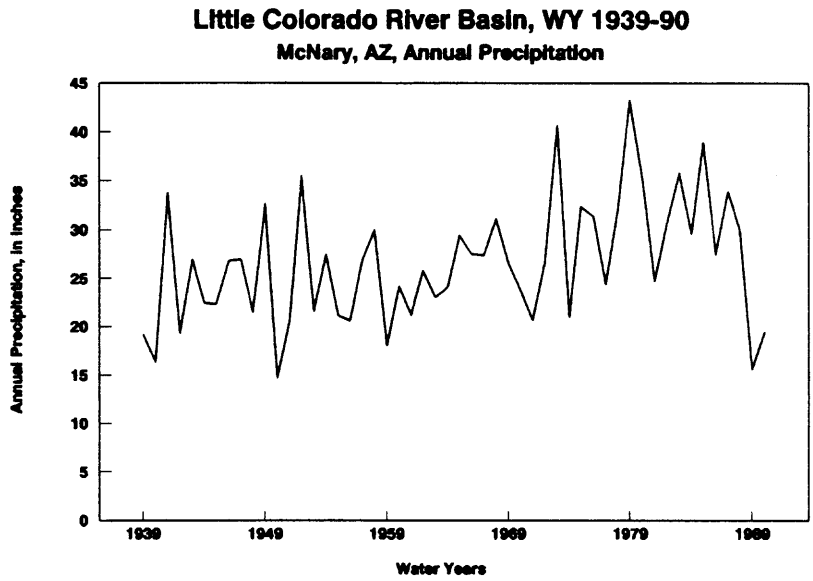


Figure 160. McNary, AZ, Annual Precipitation, WY 1939-90

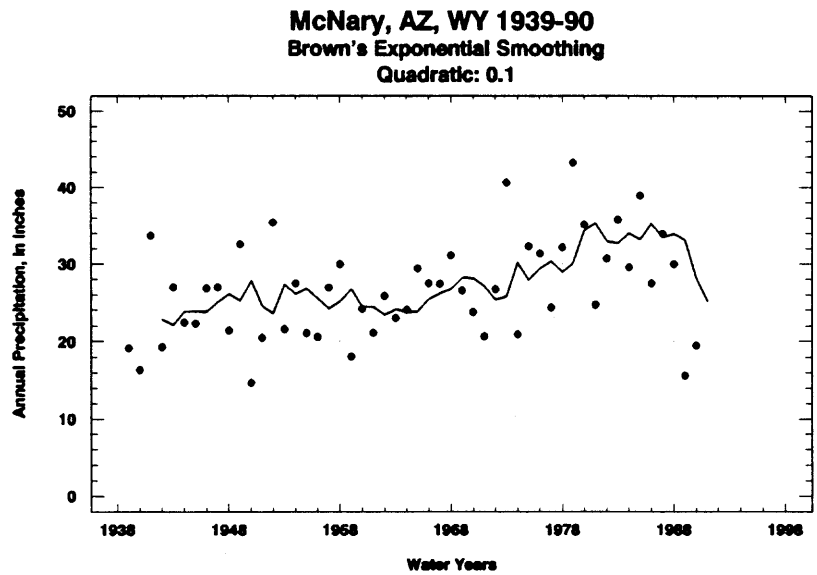


Figure 161. McNary, AZ, Smoothed Annual Precipitation, WY 1939-90

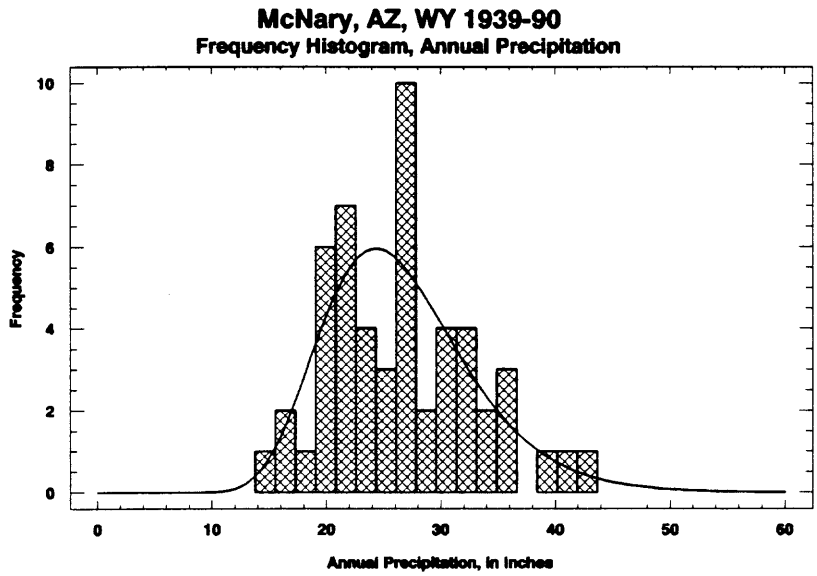


Figure 162. McNary, AZ, Histogram of Annual Precipitation

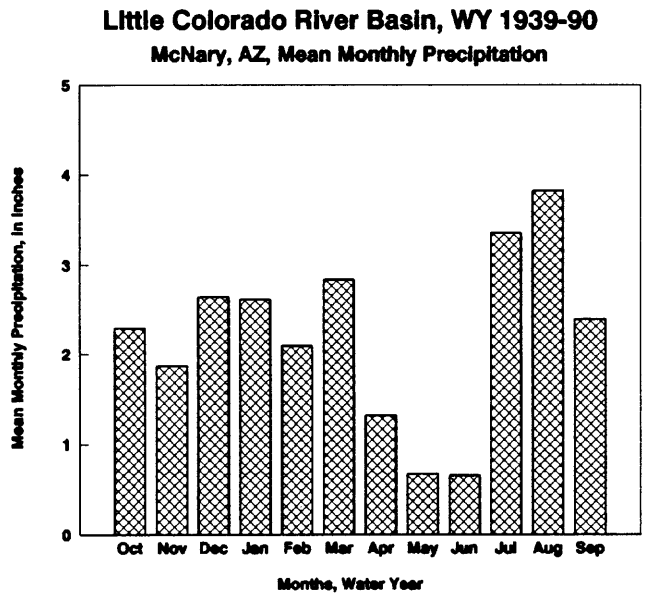


Figure 163. McNary, AZ, Monthly Distribution of Precipitation

6.2.3.33 Monument Valley, AZ

This station has replaced the Kayenta station since about 1981. The short period of record required that the majority of years be reconstructed. The local physiography is adequaltely covered under the Kayenta entry, since Monument Valley lies only about 15 miles distance to the northeast. This is a station which lies about thirty miles northeast of the northernmost border of the LCR Basin and is included in the study, along with Kayenta, to provide interpolation of missing data from nearby LCR stations, and to enable greater resolution on isohyetal maps.

The precipitation trends for this station, which may not be representative due to the extensive reconstruction in a region with few stations available for interpolation, indicates a gradual decline from 1939 to 1990.

The histogram shows an irregular lognormal distribution with a peak at about six inches. The distribution is positively skewed. The monthly distribution indicates a peak from July through October, with a gradual decline from November through the annual minimum in June. This is an extremely dry area, with an average annual precipitation of just under six and one-half inches.

Table 46. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Monument Valley, AZ
Station No.: 5564
Elevation: 5564
Latitude: 36d 59m
Longitude: 110d 06m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.16	0.21	0.42	0.49	0.12	0.74	0.24	0.27	0.01	1.15	0.20	1.00	5.02
*1940	0.00	0.18	0.00	0.12	0.81	0.23	0.45	0.26	0.22	0.91	1.10	2.28	6.55
*1941	1.16	0.90	2.41	1.13	1.25	1.83	1.47	1.21	0.52	0.80	1.49	1.49	15.67
*1942	3.00	0.53	0.65	0.01	0.36	0.34	1.13	0.06	0.00	0.45	0.76	0.41	7.70
*1943	1.51	0.06	0.84	0.57	0.16	1.21	0.12	0.22	0.22	0.40	2.33	0.27	7.91
*1944	0.54	0.29	0.69	0.96	0.19	0.55	1.16	0.98	0.03	0.57	0.73	0.83	7.52
*1945	0.06	1.20	0.15	0.79	0.35	0.81	0.71	0.17	0.26	1.97	1.57	0.00	8.03
*1946	0.57	0.01	0.13	0.00	0.09	0.74	1.79	0.21	0.00	1.96	1.60	0.32	7.42
*1947	0.40	0.89	0.00	0.18	0.00	0.01	0.01	0.58	0.16	0.47	2.57	0.71	5.96
*1948	2.73	0.35	0.78	0.28	1.48	0.70	0.33	0.05	0.67	0.41	1.49	0.68	9.96
*1949	1.49	0.10	1.10	2.07	0.78	0.49	0.36	0.59	0.99	0.78	0.34	0.31	9.38
*1950	1.42	0.34	0.08	0.00	0.44	0.34	0.06	0.24	0.52	0.96	0.37	0.36	5.15
*1951	0.00	0.11	0.01	0.67	0.02	0.11	0.54	0.82	0.00	0.35	0.85	0.46	3.94
*1952	0.52	0.97	1.00	1.24	0.33	0.30	1.00	0.18	0.63	1.22	0.85	1.92	10.16
*1953	0.00	1.32	0.32	0.04	0.30	0.11	0.60	0.01	0.02	2.70	1.93	0.21	7.56
*1954	0.33	0.63	0.21	0.33	0.12	0.33	0.09	0.64	0.58	1.86	0.44	1.74	7.31
*1955	0.79	0.23	0.30	0.08	0.51	0.02	0.08	0.58	0.83	0.55	1.54	0.00	5.50
*1956	0.00	0.27	0.00	1.20	0.36	0.37	0.31	0.46	0.00	0.92	1.19	0.01	5.08
*1957	0.23	0.10	0.12	1.24	0.44	0.59	1.10	1.56	0.38	1.28	2.00	0.02	9.06
*1958	1.66	1.16	0.16	0.17	0.11	0.82	0.15	0.13	0.11	0.15	0.31	0.64	5.57
*1959	0.29	0.29	0.03	0.03	0.00	0.00	0.89	0.00	0.35	0.48	1.24	0.00	3.60
*1960	1.27	0.41	0.84	0.20	0.74	0.13	0.30	0.12	0.27	0.50	0.02	0.53	5.32
*1961	2.43	0.29	1.18	0.46	0.10	1.77	0.32	0.22	0.00	1.21	0.78	0.68	9.45
*1962	0.94	0.47	0.74	0.00	0.36	0.15	0.01	0.04	0.24	0.00	0.27	0.95	4.18
*1963	1.48	1.41	0.20	0.47	0.53	0.29	0.36	0.02	0.07	0.22	3.01	0.12	8.17
*1964	0.67	0.09	0.42	0.14	0.16	2.23	0.55	0.29	0.09	0.28	0.46	0.58	5.96
*1965	0.00	0.69	0.84	0.96	1.60	1.19	0.97	0.77	0.50	1.61	0.83	1.76	11.71
*1966	0.66	0.93	1.05	0.34	0.79	0.00	0.52	0.33	0.06	1.14	1.02	0.95	7.80
*1967	0.79	0.19	0.60	0.12	0.00	0.17	0.06	0.38	0.53	0.62	1.16	0.52	5.13
*1968	0.00	0.22	0.80	0.00	0.31	0.43	0.33	0.21	0.11	0.72	0.93	0.13	4.21
*1969	0.76	0.58	0.42	0.24	0.31	0.53	0.01	0.60	0.53	0.82	0.37	0.12	5.29
*1970	2.90	0.43	0.38	0.49	0.13	1.16	1.00	0.00	0.25	0.31	0.97	1.34	9.34
*1971	0.30	0.35	0.31	0.25	0.17	0.13	0.13	0.20	0.01	0.20	1.99	0.44	4.49
*1972	1.33	0.64	0.79	0.03	0.00	0.05	0.00	0.00	0.58	0.04	0.54	0.40	4.39
*1973	5.19	0.44	2.22	1.17	0.25	1.46	0.34	0.33	0.48	0.39	0.76	0.72	13.75
*1974	0.12	0.65	0.34	0.76	0.35	0.03	0.04	0.00	0.26	0.49	0.08	0.31	3.42
*1975	1.17	0.37	0.15	0.17	0.89	0.97	0.31	0.28	0.04	1.87	0.00	0.94	7.15
*1976	0.13	1.15	0.66	0.30	0.41	0.00	0.22	1.44	0.01	1.37	0.26	1.91	7.84
*1977	0.11	0.17	0.01	0.70	0.06	0.00	0.00	0.00	0.00	1.22	1.71	0.23	4.21
*1978	0.04	0.23	0.45	1.18	0.39	0.60	0.47	0.83	0.06	0.33	0.00	0.37	4.94
*1979	0.75	2.32	1.36	0.93	0.26	0.48	0.11	1.21	0.30	0.24	0.89	0.00	8.85
*1980	1.42	1.09	0.99	0.85	0.79	0.83	0.78	0.26	0.00	0.26	1.19	0.94	9.40
1981	0.56	0.03	0.00	0.00	0.16	1.79	0.63	1.27	0.28	0.37	0.44	0.58	6.11
*1982	1.27	1.01	0.00	1.19	0.12	0.42	0.00	1.04	0.00	0.00	0.93	1.17	7.15
1983	0.00	0.48	0.29	0.29	0.24	0.64	0.21	0.10	0.00	0.46	0.32	1.90	4.93
1984	0.07	0.00	0.16	0.15	0.00	0.15	0.00	0.00	0.42	0.28	0.26	0.00	1.49
*1985	1.17	0.00	1.18	0.59	0.04	0.20	0.26	0.00	0.00	1.20	0.00	1.18	5.82
*1986	0.20	0.30	0.00	0.00	0.00	0.22	0.50	0.43	0.00	0.70	1.31	0.62	4.28
*1987	0.85	1.06	0.00	0.33	0.00	0.40	0.44	0.96	0.81	1.60	4.18	0.00	10.63
1988	1.66	2.22	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.90	5.80
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.75	1.01	0.00	1.80
1990	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.18	1.63	2.93
1939-90 Average	0.84	0.53	0.49	0.44	0.32	0.50	0.40	0.38	0.23	0.75	0.94	0.66	6.48

* Denotes year in which one or more monthly records are reconstructed.

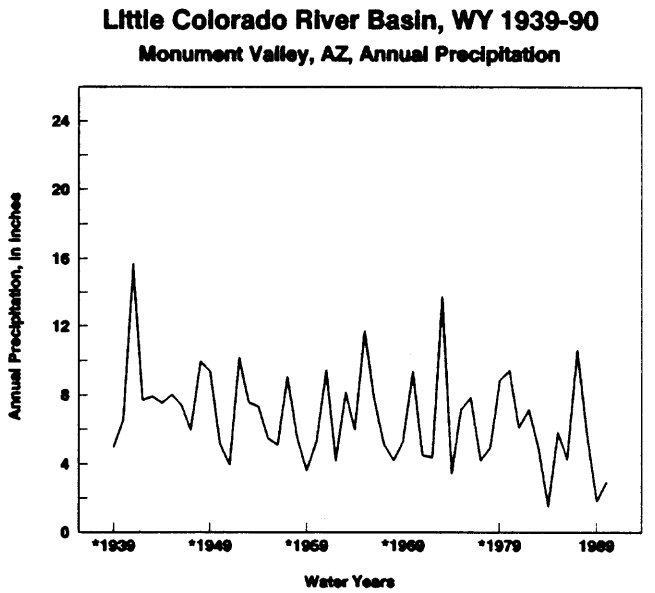


Figure 164. Monument Valley, AZ, Annual Precipitation, WY 1939-90

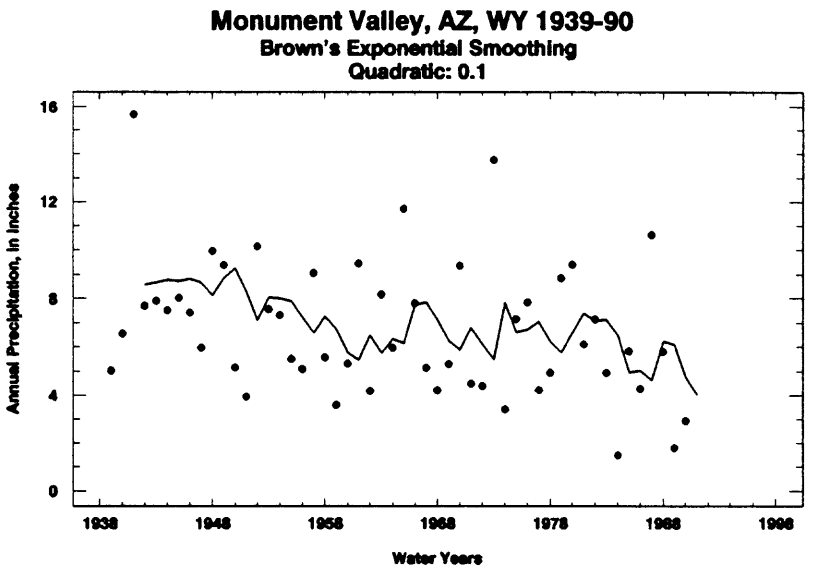


Figure 165. Monument Valley, AZ, Smoothed Annual Precipitation WY 1939-90

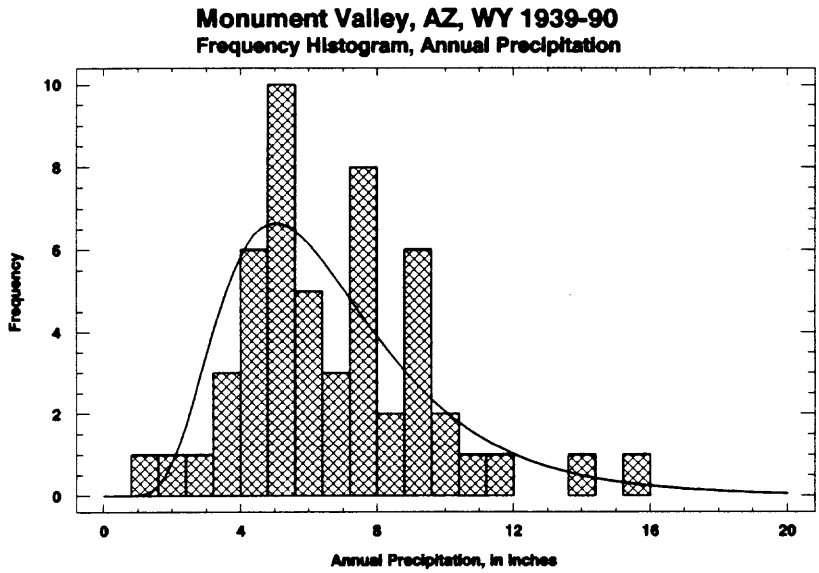


Figure 166. Monument Valley, AZ, Histogram of Annual Precipitation

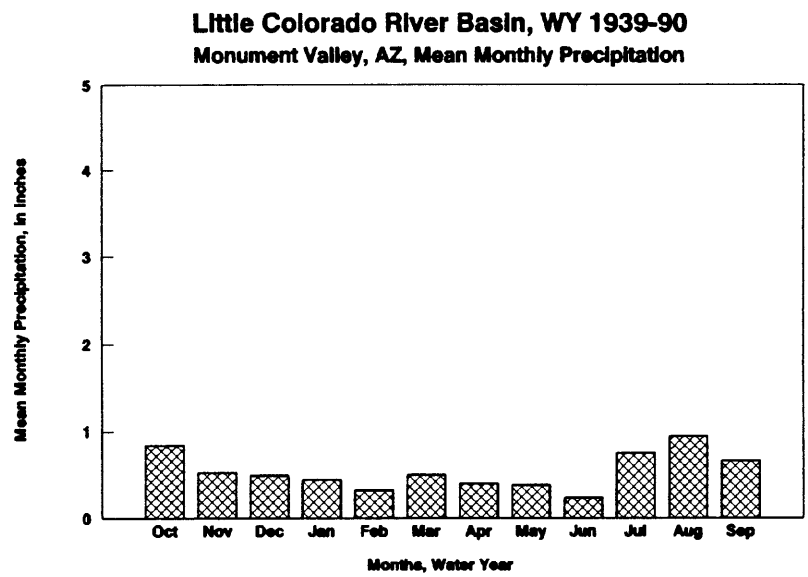


Figure 167. Monument Valley, AZ, Monthly Distribution of Precipitation

6.2.3.34 Navajo Dam, NM

Navajo Dam is located nearly 90 miles northeast of the northeastern boundary of the LCR Basin in New Mexico. Its inclusion is based upon a need to reconstruct certain missing precipitation records for LCR Basin stations from about 1980 to 1990. The period of record for Navajo Dam extends from 1964 to the present. The station is located at an elevation of 5,770 feet. Records for 1939-1963 are reconstructed. However, this reconstruction is based upon extrapolation, rather than interpolation, so the accuracy of the exercise can legitimately be questioned.

The precipitation trends for the study period, based upon the reconstruction methods described above and at the beginning of this section, indicate a decline from 1939 to 1958, followed by a gradual increase from 1959 to 1987. The trend from 1988 to 1990 indicates a steep decline.

The histogram shows a tight concentration of frequencies from eight to thirteen inches per year and a slight positive skewness indicative of a lognormal distribution. The monthly distribution shows a peak from July through October and a largely flat seasonality from November through March, after which precipitation declines to the annual minimum in June.

Table 47. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Navajo Dam, NM
Station No.: 6061
Elevation: 5770
Latitude: 36d 49m
Longitude: 107d 37m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.71	0.32	0.77	0.62	0.80	1.18	0.47	0.10	0.07	0.34	0.78	2.02	8.18
*1940	0.35	0.53	0.72	1.28	1.24	0.22	0.35	0.62	0.28	0.96	1.24	1.81	9.60
*1941	0.71	0.88	2.71	1.44	1.50	1.50	3.04	3.00	1.06	0.43	1.15	3.55	20.96
*1942	3.36	0.40	1.10	0.18	0.46	0.65	1.36	0.12	0.00	0.34	0.43	0.69	9.11
*1943	1.05	0.05	0.96	0.47	0.49	1.36	0.12	0.91	0.79	0.57	1.12	0.64	8.53
*1944	0.66	0.23	1.08	0.74	0.99	0.55	0.67	0.60	0.06	0.86	0.81	0.94	8.19
*1945	0.50	1.00	1.11	0.85	0.45	1.39	0.87	0.05	0.07	0.91	1.25	0.46	8.90
*1946	0.83	0.04	1.02	0.16	0.23	0.70	0.29	0.43	0.13	1.16	1.53	0.90	7.41
*1947	0.88	0.86	0.34	0.50	0.35	0.22	0.12	1.90	0.08	0.69	3.22	0.61	9.76
*1948	1.85	0.56	0.65	0.37	1.12	0.85	0.29	0.54	1.69	0.51	1.44	0.80	10.66
*1949	1.92	0.16	1.05	2.08	0.53	0.55	0.42	1.24	1.75	0.91	1.37	0.39	12.37
*1950	0.58	0.08	0.15	0.30	0.75	0.37	0.14	0.02	0.35	0.81	0.19	1.39	5.13
*1951	0.01	0.18	0.07	0.76	0.46	0.11	0.34	0.17	0.00	0.24	1.71	0.22	4.29
*1952	0.85	0.54	1.36	1.25	0.44	0.43	1.70	0.28	0.55	1.13	0.64	0.77	9.94
*1953	0.00	1.16	0.57	0.58	0.28	0.55	0.76	0.18	0.07	0.73	0.90	0.01	5.78
*1954	0.53	0.52	0.74	0.29	0.02	2.38	0.07	0.64	0.35	2.59	1.15	1.53	10.82
*1955	0.48	0.17	0.68	0.91	0.90	0.04	0.46	0.80	0.25	1.17	1.86	0.01	7.75
*1956	0.06	0.31	0.67	1.52	0.37	0.12	0.11	0.26	0.13	0.93	0.76	0.05	5.29
*1957	0.47	0.21	0.14	1.52	0.54	1.08	1.21	1.51	0.47	2.38	2.30	0.08	11.91
*1958	2.82	1.17	0.41	0.63	0.65	1.50	0.59	0.17	0.37	0.37	1.62	2.05	12.34
*1959	1.06	0.35	0.22	0.12	0.34	0.00	1.06	0.00	0.36	0.68	2.03	0.02	6.26
*1960	2.09	0.36	1.13	0.66	0.85	0.51	0.28	0.59	0.48	0.52	0.22	0.40	8.09
*1961	2.29	0.15	1.28	0.47	0.30	1.55	0.43	0.12	0.02	0.85	2.52	1.04	11.02
*1962	1.33	0.55	1.60	0.68	0.83	0.24	0.18	0.21	0.08	0.24	0.15	1.60	7.68
*1963	2.41	1.19	0.44	0.38	0.62	0.38	0.31	0.03	0.34	1.92	2.23	0.81	11.07
1964	1.50	0.84	0.14	0.24	0.18	0.90	1.54	0.92	0.19	2.06	1.82	1.25	11.58
1965	0.00	1.16	2.07	1.27	0.93	0.72	1.98	1.17	1.28	1.10	0.88	1.60	14.16
1966	0.89	2.14	2.78	0.36	0.49	0.23	0.51	0.20	0.47	0.70	1.20	0.48	10.45
1967	0.11	0.50	2.99	0.44	0.18	0.34	0.03	0.32	2.30	1.74	2.25	0.48	11.68
1968	0.43	0.14	1.04	0.30	0.90	0.79	1.15	0.53	0.14	1.03	2.07	0.22	8.74
1969	0.32	1.39	0.36	2.14	0.83	0.91	0.80	0.80	1.15	0.59	2.82	1.17	13.28
1970	2.09	0.73	0.79	0.17	0.03	1.58	0.63	0.00	0.66	1.52	1.48	2.73	12.41
1971	1.32	0.97	0.79	0.62	0.78	0.27	0.62	0.81	0.00	1.01	2.70	1.30	11.19
1972	1.98	0.80	1.16	0.10	0.03	0.10	0.15	0.00	0.48	0.11	1.58	0.58	7.07
1973	5.15	1.06	1.68	0.83	0.34	2.06	0.58	0.77	0.58	0.54	1.30	1.27	16.16
1974	0.29	0.43	0.12	2.21	0.34	0.45	0.64	0.05	0.04	2.27	0.20	0.35	7.39
1975	2.21	0.69	0.34	0.62	1.12	1.60	1.24	1.25	0.00	1.23	1.37	2.30	13.97
1976	0.00	1.11	0.44	0.09	1.06	0.07	0.76	2.78	0.07	1.75	0.66	1.62	10.41
1977	0.09	0.11	0.00	0.78	0.08	0.09	0.19	0.83	0.25	1.45	2.10	0.68	6.65
1978	0.20	0.69	0.43	2.91	1.68	2.55	0.43	2.02	0.30	0.05	0.19	0.86	12.31
1979	2.07	2.40	2.40	1.46	0.78	1.61	0.65	2.16	0.15	0.59	0.89	0.04	15.20
1980	0.95	1.30	0.50	1.92	2.39	1.85	0.81	0.48	0.00	0.42	0.67	1.41	12.70
1981	1.11	0.34	0.56	0.05	0.38	2.65	0.63	1.23	1.45	2.13	0.75	1.47	12.75
1982	1.91	0.77	0.00	1.55	2.06	2.65	0.28	1.12	0.00	0.16	2.58	1.50	14.58
1983	1.05	1.48	2.30	1.43	1.23	4.40	2.03	0.60	1.22	1.30	2.40	1.73	21.17
1984	1.07	2.13	3.27	0.45	0.55	1.52	1.45	0.16	0.74	0.62	3.60	1.15	16.71
1985	4.78	1.36	3.35	0.93	0.45	3.58	3.57	0.48	0.31	1.57	0.96	2.89	24.23
*1986	3.17	1.45	0.75	0.60	1.95	1.75	2.60	0.75	1.48	3.54	2.97	2.33	23.34
1987	0.97	2.96	1.45	1.00	3.45	1.01	0.62	2.16	0.40	0.58	2.25	0.01	16.86
1988	0.86	2.45	1.53	1.93	1.47	0.09	1.16	0.77	1.11	0.51	4.21	0.83	16.92
1989	0.12	1.63	1.14	1.62	1.06	0.34	0.00	0.26	0.15	0.83	0.93	0.23	8.31
1990	0.43	0.00	0.00	1.14	0.89	1.51	1.91	1.44	0.19	2.46	2.06	1.10	13.13
1939-90 Average	1.21	0.83	1.03	0.88	0.79	1.04	0.82	0.74	0.48	1.04	1.53	1.05	11.43

* Denotes year in which one or more monthly records are reconstructed.

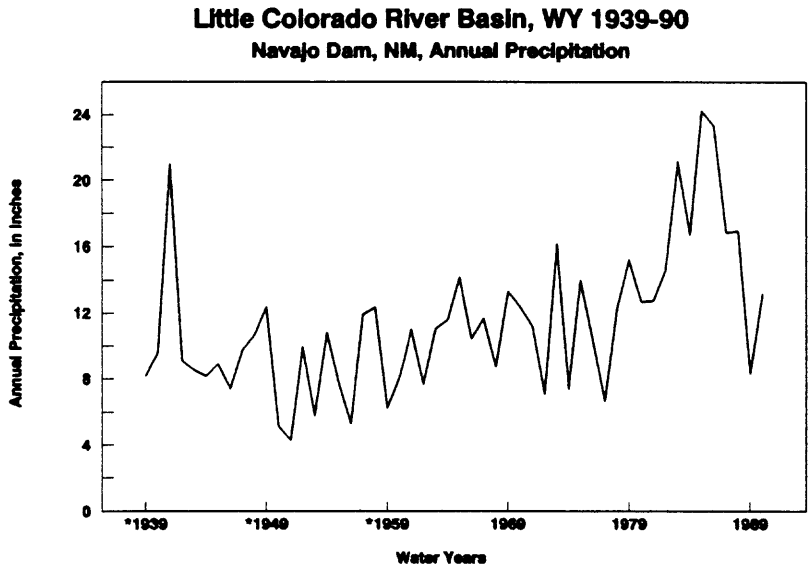


Figure 168. Navajo Dam, NM, Annual Precipitation, WY 1939-90

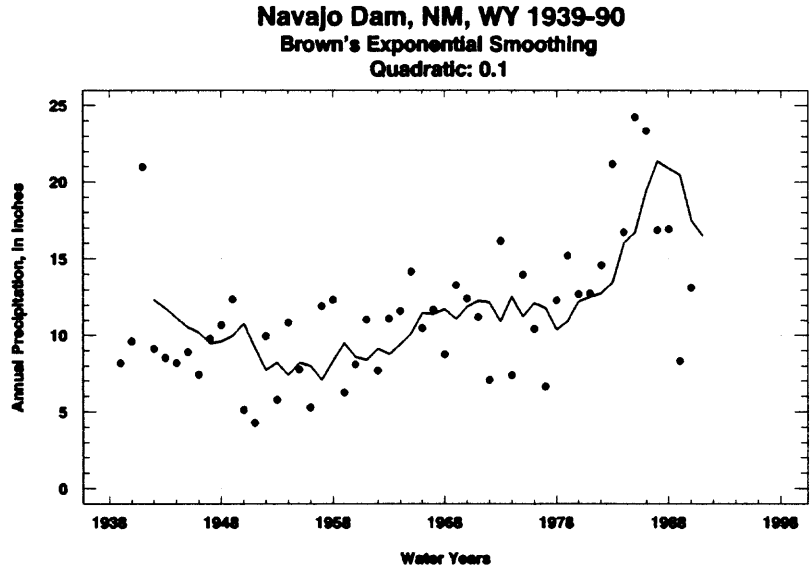


Figure 169. Navajo Dam, NM, Smoothed Annual Precipitation, WY 1939-90

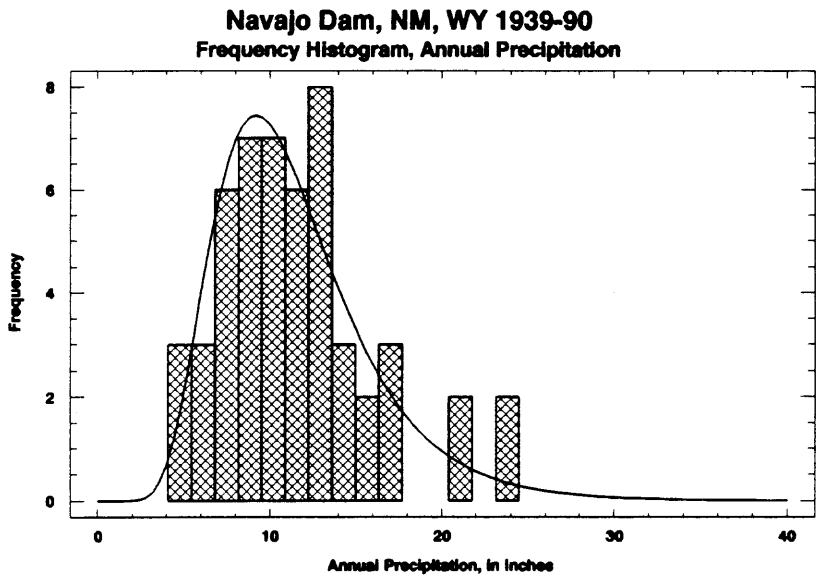


Figure 170. Navajo Dam, NM, Histogram of Annual Precipitation

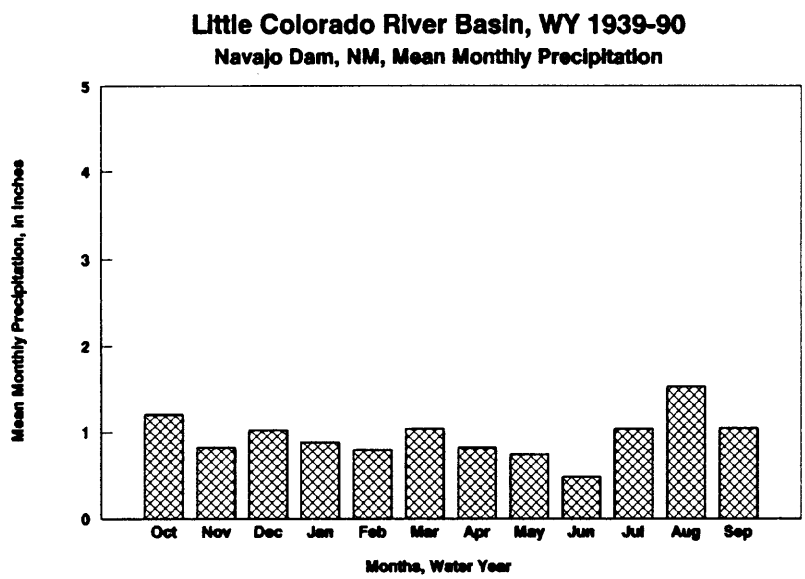


Figure 171. Navajo Dam, NM, Monthly Distribution of Precipitation

6.2.3.35 Newcomb, NM

Newcomb is located at an elevation of 5,575 feet some 45 miles north of Gallup. As with Navajo Dam, the period of record of from 1949 to 1971 provides additional data for the reconstruction of missing record from nearby LCR Basin stations in northwestern New Mexico. The period from 1939 to 1949 and from 1972 to 1990 is reconstructed.

Based upon the largely reconstructed data, the precipitation trends indicate a decline from 1939 to 1958, followed by an increase from 1959 to 1990.

The histogram shows a slight tendency toward a lognormal distribution with a sharp peak from six and nine inches and a slight positive skewness. The monthly distribution shows a peak in the months of July through October, with a gradual decline from November through the annual minimum in June.

Table 48. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Newcomb, NM
Station No.: 6098
Elevation: 5575
Latitude: 36d 18m
Longitude: 108d 43m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.17	0.15	0.51	0.55	0.95	1.25	0.52	0.25	0.01	0.73	1.01	1.04	7.13
*1940	0.32	0.42	0.29	0.56	0.66	0.21	0.26	0.64	0.24	0.57	0.80	1.89	6.85
*1941	0.58	0.59	1.82	0.88	0.68	1.26	2.06	2.08	0.86	0.63	1.38	2.67	15.48
*1942	3.07	0.29	0.54	0.00	0.34	0.32	0.89	0.02	0.00	0.52	0.67	0.75	7.40
*1943	1.12	0.03	0.35	0.29	0.10	0.75	0.15	0.54	0.27	0.44	1.56	0.59	6.19
*1944	0.51	0.06	1.17	0.43	0.52	0.29	0.39	0.33	0.00	0.61	0.85	1.19	6.36
*1945	0.44	0.82	0.91	0.62	0.15	0.71	0.54	0.02	0.07	1.06	0.87	0.34	6.53
*1946	0.99	0.00	0.91	0.28	0.19	0.59	0.23	0.42	0.07	0.98	2.18	1.29	8.13
*1947	0.35	0.81	0.07	0.26	0.20	0.16	0.07	1.49	0.10	0.83	4.13	0.88	9.34
*1948	1.97	0.52	0.33	0.47	1.02	0.65	0.29	0.19	1.07	0.65	1.49	1.53	10.18
1949	1.95	0.00	0.44	0.19	0.05	0.12	0.00	1.34	1.07	1.05	0.12	0.36	6.69
1950	0.15	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.05	0.53	0.27	0.49	1.51
1951	0.00	0.02	0.00	0.50	0.00	0.02	0.05	0.10	0.00	1.33	1.93	0.47	4.42
*1952	0.51	0.40	0.79	0.77	0.34	0.19	0.68	0.05	0.32	0.42	0.91	0.60	5.98
1953	0.00	0.87	0.05	0.05	0.03	0.03	0.26	0.50	0.26	0.58	1.97	0.00	4.60
1954	0.64	0.35	0.21	0.06	0.00	0.26	0.00	0.45	0.22	1.27	0.65	2.52	6.63
1955	0.44	0.00	0.26	0.04	0.29	0.00	0.13	0.17	0.00	0.78	1.15	0.10	3.36
*1956	0.01	0.33	0.00	1.41	0.48	0.27	0.13	0.24	0.16	0.87	0.91	0.01	4.82
*1957	0.35	0.15	0.06	0.52	0.00	0.91	1.34	1.25	0.03	2.19	1.68	0.00	8.49
1958	1.72	0.74	0.20	0.20	0.36	1.07	0.41	0.06	0.00	0.32	1.06	1.18	7.32
1959	0.59	0.48	0.04	0.00	0.16	0.00	0.60	0.00	0.92	0.10	1.42	0.24	4.55
1960	1.35	0.20	0.15	0.15	0.41	0.08	0.00	0.56	0.11	0.10	0.59	0.42	4.12
1961	1.89	0.00	1.00	0.15	0.00	1.47	0.00	0.00	0.04	0.38	2.03	0.86	7.82
1962	1.39	0.71	1.02	0.23	0.20	0.07	0.00	0.24	0.05	0.13	0.08	1.98	6.10
1963	1.78	0.73	0.27	0.28	0.65	0.10	0.00	0.00	0.00	0.11	3.46	0.85	8.23
1964	0.60	0.08	0.20	0.00	0.22	0.87	0.35	0.13	0.00	1.03	1.67	1.60	6.75
1965	0.00	1.18	0.83	0.42	0.06	0.08	0.85	0.58	0.95	3.24	0.58	0.09	8.86
1966	1.40	0.22	0.97	0.42	0.08	0.00	0.29	0.00	0.28	1.14	1.47	0.17	6.44
1967	0.40	0.04	0.80	0.04	0.00	0.05	0.00	0.54	0.58	1.50	0.32	0.98	5.25
1968	0.10	0.04	1.30	0.00	0.91	0.74	0.13	0.17	0.14	0.82	0.91	0.05	5.31
1969	0.60	1.42	0.62	0.16	0.16	0.26	0.22	0.69	0.71	1.09	0.51	0.42	6.86
1970	1.89	0.04	0.45	0.02	0.00	0.81	0.70	0.03	0.44	1.12	0.79	1.76	8.05
*1971	0.49	0.37	0.51	0.19	0.02	0.08	0.00	0.16	0.00	0.66	1.53	1.06	5.07
*1972	1.14	0.53	0.49	0.03	0.03	0.07	0.00	0.05	0.59	0.17	0.81	0.48	4.38
*1973	4.02	0.56	1.88	1.11	0.47	1.35	0.55	1.02	0.60	0.30	0.92	0.84	13.64
*1974	0.21	0.52	0.10	1.31	0.22	0.03	0.31	0.01	0.05	0.85	0.31	0.20	4.12
*1975	1.60	0.64	0.25	0.65	0.71	1.16	0.68	0.18	0.09	1.42	0.68	1.59	9.64
*1976	0.24	0.58	0.60	0.35	0.00	0.00	0.09	0.85	0.11	0.88	0.71	1.28	5.69
*1977	0.28	0.16	0.05	0.56	0.05	0.00	0.01	0.15	0.00	1.54	1.35	0.14	4.29
*1978	0.21	0.57	0.51	1.20	1.04	1.06	0.39	1.03	0.02	0.09	0.27	0.65	7.05
*1979	1.08	2.14	0.82	1.11	0.46	0.75	0.28	1.01	0.30	0.77	0.27	0.00	8.99
*1980	0.90	1.24	0.79	1.33	1.08	0.35	0.16	0.13	0.00	0.12	1.03	0.96	8.09
*1981	0.76	0.02	0.01	0.00	0.37	1.19	0.15	0.49	0.16	1.37	0.42	0.49	5.43
*1982	0.72	0.79	0.11	0.03	0.97	0.70	0.24	0.51	0.05	0.78	2.42	0.97	8.28
*1983	0.03	0.50	0.86	1.02	0.21	1.24	0.13	0.14	0.26	1.64	0.83	0.57	7.42
*1984	0.58	0.30	0.73	0.05	0.07	0.70	0.91	0.03	0.41	0.39	1.75	0.82	6.74
*1985	0.80	0.09	0.73	0.93	0.29	1.26	1.39	0.28	0.03	1.00	0.46	0.67	7.96
*1986	1.08	0.18	0.20	0.04	0.55	0.60	1.15	0.38	0.72	2.81	1.13	1.64	10.48
*1987	0.73	1.61	0.72	0.15	1.17	0.40	0.12	0.85	0.29	0.58	1.10	0.35	8.08
*1988	0.72	1.82	0.78	0.77	0.72	0.03	1.49	0.82	0.61	0.40	2.72	0.59	11.47
*1989	0.18	0.92	0.15	0.76	0.87	0.14	0.00	0.00	0.00	0.83	1.48	0.17	5.49
*1990	0.49	0.00	0.00	0.38	0.60	0.29	0.71	0.92	0.08	1.46	1.58	1.50	8.01
1939-90 Average	0.84	0.49	0.52	0.42	0.37	0.48	0.39	0.43	0.26	0.87	1.18	0.81	7.04

* Denotes year in which one or more monthly records are reconstructed.

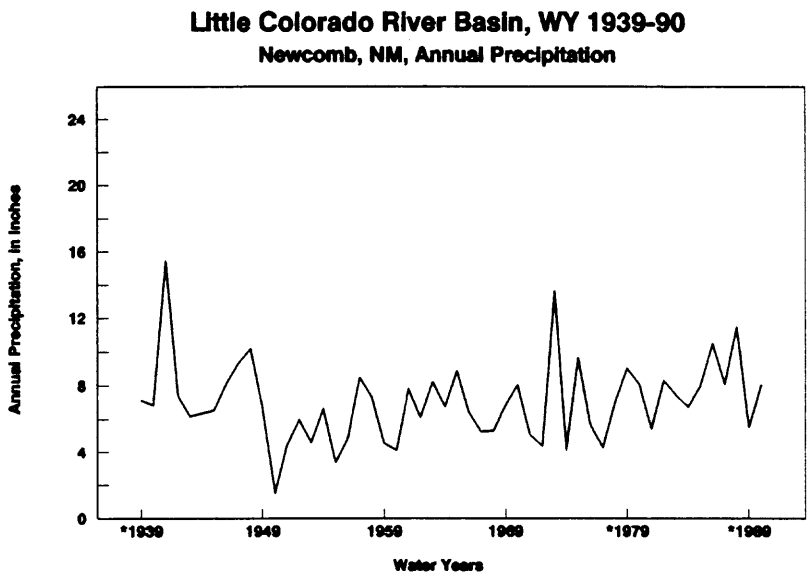


Figure 172. Newcomb, NM, Annual Precipitation, WY 1939-90

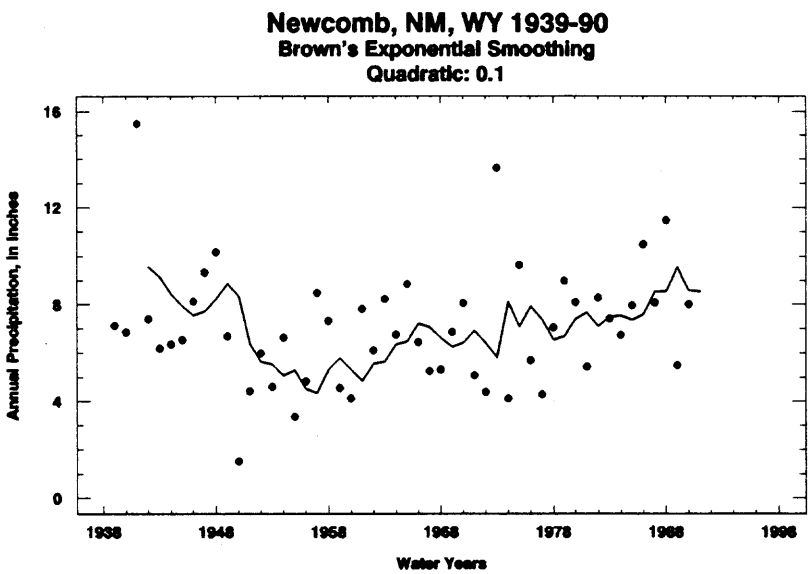


Figure 173. Newcomb, NM, Smoothed Annual Precipitation WY 1939-90

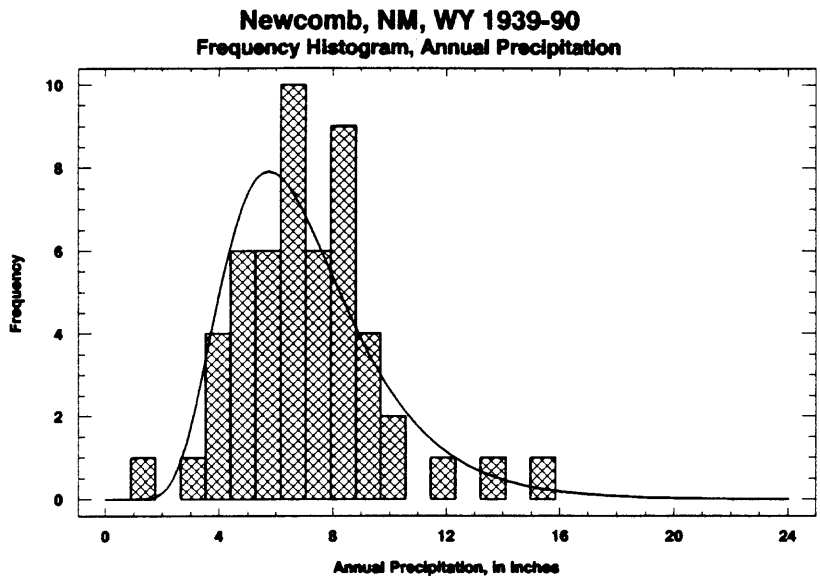


Figure 174. Newcomb, NM, Histogram of Annual Precipitation

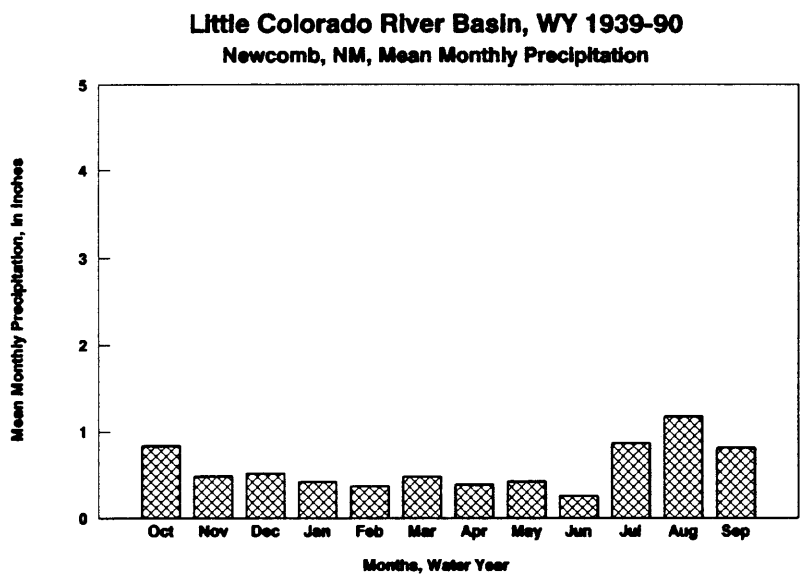


Figure 175. Newcomb, NM, Monthly Distribution of Precipitation

6.2.3.36 Oraibi, AZ

The station at Oraibi operated sporadically from 1938 through 1952 and reliably from 1960 through 1965. The record from 1952 to 1960 and from 1965 through 1990 is reconstructed. Nearby stations such as Keams Canyon and Tuba City provide some assurance of the relevance of this reconstruction.

Oraibi is located on the southern tip of Third Mesa, which overlooks the Hopi Tribal offices at Kykotsmovi. The broad Oraibi Wash valley runs from northeast to southwest just east of Oraibi. The village is estimated by archaeologists to be the oldest continuously inhabited settlement in North America, having been founded in about 900 A.D.

The precipitation trends from the reconstructed data indicate a slight decline from 1939 to 1958, followed by a gradual increase from 1959 to 1987. From 1988 to 1990, there has been an indication of another decline. The average annual precipitation is less than 9.5 inches, as compared to Keams Canyon, 35 miles to the east, at 10.6 inches. and Tuba City, 40 miles to the west, at 7.4 inches.

The histogram shows a normal to lognormal distribution with flat kurtosis and two years record of relatively wet weather. The monthly distribution shows a peak from July through October, followed by a gradual decline from November through the annual minimum in June.

Table 49. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Oraibi, AZ
Station No.: 6124
Elevation: 5930
Latitude: 35d 52m
Longitude: 110d 37m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.00	0.06	2.31	0.63	0.42	0.47	0.14	0.00	0.43	0.92	0.99	6.37
*1940	0.17	0.28	0.00	0.80	1.20	0.77	2.84	0.21	0.23	0.24	1.97	2.35	11.06
*1941	0.73	0.73	0.87	1.82	1.67	1.73	1.61	0.77	0.45	0.87	1.76	1.91	14.91
*1942	2.57	0.61	1.10	0.02	0.35	0.85	0.47	0.00	0.00	0.31	0.64	0.00	6.91
*1943	1.63	0.00	0.90	1.15	0.25	1.04	0.21	0.37	0.13	1.08	2.01	1.02	9.79
*1944	0.59	0.09	1.10	0.12	0.32	1.09	1.39	0.52	0.00	0.36	0.00	1.33	6.91
*1945	0.10	1.50	0.68	0.39	0.22	1.69	0.03	0.01	0.02	1.53	0.75	0.12	7.04
*1946	0.30	0.00	0.34	0.59	0.16	0.74	0.99	0.34	0.01	1.56	2.66	0.72	8.41
*1947	0.19	2.81	0.00	0.00	0.00	0.07	0.04	1.20	0.17	0.54	2.58	0.29	7.89
1948	2.68	0.70	0.93	0.05	0.52	0.56	0.06	0.14	0.12	0.41	0.41	0.89	7.47
*1949	2.00	0.00	1.20	0.51	0.85	0.00	0.22	0.88	0.24	0.69	1.05	0.88	8.52
*1950	1.20	0.25	0.53	0.01	0.95	0.06	0.04	0.21	0.44	2.00	0.97	1.22	7.88
*1951	0.00	0.00	0.00	0.62	0.15	0.00	1.57	0.42	0.00	0.53	1.87	0.60	5.76
*1952	0.35	0.60	0.58	1.70	0.25	0.95	1.62	0.22	0.60	0.65	1.59	1.90	11.01
*1953	0.00	1.16	0.43	0.14	0.40	0.30	0.49	0.05	0.04	2.69	2.09	0.13	7.94
*1954	0.14	0.47	0.26	0.44	0.30	1.10	0.06	0.55	0.60	1.89	0.76	1.25	7.84
*1955	0.80	0.11	0.21	0.84	0.82	0.09	0.29	0.19	1.63	1.12	2.37	0.01	8.46
*1956	0.01	0.46	0.31	1.00	0.42	0.14	0.58	0.34	0.13	1.42	0.51	0.05	5.36
*1957	0.24	0.02	0.15	2.21	0.54	0.84	0.57	1.37	0.82	1.46	2.33	0.00	10.56
*1958	1.75	1.21	0.22	0.24	0.82	1.33	0.64	0.31	0.22	0.47	1.46	1.53	10.20
*1959	0.65	0.52	0.08	0.17	0.80	0.00	0.50	0.18	0.50	0.70	1.72	0.00	5.82
*1960	1.44	0.63	2.03	0.28	0.73	0.15	0.21	0.39	0.34	0.28	0.37	0.18	7.03
1961	2.25	0.49	0.79	0.52	0.09	1.49	0.34	0.14	0.00	0.76	1.58	1.29	9.74
1962	0.80	0.67	0.54	0.84	0.85	0.28	0.17	0.00	0.00	0.21	0.32	1.06	5.74
1963	1.10	1.01	0.16	0.15	0.62	0.02	0.24	0.00	0.00	0.03	5.73	0.49	9.55
1964	0.35	0.21	0.22	0.00	0.08	0.66	1.49	0.04	0.22	2.59	1.46	1.02	8.34
*1965	0.00	0.28	1.08	1.04	1.45	0.86	0.94	1.39	0.13	1.45	0.73	2.28	11.63
*1966	0.87	1.19	2.33	0.56	0.81	0.25	0.23	0.28	0.23	1.31	1.49	0.98	10.51
*1967	0.43	0.82	1.25	0.26	0.07	0.31	0.21	0.64	1.06	2.13	2.06	1.19	10.42
*1968	0.06	0.28	2.65	0.14	0.32	0.49	0.69	0.36	0.10	1.82	1.33	0.06	8.30
*1969	0.90	0.74	1.28	1.10	0.78	0.87	0.13	0.91	0.18	1.57	1.14	1.02	10.60
*1970	1.30	0.52	0.30	0.23	0.10	2.60	0.53	0.01	0.20	0.86	1.37	1.20	9.23
*1971	0.41	0.29	0.52	0.06	0.52	0.11	0.35	0.23	0.02	1.19	2.08	1.22	7.01
*1972	1.80	0.52	1.11	0.00	0.06	0.01	0.09	0.04	1.24	0.93	1.74	0.47	8.00
*1973	7.38	0.67	1.17	1.05	1.32	2.42	0.48	0.55	0.42	1.00	0.62	0.31	17.39
*1974	0.08	0.77	0.22	1.33	0.21	0.33	0.24	0.00	0.07	1.50	0.61	0.79	6.16
*1975	1.91	0.51	0.34	0.51	0.85	1.28	0.57	0.29	0.07	1.96	0.49	1.66	10.45
*1976	0.07	1.11	0.68	0.06	1.05	0.29	0.70	1.12	0.04	2.74	0.62	1.34	9.82
*1977	0.00	0.17	0.21	0.74	0.41	0.20	0.50	0.10	0.31	2.11	1.94	1.04	7.73
*1978	0.50	0.25	0.48	1.65	1.66	1.54	0.32	0.34	0.16	0.56	0.68	0.92	9.06
*1979	1.12	3.07	1.85	2.04	0.60	1.05	0.15	1.43	0.58	0.27	1.58	0.08	13.82
*1980	1.02	0.88	0.79	2.12	2.33	1.12	0.96	0.31	0.05	1.00	1.32	0.77	12.66
*1981	0.59	0.08	0.37	0.49	0.45	1.37	0.55	1.06	0.60	1.26	1.59	1.02	9.41
*1982	1.05	0.82	0.11	1.07	1.18	0.91	0.27	1.48	0.00	1.01	2.81	1.23	11.94
*1983	0.27	0.88	2.08	0.69	0.89	1.84	0.50	0.27	0.05	2.16	1.73	3.08	14.43
*1984	0.71	0.95	0.85	0.22	0.16	0.73	0.62	0.03	0.14	2.77	2.93	0.69	10.80
*1985	1.22	0.46	2.11	1.41	0.55	1.30	2.06	0.25	0.17	1.55	0.26	1.62	12.98
*1986	1.01	2.14	0.22	0.02	0.67	1.19	0.43	0.36	0.20	1.79	2.58	1.14	11.73
*1987	1.16	1.19	0.97	1.07	0.93	0.61	0.13	0.56	0.38	1.08	2.42	0.24	10.74
*1988	1.56	1.60	1.03	0.83	1.04	0.16	1.89	0.10	1.18	0.84	2.90	0.63	13.75
*1989	0.26	1.22	0.29	0.77	0.45	0.35	0.02	0.40	0.06	0.96	1.62	0.18	6.58
*1990	0.49	0.02	0.28	0.58	0.93	0.56	0.81	0.26	0.16	1.59	1.15	2.23	9.05
1939-90 Average	0.93	0.69	0.74	0.71	0.65	0.75	0.61	0.42	0.28	1.20	1.53	0.93	9.44

* Denotes year in which one or more monthly records are reconstructed.

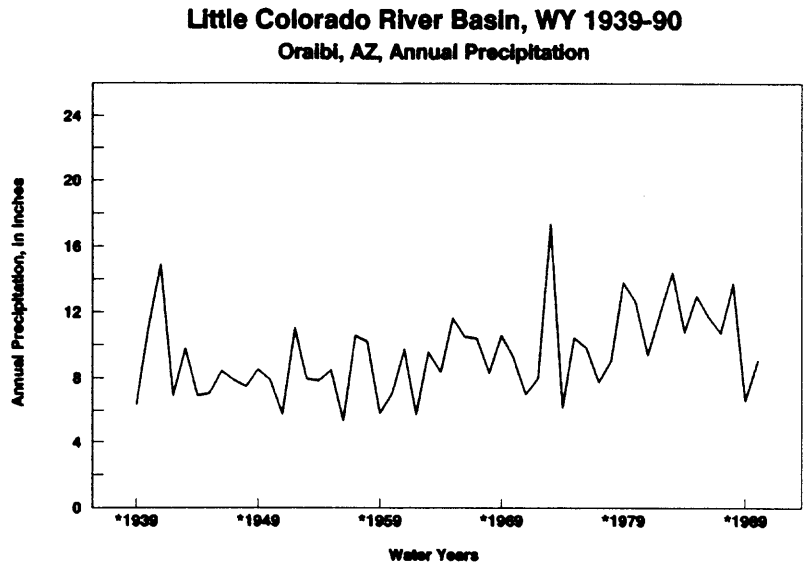
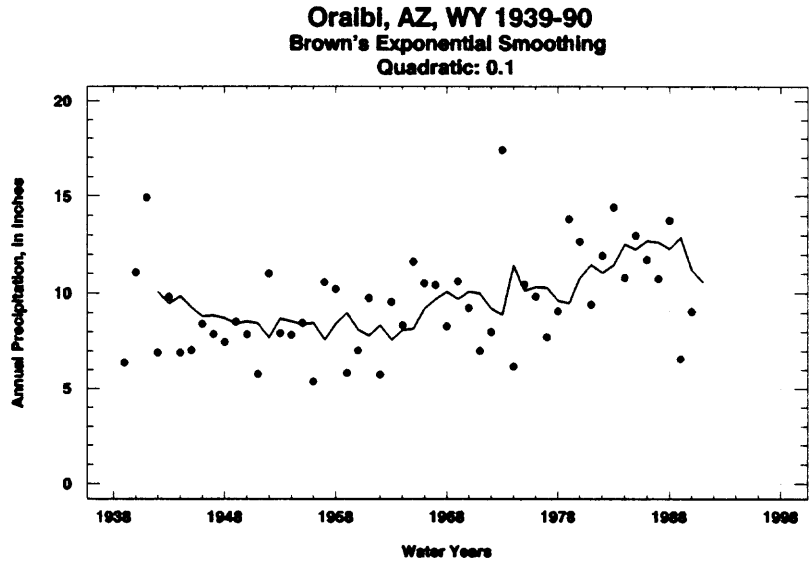


Figure 176. Oraibi, AZ, Annual Precipitation, WY 1939-90



Oraibi, AZ Smoothed Annual Precipitation, WY 1939-90

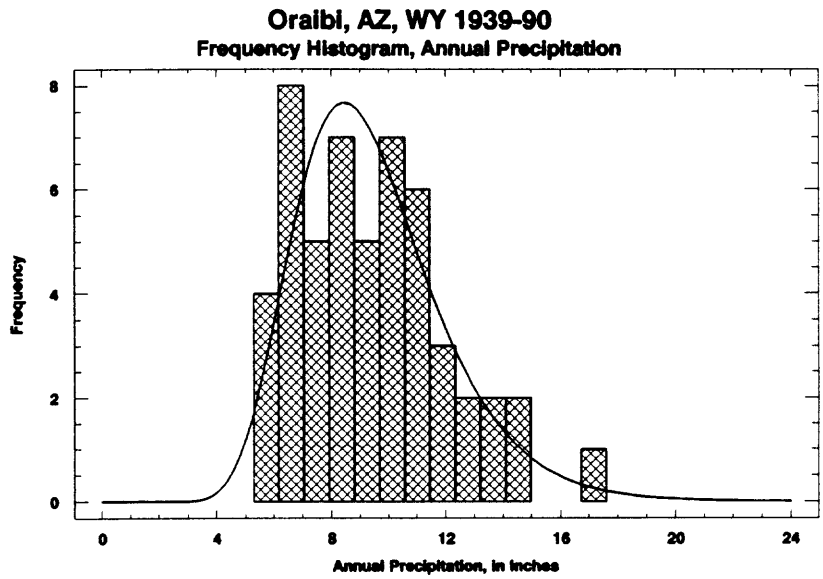


Figure 177. Oraibi, AZ, Histogram of Annual Precipitaiton

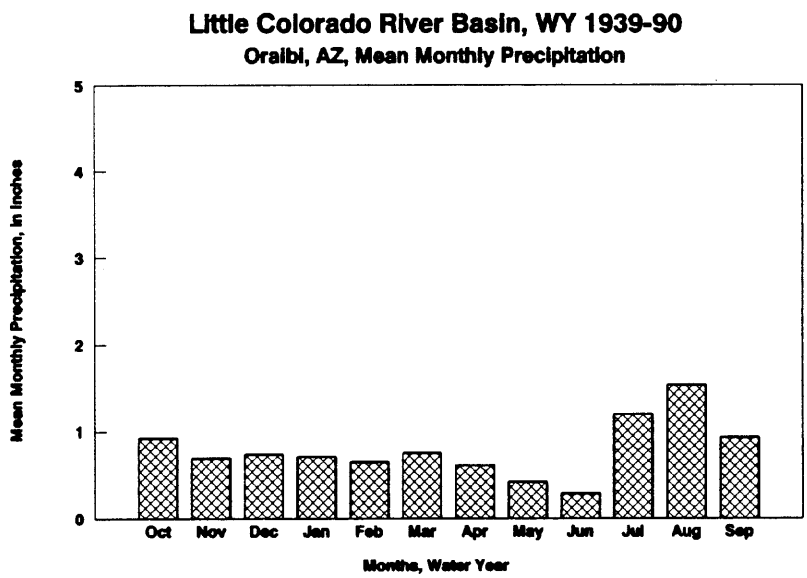


Figure 178. Oraibi, AZ, Monthly Distribution of Precipitation

6.2.3.37 Page, AZ

The Page climatological station is located about 20 miles north of the northwestern boundary of the LCR Basin at an elevation of 4,269 feet. Its period of record is recent, extending from 1958 to the present, excepting 1985. The record prior to 1958 and the record in 1985 is reconstructed. This station is included in the study due to its use in reconstructing missing data from nearby LCR stations and to provide additional resolution in isohyetal maps.

The precipitation trends at Page are essentially flat from 1939 to 1979. From 1980 to 1982 a dramatic increase was noted which peaked at 1987. There is an indication of a decline from 1988 to 1990. Note that the record from 1958 to the present is measured rather than reconstructed. The average annual precipitation of less than five and three-quarters inches is one of the driest climates in the study.

The histogram shows a largely lognormal distribution which peaks at five inches. Several wetter than normal years gives the data a positive skewness. The monthly distribution shows a slight peak from July through October, followed by a gradual decline from November through the annual minimum in June.

Table 50. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Page,AZ
Station No.: 6180
Elevation: 4269
Latitude: 36d 56m
Longitude: 111d 27m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.27	0.16	0.51	0.59	0.50	0.78	0.00	0.08	0.04	0.00	0.20	2.18	5.32
*1940	0.00	0.29	0.00	0.00	0.18	0.15	0.21	0.00	0.00	0.12	0.48	1.57	3.00
*1941	0.91	0.36	1.25	1.22	0.22	1.42	1.46	0.99	0.21	0.14	0.98	0.67	9.83
*1942	1.47	0.00	0.38	0.00	0.06	0.27	0.51	0.04	0.00	0.48	0.00	0.00	3.20
*1943	0.52	0.07	0.67	0.00	0.07	1.16	0.09	0.20	0.00	0.10	0.44	0.39	3.72
*1944	0.20	0.17	0.84	0.44	0.45	0.84	0.81	0.34	0.00	0.00	0.12	0.00	4.21
*1945	0.00	0.60	0.27	0.13	0.41	0.84	0.51	0.05	0.05	1.29	0.58	0.00	4.74
*1946	0.53	0.02	0.03	0.33	0.05	0.65	0.89	0.04	0.00	0.81	2.04	0.37	5.75
*1947	1.19	0.77	0.14	0.03	0.03	0.00	0.07	0.35	0.11	0.27	1.52	0.00	4.49
*1948	2.11	0.18	0.48	0.20	1.40	0.25	0.15	0.06	0.86	0.00	1.52	0.16	7.36
*1949	0.54	0.03	0.46	1.04	0.45	0.66	0.00	0.05	1.38	0.00	0.23	0.84	5.68
*1950	0.57	0.20	0.04	0.06	0.42	0.40	0.03	0.02	0.08	0.91	0.78	0.19	3.70
*1951	0.00	0.00	0.07	0.76	0.15	0.23	0.44	0.47	0.00	0.09	1.61	0.55	4.37
*1952	0.44	0.66	0.93	0.94	0.27	0.57	1.12	0.21	0.47	0.43	0.88	1.63	8.56
*1953	0.00	0.73	0.78	0.10	0.06	0.03	0.75	0.00	0.24	3.06	2.18	0.13	8.07
*1954	0.32	0.49	0.10	0.38	0.30	0.41	0.00	0.45	0.67	0.88	0.41	1.13	5.53
*1955	0.14	0.31	0.36	0.08	0.39	0.10	0.04	0.00	0.95	0.00	0.96	0.00	3.32
*1956	0.00	0.58	0.08	0.64	0.00	0.11	0.24	0.38	0.00	0.47	0.76	0.00	3.26
*1957	0.05	0.05	0.00	1.02	0.29	0.40	0.56	1.48	0.55	1.13	2.07	0.04	7.64
*1958	1.17	0.77	0.39	0.15	0.39	1.22	0.08	0.40	0.00	0.73	0.23	1.94	7.47
1959	0.40	0.22	0.00	0.00	0.56	0.00	0.67	0.50	0.09	0.21	0.86	0.06	3.57
1960	1.73	0.46	0.89	0.73	0.09	0.31	0.61	0.08	0.07	0.05	0.10	0.36	5.48
1961	2.25	0.21	0.60	0.18	0.07	1.49	0.40	0.12	0.00	0.20	1.56	1.54	8.62
1962	0.35	0.21	0.91	0.14	0.43	0.38	0.00	0.46	0.44	0.09	0.52	0.62	4.55
1963	0.96	0.82	0.25	0.66	0.51	1.16	0.03	0.00	0.00	0.03	2.47	0.47	7.36
1964	0.46	0.50	0.00	0.11	0.00	0.87	0.55	0.30	0.06	0.33	0.49	0.24	3.91
1965	0.00	0.27	0.84	0.38	0.87	0.86	1.05	1.89	0.81	0.46	0.63	0.44	8.50
1966	0.38	0.81	1.20	0.04	1.17	0.00	0.00	0.36	0.00	0.58	0.10	1.27	5.91
1967	0.34	0.56	0.75	0.07	0.05	0.07	0.16	1.31	0.61	0.11	0.16	1.04	5.23
1968	0.00	0.10	1.54	0.21	0.16	0.26	0.55	0.02	0.06	0.73	0.67	0.12	4.42
1969	0.10	0.28	0.61	0.55	0.48	0.51	0.10	0.32	0.16	0.34	1.09	0.30	4.84
1970	1.31	0.63	0.24	0.26	0.96	1.34	0.14	0.00	0.18	0.52	0.53	0.04	6.15
1971	0.14	0.48	0.23	0.00	0.08	0.14	0.18	0.10	0.14	0.10	0.87	0.20	2.66
1972	0.77	0.25	0.91	0.00	0.00	0.00	0.02	0.00	0.93	0.25	0.75	0.55	4.43
1973	3.89	1.01	0.87	0.60	0.54	1.31	0.29	0.84	0.75	0.44	0.48	0.13	11.15
1974	0.05	0.31	0.00	1.09	0.04	0.31	0.14	0.01	0.00	0.40	0.35	0.15	2.85
1975	1.20	0.52	0.15	0.30	0.97	1.14	0.65	0.04	0.11	0.84	0.45	0.56	6.93
1976	0.09	0.07	0.31	0.00	0.77	0.82	0.54	0.74	0.00	0.75	0.00	0.55	4.64
1977	0.23	0.11	0.00	0.35	0.09	0.13	0.03	0.26	0.08	0.99	0.68	0.13	3.08
1978	0.21	0.40	0.17	1.54	0.20	1.35	0.37	0.19	0.00	0.29	0.22	0.56	5.50
1979	0.86	2.06	4.00	2.12	0.47	1.06	0.18	0.96	0.07	0.04	0.16	0.00	11.98
1980	0.57	1.74	0.74	1.65	1.73	1.38	0.82	0.33	0.00	0.44	0.35	1.76	11.51
1981	0.30	0.00	0.04	0.25	0.24	0.82	0.27	1.50	0.05	1.19	1.26	0.48	6.40
1982	2.47	1.20	0.00	0.70	1.20	0.35	0.65	0.41	0.02	0.45	1.83	0.26	9.54
1983	0.38	0.78	0.60	0.46	0.35	1.83	0.47	0.05	0.06	1.51	0.56	1.89	8.94
*1984	0.33	0.94	0.78	0.08	0.04	0.26	0.39	0.00	0.06	1.50	1.59	0.33	6.30
*1985	0.76	0.21	1.57	1.25	0.33	1.63	1.21	0.12	0.11	0.42	0.22	0.61	8.44
1986	1.04	0.67	0.02	0.08	0.59	0.59	0.76	0.76	0.04	1.02	0.63	0.82	7.02
1987	0.92	0.81	0.33	1.00	0.67	0.37	0.10	0.57	0.08	0.74	0.87	0.02	6.48
1988	1.26	1.08	0.22	0.17	0.52	0.00	2.14	0.00	0.19	0.02	0.67	0.09	6.36
1989	0.41	0.00	0.13	0.69	0.33	0.00	0.00	0.58	0.00	0.55	1.00	0.14	3.83
1990	0.00	0.00	0.00	0.79	0.61	0.12	0.52	0.00	0.35	0.69	0.09	0.93	4.10
1939-90 Average	0.64	0.45	0.49	0.45	0.39	0.58	0.41	0.34	0.21	0.50	0.74	0.53	5.74

* Denotes year in which one or more monthly records are reconstructed.

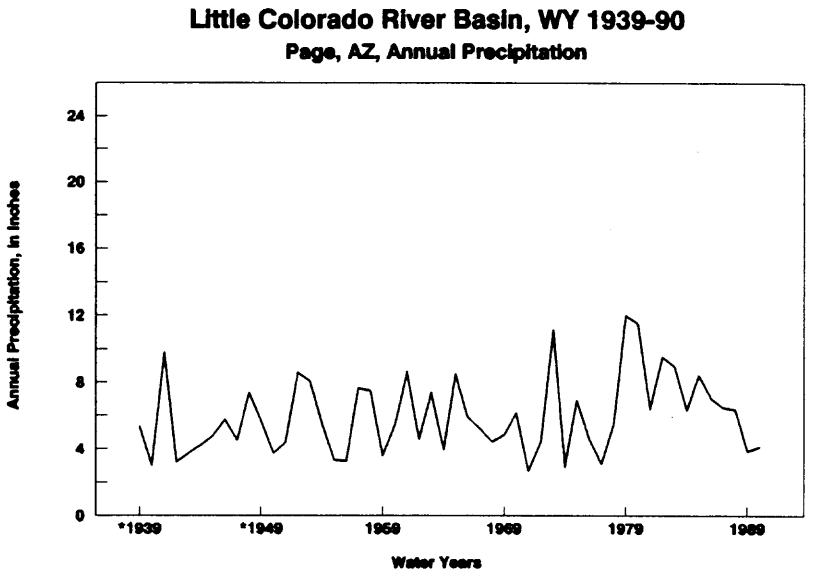


Figure 179. Page, AZ, Annual Precipitation, WY 1939-90

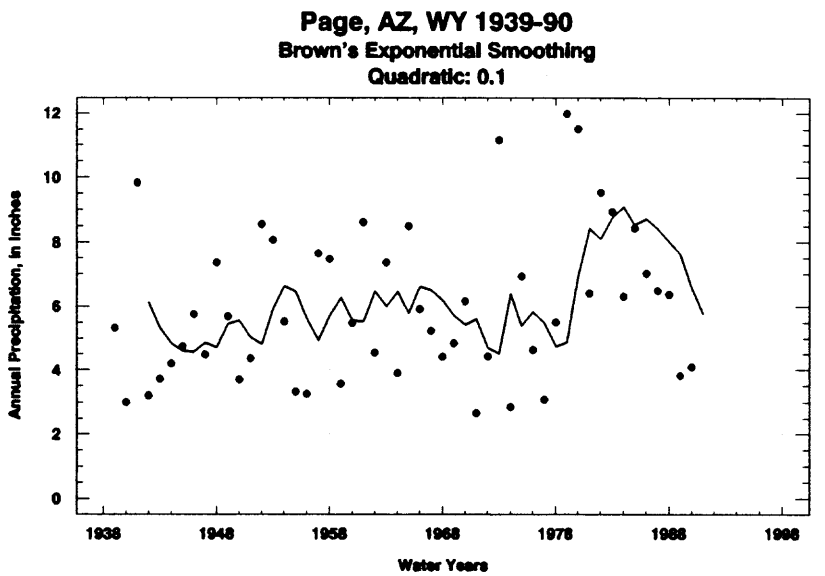


Figure 180. Page, AZ, Smoothed Annual Precipitation, WY 1939-90

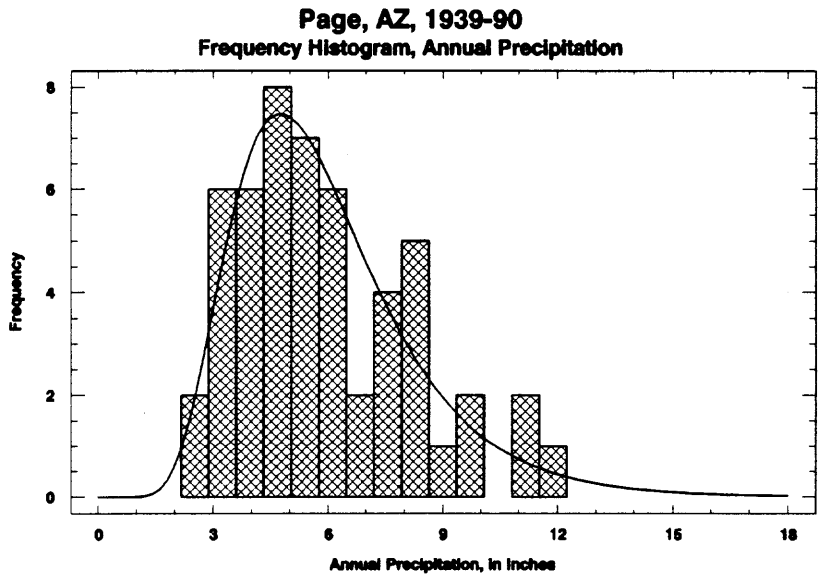


Figure 181. Page, AZ, Histogram of Annual Precipitation

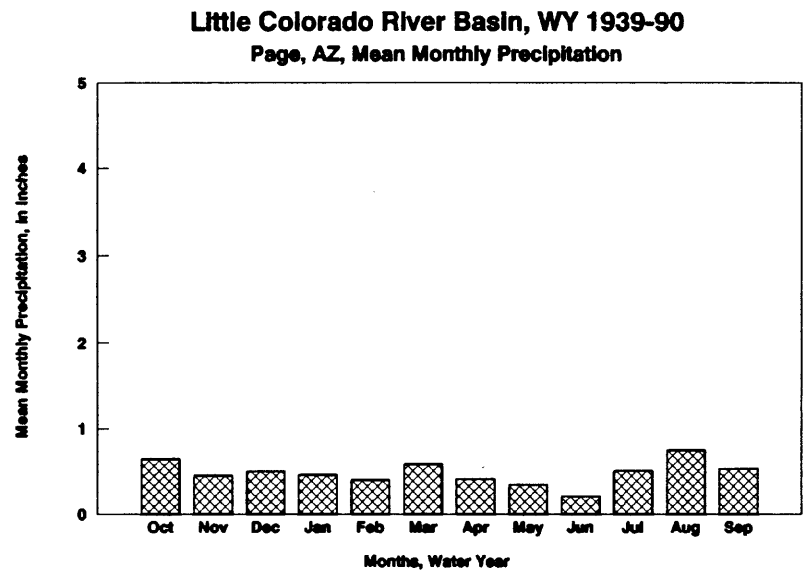


Figure 182. Page, AZ, Monthly Distribution of Precipitation

6.2.3.38 Petrified Forest National Park, AZ

This station has an important long-term record whose period is from 1931 to the present, missing only the month of January, 1939, for the entire period.

As summarized in Sellars and Hill (1974, p. 370):

"The Petrified Forest National [Park] is located at an elevation of 5,440 feet in the Valley of the Puerco River in northeastern Arizona. Actual measurements are taken at a point in the extreme southern portion of the Park, seven miles north-northeast of the confluence of the Milky Wash andthe northwestward flowing Little Colorado River. The Petrified Forest National [Park], featuring the most spectacular display of petrified wood in the world, consists of six "forested" areas, formed from trees, which existed millions of years ago, by the deposition of silica into cell tissues of the wood via the intake of ground water. To the northwest and northeast on the desolate, although quite colorful, Colorado Plateaus are, respectively, the Navajo and Apache Indian Reservations. Fifty miles to the northwest lies the southeastern tip of the famous Painted Desert which extends from that point for over seventy miles along the eastern fringes of the Little Colorado River Valley. The terrain height is nearly constant at about 5,500 to 6,000 feet in all directions within forty miles of the Petrified Forest National Park. About fifty miles to the south, stretching across the southern horizon, is found the southern rim of the forested Mogollon Plateau, with elevations exceeding 8,000 feet. The prevalent form of vegetation in the area consists of plains grass, although sagebrush is found to the west-northwest in the valley of the Little Colorado River. Along the northern side of the Mogollon Plateau pinyon and juniper are common, with forests of yellow pine (sic) prevailing at heights above 7,000 feet on the plateau.

"The Mogollon Plateau has a pronounced effect on the climate of the Petrified Forest National Park and, in fact, on the entire Colorado Plateau region. This expansive plateau serves as a giant barrier, cutting off a considerable fraction of the flow of moist air from the west and south. As a result, the Petrified Forest National [Park] receives precipitation amounts comparable to the desert regions of central Arizona. About fifty percent of its annual total of 8.69 inches falls during the summer monsoon months of July, August, and September in connection with late afternoon showers and thunderstorms that originate in moist air from the Gulf of Mexico. These rains tend to be heavy and of short duration. Occasionally, however, longer-lasting rains, although relatively gentle, may fall when tropical disturbances advance northeastward into the State from the Gulf of California.

"During the rest of the year at the Petrified Forest National Park, and especially in the spring, only minimal amounts of precipitation fall, most months averaging about half an inch or less. During the cold season months, middle latitude storms that originate in the North Pacific Ocean may be successful in penetrating the mountainous regions to the west and bring with them gentle showers preceeded by gusty winds. Slightly less than half of the slight winter precipitation falls as snow, with significant accumulations rarely occurring. The heaviest fall on record occurred during the blizzard of December, 1967."

Precipitation trends for the study period 1939-90 indicate a decline from 1939 to 1950, followed by a peak in 1971 and another minimum in 1979. A realtively sharp increase occurs from 1980 to 1988, and the beginnings of a possible decline occurs from 1988 to 1990.

The histogram shows a slight lognormal distribution with several wet seasons producing a slight positive skewness. The monthly distribution reveals that the season from July through August is the maximum precipitation, with the November through June period declining to the annual minimum.

Table 51. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Petrified Forest National Park, AZ
Station No.: 6468
Elevation: 5446
Latitude: 34d 49m
Longitude: 109d 53m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.07	0.48	1.09	2.00	0.83	1.10	0.01	0.00	0.45	1.59	1.02	8.64
1940	0.12	0.75	0.28	0.53	1.26	0.31	1.99	0.20	0.51	1.08	0.85	1.86	9.74
1941	1.02	0.75	1.49	1.90	1.33	2.72	1.02	1.07	0.37	2.69	1.45	2.48	18.29
1942	1.02	0.44	0.54	0.26	0.44	0.12	0.59	0.00	0.00	0.39	1.52	0.34	5.66
1943	1.63	0.36	0.18	0.73	0.69	0.53	0.08	0.49	0.16	1.78	2.19	1.24	10.06
1944	0.82	0.02	1.07	0.17	0.34	0.59	0.81	0.52	0.00	0.70	0.81	1.36	7.21
1945	0.49	1.23	0.54	0.20	0.30	0.41	0.10	0.00	0.16	3.73	1.66	0.06	8.88
1946	0.23	0.00	0.94	0.40	0.12	0.26	0.06	0.05	0.00	1.33	1.91	2.10	7.40
1947	0.15	0.96	0.14	0.19	0.16	0.00	0.04	0.96	0.22	0.62	2.89	0.39	6.72
1948	2.10	0.60	0.38	0.12	1.06	0.74	0.01	0.02	0.51	0.71	1.14	0.53	7.92
1949	1.52	0.00	0.68	0.50	0.15	0.17	0.24	0.40	0.58	1.03	4.33	1.72	11.32
1950	0.51	0.24	0.20	0.19	0.59	0.11	0.00	0.02	0.15	1.35	0.78	0.61	4.75
1951	0.00	0.05	0.00	0.76	0.38	0.35	0.61	0.11	0.00	0.67	2.08	0.50	5.51
1952	0.93	0.84	0.35	0.64	0.33	0.36	1.53	0.04	0.92	1.95	1.78	1.71	11.38
1953	0.00	2.29	0.25	0.08	0.04	0.79	0.84	0.11	0.06	2.19	0.66	0.00	7.31
1954	0.13	0.53	0.43	0.36	0.36	0.93	0.00	0.37	0.00	4.67	1.46	1.40	10.64
1955	0.53	0.21	0.20	0.36	0.39	0.07	0.01	0.69	1.76	1.22	3.42	0.04	8.90
1956	0.20	0.18	0.18	1.41	0.87	0.00	0.23	0.52	0.17	0.77	0.89	0.02	5.44
1957	0.57	0.10	0.13	0.83	0.65	0.58	0.21	0.72	0.60	1.07	2.23	0.00	7.69
1958	2.39	0.61	0.21	0.16	0.49	1.09	0.32	0.53	1.40	1.13	3.21	2.53	14.07
1959	0.55	0.51	0.00	0.12	0.17	0.00	0.36	0.03	0.12	1.11	1.61	0.25	4.83
1960	3.61	0.52	1.30	0.71	0.26	0.58	0.19	0.49	0.36	0.19	0.61	0.39	9.21
1961	1.43	0.02	0.61	0.18	0.11	0.85	0.09	0.15	0.00	0.35	1.58	1.12	6.49
1962	1.78	0.83	0.31	0.33	0.46	0.28	0.00	0.00	0.86	0.48	0.78	1.58	7.69
1963	1.14	0.89	0.20	0.16	1.29	0.25	0.29	0.00	0.00	0.21	2.11	1.27	7.81
1964	1.09	0.76	0.16	0.06	0.09	0.12	0.60	0.16	0.12	2.21	2.53	1.75	9.65
1965	0.04	0.53	0.71	0.87	0.36	0.95	0.21	0.22	1.06	1.01	0.90	0.84	7.70
1966	0.53	0.39	1.47	0.15	0.66	0.04	0.22	0.00	0.33	2.99	2.05	1.65	10.48
1967	0.61	0.34	0.74	0.14	0.00	0.22	0.18	0.47	0.15	0.94	3.71	1.10	8.60
1968	0.21	0.55	1.75	0.22	0.72	1.03	0.62	0.06	0.17	1.80	3.91	0.05	11.09
1969	1.79	0.24	0.50	0.41	0.39	0.90	0.00	1.41	0.03	0.90	1.68	1.92	10.17
1970	0.97	1.13	0.49	0.49	0.16	0.94	0.89	0.05	0.11	1.50	0.89	2.44	10.06
1971	0.55	0.01	0.16	0.17	0.15	0.00	0.49	0.00	0.00	0.78	1.16	3.07	6.54
1972	1.60	0.30	0.63	0.00	0.00	0.00	0.00	1.13	0.72	0.44	0.82	0.54	6.18
1973	3.95	0.64	0.45	0.21	1.41	0.83	1.29	1.77	0.58	0.29	1.13	0.01	12.56
1974	0.05	0.81	0.00	1.00	0.04	0.29	0.00	0.00	0.00	1.43	2.03	0.34	5.99
1975	3.07	0.07	0.03	0.31	0.80	0.90	0.45	0.38	0.02	1.20	0.62	2.36	10.21
1976	0.00	0.44	0.56	0.23	0.30	0.17	0.10	1.25	0.03	1.58	0.66	1.39	6.71
1977	0.73	0.03	0.29	1.64	0.30	0.48	0.47	0.02	0.14	2.19	0.62	1.29	8.20
1978	1.09	0.40	0.37	1.22	0.93	1.62	0.08	0.82	0.12	0.34	1.21	0.37	8.57
1979	1.37	2.09	1.76	0.85	0.05	0.87	0.14	1.84	0.78	0.17	1.65	0.06	11.63
1980	0.91	0.96	0.67	1.56	1.78	0.98	0.26	0.22	0.00	0.60	1.24	1.57	10.75
1981	0.67	0.00	0.96	0.72	0.63	1.39	0.54	0.38	0.22	2.04	1.50	0.61	9.66
1982	1.10	0.49	0.00	1.18	0.88	0.78	0.07	0.86	0.30	0.96	1.00	2.85	10.47
1983	0.04	0.99	1.40	0.32	0.33	0.74	0.18	0.26	0.05	2.07	2.09	2.55	11.02
1984	1.23	0.51	0.83	0.02	0.00	1.32	0.33	0.01	0.77	2.79	2.40	3.45	13.66
1985	1.50	0.09	1.73	1.07	0.70	1.05	1.54	0.15	0.17	2.63	0.51	1.46	12.60
1986	1.98	0.90	0.10	0.05	0.87	1.15	0.17	0.21	0.20	3.37	1.25	0.85	11.10
1987	1.67	1.23	1.79	0.87	0.73	0.97	0.13	0.60	0.18	1.26	1.19	0.29	10.91
1988	1.10	1.10	0.60	0.43	0.60	0.00	2.18	0.01	1.95	0.55	2.33	1.15	12.00
1989	0.36	0.73	0.10	0.76	0.14	1.17	0.00	0.00	0.00	2.59	2.01	1.06	8.92
1990	0.52	0.00	0.25	0.05	0.26	0.47	0.49	0.26	0.00	2.60	1.94	2.36	9.20
1939-90 Average	0.99	0.55	0.57	0.53	0.53	0.62	0.43	0.39	0.33	1.41	1.66	1.19	9.20

* Denotes year in which one or more monthly records are reconstructed.

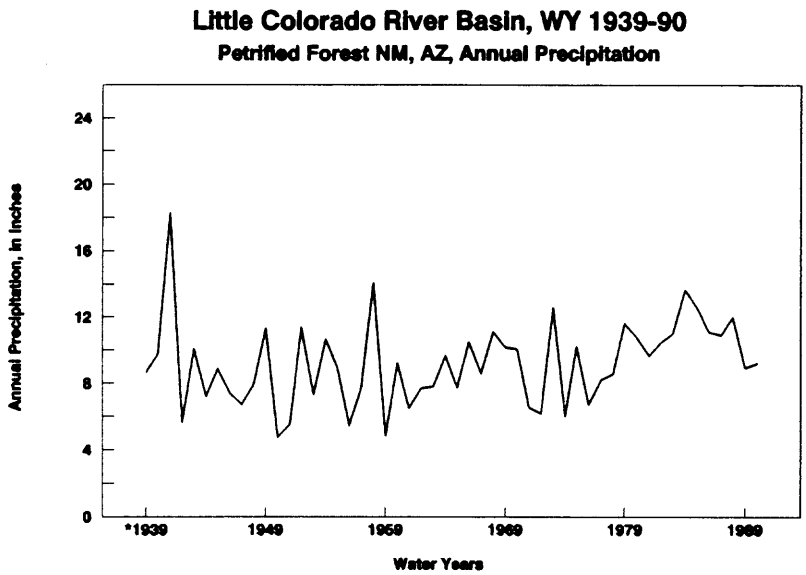


Figure 183. Petrified Forest NP, Annual Precipitation, WY 1939-90

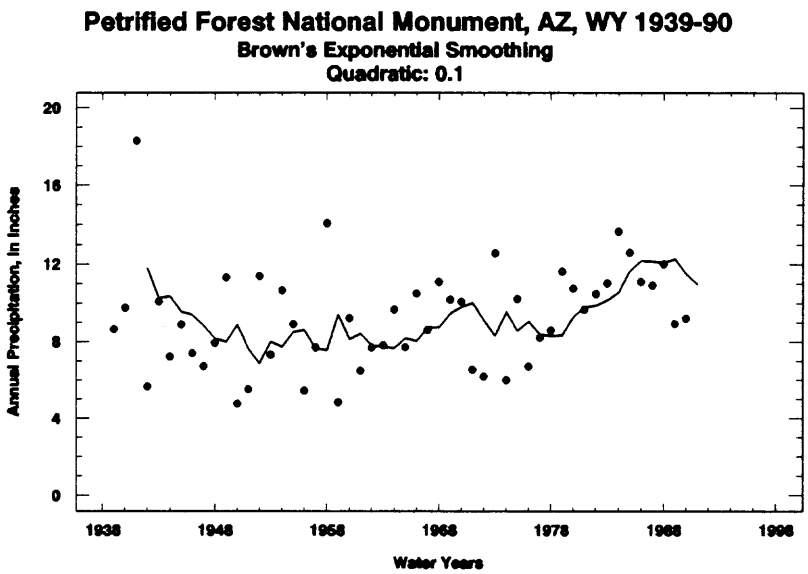


Figure 184. Petrified Forest NP, Smoothed Annual Precipitation, WY 1939-90

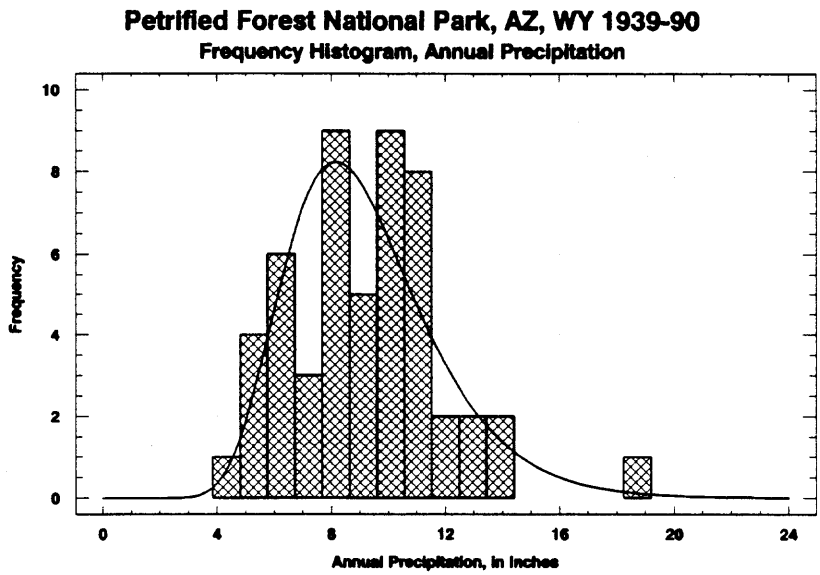


Figure 185. Petrified Forest NP, Histogram of Annual Precipitation

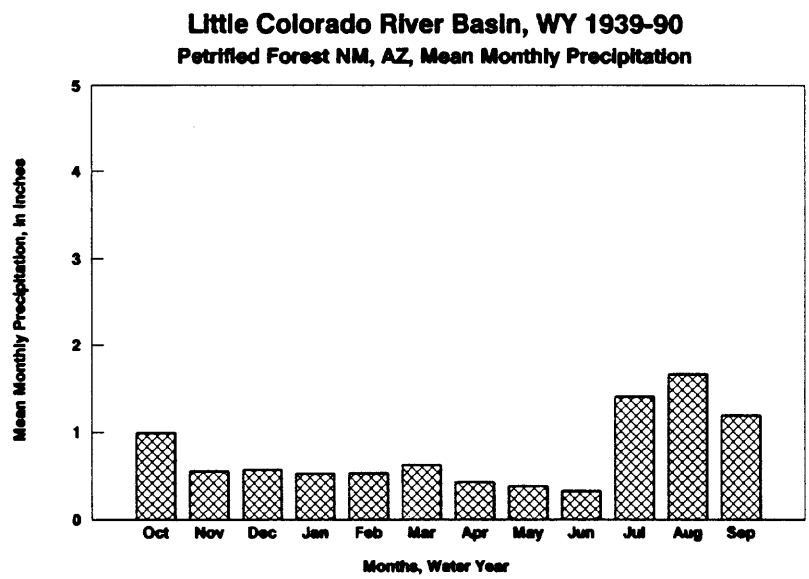


Figure 186. Petrified Forest NP, Monthly Distribution of Precipitation

6.2.3.39 Saint Johns, AZ

The period of record for Saint Johns is sporadic from 1889 to 1892, 1902 to 1907, and 1909 through 1912. The record is almost continuous from 1913 to the present, with some months missing in 1919 and 1925.

As summarized in Sellars and Hill (1974, p. 426):

> "Saint Johns is located at an elevation of 5,730 feet in the plateau country of east-central Arizona. It lies 18 miles west of the New Mexico border. The Little Colorado River flows from south to north just to the east of the town, and is the source of the water in the Lyman and Zion Reservoirs, ten miles to the south and northwest, respectively. The well-known Petrified Forest National Monument [Park] lies to the northwest at a distance of about forty miles. The highest elevations in the area are reached on Baldy Peak, at 11,500 feet in the beautiful White Mountains, forty miles to the south-southwest of Saint Johns. Also to the south, the Mogollon Plateau, containing some of the finest pine forests in the state and rising above 7,500 feet along its southern rim, forms a great arc about Saint Johns, extending from the White Mountains northwestward to the San Francisco Mountains of north-central Arizona. The vegetation in the non-irrigated, semi-desert country near Saint Johns consists mainly of plains grass, juniper, and pinyon.
>
> "Saint Johns lies near one of the drier sections of Arizona. As a result, it does not receive enough precipitation in an average year to make crop growing profitable without irrigation. Conditions are aggravated by the seasonal distribution of precipitation. Winter precipitation, which is of the greatest benefit to crops, is usually light. The storms that affect Arizona in the cooler months enter the state from the west. By the time that they reach Saint Johns they are relatively dry, having lost much of their moisture over the Mogollon Plateau to the west and south. Fortunately, spring runoff of melted snow from the White Mountains area, via the Little Colorado River, is normally sufficient to fill the two nearby reservoirs. Snow is common at Saint Johns in winter, accounting for better than half of the total precipitation.
>
> "While winter precipitation, when it occurs, is usually widespread and long-lasting, that of summer is spotty and brief. But it is intense enough and consistent enough to make this the wettest season of the year at Saint Johns. Moderate to heavy afternoon showers and thundershowers develop somewhere in the vicinity on almost every day from the middle of July until the end of August. Precipitation is heaviest in the White Mountains area. The source for this moisture is usually the Gulf of Mexico. However, once or twice each summer heavy rains may fall from air that is associated with a surge of tropical moisture from the Pacific Ocean."

The precipitation trends for the 1939 to 1990 study period are essentially flat from 1939 through 1980. From 1980 through 1987, there is a moderate increase, followed by what may be a decrease from 1988 through 1990.

The histogram for the area is slightly lognormal with a sharp peak at eleven inches. Several very wet seasons induce a slight positive skewness for the distribution. The monthly distribution shows that the heaviest period is from July to October, with a decline from November to the seasonal minimum in June.

Table 52. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Saint Johns, AZ
Station No.: 7435
Elevation: 5790
Latitude: 34d 31m
Longitude: 109d 23m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.00	0.00	0.50	0.72	1.14	0.49	0.74	0.33	0.06	1.37	0.76	0.87	6.98
1940	0.06	0.63	0.36	0.69	1.00	0.48	0.33	0.35	1.37	2.28	1.99	3.24	12.78
1941	0.51	1.14	1.56	1.44	1.47	2.45	1.43	1.68	0.23	2.03	0.88	3.08	17.90
*1942	1.08	0.48	0.74	0.50	0.64	0.68	0.57	0.00	0.00	0.33	1.97	0.91	7.90
1943	2.07	0.06	1.23	1.02	0.46	0.97	0.09	0.62	0.47	0.26	3.17	1.25	11.67
1944	0.56	0.03	0.70	0.10	0.71	0.53	0.62	0.40	0.00	1.44	1.26	2.04	8.39
1945	1.01	0.75	0.52	0.34	0.64	0.39	0.21	0.13	0.25	0.98	2.22	0.03	7.47
1946	0.31	0.00	1.25	1.91	0.15	0.50	0.29	0.10	0.09	2.61	3.94	2.64	13.79
1947	0.09	0.41	0.11	0.28	0.00	0.00	0.00	1.30	0.95	1.00	2.67	1.08	7.89
1948	2.06	0.33	0.36	0.11	2.53	1.18	0.25	0.39	0.09	1.86	1.40	1.43	11.99
1949	1.46	0.02	0.34	0.64	0.45	0.26	0.37	0.28	2.58	4.49	2.53	1.36	14.78
1950	0.47	0.32	1.45	0.07	0.35	0.92	0.10	0.02	0.12	1.56	0.75	0.74	6.87
1951	0.00	0.00	0.00	1.01	0.25	0.56	1.07	0.11	0.00	1.11	2.84	0.87	7.82
1952	0.87	0.51	0.98	1.11	0.55	1.24	1.42	0.24	1.05	2.11	1.32	2.32	13.72
1953	0.00	1.56	0.34	0.11	0.47	1.33	0.78	0.20	0.10	4.62	0.65	0.00	10.16
1954	0.18	0.45	0.61	0.33	0.16	1.62	0.00	0.42	0.02	5.47	0.98	1.40	11.64
1955	0.53	0.00	0.55	0.52	0.22	0.13	0.01	0.35	1.11	2.14	4.23	0.00	9.79
1956	0.95	0.09	0.38	1.15	1.96	0.08	0.40	0.20	0.27	1.26	1.25	0.06	8.05
1957	0.35	0.10	0.02	0.51	0.34	0.84	0.19	0.64	0.39	2.88	5.66	0.00	11.92
1958	2.84	0.55	0.22	0.40	0.47	1.63	0.34	0.22	0.58	1.99	2.88	2.90	15.02
1959	0.89	0.22	0.08	0.66	0.19	0.00	1.24	0.00	0.42	3.46	1.91	0.27	9.34
1960	3.76	0.41	1.97	0.94	0.35	0.53	0.33	0.28	0.97	0.56	0.92	0.37	11.39
1961	2.63	0.03	0.53	0.23	0.19	1.92	0.18	0.18	0.00	0.99	1.83	1.29	10.00
1962	2.50	0.63	0.81	0.83	0.38	0.74	0.06	0.02	0.07	0.34	0.94	1.79	9.11
1963	0.75	1.16	0.87	0.33	0.40	0.26	0.10	0.03	0.00	0.99	2.97	1.47	9.33
1964	0.98	0.78	0.13	0.76	0.35	0.53	0.68	0.01	0.03	3.02	3.15	2.96	13.38
1965	0.05	0.91	0.70	0.90	0.86	0.51	0.30	0.87	1.18	2.77	1.07	1.62	11.74
1966	0.37	0.42	2.30	0.13	0.30	0.00	0.70	0.00	0.19	1.55	1.29	0.24	7.49
1967	0.26	0.28	0.10	0.15	0.11	0.41	0.10	0.33	1.30	3.82	3.06	1.30	11.22
1968	0.19	0.52	2.02	0.20	0.55	1.51	0.33	0.42	0.11	3.08	1.23	0.52	10.68
1969	0.68	0.42	1.26	0.60	0.27	1.08	0.05	0.96	0.00	1.69	1.99	0.82	9.82
1970	1.40	0.63	0.36	0.47	0.42	1.26	0.85	0.33	0.18	1.39	1.09	1.73	10.11
1971	0.98	0.04	0.43	0.55	0.52	0.33	0.48	0.00	0.00	0.72	2.05	3.30	9.40
1972	0.80	0.51	1.29	0.39	0.00	0.00	0.09	0.20	3.78	0.86	2.30	0.56	10.78
1973	3.28	0.52	0.39	0.85	1.56	1.72	1.30	1.03	0.52	1.95	1.09	0.07	14.28
1974	0.04	0.44	0.00	1.51	0.17	0.34	0.08	0.14	0.00	1.80	1.88	1.21	7.61
1975	3.93	0.16	0.11	0.51	1.62	0.86	0.62	0.38	0.00	3.59	1.21	3.52	16.51
1976	0.00	0.69	0.81	0.30	0.23	1.18	0.28	1.15	0.51	2.85	1.77	1.40	11.17
1977	0.44	0.58	0.22	0.95	0.63	1.21	0.32	0.02	1.48	1.90	1.78	1.25	10.78
1978	1.31	0.42	0.28	1.19	1.32	2.55	0.16	0.92	0.00	0.48	2.07	0.81	11.51
1979	0.69	1.79	1.38	0.72	0.22	0.42	0.60	2.43	0.19	0.20	0.68	0.10	9.42
1980	1.32	1.60	0.64	1.20	1.72	1.45	0.57	0.08	0.00	0.24	1.63	2.05	12.50
1981	0.19	0.19	1.18	0.50	0.38	1.04	1.22	0.37	0.38	2.49	2.69	0.93	11.56
1982	0.72	0.40	0.12	1.24	0.43	1.00	0.00	1.28	0.50	1.84	4.74	1.37	13.64
1983	0.00	1.08	1.78	1.76	0.11	0.65	0.54	0.41	1.30	1.71	1.54	2.26	13.14
1984	1.17	0.72	0.62	0.00	0.00	1.66	0.57	0.00	0.52	2.37	8.06	2.83	18.52
1985	2.09	0.00	0.96	2.47	1.01	0.76	1.31	0.60	0.55	1.76	0.52	2.47	14.50
1986	1.39	0.68	0.65	0.06	1.09	1.38	0.02	0.13	0.89	3.33	2.30	1.70	13.62
1987	2.19	2.00	1.37	0.91	1.48	0.54	0.05	0.16	0.86	1.24	1.44	0.50	12.74
1988	1.33	0.69	0.42	0.03	0.50	0.00	2.23	0.07	1.32	1.06	4.47	0.34	12.46
1989	1.19	0.40	0.55	0.32	0.36	0.34	0.00	0.04	0.00	1.29	1.39	0.26	6.14
1990	1.41	0.00	0.23	0.12	0.09	0.41	0.66	0.47	0.11	2.67	2.25	1.72	10.14
1939-90 Average	1.04	0.51	0.71	0.67	0.61	0.82	0.49	0.41	0.52	1.92	2.13	1.33	11.16

* Denotes year in which one or more monthly records are reconstructed.

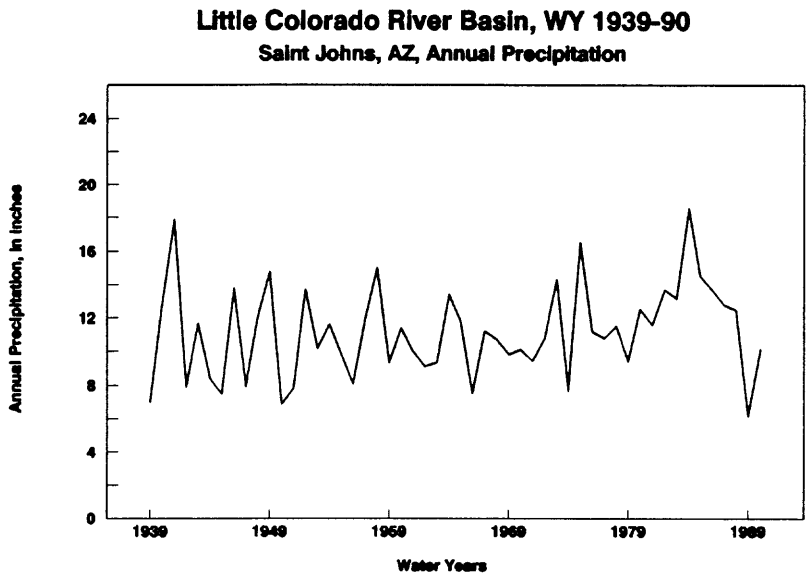


Figure 187. Saint Johns, AZ, Annual Precipitation, WY 1939-90

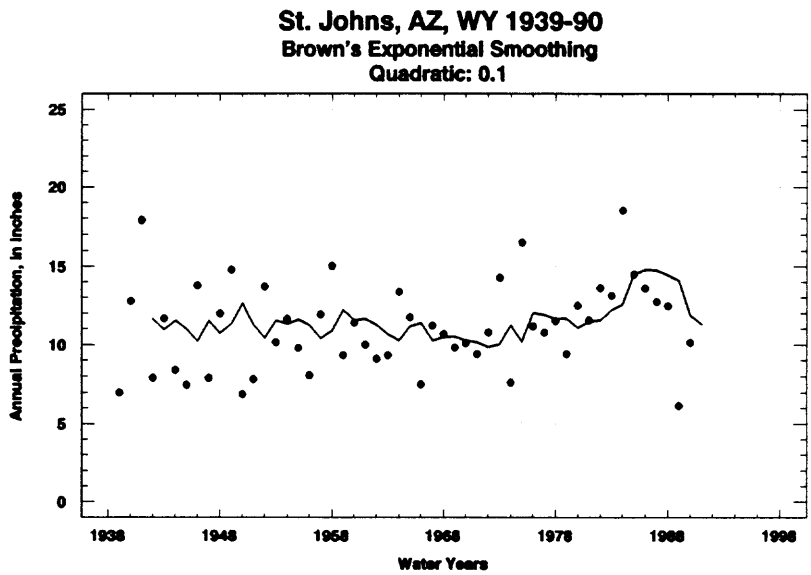


Figure 188. Saint Johns, AZ, Smoothed Annual Precipitation, WY 1939-90

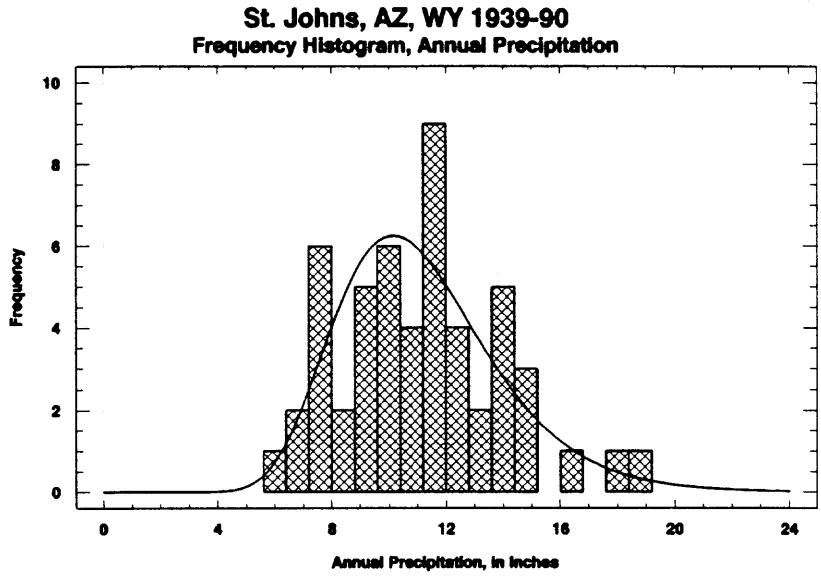


Figure 189. Saint Johns, AZ, Histogram of Annual Precipitation

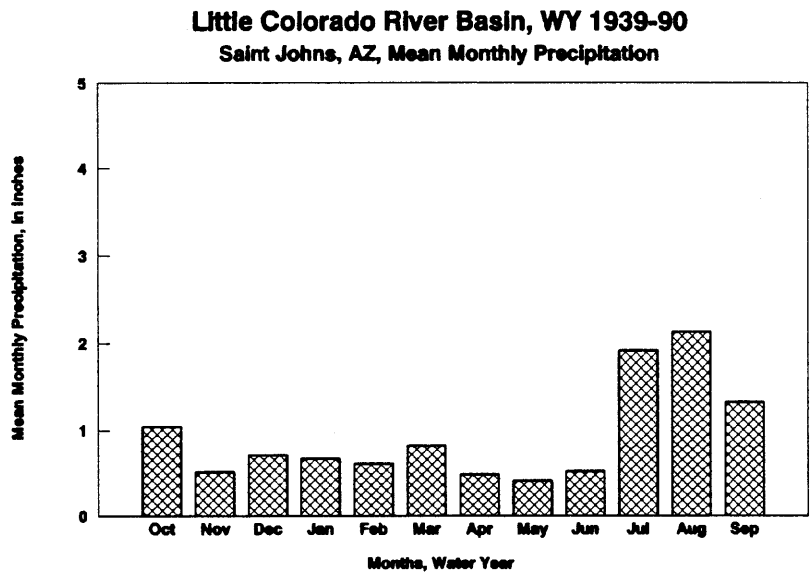


Figure 190. Saint Johns, AZ, Monthly Distribution of Precipitation

6.2.3.40 Shiprock, NM

Shiprock is located at an elevation of 4,870 feet in extreme northwestern New Mexico. It is about fifty miles northeast of the northeast boundary of the Little Colorado River Basin. It is included in the study for the purposes of interpolation of missing data in nearby LCR Basin station records, as well as providing additional resolution in isohyetal maps of the basin. The period of record is from 1926 through 1942 and from 1945 through the present. Many missing months are noted in 1952, 1953, 1963, 1971, and 1972. Single months are missing in other years. The missing record is reconstructed.

The precipitation trends, as noted from the reconstructed record, indicate a decline from 1939 through 1956, followed by a gradual increase from 1957 through 1990.

The histogram indicates a slight lognormal distribution with very flat kurtosis and a barely noticeable positive skewness due to two wet years. The monthly distribution demonstrates that the majority of the annual precipitation occurs in the months of August through October, with the remainder of the year in a slight decline to the annual minimum in June.

Table 53. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Shiprock, NM
Station No.: 8284
Elevation: 4870
Latitude: 36d 47m
Longitude: 108d 42m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.50	0.30	0.26	0.07	0.19	1.22	0.35	0.30	0.00	1.03	1.90	2.42	8.54
1940	0.23	0.31	0.13	0.95	0.74	0.20	0.40	0.16	0.07	0.54	0.79	2.61	7.13
1941	0.69	0.17	1.53	0.87	1.81	1.09	2.11	2.48	0.63	0.25	0.81	2.05	14.49
*1942	2.88	0.33	0.54	0.00	0.12	0.22	1.01	0.04	0.00	0.29	0.34	0.35	6.12
*1943	0.80	0.02	0.37	0.00	0.10	0.71	0.03	0.70	0.35	0.18	0.48	0.46	4.19
*1944	0.44	0.13	1.06	0.50	0.58	0.21	0.68	0.65	0.01	0.00	0.72	1.45	6.43
1945	0.32	0.77	0.81	0.35	0.43	0.85	0.65	0.04	0.02	0.31	0.78	0.17	5.50
1946	0.87	0.00	0.57	0.03	0.12	0.73	0.21	0.45	0.09	0.69	1.23	0.41	5.40
1947	0.43	0.88	0.14	0.10	0.30	0.09	0.15	1.32	0.00	0.05	2.78	1.07	7.31
1948	1.74	0.27	0.19	0.00	0.80	0.30	0.35	0.05	1.19	0.83	2.03	0.33	8.08
1949	1.84	0.08	0.67	0.74	0.17	0.32	0.42	0.80	2.63	0.69	0.23	0.23	8.82
1950	0.62	0.06	0.01	0.21	0.38	0.04	0.03	0.00	0.14	0.57	0.11	0.58	2.75
1951	0.00	0.00	0.08	0.44	0.42	0.03	0.16	0.21	0.00	0.06	0.54	0.69	2.63
*1952	0.41	0.68	0.81	1.24	0.31	0.04	1.00	0.23	0.48	0.99	0.22	0.27	6.68
*1953	0.00	0.78	0.59	0.00	0.11	0.30	0.72	0.00	0.02	0.87	2.38	0.00	5.77
1954	1.51	0.05	0.35	0.00	0.00	0.86	0.00	0.53	0.20	1.35	0.74	0.95	6.54
1955	0.39	0.16	0.72	0.19	1.13	0.00	0.11	0.73	0.51	1.00	0.73	0.10	5.77
*1956	0.00	0.25	0.25	1.53	0.11	0.45	0.01	0.49	0.20	0.35	0.53	0.00	4.17
1957	0.27	0.01	0.00	0.88	0.42	1.24	1.34	1.09	0.40	2.16	1.12	0.27	9.20
1958	2.32	0.99	0.29	0.20	0.30	1.13	0.37	0.24	0.11	0.11	1.05	0.43	7.54
1959	0.06	0.02	0.00	0.00	0.04	0.02	0.64	0.01	0.58	0.04	0.77	0.14	2.32
1960	1.65	0.21	0.33	0.33	0.38	0.19	0.16	0.24	0.42	0.13	0.10	0.25	4.39
1961	1.92	0.00	1.11	0.35	0.00	1.15	0.31	0.24	0.00	0.25	0.57	1.21	7.11
*1962	0.97	1.35	0.55	0.05	0.51	0.00	0.22	0.00	0.00	0.00	0.00	1.33	4.98
*1963	2.03	1.12	0.00	0.43	0.64	0.21	0.00	0.00	0.06	0.32	2.76	0.62	8.20
1964	0.00	0.24	0.35	0.14	0.04	1.18	0.57	0.28	0.00	0.43	0.69	2.22	6.14
1965	0.00	1.13	0.94	0.89	0.34	0.24	1.10	1.27	1.07	0.52	0.20	0.46	8.16
1966	2.13	1.00	0.83	0.14	0.24	0.00	0.23	0.44	0.00	0.63	0.40	0.15	6.19
1967	0.14	0.14	1.35	0.22	0.19	0.00	0.03	0.34	0.41	0.37	1.33	0.42	4.94
1968	0.37	0.04	1.50	0.07	0.30	0.02	0.38	0.20	0.18	0.04	0.15	1.47	4.72
1969	0.85	0.44	0.50	2.41	0.32	0.40	0.02	1.22	1.21	0.10	0.07	1.04	8.58
*1970	5.03	0.53	0.18	0.00	0.00	0.99	0.65	0.00	0.66	0.48	0.17	1.97	10.65
*1971	0.44	0.40	0.17	0.30	0.43	0.10	0.00	0.87	0.00	1.77	1.24	0.42	6.14
1972	1.12	0.46	0.45	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.98	0.47	4.22
1973	2.12	0.10	1.06	0.50	0.77	0.48	0.68	1.81	0.71	0.35	0.73	0.55	9.86
1974	0.08	0.60	0.01	2.75	0.10	0.12	0.73	0.00	0.00	0.18	0.45	0.00	5.02
1975	1.96	1.46	0.50	0.25	0.48	0.57	0.64	0.38	0.37	1.20	1.92	1.55	11.28
1976	0.22	0.86	0.21	0.14	0.05	0.00	0.00	0.19	0.00	0.00	0.46	0.90	3.03
1977	0.73	0.10	0.03	0.13	0.00	0.00	0.00	0.47	0.00	1.72	0.30	0.20	3.68
1978	0.24	0.64	0.53	1.11	0.83	1.40	0.19	1.41	0.09	0.14	0.32	0.72	7.62
1979	1.14	0.90	0.84	0.65	0.22	0.35	0.21	0.69	0.00	1.03	0.10	0.04	6.17
1980	1.55	1.14	0.70	1.78	0.78	0.58	0.16	0.31	0.00	0.07	1.10	1.55	9.72
1981	1.01	0.10	0.05	0.05	0.49	0.69	0.05	0.25	0.06	1.22	0.56	0.48	5.01
*1982	0.78	0.43	0.02	0.25	1.19	0.65	0.21	1.07	0.00	0.50	3.34	0.93	9.37
1983	0.18	0.82	1.79	1.31	0.51	0.90	0.12	0.23	0.29	0.52	0.18	0.97	7.82
1984	0.04	0.70	0.59	0.09	0.06	0.73	0.61	0.11	0.17	0.12	0.65	0.27	4.14
*1985	0.75	0.18	0.99	0.34	0.13	1.74	1.96	0.26	0.06	0.71	0.00	0.20	7.32
*1986	0.76	0.60	0.20	0.09	0.93	0.45	1.05	0.98	0.75	2.22	1.06	1.62	10.71
1987	0.67	2.21	0.82	0.20	1.19	0.38	0.22	0.56	0.13	0.21	1.03	0.04	7.66
1988	0.62	1.59	0.71	0.73	1.36	0.00	0.83	0.24	0.75	0.08	2.65	0.61	10.17
1989	0.30	0.60	0.40	0.93	0.76	0.23	0.00	0.03	0.00	1.49	3.34	0.33	8.41
1990	0.69	0.00	0.00	0.67	0.67	0.31	0.97	0.93	0.01	0.65	2.47	1.45	8.82
1939-90 Average	0.90	0.51	0.52	0.49	0.43	0.46	0.44	0.49	0.30	0.57	0.95	0.76	6.84

* Denotes year in which one or more monthly records are reconstructed.

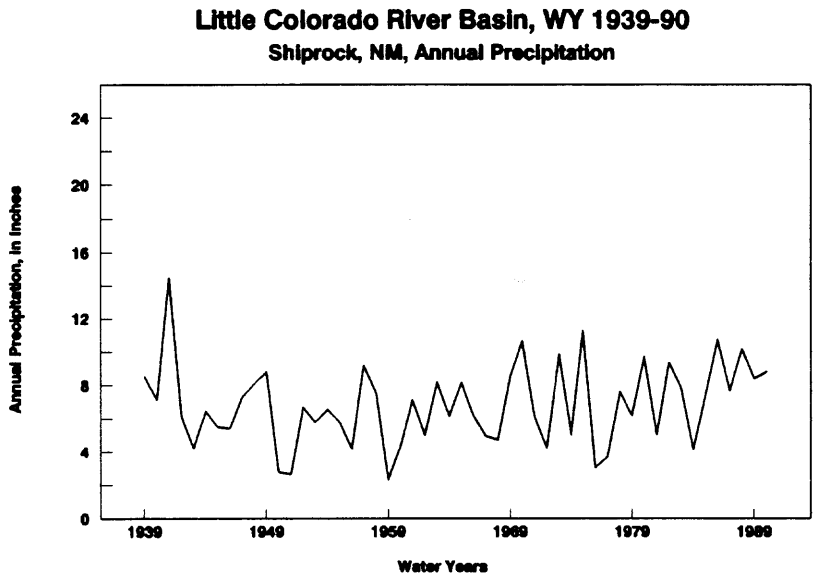


Figure 191. Shiprock, NM, Annual Precipitation, WY 1939-90

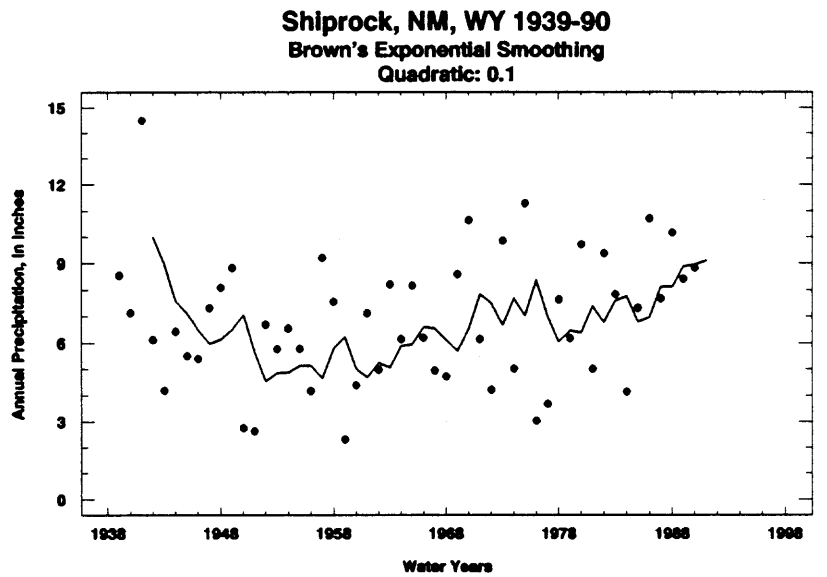


Figure 192. Shiprock, NM, Smoothed Annual Precipitation, WY 1939-90

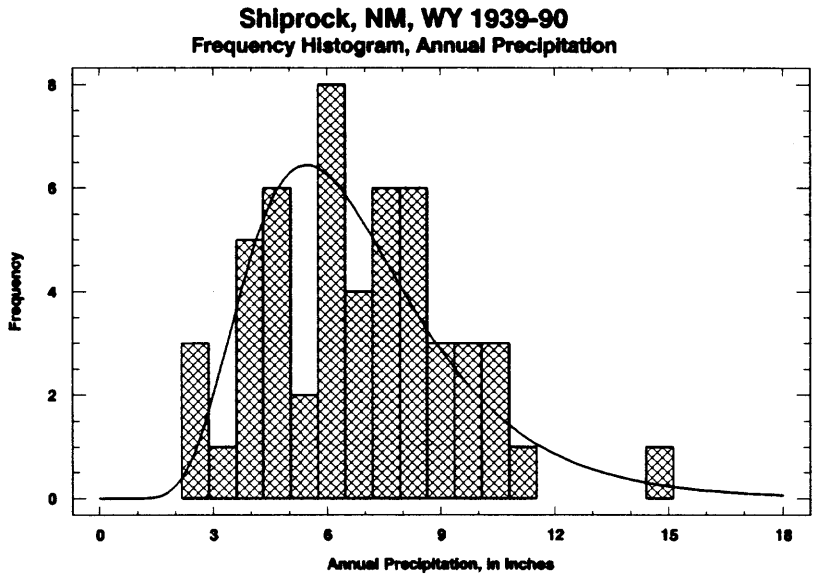


Figure 193. Shiprock, NM, Histogram of Annual Precipitation

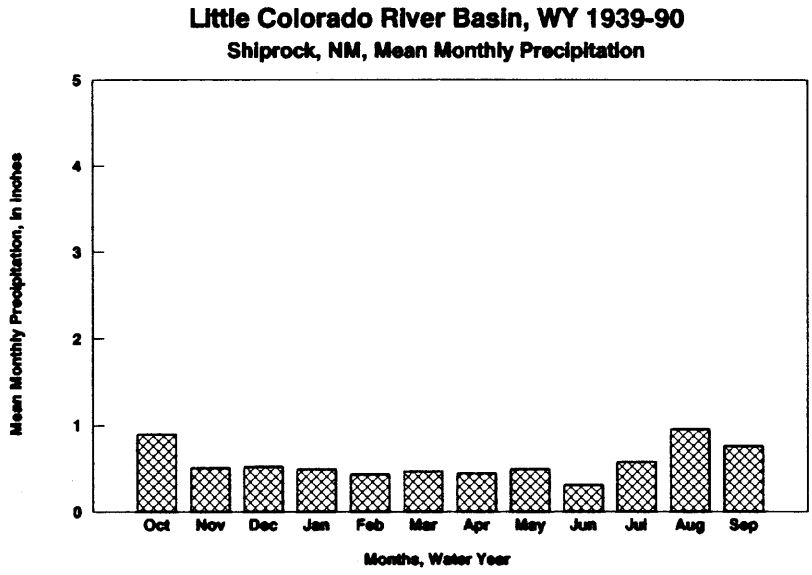


Figure 194. Shiprick, NM, Monthly Distribution of Precipitation

6.2.3.41 Show Low, AZ

The period of record for Show Low is from 1890 through 1898, from 1916 to 1926, and from 1952 through the present, with some months of record in 1950.

As summarized in Sellars and Hill (1974, p. 470):

> "Show Low City (sic) lies at an elevation of 6,400 feet on the forest-covered Mogollon Plateau of east-central Arizona. The southern rim of this massive plateau, four miles to the south, coincides with the northern boundary of the Fort Apache [White Mountain Apache] Indian Reservation. Elevations on the plateau exceeding 7,500 feet are found west of Show Low, with Promontory Butte on Mogollon Mesa rising to 7,915 feet about sixty miles to the west-northwest. The terrain to the northeast is essentially flat, sloping gradually downward to the Little Colorado River at a distance of thirty-five miles. Show Low is located in the eastern section of the Sitgraves National Forest, featuring beautiful stands of ponderosa pine. The vegetation type to the north is basically a function of elevation, with juniper and pinyon between 5,800 and 6,100 feet, plains grass between 5,800 and 5,100 feet, and sagebrush prevailing in the valley of the Little Colorado River. In the rougher terrain to the south, the vegetation ranges from ponderosa pine on the plateau through juniper and chaparral at intermediate elevations to cacti and palo verde in the low-lying river valleys.
>
> "Because it is located on the relatively flat eastern portion of the Mogollon Plateau, near the point where the southern rim attains its lowest elevations, Show Low receives considerably less precipitation than the more rugged and exposed regions to the west and south. Most of the 15.35 inches of presentation that falls in an average year is recorded in the summer and winter months. During the former, tropical air from the Gulf of Mexico penetrates into central Arizona, triggering showers and thundershowers almost daily. Some of the heaviest summer rains at Show Low City are associated with dissipating tropical disturbances that move northeastward into Arizona from the Gulf of California or the adjoining Pacific Ocean.
>
> "Winter precipitation at Show Low City is normally longer-lasting although much less intense, than the showers of summer. It usually originates in eastward-moving middle latitude storms that form in the North Pacific Ocean. Unfortunately, a great deal of the moisture associated with these cyclonic storms is lost on the windward slopes of the Mogollon Plateau, limiting the potential winter precipitation at Show Low City. Over fifty percent of the winter showers occur in the form of snow, with just under forty inches of snow being measured in most years."

Precipitation trends for the 1939-90 study period show a decline from 1939 through 1960. There is a gradual increase in the period of 1961 through 1988, followed by the beginnings of a decline from 1988 through 1990.

The histogram shows a slight lognormal trend, with flat kurtosis and a slight positive skewness due to several wet years up to 28 inches. Several peaks are noted for 14, 16, and 17 inches. Monthly distribution peaks in the months of July through October, with a gradual decline from December to the annual minimum in June.

Table 54. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Show Low,AZ
Station No.: 7855
Elevation: 6400
Latitude: 34d 15m
Longitude: 110d 02m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.27	0.06	1.85	2.13	1.54	1.14	1.37	0.03	0.22	1.01	2.03	1.82	13.47
*1940	0.20	1.00	0.52	0.77	1.73	0.50	1.08	0.20	0.35	1.17	2.73	4.34	14.58
*1941	1.84	1.78	2.95	2.61	2.48	3.94	2.04	0.85	0.47	2.51	3.24	3.17	27.90
*1942	1.38	1.74	1.84	1.02	1.41	0.64	1.48	0.01	0.00	1.16	1.92	0.98	13.59
*1943	3.07	0.12	2.64	0.79	0.84	1.89	0.39	0.57	0.38	1.46	3.34	1.81	17.29
*1944	1.26	0.03	1.70	0.58	2.11	1.39	1.28	0.52	0.03	1.86	2.71	2.62	16.07
*1945	0.62	1.75	1.22	0.91	0.72	2.21	0.36	0.05	0.23	2.77	3.29	0.37	14.50
*1946	1.35	0.03	2.06	1.72	0.54	0.84	0.98	0.00	0.02	2.79	4.48	4.62	19.43
*1947	0.98	1.93	1.26	0.47	0.54	0.09	0.09	2.54	0.32	1.66	4.87	1.97	16.72
*1948	2.95	1.24	1.02	0.30	2.14	1.15	0.10	0.15	0.51	2.61	2.23	1.08	15.48
*1949	2.07	0.07	2.34	3.24	0.89	0.75	0.49	0.50	1.21	4.51	2.68	2.31	21.07
*1950	1.65	0.62	2.45	0.17	0.58	0.48	0.00	0.10	0.45	2.89	1.42	1.37	12.17
*1951	0.20	0.27	0.03	2.01	1.03	1.10	1.62	0.44	0.00	2.22	5.03	0.96	14.92
*1952	1.68	0.45	3.10	4.23	0.64	1.51	1.76	0.00	0.89	3.66	2.08	1.40	21.40
*1953	0.00	3.44	1.07	0.05	0.77	1.11	1.08	0.05	0.54	3.81	1.20	0.00	13.12
1954	0.13	0.79	0.28	0.89	0.25	5.23	0.00	0.79	0.77	3.26	1.88	2.12	16.39
1955	0.42	0.31	1.22	1.31	0.96	0.02	0.16	0.03	2.19	3.14	2.31	0.00	12.07
1956	0.11	0.78	1.17	1.44	1.70	0.19	0.94	0.13	0.18	2.60	1.62	0.00	10.86
1957	1.24	0.02	0.28	3.54	0.44	0.78	0.54	0.31	0.41	2.11	3.13	0.40	13.20
1958	2.22	0.70	0.18	0.56	1.82	2.04	1.21	0.48	0.53	0.81	3.25	2.66	16.46
1959	2.08	1.11	0.08	0.54	2.37	0.00	0.33	0.01	0.84	1.53	3.32	0.40	12.61
1960	6.04	1.20	4.31	1.92	0.51	1.22	0.44	0.74	0.21	0.76	1.52	0.55	19.42
1961	3.37	1.03	0.94	0.10	0.31	1.86	0.00	0.00	0.00	2.06	3.28	1.05	14.00
1962	3.17	1.21	1.36	1.53	1.22	0.70	0.12	0.15	0.19	0.75	0.51	3.28	14.19
*1963	1.47	0.60	0.96	1.04	1.64	0.65	0.44	0.01	0.04	1.81	5.21	1.88	15.75
1964	0.55	1.96	0.20	2.03	0.95	2.37	0.30	0.00	0.00	2.64	3.35	1.36	15.71
*1965	0.00	1.45	1.06	4.43	1.91	1.17	2.09	0.55	0.39	3.48	0.25	1.42	18.20
1966	1.63	1.69	7.37	0.86	0.74	0.25	0.10	0.00	0.69	2.33	1.48	1.72	18.86
1967	0.45	1.15	2.05	0.41	0.10	1.64	0.79	0.76	0.93	2.50	3.98	1.78	16.54
1968	0.01	0.40	6.60	0.55	0.88	1.17	0.60	0.10	0.10	1.89	1.73	0.18	14.21
1969	1.32	1.15	1.45	2.01	1.28	0.46	0.08	1.70	0.00	4.39	2.40	0.64	16.88
1970	1.26	1.73	1.03	0.09	0.79	1.48	0.92	0.07	0.12	2.70	3.22	3.24	16.65
1971	2.36	0.39	1.26	0.38	0.58	0.40	0.39	0.03	0.00	1.21	4.60	3.95	15.55
1972	4.59	1.03	6.21	0.04	0.00	0.00	0.00	0.00	2.25	1.80	2.09	1.40	19.41
1973	6.91	2.00	2.72	0.86	3.40	3.62	1.00	1.40	0.61	2.06	0.64	0.00	25.22
1974	0.04	0.54	0.00	2.88	0.15	1.24	0.28	0.00	0.00	2.70	1.18	1.64	10.65
1975	4.13	0.36	0.73	1.17	1.27	2.03	0.98	0.35	0.00	1.85	1.53	3.10	17.50
1976	0.11	1.93	0.72	0.11	2.32	1.57	1.12	1.56	0.18	3.29	3.63	1.85	18.39
1977	0.97	0.50	0.20	1.38	0.88	1.02	0.95	0.49	0.58	4.07	3.86	2.79	17.69
1978	2.08	1.13	0.42	1.99	3.65	3.33	0.90	0.97	0.25	2.09	2.91	1.80	21.52
1979	1.50	6.73	4.07	3.47	0.72	2.71	0.38	2.59	0.04	1.77	2.21	0.40	26.59
1980	0.64	0.90	1.48	3.68	5.08	2.23	0.44	0.15	1.01	1.48	2.92	0.77	20.78
1981	0.32	0.03	1.03	0.70	1.03	2.23	0.58	0.45	0.46	3.13	0.75	1.05	11.76
1982	1.82	1.48	0.00	2.38	1.48	1.88	0.13	1.21	0.00	3.19	3.40	1.58	18.55
1983	0.03	2.59	2.71	1.17	0.75	2.35	0.81	0.17	0.05	2.92	2.96	3.42	19.93
*1984	2.35	1.83	1.52	0.54	0.00	0.87	1.29	0.18	0.73	2.66	5.08	3.04	20.09
1985	3.78	0.00	3.51	1.33	1.05	1.46	1.70	0.02	0.12	5.69	1.95	2.01	22.62
1986	1.74	2.04	0.62	0.05	0.84	0.75	0.53	0.72	0.66	2.28	3.41	1.62	15.26
1987	1.68	4.53	2.30	1.90	2.12	1.05	0.22	0.82	0.36	3.68	3.21	1.06	22.93
1988	1.14	1.96	1.41	0.94	1.05	0.04	1.68	0.18	1.40	1.24	9.03	0.48	20.55
1989	0.64	0.46	0.99	0.85	1.01	1.67	0.00	0.16	0.00	1.26	3.07	0.23	10.34
1990	1.08	0.17	0.72	0.14	0.65	0.41	1.13	0.84	0.07	2.51	3.07	2.81	13.60
1939-90 Average	1.59	1.20	1.72	1.35	1.23	1.36	0.72	0.46	0.42	2.42	2.83	1.66	16.97

* Denotes year in which one or more monthly records are reconstructed.

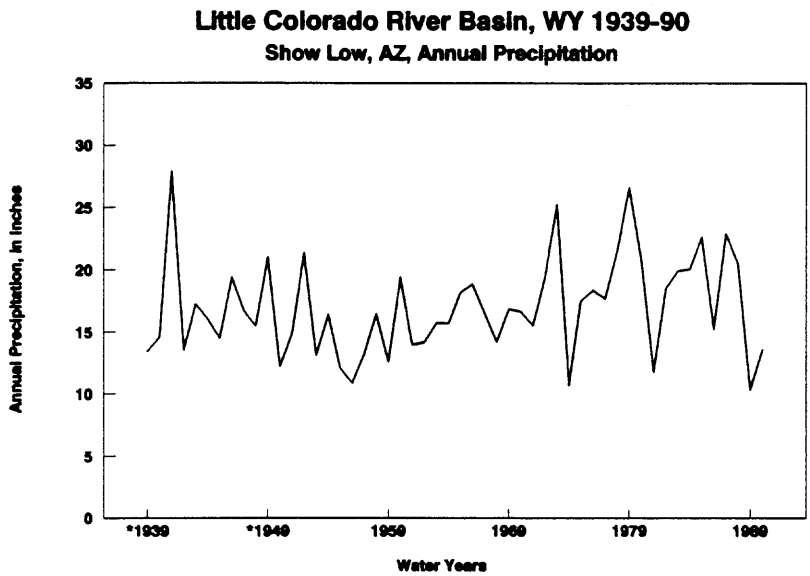


Figure 195. Show Low, AZ, Annual Precipitation, WY 1939-90

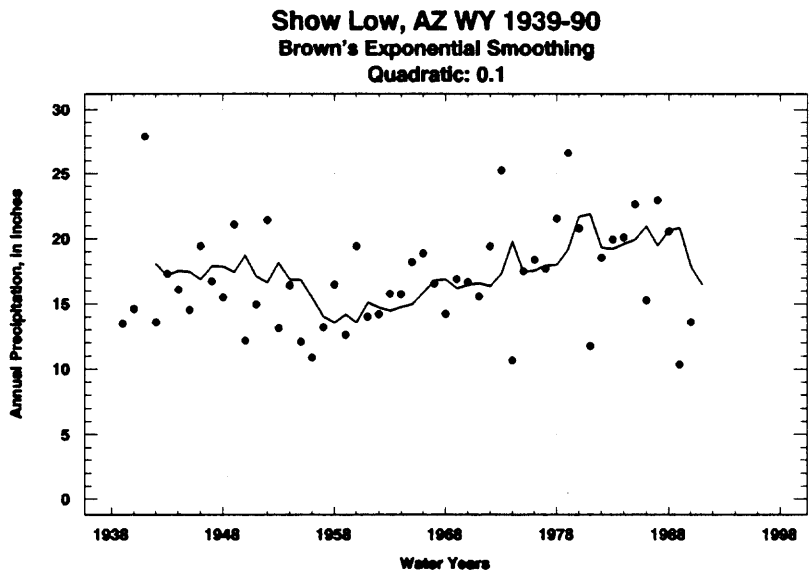


Figure 196. Show Low, AZ, Smoothed Annual Precipitation, WY 1939-90

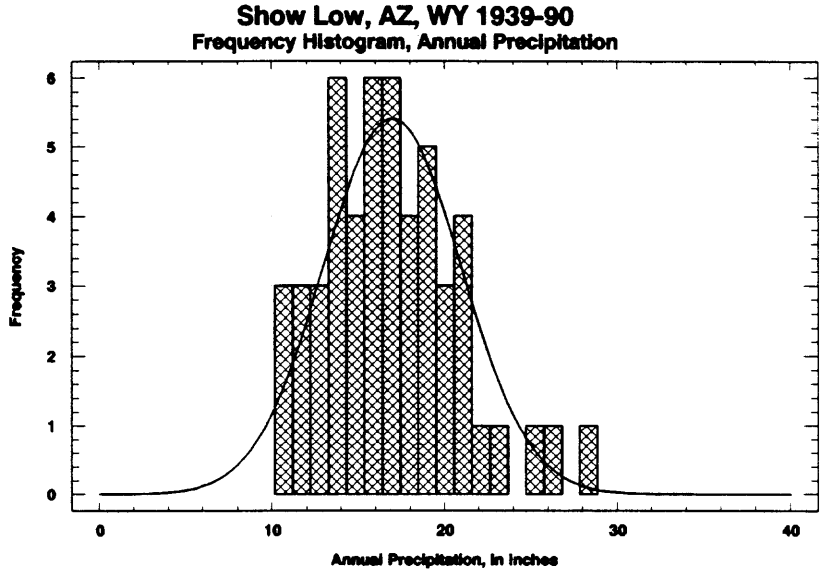


Figure 197. Show Low, AZ, Histogram of Annual Precipitation

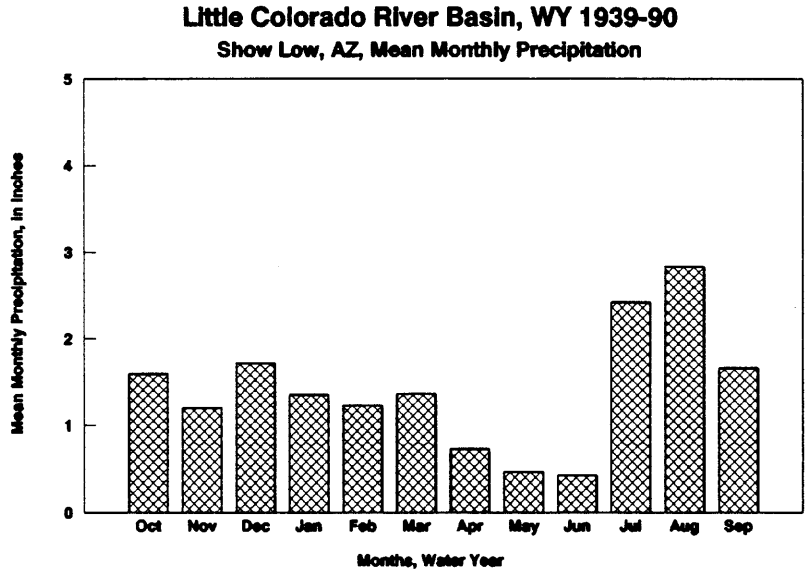


Figure 198. Show Low, AZ, Monthly Distribution of Precipitation

6.2.3.42 Snowflake, AZ

The period of record for Snowflake is from 1897 to 1906 and from 1911 through the present, with some months missing in 1939-40, 1943-44, and 1966-67. The missing record for the 1939-90 study period is reconstructed.

As summarized in Sellars and Hill (1974, p. 480):

"Snowflake is located at an elevation of about 5,600 feet in east-central Arizona. It lies in a broad flat valley on the southern edge of the barren, but picturesque, desert country of the northeastern corner of the state. The Little Colorado River flows northwestward about fifteen miles north of the town. The popular Petrified Forest National Monument [Park] is located 25 miles to the northeast. The terrain slopes upward to the south, reaching elevations above 7,000 feet along the southern rim of the lake-studded, Mogollon Plateau, twenty miles from Snowflake. Highest elevations within fifty miles of the town are found on Greens Peak and Baldy Peak in the White Mountains, a popular summer vacation spot, 45 miles to the southeast. Both peaks rise above 10,000 feet. The natural vegetation in the area varies from sagebrush and plains grass in the river valleys and on the low desert plateaus to the north to juniper and pinyon at intermediate elevations to the south. Ponderosa pine is common in the White Mountains and in Sitgreaves National Forest on the north sloping inclines of the Mogollon Plateau.

"Snowflake has a semi-arid climate, being protected from invasions of particularly severe and moist storms by an almost continuous chain of mountains extending across the western and southern horizons. Precipitation amounts are moderately high only in midsummer, when deep layers of moist tropical air from the Gulf of Mexico successfully penetrate the mountain barrier, usually passing through a depression which exists between the White Mountains and the Mogollon Plateau. Numerous late afternoon showers and thundershowers develop in this air as it flows over the strongly heated surface. Although these showers rarely last longer than half an hour, they are intense enough and frequent enough to account for the major part of the summer precipitation. In some years dissipating tropical disturbances moving northward from the Gulf of California and the adjacent parts of the Pacific Ocean produce heavy rains which may continue for several days.

"From October through June, Snowflake has dry windy weather. Most of the storms that affect the area during this period originate in the North Pacific Ocean and move into Arizona from the north or northwest. As a result of their long trajectory over land, much of it mountainous, these storms usually contain little moisture by the time they reach Snowflake and, thus, can only produce light showers. They are generally accompanied by strong winds which may blow steadily for several days, first from the south, then from the north. About one half of the winter precipitation occurs as snow. Howerver because amounts are normally small, it rarely accumulates to a depth of more than a few inches."

Precipitation trends for the 1939-90 study period indicate a slight decline from 1939 through 1950, followed by a gradual increase from 1951 through 1988, with a single sharp peak at 1970. From 1988 through 1990, there may be the beginnings of a decline.

The histogram shows a lognormal trend, with peaks at 10 and 14 inches. A moderate number of wet years gives the distribution a distinct positive skewness.

Monthly distribution displays a noticeable peak in July and August, with a somewhat reduced September and October high. From November through June, there is a gradual decline to the annual minimum.

Table 55. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Snowflake,AZ
Station No.: 8012
Elevation: 5642
Latitude: 34d 30m
Longitude: 110d 05m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.84	0.10	0.12	1.44	1.04	0.92	1.19	0.00	0.65	0.33	1.48	1.41	9.52
*1940	0.41	0.94	0.45	0.50	1.12	0.52	0.96	0.00	0.64	1.77	2.30	2.63	12.24
1941	1.96	1.10	1.82	1.78	1.05	2.27	1.40	0.61	0.69	2.18	2.01	2.37	19.24
1942	0.49	0.39	1.20	0.80	0.60	0.11	1.67	0.00	0.00	0.38	0.98	0.43	7.05
*1943	2.38	0.00	1.05	0.93	0.19	0.62	0.29	0.49	0.21	1.14	2.24	1.86	11.39
*1944	0.45	0.00	1.86	0.30	1.06	0.98	1.12	0.45	0.00	1.30	1.87	0.99	10.39
1945	0.13	0.88	0.67	0.51	0.29	0.24	0.18	0.08	0.22	3.26	2.83	0.19	9.48
1946	0.46	0.00	0.35	1.23	0.20	0.34	0.39	0.00	0.00	3.04	3.61	3.64	13.26
*1947	0.20	1.30	0.06	0.20	0.00	0.00	0.00	1.87	0.04	0.81	2.65	1.50	8.63
1948	3.72	1.36	0.50	0.28	0.93	0.74	0.04	0.00	0.96	2.88	2.45	0.73	14.59
1949	0.22	0.00	0.92	1.88	0.57	0.47	0.23	0.69	0.68	1.26	1.38	1.57	9.87
1950	1.13	0.19	0.81	0.01	0.29	0.29	0.03	0.04	0.21	1.21	0.49	1.10	5.80
1951	0.01	0.12	0.00	1.48	0.43	0.32	0.74	0.21	0.00	0.62	4.25	0.52	8.70
1952	0.67	0.91	1.13	1.75	0.63	1.00	1.63	0.02	0.69	2.93	2.00	3.26	16.62
1953	0.00	2.53	0.45	0.03	0.16	0.84	0.87	0.04	0.32	3.95	1.70	0.00	10.89
1954	0.07	0.62	0.92	0.64	0.16	1.11	0.02	1.25	0.21	2.19	2.06	3.64	12.89
1955	0.45	0.02	0.23	0.79	0.16	0.02	0.05	0.17	1.86	2.46	4.26	0.01	10.48
1956	0.01	0.26	0.24	0.91	1.58	0.08	0.49	0.19	0.15	2.63	2.72	0.40	9.66
1957	0.88	0.10	0.04	1.58	0.15	0.58	0.30	0.74	1.00	1.27	3.96	0.04	10.64
1958	2.64	0.26	0.00	0.41	0.72	0.88	0.84	0.21	1.15	1.06	4.72	2.48	15.37
1959	0.71	0.48	0.08	0.26	0.72	0.00	0.62	0.00	0.59	0.69	2.32	0.40	6.87
1960	5.32	0.71	1.46	0.66	0.33	0.53	0.28	0.52	0.29	0.76	1.39	0.56	12.81
1961	1.55	0.02	0.48	0.05	0.19	1.45	0.09	0.04	0.12	1.48	1.81	0.70	7.98
1962	2.24	0.79	0.75	1.26	0.86	0.54	0.13	0.00	0.70	0.66	1.17	2.50	11.60
1963	1.02	0.77	0.37	0.49	0.32	0.31	0.10	0.00	0.03	0.43	2.80	0.71	7.35
1964	0.64	0.61	0.14	0.19	0.06	0.77	0.69	0.24	0.29	1.68	4.61	4.17	14.09
1965	0.12	0.89	0.41	0.78	0.71	0.59	0.63	0.34	0.90	1.70	2.92	1.01	11.00
*1966	0.68	0.49	2.36	0.56	0.20	0.08	0.04	0.01	0.38	2.67	1.89	1.41	10.77
*1967	0.74	0.83	1.42	0.33	0.01	0.47	0.37	0.90	0.75	4.71	2.28	0.26	13.06
1968	0.00	0.48	4.16	0.18	0.52	1.21	0.71	0.36	0.05	4.47	1.76	0.29	14.19
1969	1.91	0.55	0.43	0.44	0.86	0.79	0.04	2.90	0.00	4.59	5.65	0.61	18.77
1970	1.08	1.10	0.64	0.31	0.34	1.05	0.40	0.00	0.00	2.35	2.09	1.55	10.91
1971	0.72	0.04	0.32	0.20	0.20	0.35	0.59	0.00	0.00	0.45	4.10	2.45	9.42
*1972	2.80	0.67	2.26	0.05	0.00	0.02	0.00	0.56	0.89	0.61	2.80	0.44	11.10
1973	4.83	0.95	0.94	0.60	1.98	2.27	0.61	1.35	0.10	0.46	1.81	0.03	15.93
1974	0.00	0.32	0.03	1.43	0.05	0.24	0.04	0.00	0.00	3.50	1.35	1.19	8.15
1975	3.04	0.10	0.11	0.33	1.08	1.14	0.48	0.53	0.00	2.22	2.12	3.89	15.04
1976	0.02	0.57	0.59	0.15	1.05	1.09	0.42	1.56	0.35	2.69	1.03	1.67	11.19
1977	1.03	0.23	0.00	0.59	0.35	0.48	1.18	0.00	0.67	2.40	1.57	3.08	11.58
1978	1.63	0.47	0.22	1.41	1.21	2.41	0.11	0.81	0.33	1.55	1.96	1.45	13.56
1979	1.47	3.90	1.70	1.44	0.07	1.42	0.21	2.68	0.13	0.28	1.53	0.05	14.88
1980	0.48	0.47	1.30	1.05	2.33	1.56	0.34	0.26	0.00	1.37	3.43	0.35	12.94
1981	0.27	0.00	0.69	0.57	0.44	1.70	0.50	0.67	0.61	2.25	1.07	0.74	9.51
1982	0.82	0.82	0.00	1.05	0.88	0.86	0.09	0.80	0.05	2.28	1.94	1.49	11.08
1983	0.00	1.19	2.05	0.67	0.53	1.20	0.21	0.12	0.07	1.81	1.81	3.52	13.18
1984	1.58	1.14	1.22	0.07	0.00	1.77	0.27	0.00	0.30	3.74	3.36	5.25	18.70
1985	1.65	0.26	1.98	1.48	0.90	1.03	1.56	0.12	0.05	2.22	2.17	2.46	15.88
1986	1.05	1.89	0.26	0.02	1.06	1.06	0.17	0.50	0.07	2.61	2.53	0.79	12.01
1987	1.86	2.11	1.83	1.71	1.22	0.74	0.23	0.67	0.74	1.55	3.46	0.51	16.63
1988	1.31	1.24	1.08	0.69	0.64	0.00	2.05	0.19	1.44	0.57	5.20	0.66	15.07
1989	0.90	0.31	0.33	0.57	0.25	1.72	0.00	0.00	0.00	5.61	1.42	1.04	12.15
1990	0.69	0.10	0.40	0.05	0.36	0.34	0.25	0.52	0.32	1.20	2.93	2.19	9.35
1939-90 Average	1.14	0.68	0.82	0.71	0.60	0.80	0.50	0.46	0.38	1.97	2.47	1.47	11.99

* Denotes year in which one or more monthly records are reconstructed.

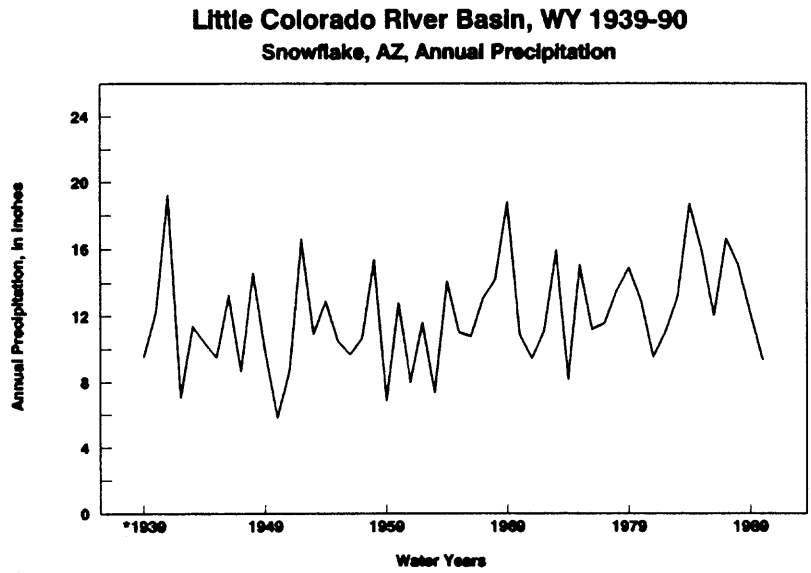


Figure 199. Snowflake, AZ, Annual Precipitation, WY 1939-90

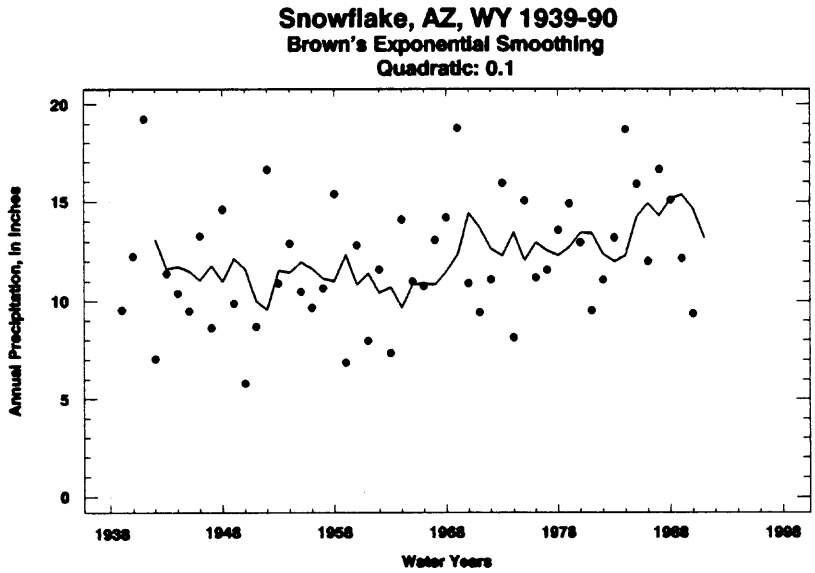


Figure 200. Snowflake, AZ, Smoothed Annual Precipitation, WY 1939-90

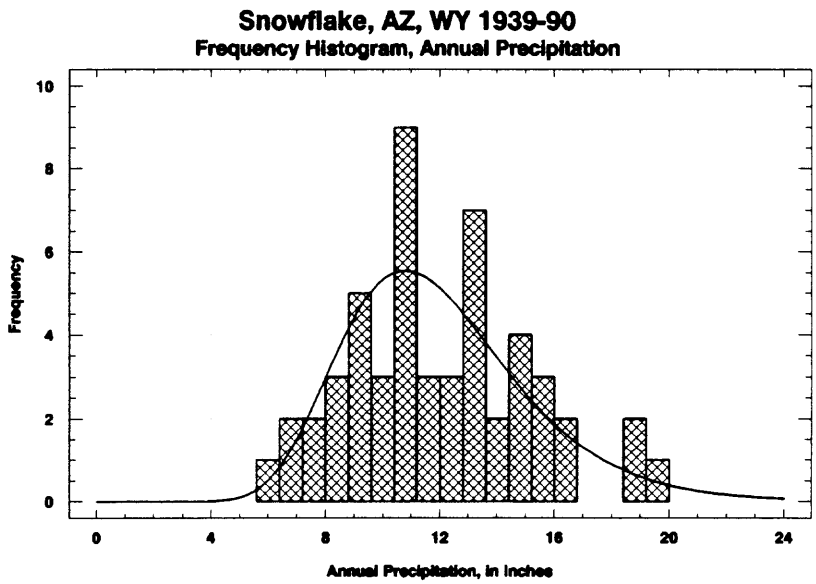


Figure 201. Snowflake, AZ, Histogram of Annual Precipitation

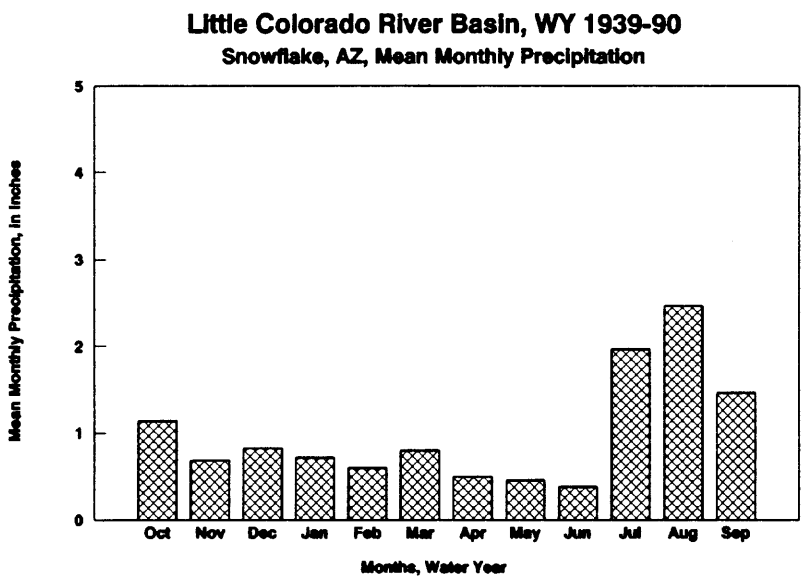


Figure 202. Snowflake, AZ, Monthly Distribution of Precipitation

6.2.3.43 Springerville, AZ

The period of record for Springerville has a one year 1890-91 sporadic record and an almost continuous record from 1912 to the present, with several months missing. These months have been reconstructed.

As summarized in Sellars and Hill (1974, p. 486):

"Springerville is located in east-central Arizona near the New Mexico border in an area containing some of the finest high altitude grazing land in Arizona. It is at an elevation of about 7,000 feet. The surrounding terrain, and that for some distance in the northwest and northeast quadrants, is relatively flat, broken only by numerous low, grassy hills. In the southwest and southeast quadrants lies some of the most beautiful pine forest country in the state, laced by numerous mountain streams and high altitude lakes. Escudillo Mountain, about fifteen miles to the southeast, is 10,955 feet high at the summit. Baldy Peak, the second highest peak in the state, is in the White Mountains about 22 airline miles to the southwest. It rises to 11,490 feet.

"Springerville gets the major part of its precipitation in the summer, with that in July, August, and September accounting for more than sixty percent of the total for an average year. This summertime precipitation falls almost entirely during thundershowers which form in the moist, warm flow of air moving over Arizona from the Gulf of Mexico. Winter precipitation comes largely from storms from the Pacific Ocean which have moved into the state from southern California. Since the moisture associated with these storms normally advances from the southwest quadrant, a large part of it falls as rain or snow over the steep slopes of the Mogollon Rim and the White Mountains, before reaching the Springerville area. For this reason, Springerville does not have the marked secondary precipitation maximum in the winter characteristic of many Arizona stations. Because of its altitude, nearly all of the precipitation occuring during December, January, and February and the majority of that in November and March, falls as snow."

The precipitation trends for the 1939-90 study period are essentially flat, with maxima in 1949,1970, and 1987. The minima are at 1947, and 1977, for the smoothed data.

The histogram shows a near normal distribution, with maxima at seven, thirteen, fourteen and fifteen inches. There is flat kurtosis for the data set, and little, if any, skewness. The monthly distribution maximum is in July and August, with declining precipitation in September and October. The period from November through May and June, the annual minima, is essentially flat.

Table 56. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Springerville, AZ
Station No.: 8162
Elevation: 7060
Latitude: 34d 08m
Longitude: 109d 17m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.00	0.10	0.28	0.56	0.65	0.48	1.47	0.11	0.00	1.21	2.20	1.87	8.93
1940	0.75	0.49	0.32	0.50	0.80	0.11	0.45	1.00	0.74	2.34	3.14	3.29	13.93
1941	0.34	0.53	0.84	1.52	0.80	1.64	1.03	0.58	1.30	1.94	1.76	2.60	14.88
1942	0.66	0.47	0.54	0.47	0.24	0.52	0.11	0.00	0.00	2.39	1.22	0.63	7.25
1943	0.75	0.00	0.64	1.18	0.48	0.61	0.12	0.95	0.40	0.99	5.46	0.98	12.56
1944	0.46	0.00	0.35	0.21	0.37	0.74	0.08	0.18	0.00	2.31	1.90	1.76	8.36
1945	0.75	0.52	0.29	0.17	0.15	0.32	0.00	0.00	0.05	1.94	2.97	0.80	7.96
1946	1.07	0.00	0.79	1.27	0.00	0.39	0.09	0.00	0.24	2.35	3.74	3.93	13.87
1947	0.40	0.64	0.22	0.29	0.00	0.48	0.00	0.74	0.11	2.91	5.42	1.06	12.27
1948	1.28	0.65	0.57	0.56	2.34	1.42	0.10	0.35	0.00	2.39	2.47	1.01	13.14
1949	1.21	0.26	0.56	1.02	0.15	0.13	0.06	0.24	0.64	1.87	3.20	2.81	12.15
1950	0.75	0.00	0.77	0.02	0.07	0.34	0.03	0.04	0.31	2.39	1.31	1.24	7.27
1951	0.09	0.00	0.00	0.40	0.17	0.72	0.63	0.24	0.00	1.83	1.60	0.63	6.31
1952	0.98	0.02	0.85	1.52	0.15	0.62	0.99	0.29	0.95	1.49	1.07	1.58	10.51
1953	0.00	0.77	0.16	0.04	0.38	0.91	0.56	0.10	0.30	4.84	1.66	0.00	9.72
1954	0.21	0.34	0.59	0.17	0.06	1.25	0.00	0.23	0.36	3.84	1.52	3.56	12.13
1955	0.66	0.00	0.24	0.91	0.24	0.00	0.04	0.50	0.58	3.87	6.18	0.22	13.44
1956	1.40	0.08	0.35	1.18	0.62	0.12	1.24	0.12	0.92	1.14	2.36	0.35	9.88
1957	0.21	0.00	0.00	0.21	0.31	0.45	0.17	0.75	0.93	2.86	5.33	0.22	11.44
1958	1.51	0.27	0.00	0.60	0.63	1.56	0.69	0.79	0.50	3.78	2.78	2.05	15.16
1959	1.62	0.17	0.10	0.85	0.38	0.04	0.78	0.00	0.78	3.45	4.03	0.19	12.39
1960	3.21	0.30	0.98	0.45	0.15	0.44	0.01	0.34	0.03	0.80	1.27	0.53	8.51
1961	2.81	0.00	1.14	0.04	0.10	0.97	0.22	0.07	0.06	3.02	2.50	2.14	13.07
1962	3.04	1.62	1.08	1.63	0.46	0.33	0.07	0.05	0.68	1.24	1.77	2.89	14.86
1963	0.83	1.00	0.43	0.65	0.36	0.49	0.00	0.00	0.00	2.88	4.03	1.28	11.95
1964	1.03	0.64	0.05	0.00	0.44	0.45	0.42	0.14	0.00	1.66	4.42	2.76	12.01
1965	0.53	1.37	0.37	0.70	0.78	0.03	0.61	0.44	0.77	3.17	1.28	2.37	12.42
1966	0.40	0.22	1.42	0.47	0.40	0.03	0.28	0.00	0.78	2.24	2.06	2.04	10.34
1967	0.55	0.52	0.59	0.01	0.00	0.47	0.01	0.37	1.79	5.46	4.08	3.46	17.31
1968	0.20	0.53	1.24	0.03	0.26	0.60	0.33	0.36	0.05	1.98	4.59	0.82	10.99
1969	0.18	0.53	0.23	0.07	0.08	0.58	0.20	1.30	0.05	1.85	3.53	1.19	9.79
1970	0.80	0.25	0.28	0.16	0.18	0.92	0.40	0.00	0.32	1.63	1.72	1.08	7.74
1971	1.46	0.00	0.11	0.00	0.84	0.03	0.22	0.00	0.00	1.32	4.86	2.20	11.04
1972	1.20	0.68	0.75	0.07	0.00	0.00	0.05	0.08	1.92	1.67	4.05	0.33	10.80
1973	3.20	0.15	0.19	0.35	0.79	0.97	0.05	0.61	0.35	2.76	0.82	0.00	10.24
1974	0.00	1.95	0.00	0.76	0.00	0.23	0.00	0.00	0.00	1.24	2.38	0.88	7.44
1975	2.93	0.14	0.08	0.40	1.95	0.48	0.13	0.33	0.00	3.34	1.83	3.43	15.04
1976	0.04	0.33	0.34	0.01	0.31	0.33	0.34	0.61	0.03	4.70	2.78	1.17	10.99
1977	0.55	0.57	0.00	0.40	0.45	0.56	0.12	0.02	0.56	5.32	4.09	1.23	13.87
1978	1.25	0.41	0.29	0.62	0.79	1.41	0.15	0.51	0.01	2.10	4.26	0.80	12.60
1979	0.77	1.85	0.93	1.58	0.36	0.67	0.17	1.77	0.45	0.90	3.58	1.54	14.57
1980	0.16	0.31	0.39	2.23	1.52	0.70	0.61	0.29	0.42	2.32	4.22	0.66	13.83
1981	0.47	0.08	0.19	0.34	0.41	1.11	0.30	0.48	1.21	4.97	0.49	1.57	11.62
1982	0.51	0.34	0.03	0.20	0.69	0.77	0.01	0.33	0.32	2.04	4.67	1.35	11.26
1983	0.02	0.54	0.97	0.94	0.38	0.36	0.31	0.45	0.30	3.83	3.40	2.46	13.96
1984	1.93	0.42	0.05	0.02	0.00	0.49	1.56	0.17	0.16	3.23	2.92	4.02	14.97
1985	1.17	0.01	1.30	0.17	0.30	0.15	0.56	0.41	0.54	0.88	1.05	1.39	7.93
1986	0.65	0.38	0.15	0.04	0.63	0.24	0.04	0.14	1.45	2.31	5.29	0.66	11.98
1987	1.72	1.82	1.25	0.65	1.58	0.47	0.28	0.40	0.57	3.22	2.45	0.91	15.32
1988	0.67	0.69	1.08	0.30	0.28	0.00	0.94	0.00	1.61	2.53	5.32	0.23	13.65
1989	1.04	0.16	0.55	0.61	0.17	0.34	0.00	0.00	0.00	3.17	1.44	0.52	8.00
1990	1.50	0.00	0.15	0.08	0.15	0.26	0.72	1.08	0.09	2.81	2.65	3.71	13.20
1939-90 Average	0.96	0.44	0.48	0.53	0.46	0.53	0.34	0.35	0.45	2.55	2.98	1.55	11.63

* Denotes year in which one or more monthly records are reconstructed.

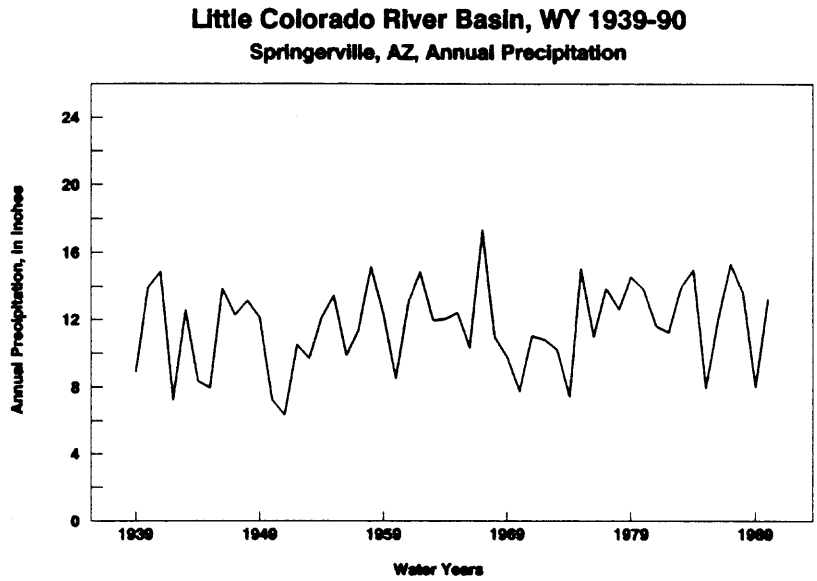


Figure 203. Springerville, AZ, Annual Precipitation, WY 1939-90

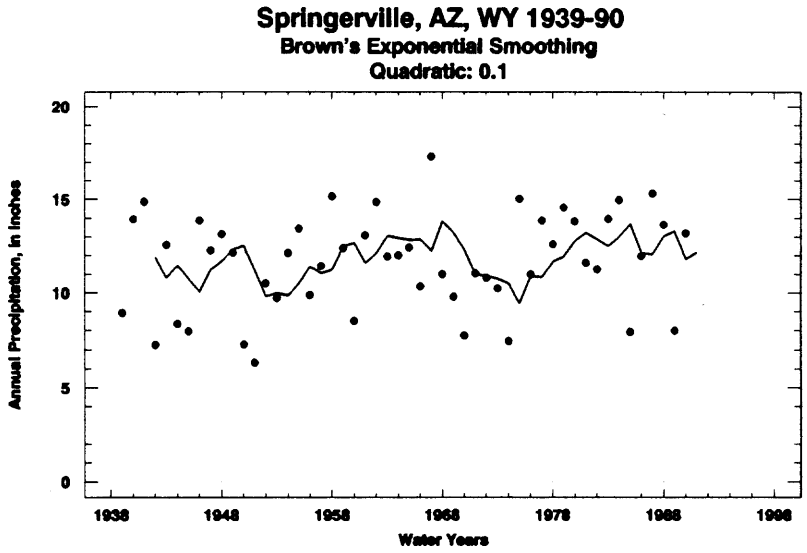


Figure 204. Springerville, AZ, Smoothed Annual Precipitation, WY 1939-90

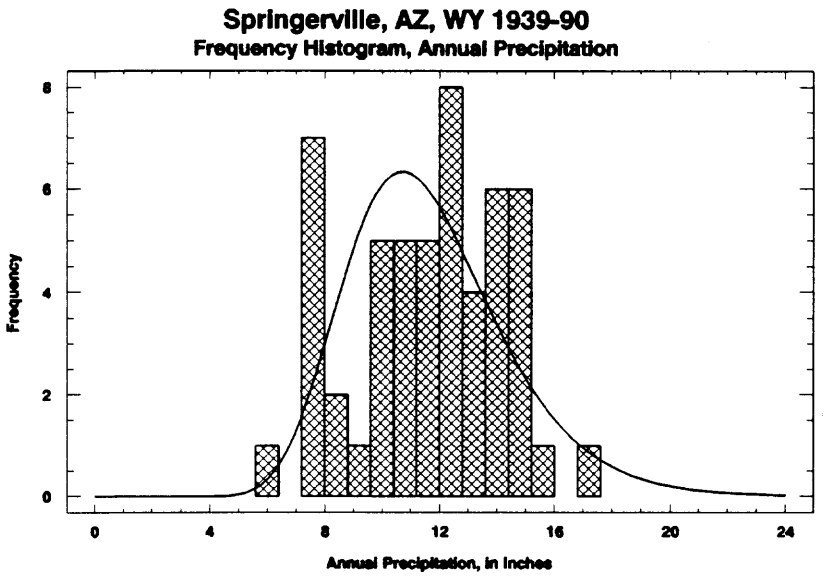


Figure 205. Springerville, AZ, Histogram of Annual Precipitation

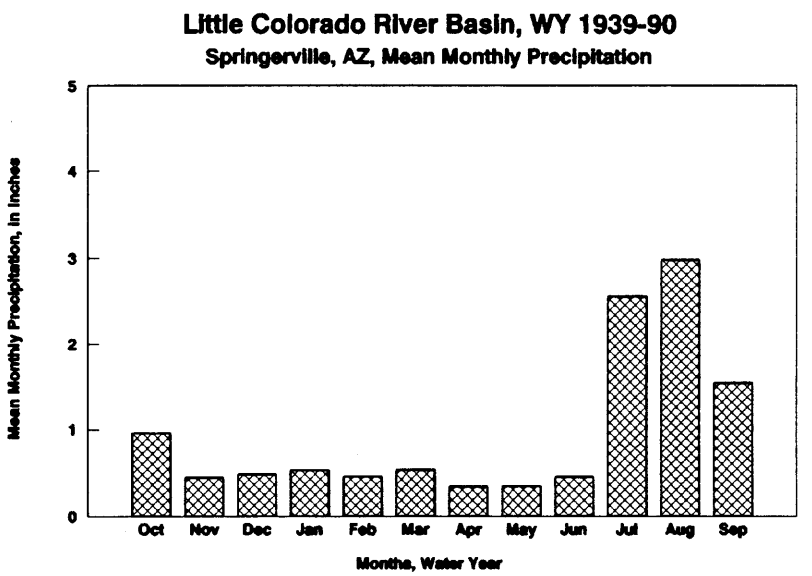


Figure 206. Springerville, AZ, Monthly Distribution of Precipitation

6.2.3.44 Sunset Crater National Monument, AZ

The period of record for this station extends from 1970 through the present - a relatively recently established station. Due to the proximity of long-term high altitude stations at Flagstaff and Fort Valley, the period from 1939 to 1970 was reconstructed.

The Sunset Crater National Monument station is located at an elevation of 6,960 feet at the Monument headquarters. The mountain from which the Monument gets its name was formed by a volcanic eruption in the late 1100 A.D. period. Lying to the south and southeast are the Cinder Hills, formed at about the same time. The eruption is felt to have forced the Sinagua Indians from the Flagstaff area, and even the Hopi (Anasazi) from the Wupatki National Monument area. Directly to the east and northeast, the Little Colorado River flows mostly northward some five miles away. The abrupt decline in elevation from Sunset Crater to the river affords one of the most breathtaking long-distance views in the state. Navajo Mountain, some 90 miles to the northeast is easily visible, as is the colorful Painted Desert, some five to twenty miles northeast of the Little Colorado River, and the Hopi Buttes, some 90 miles to the east-northeast. The predominant vegetation in the Monument is ponderosa pine, with pinyon and juniper in the elevations intermediate to the plains grassland and sagebrush at the lower elevations. The San Francisco Mountains rise to 12,600 feet only ten miles away, and the vegetation for many miles to the west and south are primarily ponderosa pine forests.

Due to the proximity of the San Francisco Mountains, Sunset Crater enjoys a year round heavy precipitation. The orographic effects of the rain shadow from the mountains are minimized by the high elevation of the monument. Accordingly, the climate is similar to that of Flagstaff and Fort Valley, with a slightly diminished annual average precipitation.

The precipitation trends for the study period 1939-90 are essentially flat, with a minimum centered on 1981.

The histogram shows a nearly normal distribution, with narrow kurtosis and minimal positive skewness. The monthly distribution is heavily weighted toward the July and August months, with lesser amounts noted in the September through March winter to spring months. The months of April through June indicate a sharp decline to the annual minimum in June.

Table 57. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Sunset Crater National Monument, AZ
Station No.: 8329
Elevation: 6960
Latitude: 35d 22m
Longitude: 111d 32m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.61	0.43	2.73	1.66	1.71	0.95	0.91	0.10	0.02	0.65	2.85	3.39	16.00
*1940	0.36	1.34	0.16	1.94	2.34	0.45	1.91	0.43	1.11	0.62	2.14	3.93	16.73
*1941	3.01	0.97	2.92	1.65	1.98	2.21	2.98	0.66	0.72	1.82	1.74	3.04	23.70
*1942	3.99	0.95	2.31	0.97	1.72	0.83	1.16	0.02	0.01	1.52	1.67	0.79	15.92
*1943	1.24	0.20	1.66	3.30	1.27	1.90	0.89	0.12	0.25	1.47	3.74	1.57	17.58
*1944	1.42	0.16	1.99	1.50	2.97	1.92	1.70	0.96	0.08	1.21	1.25	1.06	16.20
*1945	0.55	1.91	1.62	1.81	0.64	3.78	0.63	0.02	0.07	3.02	2.58	0.30	16.94
*1946	0.88	0.09	2.40	1.09	0.56	1.01	2.52	0.20	0.05	3.04	3.76	1.01	16.59
*1947	1.22	1.81	1.23	0.65	0.20	0.29	0.10	1.18	0.06	1.11	3.81	0.69	12.35
*1948	1.56	0.95	1.69	0.49	1.73	1.51	0.35	0.18	0.38	1.50	2.95	0.97	14.25
*1949	1.57	0.04	2.44	5.35	1.20	0.70	0.39	1.06	1.50	3.15	1.90	2.50	21.80
*1950	2.77	0.65	1.40	1.11	1.47	1.10	0.16	0.31	0.24	4.04	1.30	1.04	15.60
*1951	0.03	0.25	0.11	1.28	1.16	0.81	1.76	0.76	0.00	2.82	4.47	0.64	14.10
*1952	1.73	1.01	4.66	3.09	0.75	2.93	1.72	0.11	0.31	2.77	2.91	2.51	24.51
*1953	0.00	2.43	1.20	0.60	0.41	0.97	0.96	0.23	0.11	3.68	3.02	0.06	13.68
*1954	0.41	1.20	0.45	1.64	1.07	3.47	0.34	0.67	0.87	2.93	1.62	2.42	17.08
*1955	0.82	0.23	0.51	2.08	1.41	0.17	0.46	0.33	3.11	2.91	4.26	0.04	16.32
*1956	0.16	1.21	0.86	1.61	1.00	0.28	0.93	0.24	1.48	2.11	1.39	0.08	11.34
*1957	0.65	0.02	0.41	5.22	0.81	1.23	0.82	1.88	1.16	2.69	2.53	0.00	17.43
*1958	3.18	2.59	0.51	0.36	2.22	2.86	1.38	0.63	0.44	1.04	3.09	6.13	24.42
*1959	0.97	1.05	0.06	0.48	3.10	0.05	0.82	0.67	0.76	2.94	3.41	3.34	17.64
*1960	2.08	0.37	3.04	1.26	1.37	0.87	1.04	0.67	0.48	1.04	2.40	1.51	16.12
*1961	3.31	1.01	0.80	0.74	0.26	2.58	0.36	0.24	0.24	1.92	3.48	1.76	16.70
*1962	2.97	1.14	2.34	2.48	2.55	1.05	0.10	0.72	0.53	1.60	0.95	2.19	18.61
*1963	1.40	1.07	0.83	0.89	1.01	0.74	1.16	0.02	0.04	0.65	5.25	1.49	14.55
*1964	1.29	1.12	0.29	0.90	0.36	2.33	1.63	0.51	0.38	3.91	3.00	1.42	17.14
*1965	0.04	1.01	1.64	2.27	1.59	2.02	3.68	0.97	0.31	3.43	1.18	3.29	21.44
*1966	0.21	2.92	4.84	0.90	0.93	0.80	0.29	0.18	0.79	2.55	2.38	1.35	18.16
*1967	0.72	1.61	3.93	0.70	0.04	0.79	1.10	0.45	1.30	4.53	2.84	2.36	20.36
*1968	0.29	0.59	6.04	0.80	0.63	0.84	1.43	0.51	0.21	2.89	2.55	0.07	16.86
*1969	1.33	0.82	1.80	3.03	2.72	2.09	0.14	1.09	0.10	2.73	2.46	1.49	19.79
*1970	1.25	1.37	0.51	0.05	0.22	4.93	0.34	0.06	0.01	3.05	5.15	0.98	17.92
1971	0.77	0.78	0.78	0.08	0.62	0.14	0.32	0.53	0.00	2.06	5.09	1.35	12.52
1972	2.53	0.14	2.19	0.00	0.06	0.00	0.56	0.00	2.05	5.10	1.77	0.88	15.28
1973	8.90	0.72	1.89	0.87	2.58	3.67	0.90	0.77	0.50	2.35	1.69	0.00	24.84
1974	0.28	0.97	0.00	1.83	0.26	0.33	0.48	0.00	0.00	1.90	2.75	0.84	9.64
1975	2.01	0.72	1.02	0.67	0.54	3.07	0.84	1.11	0.00	3.00	0.63	2.32	15.93
1976	0.52	1.32	1.32	0.03	1.94	1.04	0.70	2.33	0.01	3.89	0.46	3.00	16.56
1977	1.19	0.28	0.38	0.97	0.55	0.59	0.66	0.22	0.48	2.38	2.45	2.22	12.37
1978	0.53	0.25	0.31	1.55	3.47	1.51	0.27	0.10	0.03	1.43	0.83	0.84	11.12
1979	2.81	6.08	2.20	3.08	0.85	0.70	0.14	1.61	0.45	0.65	1.69	0.04	20.30
1980	1.29	1.00	1.15	1.56	3.71	1.52	0.68	0.87	0.26	3.03	1.76	0.77	17.60
1981	0.22	0.00	0.76	1.24	0.32	1.57	1.03	0.18	2.28	6.01	2.90	3.10	19.61
1982	1.37	1.51	0.11	2.35	1.82	2.22	0.48	1.28	0.00	1.46	4.90	2.80	20.30
1983	0.33	2.55	2.57	0.58	1.48	1.51	0.84	0.35	0.00	1.77	2.36	4.93	19.27
1984	0.52	1.47	1.09	0.59	0.11	1.11	0.27	0.74	0.06	1.93	3.02	1.34	12.25
1985	0.67	1.04	3.54	2.18	1.40	2.36	2.30	0.25	0.08	1.74	0.95	1.62	18.13
1986	1.60	4.37	0.13	0.06	1.42	1.27	0.80	0.43	0.78	3.68	3.57	1.50	19.61
1987	1.12	2.39	1.95	1.79	2.13	1.50	0.19	1.03	0.69	1.92	3.12	0.87	18.70
1988	1.84	2.76	2.50	0.76	1.54	0.12	1.58	0.02	3.43	1.08	3.18	1.44	20.25
1989	0.52	1.00	0.95	1.72	0.30	1.24	0.00	0.39	0.02	1.62	2.29	0.14	10.19
1990	0.20	0.00	1.37	1.95	1.72	0.75	1.21	0.64	0.29	5.02	3.24	6.75	23.14
1939-90 Average	1.37	1.19	1.61	1.46	1.31	1.44	0.93	0.56	0.55	2.45	2.63	1.73	17.22

* Denotes year in which one or more monthly records are reconstructed.

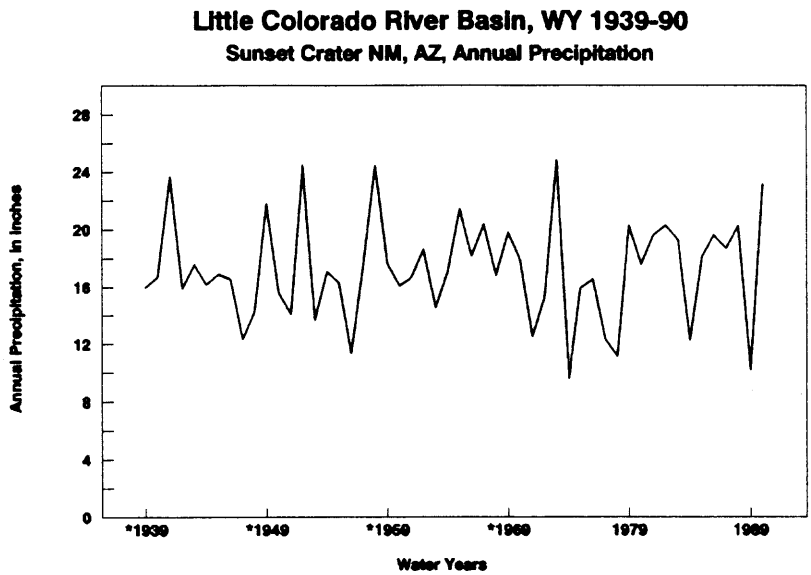


Figure 207. Sunset Crater NM, AZ, Annual Precipitation, WY 1939-90

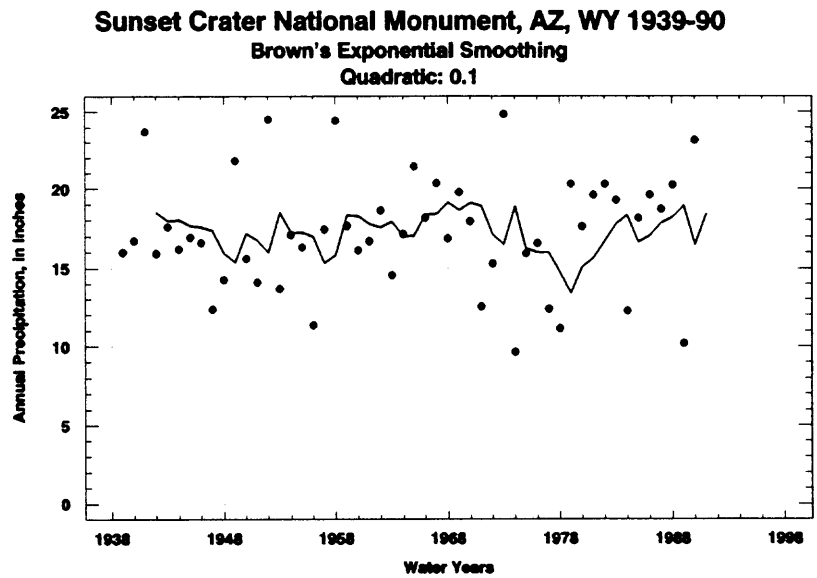


Figure 208. Sunset Crater NM, AZ, Smoothed Annual Precipitation, WY 1939-90

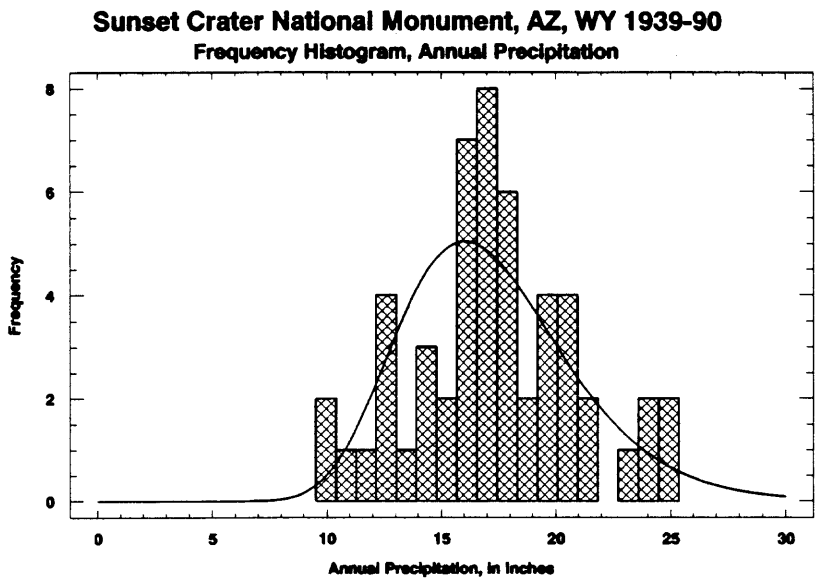


Figure 209. Sunset Crater NM, AZ, Histogram of Annual Precipitation

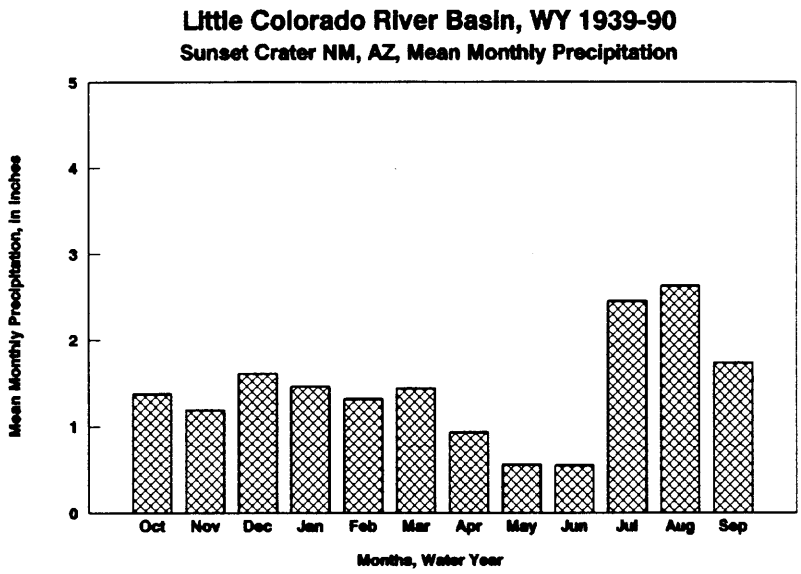


Figure 210. Sunset Crater NM, AZ, Monthly Distribution of Precipitation

6.2.3.45 Teec Nos Pos, AZ

The period of record for this station extends from 1962-63 through the present, with 1971-72 largely missing. For this reason, much of the record for the 1939-90 study period is reconstructed. The station location in the extreme northeast corner of Arizona places it well outside the LCR Basin, but its record was included to aid in the reconstruction of missing record from LCR Basin stations and to provide resolution for the isohyetal maps.

The precipitation trends for the reconstructed period indicate a decline from 1939 through 1962, followed by a slight increase from 1963 through 1987. There is an indication of a decline from 1987 through 1990.

The histogram shows a near-perfect lognormal distribution with moderate kurtosis and slight positive skewness. The peak frequency is centered at eight inches. The monthly distribution indicates a maximum during July through October, with a modest decline from November through the annual minimum in June.

Table 58. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Teec Nos Pas, AZ
Station No.: 8468
Elevation: 5290
Latitude: 36d 54m
Longitude: 109d 06m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.32	0.20	0.61	0.42	0.27	1.06	0.50	0.28	0.00	0.85	1.33	2.75	8.59
*1940	0.22	0.43	0.24	0.99	1.03	0.15	0.59	0.61	0.07	0.64	1.29	2.37	8.62
*1941	0.66	0.66	2.26	1.14	2.02	1.09	2.55	2.13	0.92	0.87	1.46	2.26	18.02
*1942	3.04	0.46	0.67	0.12	0.39	0.42	1.22	0.02	0.00	0.37	0.81	0.45	7.98
*1943	1.32	0.05	1.11	1.30	0.21	1.73	0.20	0.59	0.19	0.41	2.60	0.65	10.37
*1944	0.66	0.30	0.97	0.69	0.32	0.58	0.97	1.12	0.01	0.46	0.94	1.45	8.47
*1945	0.20	0.90	0.69	0.60	0.46	1.04	0.68	0.03	0.14	0.73	0.76	0.23	6.45
*1946	0.91	0.00	0.61	0.11	0.20	0.66	0.31	0.45	0.05	1.48	1.38	0.58	6.73
*1947	0.59	1.00	0.24	0.14	0.22	0.17	0.09	1.38	0.09	0.45	2.88	1.11	8.36
*1948	1.95	0.51	0.57	0.22	1.08	0.55	0.43	0.13	1.11	0.66	1.81	0.84	9.87
*1949	2.16	0.20	0.83	0.97	0.27	0.47	0.28	0.75	1.68	1.11	0.49	0.55	9.77
*1950	0.72	0.07	0.09	0.19	0.42	0.14	0.03	0.04	0.27	0.71	0.23	0.62	3.53
*1951	0.00	0.10	0.08	0.48	0.34	0.10	0.34	0.38	0.00	0.51	1.13	0.37	3.82
*1952	0.67	0.70	0.79	1.34	0.19	0.26	1.15	0.25	0.45	1.06	0.50	0.78	8.14
*1953	0.00	1.08	0.53	0.19	0.30	0.26	0.70	0.11	0.11	1.18	1.73	0.02	6.19
*1954	1.54	0.36	0.47	0.11	0.04	1.45	0.07	0.50	0.16	2.05	0.67	1.77	9.20
*1955	0.64	0.10	0.53	0.28	0.84	0.03	0.17	0.55	0.88	0.96	1.25	0.10	6.31
*1956	0.00	0.31	0.17	1.66	0.43	0.36	0.21	0.37	0.14	0.87	0.94	0.01	5.48
*1957	0.38	0.16	0.12	0.97	0.48	0.88	1.43	1.64	0.18	2.10	1.99	0.08	10.42
*1958	2.08	0.66	0.20	0.34	0.41	1.21	0.40	0.20	0.18	0.15	0.77	1.00	7.61
*1959	0.39	0.30	0.10	0.05	0.24	0.00	0.90	0.01	0.41	0.22	1.63	0.00	4.26
*1960	1.60	0.27	0.68	0.42	0.60	0.23	0.10	0.43	0.35	0.51	0.26	0.16	5.62
*1961	1.76	0.14	1.09	0.45	0.15	1.68	0.31	0.18	0.00	0.43	1.30	0.76	8.23
*1962	0.67	0.85	0.88	0.13	0.42	0.13	0.12	0.15	0.72	0.02	0.15	1.17	5.40
1963	1.88	2.05	0.09	0.78	1.02	0.28	0.15	0.00	0.10	0.75	2.13	0.00	9.23
1964	1.63	0.17	0.00	0.26	0.57	1.97	0.41	0.72	0.10	0.30	0.29	1.16	7.58
1965	0.00	1.06	0.94	1.66	0.77	1.45	0.70	0.63	1.19	2.15	0.28	1.05	11.88
1966	1.03	1.00	1.64	0.30	0.42	0.00	0.85	0.03	0.37	0.52	1.25	0.97	8.38
1967	0.15	0.16	1.21	0.15	0.02	0.29	0.00	0.54	0.50	1.32	1.59	0.29	6.22
1968	0.03	0.15	1.19	0.20	0.83	1.06	0.87	0.43	0.07	0.96	1.60	0.00	7.39
1969	0.50	0.20	0.57	0.92	0.74	0.66	0.16	0.29	1.48	1.12	0.16	0.18	6.98
1970	3.43	0.72	0.66	0.27	0.06	1.71	0.41	0.00	0.34	0.61	0.64	2.72	11.57
*1971	0.83	0.54	0.24	0.43	0.04	0.22	0.00	0.74	0.00	0.56	1.67	0.94	6.21
*1972	1.23	0.56	0.61	0.03	0.00	0.08	0.00	0.00	0.80	0.20	0.86	0.49	4.85
*1973	3.91	0.91	1.63	0.33	0.62	0.99	0.53	0.39	1.14	0.52	2.20	1.03	14.20
1974	0.14	0.43	0.24	1.55	0.56	0.22	0.13	0.00	0.00	0.26	0.30	0.10	3.93
1975	1.63	0.61	0.29	0.35	1.14	1.72	0.17	0.31	0.01	1.43	0.04	1.06	8.76
*1976	0.03	0.63	0.64	0.05	0.02	0.01	0.22	1.26	0.00	0.16	0.20	3.01	6.23
1977	0.00	0.10	0.00	1.15	0.00	0.00	0.00	0.10	0.00	1.68	0.87	0.45	4.35
1978	0.20	0.42	0.73	1.14	0.57	0.71	0.50	0.87	0.14	1.75	0.10	0.51	7.64
1979	1.00	2.77	2.09	1.32	0.19	1.10	0.22	1.11	0.22	0.74	2.40	0.00	13.16
1980	2.19	0.47	0.92	0.83	0.91	0.59	0.66	0.24	0.00	0.54	1.01	0.44	8.80
1981	0.61	0.05	0.26	0.13	0.29	1.44	0.11	0.70	0.52	2.45	1.86	0.32	8.74
1982	1.25	0.60	0.15	0.22	0.59	0.55	0.23	1.60	0.00	1.35	2.43	1.10	10.07
1983	0.29	0.70	0.75	1.04	0.35	1.98	0.66	0.33	0.41	2.50	0.30	0.77	10.08
1984	0.00	0.73	1.30	0.02	0.03	0.65	0.90	0.01	0.29	0.58	1.12	0.40	6.03
1985	1.29	0.06	1.27	0.79	0.23	1.84	1.51	0.50	0.00	1.00	0.05	1.17	9.71
1986	0.97	0.52	0.26	0.05	0.36	0.67	0.56	0.38	0.24	1.43	1.67	1.86	8.97
1987	0.45	1.49	0.08	0.19	0.77	0.38	0.60	0.72	0.10	1.17	0.98	0.26	7.19
1988	0.84	1.53	0.53	1.00	0.71	0.06	1.33	0.80	0.49	0.03	0.65	0.55	8.52
1989	0.21	0.69	0.43	0.48	0.55	0.02	0.00	0.02	0.65	0.62	1.04	0.20	4.91
1990	0.53	0.00	0.00	0.30	0.85	0.22	0.38	0.59	0.03	0.57	0.73	0.21	4.41
1939-90 Average	0.94	0.56	0.64	0.56	0.47	0.68	0.50	0.49	0.33	0.89	1.09	0.79	7.95

* Denotes year in which one or more monthly records are reconstructed.

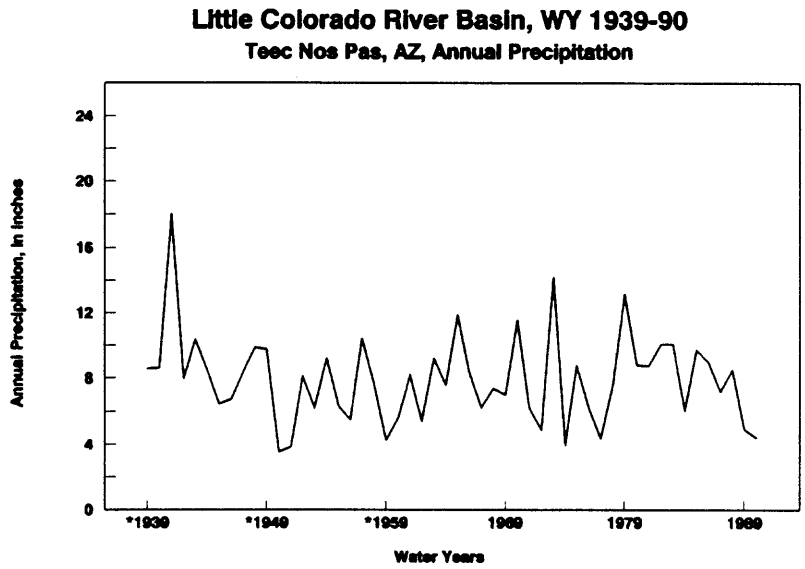


Figure 211. Teec Nos Pas, AZ, Annual Precipitation, WY 1939-90

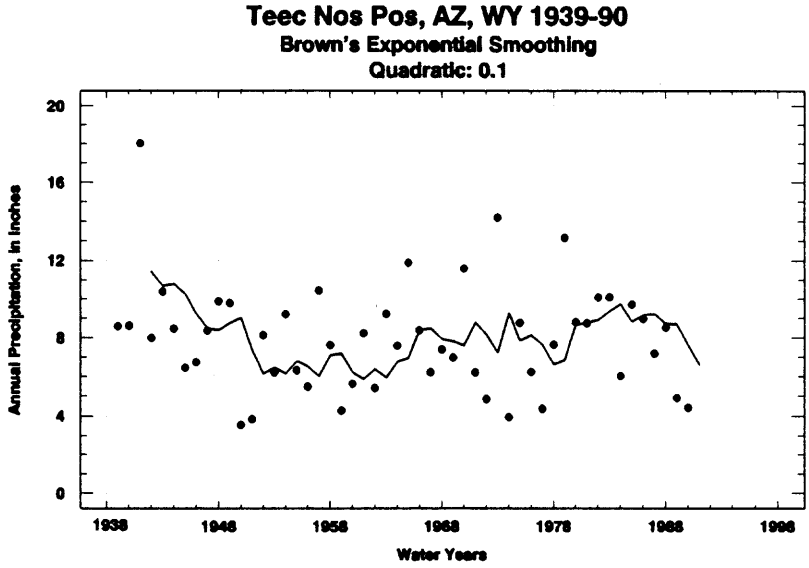


Figure 212. Teec Nos Pas, AZ, Smoothed Annual Precipitation

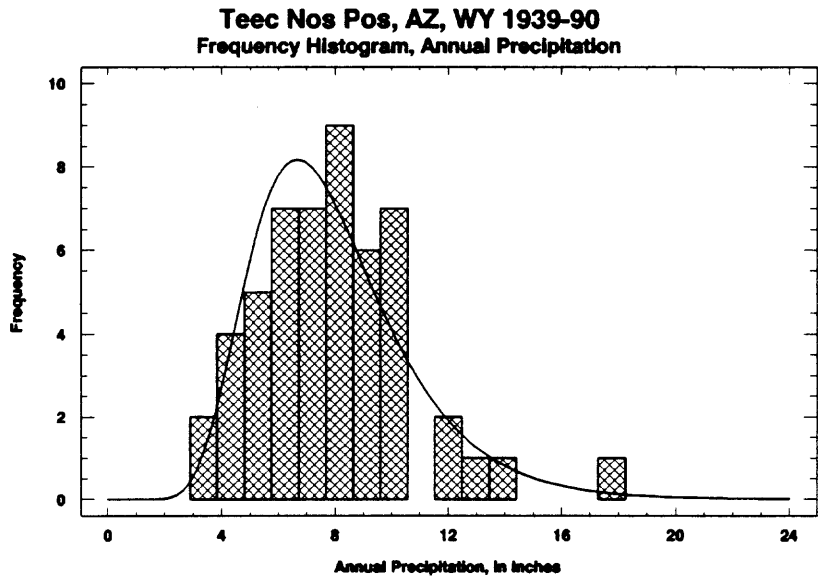


Figure 213. Teec Nos Pas, AZ, Histogram of Annual Precipitation

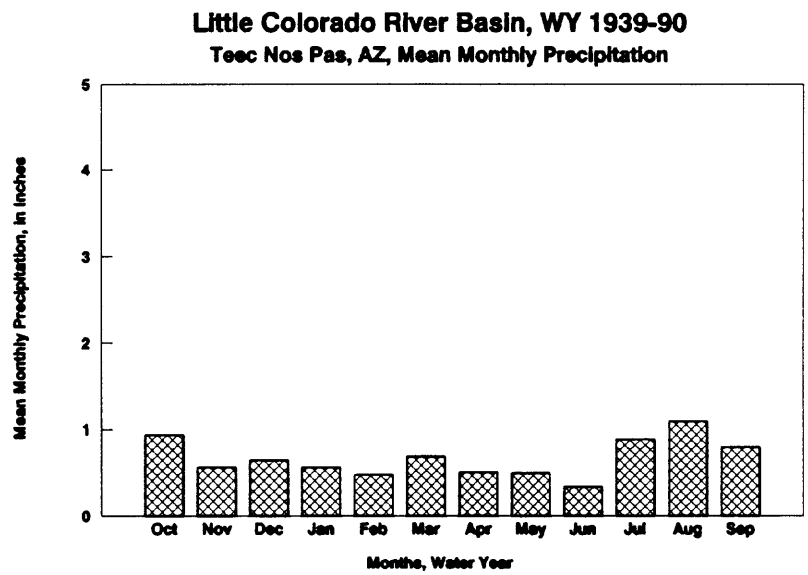


Figure 214. Teec Nos Pas, AZ, Monthly Distribution of Precipitation

6.2.3.46 Tohatchi, NM

This station is located at an elevation of 6,420 feet elevation just outside the LCR Basin in northwestern New Mexico. Its record is included in the study for the purpose of reconstructing missing record from nearby LCR Basin stations and to provide resolution to the isohyetal maps.

The period of record is from 1914 to 1920, with some months missing and from 1924 to the present, with months missing in 1944-47, 1972-73, 1975, 1979, and 1988-89.

The precipitation trends indicate a sharp increase from 1939-1949, a decline from 1950-1959, a sharp increase from 1960-1969, a decline from 1970-1987, an increase from 1988-89, and the beginnings of a decline from 1989-90.

The histogram shows a normal distribution with the central peak missing. Maxima occur at eight and twelve inches. The distribution is nearly symmetrical. The monthly distribution reveals a sharp maximum from July through October, followed by a gradual decline from November through the annual minimum in June.

Table 59. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Tohatchi, NM
Station No.: 8919
Elevation: 6420
Latitude: 35d 51m
Longitude: 108d 44m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.11	0.09	0.76	1.14	1.77	1.26	0.94	0.31	0.00	1.01	0.30	0.59	8.28
1940	0.46	0.54	0.35	0.45	0.72	0.23	0.17	0.95	0.51	0.71	1.42	1.82	8.33
1941	0.89	0.73	1.88	0.55	0.20	1.41	1.57	1.97	0.94	0.43	2.28	1.91	14.76
1942	3.41	0.39	0.58	0.05	0.70	0.11	1.03	0.00	0.00	1.29	1.16	0.98	9.70
*1943	1.36	0.05	0.20	1.31	0.01	0.23	0.37	0.22	0.13	1.17	2.89	0.59	8.53
*1944	1.12	0.13	1.10	0.45	0.82	0.77	0.53	0.59	0.01	1.13	1.03	1.19	8.87
*1945	0.69	1.29	0.99	0.79	0.00	0.70	0.26	0.05	0.09	3.27	2.67	0.25	11.05
*1946	1.08	0.02	1.36	0.53	0.20	0.44	0.34	0.24	0.00	1.77	4.48	2.20	12.67
1947	0.32	1.02	0.18	0.50	0.06	0.10	0.05	1.70	0.11	1.33	5.88	1.74	12.99
*1948	2.18	0.77	0.67	0.16	0.86	1.10	0.30	0.53	0.94	1.68	0.85	1.61	11.65
*1949	2.58	0.09	1.20	1.06	0.33	0.25	0.43	1.82	1.04	1.63	0.97	1.02	12.42
*1950	0.62	0.03	0.57	0.29	1.14	0.39	0.11	0.06	0.34	1.15	0.21	1.24	6.15
1951	0.03	0.24	0.19	0.80	0.60	0.21	1.13	0.16	0.02	0.68	2.07	0.57	6.70
1952	0.61	0.48	1.10	1.55	0.16	0.44	1.69	0.06	0.85	1.67	0.78	0.59	9.98
1953	0.00	1.48	0.59	0.31	0.41	0.49	0.52	0.30	0.39	1.56	1.09	0.04	7.18
1954	0.90	0.32	0.40	0.65	0.10	1.74	0.12	1.13	0.20	2.60	1.01	1.79	10.96
1955	0.33	0.07	0.58	0.50	0.75	0.02	0.49	0.87	0.30	1.22	2.69	0.02	7.84
1956	0.39	0.45	0.87	0.65	0.40	0.11	0.14	0.28	0.35	0.76	1.09	0.02	5.51
1957	0.60	0.14	0.04	1.68	0.60	0.99	1.00	1.48	0.58	3.91	1.24	0.00	12.26
1958	2.05	1.16	0.38	0.24	0.57	1.06	0.52	0.37	0.44	1.12	1.69	1.13	10.73
1959	0.60	0.16	0.16	0.12	0.69	0.27	0.53	0.00	0.62	0.36	3.11	0.31	6.93
1960	1.83	0.53	1.31	0.70	0.67	0.80	0.05	0.43	0.54	0.25	0.33	0.66	8.10
1961	1.94	0.09	0.73	0.35	0.41	1.85	0.34	0.30	0.12	1.31	3.08	1.26	11.78
1962	2.22	0.99	1.43	0.49	0.81	0.42	0.15	0.18	0.13	0.81	0.57	3.27	11.47
1963	3.38	0.94	0.58	0.46	0.67	0.11	0.15	0.00	0.08	1.22	3.40	0.95	11.94
1964	0.86	0.45	0.16	0.26	0.44	0.37	1.04	0.26	0.03	2.32	3.34	2.31	11.84
1965	0.00	1.32	1.28	1.08	0.51	0.44	0.80	0.84	0.97	4.22	1.48	1.40	14.34
1966	0.82	1.04	2.20	0.27	0.31	0.73	0.20	0.18	0.74	2.22	3.42	2.31	14.44
1967	0.41	0.13	1.22	0.27	0.00	0.28	0.00	0.42	1.87	2.96	1.14	1.03	9.73
1968	0.03	0.10	2.42	0.50	0.00	0.98	0.28	0.56	0.00	0.95	1.82	0.36	8.00
1969	0.70	0.43	0.39	0.30	0.60	1.05	1.40	0.73	0.19	0.60	2.23	1.78	10.40
1970	1.82	0.23	0.16	0.02	0.00	1.10	0.16	0.00	0.14	1.69	1.46	2.05	8.83
1971	0.26	0.20	0.37	0.75	0.17	0.34	0.00	0.01	0.00	0.72	1.04	1.80	5.66
1972	0.76	0.26	0.44	0.05	0.00	0.00	0.00	0.30	0.08	0.52	0.58	0.43	3.42
1973	4.52	1.14	0.26	0.37	0.46	1.10	0.13	1.62	0.85	0.38	0.68	0.13	11.64
1974	0.09	0.36	0.00	0.71	0.04	0.00	0.04	0.00	0.00	1.17	0.98	0.50	3.89
*1975	0.53	0.03	0.24	0.83	0.83	1.28	0.43	0.00	0.00	2.66	0.71	3.18	10.72
1976	0.00	0.10	0.30	0.00	0.00	0.00	0.10	0.93	0.00	0.45	1.13	0.23	3.24
1977	0.35	0.45	0.00	0.05	0.05	0.00	0.05	0.02	0.10	2.45	2.77	0.10	6.39
*1978	0.25	1.02	0.00	0.92	0.27	0.73	0.30	0.98	0.08	0.65	1.28	0.43	6.92
*1979	1.38	3.05	0.53	1.28	0.29	1.13	0.14	1.39	0.57	0.80	0.59	0.04	11.18
1980	0.22	2.02	0.40	1.15	2.69	0.30	0.00	0.00	0.00	0.00	1.01	0.78	8.57
1981	0.13	0.04	0.15	0.00	0.33	0.91	0.12	0.00	0.10	1.28	0.70	0.28	4.04
1982	0.50	0.53	0.00	0.17	1.75	0.41	0.09	0.00	0.18	1.28	1.48	0.44	6.83
1983	0.10	0.43	0.57	0.94	0.05	0.58	0.10	0.15	0.10	1.02	1.14	0.56	5.74
1984	0.67	0.14	0.82	0.07	0.01	0.96	0.72	0.10	0.38	0.26	1.32	0.82	6.27
1985	0.68	0.19	0.67	0.86	0.56	0.98	1.33	0.14	0.17	1.49	0.52	0.12	7.71
1986	1.16	0.36	0.32	0.00	0.45	0.62	2.42	0.71	1.47	1.70	2.58	1.29	13.08
1987	0.84	2.37	0.60	0.05	0.34	0.19	0.00	1.80	1.51	1.02	1.05	0.83	10.60
*1988	0.52	1.62	1.55	0.21	0.64	0.00	1.56	0.16	0.14	1.16	4.04	0.58	12.18
*1989	0.25	0.98	0.13	0.62	1.21	0.15	0.00	0.00	0.00	1.36	1.08	0.27	6.05
1990	0.50	0.00	0.04	0.13	0.59	0.38	0.39	1.12	0.07	2.65	0.77	0.97	7.61
1939-90 Average	0.92	0.60	0.64	0.53	0.50	0.59	0.48	0.51	0.36	1.38	1.67	0.98	9.16

* Denotes year in which one or more monthly records are reconstructed.

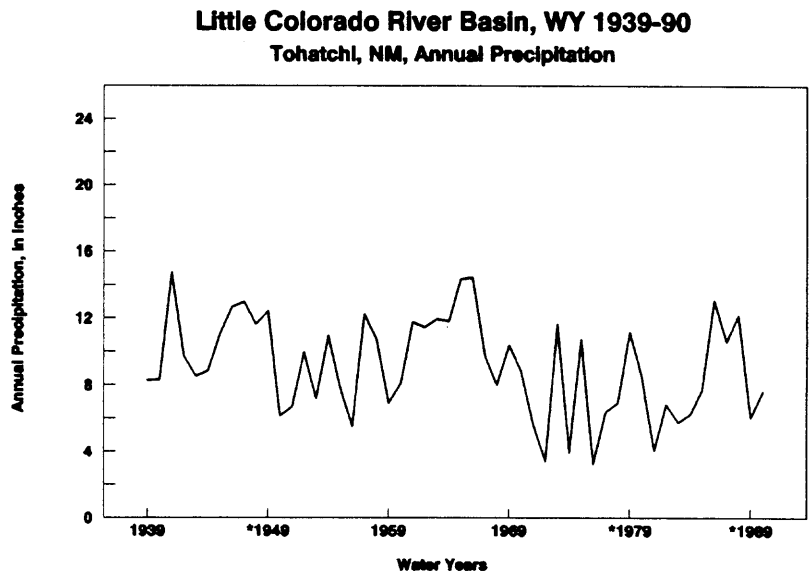


Figure 215. Tohatchi, NM, Annual Precipitation, WY 1939-90

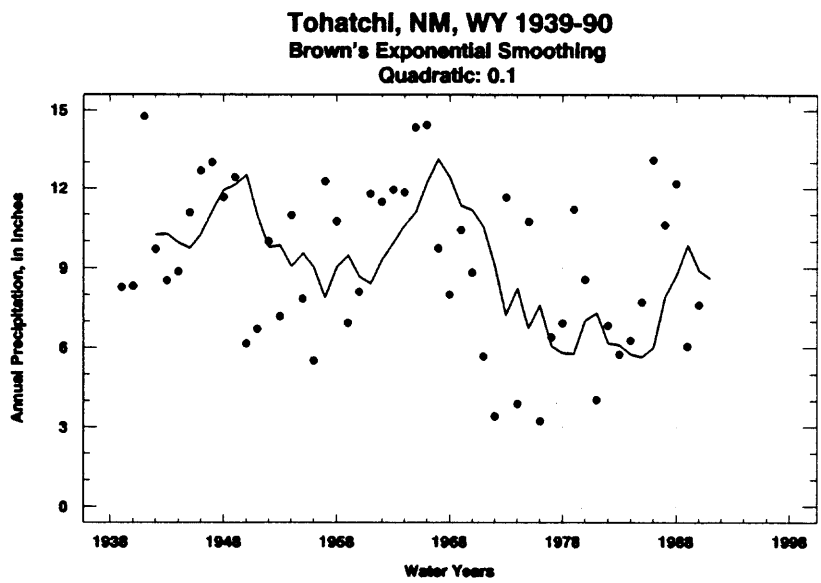


Figure 216. Tohatchi, AZ, Smoothed Annual Precipitation, WY 1939-90

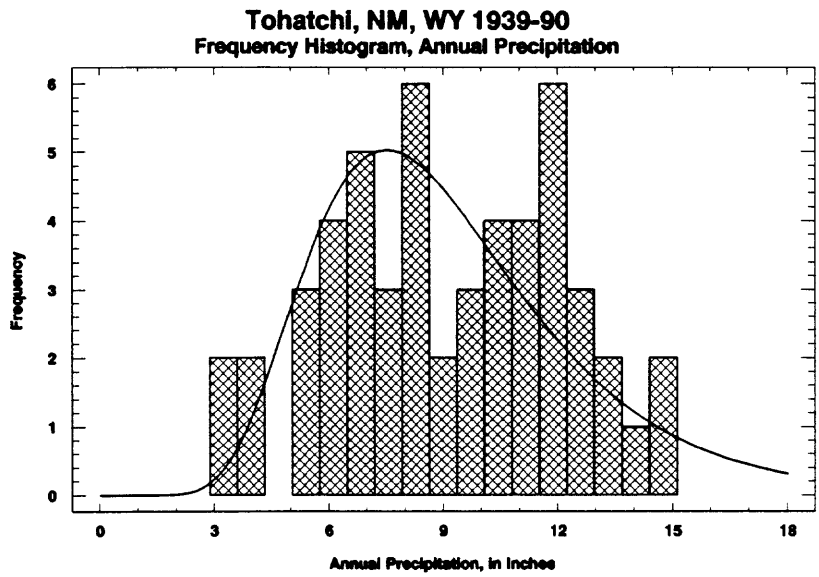


Figure 217. Tohatchi, NM, Histogram of Annual Precipitation

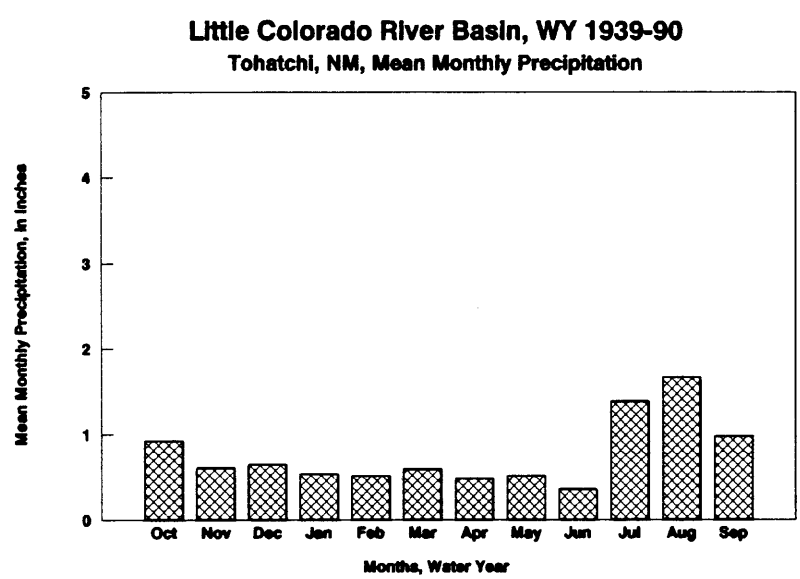


Figure 218. Tohatchi, NM, Monthly Distribution of Precipitation

6.2.3.47 Tuba City, AZ

The period of record for Tuba City extends almost continuously from 1897 through 1976, with missing months in 1897-1901, 1904-1909, 1918-20, 1929-30, and 1936-42. The missing months from 1939 through 1990 are reconstructed.

As summarized in Sellars and Hill (1974, p. 522):

"Tuba City is located at an elevation of about 5,000 feet in the barren plateau country of north-central Arizona. It lies on a desert mesa a few miles north of Moenkopi Wash which slopes gently downward into the valley of the Little Colorado River twenty miles to the southwest. Grand Canyon National Park, one of the worlds greatest national spectacles, is located thirty miles to the west. The Colorado River flows through this great canyon, first from the north, then from the east, appearing a mere thread when viewed from the rim almost a mile above. The multi-colored Painted Desert covers most of the area between Tuba City and the Grand Canyon, extending southeastward along the east bank of the Little Colorado River. Sixty miles to the south-southwest, Humphreys Peak, the highest point in the state, rises to 12,611 feet in the San Francisco Mountains. The forest-covered Mogollon Plateau, with average elevations greater than 7,500 feet, extends southeastward from these mountains into east-central Arizona. The country north and eastward from Tuba City, on the Navajo and Hopi Indian Reservations, consists mainly of broad plateaus and rugged mesas. These include the Kaibito Plateau, centered thirty miles to the north, the Moenkopi Plateau, 20 miles to the southeast, and the Black Mesa, 50 miles to the northeast. The prevailing vegetation types in the area are sagebrush and plains grass at lower elevations and pinyon and juniper on the high plateaus and mesas. Palo verde and cacti are found near the bottom of the Grand Canyon, while stands of ponderosa pine are common along the north and south rim [of Grand Canyon].

"Tuba City has a very dry climate, receiving less than seven inches of precipitation in most years. The high country to the west and south make it nearly impossible for air masses to move directly into the area without first losing their moisture. The heaviest and most consistent precipitation falls during the summer, usually from afternoon thunderstorms that spread out from the Grand Canyon. Although these storms are observed nearly every day from the first part of July until the end of August, they are rarely intense enough to produce more than blowing sand and light rain showers at Tuba City. The heaviest rain of summer are frequently associated with the remnants of a tropical disturbance that has moved northward from the Pacific Ocean. Precipitation from this source may continue, on and off, for several days, flooding much of the lowlands.

"During the cooler half of the year precipitation may fall from middle latitude storms moving eastward across the country. These storms are noted for the vicious winds which accompany them, particularly when they advance into the area from a northerly direction. Heaviest precipitation usually occurs from storms that move into Arizona from the west or southwest, having formed or intensified off the California coast. About forty percent of the winter precipitation falls as snow. However amounts are so small that this snow rarely remains on the ground for more than a few days."

Precipitation trends for the 1939-90 study period indicate a gradual decline from 1939 through 1976, followed by a sharp increase from 1977 through 1986. After a flat trend from 1986 to 1988, there is a period which indicates another decline.

The histogram shows a distinct lognormal distribution, with flat kurtosis and a slight positive skewness. A few very wet years are noted, with a seconday maximum centered at fourteen inches. The monthly distribution displays a slight July through October maximum, with a gradual decline from November throught the annual June minimum.

Table 60. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Tuba City, AZ
Station No.: 8792
Elevation: 5030
Latitude: 36d 08m
Longitude: 111d 14m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.29	0.97	0.46	0.25	0.07	0.03	0.14	0.02	0.00	0.55	2.85	5.62
*1940	0.00	0.47	0.00	0.32	1.01	0.26	0.99	0.21	0.23	0.16	1.45	1.21	6.31
*1941	1.31	0.49	1.12	1.95	1.10	2.68	1.12	0.50	0.40	0.56	1.03	1.81	14.07
1942	2.27	0.48	0.80	0.10	0.50	0.56	0.18	0.00	0.00	0.66	0.57	0.28	6.40
1943	0.66	0.00	2.13	0.62	0.35	1.24	0.50	0.00	0.07	0.21	1.90	0.94	8.62
1944	0.53	0.00	0.35	0.10	0.56	0.89	1.05	0.43	0.06	0.00	0.62	0.05	4.64
1945	0.00	0.72	0.60	0.25	0.33	0.09	0.00	0.00	0.00	1.61	0.83	0.00	4.43
1946	0.26	0.00	0.58	0.79	0.05	0.75	0.62	0.35	0.00	0.97	1.85	0.31	6.53
1947	0.19	0.89	0.22	0.00	0.00	0.15	0.00	0.88	0.08	0.74	2.27	0.24	5.66
1948	1.92	0.67	0.87	0.04	0.24	0.06	0.00	0.64	0.18	0.14	0.86	0.33	5.95
1949	0.79	0.07	0.94	0.63	0.27	0.24	0.03	0.12	1.56	0.72	1.35	0.82	7.54
1950	1.36	0.53	0.17	0.09	1.01	0.40	0.00	0.05	0.00	2.35	2.18	0.26	8.40
1951	0.00	0.00	0.00	0.16	0.02	0.08	0.66	0.31	0.00	0.31	1.35	0.32	3.21
1952	1.13	0.76	0.81	1.52	0.32	1.20	1.39	0.50	0.60	0.63	0.88	3.94	13.68
1953	0.00	1.46	0.81	0.11	0.28	0.10	0.52	0.00	0.07	1.82	1.87	0.00	7.04
1954	0.38	0.15	0.05	0.44	0.11	0.65	0.00	0.99	0.00	0.36	0.47	1.02	4.62
1955	0.18	0.17	0.04	0.43	0.64	0.29	0.18	0.00	1.25	0.63	0.77	0.00	4.58
1956	0.00	0.00	0.02	0.32	0.22	0.00	0.26	0.42	0.01	0.97	0.83	0.07	3.12
1957	0.12	0.00	0.12	1.31	0.02	0.65	0.25	1.73	0.75	0.93	1.12	0.05	7.05
1958	1.31	0.76	0.14	0.00	0.50	1.28	0.62	0.63	0.15	0.35	0.27	0.88	6.89
1959	0.50	0.13	0.00	0.03	0.46	0.00	0.00	0.10	0.07	0.07	1.06	0.06	2.48
1960	0.74	0.66	0.73	0.40	0.51	0.34	0.27	0.11	0.07	0.05	0.17	0.45	4.50
1961	1.85	0.45	1.10	0.25	0.06	1.32	0.40	0.13	0.00	0.61	0.74	0.57	7.48
1962	0.45	0.22	1.02	0.35	0.30	0.14	0.04	0.28	0.04	0.15	0.17	0.62	3.78
1963	1.52	0.91	0.45	0.10	0.43	0.30	0.11	0.00	0.03	0.02	1.59	0.24	5.70
1964	0.83	0.23	0.02	0.15	0.00	0.50	0.82	0.12	0.17	1.05	1.08	0.62	5.59
1965	0.00	0.26	0.29	1.21	1.46	0.74	0.96	1.35	0.26	0.67	0.19	3.05	10.44
1966	0.63	0.59	1.61	0.16	0.65	0.28	0.24	0.32	0.02	0.27	0.45	0.47	5.69
1967	0.30	0.43	0.47	0.25	0.00	0.00	0.10	0.29	0.17	0.64	0.76	0.50	3.91
1968	0.08	0.06	1.59	0.06	0.08	0.27	0.67	0.24	0.10	0.88	1.30	0.02	5.35
1969	0.44	0.31	0.53	0.42	0.48	0.38	0.03	0.66	0.58	0.98	0.82	1.00	6.63
1970	1.03	0.60	0.12	0.23	0.02	2.27	0.18	0.00	0.04	0.25	0.22	0.36	5.32
1971	0.07	0.11	0.00	0.00	0.39	0.00	0.00	0.22	0.00	1.25	0.93	0.79	3.76
1972	1.05	0.10	0.11	0.00	0.00	0.00	0.00	0.00	1.12	0.19	0.49	0.41	3.47
1973	7.69	0.57	0.70	1.22	1.66	1.76	0.06	0.69	0.43	0.32	0.38	0.16	15.64
1974	0.00	0.28	0.00	0.80	0.22	0.14	0.30	0.00	0.00	0.65	0.26	0.52	3.17
1975	1.36	0.55	0.12	0.35	0.00	0.84	0.38	0.23	0.00	1.93	0.12	0.59	6.47
*1976	0.00	0.23	1.15	0.03	1.09	0.55	0.77	1.00	0.02	1.70	0.16	1.42	8.12
*1977	0.22	0.10	0.09	0.59	0.14	0.32	0.33	0.21	0.34	1.75	1.66	0.50	6.26
*1978	0.47	0.42	0.54	1.67	1.26	1.76	0.45	0.28	0.09	0.76	0.87	1.01	9.57
*1979	1.04	3.53	2.30	2.12	0.66	1.34	0.20	1.28	0.32	0.34	1.31	0.14	14.59
*1980	0.54	1.21	0.97	2.43	2.43	1.23	0.97	0.31	0.07	1.25	1.29	1.05	13.74
*1981	0.35	0.03	0.27	0.44	0.44	1.20	0.51	0.84	0.41	1.23	2.28	1.36	9.34
*1982	1.53	1.05	0.08	1.22	1.86	0.66	0.46	1.35	0.10	0.42	2.28	0.94	11.93
*1983	0.18	1.32	2.17	0.71	0.77	0.77	0.55	0.11	0.06	2.56	2.29	2.95	14.44
*1984	0.89	0.80	0.35	0.26	0.11	0.51	0.35	0.08	0.15	1.88	1.93	1.06	8.39
*1985	0.70	0.54	2.13	1.56	0.49	1.40	1.33	0.08	0.24	1.31	0.64	1.35	11.78
*1986	0.94	2.56	0.10	0.05	0.77	1.06	0.60	0.62	0.36	1.88	2.42	1.09	12.46
*1987	1.22	1.29	1.02	1.13	1.12	0.66	0.14	0.69	0.43	1.36	1.10	0.70	10.86
1988	1.29	1.30	0.41	0.40	0.81	0.00	2.13	0.02	0.78	0.60	1.15	0.45	9.34
1989	0.20	0.49	0.02	0.43	0.21	0.35	0.00	0.52	0.09	0.53	0.64	0.00	3.48
1990	0.32	0.00	0.06	0.57	0.98	0.13	0.96	0.08	0.09	1.24	0.66	2.04	7.13
1939-90 Average	0.79	0.56	0.60	0.56	0.53	0.63	0.44	0.39	0.23	0.83	1.05	0.81	7.41

* Denotes year in which one or more monthly records are reconstructed.

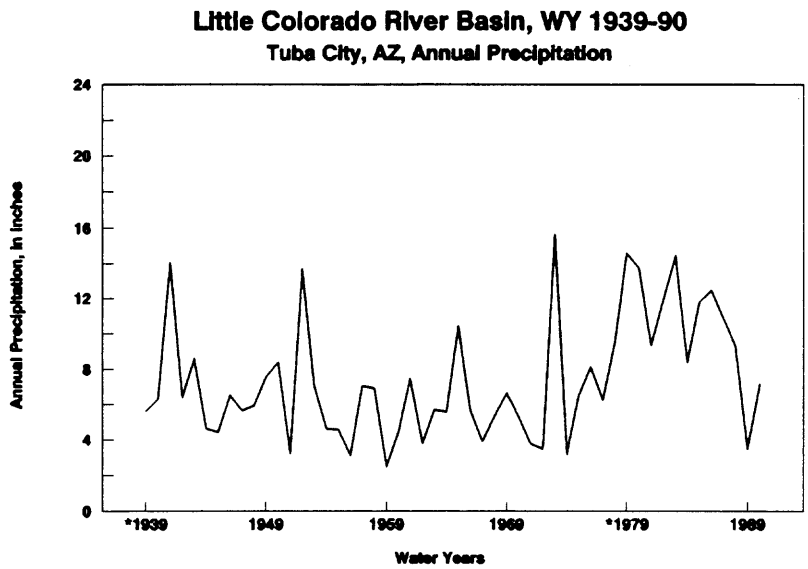


Figure 219. Tuba City, AZ, Annual Precipitation, WY 1939-90

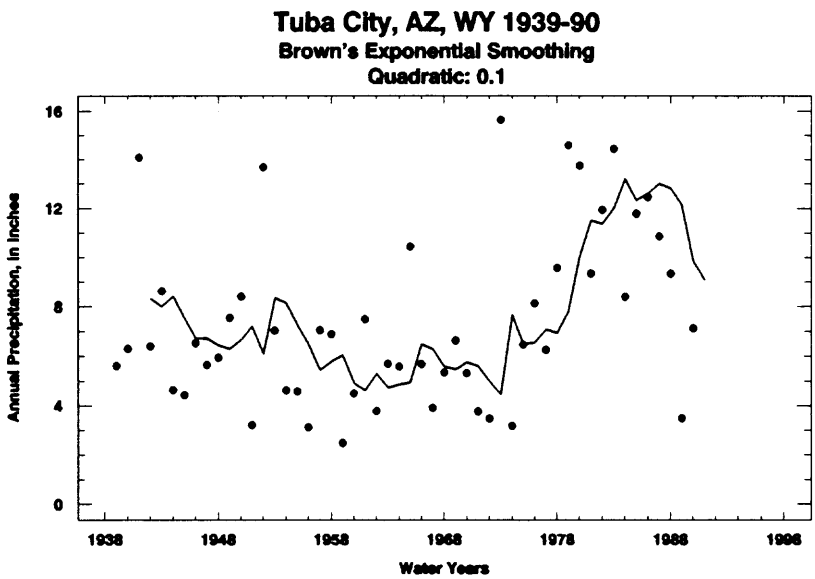


Figure 220. Tuba City, AZ, Smoothed Annual Precipitation, WY 1939-90

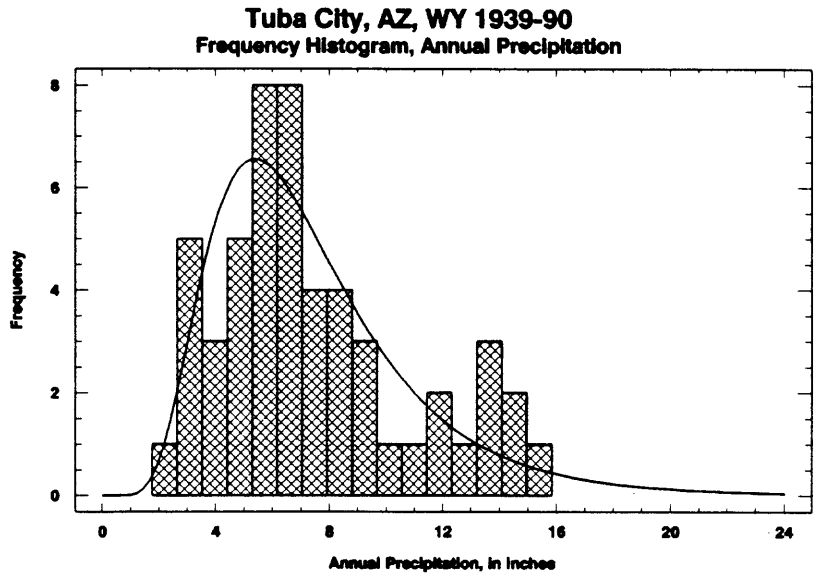


Figure 221. Tuba City, AZ, Histogram of Annual Precipitation

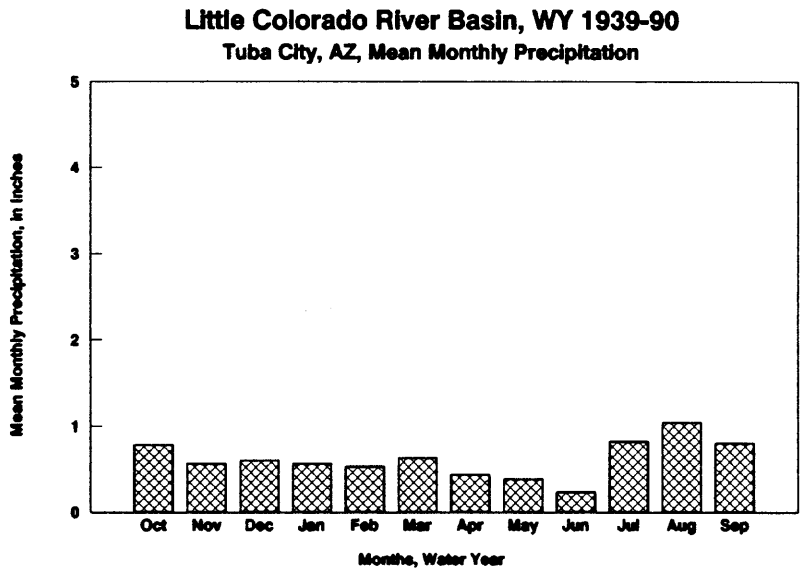


Figure 222. Tuba City, AZ, Monthly Distribution of Precipitation

6.2.3.48 Wahweap, AZ

The period of record for the Wahweap station is from 1961 through the present. The 1939-1961 record is reconstructed.

Wahweap lies on the southwestern shores of Lake Powell, near the Glen Canyon Dam on the Colorado River. The desert plateau through which Glen Canyon is cut is vegetated by plains grass and some sagebrush. To the west of Wahweap lies the Vermillion Cliffs and the Kaibab Plateau, which rises over 9,000 feet. To the south and east are the Navajo and Hopi Indian Reservations. This station lies just outside the northwest boundary of the LCR Basin, and is included in the study area to aid in the interpolation of missing data from the northwest areas of the Basin and to provide resolution for isohyetal maps.

The precipitation trends for the 1939-90 study period imply a gradual increase from 1939 to 1974. From 1974 through 1987, there has been a sharp increase. Since 1987, there is evidence of another decline.

The histogram shows a pronounced lognormal distribution, with moderate kurtosis and a slight positive skewness associated with recent wet years. The monthly distribution reveals a slight maximum from July through October, followed by a gradual decline from November through the annual minimum in June.

Table 61. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Wahweap, AZ
Station No.: 9114
Elevation: 3730
Latitude: 36d 54m
Longitude: 111d 29m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.24	0.12	0.03	0.22	0.28	0.62	0.00	0.09	0.05	0.00	0.04	1.51	3.19
*1940	0.00	0.18	0.00	0.00	0.00	0.06	0.07	0.00	0.00	0.07	0.13	1.22	1.74
*1941	0.71	0.28	1.06	1.14	0.00	1.23	1.18	1.01	0.10	0.00	0.76	0.48	7.95
*1942	1.18	0.00	0.05	0.00	0.00	0.12	0.42	0.03	0.00	0.33	0.00	0.00	2.13
*1943	0.40	0.05	0.46	0.00	0.00	0.99	0.01	0.22	0.00	0.00	0.00	0.30	2.42
*1944	0.03	0.16	0.74	0.28	0.11	0.66	0.71	0.30	0.00	0.00	0.00	0.00	2.99
*1945	0.00	0.43	0.11	0.00	0.31	0.40	0.45	0.04	0.05	1.03	0.23	0.00	3.05
*1946	0.41	0.00	0.00	0.19	0.00	0.56	0.66	0.02	0.00	0.55	1.80	0.21	4.39
*1947	1.06	0.50	0.00	0.00	0.00	0.00	0.05	0.27	0.08	0.07	1.14	0.00	3.18
*1948	2.12	0.05	0.29	0.13	1.21	0.05	0.12	0.04	0.81	0.00	1.37	0.01	6.20
*1949	0.39	0.01	0.18	0.43	0.28	0.60	0.00	0.03	1.34	1.83	0.01	0.60	5.70
*1950	0.39	0.16	0.00	0.00	0.25	0.29	0.03	0.00	0.03	0.54	0.68	0.05	2.42
*1951	0.00	0.00	0.04	0.61	0.02	0.11	0.26	0.46	0.00	0.00	1.08	0.52	3.10
*1952	0.23	0.60	0.32	0.45	0.36	0.14	0.96	0.21	0.41	0.16	0.64	1.52	6.01
*1953	0.00	0.59	0.68	0.01	0.00	0.00	0.67	0.00	0.19	2.72	2.02	0.11	6.97
*1954	0.30	0.39	0.03	0.20	0.18	0.00	0.00	0.38	0.62	0.54	0.31	1.01	3.96
*1955	0.07	0.29	0.30	0.00	0.21	0.08	0.00	0.00	0.86	0.00	0.48	0.00	2.29
*1956	0.00	0.36	0.00	0.45	0.00	0.10	0.14	0.35	0.00	0.16	0.56	0.00	2.13
*1957	0.00	0.06	0.00	0.35	0.18	0.31	0.44	1.31	0.41	0.88	1.71	0.05	5.70
*1958	1.00	0.88	0.28	0.04	0.00	1.04	0.00	0.37	0.00	0.31	0.00	1.12	5.03
*1959	0.07	0.06	0.00	0.00	0.00	0.00	0.60	0.39	0.00	0.00	0.00	0.40	1.52
*1960	1.63	0.47	0.23	0.46	0.07	0.21	0.28	0.00	0.03	0.00	0.00	0.13	3.50
*1961	1.77	0.30	0.64	0.06	0.00	0.92	0.19	0.00	0.00	0.56	1.28	1.31	7.03
1962	0.23	0.00	0.18	0.05	0.37	0.26	0.00	0.32	0.06	0.00	0.14	0.69	2.30
1963	0.82	0.55	0.06	0.45	0.54	1.26	0.06	0.12	0.03	0.28	1.23	0.96	6.36
1964	0.34	0.35	0.00	0.17	0.00	0.23	0.63	0.50	0.20	0.16	0.54	0.00	3.12
1965	0.00	0.11	0.43	0.26	0.34	0.46	1.14	1.89	0.30	0.49	0.40	0.36	6.18
1966	0.35	0.98	1.03	0.01	0.57	0.00	0.00	0.43	0.03	0.09	0.62	0.51	4.62
1967	0.36	0.53	0.86	0.00	0.00	0.05	0.37	0.33	0.33	0.03	0.48	1.27	4.61
1968	0.02	0.02	1.17	0.19	0.24	0.23	0.45	0.04	0.01	1.45	0.57	0.11	4.50
1969	0.07	0.21	0.35	0.37	0.62	0.62	0.00	0.26	0.29	0.17	0.96	0.01	3.93
1970	1.00	0.09	0.18	0.22	0.36	1.04	0.11	0.00	0.07	0.64	0.60	0.10	4.41
1971	0.18	0.37	0.28	0.18	0.14	0.07	0.00	0.17	0.03	0.19	0.81	0.32	2.74
1972	0.68	0.36	0.40	0.00	0.00	0.00	0.00	0.00	2.85	0.70	0.65	0.50	6.14
1973	3.83	1.52	0.61	0.35	0.70	0.97	0.46	1.16	0.49	0.09	0.08	0.81	11.07
1974	0.03	0.29	0.00	1.09	0.02	0.20	0.10	0.00	0.00	0.30	0.14	0.10	2.27
1975	0.99	0.43	0.12	0.36	0.70	1.07	0.72	0.07	0.22	0.89	0.42	0.35	6.34
1976	0.08	0.47	0.18	0.00	0.55	0.75	0.38	0.37	0.00	1.18	0.00	0.76	4.72
1977	0.21	0.05	0.00	0.10	0.10	0.06	0.00	0.18	0.11	0.92	0.30	0.08	2.11
1978	0.21	0.23	0.31	1.44	0.05	1.08	0.51	0.37	0.00	0.61	0.42	1.29	6.52
1979	1.06	2.59	1.61	1.78	0.67	1.34	0.29	1.02	0.27	0.00	0.26	0.00	10.89
1980	0.26	1.77	1.04	1.74	2.27	1.25	0.81	0.30	0.00	0.51	0.86	0.93	11.74
1981	0.30	0.01	0.02	0.13	0.47	1.23	0.34	0.00	0.14	0.21	1.08	1.22	5.15
1982	1.97	1.44	0.01	0.78	5.39	0.24	0.64	0.42	0.00	0.35	1.37	0.12	12.73
*1983	0.34	1.79	1.35	0.73	0.75	1.87	0.29	0.18	0.18	4.07	4.13	1.70	17.38
1984	0.38	1.34	0.30	0.00	0.00	0.22	0.38	0.00	0.16	0.94	0.48	0.08	4.28
1985	0.69	0.13	1.07	0.50	0.16	1.78	0.68	0.07	0.12	0.87	0.02	0.36	6.45
1986	0.91	1.89	0.00	0.02	0.21	0.89	0.39	0.62	0.16	1.86	0.69	0.66	8.30
1987	0.95	0.68	0.38	0.28	0.64	0.69	0.04	0.27	0.06	0.84	0.88	0.02	5.73
1988	1.14	1.21	0.15	0.22	0.53	0.00	1.78	0.08	0.32	0.00	0.72	0.30	6.45
1989	0.13	0.14	0.22	1.98	0.00	0.06	0.00	0.58	0.00	0.28	0.96	0.00	4.35
1990	0.20	0.00	0.01	0.58	0.82	0.10	0.89	0.91	0.27	0.82	0.59	1.31	6.50
1939-90 Average	0.57	0.49	0.34	0.37	0.40	0.51	0.36	0.31	0.22	0.55	0.67	0.49	5.28

* Denotes year in which one or more monthly records are reconstructed.

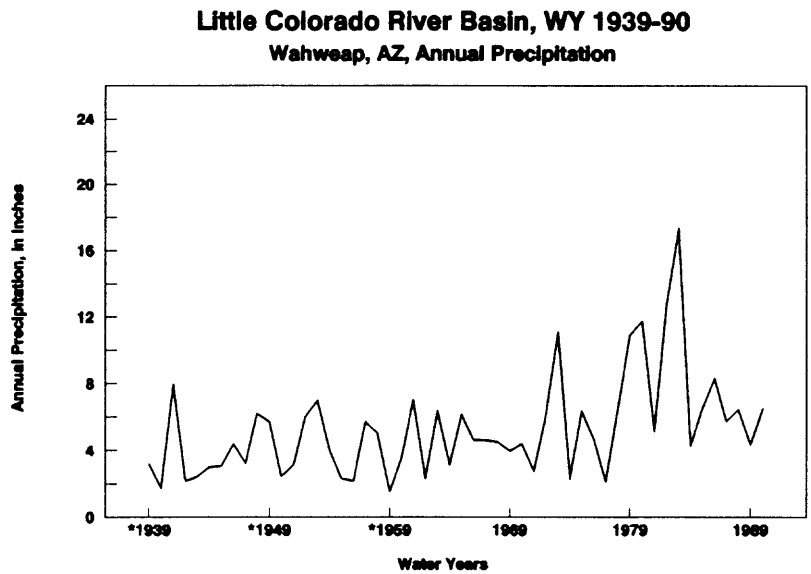


Figure 223. Wahweap, AZ, Annual Precipitation, WY 1939-90

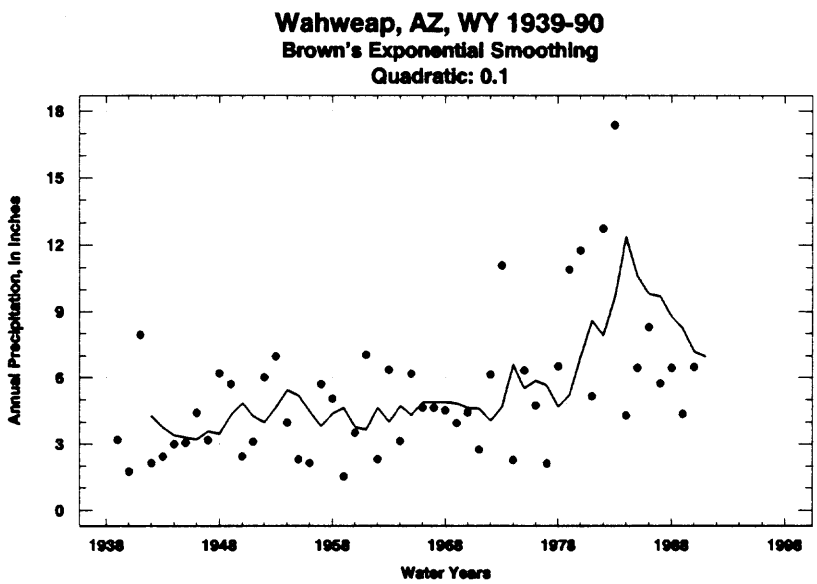


Figure 224. Wahweap, AZ, Smoothed Annual Precipitation, WY 1939-90

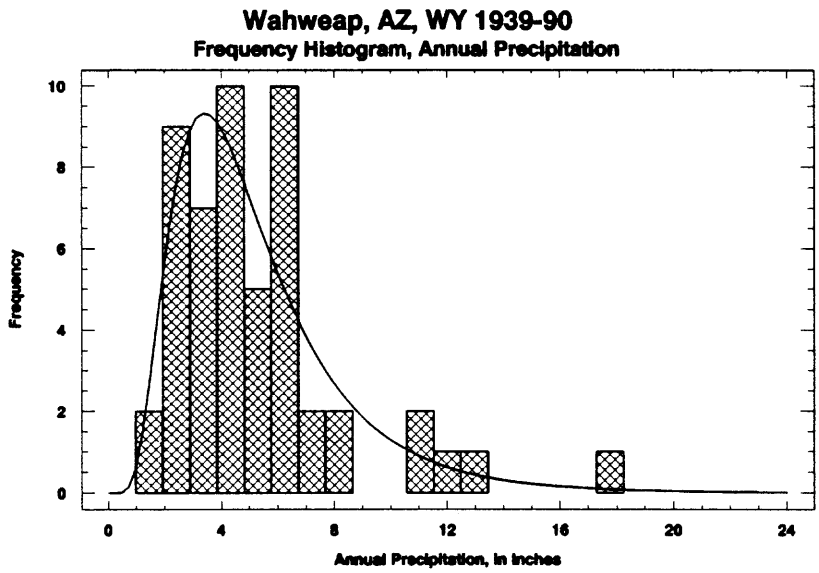


Figure 225. Wahweap, AZ, Histogram of Annual Precipitation

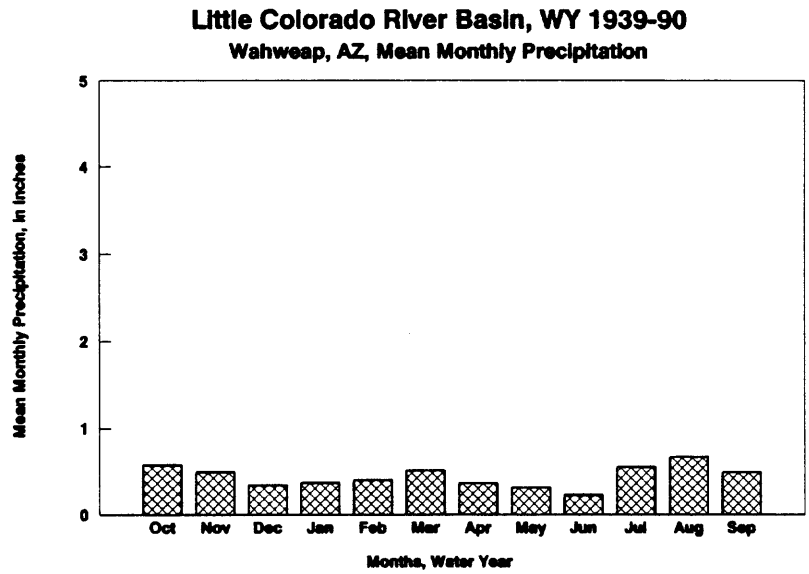


Figure 226. Wahweap, AZ, Monthly Distribution of Precipitation

6.2.3.49 Walnut Canyon National Monument, AZ

The period of record for this relatively recently established station is continuous from 1951 to the present. The period of 1939 to 1951 is reconstructed.

Walnut Canyon National Monument is located about 20 miles east of Flagstaff at an elevation of 6,693 feet near the eastern edge of the Coconino Plateau. The Monument protects numerous Sinagua Indian cliff dwellings along the canyon of Walnut Creek, a tributary of San Francisco Creek, which empties into the Little Colorado River at Leupp, some 40 miles away, prior to the construction of Leupp Dam and reservoir about a mile southwest of Leupp, on the southern border of the Navajo Indian Reservation. There are indications from pictographs in the area that the Sinagua are related to the prehistoric Anasazi Indians and the present day Hopi Indians. The area seems to have been abandoned near the time of the eruption of Sunset Crater at almost 1100 A.D. The alluvial deposits along the creek bed seem to have been used for the growing of corn, beans, and squash. The pinyon which are at lower elevations, were harvested for the nutritious seeds (nuts) of the trees.

The immediate vicinity is vegetated by ponderosa pine, but the steep slopes of the Coconino Plateau are covered by pinyon and juniper at intermediate elevations, the lower elevations are vegetated by plains grass, and the Little Colorado River Valley some 20 miles to the east is characterized by sagebrush. The precipitous decrease in elevation to the east towards the community of Winslow enables broad views of the Painted Desert and the Little Colorado River valley. The San Francisco Mountains are nearby at an elevation of some 12,600 feet, and the Mogollon Plateau with its famous southern rim lies about 20 to 30 miles to the south. The proximity of the high mountains and plateaus enables precipitation exceeding seventeen inches in an average year. In the winter months, most of the precipitation falls as snow.

The precipitation trends for the 1939-90 study period indicate a gradual increase throughout the period, similar to the trends of Flagstaff.

The histogram is largely normally distributed, with a very sharp peak at eighteen inches. A very slight positive skewness is noted due to four very wet years. The monthly distribution shows a sharp peak in July and August, followed by a gradual decline from November until the annual minimum in June.

Table 62. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Walnut Canyon National Monument, AZ
Station No.: 9156
Elevation: 6683
Latitude: 35d 10m
Longitude: 111d 31m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.54	0.40	2.40	1.46	1.43	0.84	0.66	0.11	0.00	0.70	2.65	3.06	14.25
*1940	0.34	1.32	0.08	1.58	2.24	0.39	1.76	0.31	1.09	0.49	2.06	3.86	15.51
*1941	3.03	1.12	3.04	1.44	1.69	1.88	2.93	0.69	0.63	1.81	1.42	3.04	22.71
*1942	4.32	0.80	2.20	0.96	1.56	0.70	1.22	0.01	0.00	1.50	1.97	0.71	15.95
*1943	1.21	0.21	1.42	3.17	1.22	1.83	0.86	0.16	0.20	1.51	3.61	1.56	16.96
*1944	1.42	0.17	2.19	1.70	3.08	1.96	1.73	1.13	0.03	1.36	1.09	1.13	16.98
*1945	0.55	2.06	1.76	2.11	0.50	4.21	0.76	0.02	0.08	2.98	2.45	0.33	17.80
*1946	0.87	0.09	2.31	0.91	0.61	0.96	2.73	0.37	0.03	3.15	3.84	1.25	17.12
*1947	1.30	1.66	1.06	0.42	0.20	0.27	0.09	1.10	0.02	0.98	3.68	0.64	11.41
*1948	1.51	0.85	1.60	0.58	1.88	1.59	0.35	0.09	0.39	1.33	2.40	0.93	13.50
*1949	1.63	0.01	2.40	5.65	1.16	0.71	0.38	1.04	1.46	2.96	1.69	2.53	21.62
*1950	3.10	0.62	1.30	1.04	1.33	0.86	0.19	0.31	0.24	3.90	1.18	0.93	14.99
*1951	0.01	0.28	0.07	1.29	1.17	1.25	2.29	0.81	0.00	1.45	3.26	0.92	12.80
1952	1.76	1.05	5.17	3.13	0.82	3.46	1.10	0.12	0.04	3.95	1.85	2.23	24.68
1953	0.00	2.93	1.38	0.32	0.20	1.22	1.15	0.25	0.00	3.06	2.95	0.04	13.50
1954	0.32	1.62	0.45	1.97	1.09	4.01	0.59	0.50	0.38	3.21	1.22	3.36	18.72
1955	0.84	0.32	0.63	1.78	1.18	0.04	0.60	0.65	3.38	2.98	3.18	0.07	15.65
1956	0.05	1.25	0.98	1.47	1.17	0.32	0.92	0.12	1.34	2.13	1.23	0.00	10.98
1957	0.38	0.00	0.42	6.93	0.51	1.66	0.63	2.02	1.10	1.25	2.12	0.00	17.02
1958	3.58	2.20	0.33	0.36	2.13	2.68	1.44	0.46	0.20	0.70	3.55	5.76	23.39
1959	1.03	1.22	0.02	0.27	3.27	0.08	0.66	1.48	0.75	2.21	3.13	0.34	14.46
1960	2.23	0.42	3.86	1.18	1.90	0.94	1.18	0.64	0.39	1.20	1.85	0.98	16.77
1961	3.47	1.05	0.47	0.75	0.06	2.91	0.33	0.25	0.00	1.73	3.34	2.74	17.10
1962	1.69	1.47	2.07	3.37	3.13	1.32	0.01	0.53	0.32	0.87	0.59	2.87	18.24
1963	1.45	1.04	0.79	0.75	1.23	1.52	1.23	0.00	0.00	0.58	5.78	2.22	16.59
1964	1.07	0.78	0.44	0.92	0.38	3.02	1.57	0.40	0.27	4.62	3.46	0.75	17.68
1965	0.03	1.00	1.91	2.48	1.28	2.65	4.08	1.79	0.03	2.61	0.81	2.00	20.67
1966	0.41	3.82	4.95	1.17	0.35	0.55	0.27	0.07	0.94	2.78	1.60	1.16	18.07
1967	0.74	1.66	4.12	0.68	0.00	0.56	1.16	0.46	1.23	4.25	1.69	3.49	20.04
1968	0.12	0.57	8.29	0.85	0.52	0.62	1.23	0.81	0.14	3.40	4.11	0.13	20.79
1969	1.30	0.57	1.61	2.80	2.46	2.44	0.12	1.11	0.15	2.42	2.62	0.89	18.49
1970	1.41	1.45	0.42	0.29	0.25	5.94	1.07	0.00	0.00	3.13	1.92	1.94	17.82
1971	0.19	1.06	1.13	0.10	1.20	0.05	0.29	0.71	0.00	2.19	2.55	1.88	11.35
1972	3.56	0.41	3.08	0.00	0.00	0.00	0.60	0.11	2.53	2.25	3.09	1.22	16.85
1973	9.58	1.64	3.32	0.97	3.18	4.94	1.01	0.51	0.42	2.46	0.51	0.00	28.54
1974	0.04	1.37	0.07	2.37	0.38	0.66	0.39	0.00	0.09	3.14	1.00	1.05	10.56
1975	2.69	0.94	0.42	0.98	1.25	1.81	1.38	1.69	0.00	3.08	0.34	2.61	17.19
1976	0.67	2.39	1.50	0.00	3.19	1.25	1.54	2.16	0.05	2.01	0.35	1.82	16.93
1977	0.99	0.15	0.68	2.38	0.72	0.57	0.43	0.66	0.13	1.87	1.72	1.65	11.95
1978	0.94	1.11	0.97	2.12	3.35	5.39	1.04	0.24	0.08	0.83	0.95	0.33	17.35
1979	0.74	3.23	4.94	3.53	1.14	1.43	0.23	2.63	0.50	0.65	2.05	0.23	21.30
1980	1.27	1.14	2.33	4.54	4.74	2.04	0.38	0.26	0.12	1.45	2.37	0.43	21.07
1981	0.59	0.00	0.56	1.09	0.88	2.54	1.43	0.45	0.86	3.42	3.41	2.20	17.43
1982	1.96	1.58	0.03	3.34	2.61	3.59	0.16	0.65	0.00	3.50	2.29	3.19	22.90
1983	0.45	3.29	3.53	0.82	1.81	2.74	1.40	0.05	0.06	2.50	3.16	5.04	24.85
1984	0.66	0.90	1.99	0.44	0.04	0.84	0.19	0.13	0.02	3.94	3.00	1.10	13.25
1985	1.80	0.62	3.74	2.28	1.21	2.96	2.92	0.49	0.34	1.39	0.96	1.96	20.67
1986	2.01	5.33	0.09	0.09	1.53	2.70	1.01	0.96	1.35	2.13	8.71	3.06	28.97
1987	1.55	1.45	1.14	3.57	2.37	1.54	0.36	0.71	0.38	2.43	5.63	1.30	22.43
1988	2.20	3.38	1.62	1.13	1.89	0.17	2.88	0.08	2.46	0.60	2.65	1.18	20.24
1989	0.73	1.14	0.60	1.74	1.11	1.29	0.00	0.64	0.00	1.74	4.03	0.47	13.49
1990	0.69	0.00	1.10	0.92	2.34	1.26	0.97	0.68	0.09	2.37	1.77	5.07	17.26
1939-90 Average	1.44	1.25	1.79	1.66	1.44	1.75	1.04	0.61	0.47	2.21	2.48	1.69	17.82

* Denotes year in which one or more monthly records are reconstructed.

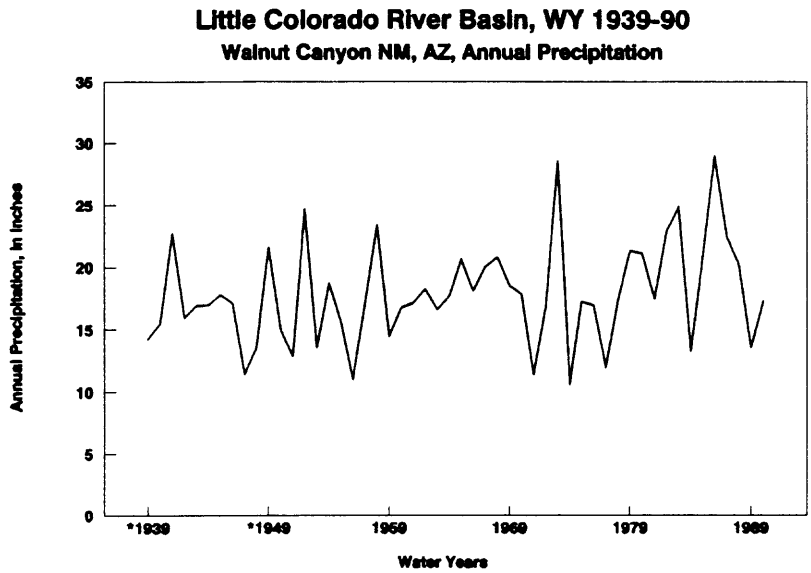


Figure 227. Walnut Cyn NM, AZ, Annual Precipitation, WY 1939-90

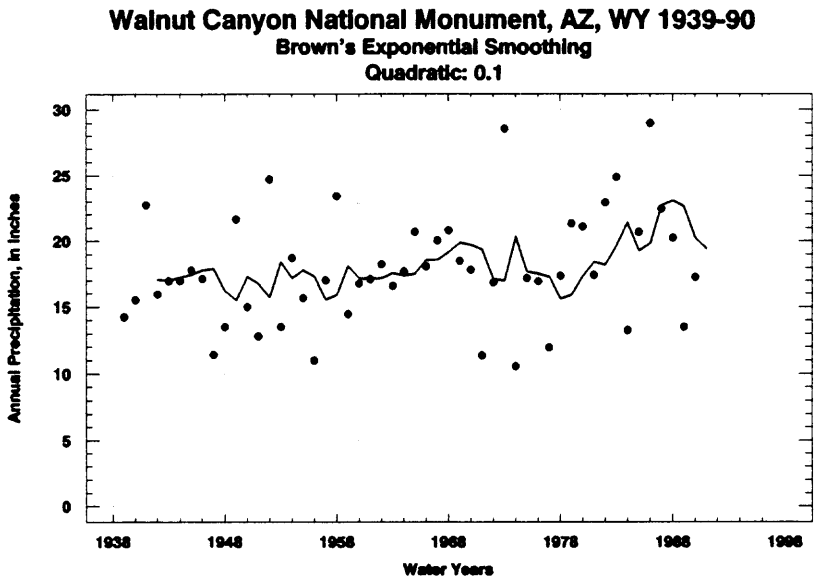


Figure 228. Walnut Cyn NM, AZ, Smoothed Annual Precipitation, WY 1939-90

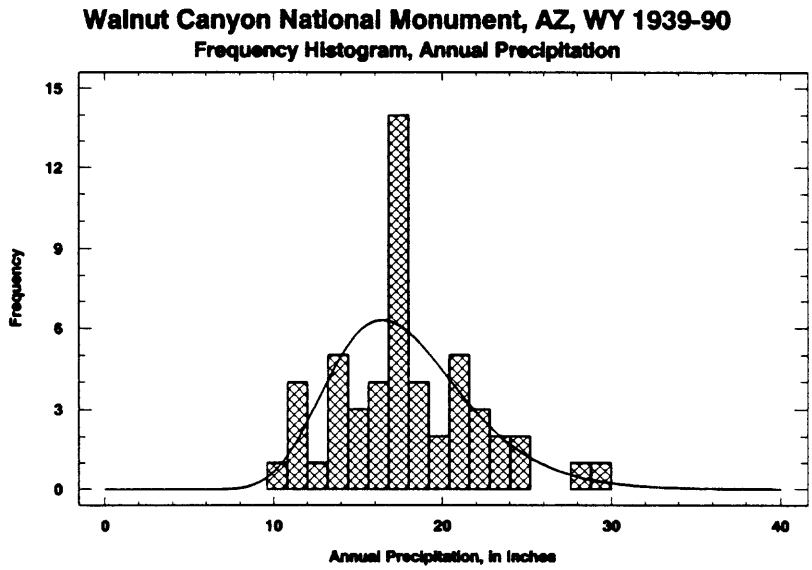


Figure 229. Walnut Cyn NM, AZ, Histogram of Annual Precipitation

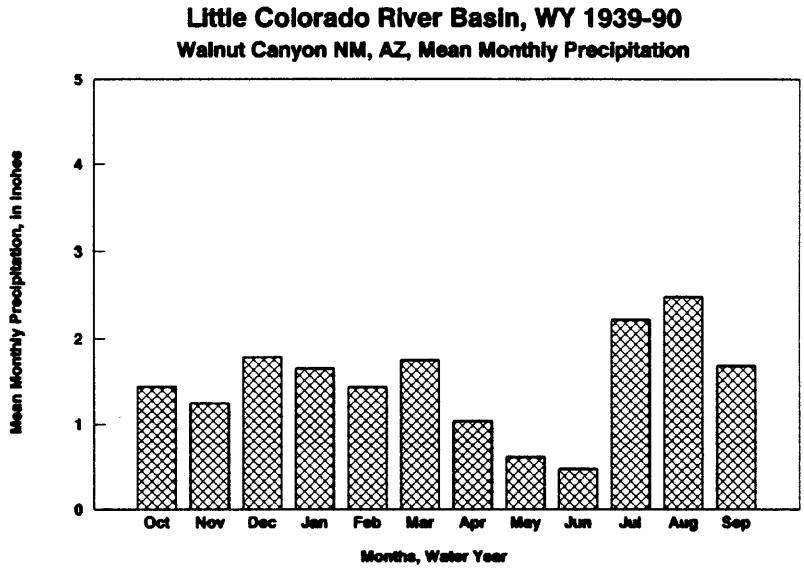


Figure 230. Walnut Cyn NM, AZ, Monthly Distribution of Precipitation

6.2.3.50 Whiteriver, AZ

This station is located on the White Mountain Apache Indian Reservation, just outside the LCR Basin, the southerly boundary of which lies on the Mogollon Rim about 10 miles to the north. This station is included due to its relatively long-term and constant period of record from 1931 through 1934 and 1941 to the present. Its inclusion enables the interpolation of missing data from nearby LCR Basin stations, and improves resolution of isohyetal maps.

As summarized in Sellars and Hill (1974, p. 550):

"Whiteriver is located at an elevation of about 5,300 feet in the mountainous country of east-central Arizona. It lies on the west bank of the North Fork of the White River near the center of the Fort Apache [White River Apache] Indian Reservation. The river flows southwestward for fifteen miles to its confluence with the Black and Salt Rivers in the deep Salt River Canyon. Its headwaters are in the majestic White Mountains to the east and northeast. These mountains are a very popular summer vacationing spot for the heat weary residents of the southwestern part of Arizona. They include several high peaks, foremost of which are Baldy Peak, at an elevation of 11,490 feet, 25 miles east-northeast of Whiteriver, and Greens Peak, at 10,115 feet, 30 miles to the northeast. The southern boundary of Sitgreaves National Forest lies twenty miles to the north on the Mogollon Plateau, which extends westward into the central part of the state. The southern rim of this plateau has a mean elevation of about 7,500 feet. The terrain slopes irregularly downward to the west and south of Whiteriver into the valleys of the Salt and Gila Rivers. San Carlos Lake, formed by Coolidge Dam, is located on the westward flowing Gila River, fifty miles to the south. The Natanes Plateau and the San Carlos [Apache] Indian Reservation lie between Whiteriver and the Gila River. The vegetation in the immediate vicinity of Whiteriver consists mainly of ponderosa pine forests, chaparral, and oak woodland. Creosote bush and mesquite may be found in the river valleys and canyons.

"Whiteriver's location near the White Mountains guarantees it more precipitation than is received in the lower and less exposed regions to the south and west. This is particularly true during the summer thunderstorm season. From early July until the end of August, when moist tropical air from the Gulf of Mexico covers much of the state, these storms form almost daily over the high mountain peaks. Usually they spread out over Whiteriver in the middle afternoon, producing light to moderate showers, occasionally accompanied by gusty winds. In some summers a considerable part of the total precipitation may be associated with weak tropical disturbances moving northward from the Pacific Ocean. However, these storms are very rare and probably account for only a small part of Whiteriver's mean annual precipitation.

"Whiteriver also receives moderate amounts of precipitation during the winter, generally from middle latitude storms that advance into Arizona from the Pacific Ocean. These storms are particularly severe when they move or form unusually far south and follow a northeastward track through the state. Their intensity and frequency of occurrence vary greatly from one year to the next. As an extreme example, Whiteriver received only 2.35 inches of precipitation between December 1903 and April 1904, while during the same period in the following year, 21.30 inches were recorded. Only about thirty percent of the winter precipitation falls as snow, and this rarely accumulates to a depth of more than a foot."

Precipitation trends for the 1939-90 study period show an increase from 1939 to 1958, a decrease from 1958 to 1973, and a sharp increase from 1979 to 1987. From 1988 to 1989, the beginnings of a decrease are evident.

The histogram shows a nearly perfect lognormal distribution centered at a peak near sixteen inches. An outlying dry year disrupts the positive skew formed by several wet years. The monthly distribution shows a sharp peak in July and August, followed by a season of relatively flat means until March. April and May dip rapidly to the annual minimum in May and June.

Table 63. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Whiteriver 1 SW, AZ
Station No.: 9271
Elevation: 5120
Latitude: 33d 50m
Longitude: 109d 58m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.00	0.00	0.00	0.96	0.00	0.54	1.01	0.01	0.16	0.69	1.92	0.29	5.58
*1940	0.33	0.70	0.53	0.09	0.75	0.13	0.58	0.11	0.15	1.17	2.20	5.45	12.19
1941	1.18	2.90	4.06	3.63	3.12	5.57	1.18	0.48	0.10	0.90	3.26	3.17	29.55
1942	1.20	1.60	2.10	1.03	0.97	0.53	1.48	0.00	0.00	2.11	1.57	1.15	13.74
1943	2.46	0.08	2.54	2.22	1.13	2.71	0.21	0.53	0.28	1.71	2.57	1.58	18.02
1944	1.63	0.01	1.80	0.54	1.62	1.16	0.85	0.40	0.00	2.04	2.30	3.71	16.06
1945	0.30	2.01	1.16	0.77	0.49	1.98	0.26	0.00	0.16	1.59	2.94	0.34	12.00
1946	3.02	0.00	1.91	1.84	0.39	0.47	0.44	0.00	0.00	2.05	6.04	4.11	20.27
1947	0.70	2.02	1.75	0.27	1.05	0.02	0.05	2.35	0.03	2.58	4.16	2.39	17.37
1948	2.99	1.03	1.07	0.24	2.34	1.31	0.09	0.00	0.29	2.69	1.95	1.13	15.13
1949	2.45	0.02	2.03	2.72	0.50	0.82	0.45	0.47	0.55	5.46	2.35	1.61	19.43
1950	1.60	0.40	1.72	0.82	0.88	1.19	0.27	0.17	0.51	3.45	2.89	1.22	15.12
1951	0.46	0.18	0.00	2.09	0.80	0.94	2.06	0.49	0.00	1.19	5.48	1.02	14.71
1952	1.42	1.26	3.08	3.26	0.61	2.79	2.93	0.04	1.05	2.11	3.79	1.18	23.52
1953	0.00	3.22	0.83	0.70	0.31	2.78	1.44	0.11	0.72	2.45	2.31	0.00	14.87
1954	0.07	0.47	0.61	1.19	0.53	3.97	0.00	0.48	2.09	3.18	5.74	3.17	21.50
1955	0.15	0.11	0.53	2.28	0.85	0.04	0.08	0.00	1.28	1.64	6.34	0.08	13.38
1956	0.80	0.99	1.18	2.77	1.57	0.00	1.12	0.00	0.20	3.57	2.34	0.03	14.57
1957	0.64	0.00	0.44	3.58	0.53	1.58	0.43	0.79	0.85	3.74	4.82	1.75	19.15
1958	2.98	0.98	0.64	0.00	3.21	4.37	1.21	0.16	1.17	1.04	1.71	4.45	21.92
1959	1.89	1.01	0.10	0.17	1.01	0.00	0.59	0.00	0.29	3.75	3.57	0.34	12.72
1960	4.08	1.62	2.82	2.88	0.65	1.42	0.10	0.72	0.09	2.02	2.46	0.87	19.73
1961	2.09	0.20	1.19	0.75	0.26	0.19	0.41	0.00	0.66	2.92	6.19	1.25	16.11
1962	2.53	1.12	2.00	1.90	1.24	0.90	0.02	0.05	0.20	2.56	0.49	3.91	16.92
1963	1.24	1.21	1.42	1.06	2.03	1.00	0.40	0.00	0.12	1.90	5.76	1.61	17.75
1964	1.05	1.33	0.16	0.72	0.24	1.33	1.05	0.01	0.02	2.96	2.86	3.17	14.90
1965	1.17	1.08	0.83	2.42	1.71	1.32	1.36	0.30	0.82	4.66	0.76	1.09	17.52
1966	1.03	2.74	5.95	0.80	0.74	0.34	0.69	0.05	1.27	1.98	6.21	1.12	22.92
1967	0.36	0.90	1.67	0.31	0.12	1.68	0.34	0.73	0.39	3.94	3.34	1.44	15.22
1968	0.40	1.45	3.08	0.91	1.39	1.90	1.35	0.01	0.19	2.88	5.27	0.88	19.71
1969	0.46	1.50	1.91	1.90	0.85	1.23	0.34	1.54	0.00	3.10	2.91	0.96	16.70
1970	0.88	1.57	0.68	0.32	0.58	2.47	1.01	0.03	0.29	1.42	2.29	2.75	14.29
1971	1.14	0.22	1.08	0.45	0.47	0.12	0.52	0.16	0.00	2.70	5.38	2.61	14.85
1972	4.39	1.12	2.11	0.00	0.00	0.00	0.00	0.05	2.68	3.05	2.46	1.99	17.85
1973	6.53	2.11	1.66	0.62	2.07	4.14	0.50	2.18	1.07	2.71	2.09	0.08	25.76
1974	0.02	1.34	0.02	2.64	0.17	2.31	0.24	0.01	0.13	2.81	1.02	0.76	11.47
1975	5.00	0.29	0.51	0.90	2.03	2.73	2.64	0.21	0.00	3.27	1.04	2.49	21.11
1976	0.12	1.19	0.55	0.56	1.73	1.25	1.58	2.23	0.01	2.79	3.23	1.94	17.18
1977	1.08	0.39	0.09	2.57	0.21	1.20	0.47	0.43	1.24	5.47	2.75	2.95	18.85
1978	2.77	0.52	0.64	3.26	3.24	5.80	0.39	0.83	0.18	1.27	4.57	0.65	24.12
1979	2.07	4.98	4.32	3.87	0.93	2.60	0.36	2.59	0.43	1.31	2.25	0.53	26.24
1980	0.28	1.09	0.70	4.55	5.64	2.50	0.87	0.56	0.01	6.06	4.80	1.19	28.25
1981	1.12	0.21	1.11	0.43	1.44	4.21	0.86	0.39	1.35	2.36	2.48	1.31	17.27
1982	0.92	1.63	0.04	3.28	2.52	2.45	0.25	1.64	0.02	3.20	7.03	2.56	25.54
1983	0.02	3.02	2.97	2.62	1.76	4.17	0.76	0.09	0.00	2.53	4.39	4.49	26.82
1984	3.24	2.52	2.76	0.52	0.00	0.22	1.17	0.20	1.19	2.28	5.66	1.91	21.67
1985	4.87	1.02	4.85	2.46	1.98	2.06	1.68	0.09	0.42	1.90	2.41	3.05	26.79
1986	1.95	2.28	0.19	0.33	2.61	2.50	0.09	0.00	1.43	1.42	4.40	1.54	18.74
1987	1.24	2.79	2.70	1.59	1.93	2.22	0.81	0.48	0.60	1.78	2.36	1.70	20.20
1988	1.01	1.50	2.33	1.78	0.52	0.30	3.63	0.10	0.42	2.61	7.76	0.30	22.26
1989	1.24	0.88	0.54	1.73	0.94	2.43	0.00	0.11	0.00	0.89	2.63	0.21	11.60
*1990	1.67	0.34	0.55	0.69	0.97	0.83	0.71	0.25	0.00	2.22	1.14	2.32	11.69
1939-90 Average	1.58	1.21	1.53	1.54	1.22	1.74	0.79	0.44	0.48	2.54	3.44	1.77	18.29

* Denotes year in which one or more monthly records are reconstructed.

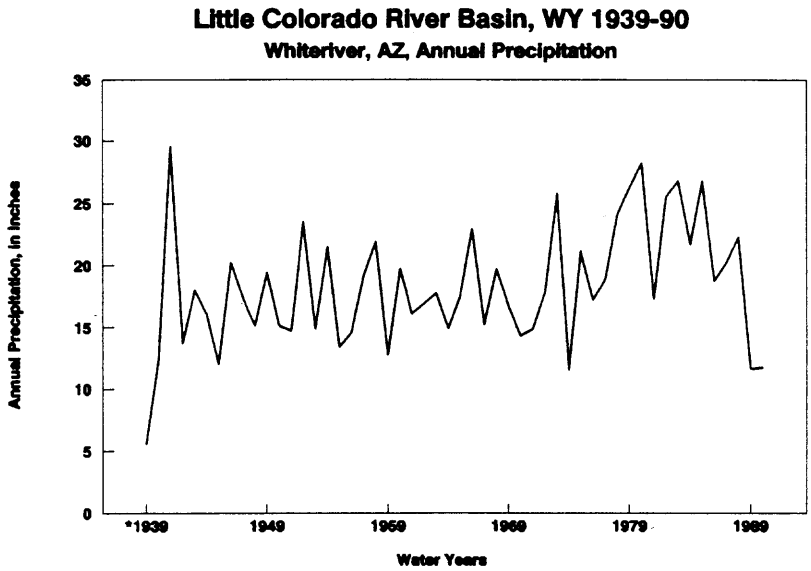


Figure 231. Whiteriver, AZ, Annual Precipitation, WY 1939-90

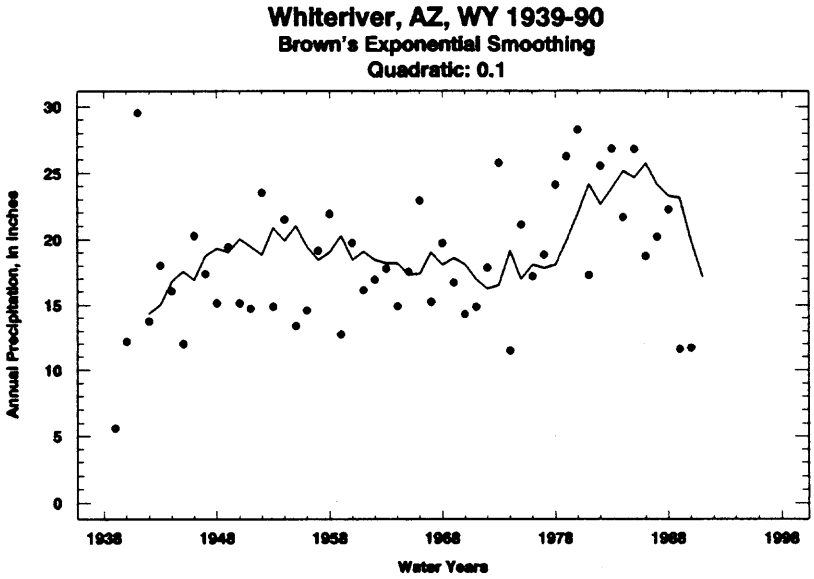


Figure 232. Whiteriver, AZ, Smoothed Annual Precipitation, WY 1939-90

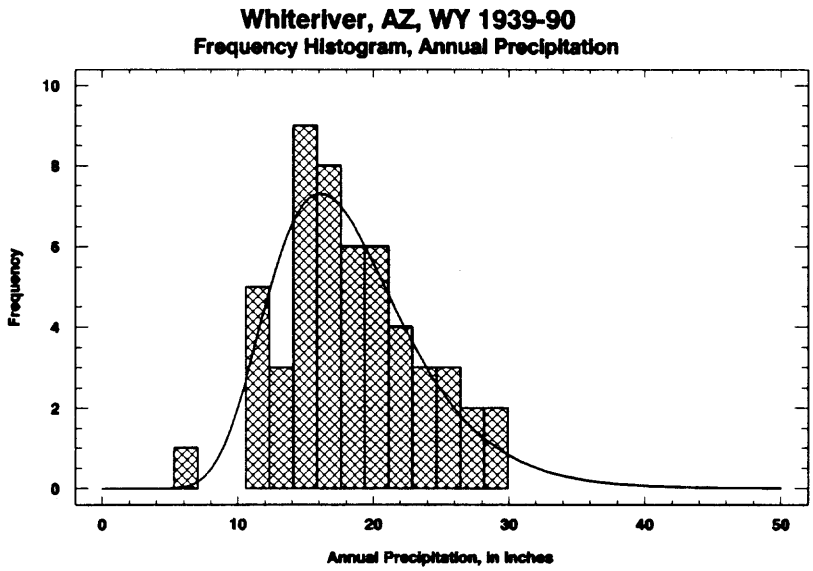


Figure 233. Whiteriver, AZ, Histogram of Annual Precipitation

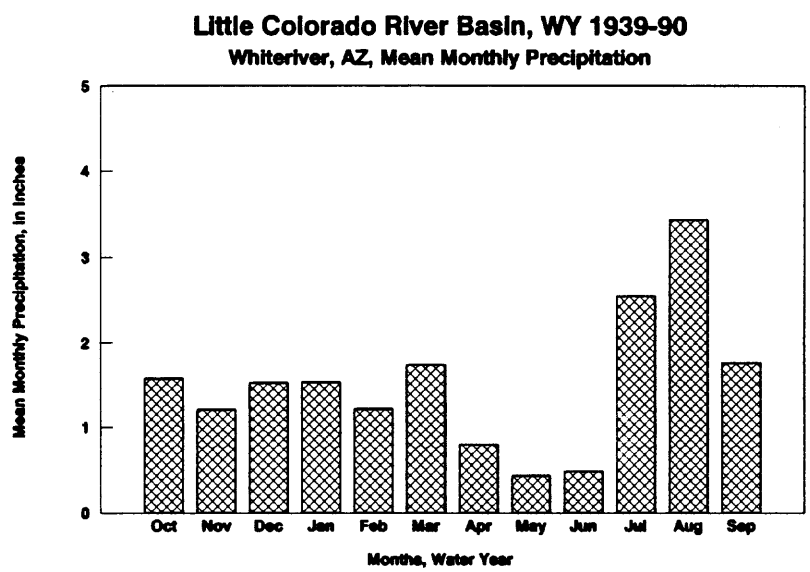


Figure 234. Whiteriver, AZ, Monthly Distribution of Precipitation

6.2.3.51 Window Rock, AZ

Window Rock has a nearly continuous period of record from 1931 to the present, with few months missing. The previous Fort Defiance station, fifteen miles away, has a period from 1897 to 1906 and from 1930 to 1931, augmenting the Window Rock record for long-term trends.

As summarized in Sellars and Hill (1974, p. 566):

"Window Rock is located at an elevation of 6,750 feet on the Navajo Indian Reservation in extreme northeastern Arizona about one mile west of the New Mexico border. The town lies on the east bank of Black Creek in a narrow valley which has its drainage on the barren desert mesas and plains to the south. The valley walls slope sharply upward to the west, reaching elevations in excess of 8,000 feet on the broad forested plateau centered ten miles northwest of Window Rock. The southern foothills of the Chuska Mountains flank the valley on the east. This range rises to 9,500 feet on Roof Butte and Matthews Peak, both about fifty miles north of Window Rock. In New Mexico the Zuni Mountains, 60 miles to the southeast, also have elevations above 9,000 feet. Canyon de Chelly National Monument, noted for its finger-like steep walled canyons, is located thirty miles to the southwest, while the northern boundary of the famous Petrified National Monument [Park] is found fifty miles to the southwest in the valley of the Puerco River. The vegetation in the area consists mainly of plains grass on the valley floors, pinyon and juniper on the valley slopes and mesas, and ponderosa pine forests on the high plateaus and mountains.

"The climate of Window Rock is strongly influenced by its location in the high barren plateau country of northeastern Arizona. Moderate amounts of precipitation fall consistently only from about the middle of July until the first week in September. During this period afternoon thunderstorms frequently form over the nearby mountains in moist tropical air that has moved into the state from the south, usually from the Gulf of Mexico. When these storms spread over Window Rock, as they often do, they are accompanied by gusty winds and moderate to heavy rain showers. Precipitation from a single thunderstorm rarely lasts longer than half an hour. More continuous, although still showery type, precipitation occurs when the moist air is associated with the remnants of a tropical disturbance moving northward from the Pacific Ocean. Fully developed storms of this type are responsible for the record summer rainfalls over most of Arizona. However, they occur very infrequently and in most years not at all.

"In some years Window Rock receives moderately heavy precipitation during the winter. This is normally associated with middle latitude storms that form in the Pacific Ocean and advance unusually far south on their eastward journey across the country. These storms are especially severe when they intensify off the coast of southern California before moving inland. During most years, when the middle latitude storm track is near or slightly north of its normal position, winters at Window Rock are windy and dry. Winter precipitation is usually gentler than that of summer. However, it normally lasts longer and is spread over a wider area. At Window Rock about 70 percent of the winter precipitation falls as snow, but, since amounts are usually slight, it rarely accumulates to a depth of more than a foot."

The precipitation trends for the 1939 to 1990 study period show a moderate decline from 1939 to 1960, a sharp increase from 1960 to 1967, a flat period from 1967 to 1979, a decline from 1980 to 1985, an increase from 1985 to 1988, and the beginnings of perhaps a decline from 1988 through 1990.

The histogram shows a largely lognormal distribution with flat kurtosis, and a slight positive skewness formed by a single wet year. The monthly distribution has a moderate peak in July and August, followed by somewhat lesser precipitation in September and October. The period from November to June declines to the annual minimum.

Table 64. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Window Rock 4 SW, AZ
Station No.: 9410
Elevation: 6750
Latitude: 35d 37m
Longitude: 109d 07m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.09	0.51	0.68	1.37	1.36	0.98	1.10	0.12	0.00	1.07	1.41	1.91	10.60
1940	0.58	0.47	0.43	0.66	1.16	0.44	0.54	0.59	0.45	1.19	2.80	3.29	12.60
1941	1.00	0.95	2.23	1.51	1.77	1.94	2.02	3.02	0.35	1.32	3.04	2.80	21.95
1942	4.23	0.53	1.20	0.15	1.45	0.51	1.12	0.02	0.00	0.86	0.97	0.70	11.74
1943	1.66	0.05	1.41	0.50	0.10	0.88	0.43	0.22	0.63	1.33	1.98	0.94	10.13
1944	1.06	0.24	1.41	0.45	1.05	0.80	1.43	0.69	0.66	1.24	1.27	2.40	12.70
1945	0.71	0.95	1.34	0.78	0.40	1.21	0.21	0.03	0.16	5.57	4.48	0.34	16.18
1946	0.99	0.00	1.60	0.36	0.20	0.59	0.32	0.12	0.05	1.94	3.55	2.59	12.31
1947	0.58	1.08	0.51	0.98	0.09	0.18	0.02	1.12	0.27	0.82	4.09	1.46	11.20
1948	1.56	0.95	0.92	0.44	0.80	1.34	0.34	0.94	0.85	3.79	1.48	1.32	14.73
1949	2.06	0.00	1.23	1.49	0.55	0.70	0.66	1.10	1.17	3.25	0.98	1.00	14.19
1950	0.75	0.07	1.50	0.34	0.87	0.31	0.00	0.05	0.27	2.18	0.34	0.86	7.54
1951	0.00	0.04	0.06	1.18	0.55	0.41	0.76	0.21	0.04	1.17	1.97	0.53	6.92
1952	1.01	0.66	1.43	1.43	0.46	0.69	2.77	0.15	1.14	1.19	1.86	0.72	13.51
*1953	0.00	1.36	0.57	0.46	0.31	0.83	0.32	0.23	0.61	2.42	1.06	0.00	8.17
1954	0.84	0.38	0.51	0.82	0.24	1.68	0.13	0.74	0.12	2.77	1.12	1.88	11.23
1955	1.28	0.07	0.35	0.73	0.75	0.05	0.47	1.15	0.51	0.90	2.69	0.12	9.07
1956	0.00	0.30	0.82	0.84	0.21	0.04	0.14	0.36	0.10	2.67	1.55	0.00	7.03
1957	0.67	0.06	0.15	1.92	0.76	0.81	0.92	1.75	0.35	2.62	3.55	0.00	13.56
1958	2.21	1.08	0.34	0.22	0.62	1.41	0.55	1.10	0.25	0.71	2.41	1.36	12.26
1959	0.57	0.45	0.11	0.72	0.84	0.00	0.72	0.01	0.60	1.11	2.50	0.20	7.83
1960	1.65	0.67	1.86	0.98	0.87	0.57	0.05	0.34	0.04	0.25	0.95	0.28	8.51
1961	3.25	0.19	0.79	0.62	0.89	1.49	0.33	0.00	0.12	2.20	2.62	1.39	13.89
1962	2.56	0.88	1.63	0.99	1.13	0.40	0.00	0.06	0.05	0.29	1.02	2.67	11.68
1963	2.65	0.94	0.43	0.35	0.51	0.69	0.27	0.00	0.06	0.79	5.87	1.37	13.93
1964	0.87	0.50	0.24	0.20	0.59	0.58	1.04	0.07	0.00	2.94	5.54	3.36	15.93
1965	0.00	1.18	1.07	1.64	1.08	0.65	1.03	0.51	1.56	3.48	2.39	0.94	15.53
1966	0.67	1.16	2.70	0.25	0.54	0.32	0.33	0.01	0.28	2.00	1.59	1.23	11.08
1967	0.31	0.39	2.04	0.35	0.03	0.47	0.12	0.19	1.17	2.64	3.18	1.01	11.90
1968	0.04	0.34	1.81	0.16	0.69	1.39	1.34	0.14	0.28	1.11	4.73	0.16	12.19
1969	0.62	1.16	1.18	0.76	0.98	1.35	0.56	0.88	0.49	1.95	2.93	0.51	13.37
1970	2.47	0.52	0.44	0.21	0.25	1.86	0.62	0.06	0.56	1.02	2.77	2.48	13.26
1971	0.88	0.45	0.67	0.12	0.67	0.24	0.34	0.35	0.00	1.24	2.33	2.43	9.72
1972	1.78	0.76	1.64	0.05	0.05	0.01	0.10	0.24	1.83	0.68	1.76	1.49	10.39
1973	5.54	0.94	1.00	0.60	1.26	2.02	0.73	0.96	0.79	1.65	1.48	0.41	17.38
1974	0.36	0.69	0.07	1.44	0.39	0.19	0.44	0.00	0.18	2.90	0.17	1.92	8.75
1975	3.68	0.39	0.28	1.09	1.12	1.61	0.59	0.09	0.00	3.87	0.62	2.95	16.29
1976	0.00	0.80	0.81	0.19	0.80	0.13	0.54	0.70	0.17	2.72	0.97	0.71	8.54
1977	0.32	0.07	0.14	0.38	0.61	0.95	0.13	0.25	0.52	1.23	2.94	1.14	8.68
1978	0.49	1.05	0.31	0.51	0.96	1.64	0.28	1.67	0.00	1.12	1.24	1.10	10.37
1979	1.87	2.78	2.06	1.64	0.28	1.45	0.27	0.86	0.85	0.00	0.82	0.01	12.89
1980	0.92	0.94	0.61	2.10	1.70	1.17	0.37	0.53	0.00	0.27	0.60	1.89	11.10
1981	0.35	0.05	0.30	0.25	0.44	1.05	0.45	0.24	0.64	2.43	0.85	0.65	7.70
1982	1.60	3.27	0.00	0.74	1.24	1.45	0.21	0.41	0.00	2.42	4.02	1.88	17.24
1983	0.44	1.73	0.86	0.34	0.79	1.26	0.37	0.22	0.09	0.97	0.58	1.63	9.28
*1984	1.24	0.93	2.62	0.34	0.06	1.45	1.07	0.07	0.00	1.12	2.22	1.62	12.74
1985	2.95	0.17	1.09	1.07	0.15	1.13	2.66	0.55	0.00	1.92	0.89	2.48	15.06
1986	1.81	1.32	0.52	0.03	1.20	1.27	0.92	0.82	0.63	4.36	2.56	1.45	16.89
1987	0.38	2.93	0.51	1.22	0.88	0.60	0.43	0.10	0.42	3.10	1.83	0.16	12.56
1988	1.16	1.38	1.30	0.53	0.70	0.02	2.24	0.14	1.33	1.75	2.97	0.36	13.88
1989	0.26	0.88	0.25	1.13	0.77	0.36	0.00	0.03	0.27	1.60	0.51	0.43	6.49
1990	0.95	0.25	0.10	0.49	0.65	0.51	0.44	0.93	0.04	2.86	2.12	1.77	11.11
1939-90 Average	1.23	0.77	0.93	0.73	0.71	0.85	0.64	0.48	0.40	1.87	2.12	1.28	12.00

* Denotes year in which one or more monthly records are reconstructed.

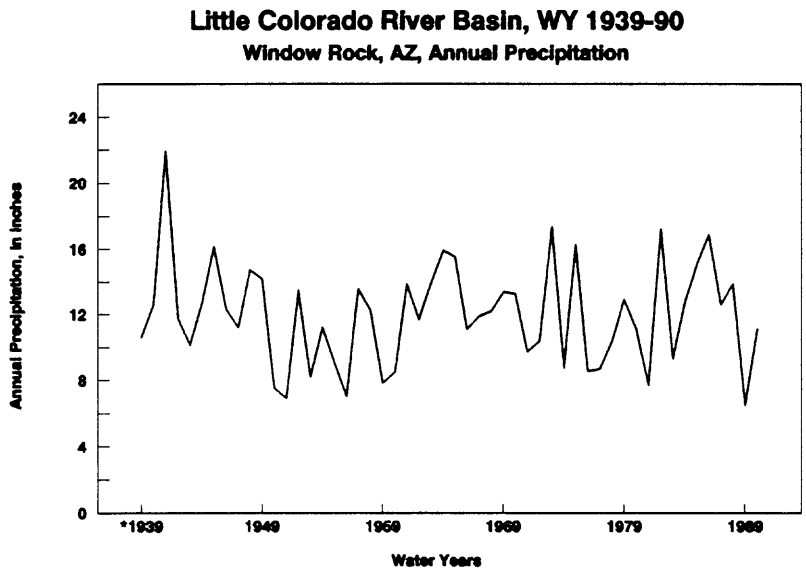


Figure 235. Window Rock, AZ, Annual Precipitation, WY 1939-90

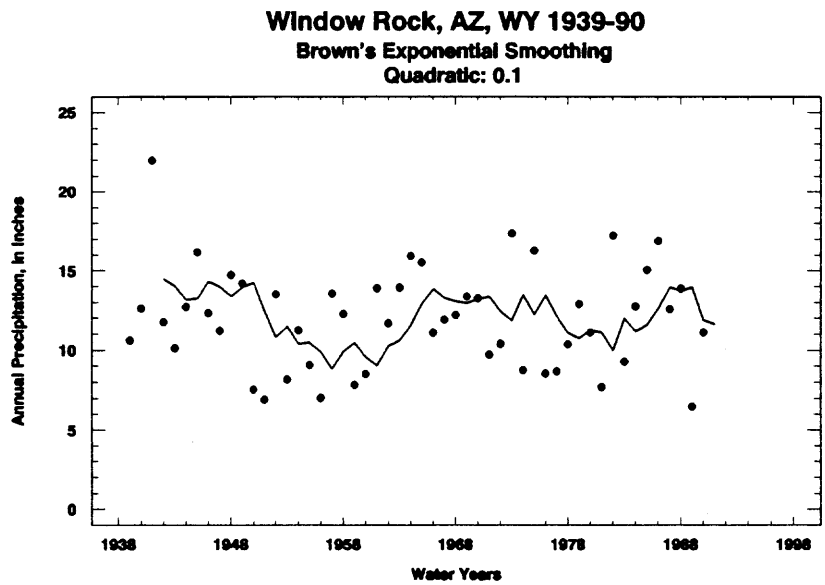


Figure 236. Window Rock, AZ, Smoothed Annual Precipitation, WY 1939-90

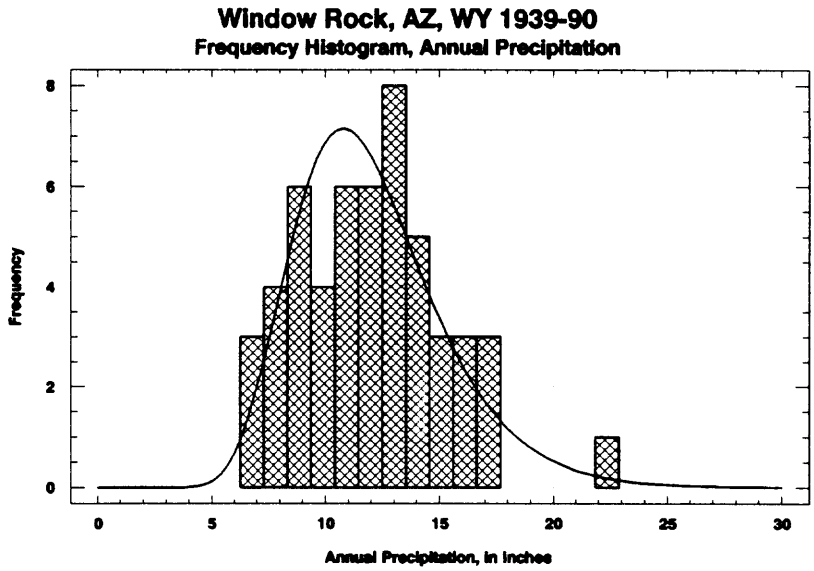


Figure 237. Window Rock, AZ, Histogram of Annual Precipitation

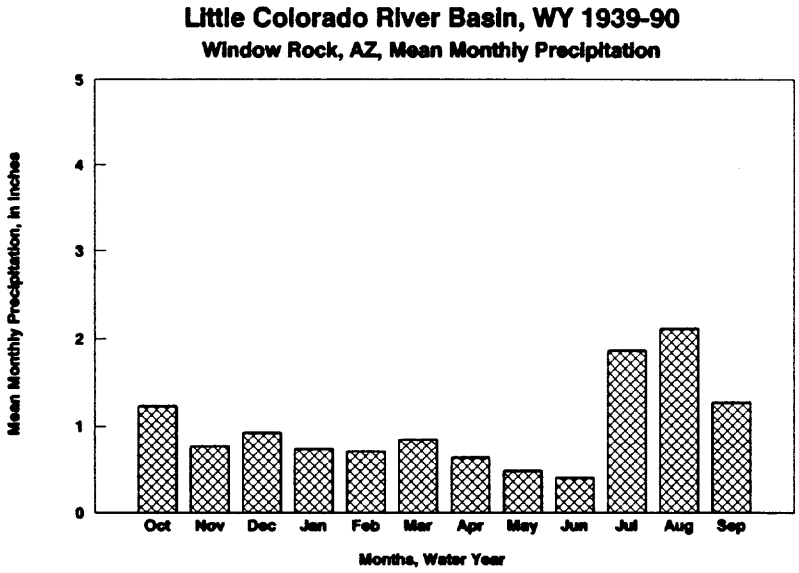


Figure 238. Window Rock, AZ, Monthly Distribution of Precipitation

6.2.3.52 Winslow, AZ

The period of record for Winslow is sporadic from 1888 to 1890, from 1892-83, from 1899 to 1901, from 1909 to 1912, and from 1915 to 1931. According to the Winslow Chamber of Commerce, the record from 1931 to 1948 is lost. From 1948 to the present, the record is continuous. Missing record from 1939 to 1948 is reconstructed.

As summarized in Sellars and Hill (1974, p. 570):

> "Winslow is located at an elevation of 4,900 feet in the Little Colorado River Valley of northeastern Arizona. It lies about two miles west of the northward flowing Little Colorado River. To the northeast, on the barren, but colorful, Colorado Plateau, are the Navajo and Hopi Indian Reservations. The famous Painted Desert lies about thirty miles to the northwest. Directly west of the Painted Desert and sixty miles from Winslow, majestic Humphreys Peak in the San Francisco Mountains rises to an elevation of 12,611 feet. Southwestward from these mountains stretches the forest-covered Mogollon Plateau. This plateau, with elevations in excess of 8,000 feet along its southern rim, extends along Winslow's southern horizon, at a distance of about fifty miles from the town. Sagebrush in the valleys and plains grass on the desert plateaus are the vegetation types commonly found near Winslow. Stands of pinyon and juniper are present on the higher mesas to the northeast and along the north side of the Mogollon Plateau. Yellow pine forests are found above 7,000 feet on this Plateau and in the San Francisco Mountains.
>
> "The effect of the Mogollon Plateau on the climate of Winslow and the Colorado Plateau cannot be underestimated. This massive barrier cuts off much of the flow of moist air from the west and south, with the result that the area receives only slightly more precipitation than the arid southwestern part of Arizona. More than half of Winslow's annual total of 7.37 inches falls in July, August, and September, when afternoon showers and thundershowers develop in moist air that has entered the state from the Gulf of Mexico. This air frequently moves over the lower eastern sections of the Mogollon Plateau and down the Little Colorado River Valley into Winslow. Showers are normally brief and light, rarely reaching the intensity of the storms experienced in southeastern Arizona. Occasionally longer-lasting, but still gentle, precipitation falls from deep layers of moist air brought into the area by the circulation around a tropical disturbance centered in the Pacific Ocean or the Gulf of California.
>
> "During the rest of the year, but particularly in May and June, Winslow receives very little precipitation, most months averaging about half an inch. In winter, cyclonic storms from the Pacific Ocean may successfully penetrate the mountain barrier to the west or move in from the north to give Winslow several hours of gentle showers, often preceeded and followed by strong winds. About half of the winter precipitation falls as snow, but this rarely stays on the ground for more than a few days, except on the protected north slopes. In December 1967, almost 40 inches of snow fell during a series of storms that isolated much of northeastern Arizona."

Precipitation trends for the WY 1939-90 study period show a gradual decline from 1939 to 1969, followed by an increase from 1970 to 1986. From 1987 to 1989 is flat, with the beginnings of a decline evident from 1989 to 1990.

The histogram show a classic lognormal distribution, with a peak at eight inches, and a few wet years providing a positive skewness. The monthly distribution is heaviest in July and August, followed by a drier September and October. From November to March there is a flat distribution followed by a decline from April to the annual minimum in June.

Table 65. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Winslow WSO AP, AZ
Station No.: 9439
Elevation: 4890
Latitude: 35d 01m
Longitude: 110d 44m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.03	0.05	0.00	0.50	0.13	0.46	0.59	0.05	0.05	0.09	0.87	0.56	3.38
*1940	0.14	0.66	0.26	0.33	0.57	0.28	0.87	0.09	1.06	1.12	1.39	2.37	9.13
*1941	1.15	0.76	1.66	1.48	0.61	1.61	1.78	0.92	0.46	1.42	2.10	1.93	15.90
*1942	1.56	0.46	0.64	0.35	0.35	0.07	1.02	0.00	0.00	0.46	0.97	0.49	6.35
*1943	1.52	0.17	0.40	0.41	0.31	0.49	0.00	0.29	0.00	0.58	1.33	1.37	6.87
*1944	0.46	0.00	1.04	0.24	0.77	0.74	1.01	0.59	0.00	0.47	0.80	1.28	7.39
*1945	0.05	0.64	0.53	0.31	0.16	0.02	0.13	0.03	0.14	2.09	0.92	0.11	5.13
*1946	0.30	0.00	0.58	0.50	0.07	0.38	0.02	0.04	0.00	1.52	2.11	2.02	7.54
*1947	0.00	0.62	0.07	0.12	0.00	0.00	0.01	0.91	0.09	0.49	2.98	0.61	5.89
*1948	2.72	1.05	0.48	0.58	0.58	0.56	0.02	0.03	0.27	0.43	1.99	0.17	8.88
1949	0.37	0.00	0.66	1.10	0.52	0.34	0.16	0.31	1.54	0.77	0.58	2.02	8.37
1950	0.63	0.27	0.60	0.01	0.55	0.15	0.00	0.06	0.00	2.72	0.59	0.72	6.30
1951	0.00	0.04	0.07	0.45	0.03	0.29	1.18	0.47	0.00	0.86	1.79	0.15	5.33
1952	0.69	0.41	0.64	0.82	0.31	0.85	0.97	0.00	0.06	1.50	2.20	1.06	9.51
1953	0.00	1.67	0.19	0.00	0.14	0.07	0.76	0.01	0.00	1.99	2.31	0.00	7.14
1954	0.00	0.32	0.54	0.28	0.24	0.58	0.12	0.13	0.51	2.50	0.60	1.45	7.27
1955	0.35	0.06	0.13	0.34	0.01	0.14	0.20	0.30	2.12	1.05	2.30	0.00	7.00
1956	0.02	0.08	0.38	0.64	1.01	0.21	0.42	0.20	0.37	1.55	1.04	0.01	5.93
1957	0.21	0.09	0.00	1.06	0.66	1.13	0.17	0.48	0.22	2.26	2.18	0.00	8.46
1958	2.45	0.26	0.01	0.04	0.59	0.87	0.56	0.26	0.23	0.17	1.24	2.40	9.08
1959	0.32	0.35	0.02	0.09	0.42	0.00	0.28	0.62	0.36	0.98	1.08	0.23	4.75
1960	1.83	0.39	1.50	0.64	0.33	0.36	0.23	0.50	0.09	0.94	0.53	0.44	7.78
1961	1.55	0.17	1.12	0.00	0.40	0.86	0.18	0.04	0.00	0.65	2.29	1.49	8.75
1962	0.85	0.41	0.76	0.83	0.58	0.48	0.00	0.08	0.14	0.05	0.74	0.87	5.79
1963	1.66	1.07	0.05	0.52	0.75	0.38	0.30	0.00	0.02	0.15	4.80	1.16	10.86
1964	1.05	0.36	0.31	0.03	0.14	0.49	0.27	0.04	0.17	1.63	2.81	1.36	8.66
1965	0.04	0.33	0.37	1.42	0.45	0.97	0.44	0.92	0.33	1.47	0.70	0.91	8.35
1966	0.16	0.30	1.45	0.68	0.66	0.26	0.12	0.00	0.32	1.34	0.96	0.98	7.23
1967	0.97	0.75	0.26	0.10	0.01	0.24	0.10	0.27	1.06	2.67	1.09	0.49	8.01
1968	0.11	0.36	3.73	0.00	0.27	0.56	0.50	0.03	0.12	0.83	0.15	0.23	6.89
1969	0.70	0.70	0.45	0.12	0.66	0.45	0.09	1.22	0.00	1.16	0.83	0.26	6.64
1970	0.40	0.36	0.40	0.27	0.07	0.70	0.23	0.00	0.02	0.57	1.80	0.96	5.78
1971	0.25	0.11	0.13	0.07	0.25	0.00	0.52	0.07	0.00	0.20	1.40	1.74	4.74
1972	0.97	0.06	0.95	0.00	0.00	0.00	0.02	0.02	3.22	1.20	0.72	0.15	7.31
1973	5.61	0.58	0.73	0.23	2.05	2.07	0.11	0.09	0.31	0.38	1.40	0.07	13.63
1974	0.00	0.88	0.05	0.84	0.03	0.15	0.02	0.00	0.00	0.58	0.69	1.68	4.92
1975	3.41	0.12	0.29	0.41	0.42	0.73	0.29	0.35	0.00	1.27	0.59	2.54	10.42
1976	0.00	0.38	0.68	0.09	0.45	0.19	0.19	1.14	0.15	1.55	0.90	1.11	6.83
1977	0.40	0.27	0.38	0.36	0.69	0.21	0.48	0.00	0.23	2.05	2.19	1.95	9.21
1978	0.83	0.05	0.13	0.36	0.70	0.93	0.07	0.46	0.27	0.80	0.30	0.41	5.31
1979	1.70	1.36	1.02	1.03	0.18	0.36	0.36	1.39	0.04	0.24	1.47	0.06	9.21
1980	0.28	0.18	0.54	1.18	1.36	0.78	0.45	0.03	0.17	1.71	1.29	0.64	8.61
1981	0.22	0.00	0.23	0.68	0.15	0.30	0.29	0.70	0.80	1.71	1.80	0.53	7.41
1982	1.11	0.75	0.00	1.18	0.83	0.33	0.11	1.27	0.00	2.07	2.69	0.69	11.03
1983	0.00	1.54	1.40	0.35	0.46	0.79	0.18	0.07	0.01	1.09	1.39	2.37	9.65
1984	0.69	0.49	0.77	0.00	0.21	1.20	0.08	0.05	0.03	2.32	1.53	1.96	9.33
1985	1.16	0.31	1.59	0.47	0.51	1.13	0.71	0.17	0.00	1.65	1.25	0.96	9.91
1986	1.37	0.91	0.44	0.02	0.75	0.80	0.16	0.04	0.33	2.32	0.42	0.55	8.11
1987	1.14	1.28	0.56	1.21	0.86	0.38	0.00	0.54	0.29	0.50	1.88	0.15	8.79
1988	1.29	1.39	1.28	0.24	0.82	0.00	1.28	0.09	1.30	0.64	1.47	0.04	9.84
1989	0.61	0.70	0.09	0.59	0.28	0.43	0.00	0.11	0.00	0.55	1.73	0.09	5.18
1990	0.26	0.00	0.41	0.11	0.68	0.25	0.16	0.15	0.02	1.64	0.48	0.88	5.04
1939-90 Average	0.84	0.47	0.60	0.46	0.46	0.50	0.35	0.30	0.33	1.17	1.42	0.90	7.78

* Denotes year in which one or more monthly records are reconstructed.

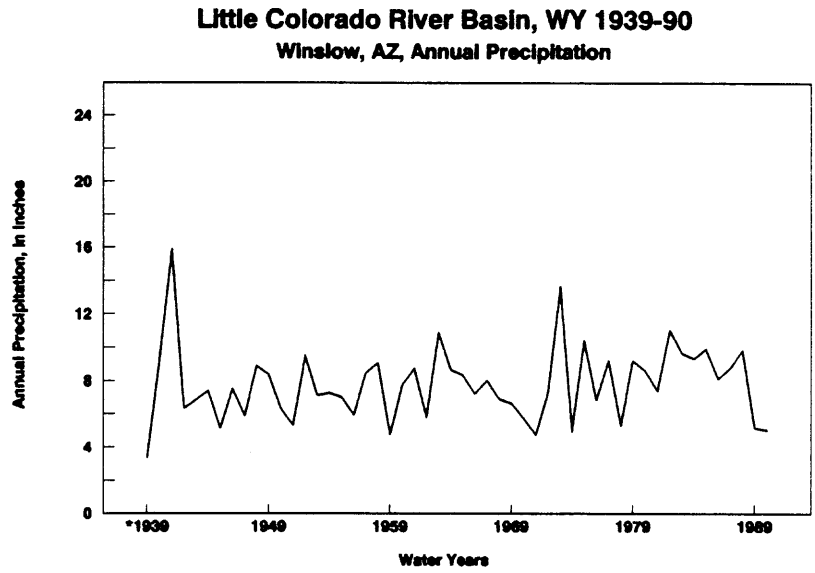


Figure 239. Winslow, AZ, Annual Precipitation, WY 1939-90

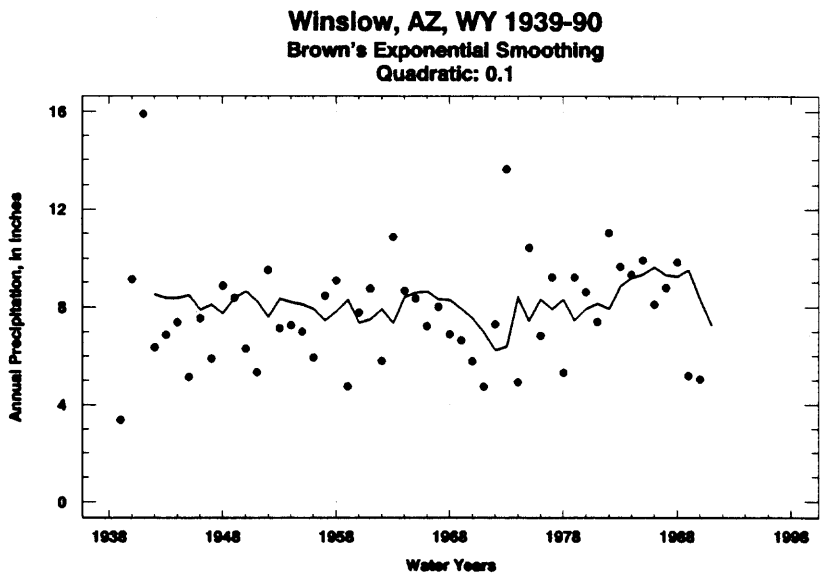


Figure 240. Winslow, AZ, Smoothed Annual Precxipitation WY 1939-90

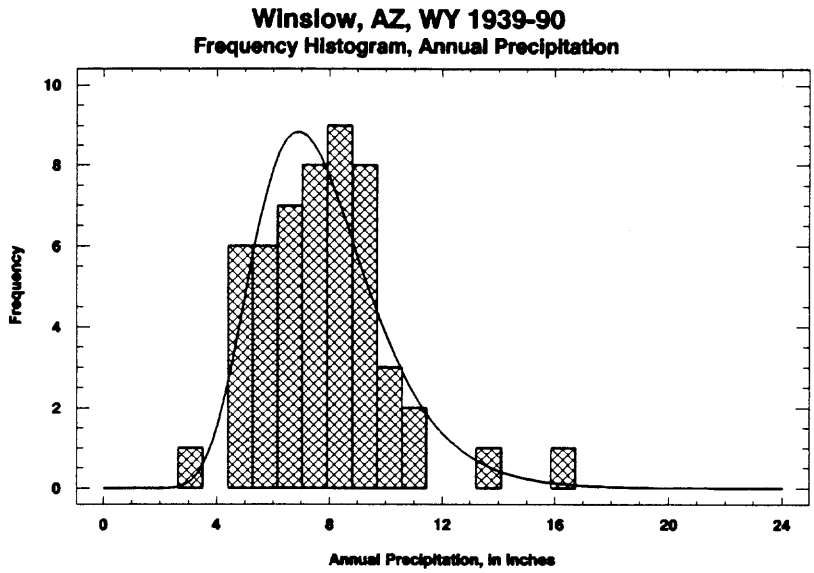


Figure 241. Winslow, AZ, Histogram of Annual Precipitation

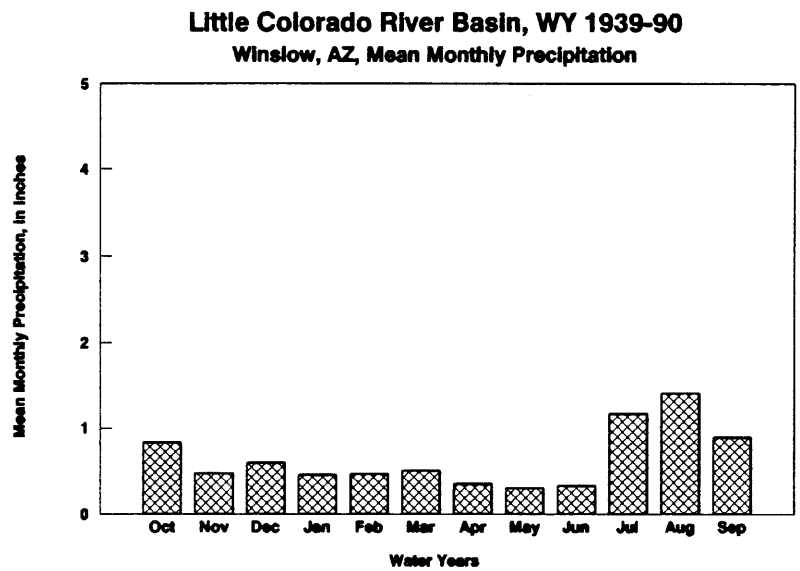


Figure 242. Winslow, AZ, Monthly Distribution of Precipitation

6.2.3.53 Wupatki National Monument, AZ

The period of record for Wupatki National Monument extends from 1940 to 1944 sporadically, and continuously from 1946 through the present, except for several missing months. The record from 1939, 1940-44, and the missing months since 1946 have been reconstructed.

As summarized in Sellars and Hill (1974, p. 574):

"Wupatki National Monument, at an elevation of about 4,900 feet, is located twenty-eight miles northeast of Flagstaff in the arid country of north-central Arizona. It lies along the sagebrush-dominated western extremity of the Little Colorado River Valley, seven miles west of the river itself. Across the Little Colorado River and about fifteen miles east of the Wupatki National Monument is found the multicolored Painted Desert which extends along the River to the northwest and southeast. The terrain to the northwest rises into the pinyon and juniper-covered 7,000 foot Coconino Plateau. Forty miles to the south, the lake-studded Coconino National Forest features picturesque forests of yellow pine. The highest elevation in the state is found in the San Francisco Mountains on Humphreys Peak, towering to an impressive 12,670 feet, twenty miles to the southwest of the monument. Flagstaff is located ten miles south-southwest of Humphreys Peak in the middle of the largest standing forest of ponderosa pine in the United States. The Wupatki National Monument contains the excavated ruins of an antiquated, although once highly developed agricultural community that flourished in the late twelfth and early thirteenth centuries. Sunset Crater, a one thousand-foot volcanic cinder cone which blew its top in 1068 and blanketed the land with volcanic ash for miles around, is located thirteen miles to the southeast, and is another of the numerous sites that attract thousands of visitors to this beautiful and refreshing region of northern Arizona.

"A desert climate exists at the Wupatki National Monument, with an average of slightly less than seven and one-half inches of precipitation falling annually. Almost fifty-five percent of this normally occurs during July, August, and September when moist, tropical air from the Gulf of Mexico rises over the strongly heated desert terrain, initiating cumulonimbus development. Thunderstorms are typically most numerous and intense on the windward side of the San Francisco Mountains and in the high elevation regions to the south. They produce relatively gentle rains when they move northward into the valley of the Little Colorado River. Longer-lasting, but still gentle, rains at the Wupatki National Monument may result from deep currents of moist air circulating around a disturbance centered in the Gulf of California or the Pacific Ocean.

"Unlike most locations in Arizona, winter precipitation at the Wupatki National Monument is almost as sparse as the minimal amounts that fall in the spring. During the eight-month period November to June, monthly precipitation averages close to 0.35 inches. The normal total for January and February is 0.68 inches, precisely the same as that for the May-June period. Both the San Francisco Mountains and the Coconino Plateau have a marked effect on the winter climate at the Wupatki National Monument. When middle latitude storms that form on the Pacific Ocean travel sufficiently far south to influence Arizona before moving eastward across the continent, some of the associated moisture is lost over the slopes of the San Francisco Range and since the prevailing winter airflow is upslope, significant amounts of rain are precipitated over the Coconino Plateau. About half of the winter precipitation falls as snow, although this rarely amounts to more than ten inches."

The precipitation trends for the study period indicate a gradual decline from 1939 to 1969, followed by a gradual increase from 1969 to 1987. From 1988 through 1990, there is an indication of another decline.

The histogram shows a definite lognormal distribution with a sharp peak at seven inches. There is moderate kurtosis and a positive skewness due to several wetter years. The monthly distribution indicates a strong peak in July and August, declining in September and October. From November through June, there is a gradual decline to the annual minimum.

Table 66. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Wupatki National Monument, AZ
Station No.: 9542
Elevation: 4907
Latitude: 35d 31m
Longitude: 111d 22m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
*1939	0.27	0.25	0.77	0.34	0.65	0.22	0.37	0.13	0.03	0.01	1.73	1.07	5.84
1940	0.00	0.83	0.00	0.44	0.63	0.18	0.53	0.11	0.73	1.28	0.62	2.41	7.76
1941	1.83	0.90	0.82	0.72	0.34	0.55	0.81	0.94	0.40	2.17	1.08	1.52	12.08
1942	1.71	0.48	0.32	0.69	0.47	0.07	0.22	0.00	0.00	1.81	1.24	0.37	7.38
*1943	0.54	0.04	0.43	1.29	0.52	0.99	0.05	0.01	0.02	1.12	2.44	1.37	8.82
*1944	0.49	0.00	1.37	0.77	1.39	1.15	0.55	0.81	0.00	0.47	0.63	0.35	7.98
*1945	0.11	1.20	0.99	1.09	0.25	1.68	0.36	0.00	0.14	3.00	0.80	0.13	9.76
*1946	0.39	0.02	1.03	0.53	0.03	0.00	0.63	0.04	0.00	1.41	2.71	0.45	7.25
1947	0.24	0.26	0.16	0.15	0.00	0.00	0.00	0.99	0.00	0.55	1.68	0.24	4.27
1948	1.73	0.24	0.43	0.04	0.47	0.34	0.13	0.06	0.22	1.61	2.22	0.41	7.90
1949	0.39	0.00	0.93	1.22	0.19	0.18	0.28	0.81	0.65	2.39	1.61	0.80	9.45
1950	0.76	0.15	0.45	0.00	0.59	0.20	0.09	0.11	0.22	3.04	0.92	0.80	7.33
*1951	0.00	0.00	0.00	0.24	0.19	0.27	0.45	0.95	0.00	0.55	2.01	0.08	4.74
1952	0.52	0.38	0.71	0.65	0.42	0.25	0.95	0.00	0.15	1.23	2.41	2.17	9.84
1953	0.00	1.09	0.27	0.01	0.38	0.32	0.15	0.00	0.00	2.18	1.83	0.00	6.23
1954	0.20	0.46	0.17	0.23	0.00	0.40	0.06	0.15	1.05	1.68	1.89	2.11	8.40
1955	0.67	0.00	0.02	0.34	0.23	0.00	0.00	0.05	2.95	1.00	2.49	0.00	7.75
1956	0.00	0.14	0.00	0.75	0.65	0.32	0.56	0.13	0.38	1.26	0.48	0.22	4.89
1957	0.11	0.03	0.00	0.61	0.48	1.00	0.28	1.07	0.31	3.05	2.24	0.00	9.18
1958	1.77	0.75	0.00	0.06	0.73	1.04	0.33	0.43	0.20	1.10	1.32	3.16	10.89
1959	0.52	0.13	0.10	0.05	1.18	0.01	0.14	0.56	0.04	1.58	1.50	0.10	5.91
1960	1.34	0.18	0.82	0.35	0.35	0.39	0.13	0.45	0.30	0.53	1.11	0.53	6.48
1961	2.09	0.66	0.57	0.11	0.07	1.53	0.11	0.00	0.07	0.78	1.80	0.74	8.53
1962	0.37	0.38	0.65	0.91	0.52	0.04	0.00	0.25	0.30	0.69	0.68	0.66	5.45
1963	0.70	0.46	0.52	0.15	0.28	0.06	0.06	0.01	0.00	0.25	3.03	0.76	6.28
1964	0.57	0.27	0.09	0.01	0.17	0.23	0.64	0.41	0.44	1.53	2.11	0.64	7.11
1965	0.00	0.28	0.22	0.79	0.17	0.42	0.65	0.78	0.25	2.15	0.75	1.14	7.60
1966	0.05	0.45	0.93	0.51	0.52	0.33	0.00	0.82	0.14	1.78	2.40	0.66	8.59
1967	0.26	0.29	0.97	0.00	0.00	0.00	0.10	0.11	0.94	1.44	1.78	1.21	7.10
1968	0.00	0.09	2.57	0.00	0.00	0.14	0.17	0.07	0.03	2.50	0.62	0.00	6.19
1969	0.52	0.17	0.38	0.13	0.51	1.13	0.00	0.97	0.15	0.60	1.45	0.83	6.84
1970	1.26	0.12	0.28	0.00	0.10	2.87	0.01	0.00	0.15	2.06	1.91	0.54	9.30
1971	0.31	0.18	0.28	0.01	0.32	0.00	0.40	0.00	0.00	0.40	4.02	1.44	7.36
1972	1.39	0.13	1.05	0.00	0.01	0.00	0.02	0.00	1.92	1.96	0.60	0.26	7.34
*1973	7.85	0.16	0.20	2.42	1.59	0.31	0.87	0.11	0.74	1.70	0.00	0.13	16.08
1974	0.00	0.52	0.04	1.11	0.02	0.30	0.14	0.00	0.00	1.16	0.76	0.68	4.73
1975	0.68	0.48	0.25	0.19	0.44	1.66	0.27	0.34	0.13	1.13	0.79	0.85	7.21
1976	0.01	0.59	0.47	0.02	0.46	0.38	0.42	0.42	0.00	2.54	0.24	2.60	8.15
1977	0.45	0.13	0.17	0.62	0.36	0.15	0.37	0.01	0.45	2.73	3.00	0.51	8.95
1978	0.50	0.31	0.41	0.52	1.67	1.59	0.10	0.02	0.01	0.67	0.42	1.33	7.55
1979	1.32	3.65	0.44	1.32	0.36	0.32	0.03	1.59	0.34	0.57	2.09	0.03	12.06
1980	0.59	0.54	0.62	0.89	1.50	0.94	0.36	0.16	0.15	1.94	0.99	0.41	9.09
1981	0.09	0.00	0.26	0.44	0.30	0.52	0.45	0.37	0.91	0.95	2.57	2.12	8.98
1982	0.69	0.95	0.00	0.96	0.27	0.29	0.42	1.96	0.00	0.60	2.21	0.26	8.61
1983	0.00	1.09	1.43	0.03	0.35	1.76	0.20	0.12	0.02	3.75	2.17	3.86	14.78
1984	0.81	0.23	0.51	0.09	0.04	1.11	0.06	0.03	0.03	1.93	2.35	0.92	8.11
*1985	0.27	0.88	1.12	1.53	0.54	0.99	1.32	0.52	0.45	0.75	0.42	1.09	9.88
1986	0.54	3.23	0.02	0.00	0.58	0.91	0.28	0.11	0.27	2.55	4.02	0.32	12.83
1987	1.15	1.68	1.47	1.84	1.42	0.38	0.14	0.25	0.40	0.54	2.00	0.11	11.38
1988	0.97	1.49	1.24	0.27	0.61	0.03	1.71	0.07	0.69	1.06	2.90	0.10	11.14
1989	0.17	0.45	0.03	1.40	0.11	0.11	0.00	0.31	0.00	0.66	1.06	0.03	4.33
*1990	0.05	0.00	0.25	0.96	0.21	0.00	0.87	0.12	0.30	1.35	0.20	1.41	5.72
1939-90 Average	0.72	0.53	0.52	0.53	0.45	0.54	0.33	0.34	0.33	1.46	1.62	0.84	8.22

* Denotes year in which one or more monthly records are reconstructed.

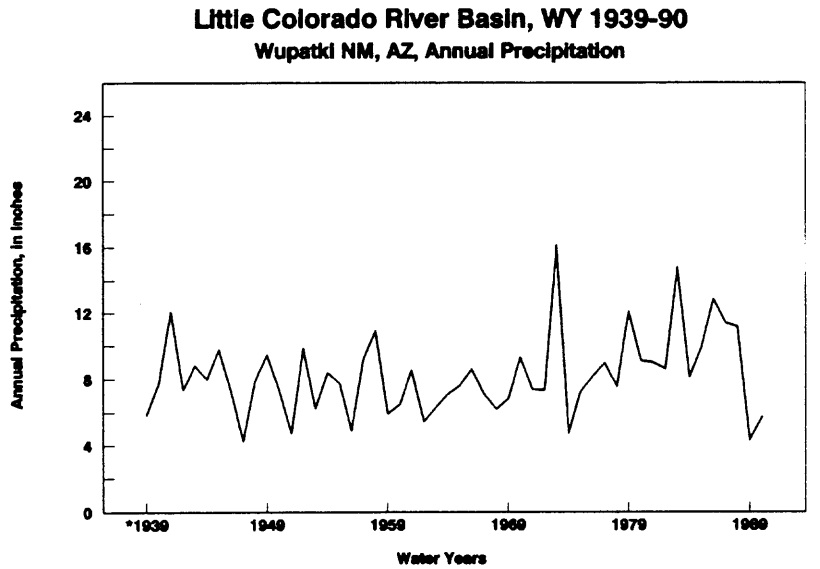


Figure 243. Wupatki NM, AZ, Annual Precipitation, WY 1939-90

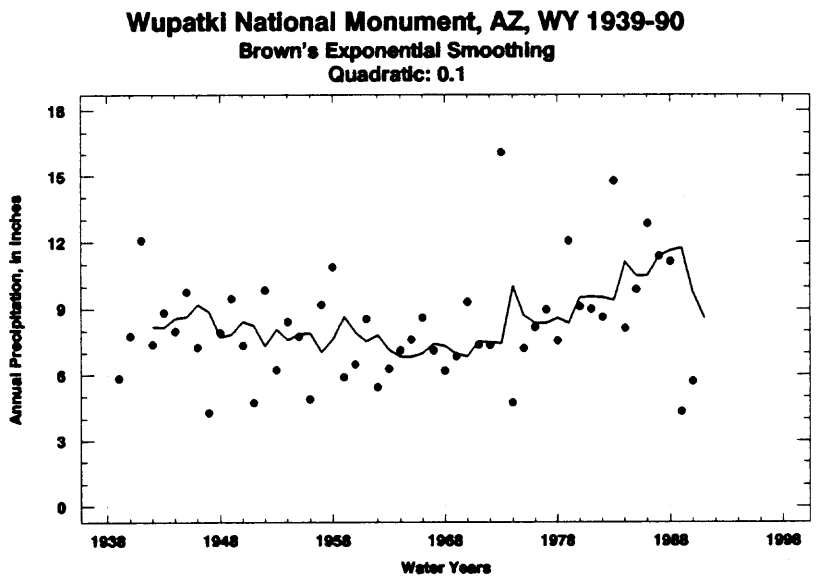


Figure 244. Wupatki NM, AZ, Smoothed Annual Precipitation, WY 1939-90

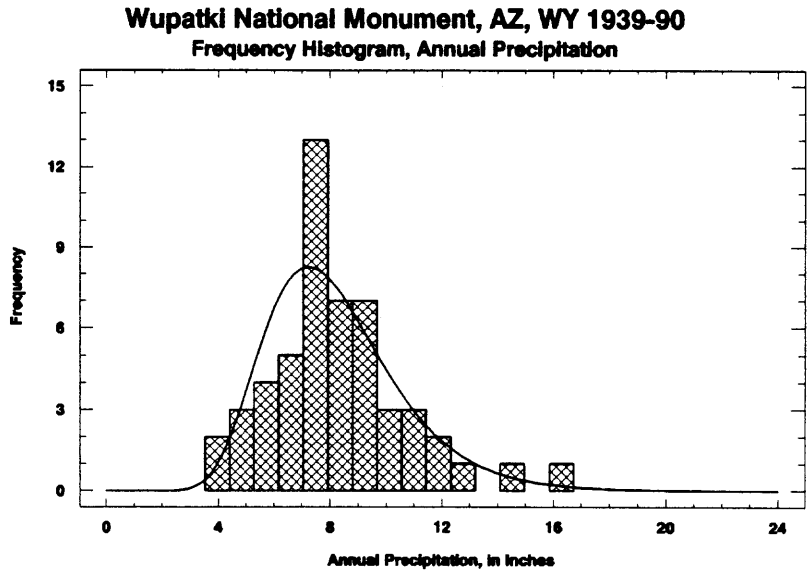


Figure 245. Wupatki NM, AZ, Histogram of Annual Precipitation

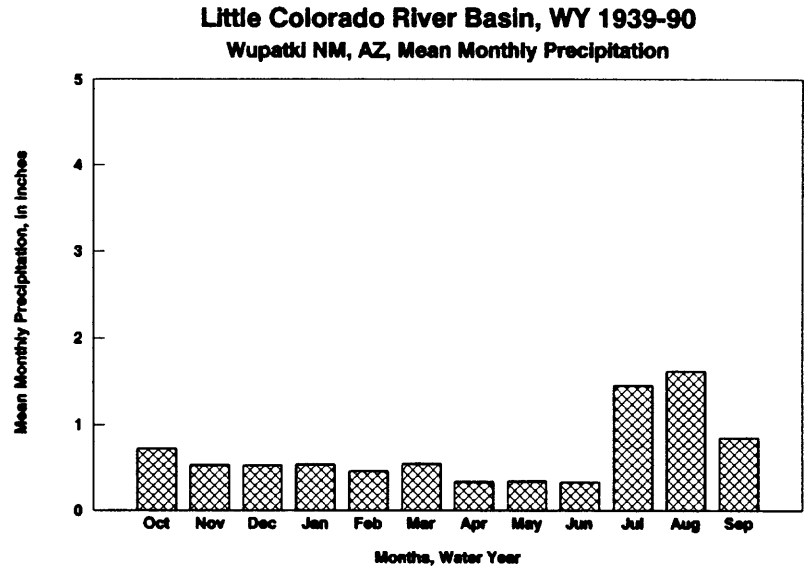


Figure 246. Wupatki NM, AZ, Monthly Distribution of Precipitation

6.2.3.54 Zuni, NM

This station is located at an elevation of 6,450 feet in east-central New Mexico, on the north bank of the westward flowing Zuni River near the Zuni Pueblo. The period of record is sporadic from 1908 to 1915 and mostly continuous from 1915 to the present, with 1973-75 and some other months missing. The record from 1939 to 1990 is reconstructed for the missing years and months.

Precipitation trends for the 1939-90 study period indicate two major cycles, one from 1939 (maximum) declining through 1952 (minimum) and increasing again to 1968 (maximum), then declining from 1968 to 1977 (minimum), and increasing once more to 1988 (maximum). The period from 1989 to 1990 indicates the beginnings of another decline.

The histogram shows a bimodal trend, with maxima at ten and thirteen inches. The distribution is slightly positively skewed, due to several wet years. The monthly distribution shows a maximum in July and August, slightly less in September and October, followed by a slow decline from November to the annual minimum in June.

Table 67. The Hopi Tribe
Little Colorado River Study - Precipitation, Reconstructed Data
Station Name: Zuni, NM
Station No.: 9897
Elevation: 6450
Latitude: 35d 04m
Longitude: 108d 50m W

Wtr Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0.21	0.05	0.51	0.99	0.81	0.27	0.88	0.02	0.00	0.75	0.66	1.39	6.54
1940	0.54	1.13	0.40	1.02	1.54	0.93	0.81	0.49	0.67	1.00	2.09	2.89	13.51
1941	1.46	1.64	2.72	2.14	1.69	3.01	1.86	1.19	0.35	1.09	1.16	3.34	21.65
1942	2.06	0.85	0.79	0.70	0.93	0.64	0.71	0.00	0.00	0.99	1.59	1.26	10.52
1943	1.32	0.17	1.29	0.73	0.26	1.02	0.48	0.48	1.17	1.02	1.64	0.54	10.12
1944	1.26	0.00	0.78	0.32	0.74	0.39	0.26	0.49	0.06	1.62	1.89	1.48	9.29
1945	0.75	1.00	0.43	0.73	0.37	1.04	0.17	0.00	0.10	1.53	2.27	0.05	8.44
*1946	0.98	0.00	1.39	0.69	0.18	0.41	0.19	0.00	0.00	1.07	3.60	1.82	10.33
*1947	0.46	1.16	0.39	0.51	0.29	0.08	0.12	1.40	0.52	1.43	4.72	0.36	11.44
*1948	1.24	0.62	0.53	0.30	1.17	1.57	0.30	0.34	0.64	1.27	0.73	1.49	10.20
1949	1.55	0.10	1.14	1.63	0.43	0.77	0.50	0.11	1.21	2.14	1.22	1.42	12.22
1950	1.05	0.12	0.62	0.86	0.56	0.42	0.02	0.00	0.18	1.39	0.07	0.74	6.03
1951	0.00	0.06	0.11	1.29	0.17	0.08	0.83	0.12	0.00	0.88	1.70	0.40	5.64
1952	0.60	0.56	1.04	0.99	0.61	0.59	2.01	0.17	1.16	1.54	2.67	0.88	12.82
1953	0.00	1.84	0.19	0.16	0.24	0.77	0.63	0.35	0.31	0.57	0.73	0.00	5.79
1954	0.59	0.44	0.45	0.23	0.29	2.57	0.30	0.88	0.09	2.12	0.63	1.48	10.07
1955	0.44	0.17	0.56	1.44	0.70	0.03	0.26	0.20	0.00	2.65	2.64	0.02	9.11
1956	0.00	0.01	0.36	2.31	0.56	0.04	0.44	0.05	0.01	3.30	0.82	0.02	7.92
1957	0.42	0.05	0.44	1.68	1.35	1.17	0.63	1.22	0.72	3.73	1.86	0.00	13.27
1958	2.62	0.83	0.50	0.33	0.68	1.09	0.60	0.16	0.29	0.92	2.33	2.54	12.89
1959	0.77	0.71	0.09	0.19	0.26	0.08	0.54	0.08	0.13	1.62	2.42	0.26	7.15
1960	2.75	0.32	1.59	0.68	0.60	0.63	0.27	0.48	0.62	0.79	0.35	0.86	9.94
1961	3.14	0.41	0.39	0.95	0.27	1.46	0.26	0.09	0.14	1.90	3.02	0.73	12.76
1962	2.46	0.34	0.81	0.98	0.85	0.35	0.48	0.03	0.05	0.57	0.58	2.19	9.69
1963	3.24	1.54	0.37	0.25	1.43	0.58	0.15	0.06	0.00	0.66	5.53	1.24	15.05
1964	2.02	1.31	0.17	0.43	0.73	0.62	0.93	0.03	0.00	3.19	2.77	1.30	13.50
1965	0.11	0.82	1.13	1.09	0.98	0.59	0.85	0.61	1.40	3.57	1.78	0.59	13.52
1966	0.64	1.03	1.90	0.33	0.58	0.40	0.83	0.00	0.04	1.47	2.75	3.21	13.18
1967	0.11	0.58	1.59	0.43	0.08	0.52	0.24	0.24	0.72	3.17	4.09	2.33	14.10
1968	0.53	0.54	1.95	0.70	0.82	2.21	1.53	0.43	0.25	2.57	3.11	0.32	14.96
1969	0.76	1.30	1.74	1.89	0.97	2.57	0.35	1.38	0.11	2.75	1.77	2.06	17.65
1970	1.75	0.96	0.47	0.64	0.78	1.54	0.79	0.11	0.82	1.77	1.37	1.84	12.84
1971	0.91	0.32	1.11	0.22	0.62	0.19	0.41	0.02	0.00	0.97	3.71	3.34	11.82
1972	1.60	0.70	1.11	0.06	0.02	0.00	0.18	0.47	1.51	0.93	0.82	0.72	8.12
*1973	6.65	1.31	1.21	0.33	0.72	1.09	0.01	1.25	0.66	3.17	0.82	0.43	17.66
*1974	0.30	0.27	0.01	1.00	0.17	0.00	0.25	0.00	0.05	1.54	0.77	1.03	5.39
*1975	2.66	0.29	0.13	0.36	0.98	0.59	0.82	0.09	0.00	1.89	0.92	2.79	11.51
1976	0.18	0.12	0.66	0.10	0.39	1.07	0.27	0.42	0.04	3.57	1.08	0.71	8.61
1977	0.76	0.10	0.67	0.87	0.08	0.10	0.16	0.15	0.21	1.66	4.13	1.27	10.16
1978	0.51	0.85	0.41	1.88	1.49	2.21	0.13	0.67	0.00	0.90	0.61	0.44	10.10
1979	0.47	1.46	1.48	1.85	0.63	0.84	0.14	1.94	0.14	1.32	1.45	0.03	11.75
1980	0.90	1.14	1.24	2.55	2.74	0.45	0.17	0.25	0.00	0.68	1.01	0.48	11.61
1981	0.34	0.00	1.03	0.31	0.79	3.27	0.70	0.47	0.32	2.99	2.28	1.39	13.89
1982	0.93	0.10	0.00	0.64	1.32	0.64	0.00	0.71	0.00	2.30	5.22	1.93	13.79
1983	0.30	0.99	1.45	1.21	0.67	1.50	1.27	0.43	0.26	3.53	2.79	1.26	15.66
1984	1.19	1.01	1.19	0.06	0.01	1.05	1.07	0.07	0.11	1.74	1.95	4.64	14.09
1985	1.82	0.44	1.85	1.29	0.52	1.59	2.04	0.09	0.15	2.29	0.17	1.24	13.49
1986	0.65	1.14	0.09	0.00	0.72	1.37	0.91	0.38	0.78	2.68	3.34	1.35	13.41
1987	1.72	2.54	1.91	1.08	1.40	0.30	0.66	0.66	1.64	2.98	1.91	0.34	17.14
1988	0.98	1.93	0.88	0.81	0.70	0.00	2.48	0.35	1.21	1.13	5.90	1.37	17.74
1989	0.07	0.63	0.06	1.09	0.42	0.03	0.00	0.19	0.00	2.95	1.75	0.11	7.30
1990	1.25	0.07	0.03	0.31	0.42	1.06	0.51	1.12	0.23	0.72	2.36	2.26	10.34
1939-90 Average	1.15	0.69	0.83	0.84	0.71	0.88	0.60	0.40	0.37	1.83	2.07	1.27	11.65

* Denotes year in which one or more monthly records are reconstructed.

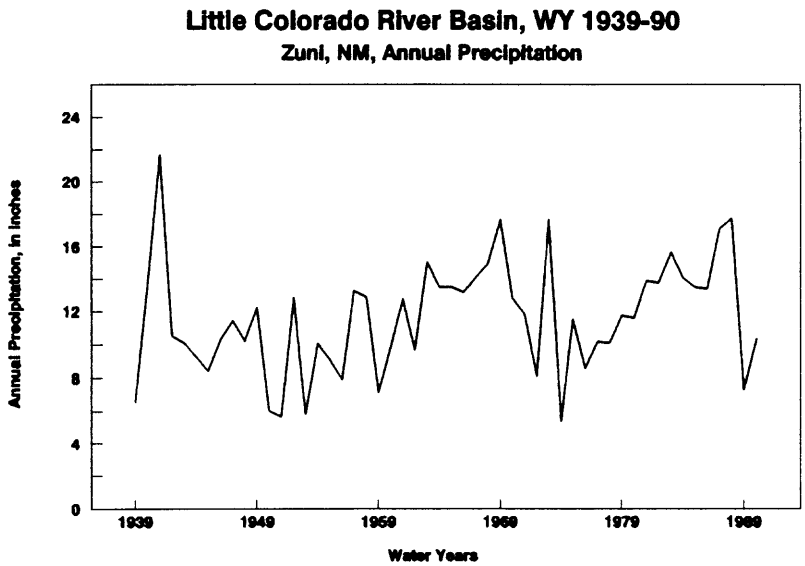


Figure 247. Zuni, NM, Annual Precipitation, WY 1939-90

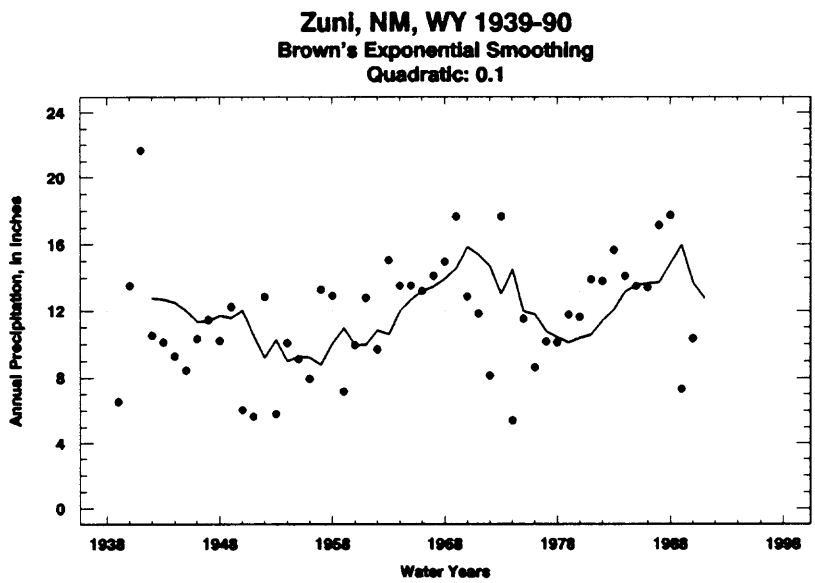


Figure 248. Zuni, NM. Smoothed Annual Precipitation, WY 1939-90

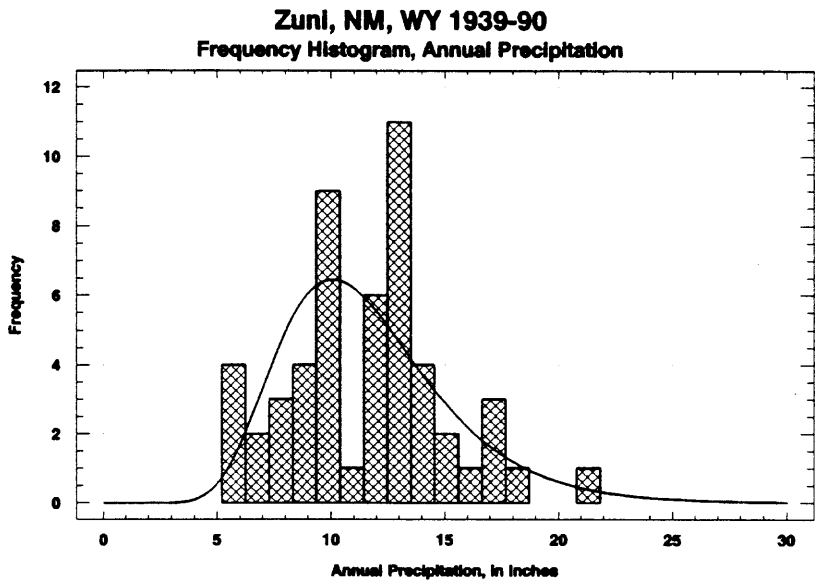


Figure 249. Zuni, NM, Histogram of Annual Precipitation

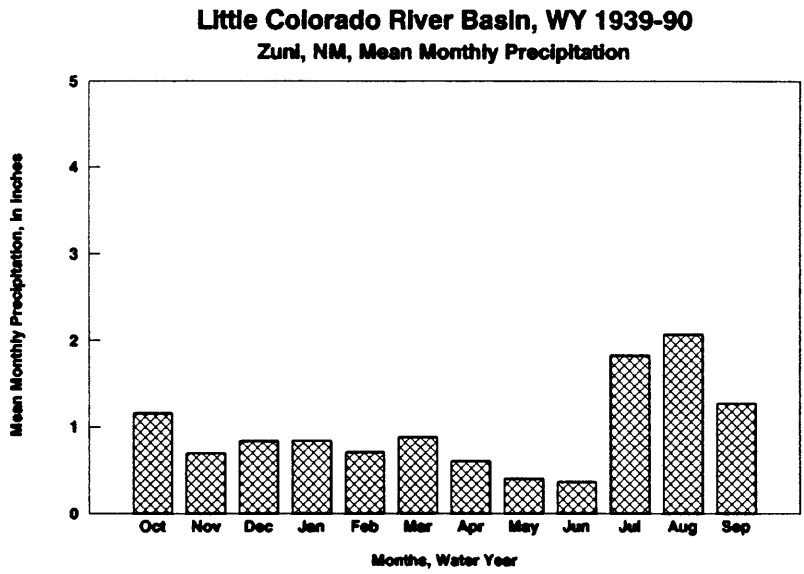


Figure 250. Zuni, NM, Monthly Distribution of Precipitation

6.2.4 Long-Term Records and Trends

This section evaluates three long-term precipitation station records (Fort Defiance, Flagstaff, and Fort Wingate) for intermediate term trends and summary statistics. These are stations located in the LCR Basin whose periods of record greatly exceed that of the 1939-90 study period. These stations are described more fully in the preceeding section (6.2.3) in terms of elevation, climate for study period, and location.

The mode, standard deviation, skewness, and kurtosis are particularly suitable for comparing the climate of the stations. The mode indicates the most frequent annual precipitation for the period of record, the standard deviation is a scale-independent measure of the variability of the precipitation, positive skewness is related to the degree of right-tailed skew to the frequency histogram (related to lognormality), and kurtosis is the degree of flatness or sharpness to the maximum of the histogram.

Several graphics are included. These comprise the exponentially smoothed time series plot of the raw data to determine trends, the frequency histogram to illustrate the characteristics of the data set in the frequency domain, and a normal probability plot to depict projected maximum annual precipitation exceedences for the station (a cumulative 99% means the 100 year storm).

The smoothed time series plot utilizes Brown's exponential smothing in which the adjacent data points are weighted in an inverse proportion to the square of the distance from the time point being smoothed. This method smooths the data set, while retaining some of the short-term variation in the time series. In cases where data is missing from the time series, the smoothing method used tends to overestimate the smoothed points adjacent to the missing data.

6.2.4.1 Flagstaff, AZ

This station has an almost complete period of record from 1888 through 1990. The long-term trend indicates a gradual decline from 1904 to 1940, followed by a gradual increase from 1940 to 1990. It will be seen in the Paleoclimate Section (6.2.7) that the 1888-1990 period corresponds to nearly one complete cycle of the Black Mesa precipitation series from 386 to 1970 A.D.period, as reconstructed from tree ring retrodictions. Fourier smoothing of the Black Mesa data reveals a long-term precipitation cycle of a little more than 80 years.

The frequency histogram reveals a bimodal distribution with maxima at 15 and 24 inches. The kurtosis is flat, and a long right-tailed skewness (positive) is noted. The cumulative frequency fitting shows a deficit in observed vs. projected values, indicative of a lognormal distribution to the observed data set. The projected 100 year exceedence for annual precipitation (from observed values) is about 35 inches. The standard deviation of 5.12 indicates a high variability in precipitation for this station. It will be noted in the variability portion of this report that high elevation stations have a higher standard deviation than the low elevation stations. This is also evident from the time series plots and the monthly distribution bar charts.

Table 68. Long-Term Summary Statistics - WY 1888-1990	
Variable:	Flagstaff, AZ Annual Precipitation
Sample size	94.
Average	20.873617
Median	20.185
Mode	17.29
Geometric mean	20.281738
Variance	26.201025
Standard deviation	5.118694
Standard error	0.527953
Minimum	11.96
Maximum	36.49
Range	24.53
Lower quartile	17.08
Upper quartile	24.39
Interquartile range	7.31
Skewness	0.697654
Standardized skewness	2.761393
Kurtosis	0.364353
Standardized kurtosis	0.721075
Coeff. of variation	24.522313

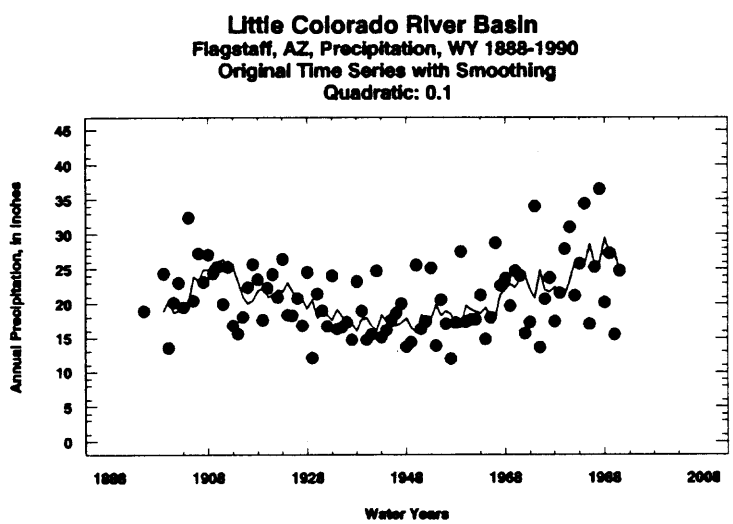


Figure 251. Flagstaff, AZ, Smoothed Long-Term Annual Precipitation

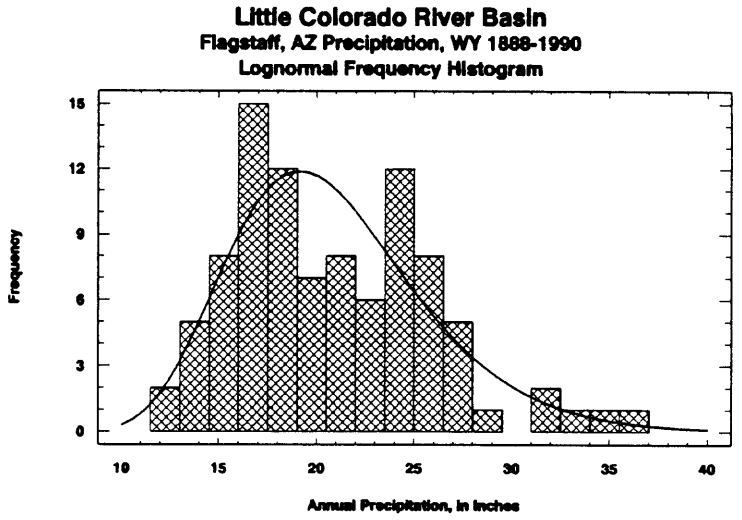


Figure 252. Flagstaff, AZ, Histogram of Long-Term Annual Precipitation

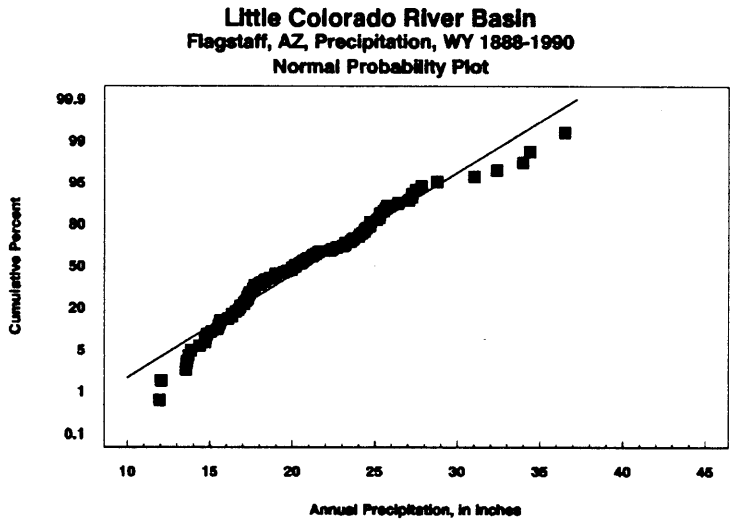


Figure 253. Flagstaff, AZ, Probability Plot, Long-Term Annual Precipitation

6.2.4.2 Fort Defiance, AZ

This station was located in the old BIA Headquarters in Fort Defiance, Arizona. The period of measured record was from 1897 through 1906 and 1930-31. The period from 1939 through 1990 was reconstructed, based upon nearby LCR Basin stations as per Section 6.2.2 of this report.

The long-term trend indicates an increase from 1897 to 1900, followed by a decline from 1940 to 1968. There was an increase from 1969 through 1990. It will be seen in the Paleoclimate Section (6.2.7) that the 1888-1990 period corresponds to nearly one complete cycle of the Black Mesa precipitation series from 386 to 1970 A.D.period, as reconstructed from treering retrodictions. Fourier smoothing of the Black Mesa data reveals a long-term precipitation cycle of a little more than 80 years.

The frequency histogram reveals a unimodal distribution with a maximum at 13 inches. The kurtosis is moderately flat, and a right-tailed skewness (positive) is noted. The cumulative frequency fitting shows a deficit in observed vs. projected values, indicative of a lognormal distribution to the observed data set. The projected 100 year exceedence for annual precipitation (from observed values) is in excess of about 22 inches. The standard deviation of 3.20 indicates a moderate variability in precipitation for this station. It will be noted in the variability portion of this report that high elevation stations have a higher standard deviation than the low elevation stations. This is also evident from the time series plots and the monthly distribution bar charts.

Table 69. Long-Term Summary Statistics - WY 1869-1990	
Variable:	Ft Defiance, AZ Annual Precipitation
Sample size	61.
Average	12.058407
Median	12.287422
Mode	12.287422
Geometric mean	11.654019
Variance	10.264647
Standard deviation	3.203849
Standard error	0.410211
Minimum	6.359741
Maximum	21.84
Range	15.480259
Lower quartile	9.674977
Upper quartile	13.597973
Interquartile range	3.922996
Skewness	0.787705
Standardized skewness	2.511615
Kurtosis	1.542835
Standardized kurtosis	2.459682
Coeff. of variation	26.56942

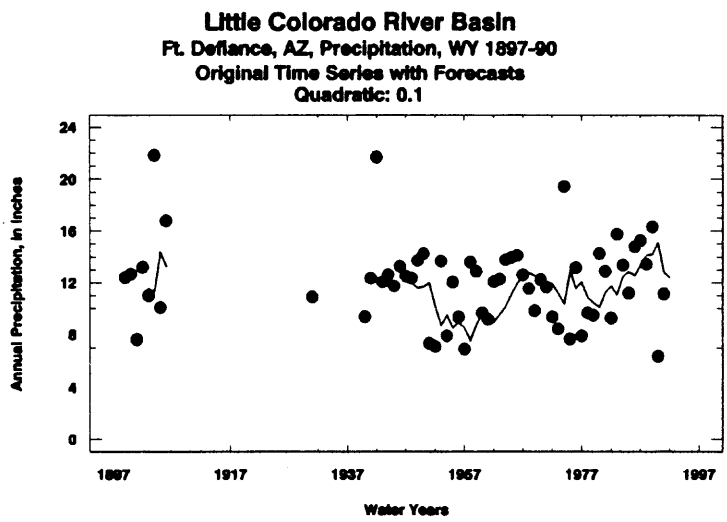


Figure 254. Fort Defiance, AZ, Smoothed Long-Term Annual Precipitation

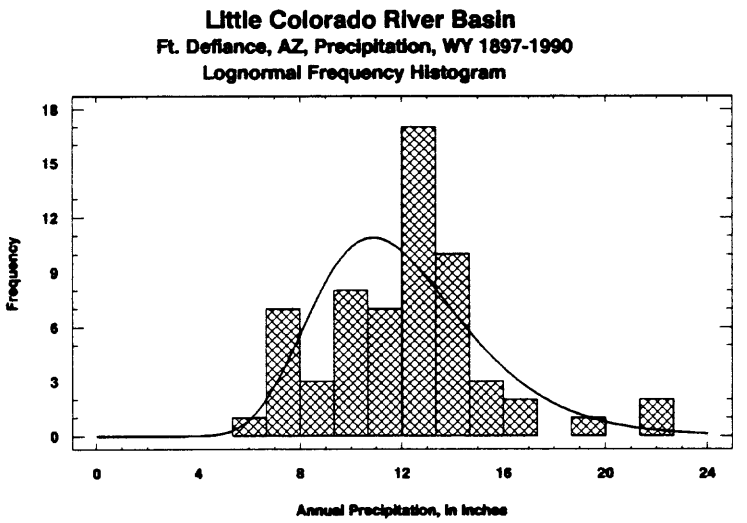


Figure 255. Fort Defiance, AZ, Histogram of Long-Term Annual Precipitation

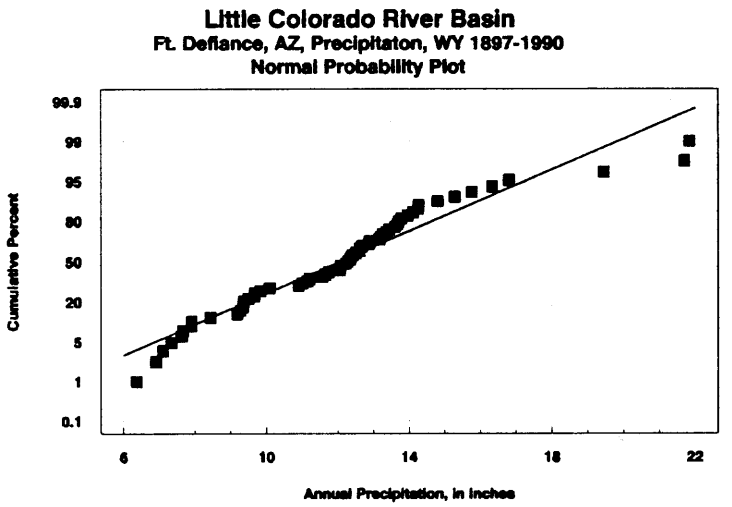


Figure 256. Fort Defiance, AZ, Probability Plot, Long-Term Annual Precipitation

6.2.4.3 Fort Wingate, NM

This station was located at old Fort Wingate, New Mexico. The period of measured record was from 1869 through 1911 and 1940-66, with 1955-56 missing. The period from 1939 through 1990 was reconstructed, based upon nearby LCR Basin stations as per Section 6.2.2 of this report.

The long-term trend indicates a decrease from 1869 to 1875, followed by a gradual increase from 1877 to 1911. There was a slight decline from 1925 through 1960, followed by an increase from 1961 through 1990. It will be seen in the Paleoclimate Section (6.2.7) that the 1888-1990 period corresponds to nearly one complete cycle of the Black Mesa precipitation series from 386 to 1970 A.D.period, as reconstructed from tree ring retrodictions. Fourier smoothing of the Black Mesa data reveals a long-term precipitation cycle of a little more than 80 years.

The frequency histogram reveals a unimodal distribution with a maximum at 13 inches. The kurtosis is moderately flat, and a right-tailed skewness (positive) is noted. The cumulative frequency fitting shows a deficit in observed vs. projected values, indicative of a lognormal distribution to the observed data set. The projected 100 year exceedence for annual precipitation (from observed values) is in excess of about 23 inches. The standard deviation of 3.51 indicates a moderate variability in precipitation for this station. It will be noted in the variability portion of this report that high elevation stations have a higher standard deviation than the low elevation stations. This is also evident from the time series plots and the monthly distribution bar charts.

Table 70. Long-Term Summary Statistics - WY 1869-1990	
Variable:	Fort Wingate, NM Annual Precipitation
Sample size	108.
Average	12.718327
Median	12.464915
Mode	11.34
Geometric mean	12.261129
Variance	12.294155
Standard deviation	3.506302
Standard error	0.337394
Minimum	6.99
Maximum	23.50
Range	16.51
Lower quartile	10.19
Upper quartile	14.623145
Interquartile range	4.43314
Skewness	0.744068
Standardized skewness	3.156815
Kurtosis	0.64541
Standardized kurtosis	1.369138
Coeff. of variation	27.56889

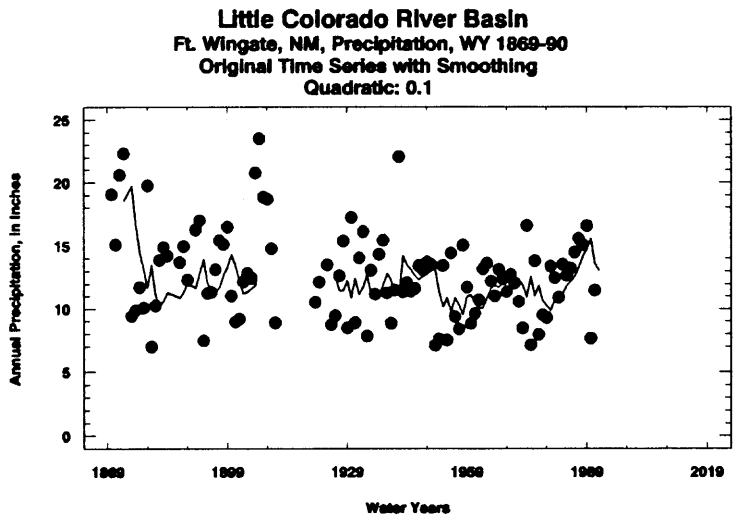


Figure 257. Fort Wingate, NM, Smoothed Long-Term Annual Precipitation

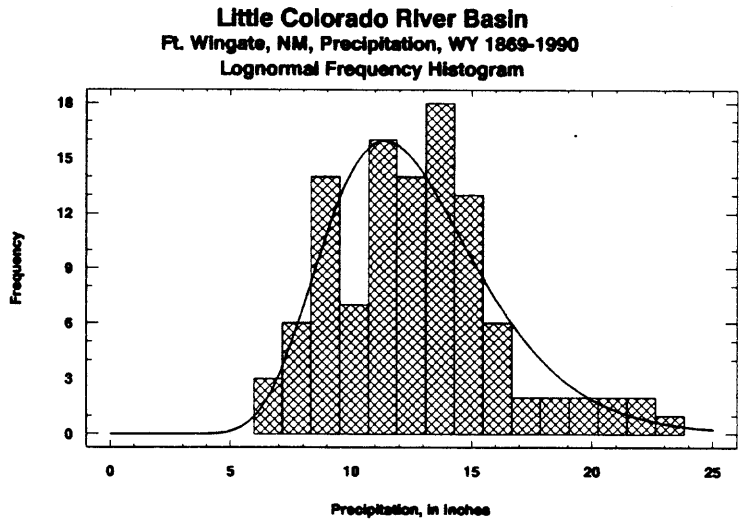


Figure 258. Fort Wingate, NM, Histogram of Long-Term Annual Precipitation

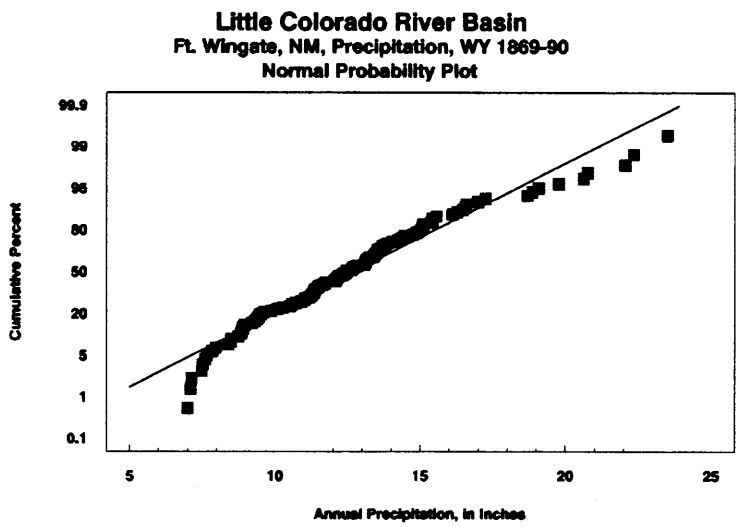


Figure 259. Fort Wingate, NM, Probability Plot, Long-Term Annual Precipitation

6.2.5 Long-Term Isohyetal Maps

The original purpose for the reconstruction of missing precipitation data was to enable higher resolution isohyetal maps of the LCR Basin to exhibit the spatial distribution of Basin precipitation for the study period mean and to examine the spatial variability of the precipitation over time. Another purpose for the reconstruction project was to investigate possible precipitation-runoff correlations in areas with sparse precipitation data to enhance the modeling accuracy for ungaged LCR tributary creeks and washes.

The isohyetal maps presented in the following subsections represent a major result of the Hopi LCR Hydrology Study. Since the primary hydrologic input for a riverine system is precipitation volume, duration, and frequency, the precipitation schema for a 27,000 square mile basin with a great elevation range determines the origin and distribution of flow in the main downstream channel.

It will be noted in the isohyetal maps by decade, that large regions of the Basin may vary in a different proportion to the majority of the Basin area. One such region is the eastern portion of the Basin in New Mexico. It will be noted that the New Mexico area does not vary from decade to decade in proportion to the western portion of the basin. This effect is perhaps due to the fact that the New Mexico portion of the LCR Basin is of relatively high altitude, being near to the Continental Divide, and manifests its own orographic effects. Additionally, the storm tracks, which move typically from southwest to northeast, may move wetter air from the Mogollon Plateau area towards the northwest New Mexico region at these times.

It is to be remembered that, according to Sellars and Hill (Sellars and Hill, 1974) that late summer meteorological events in the desert areas consist of scattered, cellular, convective storms. Because of this spatial and temporal variability in the precipitation input to the LCR system, long-term average climatological ingredients may not accurately reflect the site-specific precipitation volumes and intensities in the headwaters of tributary drainages. Thus, the monthly resolution values from the present study may not correlate well to the actual flows in tributary drainages.

Unfortunately, those areas not measured in terms of meteorological events are the headwaters of tributary LCR drainages which have not been gaged as to flow and sediment concentration and transport. Consequently, precise modeling of specific ungaged LCR tributary drainages, particularly on the Reservations, is problematical.

On the other hand, the value of the precipitation analysis within this study lies in the ability to note relative contributions of various broad drainage areas to the LCR flow and sediment regime, and to relate the water resource availability and suspended and bed load volume to a regional parent material evidenced in the surficial geology of the Basin.

Because the spatial distribution of precipitation varies over time, the mineralogical and chemical characteristics of the suspended sediment, especially, in the LCR may vary from year to year or event to event. This aspect would be particularly significant if the transport of toxic material were to originate in individual drainages.

6.2.5.1 LCR Basin Mean Annual Isohyetal Map, 1939-90

This map represents lines of equal precipitation constructed from all the LCR Basin precipitation stations individually averaged over the 1939-90 study period. For those stations whose periods of measured record are not complete, the reconstructed values as per Section 6.2.3 are utilized.

The contour interval for the map is one (1) inch. To identify specific climate stations on the map, refer to the beginning of Section 6.2.3 for the map of climate stations. It will be noted that the areas to the southwest, representing the San Francisco Mountains, the Mogollon Plateau, and the White Mountains, have an average annual precipitation of over fourteen inches. In fact, those areas closest to the San Francisco Mountains and the Mogollon Rim exhibit an average annual precipitation of over eighteen inches. To the east, in eastern Arizona and western New Mexico, the annual precipitation averages from ten inches to fourteen inches. To the northwest, just east of the San Francisco Mountains and the Kaibab Plateau, there is a depression near Tuba City and Cameron with an average annual precipitation of less than six inches.

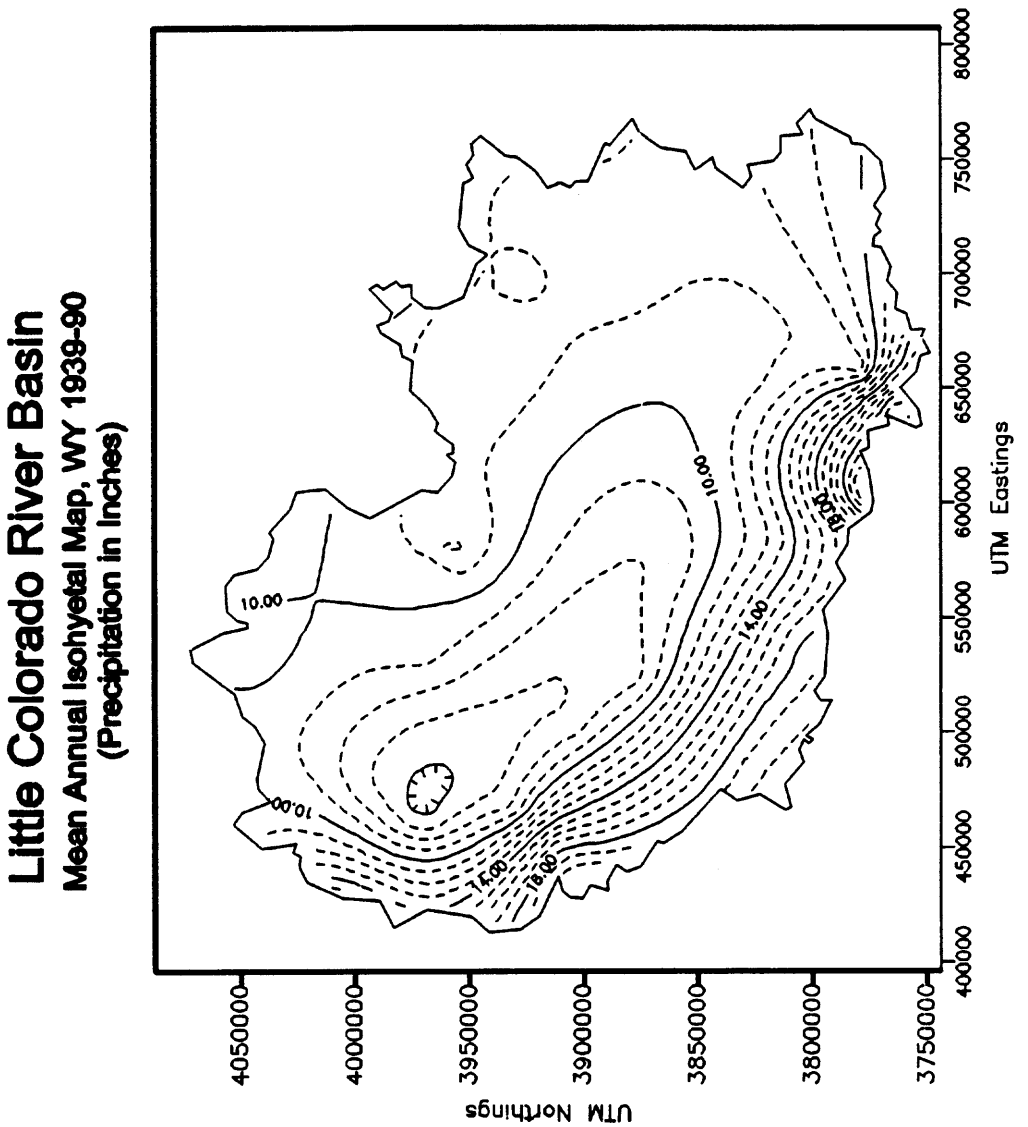


Figure 260. LCR Basin Mean Annual Isohyetal Map, WY 1939-90

6.2.5.2 Contour Map from Precipitation Station Elevations

This map is presented for comparison to the Mean Annual Isohyetal Maps which preceed and follow. It will be noted that the shapes defined by the isolines for each month and each decade follow the general outlines of this elevation contour map. It is stressed that the elevation contour map does not intend to duplicate a topographic map in any way. This map is only intended to demonstrate the strongly orographic nature of precipitation in the Little Colorado River Basin for any time period examined.

The pronounced elevation ridge to the extreme west of the map is the San Francisco Peaks, which rise to an elevation of 12,600 feet. By comparison, the elevation of the Flagstaff station is 7,004 feet. For this reason, the contour map does not accurately reflect elevation extremes in the topography; high elevation peaks normally do not provide a hospitable environment for year round weather observations.

To the south and to the southwest in this contour map are the higher elevations of the Mogollon Rim and the White Mountains. To the northeast are the mountains of northwestern New Mexico.

The depressed region in the northwest-central section of the map represents the low elevation region of the LCR Valley near Leupp and Cameron. The LCR Gorge before the confluence with the main stem Colorado River does not show, since there are no weather stations in that area.

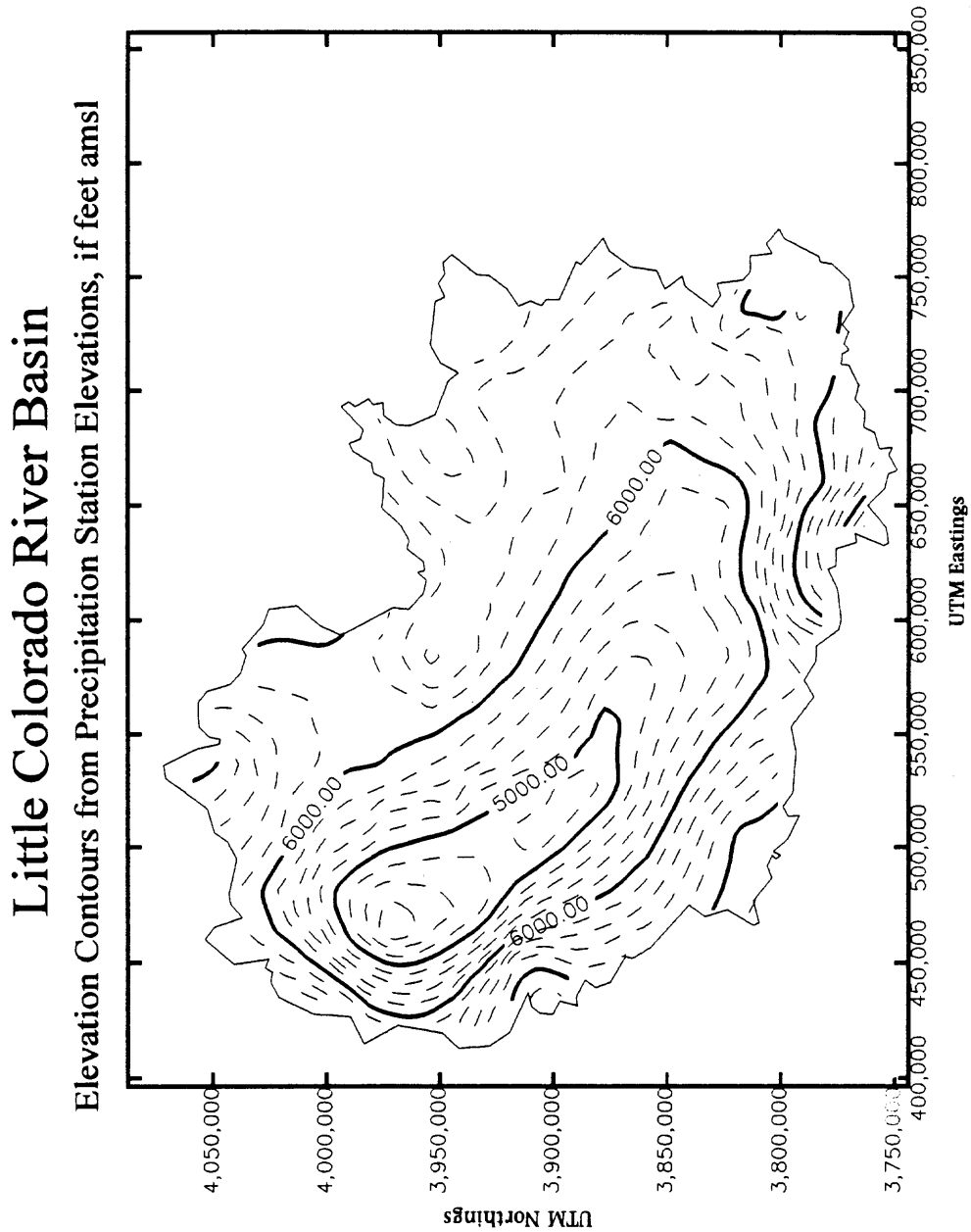


Figure 261. Contour Map from Precipitation Station Elevations

6.2.5.3 Isohyetal Maps, by Decade, 1941-90

The following maps demonstrate the variations in the distribution which take place decade by decade. In each map, the area covered by a given line of equal precipitation differs; similarly, the precipitation for a given station differs.

The maps have been constructed from data sets which consitute the average for the particular decade for all stations. Reconstructed, as well as measured, precipitation values have been used in drawing the maps in order to increase the spatial resolution.

For all decades, the isohyetal maps reflect the orographic nature of precipitation in the LCR Basin. It is interesting to note that the New Mexico portion of the basin does not necessarily synchronize with the Arizona portion decade by decade, with respect to mean precipitation.

6.2.5.3.1 The Decade of 1941 to 1950

In the 1941-50 decade, there is one very wet year, 1941, and one fairly dry year, 1948. The rest of the years are fairly close to average.

The maximum average LCR Basin precipitation for the decade occurs near McNary and Show Low at 24 inches and near Blue Ridge and Chevelon Ranger Stations on the Mogollon Rim at about 20 inches. The minimum average LCR Basin precipitation for the decade occurs near Tuba City and Cameron at about six inches. The dry area covered by the eight inches or less isoline is greater than that of the mean annual isohyetal map for the entire 1939-90 study period (Section 6.2.5.1). The area near Window Rock and Ganado are wetter during the decade, about 12 inches, than that for the study period average.

The orographic effects of altitude differences are notable, the higher elevations receiving much more precipitation than the lower elevations.

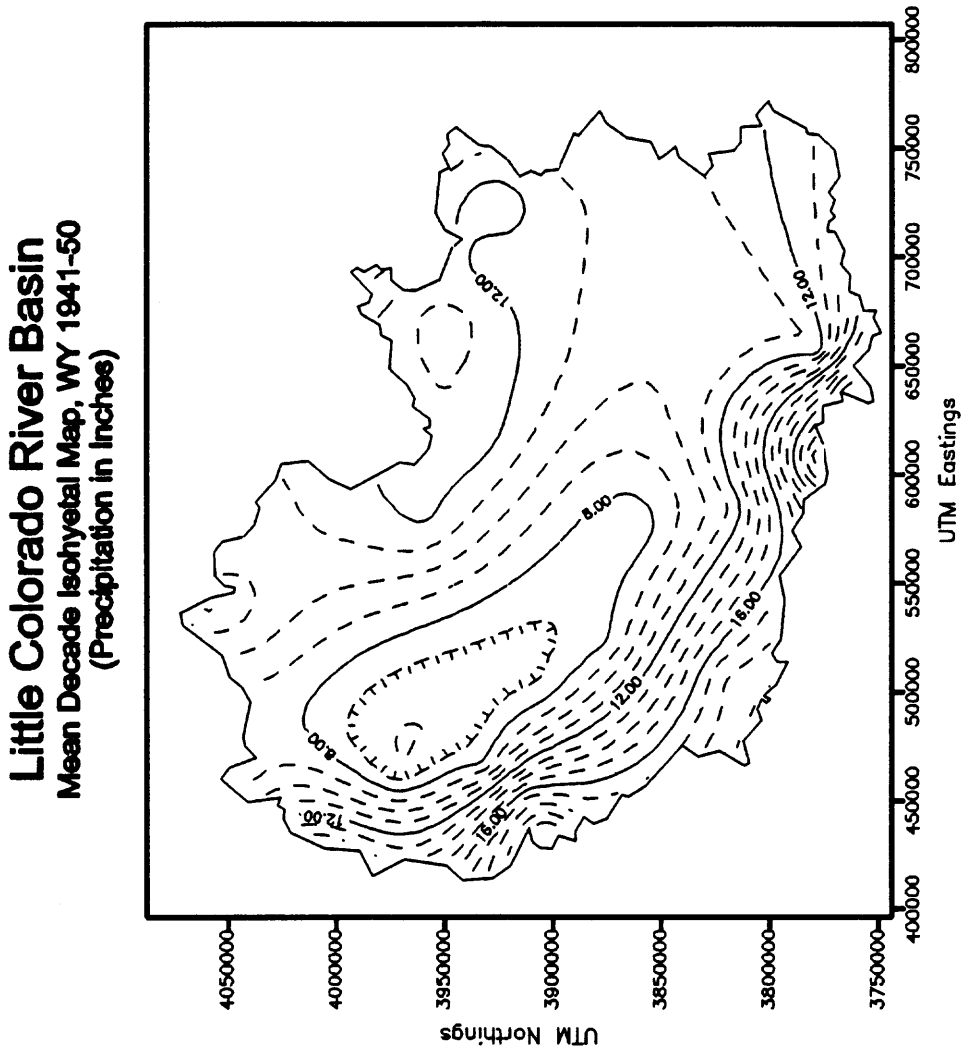


Figure 262. LCR Basin Mean Annual Isohyetal Map, WY 1941-50

6.2.5.3.2 The Decade of 1951 to 1960

The 1951-60 decade is a dryer period that either the 1939-41 decade or the study period of 1939-90. The years of 1952 and 1959 are fairly wet, but the other years correspond to a noted prolonged drought for the American southwest.

The maximum precipitation for the decade occurs near McNary, while near Tuba City and Cameron, there is an area of less than five inches of average annual precipitation for the decade. The dry area covered by the eight inches or less isoline is somewhat larger than in the previous decade (1941-50) and the study period average (Section 6.2.5.1). The area covered by the eighteen inches or greater isoline is much smaller than that of the previous decade or of the 1939-90 study period average.

The orographic effects of altitude differences are notable, the higher elevations receiving much more precipitation than the lower elevations.

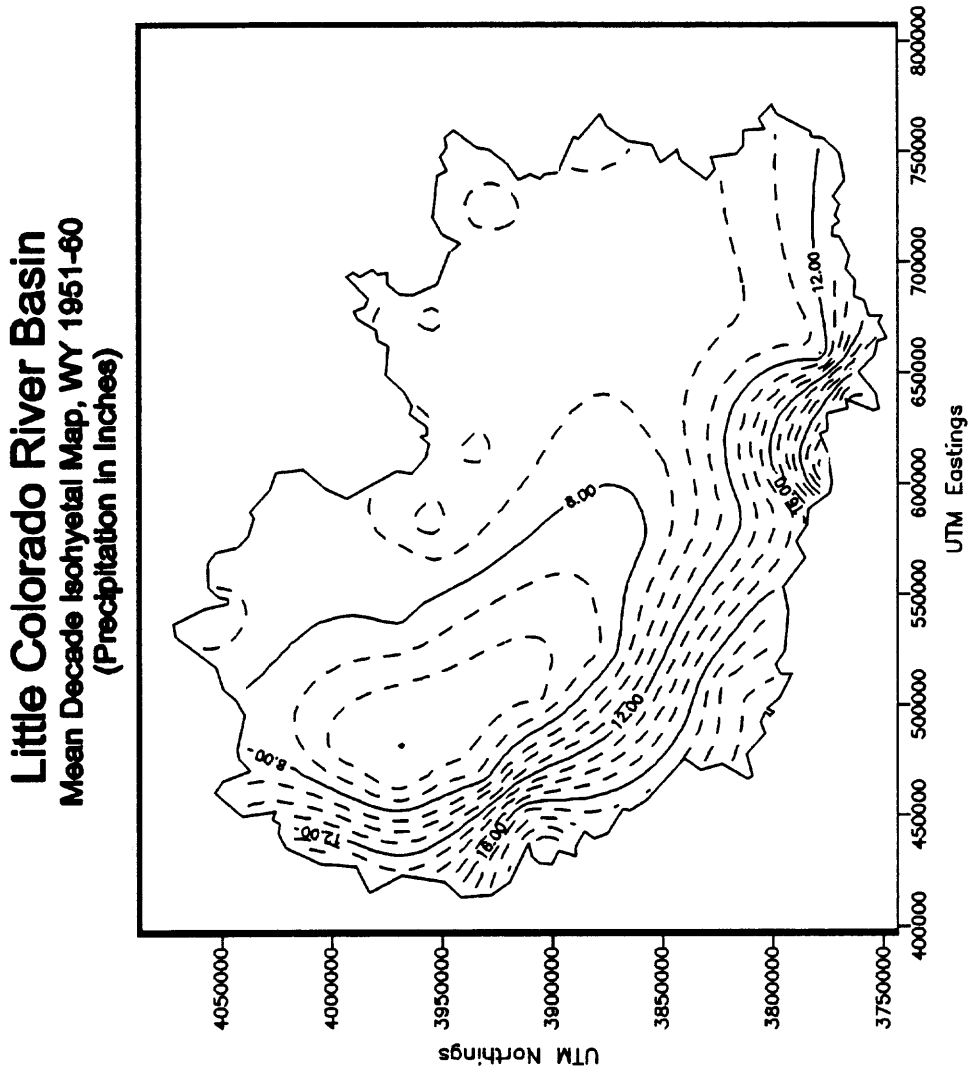


Figure 263. LCR Basin Mean Annual Isohyetal Map, WY 1951-60

6.2.5.3.3 The Decade of 1961 to 1970

The 1961 to 1970 decade was somewhat wetter than the previous decade, and even wetter than the 1939-90 study period average. The years of 1964 and 1967 were fairly wet with only 1963 falling below the study period mean.

The wettest areas were along the Mogollon Rim and the San Francisco Mountains, and the area covered by the eighteen inches or greater isoline exceeding that of the previous decade or of the 1939-90 study period mean. The area covered by the eight inches or less isoline is about the same as that for the previous decade and greater than the study period average (Section 6.2.5.1). It is notable that the New Mexico portion of the LCR Basin was substantially wetter that that of the previous decade or of the study period mean.

The orographic effects of altitude differences are notable, the higher elevations receiving much more precipitation than the lower elevations.

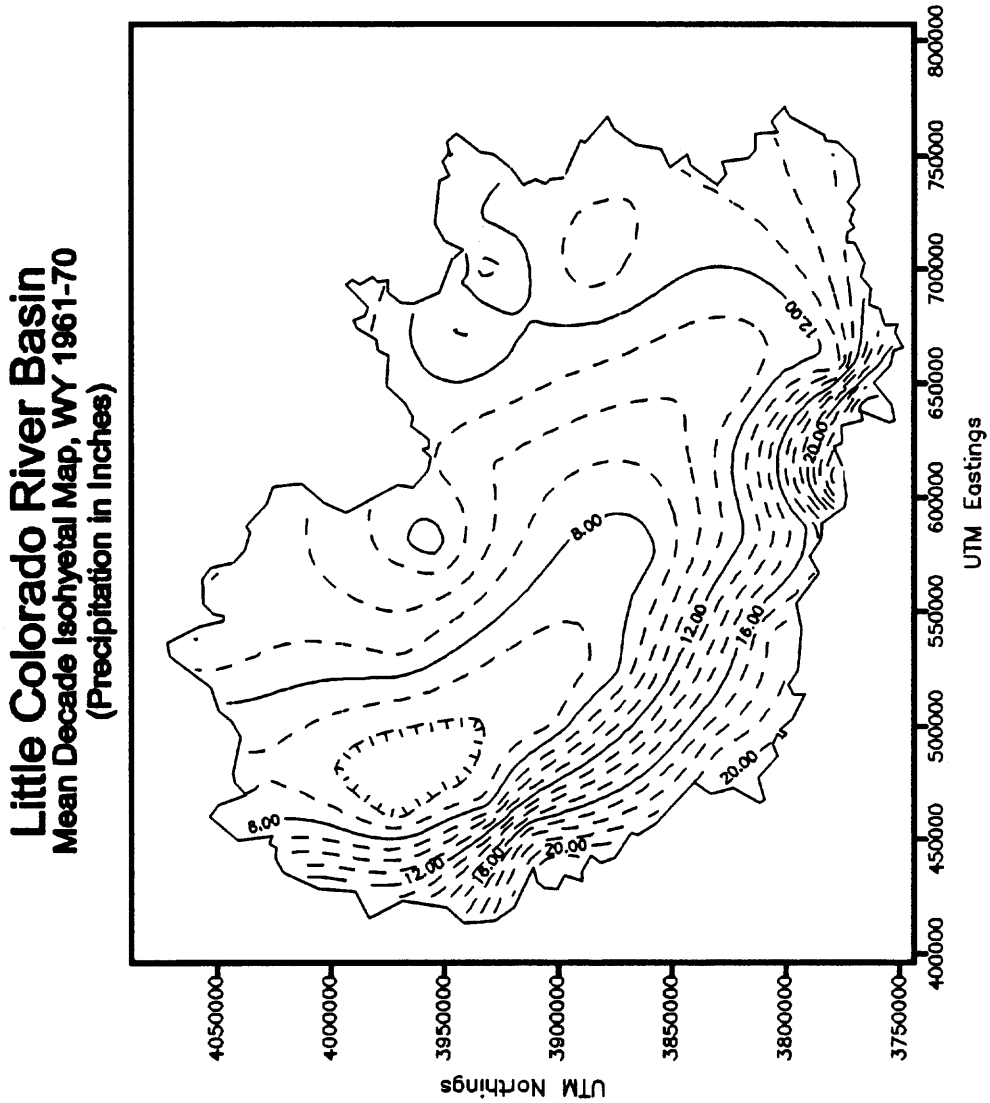


Figure 264. LCR Basin Mean Annual Isohyetal Map, WY 1961-70

6.2.5.3.4 The Decade of 1971 to 1980

The 1971-80 decade was considerably dryer for the higher elevation areas, but wetter than usual for the desert and low elevation areas, when compared to the previous decade or the 1939-90 study period average.

The area covered by the eighteen inches or greater isoline is limited to the McNary region, while there is no area of eight inches or less in the desert. In fact, no station averaged less than ten inches during the decade. The New Mexico portion of the LCR Basin was above twelve inches for the decade.

The orographic effects of altitude differences are notable, the higher elevations receiving somewhat more precipitation than the lower elevations.

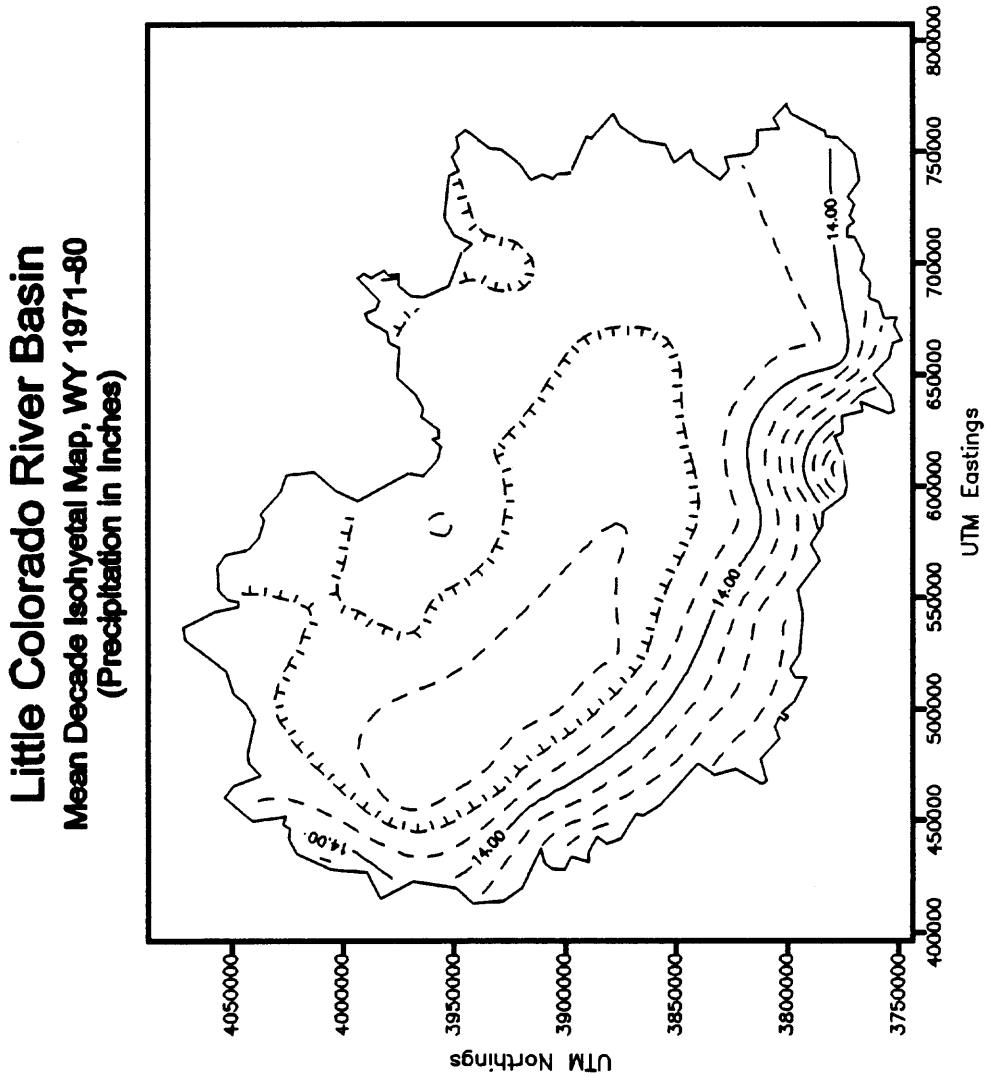


Figure 265. LCR Basin Mean Annual Isohyetal Map, WY 1971-80

6.2.5.3.5 The Decade of 1981 to 1990

The 1981-90 decade was decidedly wetter than the 1939-90 study period mean, with most of the San Francisco Mountains and the Mogollon Rim receiving over twenty inches of precipitation for the mean for the decade. Additionally, the low elevation desert areas were wetter than the study period average, with only a small area near Tuba City and Cameron receiving less than eight inches of precipitation.

The twelve inch isoline covers New Mexico and the Mogollon Rim country. Even desert areas to the north toward Page received more than twelve inches, on the average.

The orographic effects of altitude differences are notable, the higher elevations receiving much more precipitation than the lower elevations.

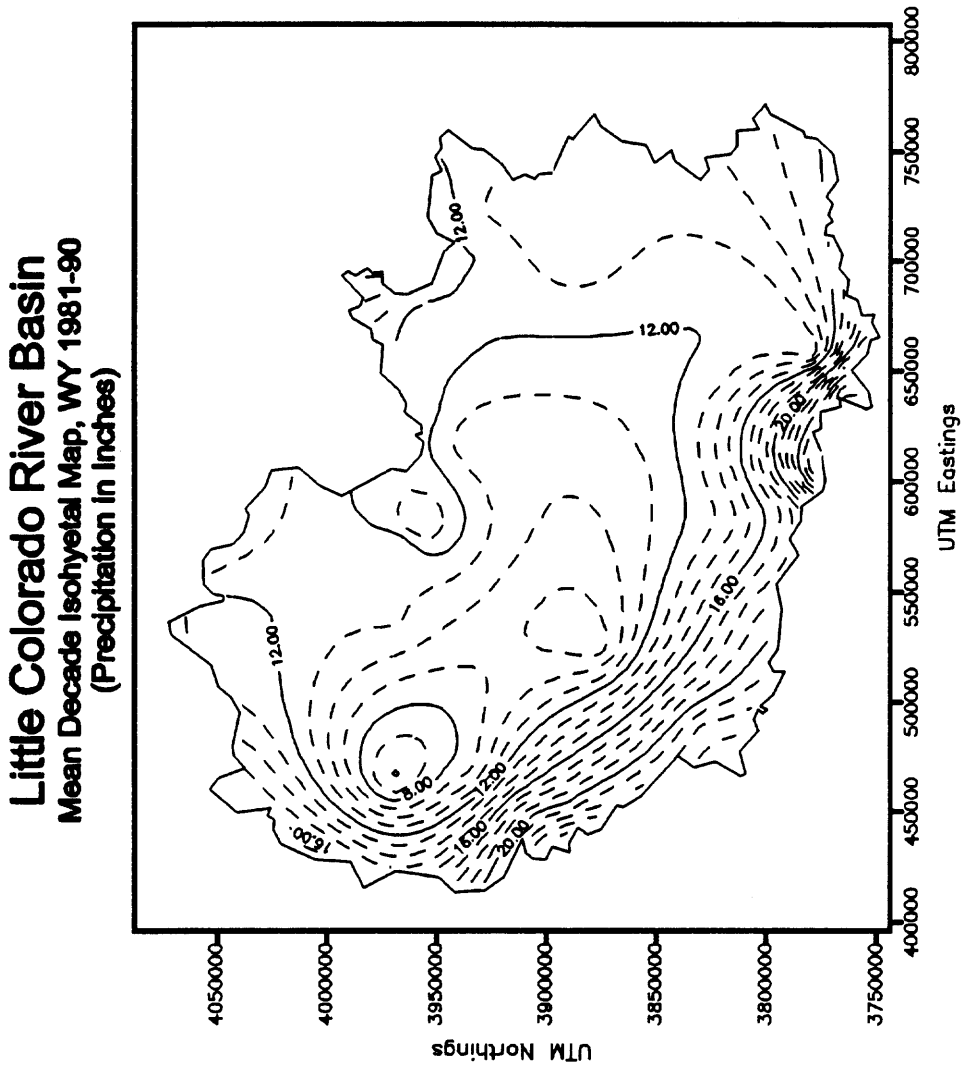


Figure 266. LCR Basin Mean Annual Isohyetal Map, WY 1981-90

6.2.5.4 Isohyetal Maps, by Month, 1939-90

This section contains isohyetal maps for each month for the mean of the entire 1939-90 study period. Also included are histograms of the monthly precipitation from the all station average, as well as time line graphs for each month for the entire study period.

It is to be noted that there is a wide variation in the monthly preciptation in the time line graphs. This variation is due not only to the annual precipitation variation, but also due to seasonal shifts from year to year. These seasonal shifts are related to the arrival date of the monsoon season, which can vary from early July to late August, and to arrival date of the winter snows, which can vary from November to January from year to year. The histograms generally show a stronger lognormal tendency than that of the annual averages, except for the months of July and September, which have greater kurtosis and lesser positive skewness than the histograms of the remaining months.

All of the monthly isohyetal maps exhibit strong orographic and elevation effects, with the higher elevations receiving much greater precipitation than the lower elevations.

6.2.5.4.1 October Isohyetal Map, WY 1939-90

The Mogollon Rim and the San Francisco Mountains areas receive over 1.20 inches of precipitation for the month of October. The desert areas around Tuba City and Cameron receive less thn 0.80 inches on average for this month. A small area around Ganado and Window Rock also receive over 1.20 inches of precipitation for an average October.

Overall, the proportion of precipitation at higher elevations is not as much greater than the desert areas as in the average annual records. Thus the precipitation in the month of October is relatively uniform throughout the LCR Basin.

The histogram is decidedly skewed in the positive direction with no left hand tail. The year to year average is less than two inches, but the 1973 Water Year saw an extreme amount of precipitation in October, over nine inches at Fort Valley.

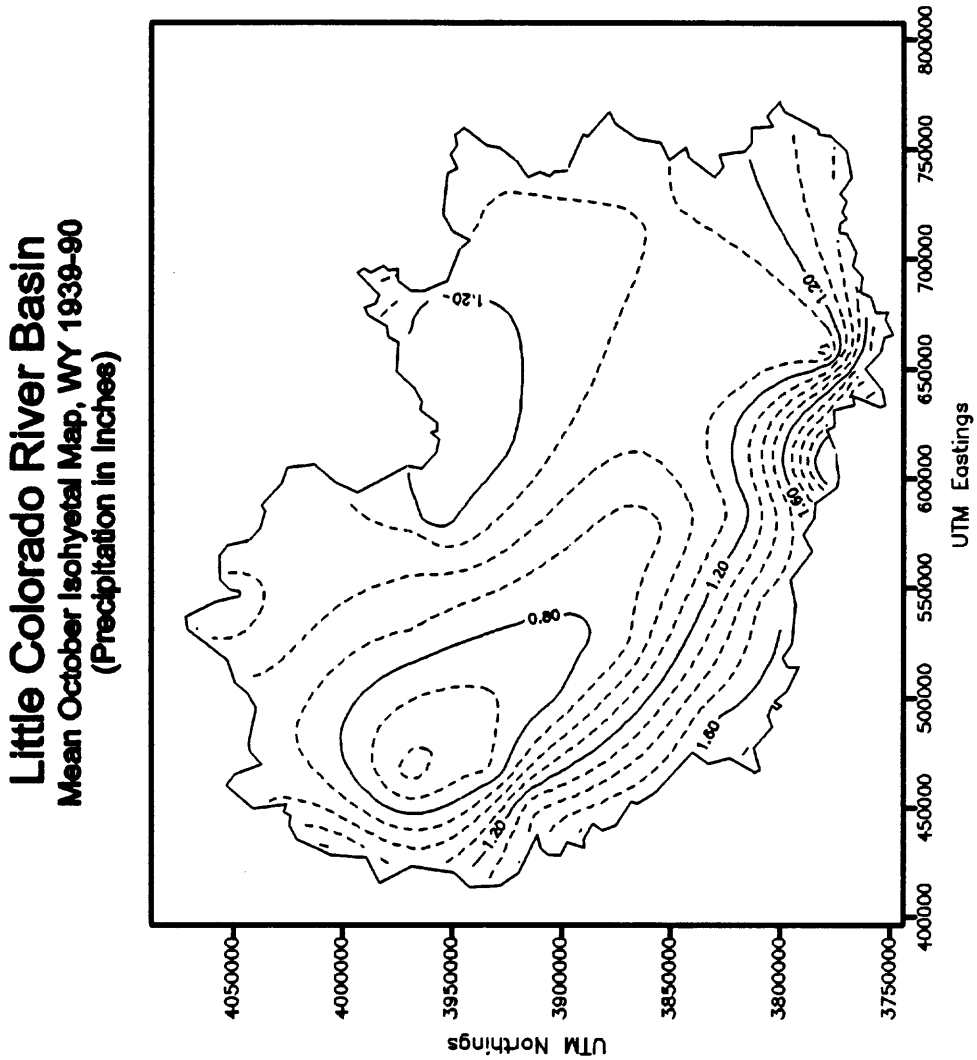


Figure 267. LCR Basin Mean October Isohyetal Map, WY 1939-90

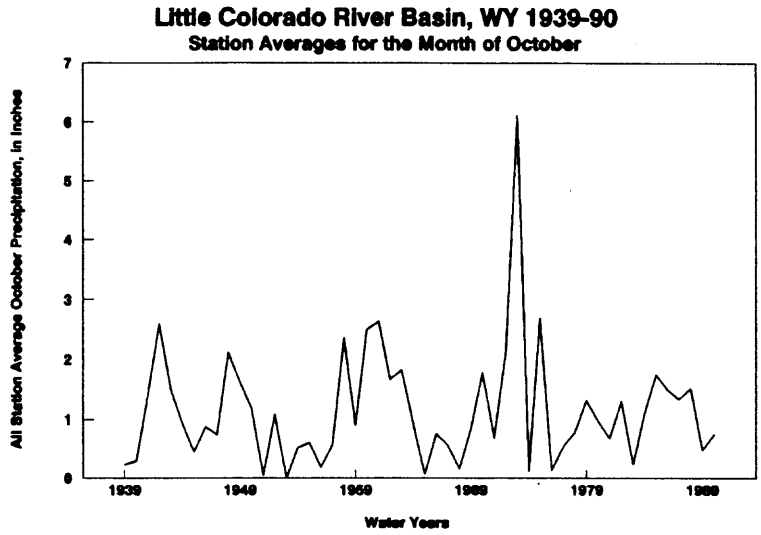


Figure 268. LCR Basin All Station Mean October Precipitation, WY 1939-90

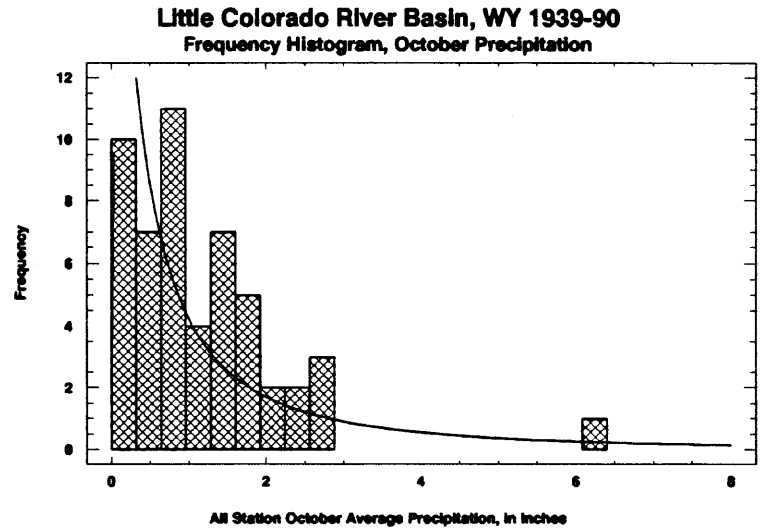


Figure 269. LCR Basin All Station Mean October Precipitation Histogram

6.2.5.4.2 November Isohyetal Map, WY 1939-90

The mean monthly precipitation for November ranges from 1.20 inches in the San Francisco Mountains and along the Mogollon Rim to less than 0.40 inches in the desert areas near Tuba City and Cameron. A wet area near Betatakin is noted for the month, which is less subdued for the annual mean isohyetal map (Section 6.2.5.1). The precipitation gradient for the desert areas and New Mexico is more subdued than certain other months and the annual mean. Orographic effects are about the same as for the annual average, with the high altitude areas receiving substantially more precipitation in November than in the desert and low elevation areas.

The histogram is decidedly lognormal, as in most months of the year, with no left hand tail. The monthly mean is less than an inch for the all station average for the study period, with November, 1979 receiving nearly four inches of precipitation at Fort Valley.

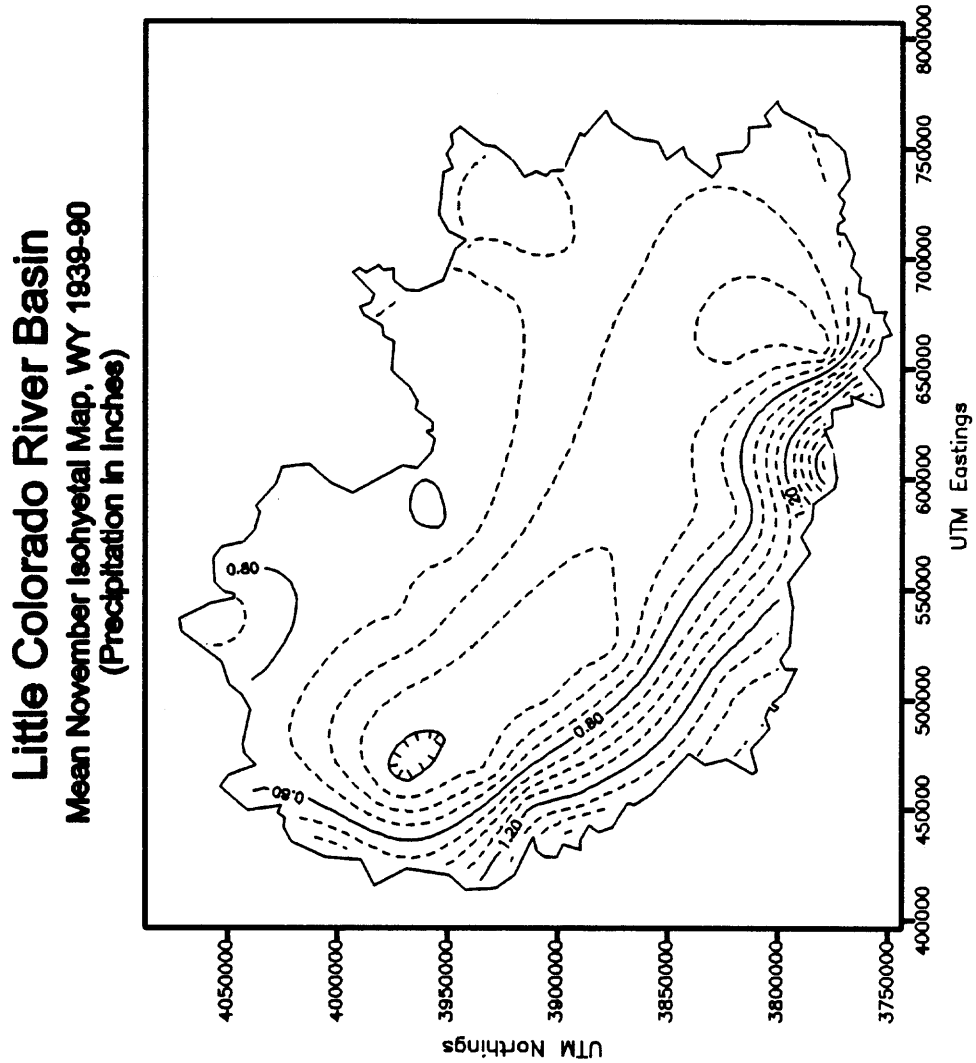


Figure 270. LCR Basin Mean November Isohyetal Map, WY 1939-90

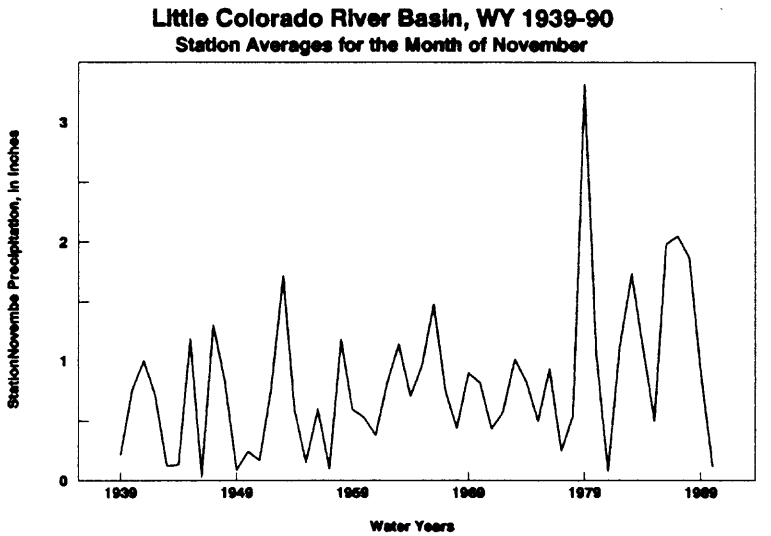


Figure 271. LCR Basin All Station Mean November Precipitation, WY 1939-90

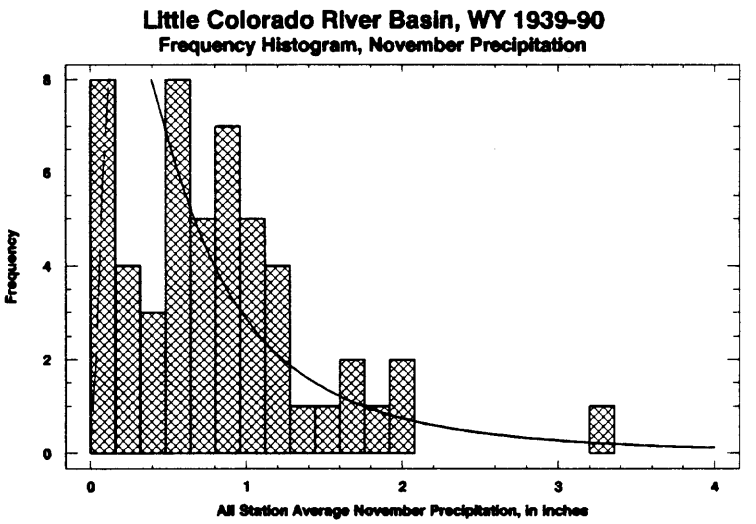


Figure 272. LCR Basin All Station Mean November Precipitation Histogram

6.2.5.4.3 December Isohyetal Map, WY 1939-90

The mean monthly precipitation for the month of December averages from 1.60 inches in the San Francisco Mountains and along the Mogollon Rim to less than 0.40 inches in the desert area near Tuba City and Cameron. A wetter area between Batatakin and Canyon de Chelly is noted at greater than 0.80 inches. The precipitation gradient for December is interesting in that there is a dry trough running from the northwest to the southeast, which is not present in the annual average isohyetal map (Section 6.2.5.1). Otherwise, the usual orographic effects are noted, with higher elevations receiving more precipitation and lower altitude desert areas receiving less precipitation.

The histogram is bimodal, with peak frequencies at about 0.50 inches and another at 1.20 inches. A decided positive skew is noted with a slight left hand tail. The time line graph indicates an annual all station average of about 1.0 inch, with very wet Decembers occuring in 1946, 1952, 1965, 1966, 1967, and 1985.

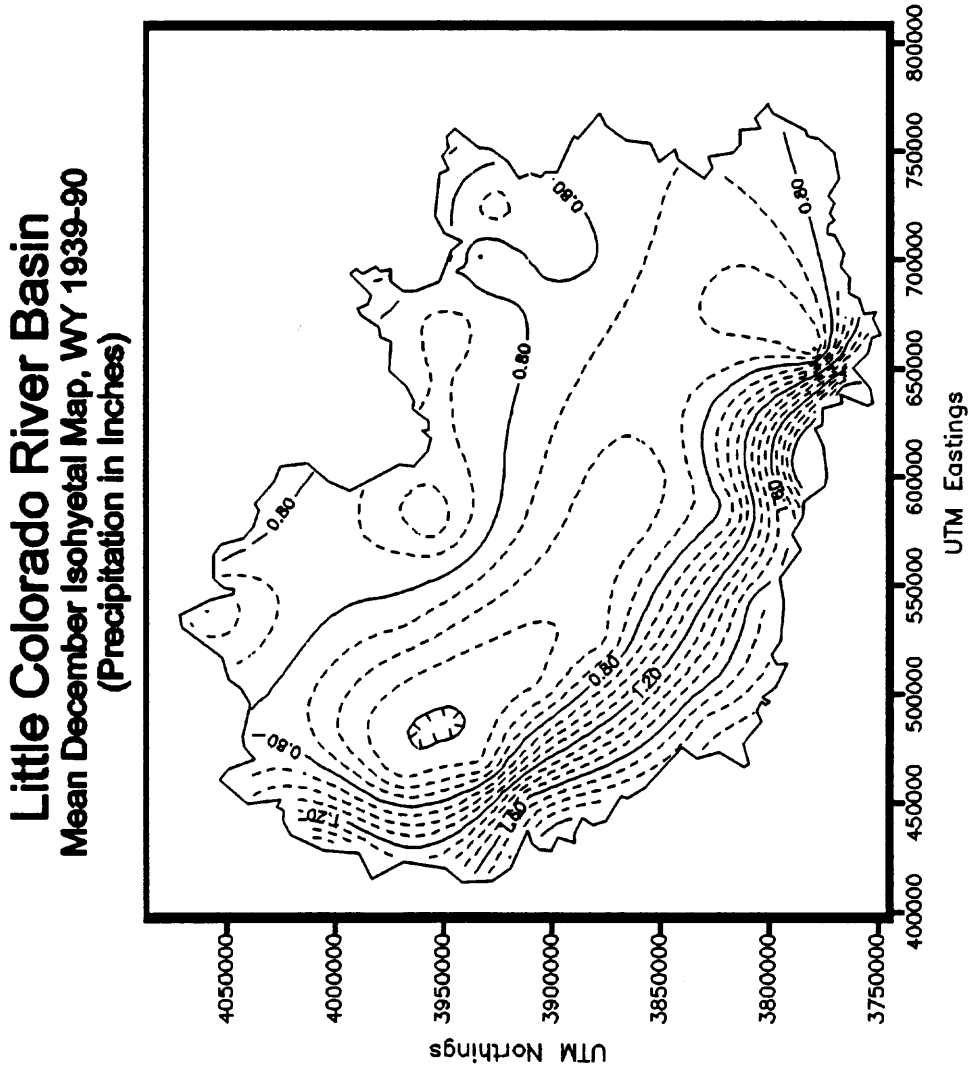


Figure 273. LCR Basin Mean December Isohyetal Map, WY 1939-90

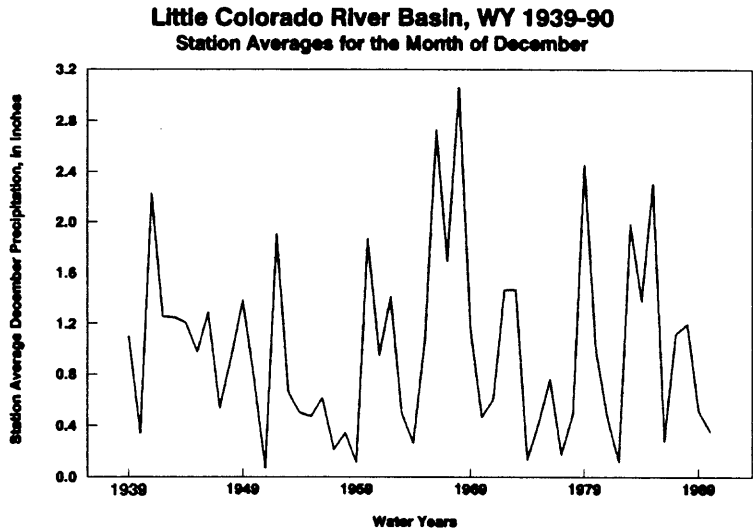


Figure 274. LCR Basin All Station Mean December Precipitation, WY 1939-90

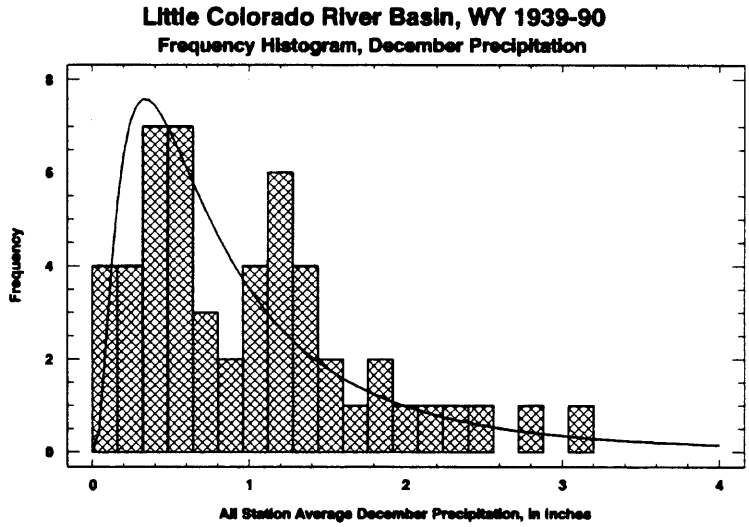


Figure 275. LCR Basin All Station Mean December Precipitation Histogram

6.2.5.4.4 January Isohyetal Map, WY 1939-90

The mean monthly precipitation for January ranges from over 1.60 inches in the San Francisco Mountains and toward the White Mountains to less than 0.40 inches in a small desert area near Tuba City and Cameron. Wetter areas near Betatakin, Klagetoh, and Gallup/Fort Wingate are noted. The precipitation gradient is irregular, with a depression near Cameron, and several isolated wetter areas mentioned above.

The histogram for January is strongly bimodal, with frequency peaks at 0.40 inches and 0.80 inches. The general frequency distribution is lognormal, with a positive skewness and a long right hand and a short left hand tail. The average all station precipitation is about 0.9 inches with very wet Januarys occuring in 1949, 1980, and 1982.

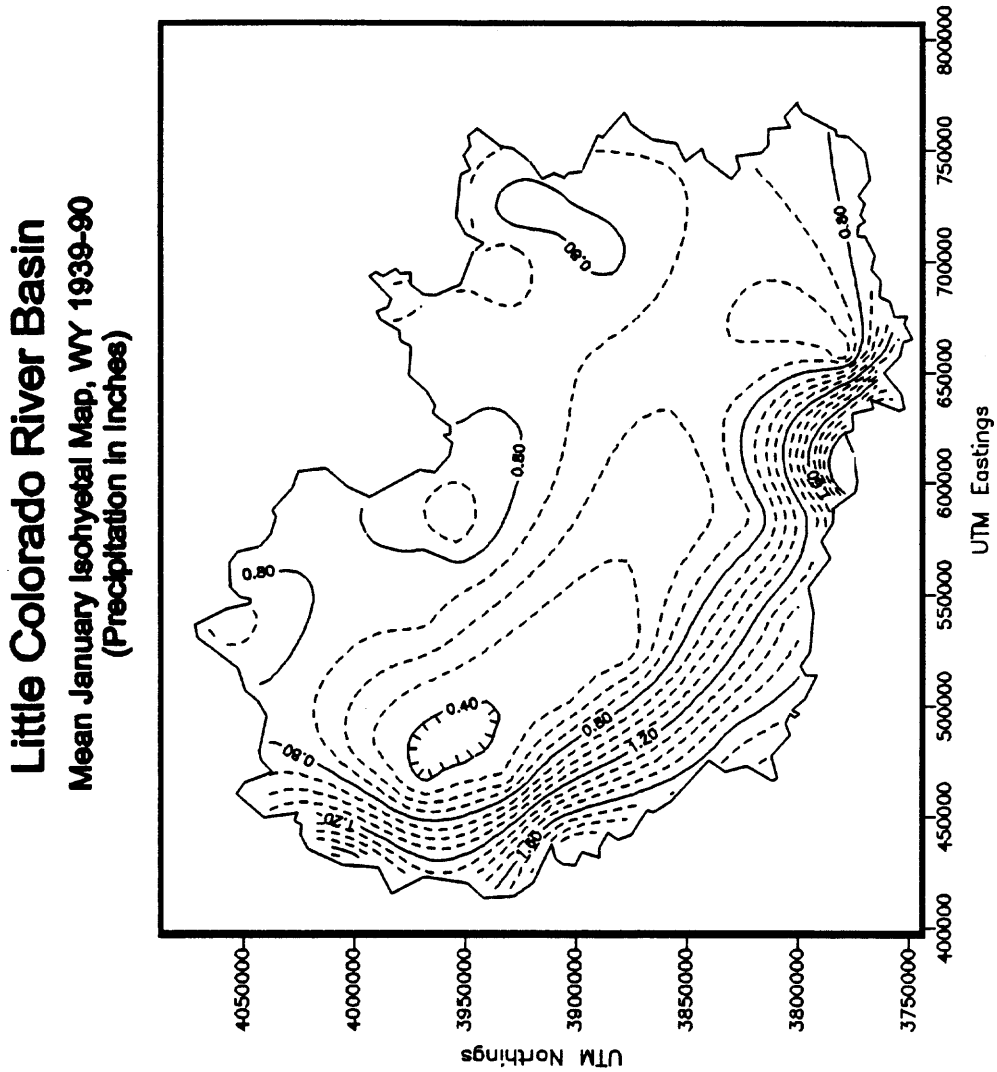


Figure 276. LCR Basin Mean January Isohyetal Map, WY 1939-90

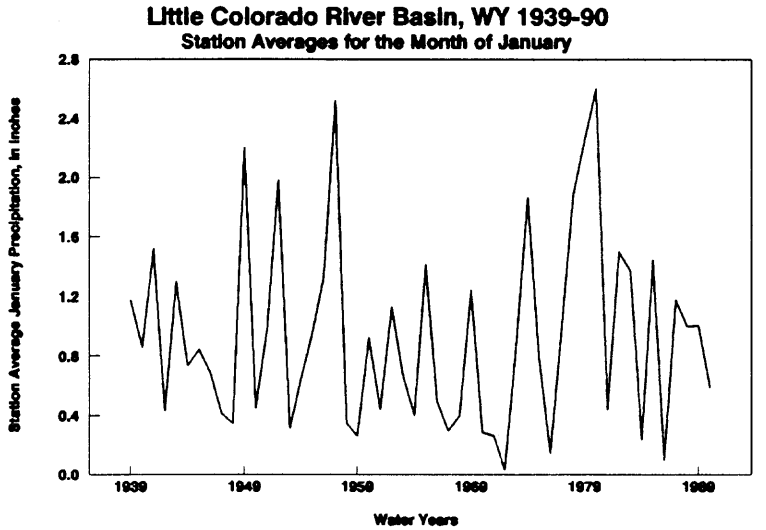


Figure 277. LCR Basin All Station Mean January Precipitation, WY 1939-90

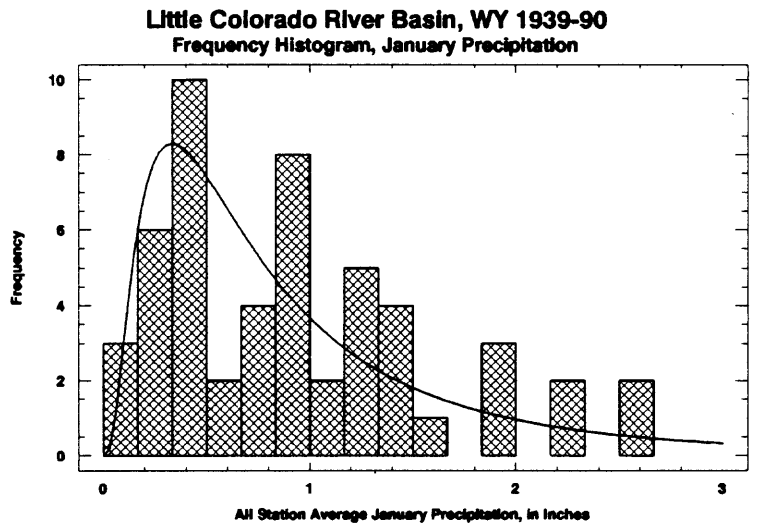


Figure 278. LCR Basin All Station Mean January Precipitation Histogram

6.2.5.4.5 February Isohyetal Map, WY 1939-90

The average precipitation for the month of February ranges from over 1.20 inches in the San Francisco Mountains and along most of the Mogollon Rim to less than 0.40 inches in a relatively large desert area near Tuba City and Cameron. A small area near Betatakin and another near Keams Canyon show an above average February precipitation of over 0.80 inches. The precipitation gradient is typical for the higher elevations to the west and southwest, and slightly irregular in the eastern and lower elevation desert areas.

The histogram shows a slightly lognormal distribution with a slight bimodality at 0.4 and 0.8 inches. A small right hand tail is provided by a single extremely wet February which occurred in 1983. The February time line graph shows and average precipitation of about 0.7 inches for the all station average for the period.

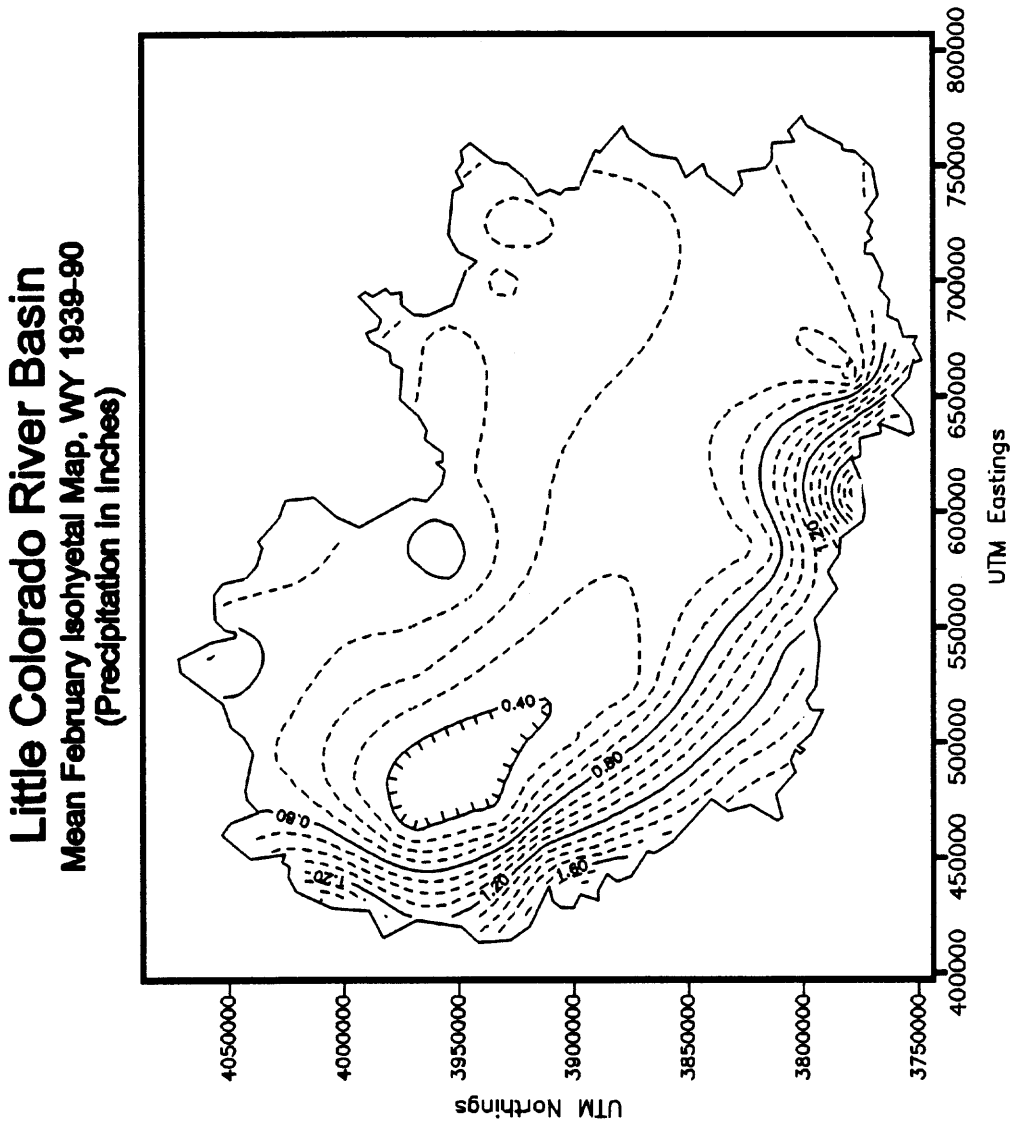


Figure 279. LCR Basin Mean February Isohyetal Map, WY 1939-90

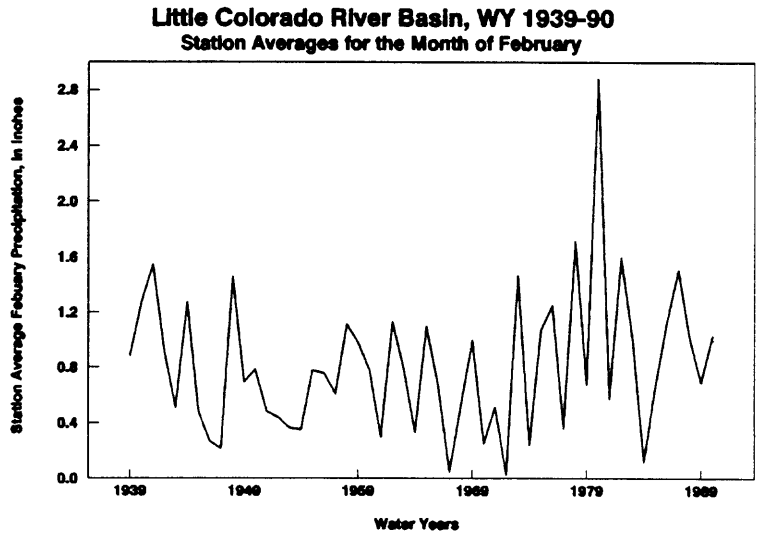


Figure 280. LCR Basin All Station Mean February Precipitation, WY 1939-90

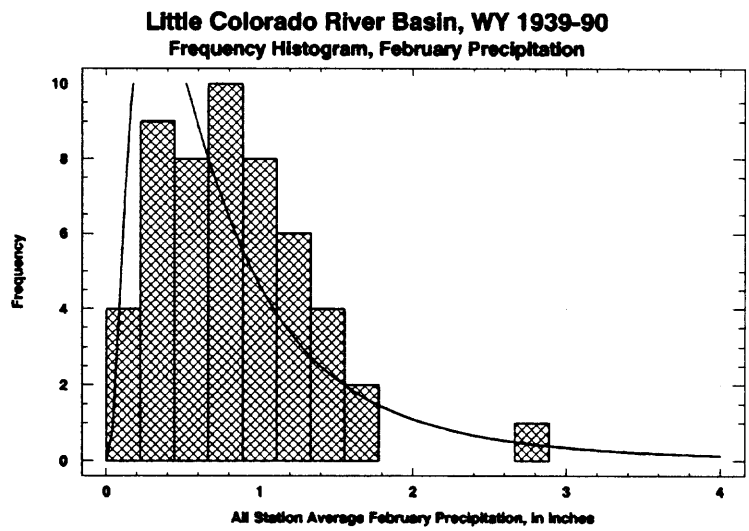


Figure 281. LCR Basin All Station Mean February Precipitation Histogram

6.2.5.4.6 March Isohyetal Map, WY 1939-90

Mean March precipitation for the study period ranges from over 1.60 inches in the San Francisco Mountains, the westerly portion of the Mogollon Rim, and the White Mountains near McNary. Less than 0.50 inches of precipitation occurs in March in the desert area near Tuba City and Cameron. There is a dry trough running from northwest to southeast, except in the extreme northwest, from Tuba City towards Pietown, New Mexico. The precipitation gradient is largely regular, exhibiting strong orographic effects, with the higher elevations receiving greater precipitation for the month.

The histogram exhibits a monomodal lognormal distribution with a frequency peak at 0.6 inches. There is a slight positive skewness. The time line graph ranges from 0.0 to 2.4 inches, with an average of about 0.9 inch. The time line graph oscillates around the 1.0 inch annual March all station mean, with a very wet March of 1970 and 1974.

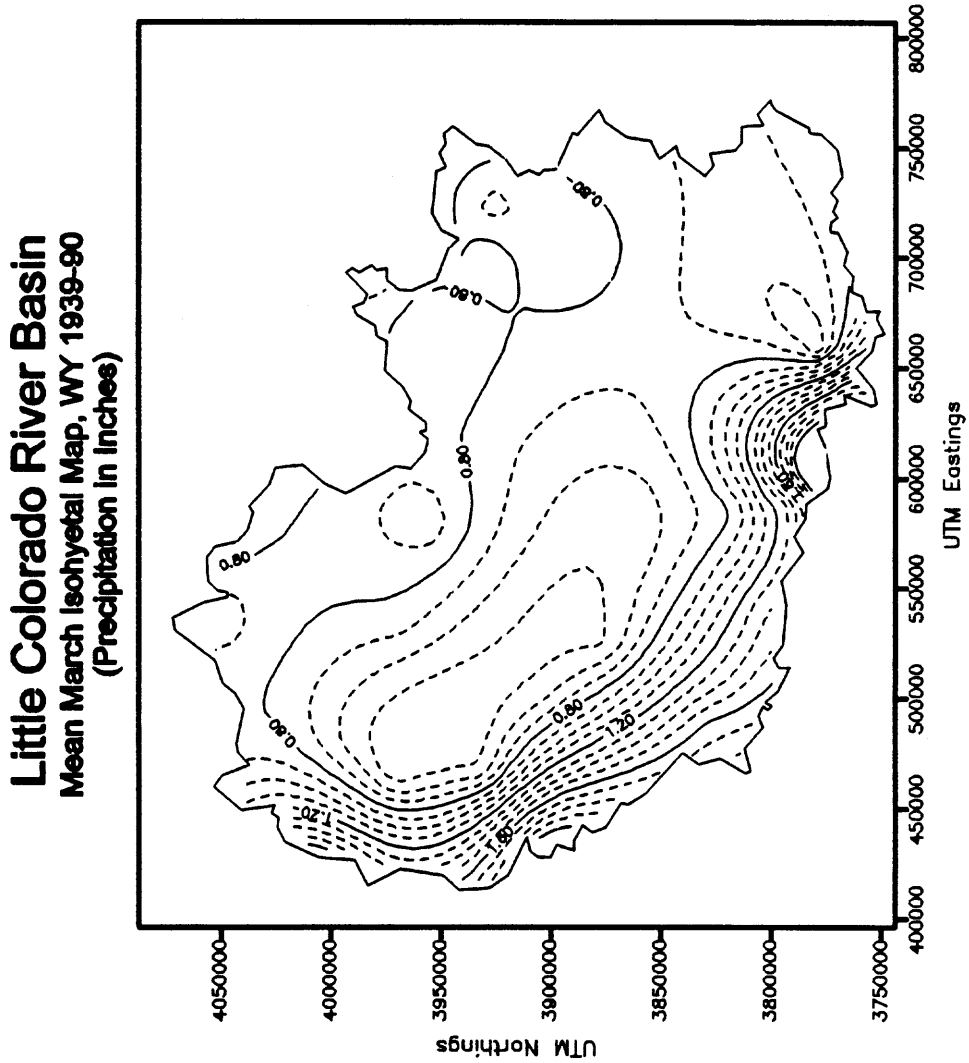


Figure 282. LCR Basin Mean March Isohyetal Map, WY 1939-90

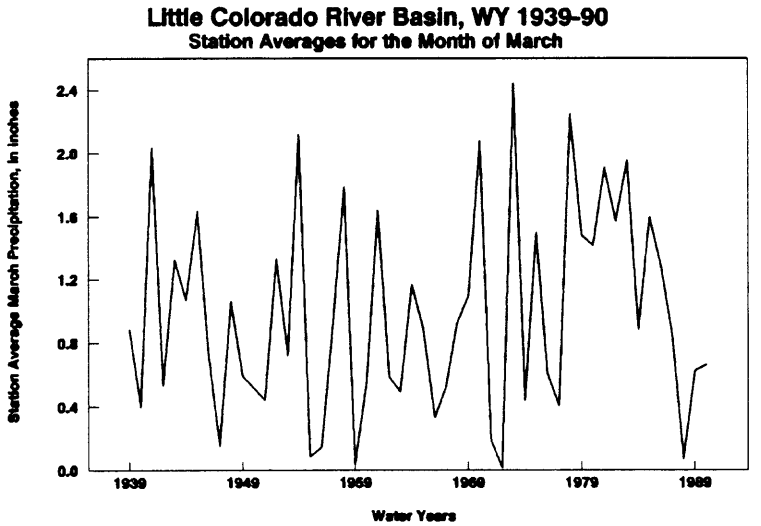


Figure 283. LCR Basin All Station Mean March Precipitation, WY 1939-90

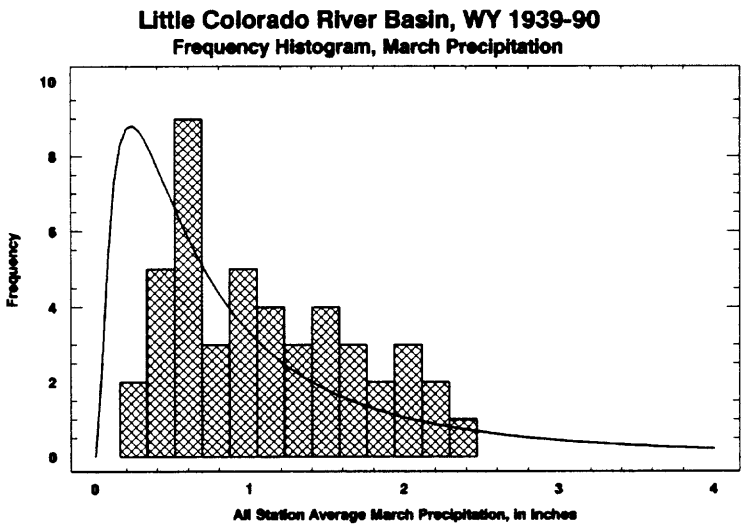


Figure 284. LCR Basin All Station Mean March Precipitation Histogram

6.2.5.4.7 April Isohyetal Map, WY 1939-90

Mean April precipitation over the 1939-90 study period ranges from over 0.80 inches in the San Francisco Mountains and the eastern portion of the Mogollon Rim to less than 0.40 inches in the desert areas of Winslow, Holbrook, Tuba City, and Cameron, and a small area surrounding the relatilvely uninhabited region east of Springerville. The precipitation gradient reflects the usual orographic effects. However, the New Mexico and northeastern portion of the LCR Basin are unusually uniform in precipitation distribution for March.

The histogram for the mean April LCR Basin precipitation is strongly bimodal, with frequency peaks at 0.2 and 0.6 inches. There is also a slight, isolated frequency peak at 1.8 inches. The time line graph shows an average for the study period of about 0.5 inches for April, with very wet seasons in 1965 and 1988.

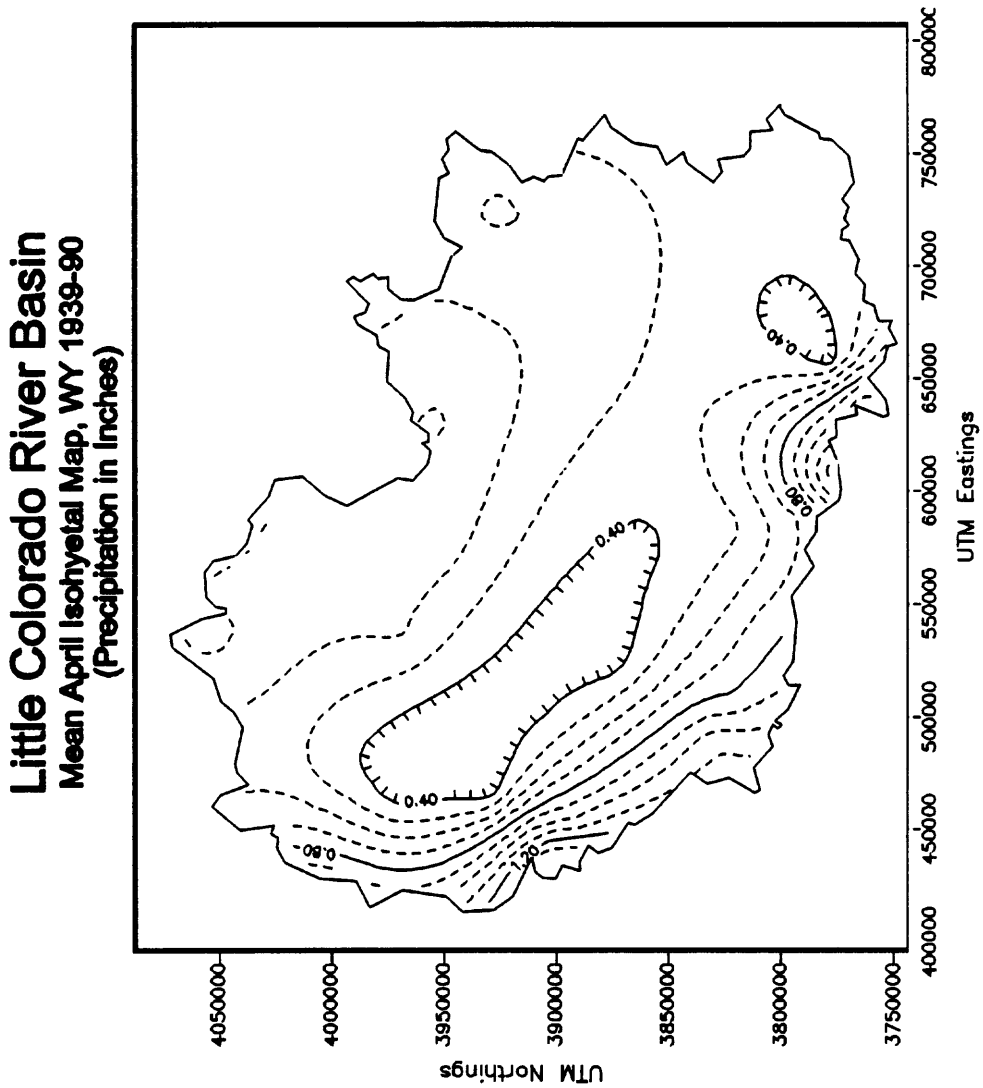


Figure 285. LCR Basin Mean April Isohyetal Map, WY 1939-90

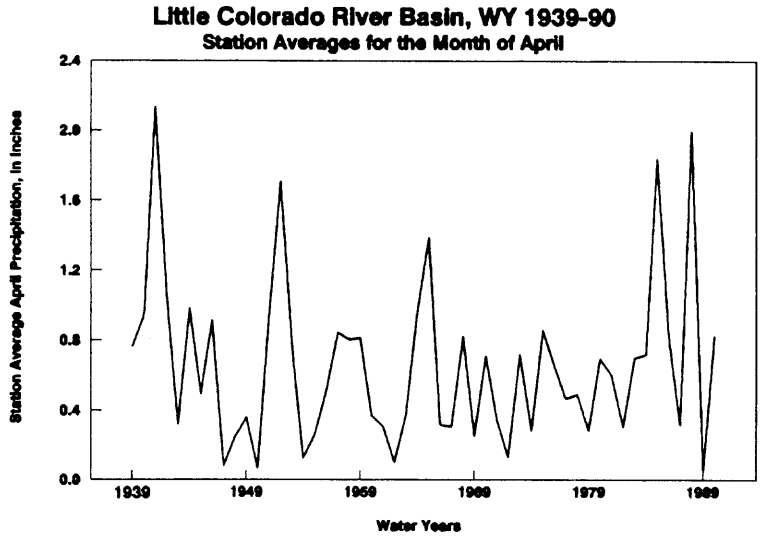


Figure 286. LCR Basin All Station Mean April Precipitation, WY 1939-90

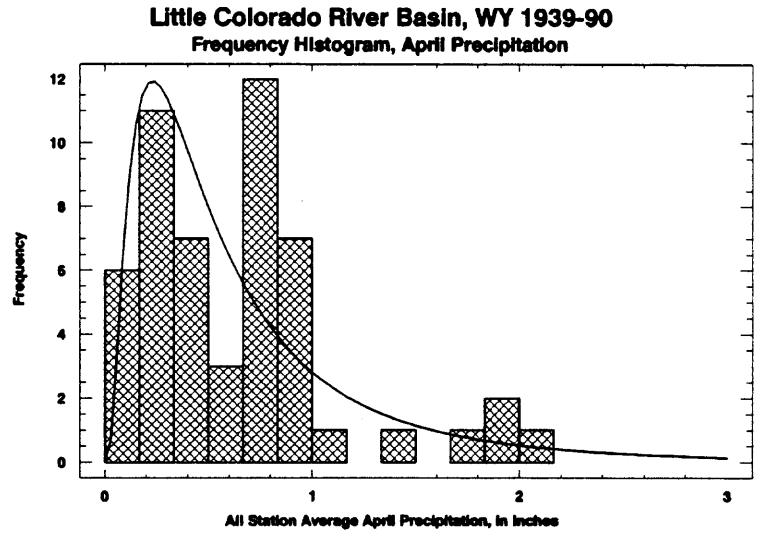


Figure 287. LCR Basin All Station Mean April Precipitation Histogram

6.2.5.4.8 May Isohyetal Map, WY 1939-90

Throughout the study period, May is one of the drier months, with an average precipitation which ranges from about 0.5 inches in the San Francisco Mountains and the western Mogollon Rim to less than 0.3 inches around Leupp and Winslow. The precipitation graph is very uniform throughout the LCR Basin.

The histogram for the all station average shows a quite regular lognormal distribution, with a frequency peak at 0.3 inches. There is a very long right hand tail due to several wet years. The time line graph shows a May average of about 0.4 inches, with numerous wetter years.

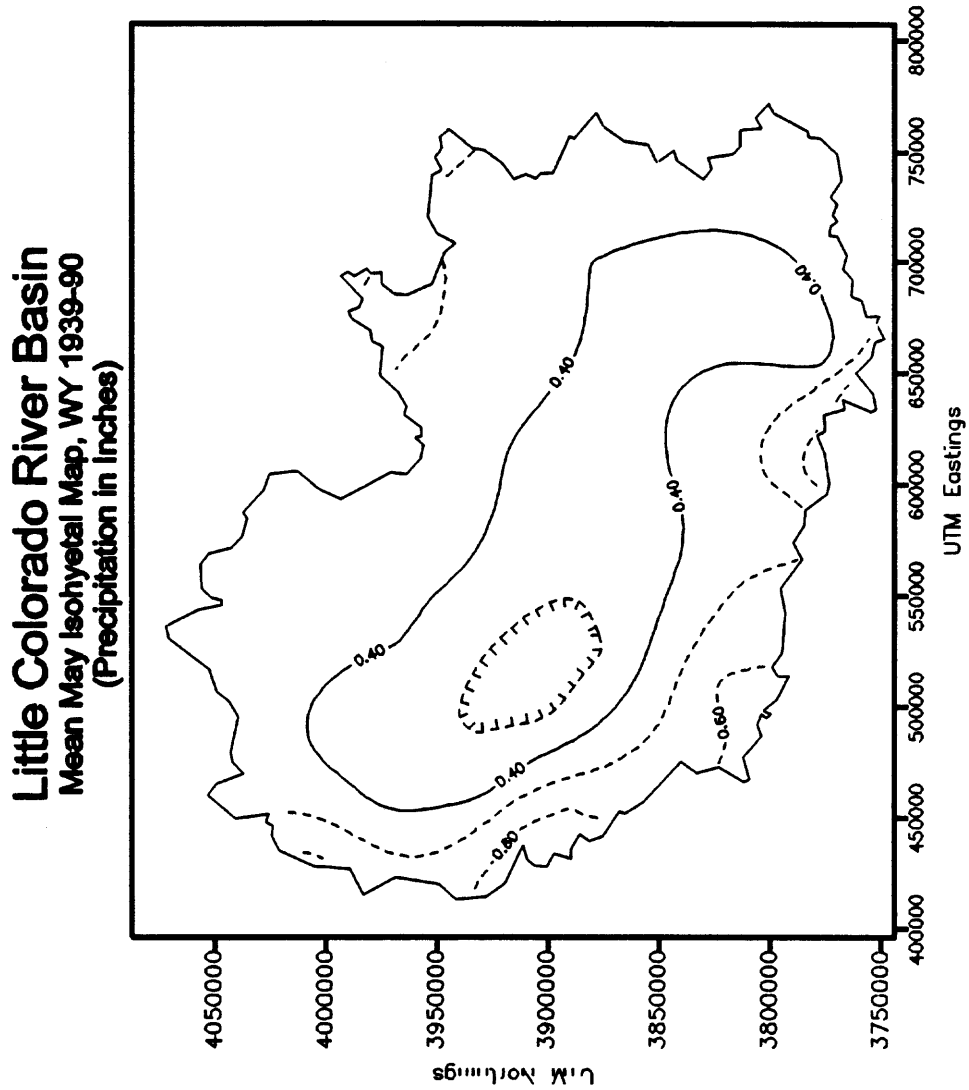


Figure 288. LCR Basin Mean May Isohyetal Map, WY 1939-90

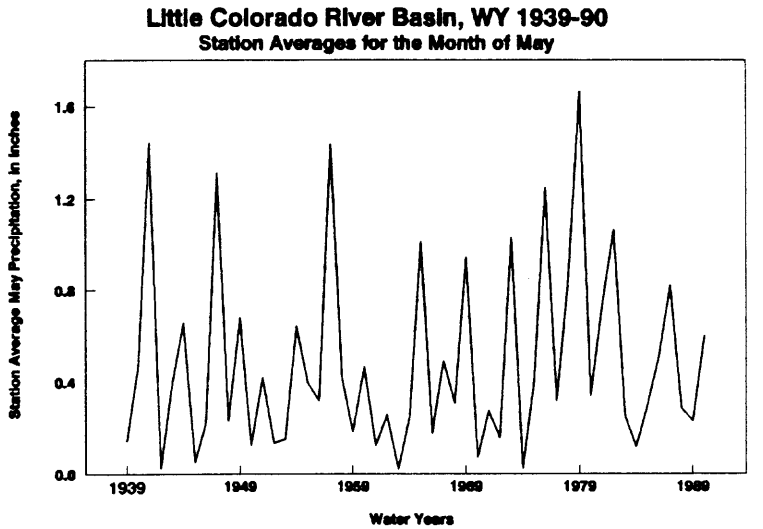


Figure 289. LCR Basin All Station Mean May Precipitation, WY 1939-90

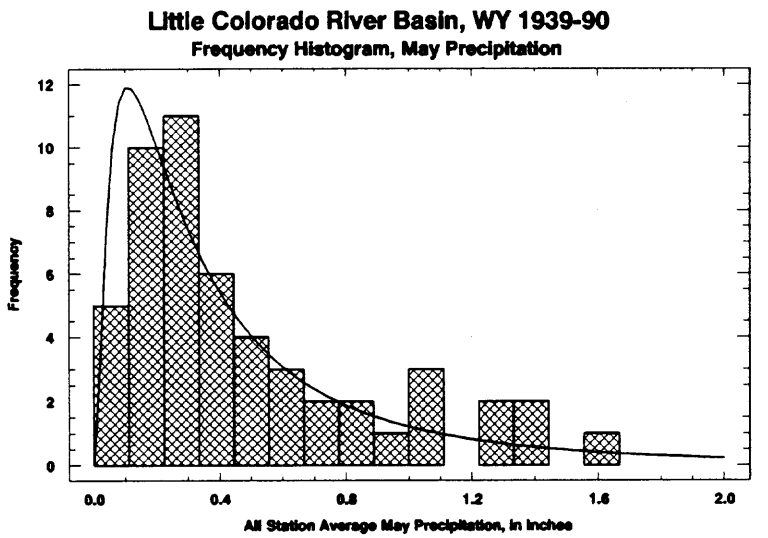


Figure 290. LCR Basin All Station Mean May Precipitation Histogram

6.2.5.4.9 June Isohyetal Map, WY 1939-90

June is the annual minimum with respect to precipitation of the year for the entire 1939-90 study period. Precipitation ranges from about 0.5 inches in the San Francisco Mountains and the White Mountains to less than 0.2 inches in a small area near Cameron. The vast majority of the area of the LCR Basin receives less than 0.4 inches of precipitation in the average June. During this period, the Little Colorado River is usually dry upstream of Blue Spring near the confluence with the main stem Colorado River. The precipitation gradient is very uniform throughout the Basin.

The histogram for the mean basin June precipitation shows an extremely lognormal distribution, with a peak frequency near 0.0 inch of rain falling. Several wetter years near 1.0 inch of rain occur at 1949, 1955, and 1972.

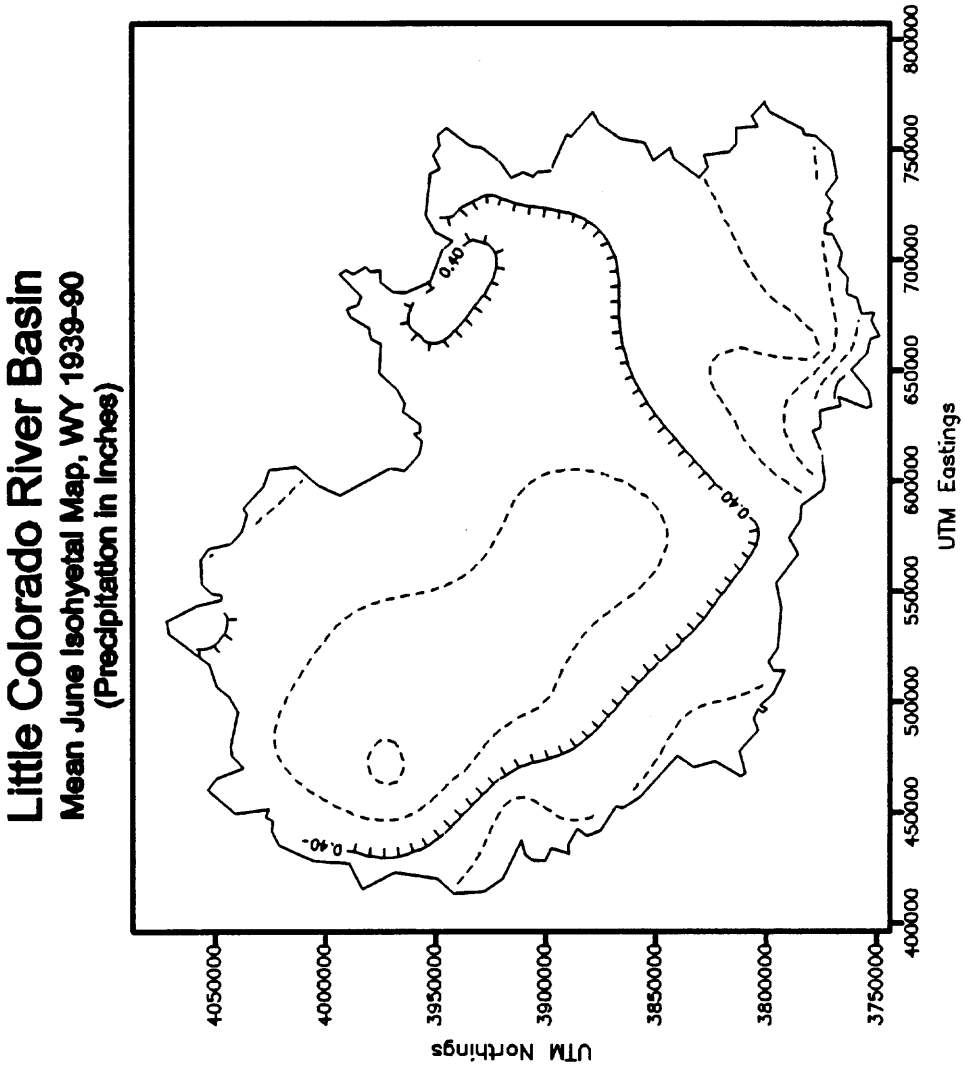


Figure 291. LCR Basin Mean June Isohyetal Map, WY 1939-90

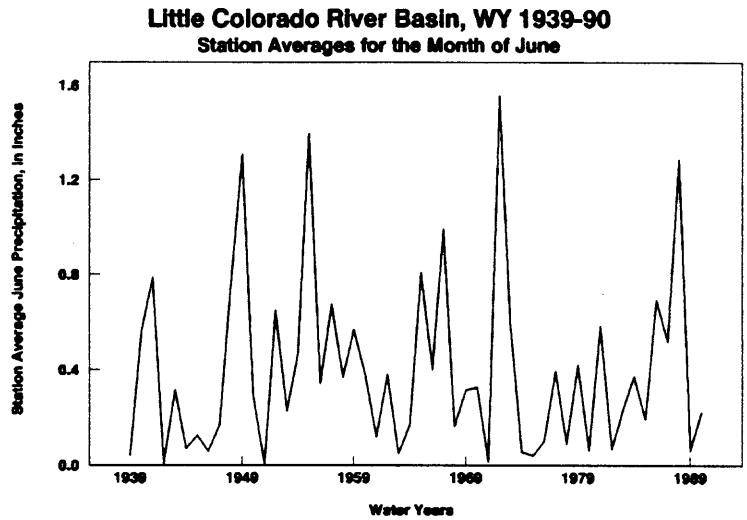


Figure 292. LCR Basin All Station Mean June Precipitation, WY 1939-90

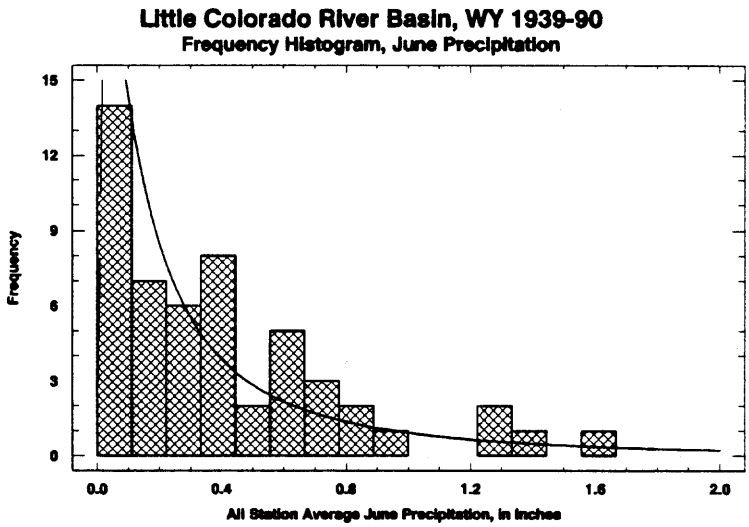


Figure 293. LCR Basin All Station Mean June Precipitation Histogram

6.2.5.4.10 July Isohyetal Map, WY 1939-90

July is one of the wetter months of the average year, with a wide variability due to the variable time of arrival of the summer monsoons. The mean precipitation ranges from over 3.00 inches near McNary and over 2.20 inches in the San Francisco Mountains and the Mogollon Rim to less than 0.80 inches in the desert area near Tuba City. The precipitation distribution is largely orographic, with most of the precipitation falling south and west of Winslow, and east and north of Holbrook. Only the northeastern portion of the LCR Basin receives less than 1.40 inches of rainfall in an average July.

The histogram for the mean July LCR Basin precipitation is strongly bimodal, with frequency peaks at 1.3 and 2.2 inches. Several wetter years give the distribution a positive skewness. The time line graph exhibits a wide variability of July precipitation centered on a mean of about 1.6 inches. Unusually wet Julys occur in 1952, 1959, 1967, 1974, and 1990.

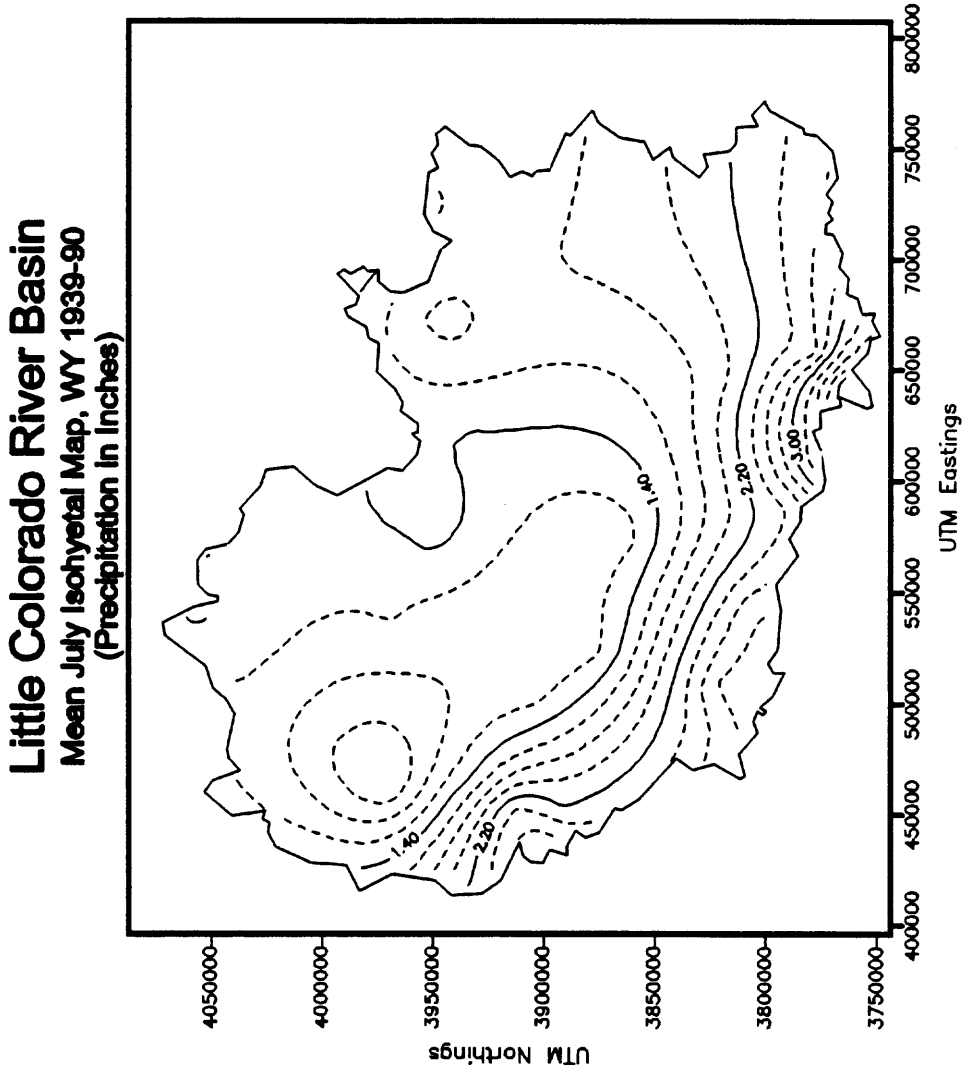


Figure 294. LCR Basin Mean July Isohyetal Map, WY 1939-90

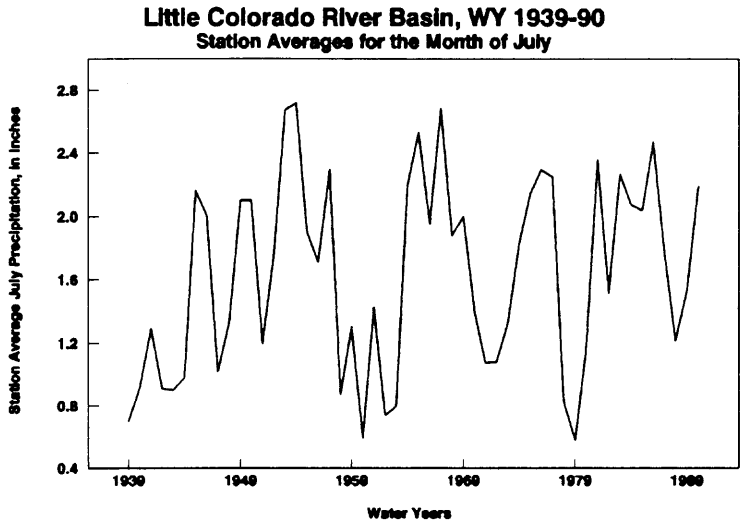


Figure 295. LCR Basin All Station Mean July Precipitation, WY 1939-90

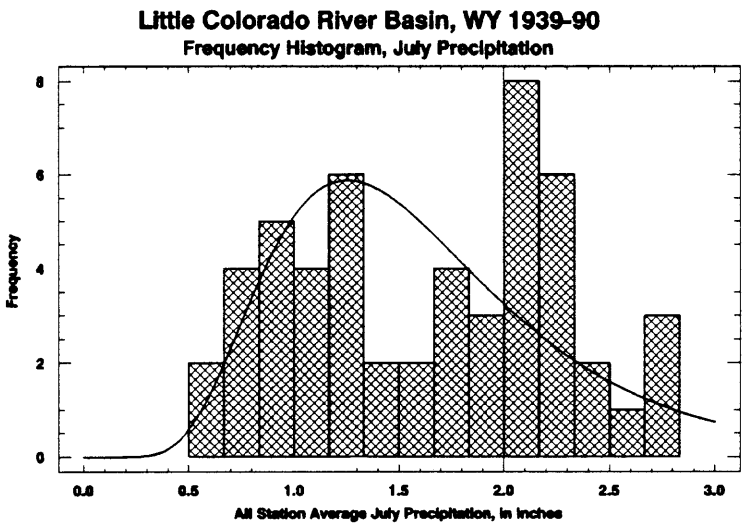


Figure 296. LCR Basin All Station Mean July Precipitation Histogram

6.2.5.4.11 August Isohyetal Map, WY 1939-90

The average August is the wettest month of the average year in the LCR Basin. Precipitation averages from a high of over 3.00 inches in that portion of the Mogollon Rim near Chevelon Ranger Station and in the McNary, Greer, and Alpine area to less than one inch in a small desert area near Tuba City. Over half of the LCR Basin receives over 2.00 inches of rain in the average August.

The histogram for the mean August LCR Basin precipitation is strongly bimodal, with frequency peaks at 1.2 and 1.8 inches. Another frequency peak is noted at 3.00 inches, which, along with several other extremely wet Augusts, accounts for the mean of over 2.00 inches. In the time line graph, notable wet Augusts occur in 1946, 1951, 1961, 1983, and 1990.

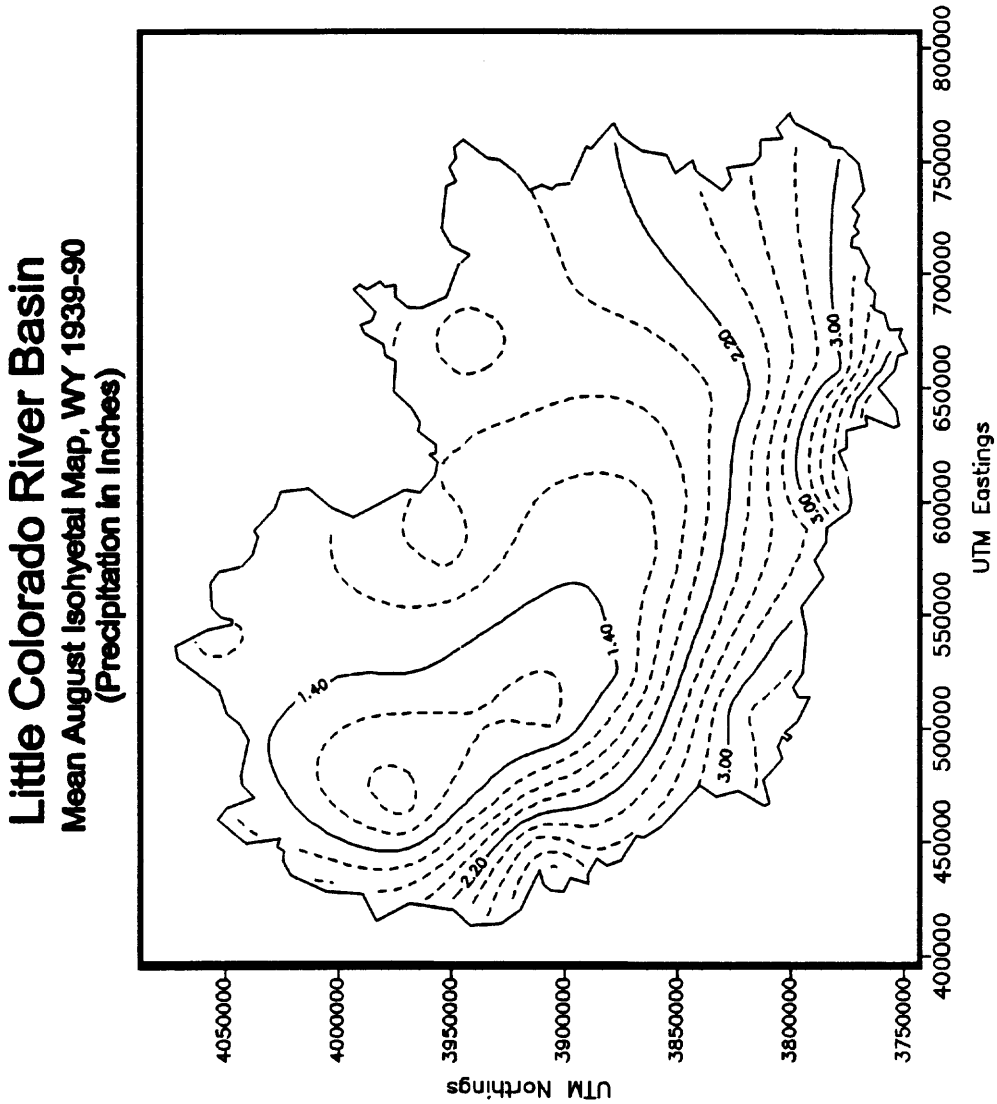


Figure 297. LCR Basin Mean August Isohyetal Map, WY 1939-90

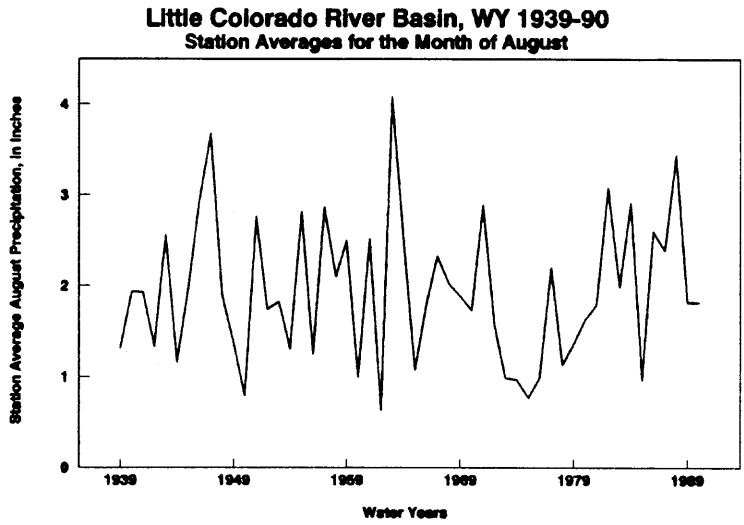


Figure 298. LCR Basin All Station Mean August Precipitation, WY 1939-90

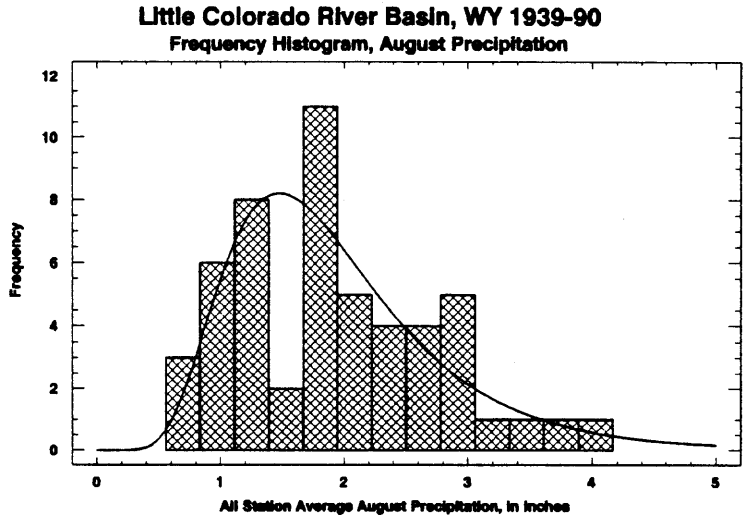


Figure 299. LCR Basin All Station Mean August Precipitation Histogram

6.2.5.4.12 September Isohyetal Map, WY 1939-90

The average September is fairly wet in the LCR Basin, but not as wet as July and August. Mean precipitation ranges from over 1.60 inches in the San Francisco Mountains and the Mogollon Rim to less than 0.80 inches in the desert area near Tuba City and Cameron. The precipitation gradient evenly slopes downward through the higher elevations toward the low elevation area near Cameron.

The histogram for the mean August LCR Basin precipitation is largely trimodal, with frequency peaks at 0.2, 0.8, and 1.6 inches. A few wetter years gives the distribution a positive skewness. The time line graph is highly variable around an average of about 1.2 inches. Notable wet Septembers include 1940, 1958, 1983, and 1990.

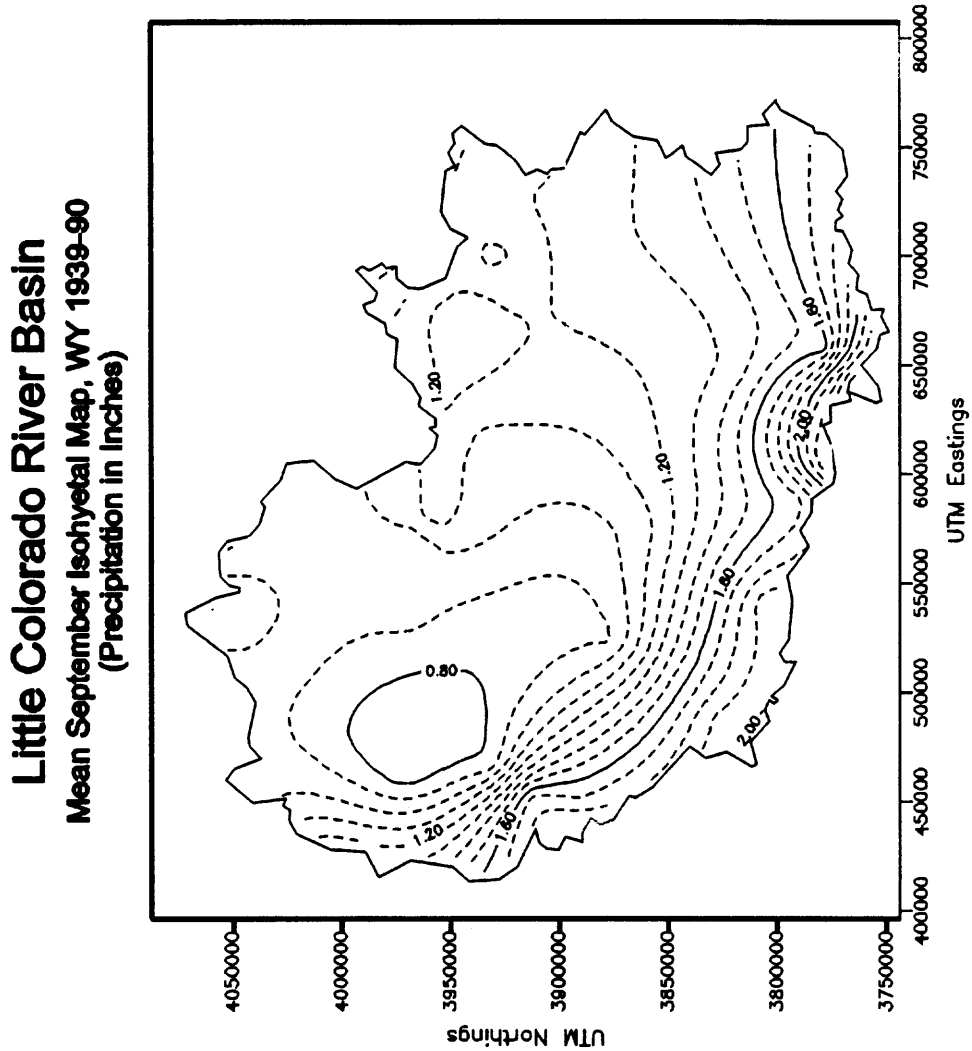


Figure 300. LCR Basin Mean September Isohyetal Map, WY 1939-90

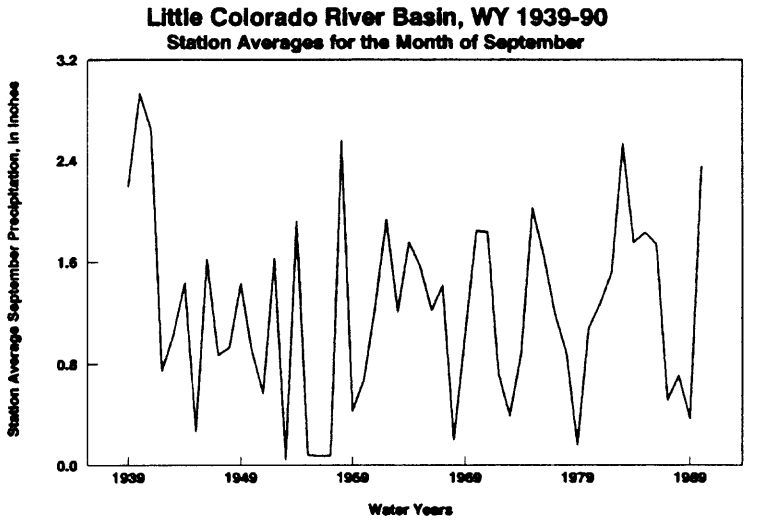


Figure 301. LCR Basin All Station Mean September Precipitation, WY 1939-90

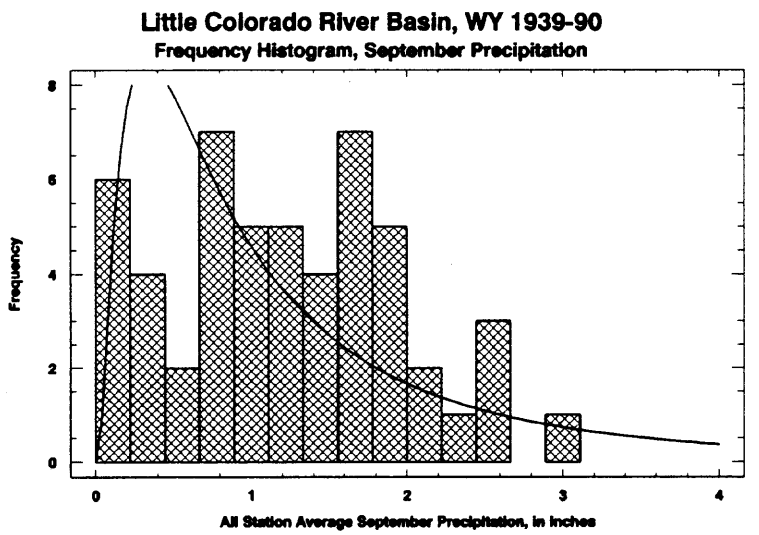


Figure 302. LCR Basin All Station Mean September Precipitation Histogram

6.2.6 Trends in Precipitation Variability

The purpose of this section of the climate investigation is to determine whether there are apparent trends in the variability of precipitation which would indicate long-term reductions or increases in the temporal or spatial variability. In turn, variations in volume and intensity of precipitation could naturally impact the Little Colorado River Basin hydrology, including available surface water flows and sediment transport for input into the system.

The precipitation variability which exists in the historical record may indicate certain environmental management decisions which will have to be made to insure sufficient water and sediment for the replenishment of main stem Colorado River beaches and for the maintenance of endangered species. Several types of variability are considered -- annual volume, intensity, and spatial distribution of variability.

6.2.6.1 Variations in Precipitation Volume

The LCR precipitation station average annual and average monthly precipitation values were plotted against the elevations of the stations. In all months and in the study period averages, the trends are strongly orographic. The higher elevations have consistently higher precipitation values than those of the low-altitude desert areas. The general trend of the plots is slightly to moderately exponential.

The monthly n-weighted standard deviation was computed for each precipitation station. The standard deviations were plotted against elevation for all stations for each month. It is noted that in all months there is a pronounced orographic effect not only in the volume of precipitation but also in the standard deviations of precipitation. Thus, the high-altitude mountainous stations vary in their volume more than the low-altitude desert stations.

The mean annual standard deviations for all stations are also presented in an isoline map format. This illustration demonstrates that the spatial distribution of precipitation variability is related to the altitude of the stations.

6.2.6.1.1 Annual Precipitation Variability

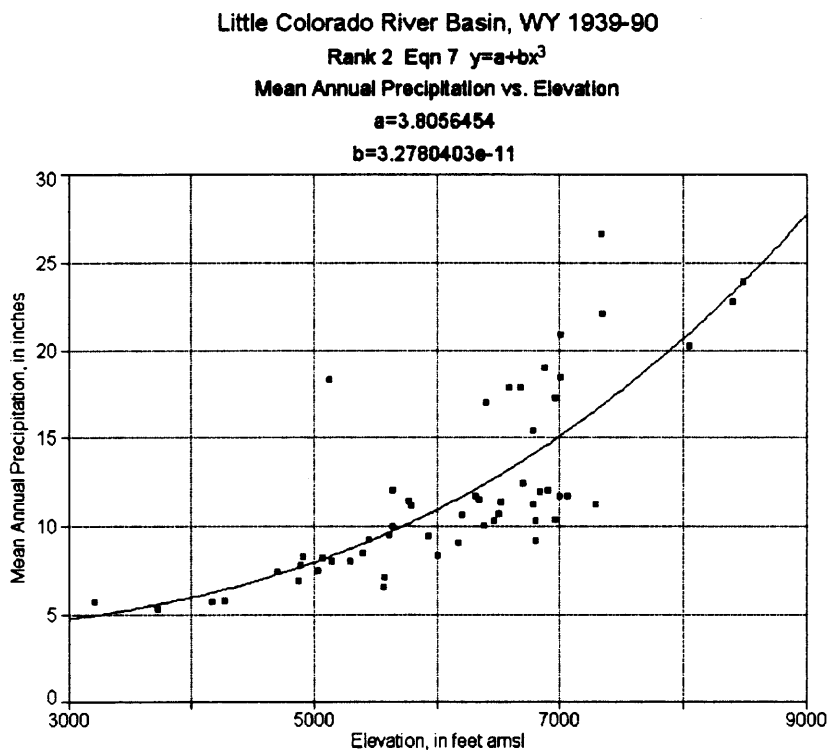


Figure 303. LCR Basin Mean Annual Precipitation vs. Elevation

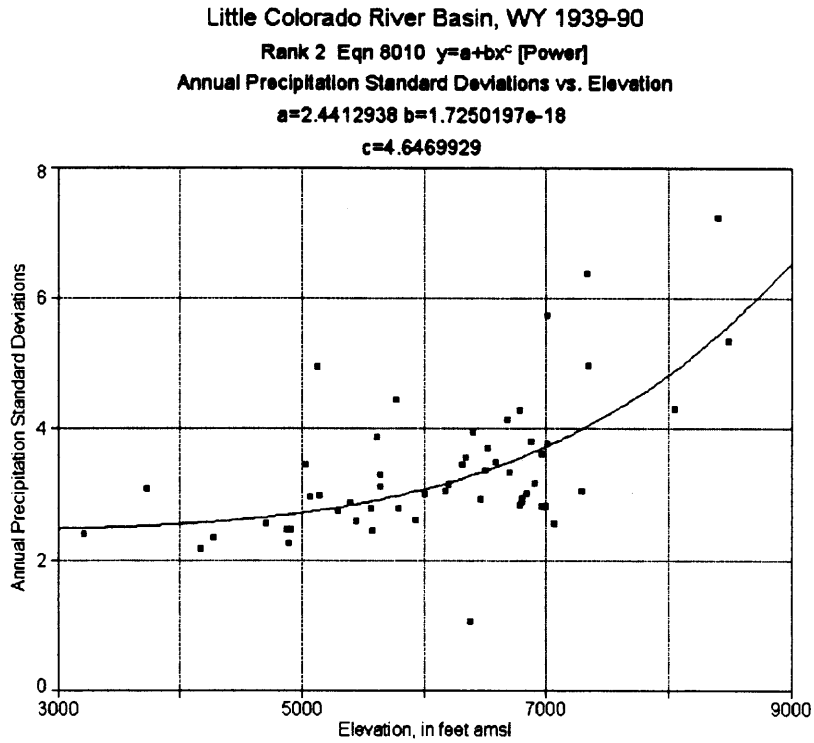


Figure 304. LCR Basin Mean Annual Precipitation Standard Deviations vs. Elevation

6.2.6.1.2 October Precipitation Variability

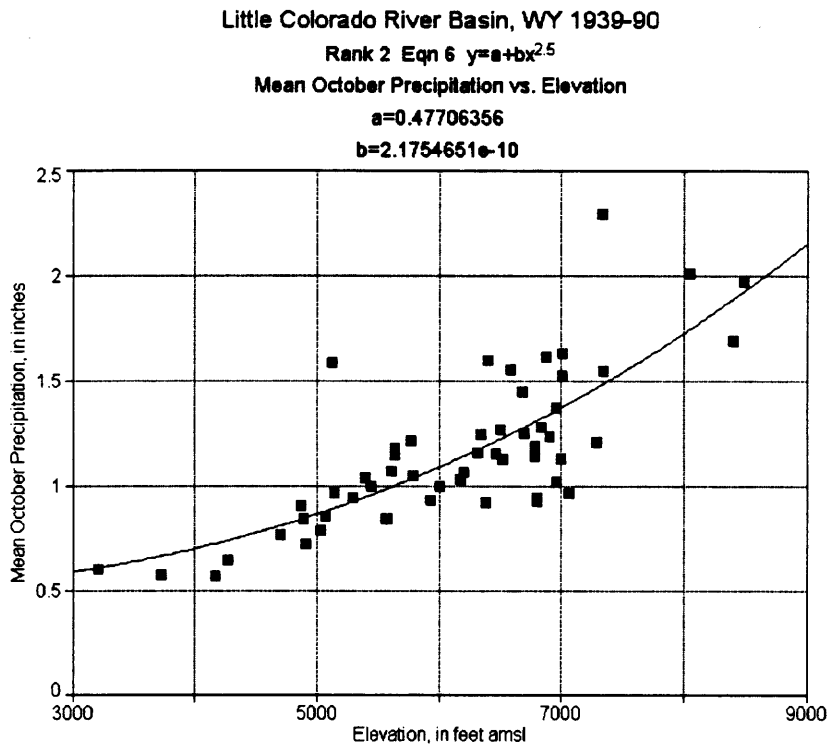


Figure 305. LCR Basin Mean October Precipitation vs. Elevation

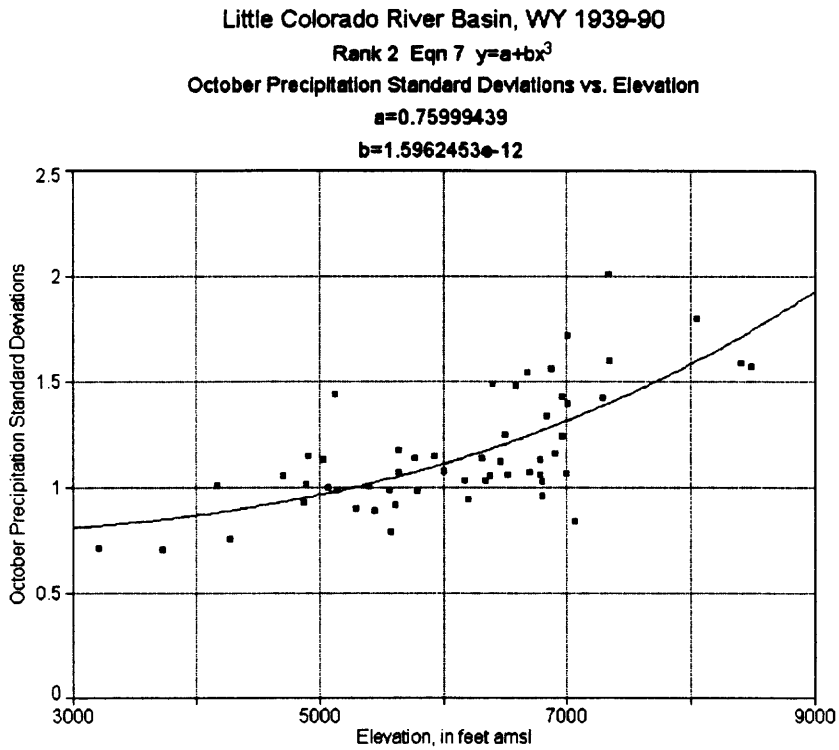


Figure 306. LCR Basin Mean October Precipitation Standard Deviations vs. Elevation

6.2.6.1.3 November Precipitation Variability

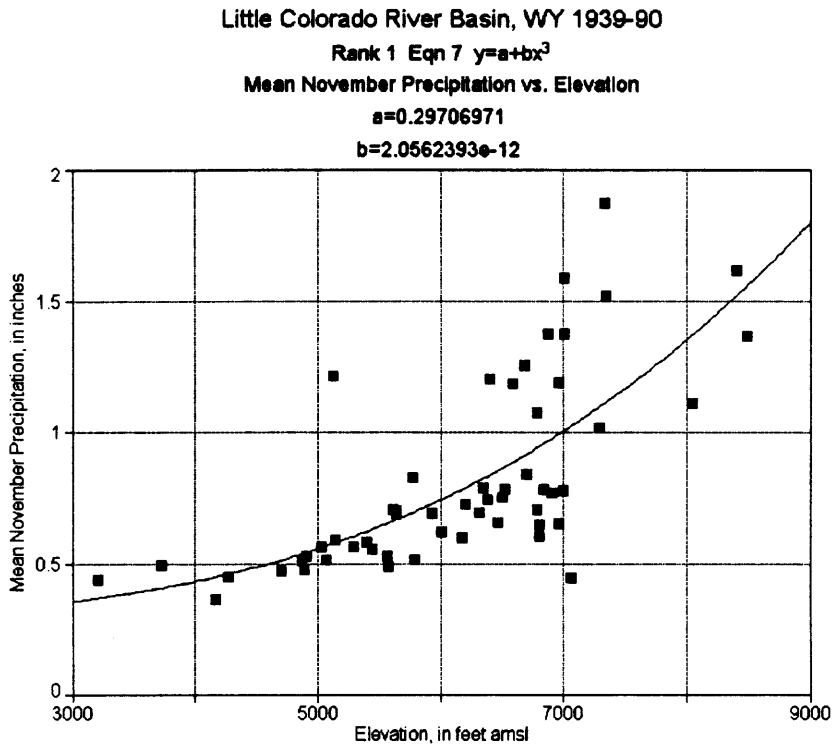


Figure 307. LCR Basin Mean November Precipitation vs. Elevation

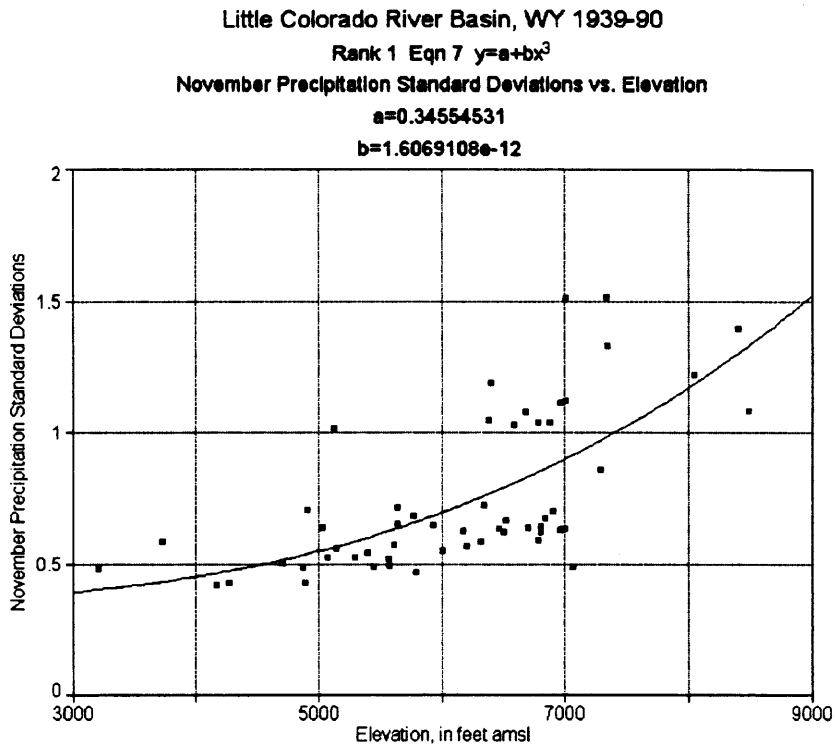


Figure 308. LCR Basin Mean November Precipitation Standard Deviations vs. Elevation

6.2.6.1.4 December Precipitation Variability

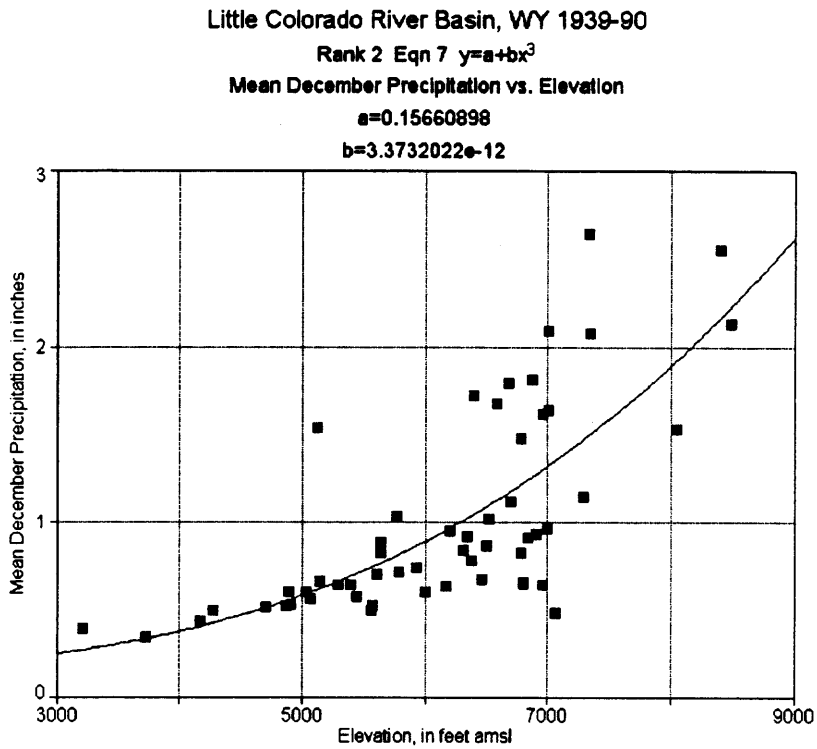


Figure 309. LCR Basin Mean December Precipitation vs. Elevation

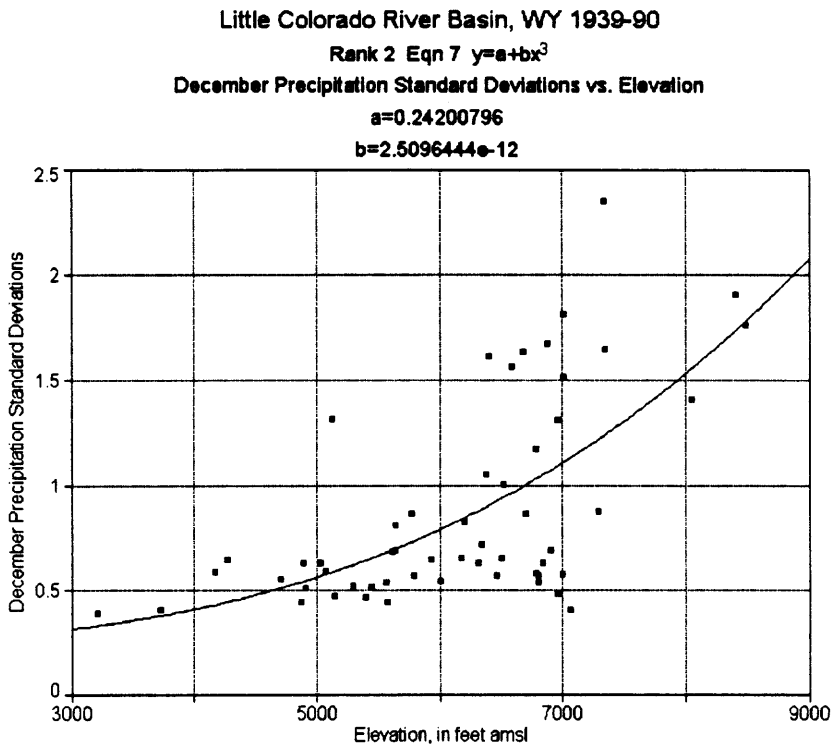


Figure 310. LCR Basin Mean December Precipitation Standard Deviations vs. Elevation

6.2.6.1.5 January Precipitation Variability

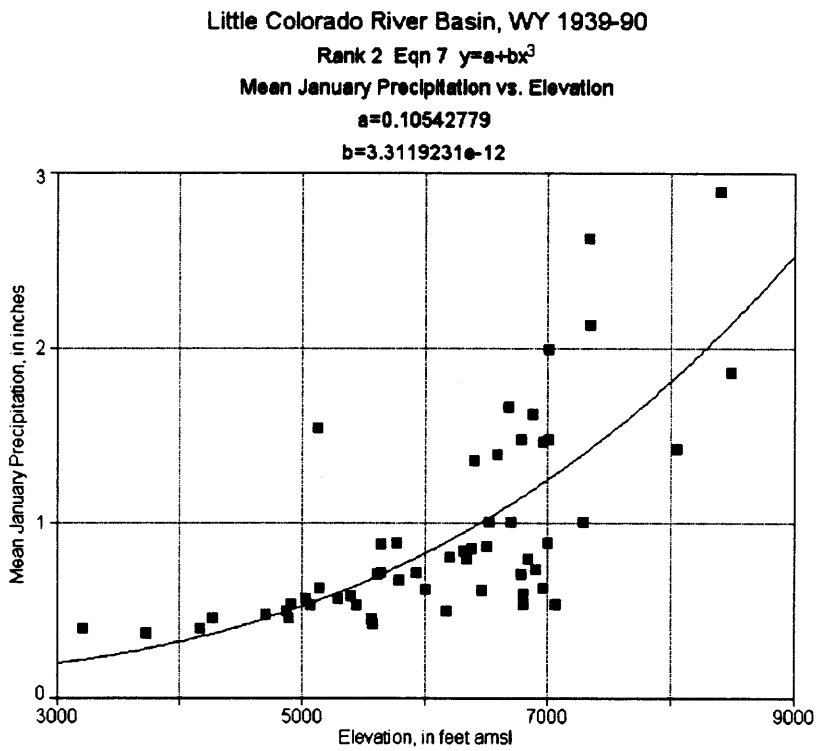


Figure 311. LCR Basin Mean January Precipitation vs. Elevation

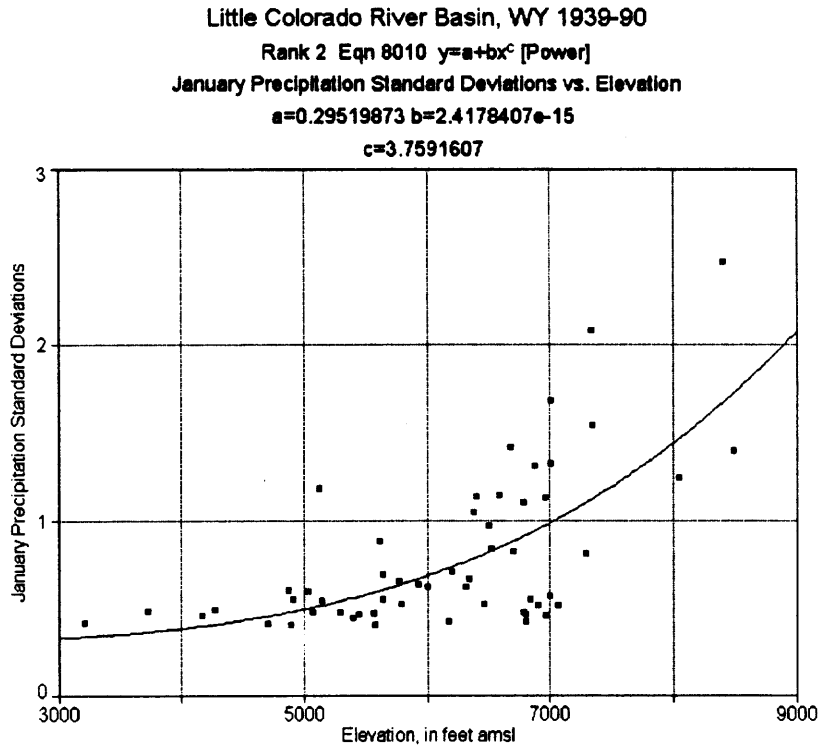


Figure 312. LCR Basin Mean January Precipitation Standard Deviations vs. Elevation

6.2.6.1.6 February Precipitation Variability

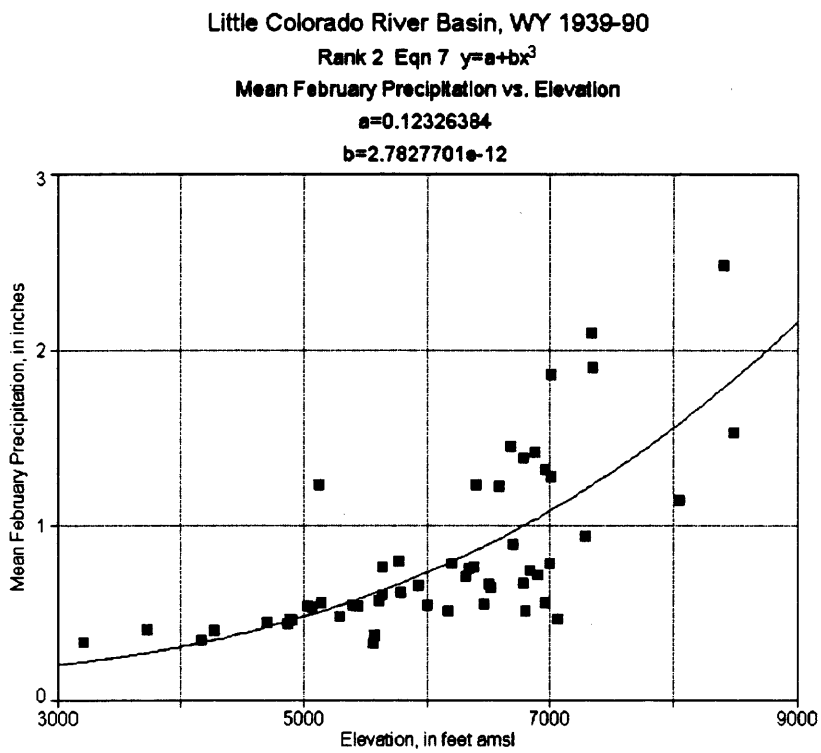


Figure 313. LCR Basin Mean February Precipitation vs. Elevation

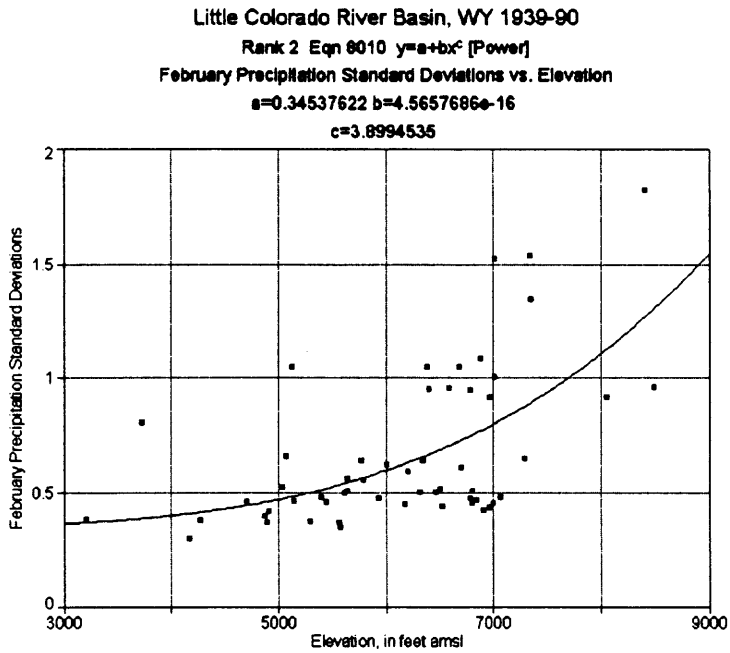


Figure 314. LCR Basin Mean February Precipitation Standard Deviations vs. Elevation

6.2.6.1.7 March Precipitation Variability

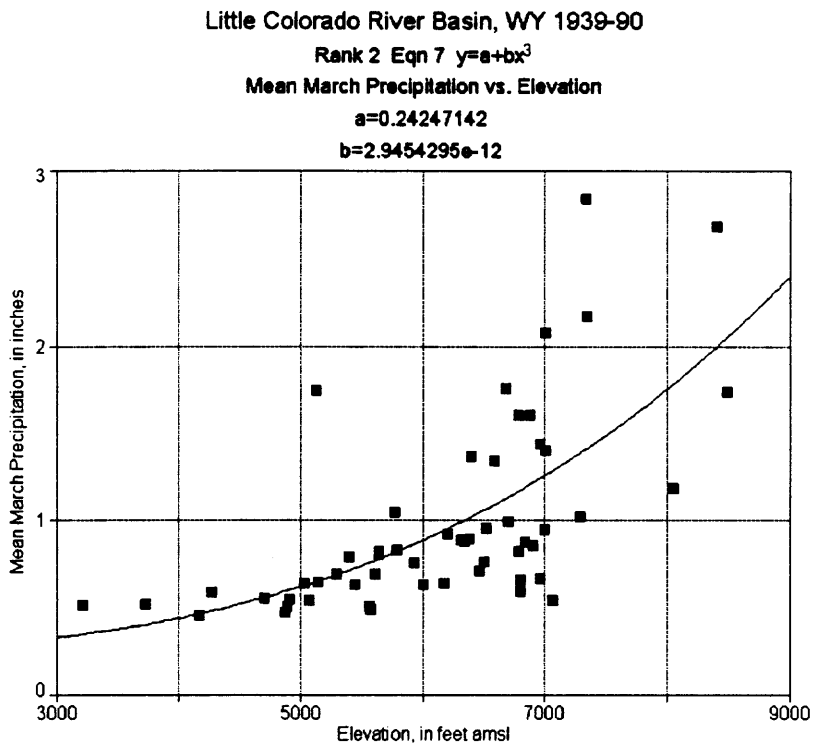


Figure 315. LCR Basin Mean March Precipitation vs. Elevation

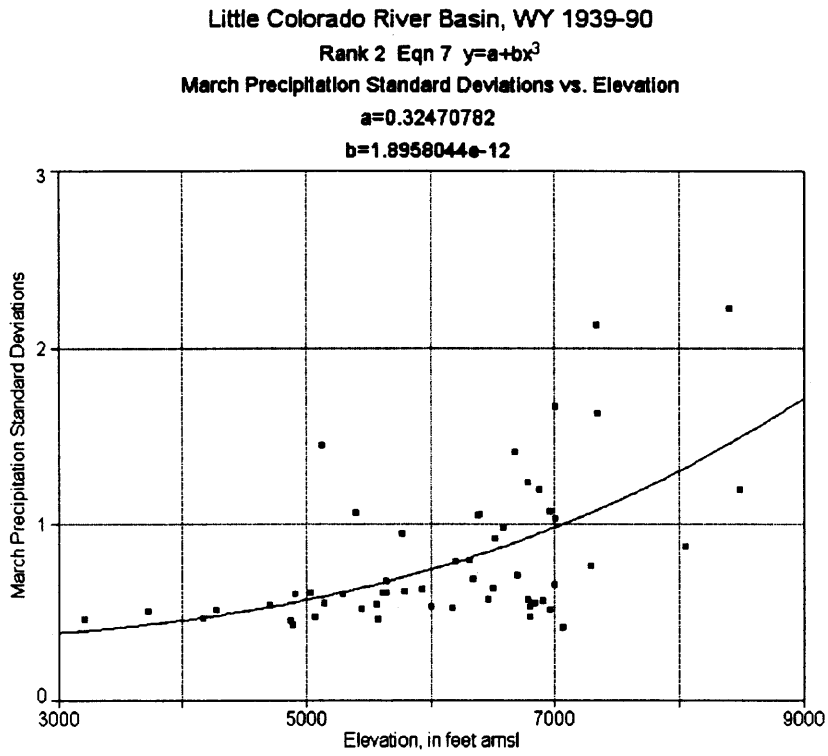


Figure 316. LCR Basin Mean March Precipitation Standard Deviations vs. Elevation

6.2.6.1.8 April Precipitation Variability

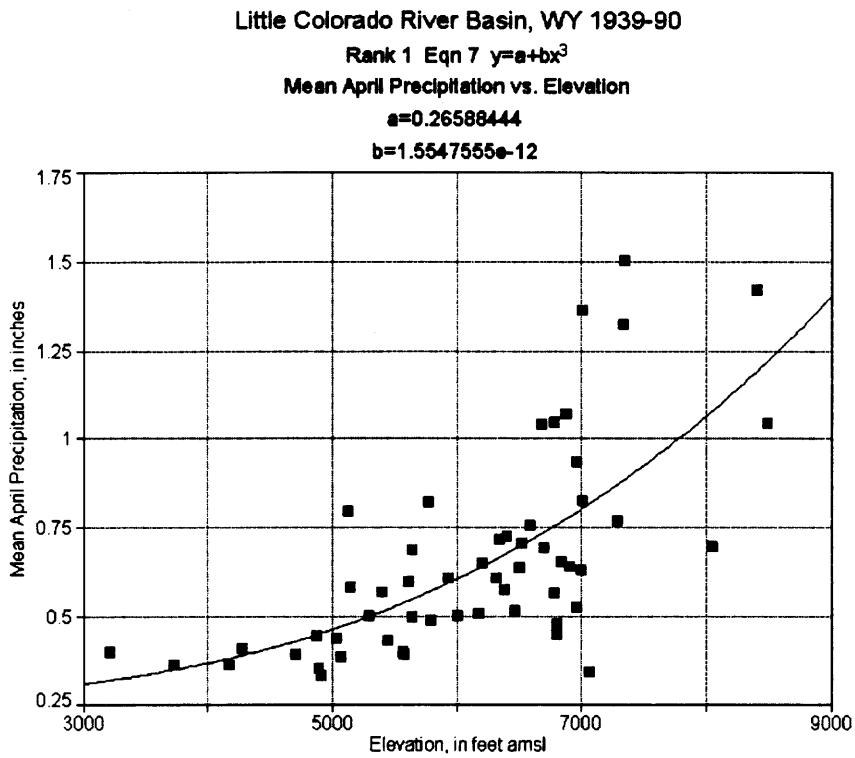


Figure 317. LCR Basin Mean April Precipitation vs. Elevation

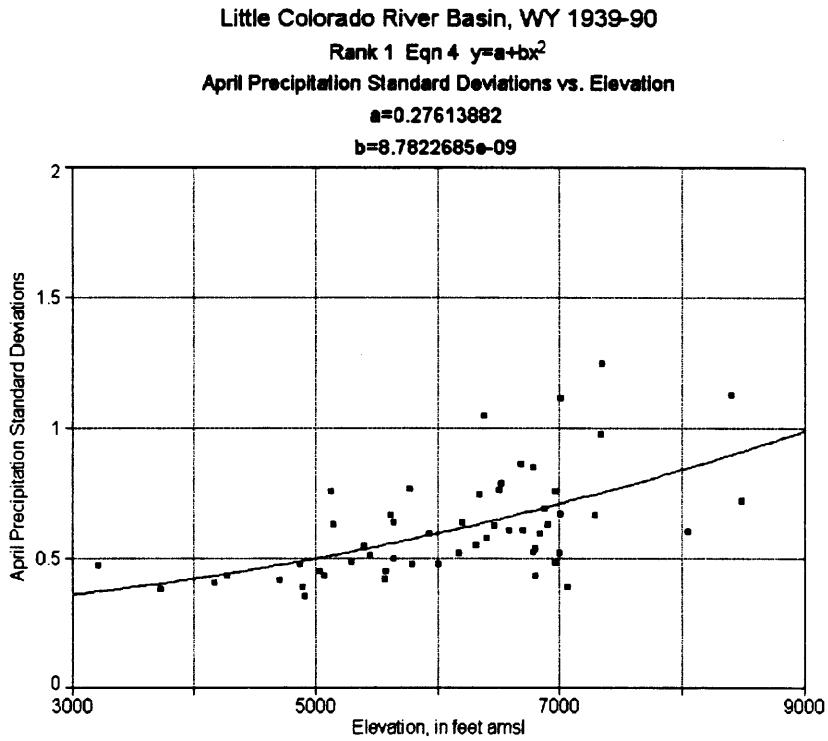


Figure 318. LCR Basin Mean April Precipitation Standard Deviations vs. Elevation

6.2.6.1.9 May Precipitation Variability

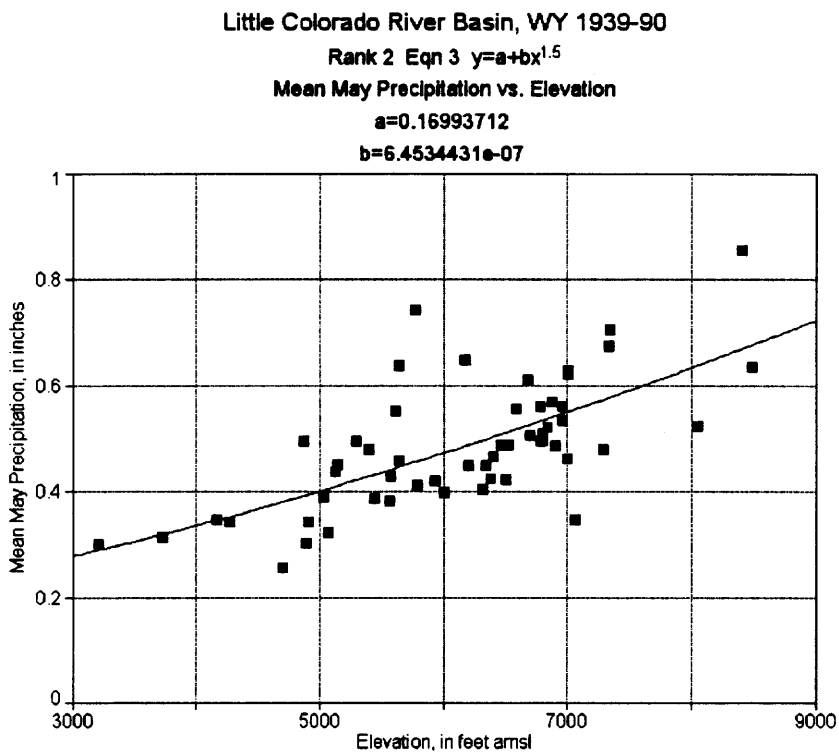


Figure 319. LCR Basin Mean May Precipitation vs. Elevation

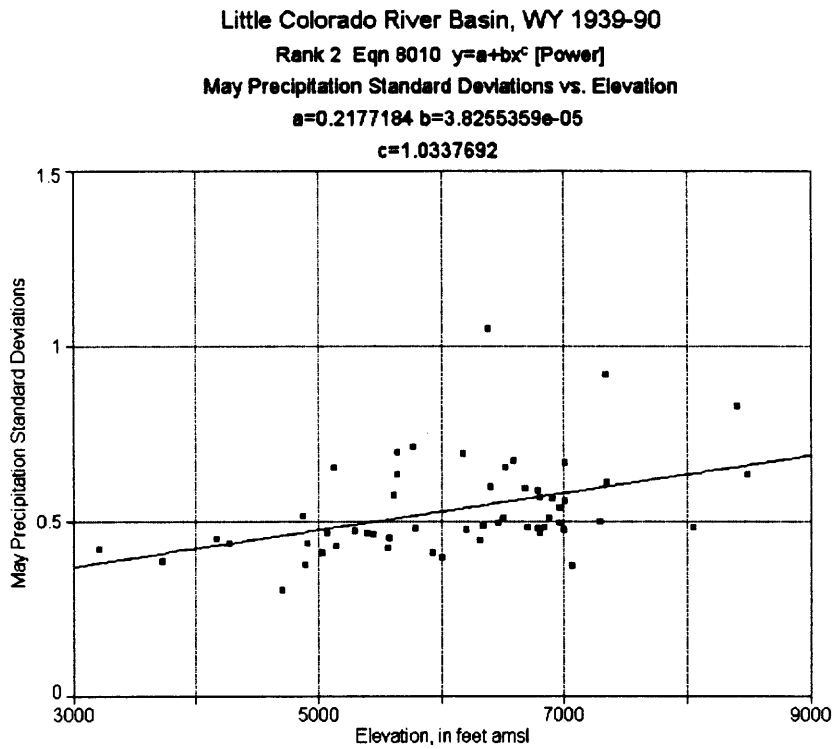


Figure 320. LCR Basin Mean May Precipitation Standard Deviations vs. Elevation

6.2.6.1.10 June Precipitation Variability

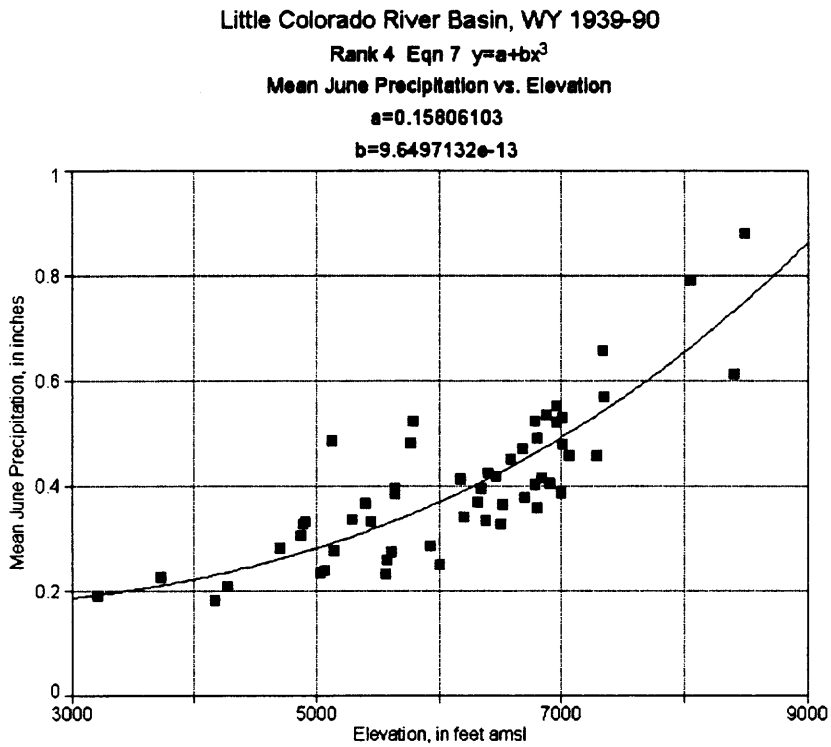


Figure 321. LCR Basin Mean June Precipitation vs. Elevation

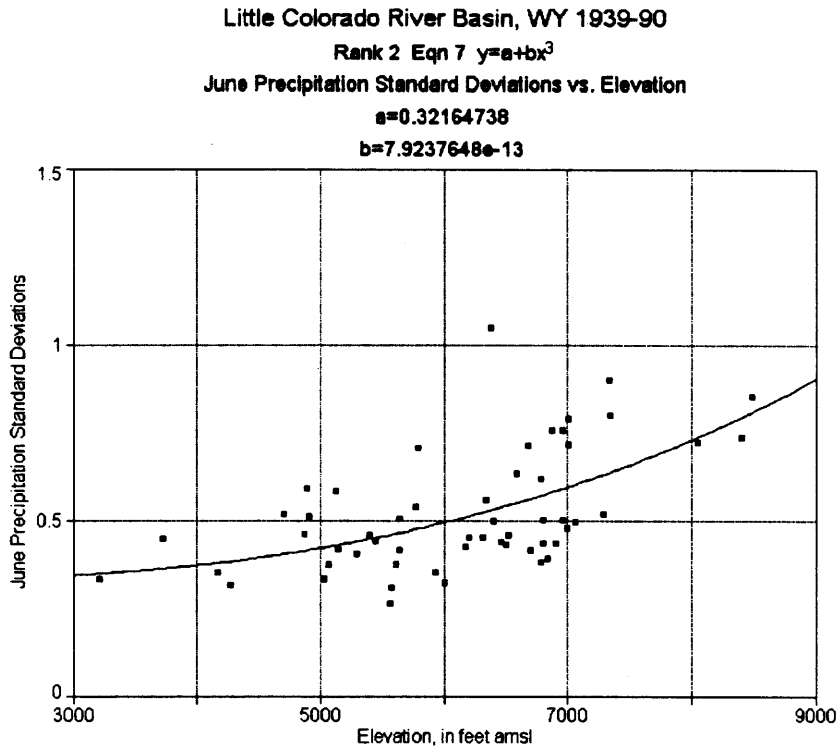


Figure 322. LCR Basin Mean June Precipitation Standard Deviations vs. Elevation

6.2.6.1.11 July Precipitation Variability

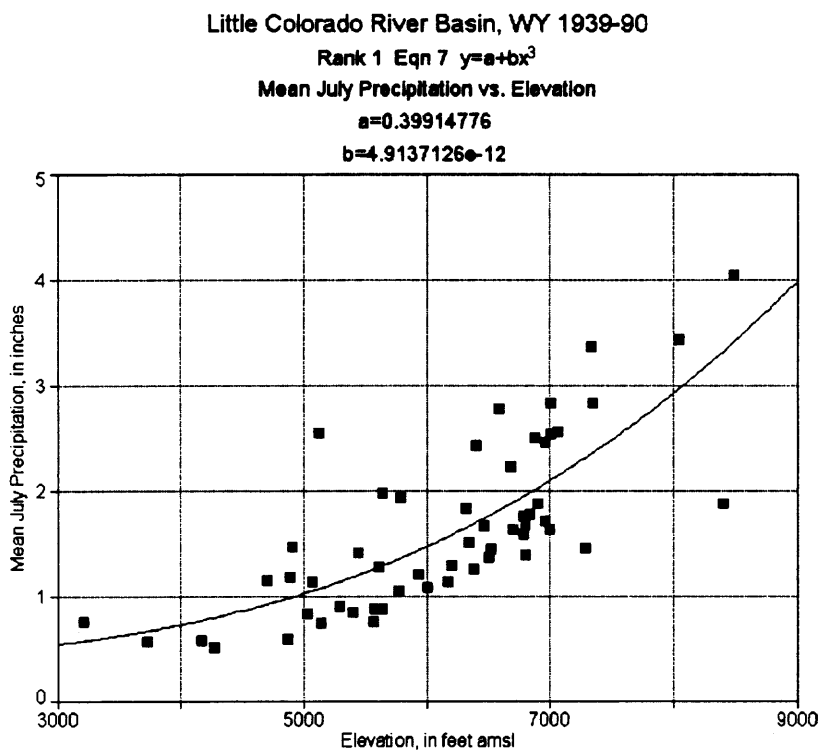


Figure 323. LCR Basin Mean July Precipitation vs. Elevation

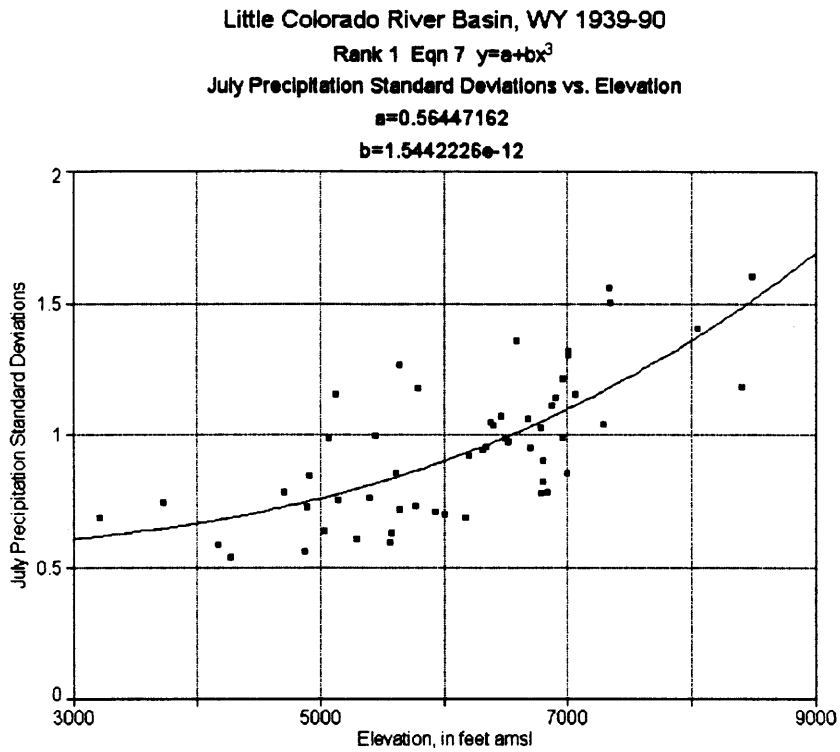


Figure 324. LCR Basin Mean July Precipitation Standard Deviations vs. Elevation

6.2.6.1.12 August Precipitation Variability

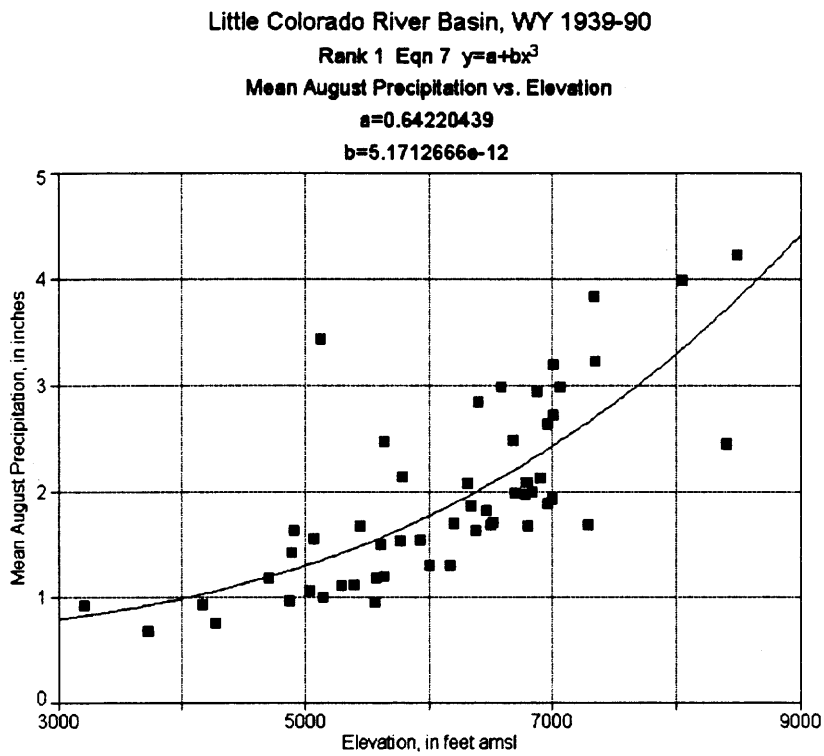


Figure 325. LCR Basin Mean August Precipitation vs. Elevation

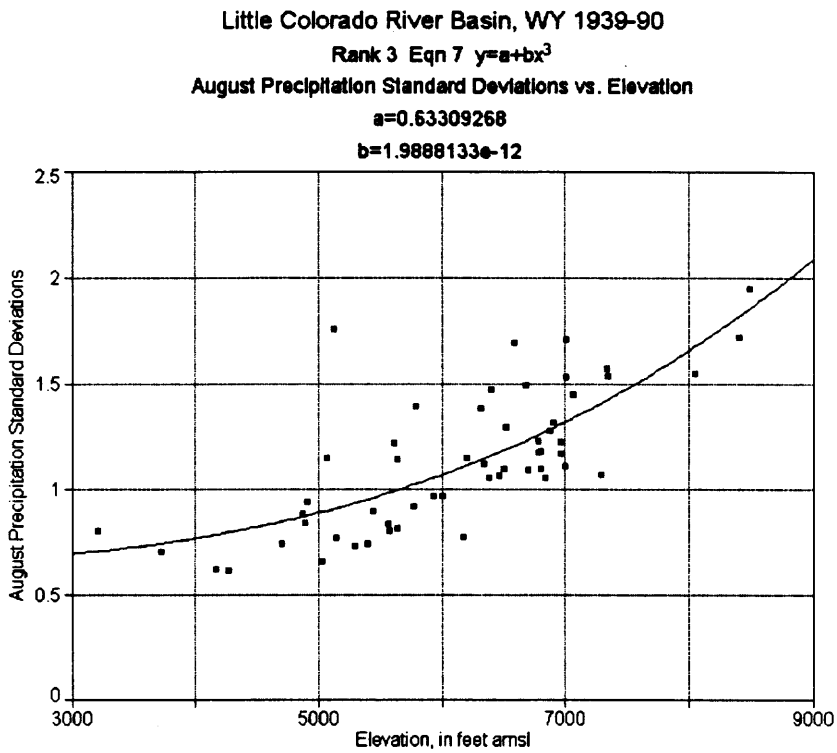


Figure 326. LCR Basin Mean August Precipitation Standard Deviations vs. Elevation

6.2.6.1.13 September Precipitation Variability

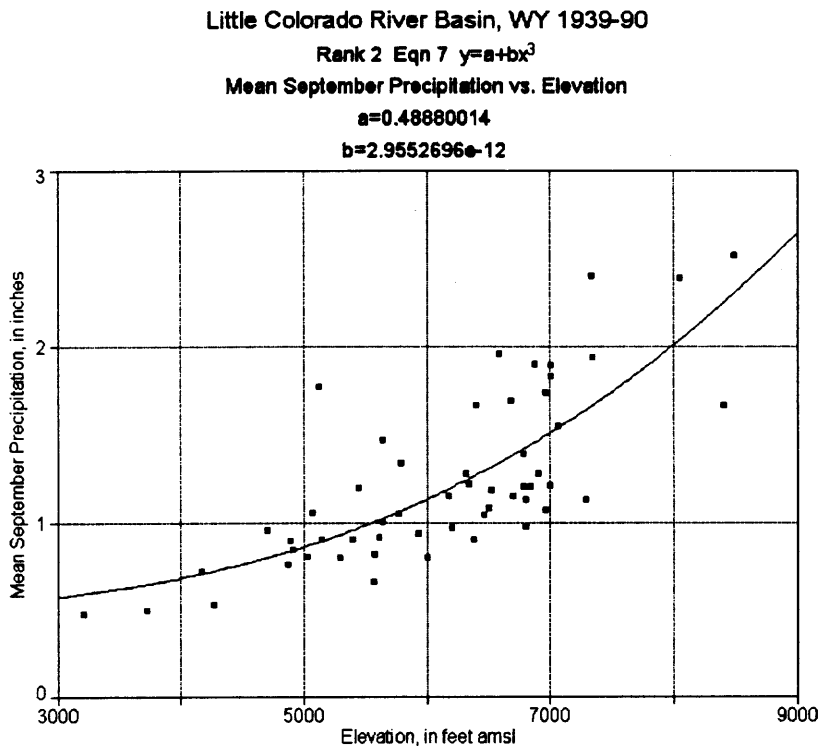


Figure 327. LCR Basin Mean September Precipitation vs. Elevation

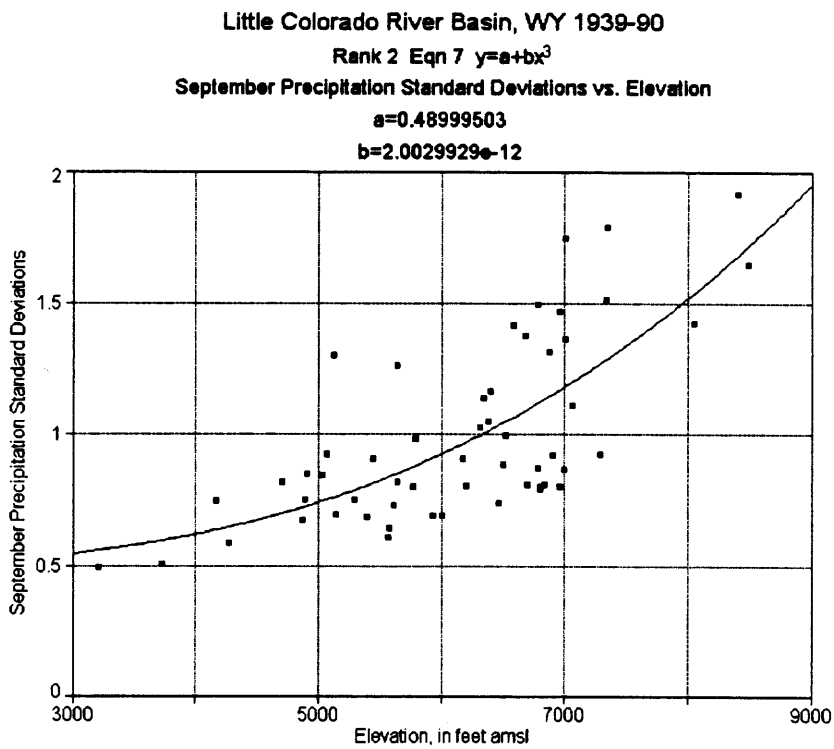


Figure 328. LCR Basin Mean September Precipitation Standard Deviations vs. Elevation

6.2.6.1.14 Spatial Distribution of Annual Precipitation Variability

The following map is an isoline plot of the standard deviations for the mean annual precipitation values for the 1939-90 study period. This diagram illustrates the orographic nature of the variability of precipitation in the basin. The highly variable ($s > 5.00$) area of the west side of the map is the Flagstaff vicinity. The highly variable area to the south is in the eastern Mogollon Rim/White Mountains area.

The standard deviations are at a minimum in the broad area extending from the southeast to northwest along the Little Colorado River Valley. The standard deviations along the Valley are less than 3.00. To the northeast toward Gallup and Fort Wingate, there is a small area with a standard deviation of less than 3.00. The region extending from Springerville and Saint Johns through Klagetoh and Keams Canyon, which corresponds geographically to middle elevation desert plateaus, has a standard deviation of between 3.00 and 4.00.

The result of this portion of the precipitation study indicates that one may observe a greater variability in the flows from the mountainous regions of the southwestern and southern portions of the LCR Basin which provide snowmelt flows to the southerly washes and the upper main stem reaches of the Little Colorado River than in the low elevation desert regions. For this reason, one could expect a greater variation in spring snowmelt flows at Cameron and Grand Falls than during the summer monsoon thunderstorm-driven flows.

This aspect of flow variability will be examined in greater detail in a subsequent section.

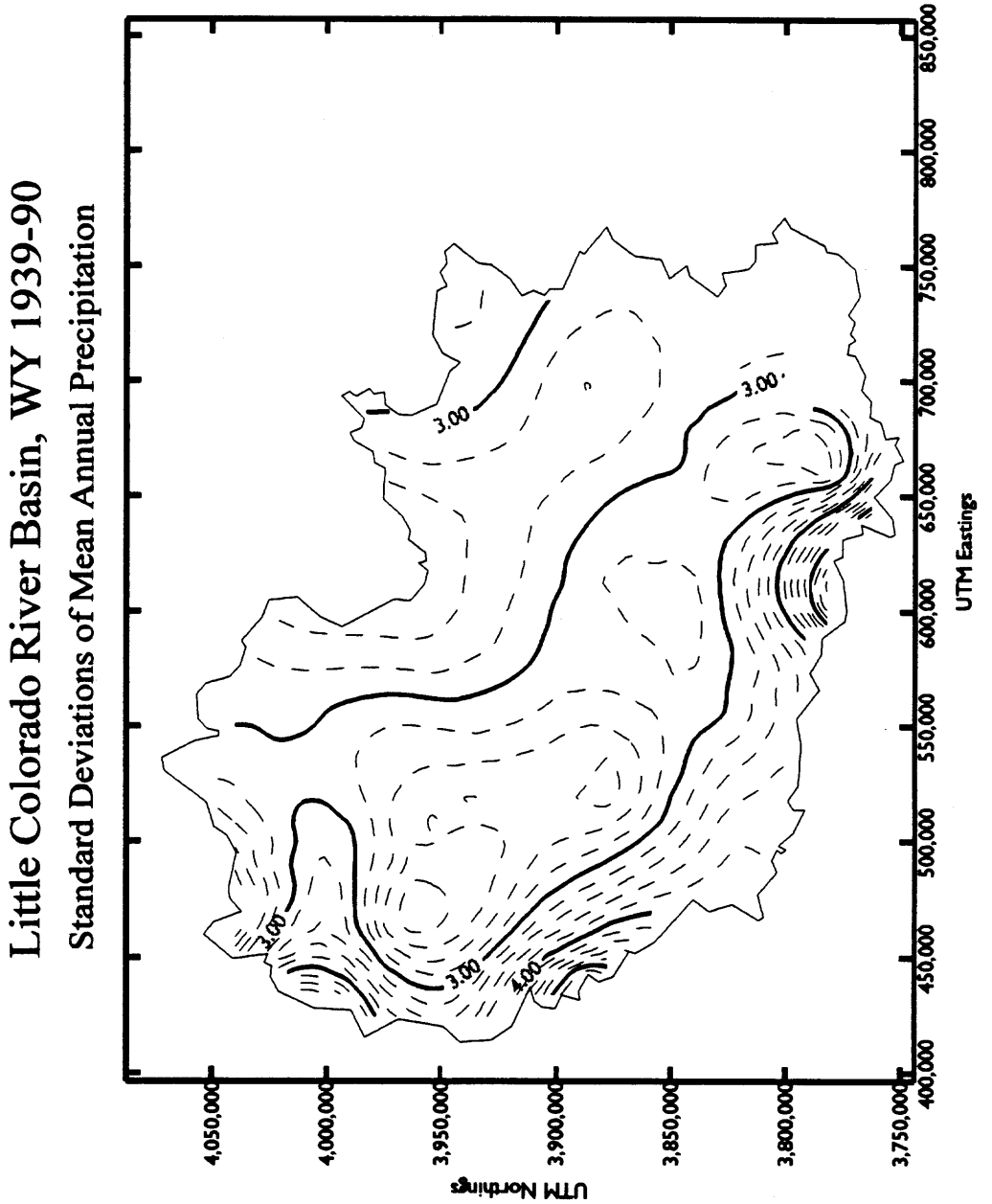


Figure 329. LCR Basin, Spatial Distribution of Precipitation Variability

The preceding analysis demonstrates the spatial variability of precipitation on an arithmetic basis. This measure is significant, since the greater variation at the higher elevations, which contribute most of the moisture in the system, will result in the greater variation in the discharges of the drainages.

Another way to examine the variability is by utilizing a more equal scale, so that the variability is examined as if the mean precipitations were equal. The most expedient approach to accomplish this equalization is by standardizing the data. Standardization enables the comparison of random variables independently of the unit of measurement. Each data point is transformed into the standard normal form according to the following equation.

$$Z_i = \frac{X_i - \overline{X}}{s}$$

Where: Z_i = the standard normal form
X_i = the ith measurement of X
$\overline{X}$ = the mean of the sample
and s = the sample standard deviation

The variation in the standardized data tends to be negatively orographic and the variation is moderately inversely proportional to the elevation of the station. The following graph of ranges of the standardized data demonstrates this negative orographic effect. In other words, the lower elevations are more variable than the higher elevations when they are set to the same scale. Unfortunately, this fact has little influence on the variation in the magnitude of discharges in the system.

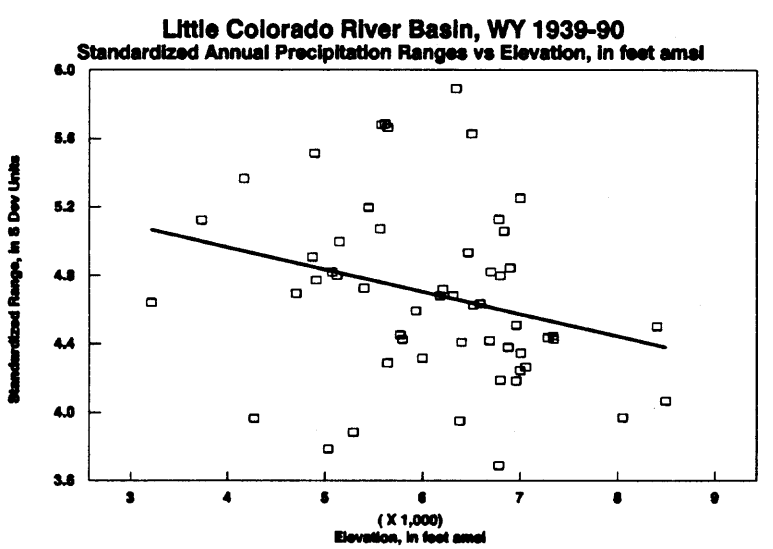


Figure 330. LCR Basin, Range of Standardized Precipitation vs. Elevation

The following map exhibits the spatial distribution of the ranges of the standardized precipitation data.

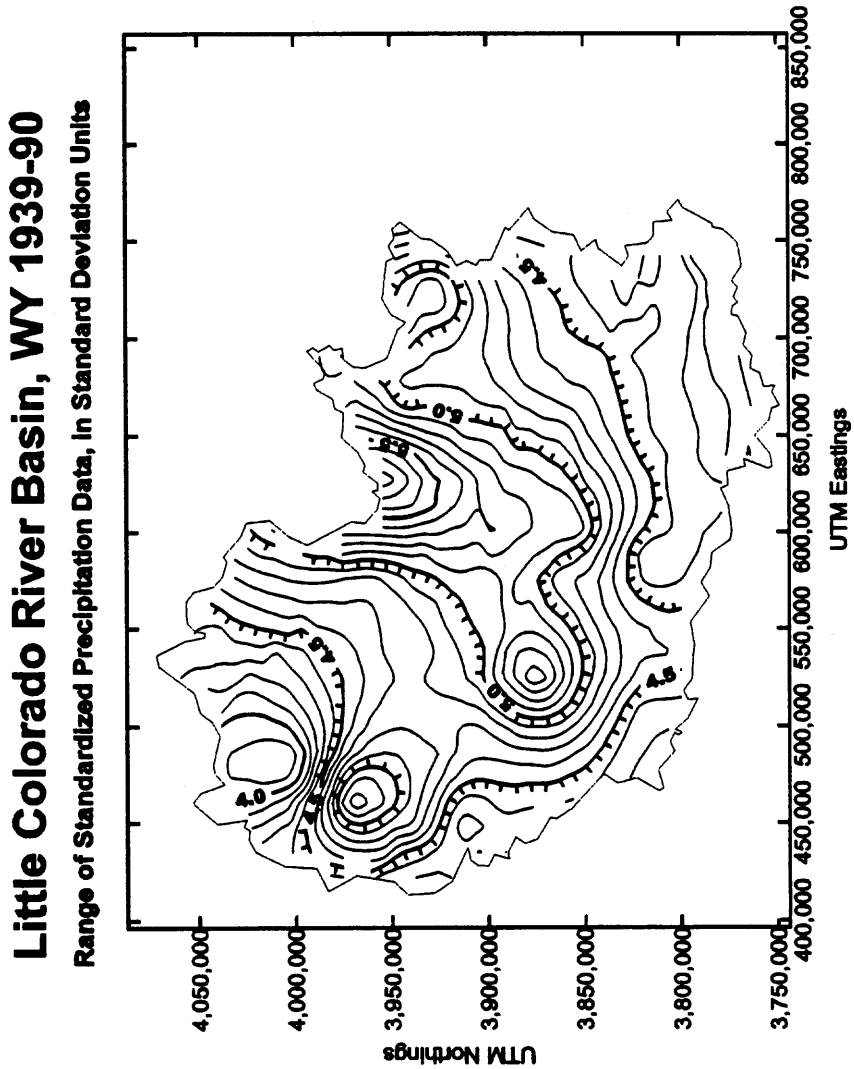


Figure 331. LCR Basin, Contour Map of Ranges of Standardized Precipitation Data

6.2.6.2 Variations in Intensity

It has been proposed by Richard Hereford of the USGS in Flagstaff, AZ, that cyclical variations in precipitation intensity alter the erosional capabilities of the sheet processed in the watershed and gully cutting in the tributary washes of the Little

Colorado River. In this manner, the alluvial valleys fill with sediment in years of intense, long duration precipitation events, and in years with intense, short duration events, the arroyos begin to cut into the alluvium again.

This matter will be examined more thoroughly in the Final Report.

6.2.6.3 Regional Climate Departure Indices

This section examines the long-term temporal trends in precipitation variability. The method consists of deriving departures from the mean precipitation on a regional basis for the study period. Two different departures are calculated, per the suggestion of Suckling (1984).

The first index Suckling calls the Simple Climate Departure Index (CDI). The equation for this index is as follows:

$$(SimpleCDI)_j = \frac{1}{n}\sum_{i=1}^{n}\frac{x_{ij}-\bar{x}_i}{\sigma_i}$$

Where:

$\bar{x}_i$ =the average value for the entire period at site i,

x_{ij} =the value for year j at site i,

σ_i = the standard deviation for x_i for the entire period, and

n = the number of sites in the region.

The second index Suckling (1984) calls the Least Squares Climate Departure Index (CDI). The equation for this index has a squared term and the index is always positive in sign. The equation is as follows:

$$(LeastSquaresCDI)_i = \left\{ \frac{1}{n} \sum_{i=1}^{n} \frac{(x_{ij} - \bar{x}_i)^2}{\sigma_i^2} \right\}^{0.5}$$

Where:

$\bar{x}_i$ = the average value for the entire period at site i,

x_{ij} = the value for year j at site i,

σ_i = the standard deviation for x_i for the entire period, and

n = the number of sites in the region.

The sign of the index is determined by the Simple CDI equation, and the value of the index is determined by the Least Squares CDI. Suckling (1984) applies this index to both precipitation and temperature. The time series graph of the resulting indices leads to an understanding of long-term regional climate trends. In the instance of this investigation of the LCR Basin, twenty-eight (28) LCR precipitation stations were utilized for calculating the regional indices for the 1939-90 study period.

First, let us examine an unmodified time series plot of the CDI's. Note the two exceptionally wet years of 1940 and 1973.

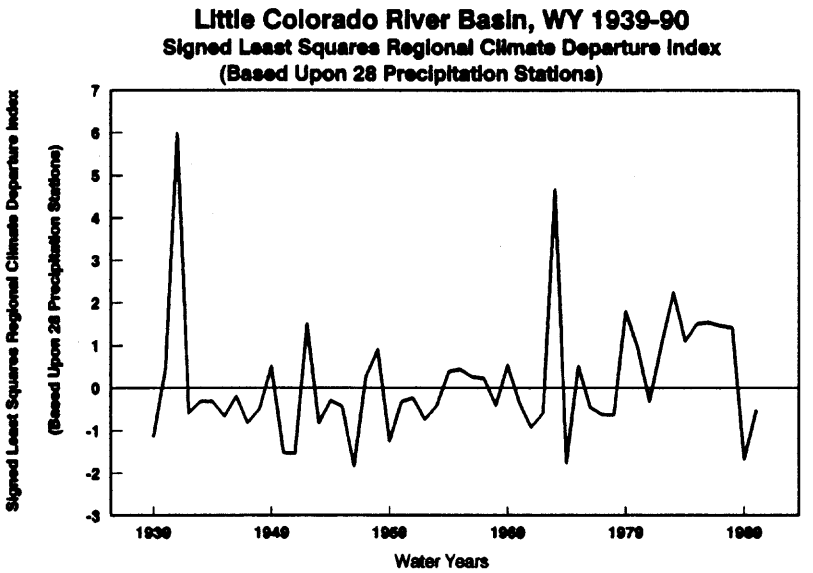


Figure 332. LCR Basin Regional Climate Departure Index, WY 1939-90

A time series plot of quadratic Brown's exponential smoothing reveals a slightly increasing trend from 1958 through 1988.

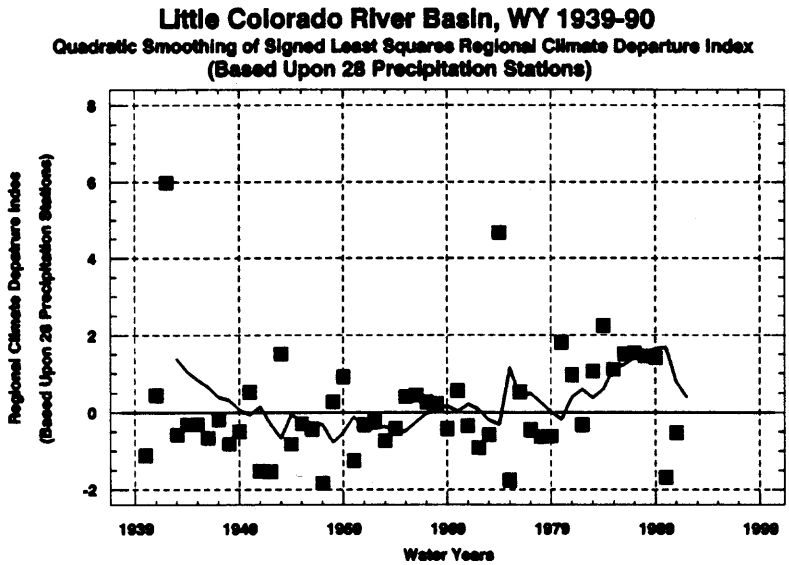


Figure 333. LCR Basin Smoothed Regional Climate Departure Index

Finally, a quadratic trend analysis was performed on the CDI's, demonstrating once again the suggestion of one half cycle of a periodic trend, as implied in the 386-1980 A.D. treering retrodiction by Dean (Section 6.2.7, following).

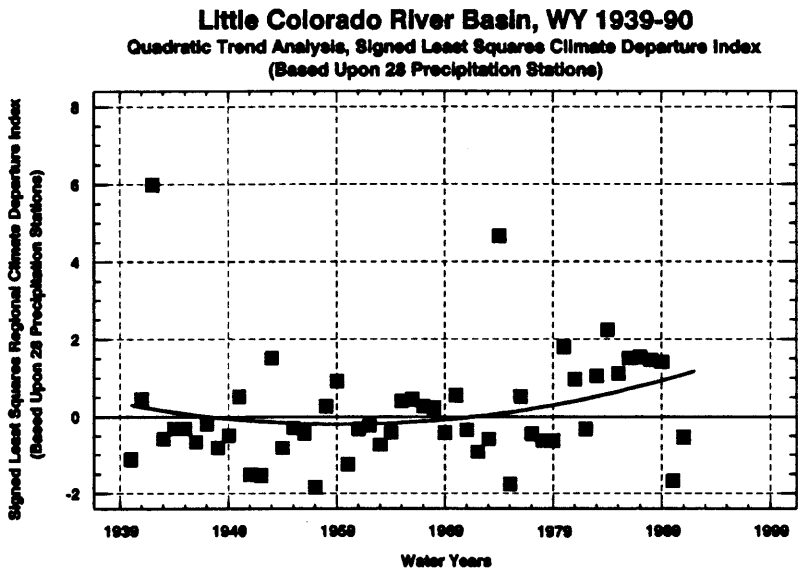


Figure 334. LCR Basin Quadratic Trend Analysis, Climate Departure Index

6.2.7 Paleoclimatology (Precipitation)

The inventor of dendrochronology began his career at Lowell Observatory. Dr. A. E. Douglas, who scouted the southwest to locate an ideal spot for Percival Lowell's observatory, was long fascinated with the cyclical variation of 9 to 11 years in the number of sunspots visible on the Sun. He felt that climate variations were somehow related to the cycle. The story is well documented that Douglas first noted that tree ring widths varied with precipitation.

Dr. H. C. Fritts at the Univ. of Arizona, Tucson Tree Ring Laboratory, has exhaustively studied the mathematics of tree growth and its climatic influences. In his book, Tree Rings and Climate, Fritts develops a linear regression methodology for the retrodiction of climatic variables based upon tree ring indices (normalized tree ring widths).

Utilizing Fritts's method, Dr. Jeffrey S. Dean, also of U of A Tree Ring Laboratory, examined the long-term trends in precipitation on Black Mesa, well within the heart of the Little Colorado River Basin. His study shows the climatic cycles of about 80 years, when Fourier analysis is utilized to remove the noise of the long time series.

6.2.7.1 Black Mesa Tree Ring Retrodiction for Precipitation

The Black Mesa precipitation data derived from treering retrodictions reveals an interesting cyclic variation in precipitation. The time series is highly auto-correlative, revealing several short-term cycles of 11 and 33 years, and a long term cycle of about 80 years. The following graphs show, first, the raw data time series, and second, the same data after Fourier smoothing.

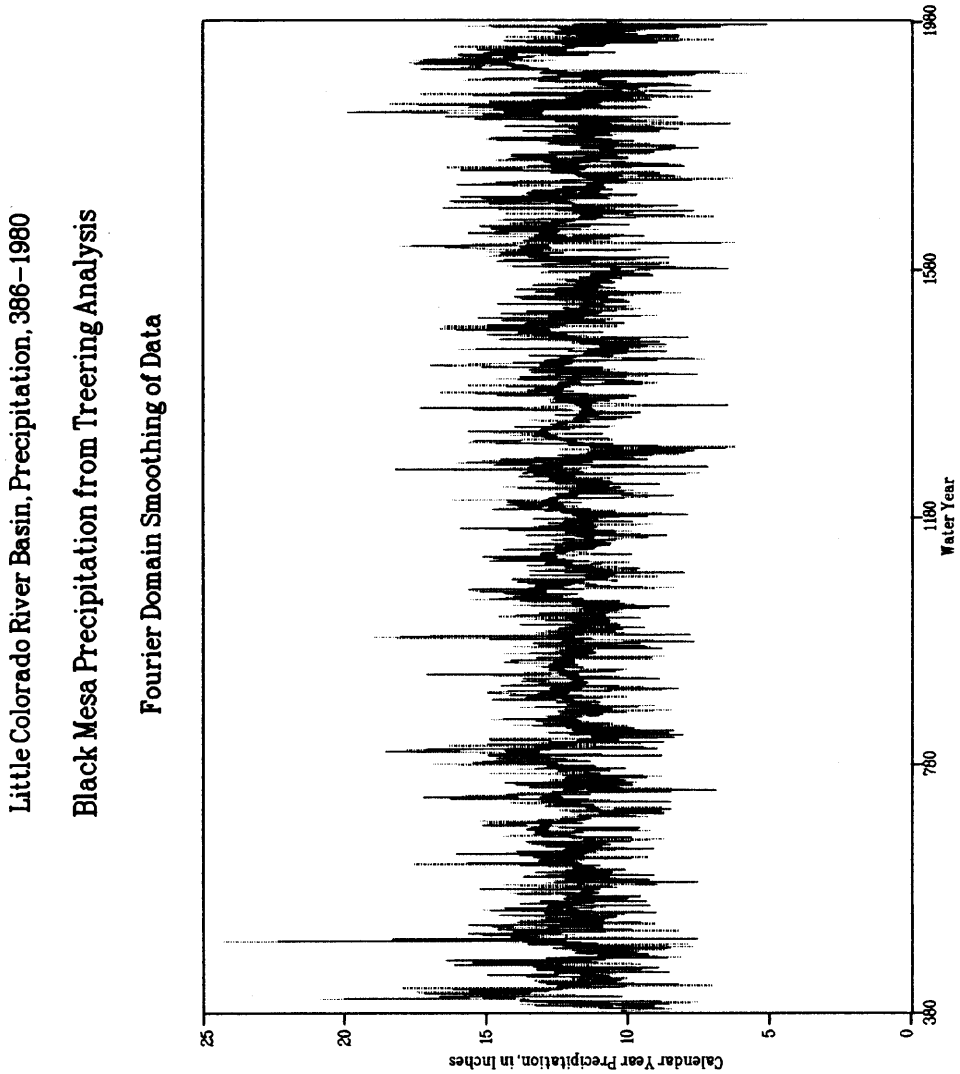


Figure 335. Raw Data Plot of Treering Retrodictions, 386-1980 A.D.

The following periodogram was utilized to identify the most common frequencies in the cyclicity of the data. The data was then filtered to isolate those frequencies. The long-term precipitation data from 386-1980 A.D. has an apparent cyclicity with a period of 80 years and another with a period of 11 years. A three year cycle was also noted, but not used in the analysis.

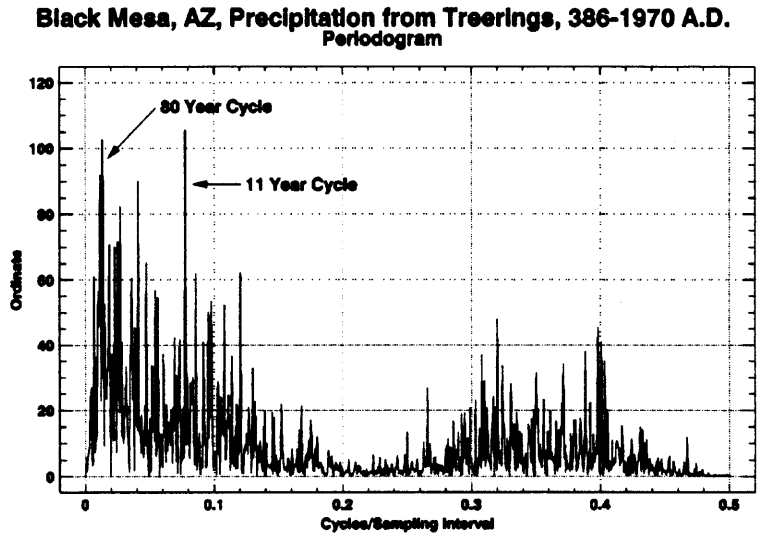


Figure 336. Periodogram of Black Mesa Precipitation, 386-1980 A.D.

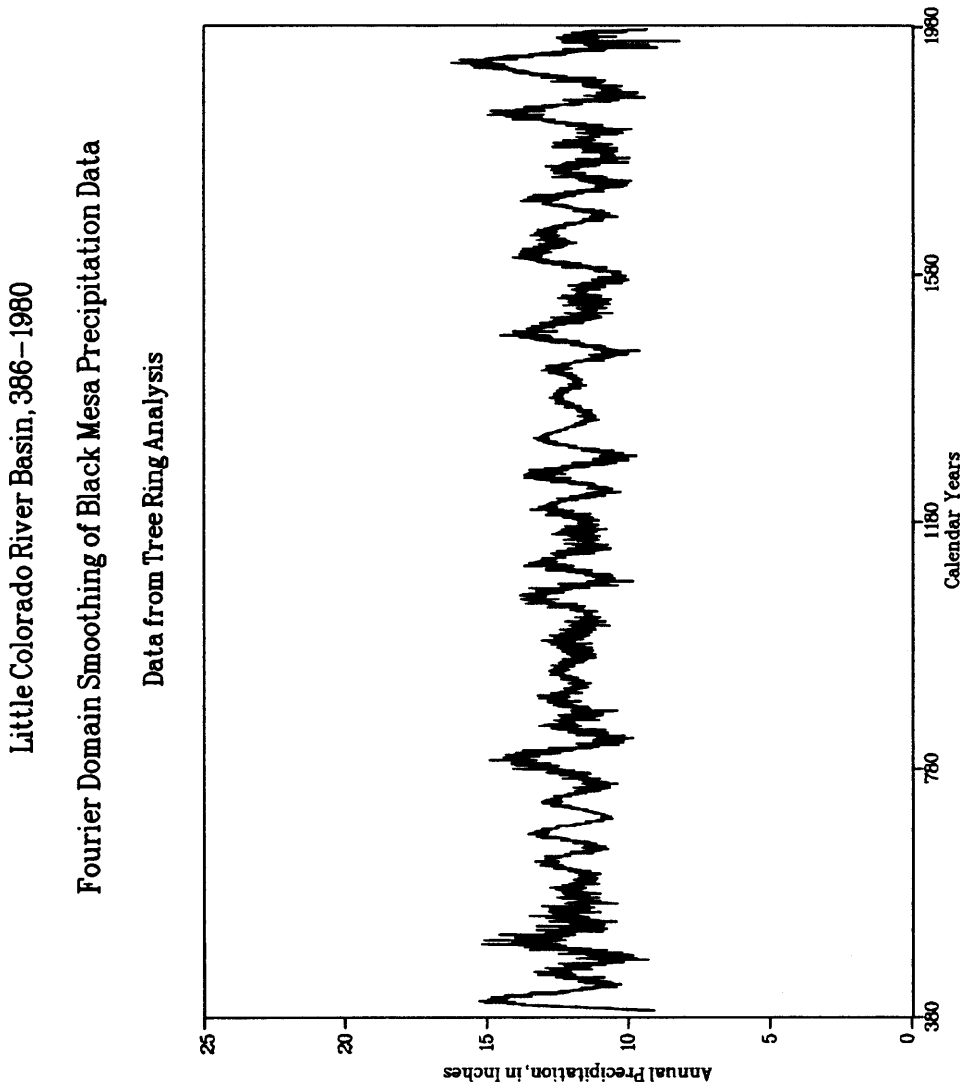


Figure 337. Plot of fourier smoother Treering Retrodictions, 386-1980 A.D.

6.2.7.2 Other Tree Ring Series in the Little Colorado River Basin

The Hopi Water Resources Program has obtained copies of several long-term tree ring series within the Little Colorado River Basin. Five series were obtained from the Tree Ring Laboratory, and a recently extended Flagstaff, AZ, series has been obtained from the Northern Arizona University Forestry Department.

The availability of long-term reconstructions of precipitation records near the sites of these tree ring series will enable correlation with the tree rings and the precipitation. About 20-30 years of overlap is available for calibration of the regression models. The results of these efforts will be included in the Final Report.

6.3 Evaporation

Evaporation records are scarce in the Little Colorado Basin. The typical use of evaporation data is to determine losses from reservoirs. Not surprisingly, most evaporation records are tabulated from measurements utilized by reservoir managers for operations purposes. It so happens that several reservoirs lying just outside the basin have extensive records, as well as the Fort Valley Experimental Forest in Flagstaff, used in a study of Lake Mary.

6.3.1 Evaporation Records for Selected Stations

Most of the evaporation stations in the vicinity of the Little Colorado River Basin lie outside the Basin. In the following assemblage of evaporation records, those stations nearest to the LCR Basin are represented for their entire period of record.

6.3.1.1 Farmington, NM, Evaporation

Table 71. The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

FARMINGTON AGRICULTURAL SCIENCE CENTER Station No. 3142

Lat = N36:42:00 Lon = W108:15:00 Elev. = 5610.7

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1978								9.88	12.69	14.32	12.76	8.12	
1979	6.14						8.10	8.08	10.32	9.51	9.97	9.30	
1980							7.11	9.67	11.83	11.86	11.14	8.15	
1981								9.51	12.07	11.10	10.50	7.65	
1982								9.53	12.81	12.04	9.72	7.32	
1983									10.47	12.52	10.94	8.72	
1984									12.34	12.37	10.65	7.85	
1985	3.36						6.17	8.74	12.26	12.68	11.62	6.99	
1986	4.75						7.45	9.86	10.91	10.86	11.36	6.75	
1987								6.07	11.52	12.74	10.46	8.47	
1988	4.85							11.53	11.05	13.03	9.75	8.55	
1989	6.16						8.58	11.47	12.39	13.83	10.56	9.36	
1990							7.60	11.59	14.57	12.72	11.35	8.83	
1991	5.77						8.48	11.58	11.00	12.61	10.97	7.84	
1992	5.81						7.67	8.67	11.88	11.88	10.79	8.18	
1993	6.32						6.90	10.01	13.78	14.61	9.94	8.95	
1994	4.91												
Average	5.34						7.56	9.73	11.99	12.42	10.78	8.19	
Maximum	6.32						8.58	11.59	14.57	14.61	12.76	9.36	
Minimum	3.36						6.17	6.07	10.32	9.51	9.72	6.75	

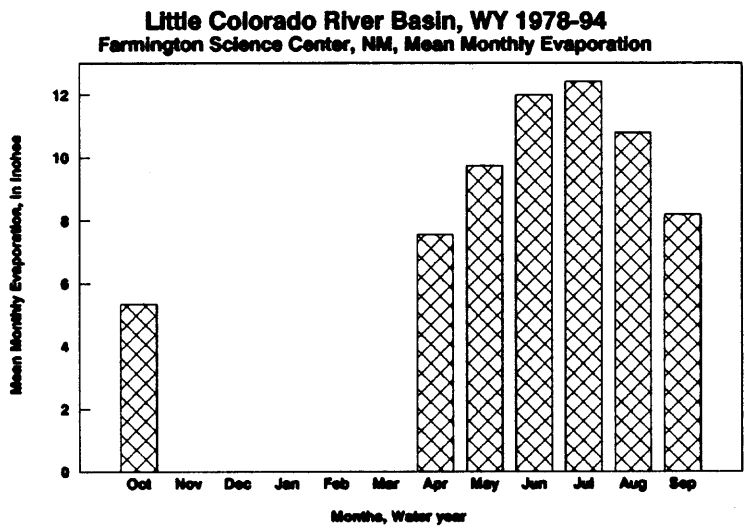


Figure 338. Farmington Agricultural Science Center, Mean Monthly Evaporation

6.3.1.2 Farmington 4E, NM, Evaporation

Table 72.The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

FARMINGTON 4 NE, NM

Lat = 34d 45m 00s Lon = 108d 10m 00s

Elev. = 5389.8 Feet

Evaporation, in Inches

Mo/Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1948					0.71	3.48	6.73	7.32	6.41	7.20	5.11	4.46	
1949	2.90	1.84					5.91						
1950						4.26	8.03	9.09	9.43	8.54	7.25	4.41	
1951	4.55					4.84	6.24	8.16	9.69	8.81	6.41	5.45	
1952	3.92					3.55	6.57	7.83	9.25	7.87	7.95	6.17	
1953	5.04	1.08					6.28	8.21	9.21	10.38	8.86	7.82	
1954	4.39	2.14					9.11	8.38	11.55	9.31	8.71	6.19	
1955	3.97						7.05	9.19	11.34	9.84	9.14	7.20	
1956	4.03							9.68	10.95	10.61	9.10	8.11	
1957								7.08	9.97	8.42	7.81	7.26	
1958	3.32							9.68	11.41	10.61	10.35	6.18	
1959	3.78						5.24	10.39	11.66	11.82	8.65	7.37	
1960	3.89						7.36	8.69	11.20	11.13	11.53	7.53	
1961								9.55	11.95	10.22	8.51	5.98	
1962								9.72	11.89	12.35	12.05	7.12	
1963	3.51												
1964	4.36								11.23	10.87	9.49	5.56	
1965	2.85								7.13			6.58	
1966									11.01	12.02	11.04	8.07	
1967							8.11	9.58	9.84	10.76	8.59	7.14	
1968								7.49	9.21	10.35	8.81	7.79	
1969							6.66	9.14	7.66	9.34	9.42	6.51	
1970						3.75	5.62	8.24	9.50	9.79	8.91	6.49	
1971							6.15	8.09	10.07	9.52	8.21	7.02	
1972							6.63	8.96	8.96	9.70	7.76	6.61	
1973								7.80	8.83	9.61	8.96	5.56	
1974							5.16	9.37	10.71	10.12	9.05	6.55	
1975								8.12	8.70	8.66	8.49	5.15	
1976							6.79	8.13	10.31	9.85	8.41	5.48	
1977									8.27				
Average	3.89	1.69			0.71	4.03	6.85	8.78	10.27	9.87	8.73	6.46	
Maximum	5.04	2.14			0.71	4.84	9.11	10.39	11.95	12.35	12.05	8.11	
Minimum	2.85	1.08			0.71	3.48	5.24	7.08	6.41	7.20	5.11	4.41	

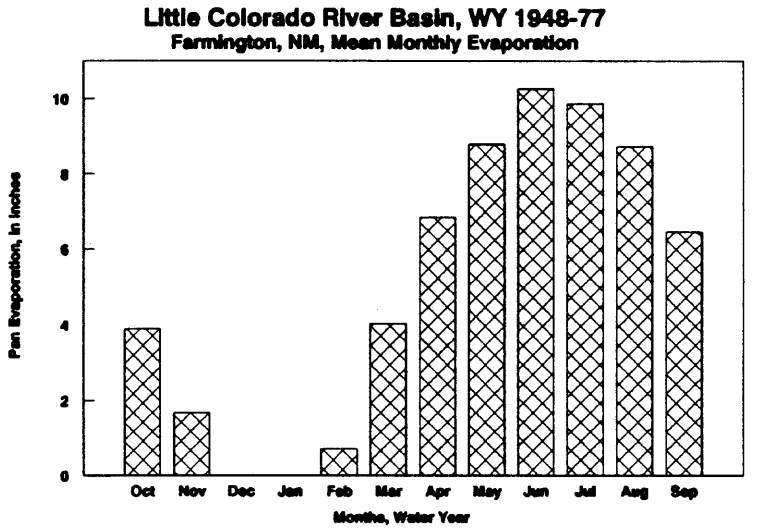


Figure 339. Farmington 4E, NM, Mean Monthly Evaporation

6.3.1.3 Fort Valley RS, AZ, Evaporation

Table 73. The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N35:16:00; Lon = W111:44:00
Elev. = 7328 Feet

FORT VALLEY RS, ARIZONA Station No. 3160

Pan Evaporation, in inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1964									7.36	7.13	6.41	4.17	
1965									6.40	6.04	4.85	3.01	
1966								5.40	7.01	6.87	5.01	3.15	
1967									6.81	4.62	3.68	2.81	
1968									7.72	5.69	4.52		
1969								6.32	7.01	5.63	4.24	2.63	
1970									6.35	6.10	3.94		
1971													
1972										7.14	5.05	4.07	
1973	1.44								7.40	6.72	4.72		
1974									8.19	5.14	5.67	3.64	
1975									8.23	6.39	5.41	3.87	
1976									8.54	4.87	5.67	2.84	
1977											4.71		
1978								5.31					
Average	1.44							5.68	7.37	6.03	4.91	3.35	
Maximum	1.44							6.32	8.54	7.14	6.41	4.17	
Minimum	1.44							5.31	6.35	4.62	3.68	2.63	

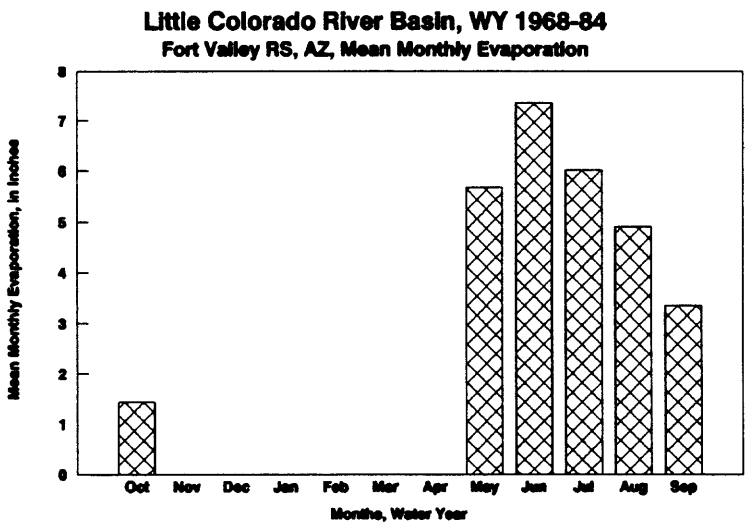


Figure 340. Fort Valley RS, AZ, Mean Monthly Evaporation

6.3.1.4 Grand Canyon NP, AZ, Evaporation

Table 74. The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Hydrology Study

GRAND CANYON NP, ARIZONA, Station No. 3596

Lat = N36:03:00; Lon = W112:09:00
Elev. = 6767.9 Feet

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1976											8.87		
1977	4.40	2.54					7.39	10.29	8.33	7.55	7.70	5.33	
1978								7.45	10.92	9.61	9.75	6.79	
1979	5.01							6.74	10.00	9.68	7.89		
1980	5.12							5.34	10.12		8.31	6.45	
1981	4.05							7.07		7.84	7.10	5.58	
1982	3.36							6.49	9.89	8.51	5.39	4.89	
1983									9.31	8.40	5.68	5.30	
1984	3.86								9.91	6.19	6.05	6.41	
1985								7.50	10.16	8.08	8.79	5.91	
1986								7.97	9.51	8.12	6.61	6.19	
1987								6.10	8.74	8.89	6.71	5.60	
1988								7.81	8.03	9.71	6.68	6.37	
1989								9.03	11.24	9.54	8.45	7.05	
1990								8.10	11.89	8.59		4.92	
1991								8.05	9.64	9.29	7.25	5.54	
1992									8.99	8.75	6.42	6.16	
1993								7.08	10.15	11.45	6.59	6.91	
Average	4.30	2.54					7.39	7.50	9.80	8.76	7.21	5.96	
Maximum	5.12	2.54					7.39	10.29	11.89	11.45	9.75	7.05	
Minimum	3.36	2.54					7.39	5.34	8.03	6.19	5.39	4.89	

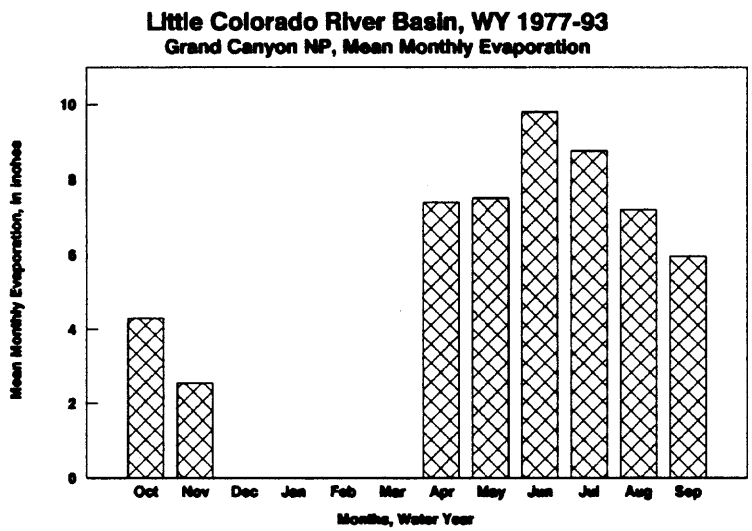


Figure 341. Grand Canyon NP, AZ, Mean Monthly Evaporation

6.3.1.5 Grand Canyon, AZ, Evaporation

Table 75.The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N36:03:00; Lon = W112:09:00
Elev. = 2068m

GRAND CANYON, AZ Station No. 3596

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1971													
1972										9.02	7.95	6.00	
1973	3.41							6.94	9.76	9.33	8.09	7.36	
1974	5.57							7.33	11.14	8.03	8.84	7.14	
1975	4.26								7.74	8.29	7.61		
Average	4.41							7.14	9.55	8.67	8.12	6.83	
Maximum	5.57							7.33	11.14	9.33	8.84	7.36	
Minimum	3.41							6.94	7.74	8.03	7.61	6.00	

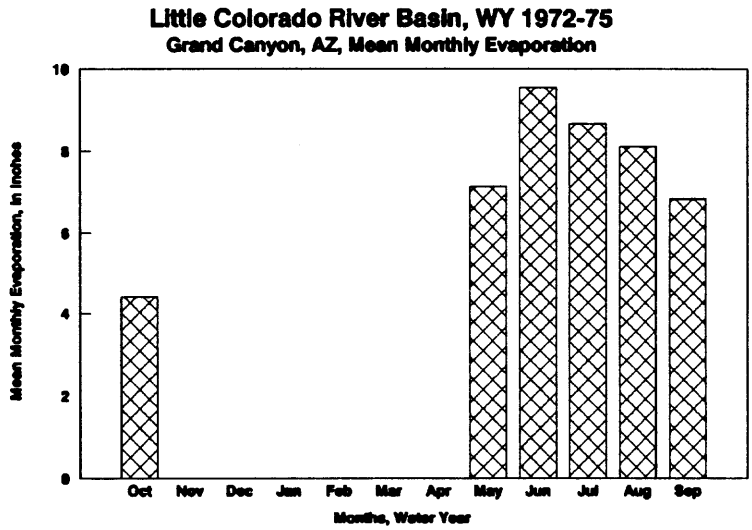


Figure 342. Grand Canyon, AZ, Mean Monthly Evaporation

6.3.1.6 Keams Canyon, AZ, Evaporation

Table 76. The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N35:49:00; Lon = W110:12:00
Elev. =6187.3Feet

KEAMS CANYON, ARIZONA; Station No. 4586

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1974	4.67							8.55					
Average	4.67							8.55					

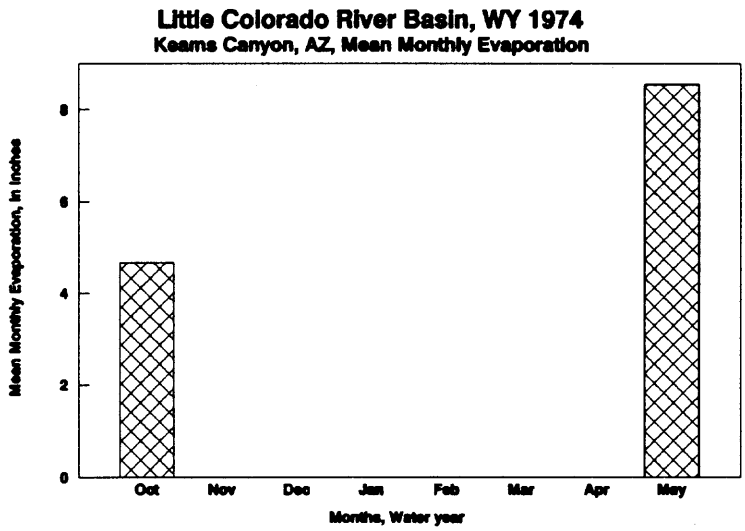


Figure 343. Keams Canyon, AZ, Mean Monthly Evaporation

6.3.1.7 McNary, AZ, Evaporation

Table 77.The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N34:07:00; Lon = W109:51:00
Elev. =7321Feet

MC NARY 2 N, ARIZONA; Station No. 5412

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1969	4.94	2.24						7.29	8.83	5.95	6.11	5.13	
1970	5.01							8.53	8.77	6.91	5.16	4.65	
1971	3.16							7.84	8.51	7.30	5.44	4.82	
1972								8.55	6.23	7.31	6.18	4.41	
1973	2.57								7.19	6.63	5.68	6.19	
1974	4.97							8.36	9.48	6.09	8.08	4.09	
1975									8.51	6.44	6.47	4.50	
1976	4.14											4.76	
1977	3.03							7.06	6.46	5.52	5.44	5.13	
1978	3.69							6.91	8.88				
Average	3.94	2.24						7.86	8.25	6.60	5.98	4.90	
Maximum	5.01	2.24						8.55	9.67	7.31	8.08	6.19	
Minimum	2.57	2.24						6.91	6.23	5.52	5.16	4.09	

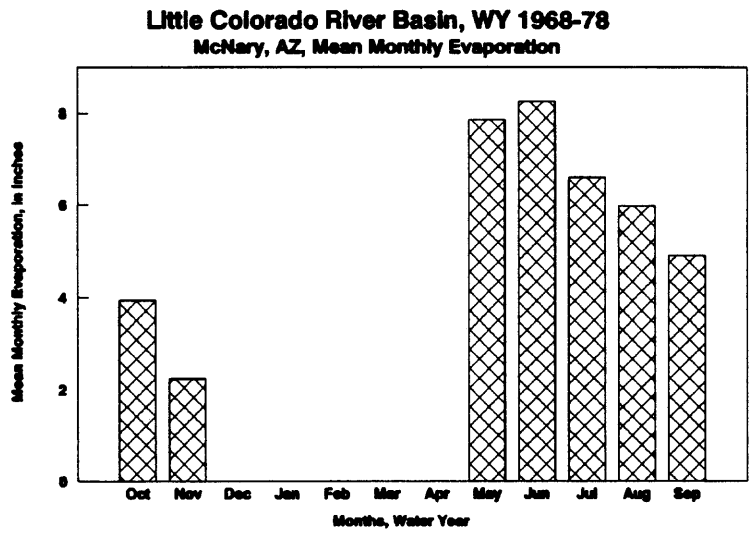


Figure 344. McNary, AZ, Evaporation

6.3.1.8 Navajo Dam, NM, Evaporation

Table 78.The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N36:49:00; Lon = W107:37:00
Elev. =5755Feet

NAVAJO DAM, NM; Station No. 6061

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1964	5.96						7.03	11.20	13.30	13.34	11.42	7.29	
1965	6.35						5.71	8.91	10.44	11.37	11.02	7.10	
1966	5.22	2.09					7.66	11.46	12.39	12.78	11.15	8.20	
1967	5.85						8.09	10.47	9.85	12.09	9.14	7.37	
1968	5.67						5.85	9.53	12.96	11.32	9.30	8.87	
1969	5.23						7.10	9.95	10.17	10.37	9.66	6.76	
1970	3.66						6.11	10.27	10.16	10.23	9.40	6.08	
1971	3.43						6.58	8.76	10.95	12.27	9.53	7.80	
1972	4.14						7.91	10.93	10.82	13.01	9.48	7.55	
1973	3.26						5.69	8.29	10.47	10.83	9.39	7.22	
1974	4.97						6.69	10.47	11.65	11.18	9.76	7.82	
1975	3.77						5.05	8.70	9.37	9.50	9.22	6.66	
1976	5.31						6.02	7.70	10.90	9.71	8.44	6.08	
1977	4.49							7.41		9.75	8.60	7.55	
1978	4.00							7.01	10.88	10.29	10.28	6.03	
1979	5.00							6.82	8.69	10.40	8.49		
1980	5.57							6.99	12.23	10.03	9.84	6.35	
1981	4.60						5.50	7.28	11.28	10.91	6.43	7.34	
1982	4.51						6.25		11.57		8.82	6.48	
1983									8.63				
1984													
1985							6.00	8.03	9.81	10.22			
1986										9.54			
1987	3.67									11.08		7.11	
1988												7.35	
1989									10.95		8.53		
1990									10.79				
1991								8.18					
1992									10.02	9.98			
1993									9.63			7.33	
Average	4.73	2.09					6.45	8.96	10.83	10.96	9.44	7.14	
Maximum	6.35	2.09					8.09	11.46	13.30	13.34	11.42	8.87	
Minimum	3.26	2.09					5.05	6.82	8.63	9.50	6.43	6.03	

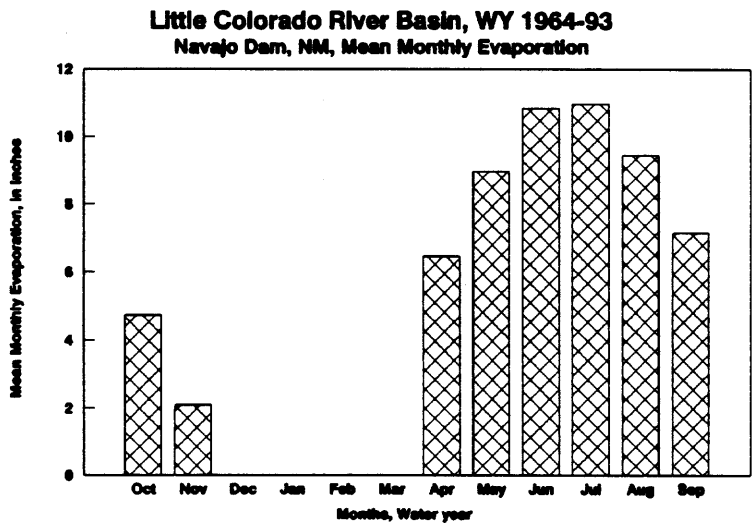


Figure 345. Navajo Dam, NM, Mean Monthly Evaporation

6.3.1.9 Page, AZ, Evaporation

Table 79. The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N36:56:00; Lon = W111:27:00
Elev. = 4258 Feet

Page, AZ; Station No. 6180

Pan Evaporation, in Inches

Mo/Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1958		1.23											
1959													
1960													
1961													
1962					2.40	4.96	10.43	12.39	13.46	15.54	14.31	9.47	
1963	5.48	2.12	0.88										
1964	5.45	2.50			2.81	4.20	7.42	9.59	12.48	13.31	10.43	8.95	
1965	5.89					3.84	6.17	10.43	11.04	11.82	10.87	9.22	
1966	4.75	2.25					8.35	11.22	13.37	13.48	13.36	8.51	
1967	5.37	2.56				6.38	8.98	9.18	11.65	12.98	11.08	7.52	
1968	6.61	3.15				5.59	7.34	11.21		13.10	10.00	9.91	
1969	5.34	2.14					8.67	11.80	12.73	12.81	11.69	8.18	
1970	5.15						6.59	11.81	13.02	11.98	11.42	10.18	
1971	4.97	2.53					5.75	11.34	15.00	15.44	10.93	9.41	
1972	5.09	1.32				7.30	8.69	11.79	11.80	14.48	12.00	8.03	
1973	3.13	1.73						9.94	11.38	12.61	12.06	8.72	
1974	5.68	2.53					8.85	12.82	13.39	12.48	11.86	9.25	
1975	4.35	1.56								11.51	11.32	7.81	
1976	5.39	2.11					7.77	9.83	12.97	12.07	12.46	7.12	
1977	4.90	2.57					9.03	10.79	13.60	12.33	10.91	8.54	
1978	5.63	2.89					8.12	10.82	14.98	13.67	12.03	7.31	
1979	5.80	1.47					7.98	8.99	11.36	13.80	11.14	8.35	
1980	5.43						7.02	8.22	12.61	12.26	10.14	7.89	
1981	4.70						7.90	10.69	12.71	11.15	8.91	6.72	
1982	3.55								11.68	12.66	8.45	6.83	
Average	5.13	2.17	0.88		2.61	5.38	7.94	10.71	12.74	12.97	11.27	8.40	
Maximum	6.61	3.15	0.88		2.81	7.30	10.43	12.82	15.00	15.54	14.31	10.18	
Minimum	3.13	1.23	0.88		2.40	3.84	5.75	8.22	11.04	11.15	8.45	6.72	

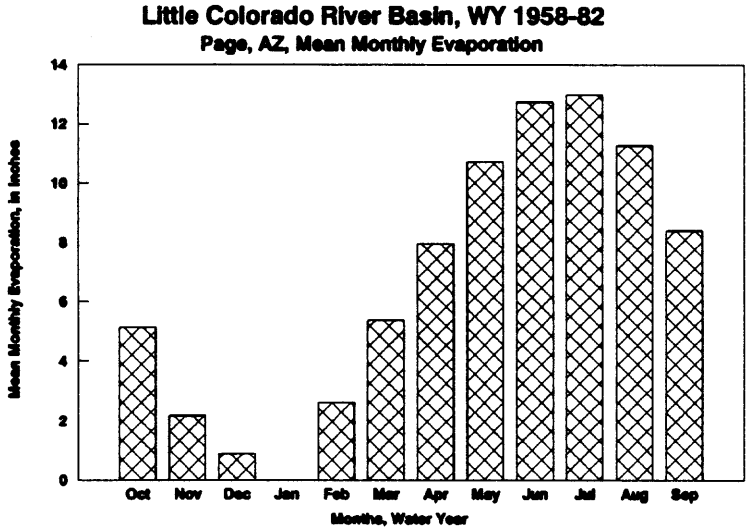


Figure 346. Page, AZ, Mean Monthly Evaporation

6.3.1.10 Shiprock, NM, Evaporation

Table 80.The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Hydrology Study

Lon = W108:41:00; Lat = N36:48:00
Elev. =4959.5Feet

Shiprock, NM; Station No. 8284

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1954										14.00	11.04	8.72	
1955	5.37						9.86	11.53	14.12	13.70	11.74	10.08	
1956	7.69						7.36	12.06	14.34	13.80	10.96	10.64	
1957	6.56						5.82	8.13		11.08	9.45	9.77	
1958	3.58							10.43	14.85	13.26			
Average	5.80						7.68	10.54	14.44	13.17	10.80	9.80	
Maximum	7.69						9.86	12.06	14.85	14.00	11.74	10.64	
Minimum	3.58						5.82	8.13	14.12	11.08	9.45	8.72	

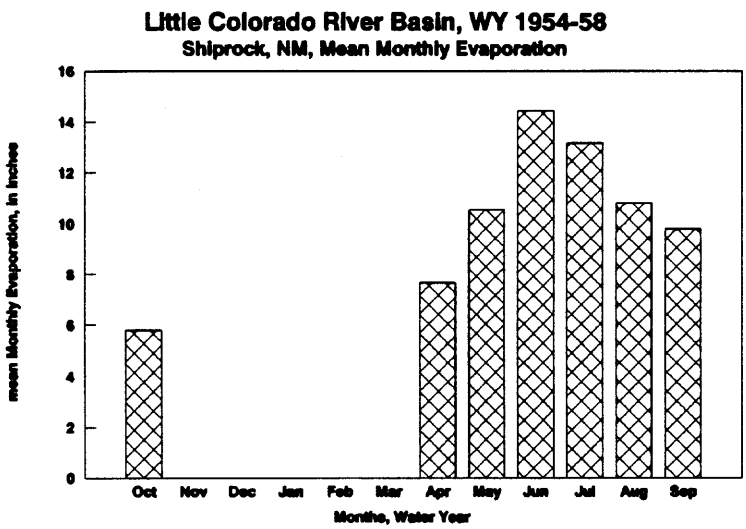


Figure 347. Shiprock, NM, Mean Monthly Evaporation

6.3.1.11 Snowflake, AZ, Evaporation

Table 81. The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N34:30:00; Lon = W110:20:00
Elev. = 6065 Feet

Snowflake, AZ; Station No. 8018

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1966								11.84	15.79	12.92	10.50	8.78	
1967	6.75	4.60						10.99	14.44	11.02	10.07	8.14	
1968	8.39								13.87	12.08	6.57	10.46	
1969								10.89				6.87	
1970									14.21	11.33	9.38	7.96	
1971									14.32	13.29	8.96	8.46	
1972									8.77	13.47	10.56	8.32	
1973								9.52	10.54	10.43	9.84	8.24	
1974	7.29							13.35	15.99	10.64	9.29	7.13	
1975	4.49	2.20							14.16	11.10	10.00	7.41	
1976								9.47		10.53	8.70	6.57	
1977								7.29	11.83	7.39	6.43	7.15	
1978	5.33							11.02	18.61				
Average	6.45	3.40						10.55	13.87	11.29	9.12	7.96	
Maximum	8.39	4.60						13.35	18.61	13.47	10.56	10.46	
Minimum	4.49	2.20						7.29	8.77	7.39	6.43	6.57	

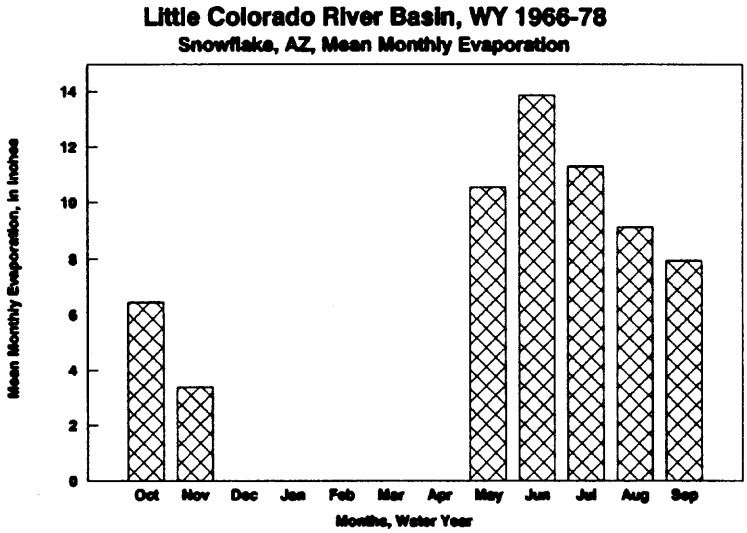


Figure 348. Snowflake, AZ, Mean Monthly Evaporation

6.3.1.12 Wahweap, AZ, Evaporation

Table 82.The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N36:59:00; Lon = W111:29:00
Elev. = 3721 Feet

Wahweap, AZ; Station No. 9114

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1962				1.95	2.93	6.07	12.01	15.54	14.47	19.96	17.69	12.21	
1963	6.60	3.07	2.60										
1964	7.43	3.41				5.85	9.89	10.60	15.31	17.96	17.22	13.14	
1965	9.55	3.90			3.14	5.99	7.76	12.66	14.36	15.33	15.86	12.62	
1966	7.49	3.60			2.03	7.49	11.96	15.88	18.58	18.52	18.13	11.67	
1967	7.98	4.11					10.92	13.02	15.54	16.41	13.72	9.45	
1968	8.16	4.37				5.26	8.40	13.69	17.41	15.42	12.71	12.76	
1969	6.76	4.19			2.72	5.39	9.14	15.76	15.57	15.89	14.88	10.75	
1970	5.72					6.21	10.86	16.55	17.16	15.27	14.62	12.79	
1971	7.24						10.46	13.77	17.42	20.05	15.06	10.98	
1972	6.42						11.75	15.95	15.54	16.10	12.67	11.13	
1973						3.99	9.59	13.06	15.04	15.43	15.36	10.85	
1974	8.05	3.84					10.60	14.91	17.07	14.76	14.58	11.30	
1975	5.98	2.92					8.32	9.60	14.71	13.41	12.38	10.26	
1976	7.16							12.13	14.86	14.63	15.33	9.73	
1977	7.08							9.57	15.19	13.66	12.29	10.62	
1978	6.84	3.53					8.23	11.89	17.00	16.69	14.17	9.48	
1979												9.80	
1980	6.76									14.07			
1981											11.38	7.42	
1982													
1983													
1984							8.28	13.17	11.83		9.11	9.79	
1985							7.99	10.78	13.83	13.05	13.62	9.59	
1986											11.54		
1987							7.76	9.50	14.49	13.96	11.42	10.01	
1988	6.09	3.13								12.81			
1989	5.85							11.54	13.08				
1990											10.65	7.26	
1991	6.03								13.33	11.41	9.93	7.93	
1992	6.62									10.29	10.18	8.36	
1993	6.56							7.80	14.62	15.62	10.69	9.83	
Average	6.97	3.64	2.60	1.95	2.71	5.78	9.64	12.73	15.29	15.25	13.41	10.39	100.36
Maximum	9.55	4.37	2.60	1.95	3.14	7.49	12.01	16.55	18.58	20.05	18.13	13.14	
Minimum	5.72	2.92	2.60	1.95	2.03	3.99	7.76	7.80	11.83	10.29	9.11	7.26	

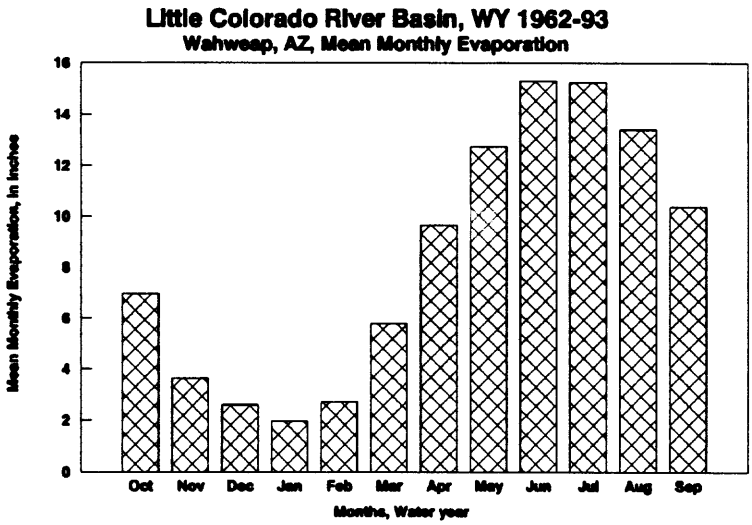


Figure 349. Wahweap, AZ, Mean Monthly Evaporation

6.3.1.13 Whiteriver, AZ, Evaporation

Table 83.The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Basin Hydrology Study

Lat = N33:50:00; Lon = W109:58:00
Elev = 5105.1 Feet

Whiteriver, AZ; Station No. 9271

Pan Evaporation, in Inches

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1968		3.99			3.43	4.70	6.63	10.58	12.88	9.48		8.72	
1969	7.06	3.56				4.88	9.22	9.72	12.95	10.39	8.26	7.63	
1970	6.13	2.98				4.36	7.57	11.93	13.12	10.31	8.79	7.98	
1971	5.52	4.60				7.72	9.08	11.12	13.12	10.55	6.86	7.72	
1972	3.82	3.12				8.55	9.96	11.78	10.75	11.04	8.82	7.68	
1973	4.14	2.50					6.96	8.32	9.80	9.51	8.65	9.34	
1974	7.24	3.74					9.02	11.23	12.48	9.01	8.85	7.10	
1975	4.44	2.91	1.57				6.33	9.40	11.81	8.29	9.74	6.94	
1976	6.75	4.34					7.09	9.32	11.91	7.36	9.89	6.44	
1977	5.16	4.17					8.27	10.30	9.78	7.63	8.04	6.62	
1978	5.69	3.70	2.54	1.69	2.45	4.82	8.03	9.82	11.91	10.37	9.71	8.19	
1979	6.19	2.56					7.98	6.87	9.23	10.82	8.46	8.49	
1980	7.18							9.80	12.64	9.55	9.17	8.09	
1981	6.23							9.34	12.79	8.83	9.17	7.88	
1982	6.67							8.91	12.09	10.56	6.58	6.46	
1983								9.90	11.52	9.87	7.71	7.59	
1984								10.28	10.09	7.63	6.90		
Average	5.87	3.51	2.06	1.69	2.94	5.84	8.01	9.92	11.70	9.48	8.48	7.68	77.18
Maximum	7.24	4.60	2.54	1.69	3.43	8.55	9.96	11.93	13.12	11.04	9.89	9.34	
Minimum	3.82	2.50	1.57	1.69	2.45	4.36	6.33	6.87	9.23	7.36	6.58	6.44	

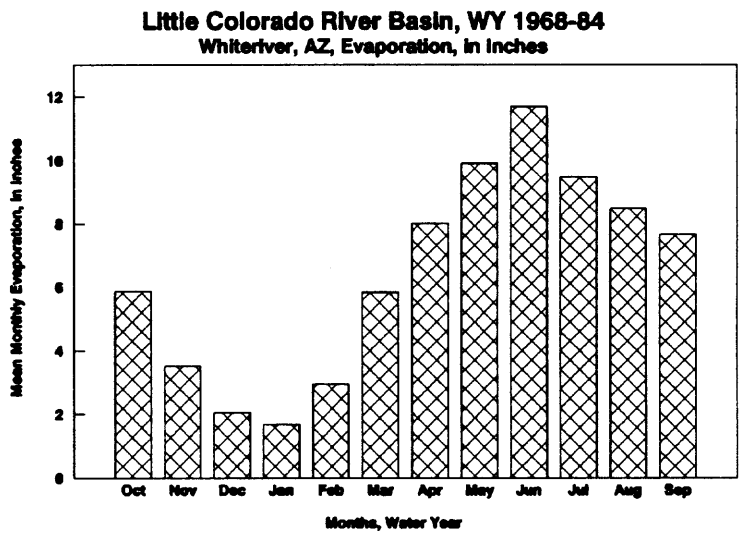


Figure 350. Whiteriver, AZ, Mean Monthly Evaporation

6.3.2 Arizona Iso-Evapotransporation Maps

The following maps are intended to illustrate the relative evapotranspiration demands from phreatophytic plants which grow along the banks of the Little Colorado River and its tributraries. These plants may account for a significant percentage of the instream losses from the system. The reference evapotranspiration values represented in the maps would have to be multiplied by a plant-specific factor to obtain the "crop" evapotranspiration demand per acre of plant. The per-acre demand would then have to be multiplied by the number of acres of plants to derive the losses in the stream in acre-feet per year or per month. The maps are for Arizona only and a LCR Basin-specific map is not available.

6.3.2.1 Arizona Annual Evapotranspiration Map

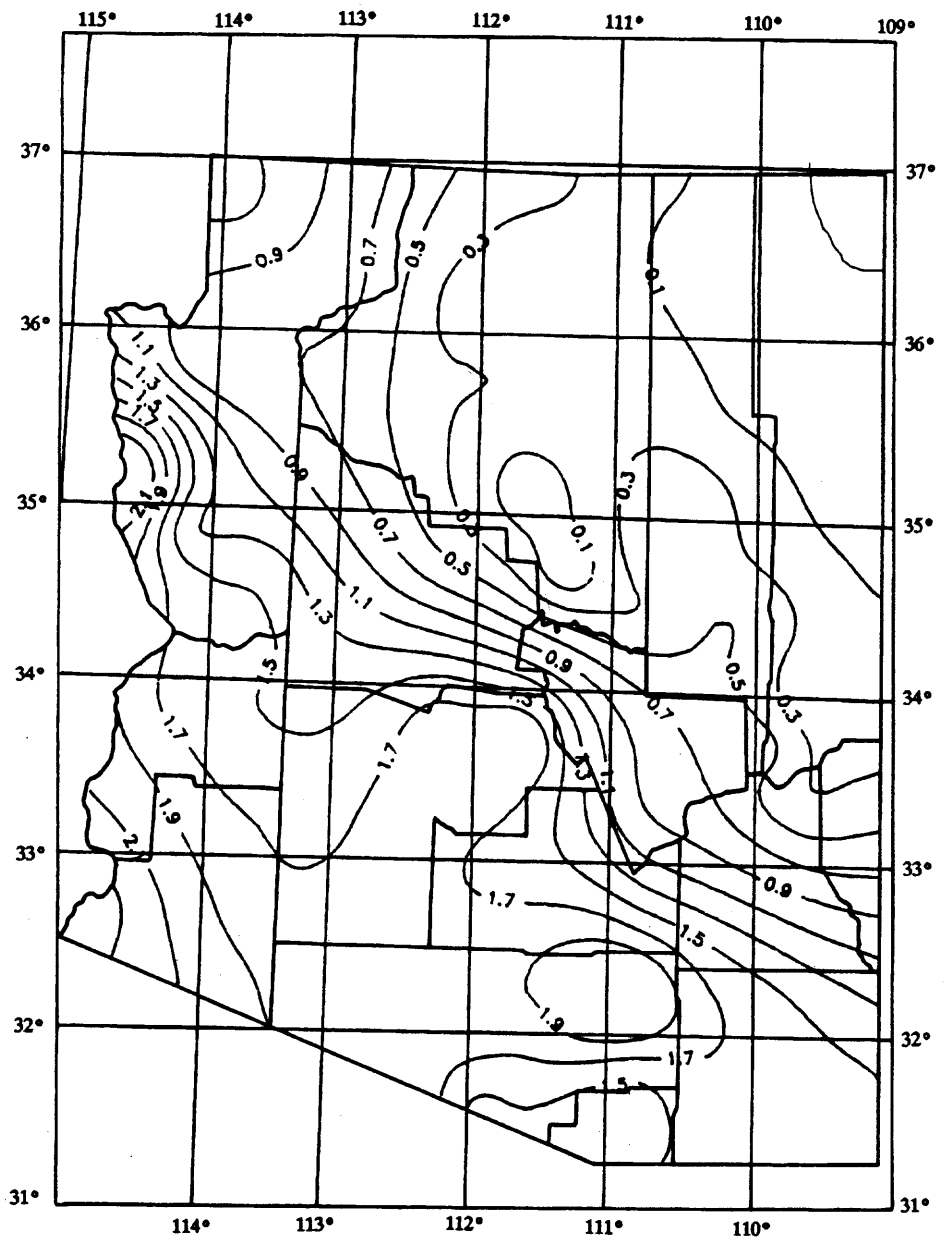
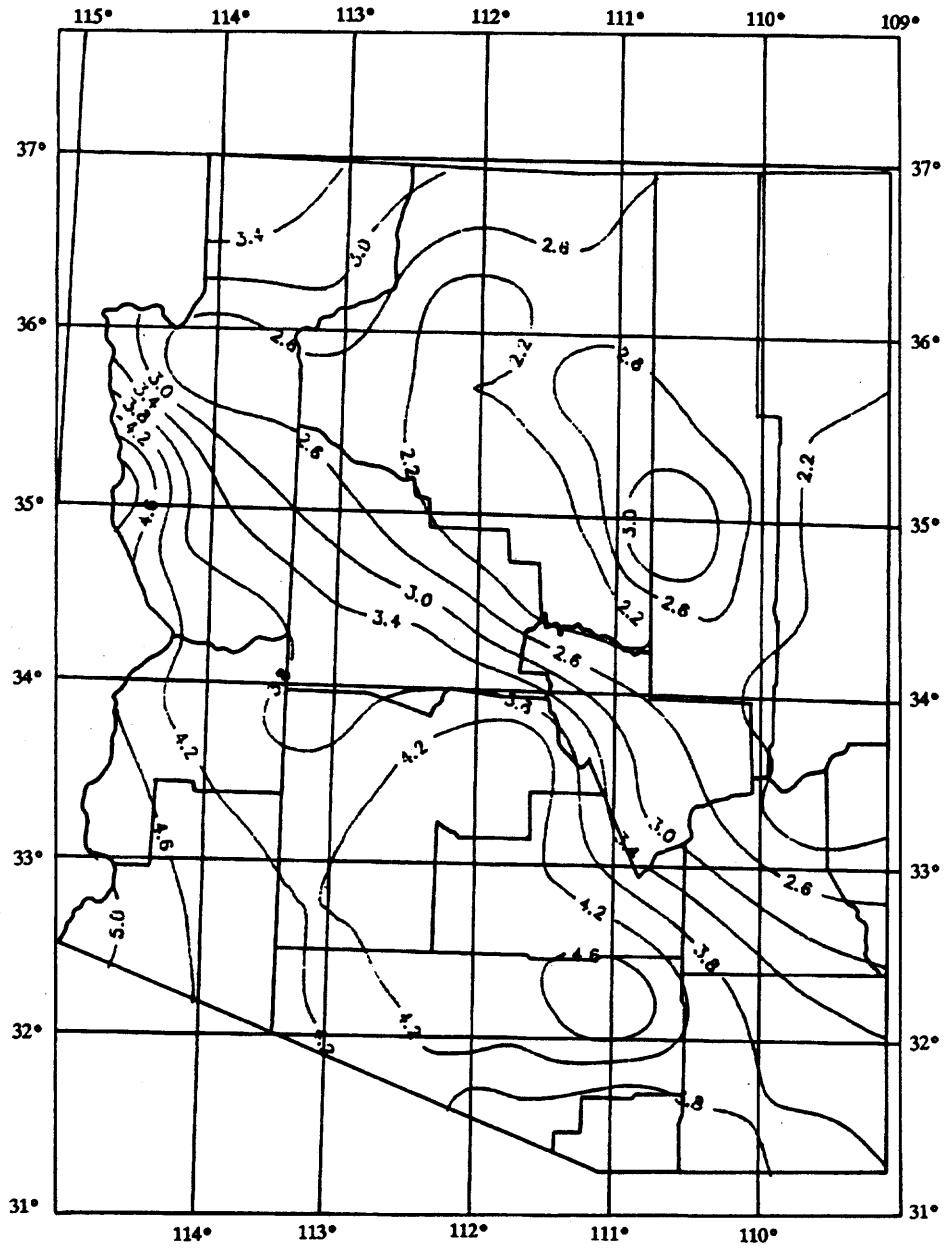


Figure 351. Arizona Annual Evapotranspiration Map

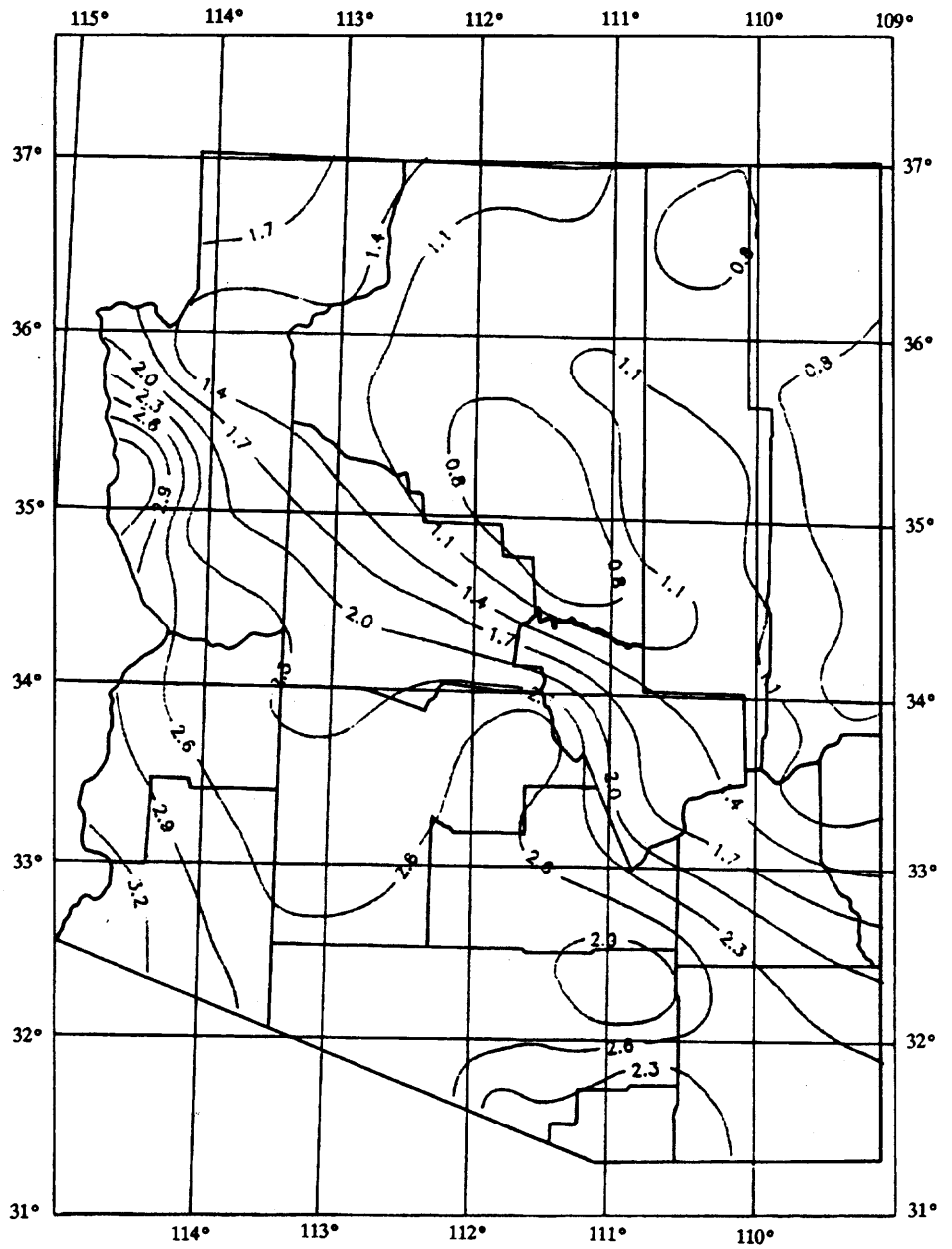
6.3.2.2 Arizona October Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – October

Figure 352. Arizona October Evapotranspiration Map

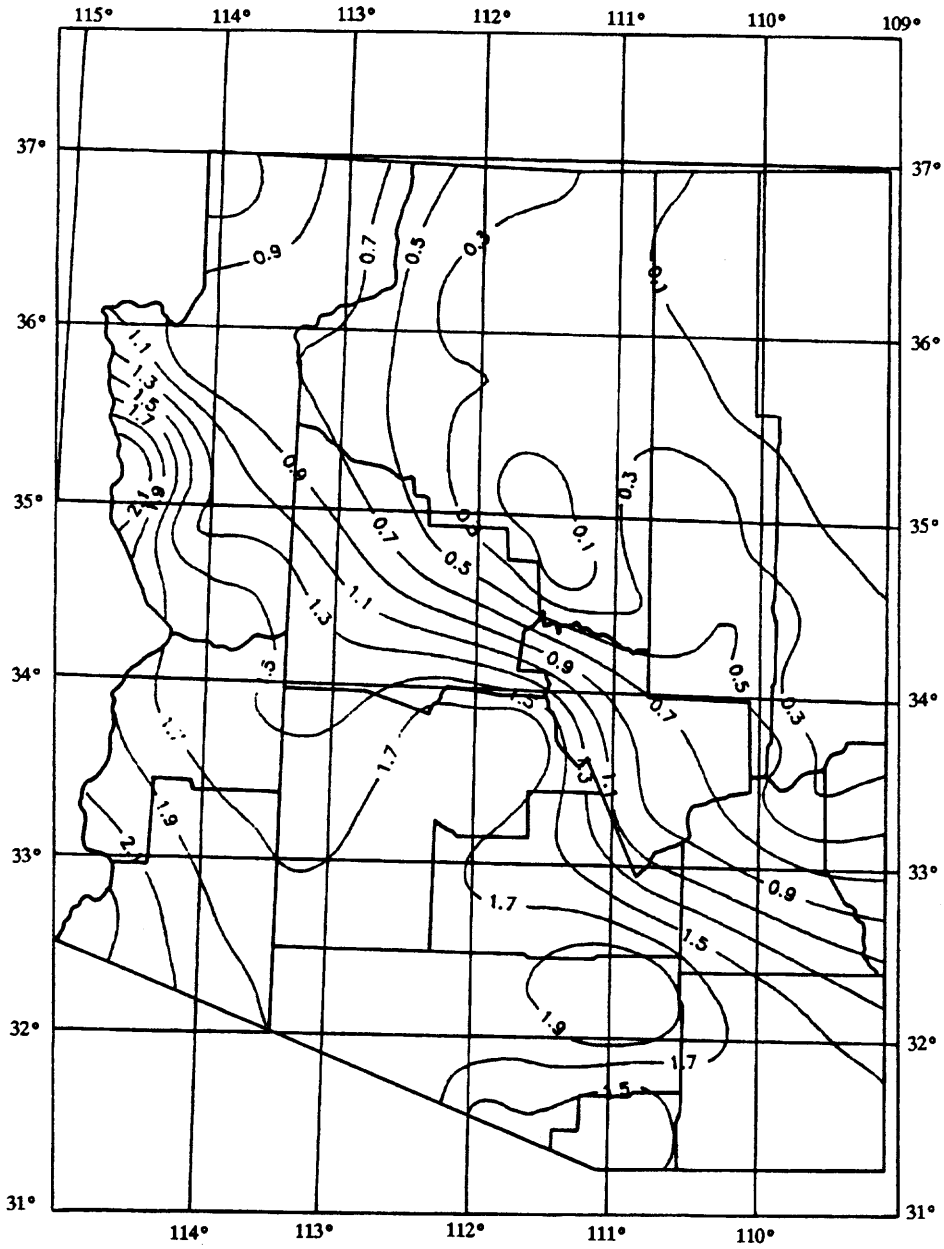
6.3.2.3 Arizona November Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – November

Figure 353. Arizona November Evapotranspiration Map

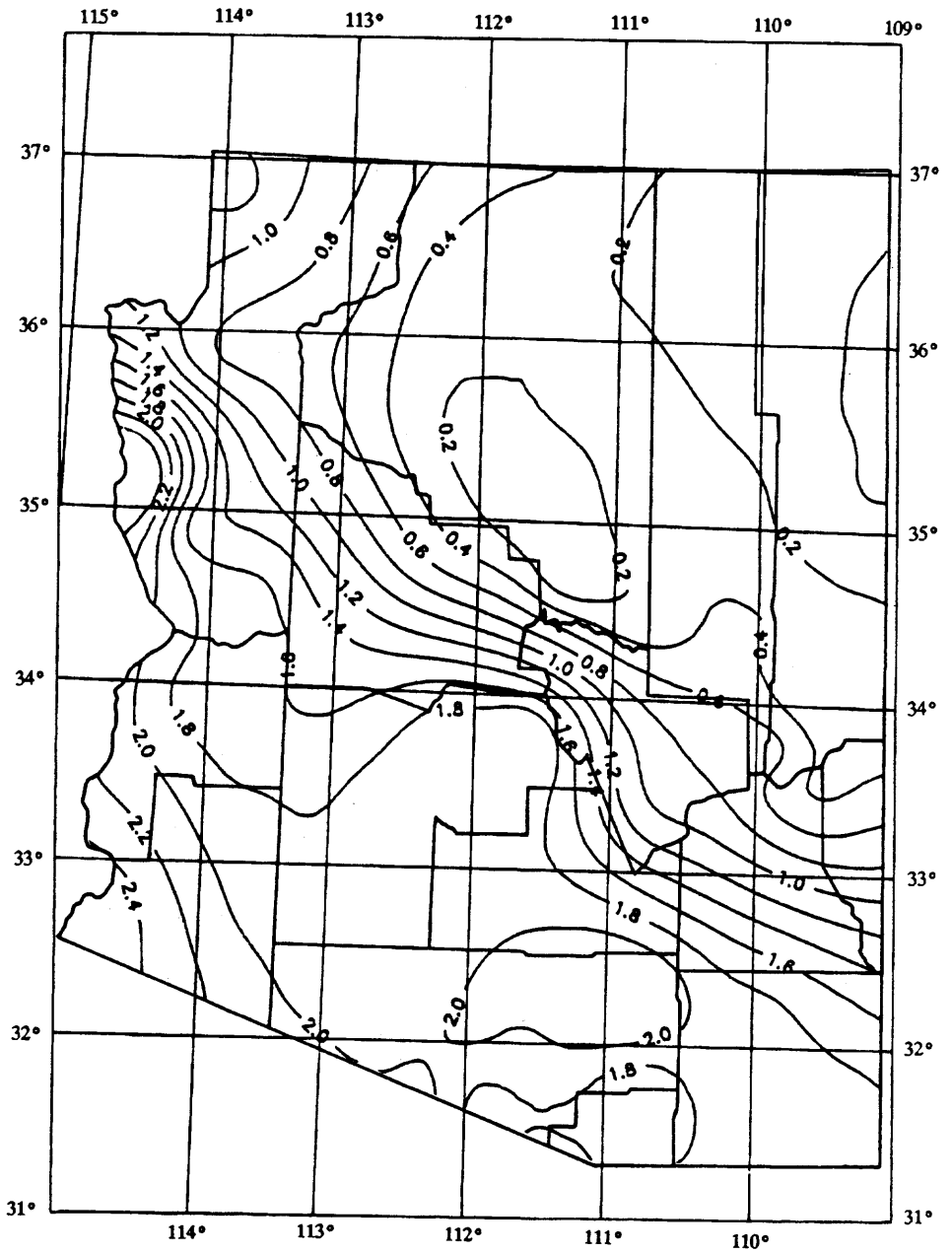
6.3.2.4 Arizona December Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – December

Figure 354. Arizona December Evapotranspiration Map

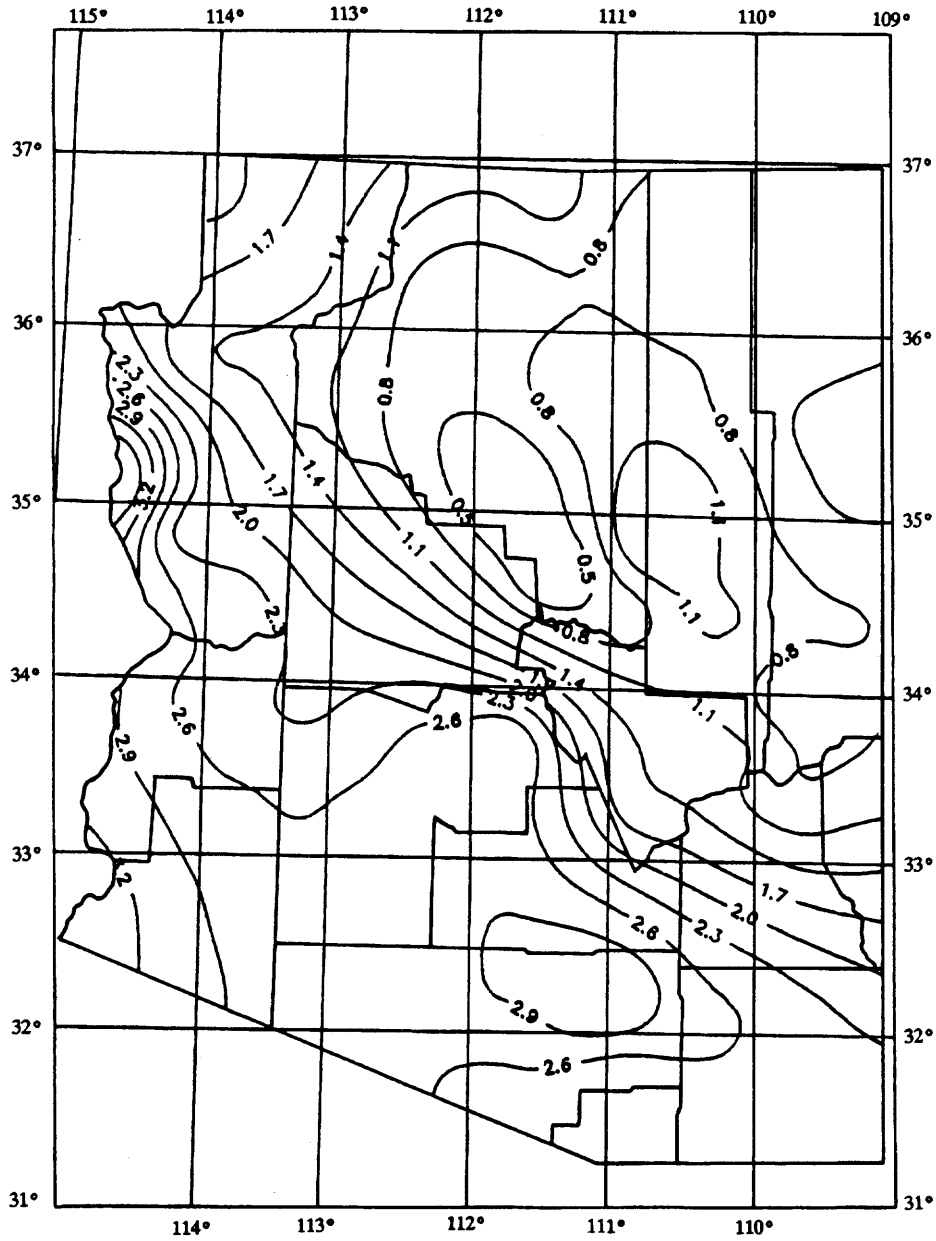
6.3.2.5 Arizona January Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – January

Figure 355. Arizona January Evapotranspiration Map

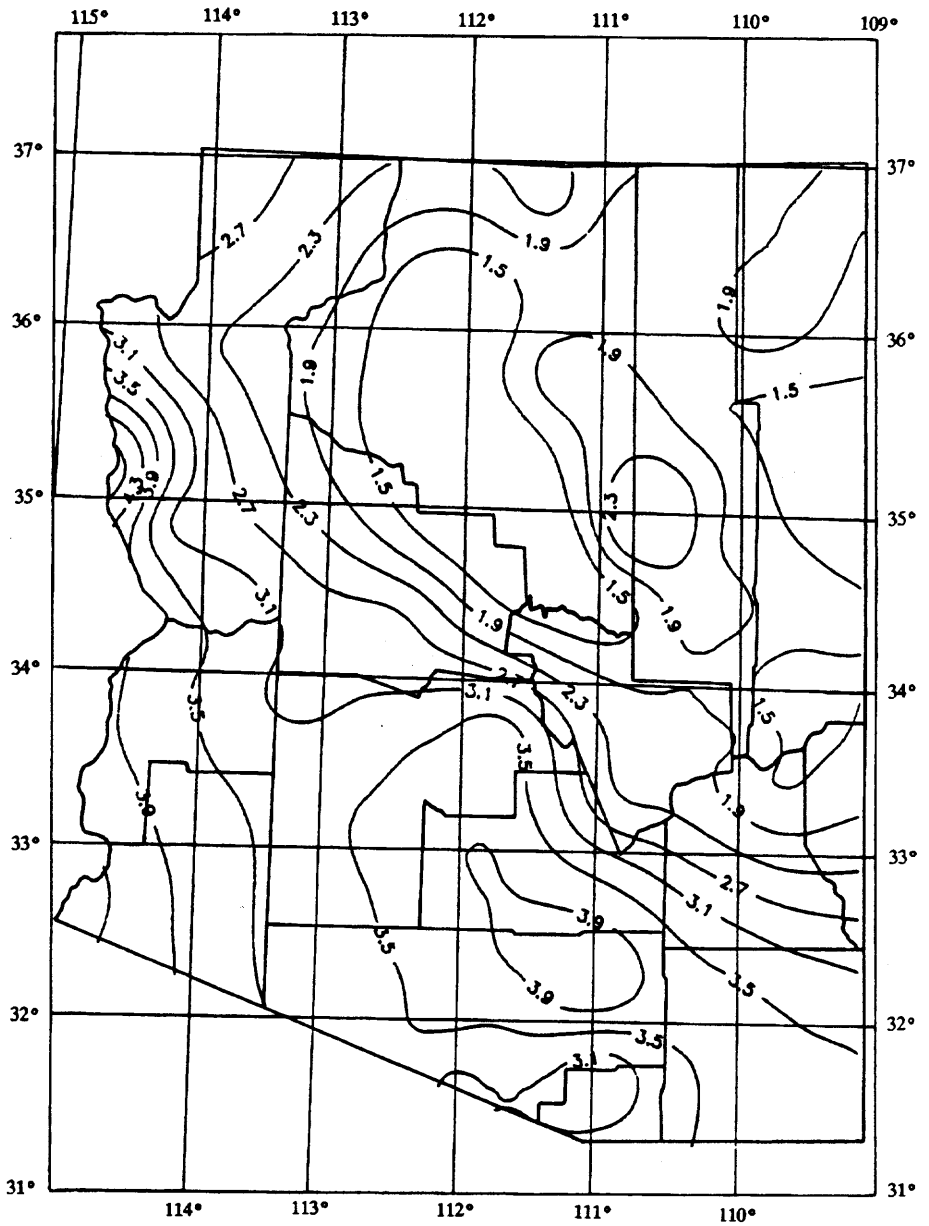
6.3.2.6 Arizona February Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – February

Figure 356. Arizona February Evapotranspiration Map

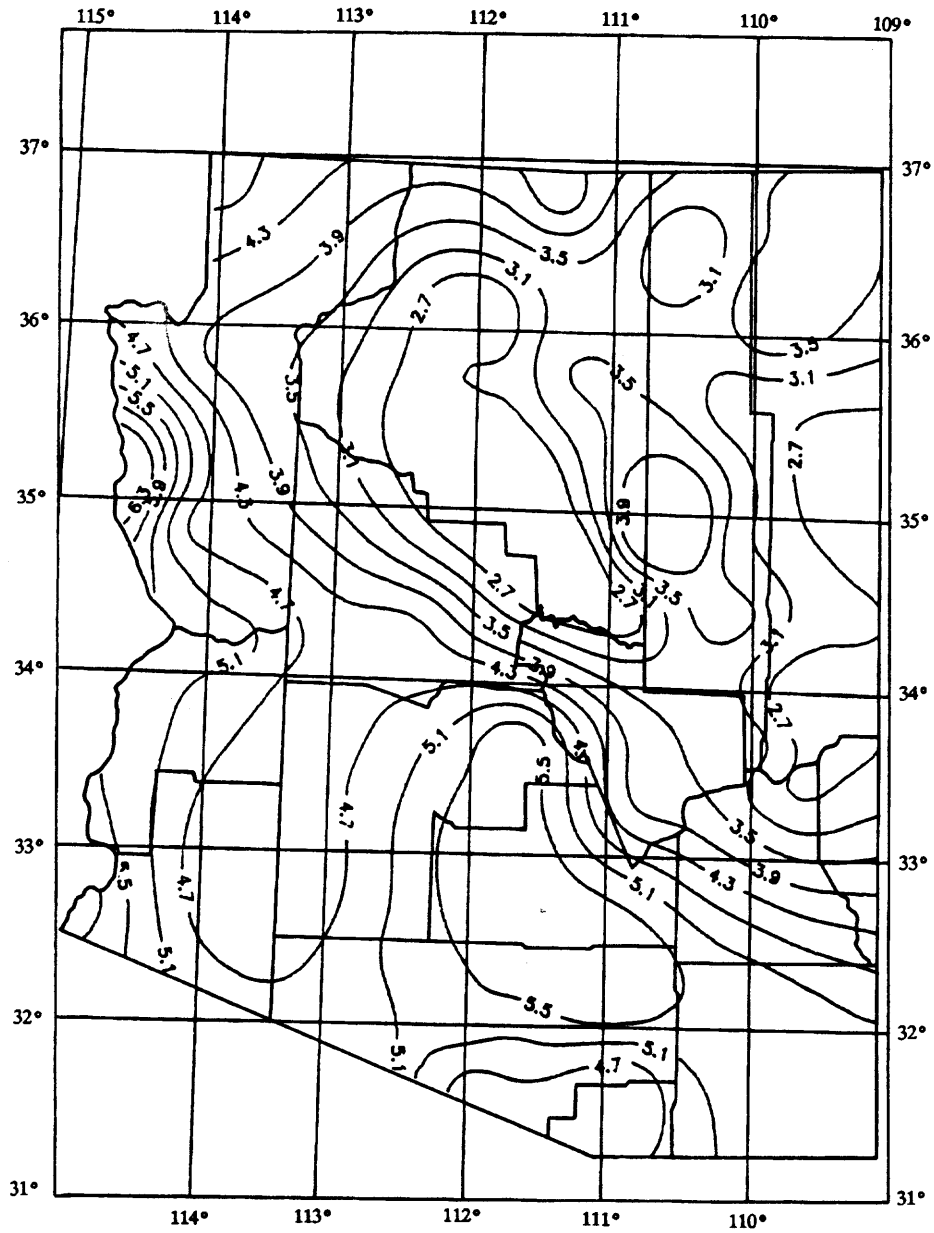
6.3.2.7 Arizona March Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – March

Figure 357. Arizona March Evapotranspiration Map

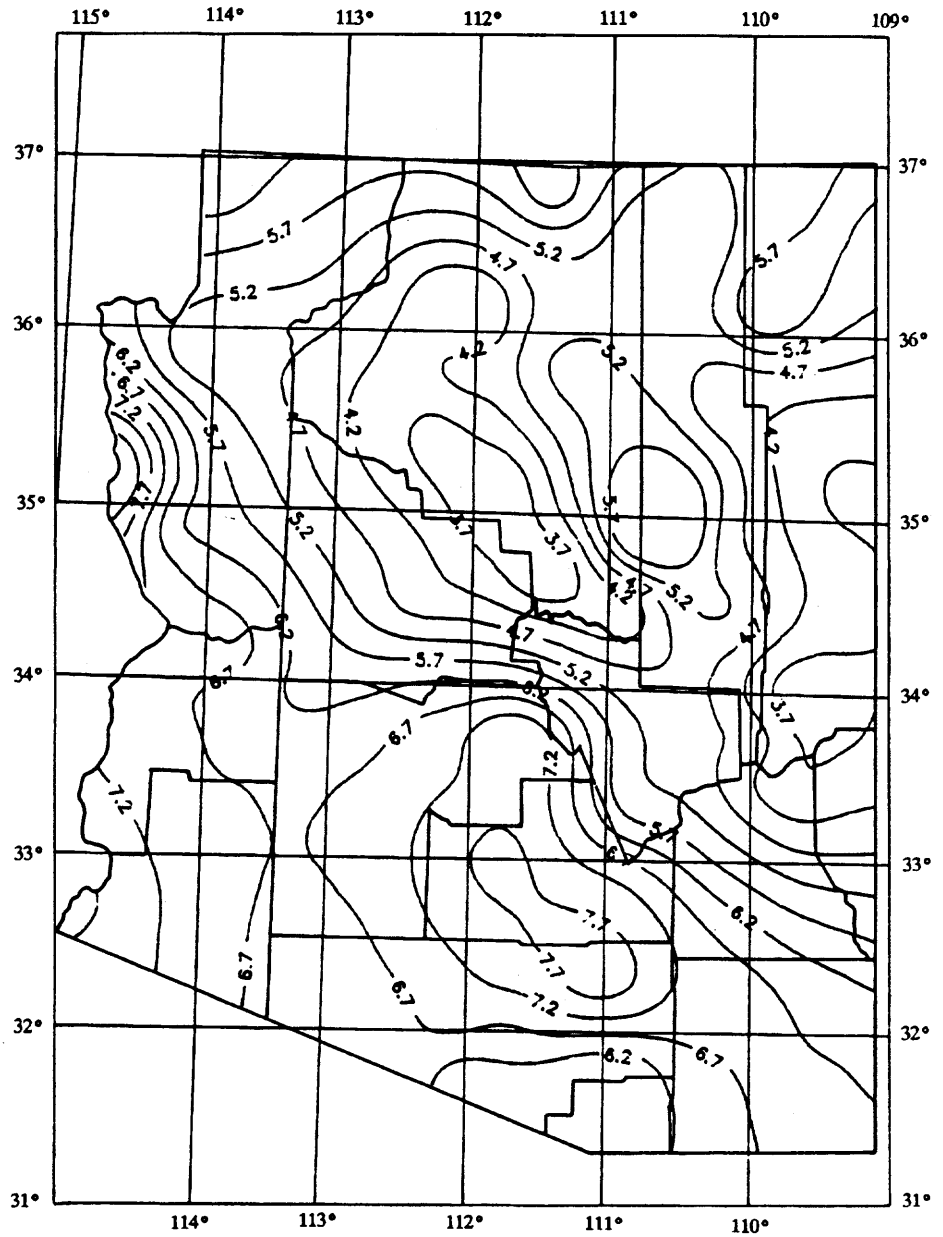
6.3.2.8 Arizona April Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – April

Figure 358. Arizona April Evapotranspiration Map

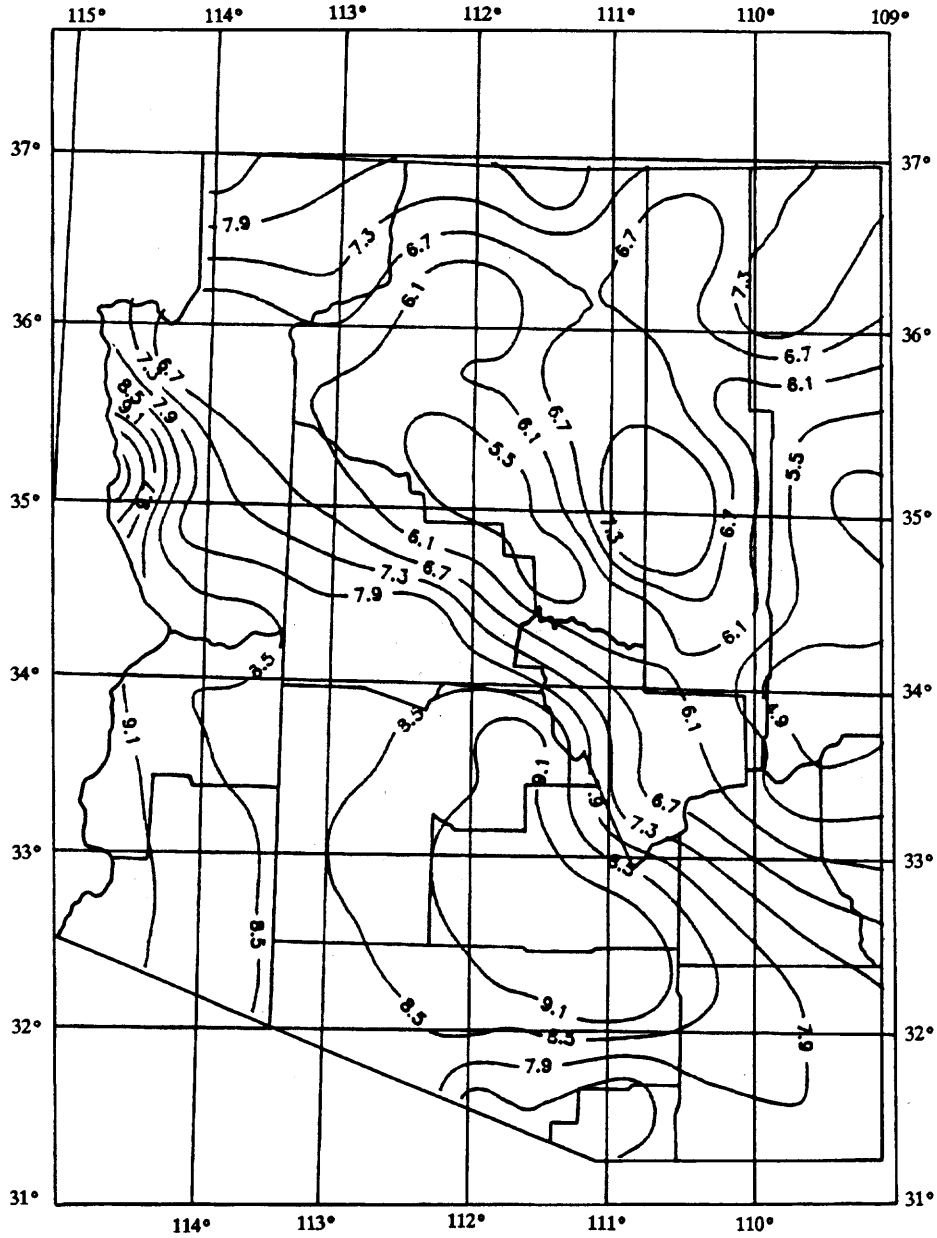
6.3.2.9 Arizona May Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – May

Figure 359. Arizona May Evapotranspiration Map

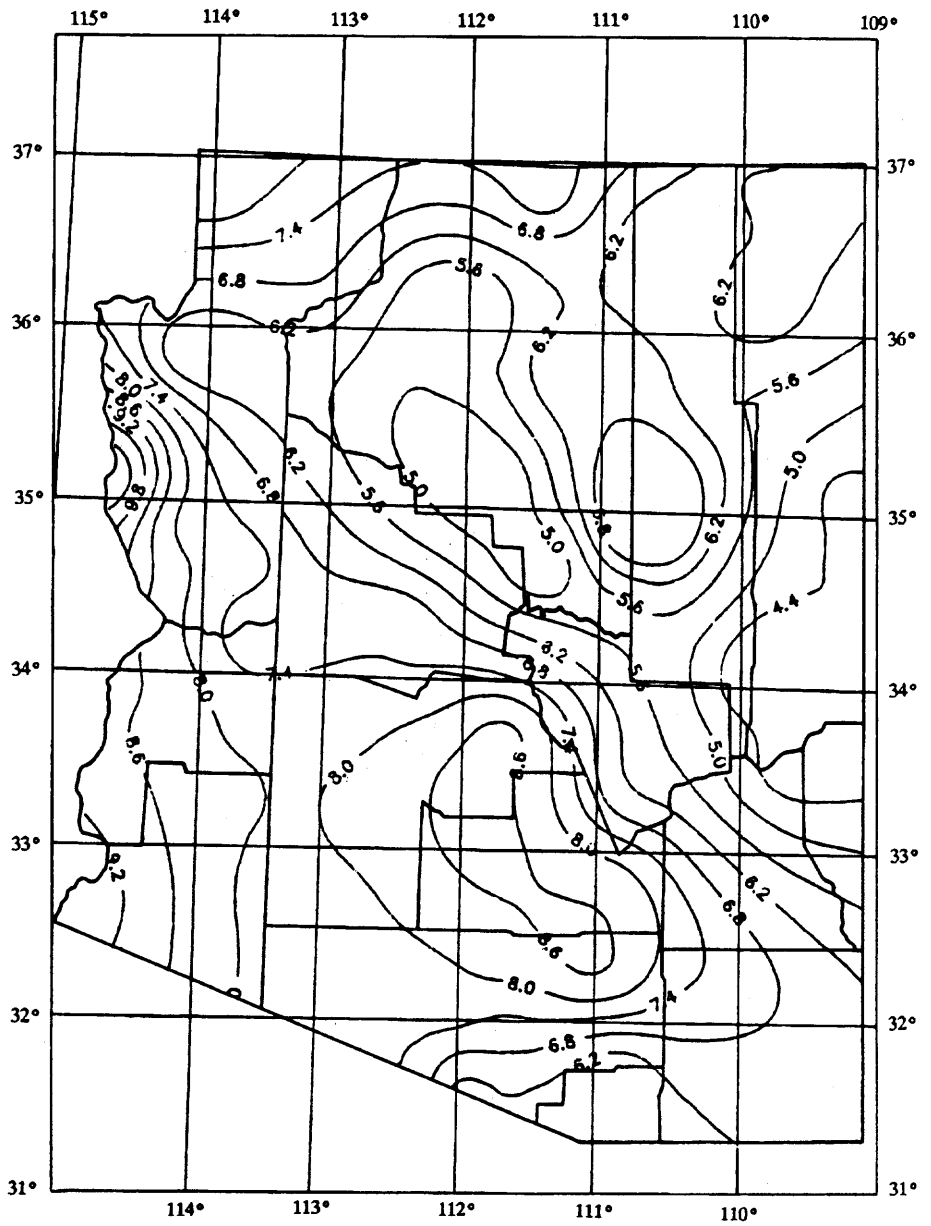
6.3.2.10 Arizona June Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – June

Figure 360. Arizona June Evapotranspiration Map

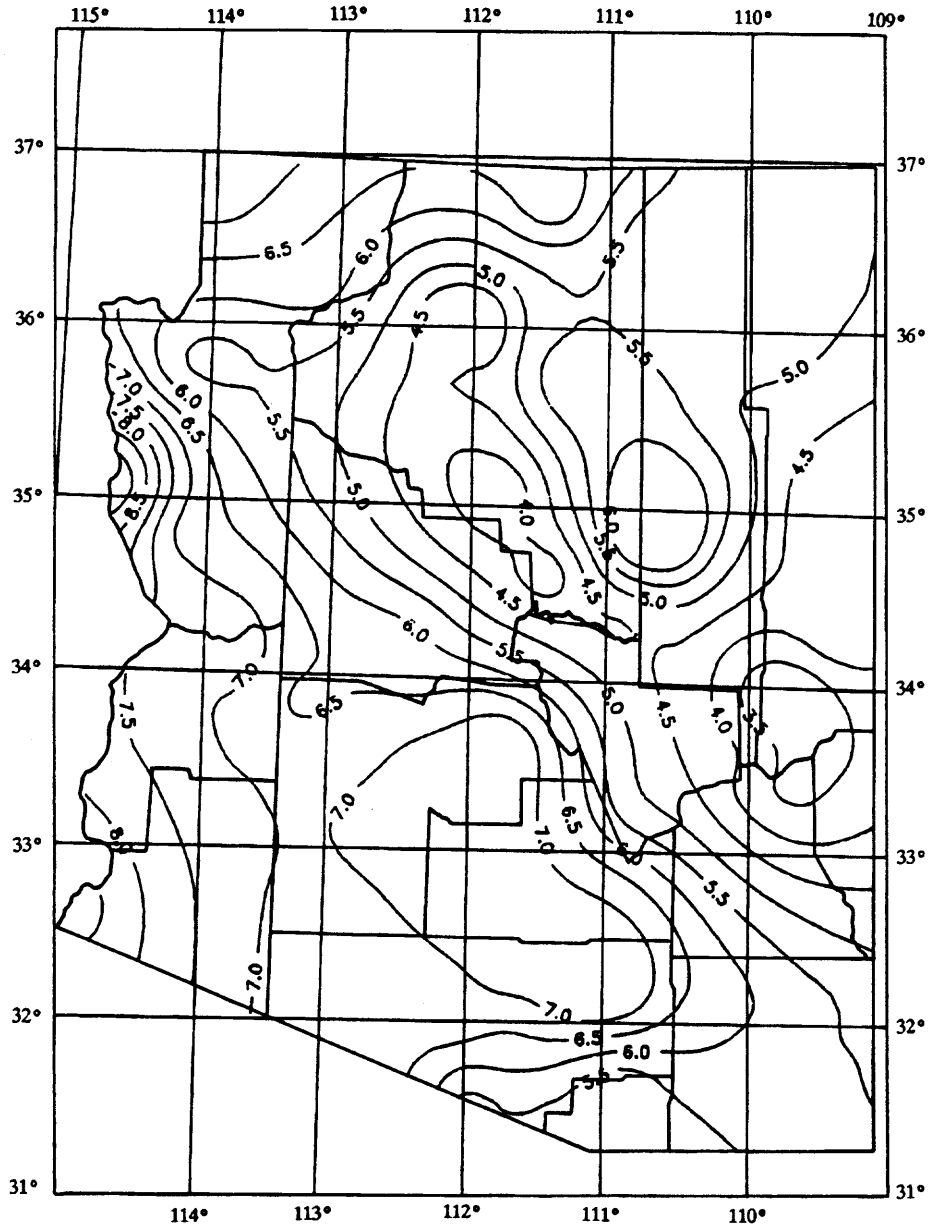
6.3.2.11 Arizona July Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – July

Figure 361. Arizona July Evapotranspiration Map

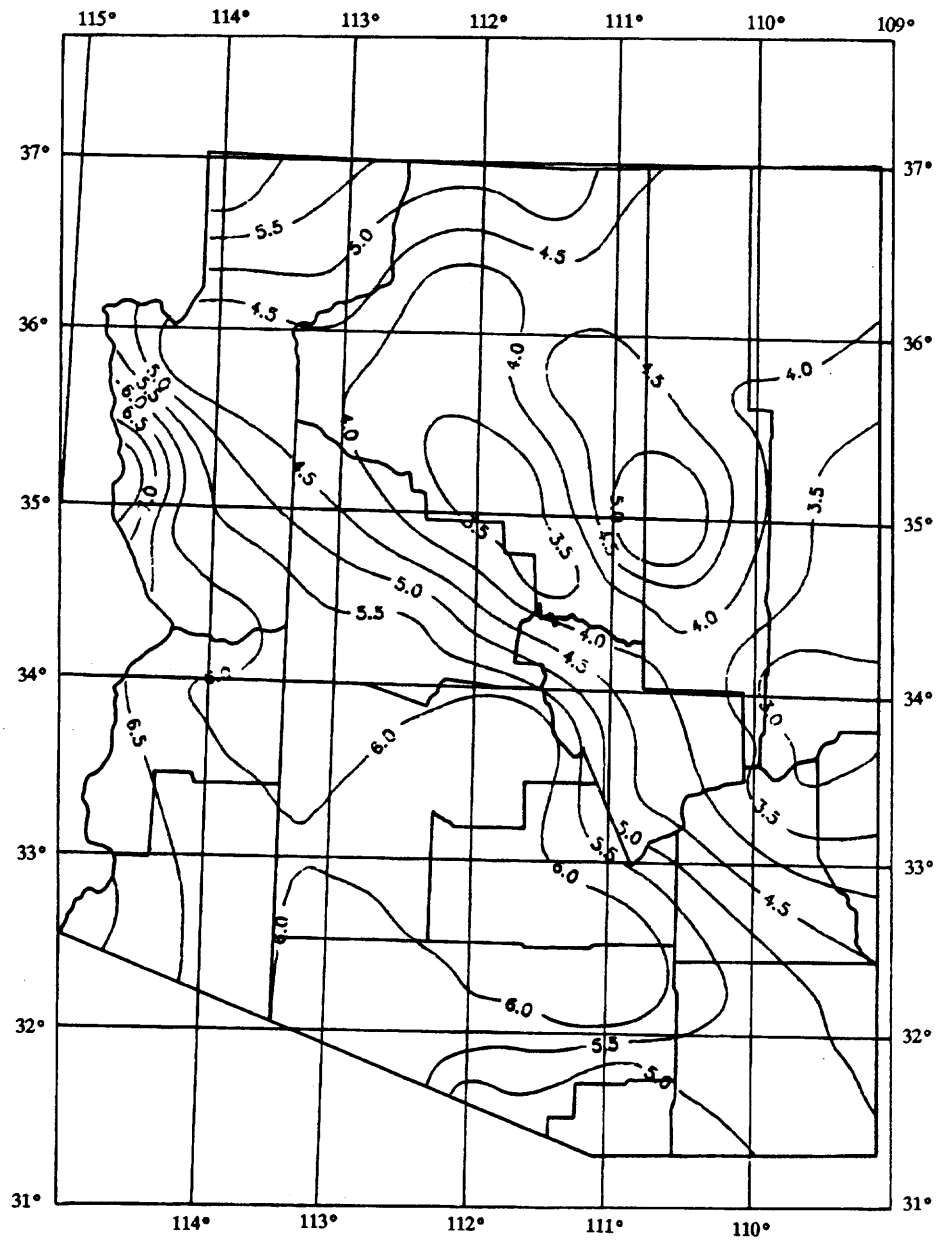
6.3.2.12 Arizona August Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – August

Figure 362. Arizona August Evapotranspiration Map

6.3.2.13 Arizona September Evapotranspiration Map



Reference Evapotranspiration (ETo) in millimeters per day – September

Figure 363. Arizona September Evapotranspiration Map

6.3.3 New Evaporation Station at Kykotsmovi

The Hopi Water Resources Program staff has installed a new evaprotation station near the Hopi government complex in Kykotsmovi. The instrumentation includes a standard evaporation pan, a standard rain and snow gage, a cumulating anemometer, and a max/min water thermometer.

This gage has been installed for the purposes of augmenting the sparse evaporation data available for northeastern Arizona. It is expected that, over a period of time, a more complete and consistent record of evaporation data will result, enabling the Hopi to better understand evaporation and the role it plays in their agricultural practices. To the hydrologists and climatologists, the station will provide badly needed resolution for existing climate information in the Hopi and Navajo reservations.

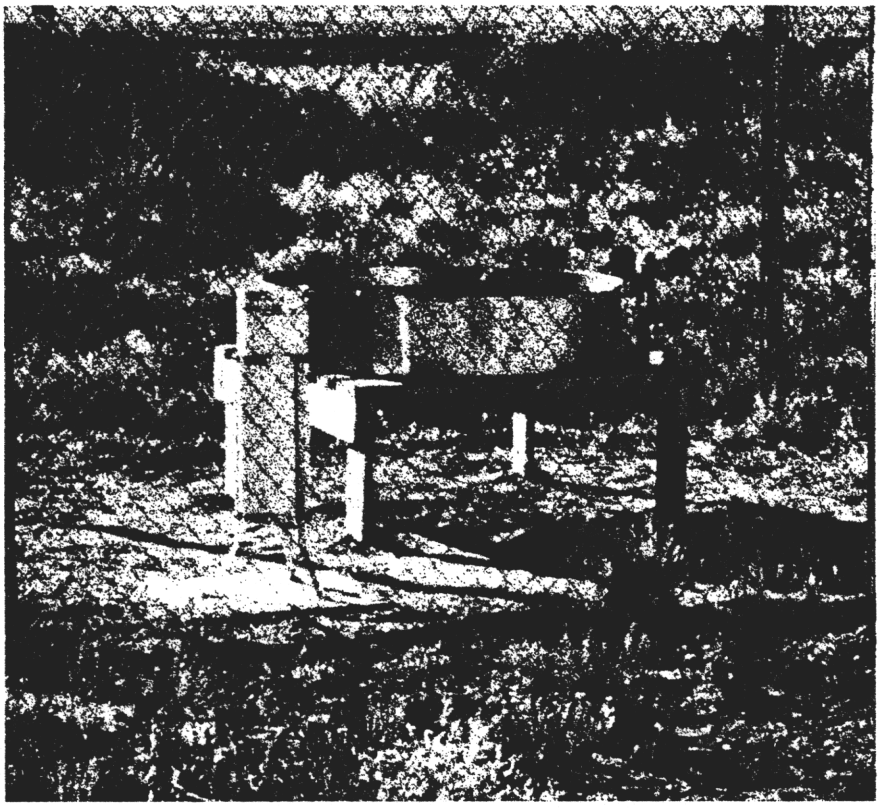


Figure 364. Kykotsmovi Evaporation Station

6.4 Temperature

A study of temperature is presently being conducted utilizing the same methodology as for precipitation. Fortunately, the number of stations is less for temperature.

6.4.1 Period of Record Statistics

To be included in Final Report

6.4.2 Long-Term Trends and Isothermal Maps

To be included in Final Report

6.5 Global Warming and Basin Climatic Trends

To be included in Final Report

7 Erosional Processes

7.1 Aeolian Erosion

Interesting information on wind erosion has been obtained for the basin. This material will be discussed in the Final Report

7.2 Thermal Erosion

To be included in Final Report

7.3 Fluvial Erosion

To be included in Final Report. This material is related to sediment transport.

8 Stream Morphology

8.1 Historical Variations in Stream Alignments

To be included in Final Report

8.2 Effects of Vegetation and Imported Plants

To be included in Final Report

9 Stream Flows for Selected Little Colorado River Gaging Stations

The purpose of this section is to examine the gaged record for historical Little Colorado River stream gaging stations and to present the results of computer modeled reconstructions for two stations for the WY 1939-90 study period.

9.1 Historical Stream Flow Records

Several long-term USGS stream flow station records have been intensely studied during this project by DBS&A and Hopi Water Resources. The hydrographic unit maps which delineate the watersheds of the Little Colorado tributaries have been digitized, as well as stream alignments for the entire basin. The following map delineates the watersheds.

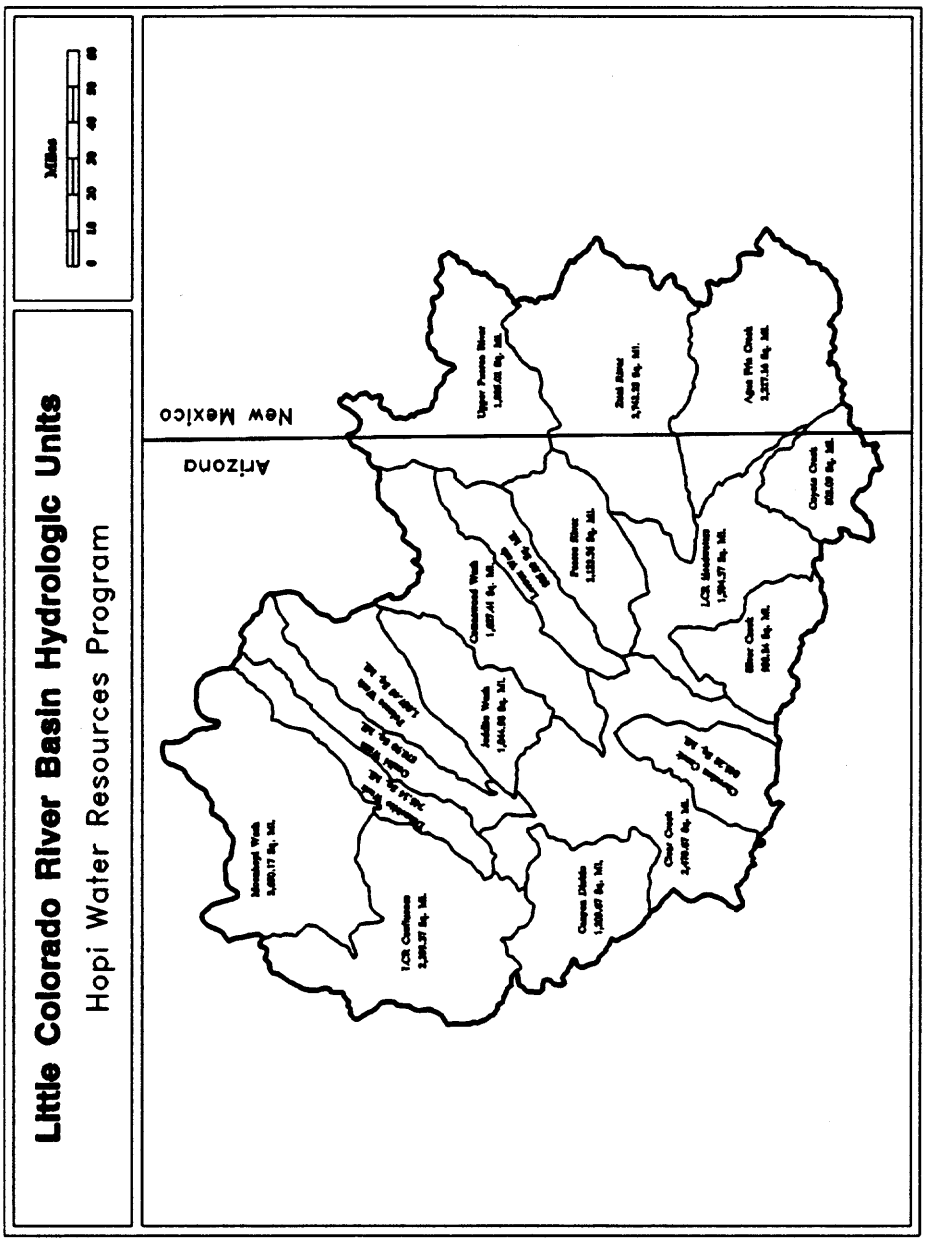


Figure 365. LCR Basin Hydrologic Units Map

The annual mean discharges for the actual gaged periods of record for several continuous record gages are shown in the following thematic map.

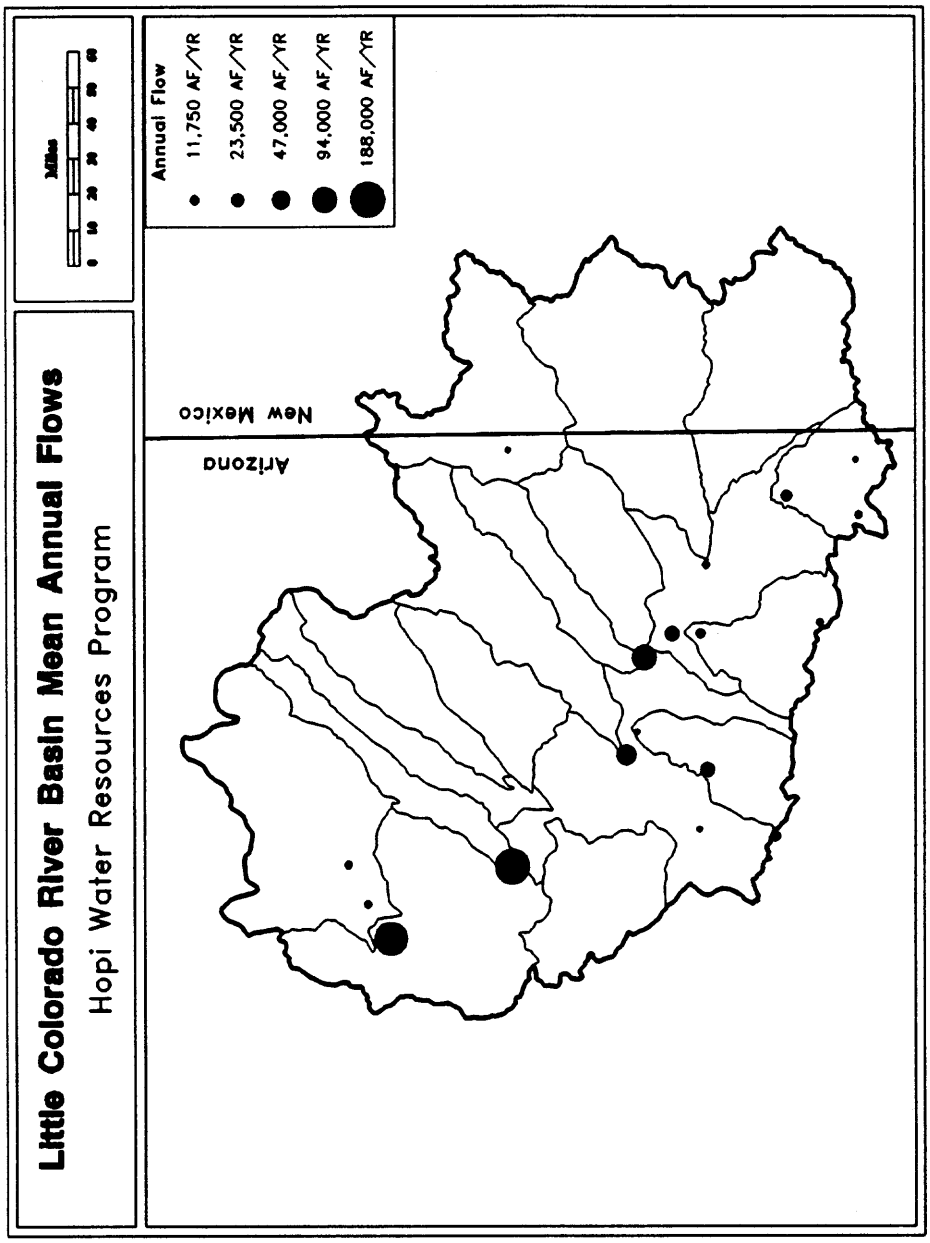


Figure 366. LCR Basin, Map of Mean Annual Discharge, Selected Stations

Monthly records for several long-term stations are tabulated in the following pages. These will form a useful basis of comparison for the modeled records.

9.1.1 Little Colorado River Near Cameron, AZ

This Little Colrado River gage enjoys a period of record from 1947 to the present (1995). It is located just upstream of the U.S. Highway 89 bridge over the LCR at Cameron Trading Post. The drainage area encompasses 26,459 square miles, of which 368 square miles is non-contributing. The broad, flat river bed at the gage has a low slope, making the conditions of calibrating the gage and working the record much easier than most other LCR gages. Although water quality records, as well as stream flows, are available from this location, the sediment sampling is conducted downstreamfrom Cameron, beyond the confluence with Moenkopi Wash.

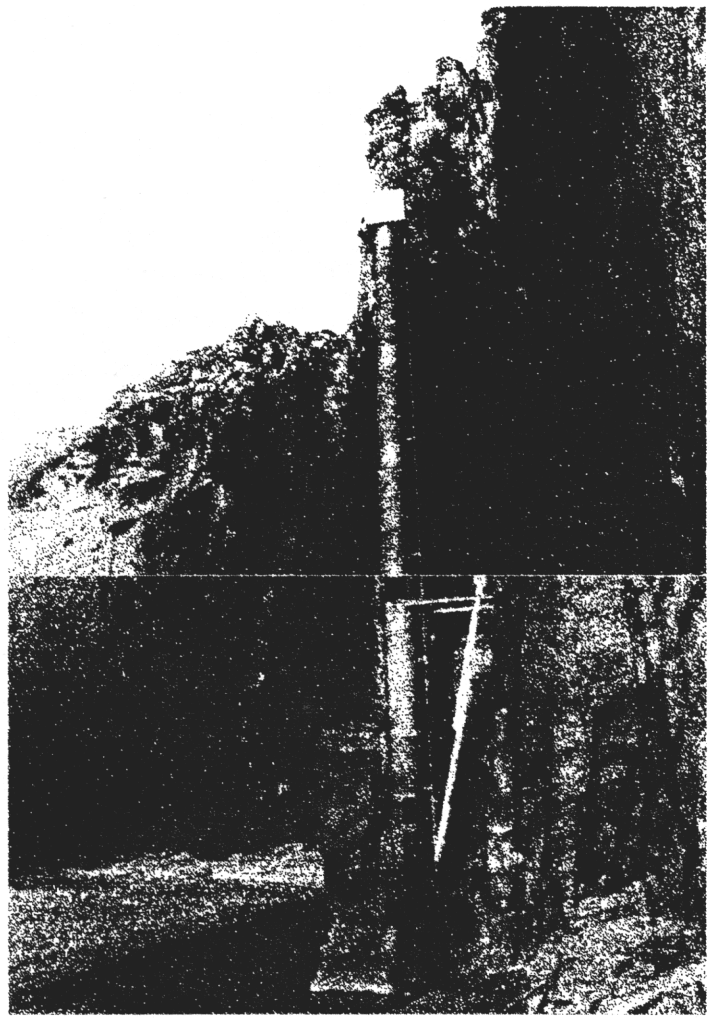


Figure 367. Stream Gage, Little Colorado River near Cameron

Table 84. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Little Colorado River near Cameron
Monthly Discharge
Elevation: 3979.20 feet above mean sea level
Drainage Area: 26,091 sq. mi.
Latitude: +35d 55m 35s N
Longitude: 111d 34m 00s W

Discharge in Acre-Feet

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1947									0	0	104,300	20,170	
1948	75,390	710	1,020	3,300	6,460	19,070	67,370	857	879	5,240	20,190	602	201,088
1949	4,440	2,180	2,070	18,340	13,640	97,140	77,890	6,010	1,690	11,760	41,370	10,750	287,280
1950	6,490	252	30	188	11,310	14,550	3,870	0	0	7,690	998	1,680	47,058
1951	0	22	94	152	14	0	454	1,310	0	3,970	26,270	17,910	50,196
1952	9,050	103	147	124,700	10,190	12,910	131,800	21,070	165	1,910	12,560	27,820	352,425
1953	114	488	3,920	1,640	1,420	15,310	5,730	0	0	14,890	15,050	227	58,789
1954	0	160	27	135	26	17,560	20,200	120	270	37,860	6,290	25,950	108,598
1955	4,160	68	63	113	176	473	22	0	35,380	12,320	139200	3,600	195,575
1956	0	0	69	121	2,030	5,170	1,230	37	0	1,980	8,690	0	19,327
1957	0	0	0	39,170	40,880	25,760	1,930	57	263	4,170	53,470	9,270	174,970
1958	12,830	12,420	1,260	307	4,900	31,260	44,540	1,620	165	444	23,090	34,420	167,256
1959	10,810	63	29	128	80	1,890	2,390	0	49	96	35,590	264	51,389
1960	6,580	34,720	19,010	18,200	8,220	88,480	18,560	24	13	0	0	382	194,189
1961	9,150	80	124	73	13	2,280	11,620	0	0	706	9,460	5,270	38,776
1962	510	3,710	6	93	46,290	14,010	85,640	1,200	0	0	167	6,130	157,756
1963	4,500	3,110	159	14	2,130	1,310	1,750	0	0	0	41,360	29,930	84,263
1964	1,850	680	0	0	0	0	27,190	3,080	60	9,940	101,900	26,200	170,900
1965	549	0	0	42,140	12,210	14,970	87,550	16,570	0	20,820	10,110	20,970	225,889
1966	416	3,920	24,490	55,820	4,330	66,880	16,950	77	0	976	17,510	11,110	202,479
1967	4,530	43	23,020	50	48	0	1,200	0	2,600	22,760	87,290	48,880	190,421
1968	450	0	117	3,940	40,260	49,080	67,110	12,310	0	6,570	33,950	1	213,788
1969	5,160	179	0	26,600	7,620	17,880	37,710	1,100	0	12,940	7,880	22,770	139,839
1970	5,650	1,160	48	63	0	5,280	4,630	0	0	729	13,590	49,520	80,670
1971	679	8	67	46	5	0	0	0	0	130	60,540	16,170	77,646
1972	75,450	6,060	28,210	6,900	322	0	0	0	182	8,780	5,200	1,480	132,584
1973	257,800	12,100	6,400	12,300	24,760	86,970	236,200	177,200	1,860	39	205	46	815,880
1974	0	0	0	656	62	8,060	4,000	0	0	6,640	6,040	2,800	28,258
1975	11,020	11,850	0	12	53	14,160	32,780	6,190	0	9,860	979	25,530	112,434
1976	177	0	892	142	12,490	17,820	35,500	9,730	0	19,120	4,020	7,670	107,561
1977	509	77	0	3,330	560	29	5,000	3	0	16,440	36,160	7,470	69,578
1978	6,020	605	168	603	5,260	115,200	47,070	2,280	202	0	243	1,210	178,861
1979	7,340	35,920	103,900	15,410	45,370	78,580	158,700	21,950	1,630	0	3,990	0	472,790
1980	267	1,870	388	8,260	121,300	45,730	104,200	36,850	94	14	4,670	9,680	333,323
1981	0	0	8	65	73	47	1,820	76	7	20,830	5,160	13,070	41,156
1982	26,010	33	1,330	3,290	21,820	71,120	32,310	3,150	0	200	42,490	25,840	227,593
1983	395	3,220	27,350	8,850	17,110	83,140	93,590	41,700	13	9,460	21,370	17,080	323,278
1984	42,350	2,510	14,080	9,610	513	4,050	1,450	0	0	17,500	75,600	44,830	212,493
1985	23,410	207	18,980	27,260	22,510	94,980	49,250	19,860	0	2,010	6,390	9,820	274,677
1986	3,000	10,890	6,700	172	9,530	20,330	10,050	0	0	15,570	8,170	12,420	96,832
1987	13,760	11,180	9,300	8,700	13,510	31,850	38,010	7,920	565	1,100	25,840	223	161,958
1988	901	44,810	15	2,130	32,400	18,580	28,250	4,190	868	1,920	30,520	15,540	180,124
1989	0	64	30	142	452	10,570	3,220	0	0	2,460	19,540	4	36,482
1990	155	0	0	21	515	14	135	2	0	7,640	8,720	18,930	36,132
Ann Mean	14,695	4,778	6,826	10,307	12,578	27,965	37,183	9,222	1,067	7,216	26,730	13,719	170,525

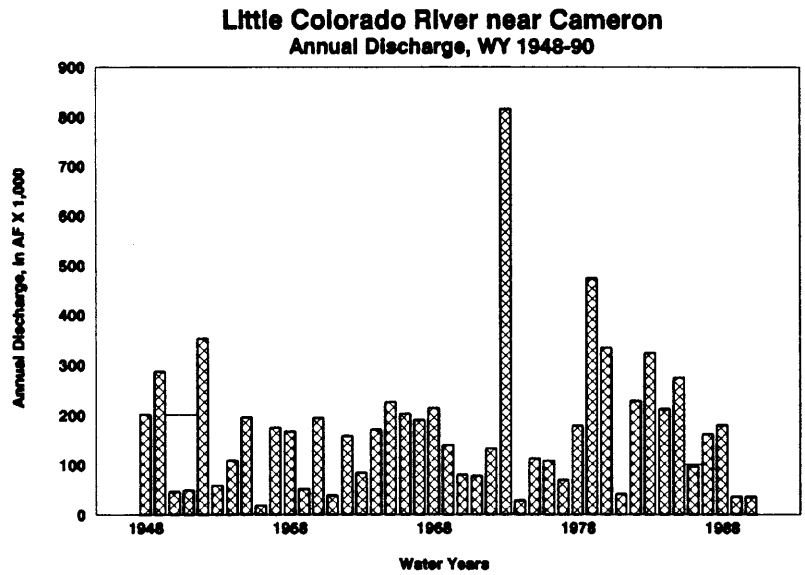


Figure 368. Annual Discharge, LCR near Cameron, WY 1948-90

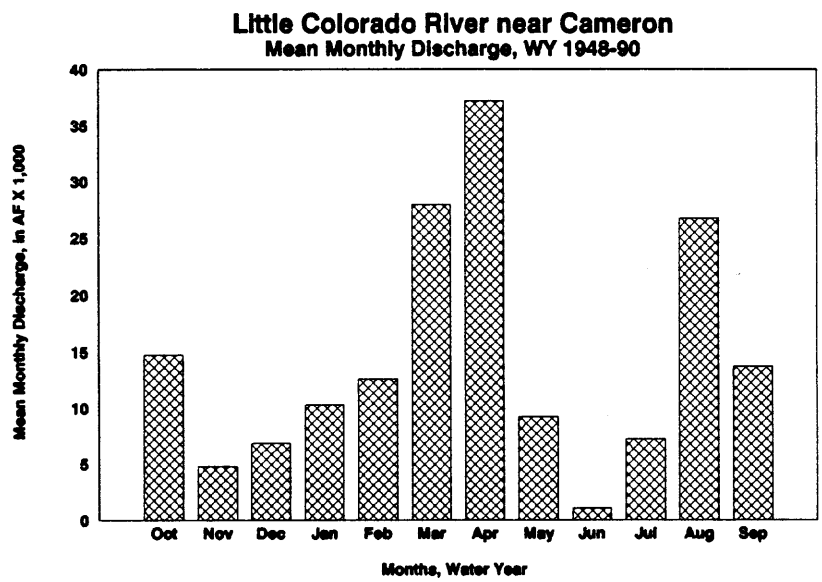


Figure 369. Mean Monthly Discharge, LCR near Cameron, WY 1948-90

9.1.2 Little Colorado River at Grand Falls, AZ

This Little Colorado River gage is located on a rock cleaved from the riverside cliff, on the southwest bank of the LCR just downstream of Grand Falls. Its period of record span two date ranges-- 1926-1960 and 1990 to the present (1995). The drainage area of 21,368 square miles, of which 368 square miles is non-contributing, encomasses all the major tributary flows except Dinnebito, Moenkopi, and Hamlin Washes. Sediment and water quality data are also available. This station was initially abandoned in 1960 in favor of LCR near Cameron after a 12 year concurrent period of record, apparently due to better control and advantageous all-weather accessibility. The site was reactivated in 1990 by USGS as part of the Glen Canyon Environmental Studies effort of the Bureau of Reclamation. It is to be hoped that this gage will continue operation into the Long-Term Monitoring Program of the Glen Canyon studies, due both to the long record available and to the need to estimate tributary flows and losses from the Grand Falls and Cameron records.

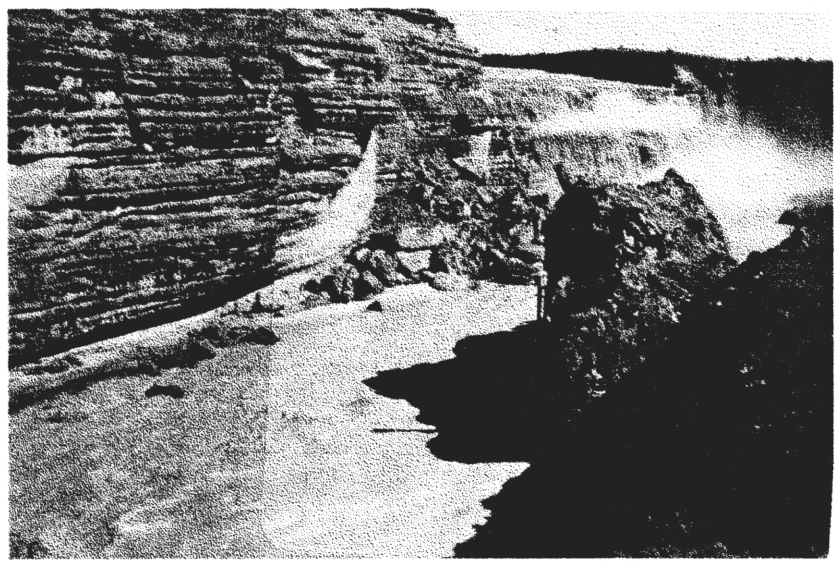


Figure 370. Stream Gage, Little Colorado River at Grand Falls

Table 85. U. S. Geological Survey
Station: Little Colorado River at Grand Falls
Elevation: 4438.90 feet above mean sea level
Hopi Tribal Database
Drainage Area: 20,700 sq. mi.
Latitude: +35d 26m 00sEasting:
Longitude: 111d 12m 00s

Monthly Discharge Data in Acre-Feet

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1926			2,410	946	474	18,730	83,940	10,870	0	688	5,530	47,930	
1927	2,370	1,120	1,000	3,000	60,980	74,950	50,500	6,050	36,990	20,660	20,840	115,300	280,387
1928	643	0	153	464	17,210	50,460	7,600	125	0	2,490	5,250	3,170	86,323
1929	87	7,300	908	543	1,420	42,350	155,300	2,420	0	96,850	110,300	93,330	419,407
1930	12,090	496	468	655	1,420	22,310	27,040	1,000	0	50,540	67,650	5,640	185,599
1931	0	1,000	4,440	1,130	12,480	29,340	13,890	12,430	2	23,230	51,340	15,870	161,213
1932	14,090	17,060	7,060	9,420	153,700	146,800	77,710	9,410	0	3,330	24,170	3,090	464,682
1933	1,900	236	89	184	7,370	25,260	18,050	10,600	0	18,280	19,610	27,650	103,512
1934	31,120	1,030	1,230	712	778	1,690	1,500	6	1,500	2,060	20,890	8,460	64,450
1935	139	0	0	19,080	27,440	38,000	72,590	2,820	0	724	32,840	21,800	195,568
1936	1,720	99	827	631	4,040	22,680	49,250	752	0	3,830	45,630	35,610	131,395
1937	335	4,920	242	18	115,800	110,900	89,090	2,530	0	6,020	2,780	6,870	334,572
1938	6,280	95	538	93	1,250	128,100	4,440	44	0	171	11,220	17,950	154,169
1939	0	0	0	377	1,610	34,250	40,120	10	0	0	2,780	4,100	81,086
1940	0	0	206	817	5,350	13,470	6,670	2	0	12,230	42,050	51,450	82,735
1941	21,650	8,600	28,770	56,698	74,900	136,700	107,600	86,370	3,970	3,820	26,700	31,010	557,719
1942	53,830	3,070	2,970	6,720	6,450	19,040	50,610	5,980	0	0	371	0	150,983
1943	666	597	0	292	6,730	53,120	12,780	0	0	0	16,730	12,080	92,858
1944	711	29	58	192	364	22,710	71,770	24,680	0	0	0	8,520	122,448
1945	2,200	1,020	1,120	508	4,900	16,810	67,280	19,590	0	9,620	35,800	666	160,793
1946	34	0	432	4,330	2,510	3,980	3,170	0	0	9,610	52,000	40,380	78,012
1947	661	14,550	4,930	3,530	8,420	6,620	815	422	0	0	74,460	12,670	116,355
1948	57,000	702	1,020	3,510	7,920	19,870	68,300	996	63	4,960	16,170	1,730	182,459
1949	2,120	2,020	3,280	16,870	13,150	85,550	76,000	6,070	4	13,340	39,290	10,750	259,643
1950	163	445	78										
1951	0	0	0	0	157	253	1,830	2,180	0	1,920	30,600	9,250	38,891
1952	0	0	0	0	0	20,840	19,980	0	0	39,310	5,400	21,990	87,482
1953													
1954	0	0	0	0	0	20,840	19,980	0	0	39,310	5,400	21,990	87,484
1955	2,710	0	0	26	79	1,160	525	0	18,080	5,280	122,100	2,340	151,914
1956	0	0	121	0	3,710	7,380	2,070	47	0	0	5,340	0	20,624
1957	0	0	0	43,300	41,710	24,810	2,990	0	0	4,470	44,360	8,140	163,597
1958	12,860	9,590	2,080	228	6,500	29,940	43,160	1,170	778	987	22,310	31,470	131,561
1959	8,890	0	0	0	0	4,240	3,200	0	0	354	30,890	282	49,533
1960	12,310	33,200	22,830	22,050	8,890	89,750	18,210	99	2				
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1990	0	0	0	0	0	0	646	0	0	5,760	6,760	8,690	15,156
1991	1,250	1,340	4,570	16,620	4,530	32,740	70,650	2,980	0	0	172	1,270	136,743
Ann Mean	7,081	3,101	2,555	6,232	17,699	39,321	36,921	5,847	1,806	11,490	30,067	19,198	179,051

Period of Record: 1926-1960, 1990-present

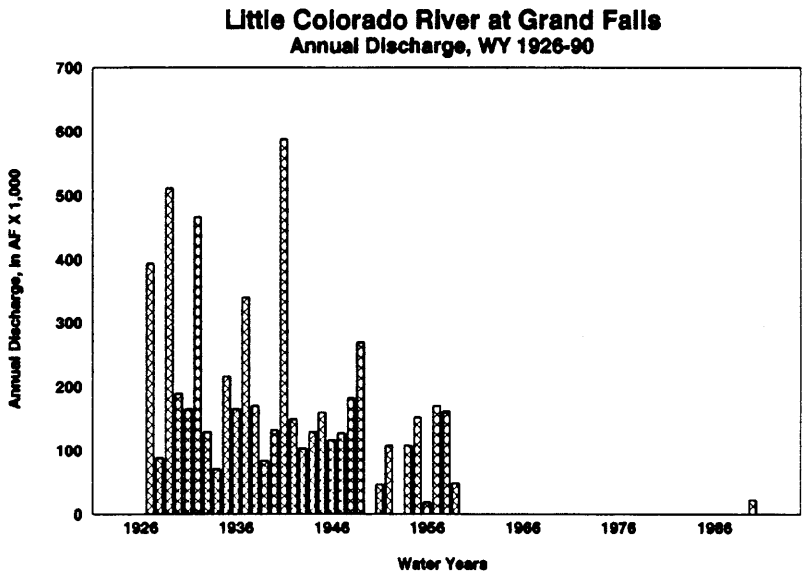


Figure 371. LCR at Grand Falls, Annual Discharge, WY 1926-90

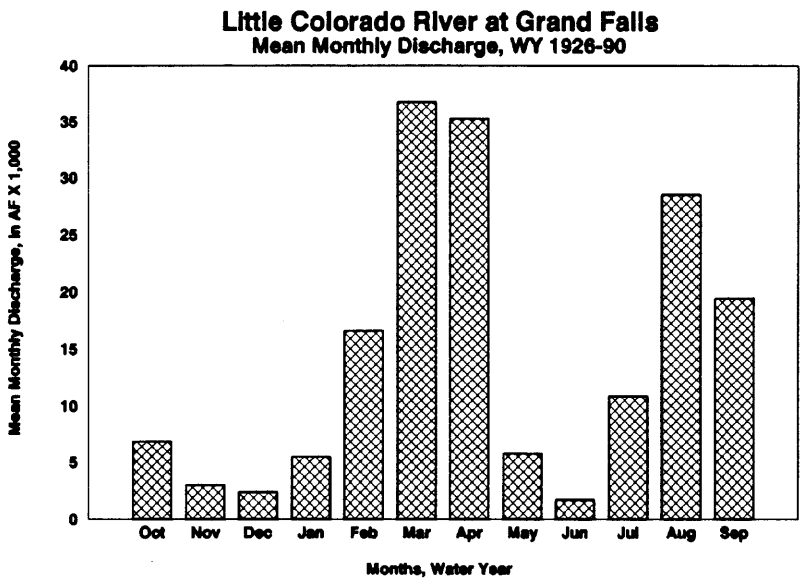


Figure 372. LCR at Grand Falls, Mean Monthly Discharge, WY 1926-90

The following graph is an illustration of the number of days in each water year in which the Little Colorado River is not flowing at the Grand Falls gage. Despite the fact that precipitation is increasing, the number of days in which the river is dry is increasing. It may be assumed that the increase in the number of no flow days is due to stream depletions, there is no correlation at present between reservoir operational data and the number of zero flow days. Changes in precipitation duration and intensity may also account for this discrepancy.

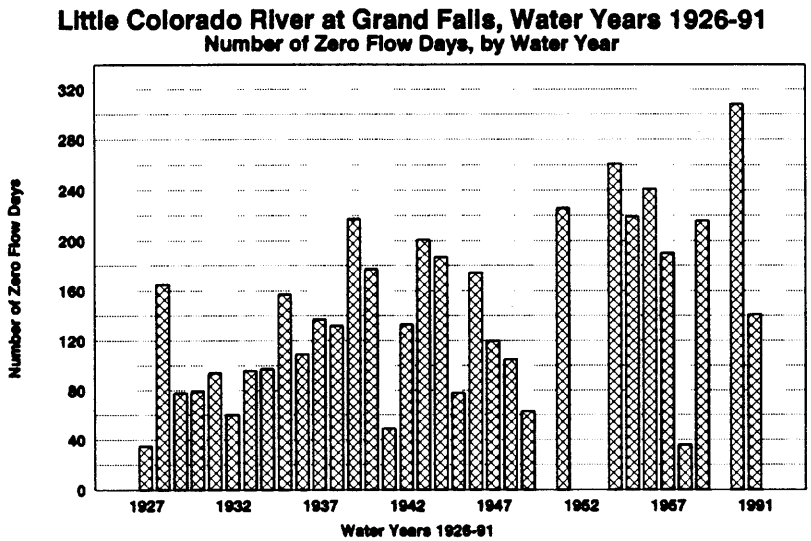


Figure 373. LCR at Grand Falls, Zero (0) Flow Days per Year, WY 1926-90

9.1.3 Little Colorado River at Holbrook, AZ

This Little Colorado River gage was located near downstream side of the old Highway 180 bridge near the right bank. The drainage area encompassed 11,462 square miles, of which 347 square miles is non-contributing. Between Holbrook and LCR at Grand Falls, several major drainages from the Mogollon Rim to the South and from the Hopi and Navajo Reservation have confluences with the Little Colorado River. Although the flow records from this station are instructive for understanding the flow and sediment regime of the river, there is some indication that the flow data may be as much as 13% (Marley, 1994) to 30% too high (USDA SCS, 1981).

Table 86. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Little Colorado River at Holbrook
Elevation: 5062.87 feet above mean sea level
Latitude: +34d 53m 52s
Longitude: 110d 09m 45s
Drainage Area: 11,115 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1905							54,490	27,930	4,910	4,170	10,020	17,940	
1906	3,120	69,020	6,920	27,770	9,450	38,190	14,570	3,320	244	1,530	4,400	4,090	182,624
1907	1,640	670	11,150	16,960	9,750	27,290	23,850						
1923													
1950	600	505	705	949	2,490	459	137	122	66	6,350	908	1,410	14,701
1951	148	421	519	775	931	476	159	127	22	1,820	18,770	866	25,034
1952	2,100	974	2,710	32,030	1,710	5,270	6,700	1,170	1,790	7,450	11,940	7,510	81,354
1953	562	1,770	5,500	1,910	576	2,890	229	257	698	16,050	4,360	161	34,963
1954	223	350	480	652	670	4,890	365	162	54	37,610	7,310	21,160	73,926
1955	1,590	502	579	657	668	522	198	240	9,600	8,580	96,080	3,030	122,246
1956	288	409	905	2,030	8,040	563	178	80	1,520	2,890	7,520	137	24,560
1957	531	318	488	1,060	1,420	561	233	143	60	12,380	56,280	5,280	78,754
1958	10,390	2,170	642	729	602	3,020	694	232	2,480	2,660	26,330	23,740	73,689
1959	2,470	698	596	697	561	368	394	294	1,430	2,730	33,400	358	43,996
1960	33,930	9,470	6,000	9,300	2,830	13,490	642	294	248	483	1,950	251	78,888
1961	5,520	432	543	676	373	468	357	369	191	1,770	11,720	7,240	29,659
1962	7,090	6,540	875	1,430	17,340	3,270	1,120	410	493	299	275	2,650	41,792
1963	19,910	5,780	604	570	3,250	351	307	254	110	151	58,890	27,090	117,267
1964	967	2,660	503	423	361	354	1,080	350	156	15,860	131,100	27,330	181,144
1956	633	927	1,030	6,590	1,620	851	1,050	515	375	39,230	8,900	23,830	85,551
1966	1,850	1,220	32,530	7,700	1,460	4,630	737	405	229	10,700	22,070	15,730	99,261
1967	3,780	419	573	450	368	295	237	242	3,320	30,650	88,940	41,970	171,244
1968	496	388	544	34,730	13,070	7,730	1,370	434	253	11,340	97,990	374	168,719
1969	28,160	2,010	467	26,320	2,900	4,490	2,880	1,020	355	23,920	45,350	42,980	180,852
1970	877	722	372	357	477	685	732	548	215	2,010	14,560	36,460	58,015
1971	2,700	260	240	196	158	207	163	245	152	346	67,710	59,760	132,137
1972	26,850	565	12,130	934	465	345	314	770	1,690	3,700	8,100	3,070	58,933
1973	57,720	3,070	2,150	1,680	9,540	77,880	60,860	36,880	1,830	415	1,260	232	253,517
1974	462	355	533	3,550	412	368	349	310	39				
Mean	7,948	4,171	3,344	6,708	3,389	7,404	6,228	2,856	1,205	9,637	33,045	14,268	96,513
Max	57,720	69,020	32,530	34,730	17,340	77,880	60,860	36,880	9,600	39,230	131,100	59,760	253,517
Min	148	260	240	196	158	207	137	80	22	151	275	137	14,701

Period of Record: 1904-07, 1949-74
Mean Discharge for period: 96,513 AF/YR

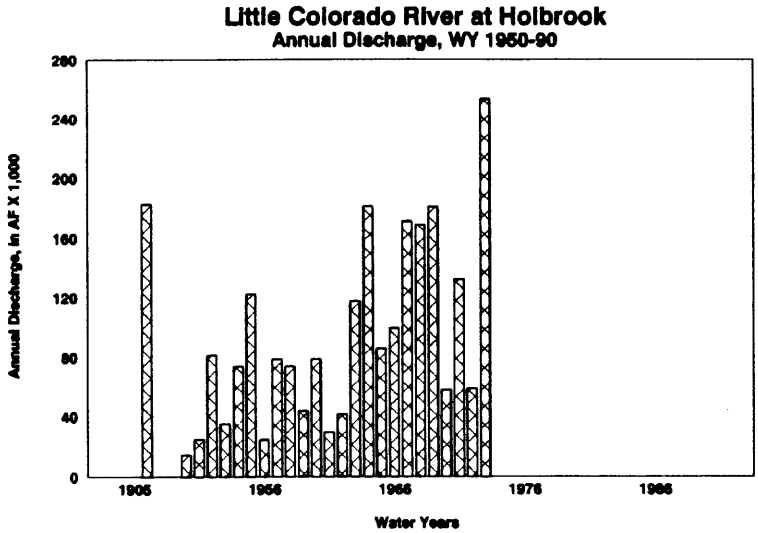


Figure 374. LCR at Holbrook, Annual Discharge, WY 1950-72

9.1.4 Moenkopi Wash near Tuba City, AZ

This gage is the first of four which have been installed on Moenkopi Wash near the Tuba City/Moenkopi area since 1941. The period of record is from 1941-1954, and 1965-1978. This gage was located on the downstream side of the U.S. Highway 89 bridge across the wash, 3,500 feet downstream from the Hamblin Wash confluence, and 11 miles upstream of the Moenkopi Wash-Little Colorado River confluence. Thus, the record includes flows from both Moenkopi and Hamblin Washes. The drainage area encompasses 2,492 square miles. Computer modeling is being conducted to adjust the flows at this gage to the flows at the present (1995) Moenkopi Wash near Moenkopi gage for the 1939-90 study period.

Flows from this gage are added to the flows from the LCR near Cameron gage for the purpose of investigating the flow-sediment and flow-water quality analyses for the record at the sediment station, LCR at Cameron, in a subsequent section in this report.

Table 87. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Moenkopi Wash near Tuba City
Elevation: 4309.00 feet above mean sea level
Latitude: +36d 01m 25s
Longitude: 111d 23m 48s
Drainage Area: 2,492 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1941	5,100	304	664	591	909	446	857	21	0	232	4,830	7,200	21,154
1942	15,230	397	238	403	288	116	56	0	0	67	551	10	17,356
1943	192	162	1,250	512	357	272	0	0	0	524	5,610	793	9,672
1944	543	165	208	298	301	383	68	53	0	0	176	222	2,417
1945	159	230	300	345	214	167	27	0	0	4,460	9,600	122	15,624
1946	809	179	599	280	169	158	25	0	0	1,550	6,970	378	11,117
1947	132	468	317	222	192	82	0	16	0	0	7,050	613	9,092
1948	9,400	225	531	305	308	143	0	0	715	1,870	999	99	14,595
1949	1,070	257	356	693	1,380	1,020	0	0	491	291	1,720	617	7,895
1950	3,620	170	186	226	245	34	0	0	0	1,330	442	978	7,231
1951	102	149	167	238	59	26	144	41	0	369	869	3,700	5,864
1952	1,880	267	542	1,070	209	204	508	26	27	183	1,770	11,340	18,026
1953	101	208	462	266	186	148	0	0	0	10,690	4,240	61	16,362
1954		120	357	220									
1965						131	183	144	0	2,910	253	2,400	
1966	142	241	368	62	191	427	11	0	0	463	314	247	2,466
1967	1,040	121	144	85	62	37	0	5	18	4,770	5,830	5,900	18,012
1968	105	121	72	288	156	137	18	0	0	1,540	3,790	0	6,227
1969	0	20	114	145	145	170	12	48	18	2,240	847	395	4,154
1970	1,030	178	143	123	51	648	113	2	0	32	3,820	3,520	9,660
1971	244	139	151	146	115	90	36	2	0	130	13,900	406	15,359
1972	407	146	284	155	127	38	0	0	60	55	1,540	15	2,827
1973	42,190	179	224	198	951	694	171	67	5	13	142	125	44,959
1974	2	68	57	175	44	320	36	0	0	1,430	122	0	2,254
1975	337	118	43	117	98	122	25	50	0	3,560	43	1970	6,483
1976	58	140	149	145	187	77	60	12	0	787	305	3,450	5,370
1977	232	158	205	213	223	106	0	4	0	4,860	1,340	3,300	10,641
1978	40	124	248	542	229	520	66	0	339	0	99	254	2,461
Mean	3,237	187	310	299	284	249	89	18	62	1,643	2,858	1,782	11,049
Max	42,190	468	1,250	1,070	1,380	1,020	857	144	715	10,690	13,900	11,340	44,959
% Total	0.2930	0.0169	0.0281	0.0270	0.0257	0.0225	0.0081	0.0016	0.0056	0.1487	0.2587	0.1613	

Period of Record: 1940-54, 1965-78
Mean Discharge for period: 11,049 AF/YR

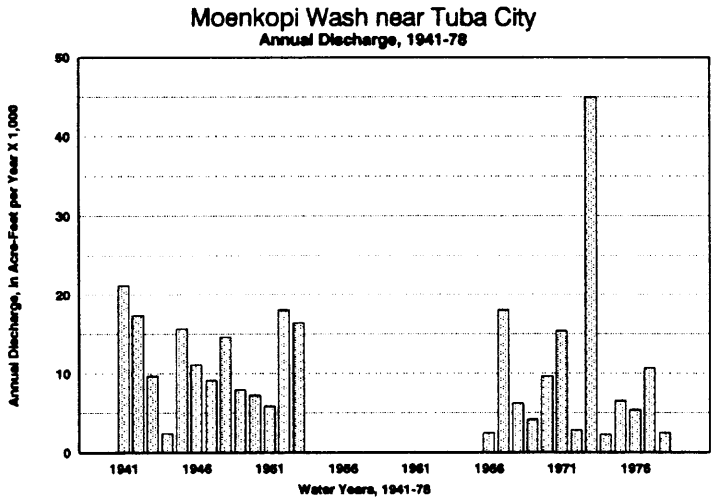


Figure 375. Moenkopi Wash near Tuba City, Annual Discharge, WY 1941-78

9.1.5 Moenkopi Wash near Moenkopi, AZ

This gage had a brief period of record from 1974-76 as a proposed replacement gage for Moenkopi Wash near Tuba City, above. Like the gage it replaces, this station had a poor low flow record due to a lack of adequate control.

Table 88. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Moenkopi Wash near Moenkopi
Elevation : ------ feet above mean sea level
Latitude: +36d 06m 36s
Longitude: 111d 09m 19s
Drainage Area: ---- sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1974	70	98	134	190	165	417	91	32	0	750	114	110	
1975	309	153	161	208	119	152	115	109	27	3370	46	2880	
1976	83	141	159	119	155	120	111	96					
Mean	154	131	151	172	146	230	106	79	14	2,060	80	1,495	4,910
Max	309	153	161	208	165	417	115	109	27	3,370	114	2,880	7,649
Min	70	98	134	119	119	120	91	32	0	750	46	110	2,171

Period of Record: 1973-76

9.1.6 Moenkopi Wash at Moenkopi, AZ

This gage was installed in 1976 as a replacement for the Moenkopi Wash near Tuba City gage, above. Unfortunately, there are only two (1976-77) years of overlap in the records of the two stations. The Tuba City gage record is being adjusted to the record of this gage by computer modeling to enable comparison and anayses of the two records as a single record.

The gage is located just above the channel of the wash, on the right bank 100 feet upstream of the Arizona Highway 264 bridge over the wash. The existence of a Navajo sandstone outcrop on the wash bed forms a stable control for the flow measurements. However, the scatter evident in the current meter calibration gagings indicates that the low flow rating is far from stable even at this location (see Section 9.4.4).

Water quality and sediment data are also available for this gage location.

Table 89. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Moenkopi Wash at Moenkopi
Elevation: 4610.00 feet above mean sea level
Latitude: +36d 06m 18s
Longitude: 11ad 12m 04s
Drainage Area: 1,629 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1976										857	211	4,650	
1977	104	113	153	192	128	139	115	61	9	5,630	780	3,530	10,954
1978	66	129	154	231	240	311	113	45	10	37	0	222	1,558
1979	141	671	830	371	1,610	198	60	100	16	0	97	0	4,094
1980	216	208	214	223	263	123	131	96	9	15	438	2,560	4,496
1981	15	68	38	177	120	123	123	66	9	3,720	730	1,210	6,399
1982	5,030	83	205	122	272	272	117	645	1	125	2,350	1,570	10,792
1983	195	214	134	184	173	161	81	68	0	1,320	2,880	7,950	13,360
1984	655	284	348	252	290	223	160	19	0	1,170	7,910	2,220	13,531
1985	372	152	154	203	274	612	157	64	3	21	200	570	2,782
1986	86	630	282	232	176	159	163	86	3	1,110	1,570	4,000	8,497
1987	1,310	690	324	474	394	331	83	198	2	221	3,340	149	7,516
1988				565	1,180	196	508	47	633	129	4,850	442	
1989	80	200	141	224	266	180	106	29	0	204	1,850	27	3,307
1990	145	100	133	211	254	150	165	64	88	1,830	989	2,950	7,079
1991	604	50			31		2	4			199		
1992													
Mean	644	257	239	262	378	227	139	106	56	1,093	1,775	2,137	7,259
Max	5,030	690	830	565	1,610	612	508	645	633	5,630	7,910	7,950	13,531
Min	15	50	38	122	31	123	2	4	0	0	0	0	1,558

Period of Record: 1976-present
Mean Discharge for period: 7,259 AF/YR

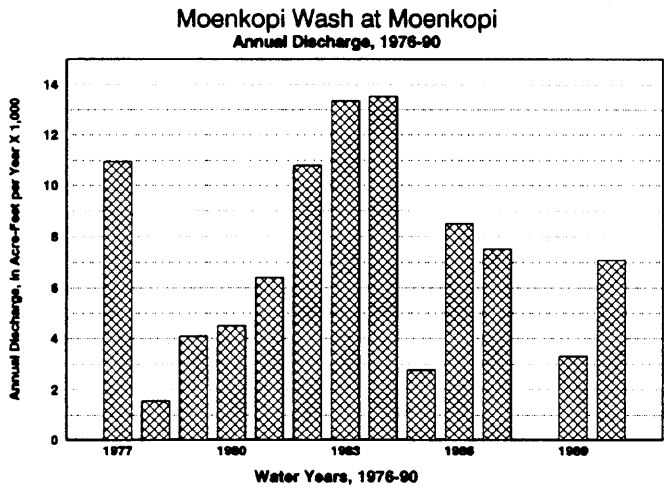


Figure 376. Moenkopi Wash at Moenkopi, Annual Discharge, WY 1976-90

9.1.7 Jacks Canyon Wash near Winslow, AZ

This is a steep and winding drainage which originates on the Mogollon Plateau near Clint's Well. The short period of record does not insure that a meaningful estimate of annual discharge is possible.

Table 90. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09399400
Station: Jacks Canyon Creek near Winslow, AZ
Elevation: .00 feet above mean sea level
Latitude: +34d 55m 17s
Longitude: 110d 47m 49s
Drainage Area: 31.8 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1970	0	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	152	66	218
1972	37	0	2,973	22	0	0	0	0	0	515	147	0	3,694
Average	12	0	991	7	0	0	0	0	0	172	100	22	1,304
Maximum	37	0	2,973	22	0	0	0	0	0	515	152	66	3,694
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0

9.1.8 Clear Creek near Winslow, AZ

Clear Creek originates on the Mogollon Rim above Blue Ridge Reservoir near Clint's Well. The Blue Ridge Reservoir is utilized to provide replacement water to the Gila River Basin in exchange for water used from that basin at the Phelps-Dodge copper mine in Clifton.

Table 91. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station: Clear Creek near Winslow, AZ
Station No. 09398000
Elevation: 4,899.5 feet above mean sea level
Latitude: +34d 58m 10s
Longitude: 111d 38m 40s
Drainage Area: 621 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0	0	2	10	13	12,873	17,058	31	0	0	0	0	29,987
1940	0	32	107	147	3,060	10,824	6,744	186	0	0	827	0	21,927
1941	3,261	4,007	10,877	8,438	26,120	39,644	43,041	39,181	184	0	0	16	174,769
1942	6	2,569	1,591	2,420	3,592	8,965	29,748	4,459	0	0	0	0	53,350
1943	0	0	0	0	4,441	29,516	9,529	73	0	0	67	10	43,636
1944	0	0	0	0	0	6,190	44,533	21,699	101	0	0	40	72,563
1945	12	63	0	0	819	8,698	46,927	18,726	2	0	0	0	75,247
1946	0	0	0	0	0	2,640	4,030	0	0	565	492	4,130	11,857
1947	111	10,346	4,108	2,003	4,887	6,401	1,132	0	0	6	1,062	433	30,489
1948	121	13	7	1,076	2,183	5,887	40,586	1,004	0	0	4	0	50,881
1949	13	14	2,424	4,524	3,650	34,856	53,211	5,252	4	0	0	10	103,958
1950	491	345	45	148	6,967	11,990	4,582	0	0	179	0	21	24,768
1951	9	30	28	30	33	592	3,203	4,329	1	0	10,436	2,725	21,416
1952	186	116	6,823	48,184	4,020	6,349	70,403	14,152	30	89	608	53	151,013
1953	43	69	129	174	634	12,739	4,733	109	10	55	110	0	18,805
1954	38	67	94	51	40	12,747	13,783	2	9	457	83	56	27,427
1955	74	82	109	116	103	1,188	1,138	106	1,494	4	12,702	552	17,668
1956	101	107	123	110	214	5,615	2,705	95	57	112	73	85	9,397
1957	100	156	123	27,667	21,749	15,261	4,110	1,100	50	103	112	50	70,581
1958	34	6,090	1,684	132	5,977	16,610	27,384	1,364	9	0	11	7,031	66,326
1959	3,175	120	179	60	84	3,534	3,853	34	0	16	700	60	11,815
1960	19	2,624	8,554	6,282	3,521	39,185	15,739	734	26	27	1	0	76,712
1961	0	0	21	165	113	1,984	12,270	59	4	0	9	53	14,678
1962	103	147	91	91	18,639	10,913	48,904	1,739	49	58	33	80	80,847
1963	99	111	120	140	1,653	2,350	1,900	272	0	0	374	3,122	10,141
1964	121	120	195	98	82	58	22,514	2,440	21	27	1,089	89	26,854
1965	60	67	115	16,804	2,243	5,228	44,452	11,818	120	222	84	54	81,267
1966	107	6,853	27,425	14,007	787	36,500	12,563	99	22	8	82	0	98,453
1967	0	0	29,493	85	52	1,056	2,402	34	23	29	41	10	33,225
1968	0	58	61	48	7,154	29,030	45,233	12,219	40	69	61	1	93,974
1969	0	0	0	23,298	2,993	11,812	26,811	2,006	59	15	86	0	67,080
1970	0	0	0	0	0	4,872	3,925	512	25	0	0	11,450	20,784
1971	26	3	0	0	0	2,325	626	2	16	0	1,898	150	5,046
1972	7,805	2,007	12,063	1,566	0	0	0	0	145	156	78	0	23,820
1973	21,370	3,882	4,062	4,852	2,735	15,072	76,889	67,071	512	27	30	0	196,502
1974	0	0	0	0	0	9,078	4,863	35	42	0	31	1	14,050
1975	3	0	8	33	99	8,595	18,760	6,669	38	163	75	2,671	37,113
1976	131	259	336	53	8,207	8,926	33,533	9,511	76	1,089	317	0	62,438
1977	0	128	192	145	118	103	3,967	67	0	0	0	4	4,724
1978	3	22	20	28	368	77,086	26,281	1,563	46	94	67	16	105,594
1979	17	8,566	69,509		6,218	27,181	78,298	18,141	135	11	249	269	208,594
1980	411	385	397	367	44,850	23,554	55,464	22,917	594	171	715	512	150,337
1981	451	489	527	597	398	454	5,948	623	406	573	532	684	11,682
1982	310	252	242	218	5,508	41,633	23,238	2,891	247	373	526	308	75,746
1983	257	3,491	10,633										
Average	868	1,193	4,278	3,818	4,416	13,866	22,659	6,212	104	107	765	790	58,808
Maximum	21,370	10,346	69,509	48,184	44,850	77,086	78,298	67,071	1,494	1,089	12,702	11,450	208,594
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	4,724

9.1.9 Chevelon Creek Fork below Wildcat Canyon near Winslow, AZ

Table 92. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09397500
Station: Chevelon Creek Fork below Wildcat Canyon near Winslow, AZ
Elevation: 5,905.16 feet above mean sea level
Latitude: +34d 38m 11s
Longitude: 110d 42m 49s
Drainage Area: 271 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1947								0	0	0	330	21	
1948	385	33	1,421	2,832	2,876	6,680	16,189	114	0	0	0	0	30,530
1949	0	0	3,681	4,120	3,687	22,562	21,973	451	0	0	0	0	56,474
1950	62	53	13	1,428	8,392	6,218	1,191	0	0	0	0	0	17,357
1951	0	0	0	0	1	3,715	1,320	2,646	1	0	12,599	755	21,037
1952	0	0	10,215	32,142	3,782	7,248	39,176	2,914	12	0	0	0	95,489
1953	0	0	267	2,664	1,794	11,713	1,326	63	0	0	0	0	17,827
1954	0	0	0	0	0	16,070	6,855	39	0	9	68		23,041
1955	0	0	0	0	0	3,240	314	16	101	0	5,843	100	9,614
1956	0	0	662	342	1,481	5,429	2,166	90	0	0	78	0	10,248
1957	0	0	0	31,490	17,092	8,775	1,155	580	4	0	0	0	59,096
1958	0	1,674	1,689	87	4,973	13,761	18,163	315	0	0	0	8,377	49,039
1959	2,822	940	486	26	772	5,254	1,487	11	0	0	814	5	12,617
1960	9	6,453	7,975	7,345	3,180	29,088	3,140	61	0	0	0	0	57,251
1961	29	117	18	0	461	5,941	5,212	14	0	0	36	0	11,828
1962	0	0	114	990	14,577	10,054	23,500	137	0	0	0	0	49,372
1963	0	0	0	0	3,481	2,521	455	16	0	0	1,424	2,588	10,485
1964	0	79	294	13	0	1,930	15,263	503	0	274	3,921	387	22,664
1965	12	0	2,828	24,549	5,673	13,166	29,663	1,960	4	0	0	203	78,058
1966	0	2,799	19,682	3,945	2,479	18,581	4,243	2,419	2	0	0	812	54,962
1967	546	410	15,890	167	170	2,153	4,739	1,979	0	134	0	0	26,188
1968	0	0	0	71	4,528	21,062	18,496	972	0	0	0	0	45,129
1969	0	15	2	22,994	2,420	12,317	8,948	305	0	0	0	0	47,001
1970	0	0	0	0	0	4,345	2,292	5	0	0	0	12,476	19,118
Average	168	547	2,836	5,878	3,557	10,079	9,881	650	5	17	1,046	1,118	35,845
Maximum	2,822	6,453	19,682	32,142	17,092	29,088	39,176	2,914	101	274	12,599	12,476	95,489
Minimum	0	0	0	0	0	1,930	314	0	0	0	0	0	9,614

9.1.10 Chevelon Creek near Winslow, AZ

Table 93. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09398000
Station: Chevelon Creek near Winslow, AZ
Elevation: 4,899.5 feet above mean sea level
Latitude: +34d 55m 35s
Longitude: 110d 31m 51s
Drainage Area: 785 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	190	171	230	246	230	14,045	8,565	246	238	192	823	466	25,642
1940	232	413	272	254	3,989	6,415	3,334	266	204	633	807	432	17,251
1941	315	2,497	8,059	5,814	16,623	22,877	21,283	12,960	161	236	361	296	91,482
1942	284	740	1,246	3,556	3,029	7,176	13,521	1,936	180	216	208	147	32,239
1943	220	161	704	988	5,659	22,022	2,787	202	238	196	684	446	34,307
1944	196	215	264	295	355	6,059	27,364	4,848	416	285	194	898	41,389
1945	297	246	267	303	2,594	6,914	27,521	2,682	323	331	1,175	251	42,904
1946	219	222	253	275	285	3,648	2,105	403	329	490	951	3,969	13,149
1947	309	8,164	2,586	1,968	4,122	3,382	301	275	249	306	1,467	262	23,391
1948	749	211	606	2,216	2,320	5,193	17,064	260	235	385	925	220	30,384
1949	279	306	2,601	3,794	3,251	21,467	21,094	679	314	284	298	594	54,961
1950	293	311	278	493	6,598	6,119	1,699	303	242	263	288	268	17,155
1951	228	236	245	230	263	2,278	903	2,217	160	270	10,495	1,713	19,238
1952	285	244	5,726	40,790	3,717	6,305	43,632	3,458	177	364	296	265	105,259
1953	285	363	208	1,479	1,784	10,691	1,610	280	269	605	359	243	18,176
1954	254	243	229	226	228	12,978	6,825	242	246	788	241	753	23,253
1955	300	248	241	239	244	1,956	415	248	1,274	787	8,626	344	14,922
1956	267	250	260	337	1,183	5,427	1,584	262	222	392	442	225	10,851
1957	243	208	234	25,979	17,741	8,168	1,016	275	246	369	593	268	55,340
1958	384	442	1,306	278	3,528	12,264	17,857	525	614	218	265	5,951	43,632
1959	3,858	502	758	339	279	4,591	1,104	218	260	391	867	222	13,389
1960	771	5,771	8,403	6,855	2,832	32,376	3,430	136	125	182	180	224	61,285
1961	405	253	356	395	348	4,731	5,168	269	238	570	324	203	13,260
1962	234	234	259	249	12,264	9,318	26,648	596	393	277	346	829	51,647
1963	322	316	269	271	3,362	3,232	878	413	261	272	1,885	2,294	13,775
1964	330	316	332	324	290	460	16,145	661	298	397	3,975	560	24,088
1965	767	2,535	4,489	26,573	5,127	11,286	27,259	1,729	479	386	386	326	81,342
1966	361	1,681	21,352	8,565	2,822	18,690	3,777	1,734	516	403	593	519	61,013
1967	340	312	14,156	253	222	1,159	4,451	1,818	403	773	778	655	25,320
1968	331	310	354	315	4,066	22,429	20,523	901	217	651	447	237	50,781
1969	394	238	227	16,661	1,974	9,265	7,743	415	638	960	443	324	39,282
1970	259	237	173	160	152	2,654	2,220	248	250	254	311		
1971	227	214	217	255	234	299	245	207	259	309	2,068	1,020	5,554
1972	15,160	2,722	17,010	1,272	224	217	231	209	338	373	300	213	38,269
Average	870	927	2,770	4,478	3,292	9,003	10,009	1,239	324	406	1,247	777	36,180
Maximum	15,160	8,164	21,352	40,790	17,741	32,376	43,632	12,960	1,274	960	10,495	5,951	105,259
Minimum	190	161	173	160	152	217	231	136	125	182	180	147	5,554

9.1.11 Little Colorado River at Woodruff, AZ

Table 94. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09394500
Station: Little Colorado River at Woodruff, AZ
Elevation: 5,130.3 feet above mean sea level
Latitude: +34d 46m 58s
Longitude: 110d 02m 37s
Drainage Area: 8,072 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1905							46,935				3,578	9,457	
1906	1,238	32,325	2,299	5,921	9,537	27,376	19,226	2,670	236	932	4,114	881	
1907	722	409	12,419	10,350	6,504	12,932	8,329						
1917												5,270	
1918	970	833	746	524	1,622	4,245							
1919				936	4,570	27,281	21,501	1,266	36	49,793	19,886	10,540	
1920	2,100	4,346	23,512										
1929								0	0	31,018	37,353	37,488	
1930	4,792	791	847	1,216	2,132	6,426	827	109	26	8,037	16,802	643	42,648
1931	385	1,898	1,166	1,404	4,639	1,369	659	881	365	10,893	28,453	11,964	64,076
1932	7,200	1,815	2,356	1,694	47,566	24,599	10,596	1,311	73	5,647	12,603	1,749	117,209
1933	1,706	1,192	992	827	2,670	5,714	131	194	853	12,569	8,830	15,933	51,611
1934	8,779	1,773											
1935													
1936	1,242	946	1,361	1,492	2,820	1,418	1,150	900	113	8,581	13,073	9,622	42,718
1937	1,787	889	783	452	14,846	14,285	6,524	219	268	3,161	1,771	1,117	46,102
1938	422	452	500	428	417	3,582	226	11	542	190	4,372	3,973	15,115
1939	242	315	424	706	843	2,013	1,277	41	0	769	2,539	1,199	10,368
1940	214	468	349	714	996	278	158	6	179	14,640	14,461	13,638	46,101
1941	2,289	1,220	3,205	10,433	6,599	37,523	21,652	15,521	761	3,266	4,939	8,031	115,439
1942	6,228	758	938	1,317	536	1,162	2,041	163	8	32	1,302	77	14,562
1943	1,971	369	575	393	500	1,456	317	46	9	2,107	10,262	2,218	20,223
1944	900	337	482	805	829	4,927	938	111	20	734	1,100	3,660	14,843
1945	746	520	486	422	474	4,237	208	14	15	8,364	19,870	508	35,864
1946	468	311	604	1,037	1,095	498	38	0	0	6,945	22,802	16,007	49,805
1947	1,513	750	654	607	630	258	83	297	42	1,121	20,549	3,624	30,128
1948	14,146	724	924	707	1,639	2,100	1,963	71	250	1,557	5,072	1,683	30,836
1949	397	374	655	4,140	3,420	8,241	1,025	195	283	3,805	27,865	3,278	53,678
1950	556	373	653	727	432	341	47	37	35	3,929	219	554	7,903
1951	65	284	325	361	361	326	70	38	0	1,357	18,159	500	21,846
1952	779	222	1,923	30,032	843	4,967	2,347	735	564	2,892	4,999	5,823	56,126
1953	273	1,093	2,275	787	515	1,985	212	159	153	4,032	1,621	82	13,187
1954	84	257	412	505	397	1,911	99	59	1	11,102	2,824	7,496	25,147
1955	705	331	352	375	351	250	7	131	5,227	3,226	58,495	956	70,406
1956	141	285	418	1,113	3,017	399	0	21	861	1,445	2,192	42	9,934
1957	258	180	324	391	839	278	61	21	27	2,291	22,001	4,230	30,901
1958	3,427	1,500	763	664	472	2,081	254	54	967	953	12,345	8,614	32,094

U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09394500
Station: Little Colorado River at Woodruff, AZ
Elevation: 5,130.3 feet above mean sea level
Latitude: +34d 46m 58s
Longitude: 110d 02m 37s
Drainage Area: 8,072 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1959	1,772	458	453	617	508	278	288	218	609	1,212	3,322	131	9,866
1960	13,341	6,050	4,663	8,862	1,484	4,483	540	225	299	546	1,191	324	42,008
1961	1,130	344	443	444	260	330	375	422	249	442	1,801	722	6,962
1962	575	1,165	379	315	6,472	2,813	761	349	450	319	366	531	14,495
1963	1,422	967	442	551	667	309	259	196	136	235	16,982	2,866	25,032
1964	499	1,402	338	369	281	304	286	300	211	4,850	13,833	10,481	33,154
1965	433	393	696	2,116	803	881	1,206	392	386	4,419	2,226	6,330	20,281
1966	484	407	9,108	4,106	1,565	2,383	709	412	239	5,479	5,931	3,979	34,802
1967	846	395	467	486	325	276	410	467	587	10,986	19,904	10,330	45,479
1968	609	370	490	3,654	7,248	4,431	1,094	327	398	7,288	9,999	313	36,221
1969	3,657	358	334	1,343	268	1,145	310	703	301	11,440	7,363	5,497	32,719
1970	728	540	405	412	454	517	473	447	269	525	2,618	6,068	13,456
1971	1,220	216	219	236	142	165	175	232	179	202	15,386	21,227	39,599
1972	11,556	893	9,810	2,022	542	238	239	651	860	687	2,666	880	31,044
1973	18,529	1,997	2,029	1,601	4,584	22,641	24,621	30,008	1,921	256	795	495	109,477
1974	231	193	139	560	343	193	179	240	99	620	2,284	4,853	9,934
1975	8,656	628	340	350	447	316	1,384	270	219	1,797	1,281	7,182	22,870
1976	177	179	749	501	2,153	227	232	348	9	6,739	951	1,339	13,604
1977	375	435	536	1,753	439	214	540	211	177	1,496	2,686	2,783	11,645
1978	1,850	470	562	864	1,138	17,433	286	507	143	1,013	3,759	704	28,729
1979	1,013	12,495	21,435	10,871	4,157	10,625	4,812	5,167	2,685	732	1,793	487	76,272
1980	612	1,027	865	2,412	27,445	9,628	9,295	4,758	125	370	2,958	1,000	60,495
1981	243	264	419	442	370	348	304	317	416	6,516	1,891	1,816	13,346
1982	1,792	242	286	1,208	1,313	1,685	319	824	337	4,122	9,224	4,725	26,077
1983	487	553	2,384	1,023	2,729	7,755	11,155	1,644	95	4,005	5,542	8,709	46,081
1984	11,494	2,517	3,493	2,721	1,379	1,392	667	327	199	8,358	18,549	36,385	87,481
1985	10,078	906	10,048	7,121	7,154	20,662	14,305	6,395	212	4,636	1,115	1,559	84,191
1986	1,439	387	857	547	582	896	234	175	169	4,978	1,340	1,355	12,959
1987	4,067	1,284	2,715	1,197	1,054	3,901	8,525	4,947	395	733	6,600	481	35,899
1988	1,147	2,964	624	1,183	1,565	333	2,375	255	1,704	836	5,417	1,643	20,046
1989	526	232	341	427	458	171	183	129	78	3,158	3,806	627	10,136
1990	191	219	199	184	167	130	102	110	52	2,163	4,152	4,934	12,603
1991	348	1,390	1,589	2,830	183	6,003	821	186	157	178	1,009	1,433	16,127
1992	250	577	828	1,221	2,990	862	423	3,753	351	1,843	27,148	8,831	49,077
1993	2,467	1,529	8,645	36,825	29,520	9,142	3,717	862	196	187	3,704	706	97,500
Average	2,600	1,078	2,130	2,603	3,395	4,645	2,635	1,397	415	4,810	9,474	5,265	37,073
Maximum	18,529	12,495	23,512	36,825	47,566	37,523	24,621	30,008	5,227	49,793	58,495	37,488	117,209
Minimum	65	179	139	184	142	130	0	0	0	32	219	42	6,962

9.1.12 Cottonwood Creek at Snowflake, AZ

Table 95. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09393400
Station: Cottonwood Wash at Snowflake, AZ
Elevation: 5,580 feet above mean sea level
Latitude: +34d 30m 20s
Longitude: 110d 05m 28s
Drainage Area: * sq. mi.**
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1982	0	0	0	0	500	1,299	0	0	0	0	0	223	2,022
1983	0	0	1,438	147	3,633	5,230	59	0	0	0	0	91	10,598
1984	331	0	583	0	0	0	0	0	0	0	0		
Average	110	0	674	49	1,378	2,176	20	0	0	0	0	157	6,310
Maximum	331	0	1,438	147	3,633	5,230	59	0	0	0	0	223	10,598
Minimum	0	0	0	0	0	0	0	0	0	0	0	91	2,022

9.1.13 Silver Creek near Snowflake, AZ

Table 96. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09393500
Station: Silver Creek near Snowflake, AZ
Elevation: 5,204.1 feet above mean sea level
Latitude: +34d 40m 00s
Longitude: 110d 02m 30s
Drainage Area: 925 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1951	61	119	112	143	125	107	77	78	50	496	6,595	316	10,230
1952	312	78	2,246	28,116	540	4,856	1,162	708	211	1,529	2,966	2,418	47,094
1953	183	318	511	349	244	1,634	103	131	75	1,529	900	135	8,065
1954	125	130	237	359	208	1,502	165	147	82	2,095	1,559	3,744	12,307
1955	218	98	98	103	130	43	55	119	1,243	2,024	7,311	152	13,549
1956	130	148	107	85	306	198	60	121	1,037	1,189	736	47	6,120
1957	135	53	80	119	369	86	44	126	105	430	2,740	115	6,359
1958	1,221	386	207	187	47	1,722	167	128	600	219	2,541	4,307	13,690
1959	1,012	247	114	79	71	41	69	74	492	697	614	35	5,504
1960	2,884	3,808	4,732	6,056	818	3,905	190	208	173	251	392	149	25,526
1961	265	130	188	168	70	97	78	190	183	185	857	199	4,571
1962	95	210	197	203	5,980	2,416	405	281	132	166	174	163	12,384
1963	363	280	244	153	105	64	70	117	82	74	4,465	1,636	9,616
1964	125	201	126	95	42	34	90	126	47	2,214	6,060	2,136	13,260
1965	43	167	262	1,510	317	548	879	217	238	762	678	439	8,025
1966	133	139	9,315	3,421	974	2,132	176	174	140	895	1,331	718	21,514
1967	480	161	271	360	111	35	56	155	262	3,262	1,971	803	9,894
1968	75	151	242	265	5,389	2,108	385	234	162	3,355	2,989	198	17,521
1969	984	245	158	627	109	453	31	265	145	4,115	2,445	613	12,159
1970	523	374	228	316	289	106	76	341	234	471	1,002	1,657	7,587
1971	623	96	68	126	32	19	14	129	131	236	3,138	10,305	16,888
1972	4,021	250	7,895	1,360	284	78	85	270	274	419	778	247	17,933
1973	5,484	1,071	1,740	843	2,019	11,607	12,611	4,340	1,585	333	414	314	44,334
1974	66	49	61	283	77	22	55	102	42	398	532	567	4,228
1975	1,297	386	127	117	147	151	934	93	133	388	371	2,893	9,012
1976	59	75	284	188	2,187	171	12	113	52	3,129	501	779	9,526
1977	191	219	159	319	152	26	56	108	102	747	1,191	1,925	7,172
1978	466	148	109	54	207	12,010	126	59	90	561	1,750	332	17,890
1979	309	6,472	16,964	10,385	3,965	8,848	2,185	395	109	53	323	110	52,097
1980	172	304	297	1,376	26,931	3,749	1,195	74	18	128	1,273	229	37,726
1981	182	194	406	329	204	191	33	124	252	1,163	404	362	5,825
1982	283	62	87	134	417	1,232	31	205	54	556	3,845	580	9,468
1983	188	166	1,455	550	1,902	5,078	2,448	239	101	608	897	2,455	18,070
1984	2,909	268	998	340	122	40	30	95	104	1,082	3,607	5,063	16,642
1985	2,331	525	7,571	4,729	4,707	7,991	1,261	1,039	146	949	817	1,212	35,263
1986	638	262	300	163	151	27	12	77	101	449	646	462	5,274
1987	907	670	384	339	617	2,280	154	115	284	313	3,052	357	11,459
1988	631	867	395	544	1,238	95	292	153	298	329	1,509	359	8,698
1989	256	125	201	179	104	9	78	59	23	1,056	535	207	4,821
1990	92	51	54	22	0	0	0	59	19	344	674	702	4,007
1991	39	93	68	327	60	4,985	623	187	162	168	744	861	10,308
1992	165	454	875	893	2,417	764	390	446	251	313	3,914	431	13,305
1993	246	275	3,588	26,228	25,740	3,056	417	271	190	210	1,658	566	64,438
Average	719	477	1,483	2,152	2,091	1,965	637	295	238	928	1,881	1,193	16,032
Maximum	5,484	6,472	16,964	28,116	26,931	12,010	12,611	4,340	1,585	4,115	7,311	10,305	64,438
Minimum	39	49	54	22	0	0	0	59	18	53	174	35	4,007

9.1.14 Silver Creek near Shumway, AZ

Table 97. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09390000
Station: Silver Creek near Shumway, AZ
Elevation: 5,913.48 feet above mean sea level
Latitude: +34d 22m 30s
Longitude: 110d 00m 30s
Drainage Area: * sq. mi.**
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1945	70	83	63	36	35	53	546	1,765	1,501	1,442	641	1,448	7,683
1946	592	20	16	19	20	27	355	1,420	1,305	1,067	746	736	6,323
1947	104	94	70	61	57	388	1,295	1,807	1,513	1,753	502	1,019	8,663
1948	313	47	61	58	70	84	893	1,634	1,531	1,479	866	724	7,760
1949	270	40	58	79	467	2,235	790	1,819	1,388	1,349	1,344	1,438	11,277
1950	459	67	80	86	86	176	765	1,615	1,706	1,164	769	644	7,617
1951	701	520	75	59	53	52	205	1,281	1,261	1,096	795	566	6,664
1952	99	50	57	3,465	138	2,730	1,333	650	1,268	1,143	1,271	1,207	13,411
1953	62	407	82	78	64	178	1,190	1,087	1,240	964	965	1,105	7,422
1954	392	56	45	66	66	66	821	1,482	1,547	1,110	1,272	668	7,591
1955	328	80	97	65	56	61	540	1,496	1,129				
Average	308	133	64	370	101	550	794	1,460	1,399	1,257	917	956	8,441
Maximum	701	520	97	3,465	467	2,730	1,333	1,819	1,706	1,753	1,344	1,448	13,411
Minimum	62	20	16	19	20	27	205	650	1,129	964	502	566	6,323

9.1.15 Silver Creek near Snowflake, AZ

Table 98. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 0939500
Station: Silver Creek near Snowflake, AZ
Elevation: 5,204.1 feet above mean sea level
Latitude: +34d 40m 00s
Longitude: 110d 02m 30s
Drainage Area: 925 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1951	61	119	112	143	125	107	77	78	50	496	6,595	316	10,230
1952	312	78	2,246	28,116	540	4,856	1,162	708	211	1,529	2,966	2,418	47,094
1953	183	318	511	349	244	1,634	103	131	75	1,529	900	135	8,065
1954	125	130	237	359	208	1,502	165	147	82	2,095	1,559	3,744	12,307
1955	218	98	98	103	130	43	55	119	1,243	2,024	7,311	152	13,549
1956	130	148	107	85	306	198	60	121	1,037	1,189	736	47	6,120
1957	135	53	80	119	369	86	44	126	105	430	2,740	115	6,359
1958	1,221	386	207	187	47	1,722	167	128	600	219	2,541	4,307	13,690
1959	1,012	247	114	79	71	41	69	74	492	697	614	35	5,504
1960	2,884	3,808	4,732	6,056	818	3,905	190	208	173	251	392	149	25,526
1961	265	130	188	168	70	97	78	190	183	185	857	199	4,571
1962	95	210	197	203	5,980	2,416	405	281	132	166	174	163	12,384
1963	363	280	244	153	105	64	70	117	82	74	4,465	1,636	9,616
1964	125	201	126	95	42	34	90	126	47	2,214	6,060	2,136	13,260
1965	43	167	262	1,510	317	548	879	217	238	762	678	439	8,025
1966	133	139	9,315	3,421	974	2,132	176	174	140	895	1,331	718	21,514
1967	480	161	271	360	111	35	56	155	262	3,262	1,971	803	9,894
1968	75	151	242	265	5,389	2,108	385	234	162	3,355	2,989	198	17,521
1969	984	245	158	627	109	453	31	265	145	4,115	2,445	613	12,159
1970	523	374	228	316	289	106	76	341	234	471	1,002	1,657	7,587
1971	623	96	68	126	32	19	14	129	131	236	3,138	10,305	16,888
1972	4,021	250	7,895	1,360	284	78	85	270	274	419	778	247	17,933
1973	5,484	1,071	1,740	843	2,019	11,607	12,611	4,340	1,585	333	414	314	44,334
1974	66	49	61	283	77	22	55	102	42	398	532	567	4,228
1975	1,297	386	127	117	147	151	934	93	133	388	371	2,893	9,012
1976	59	75	284	188	2,187	171	12	113	52	3,129	501	779	9,526
1977	191	219	159	319	152	26	56	108	102	747	1,191	1,925	7,172
1978	466	148	109	54	207	12,010	126	59	90	561	1,750	332	17,890
1979	309	6,472	16,964	10,385	3,965	8,848	2,185	395	109	53	323	110	52,097
1980	172	304	297	1,376	26,931	3,749	1,195	74	18	128	1,273	229	37,726
1981	182	194	406	329	204	191	33	124	252	1,163	404	362	5,825
1982	283	62	87	134	417	1,232	31	205	54	556	3,845	580	9,468
1983	188	166	1,455	550	1,902	5,078	2,448	239	101	608	897	2,455	18,070
1984	2,909	268	998	340	122	40	30	95	104	1,082	3,607	5,063	16,642
1985	2,331	525	7,571	4,729	4,707	7,991	1,261	1,039	146	949	817	1,212	35,263
1986	638	262	300	163	151	27	12	77	101	449	646	462	5,274
1987	907	670	384	339	617	2,280	154	115	284	313	3,052	357	11,459
1988	631	867	395	544	1,238	95	292	153	298	329	1,509	359	8,698
1989	256	125	201	179	104	9	78	59	23	1,056	535	207	4,821
1990	92	51	54	22	0	0	0	59	19	344	674	702	4,007
1991	39	93	68	327	60	4,985	623	187	162	168	744	861	10,308
1992	165	454	875	893	2,417	764	390	446	251	313	3,914	431	13,305
1993	246	275	3,588	26,228	25,740	3,056	417	271	190	210	1,658	566	64,438
Average	719	477	1,483	2,152	2,091	1,965	637	295	238	928	1,881	1,193	16,032
Maximum	5,484	6,472	16,964	28,116	26,931	12,010	12,611	4,340	1,585	4,115	7,311	10,305	64,438
Minimum	39	49	54	22	0	0	0	59	18	53	174	35	4,007

9.1.16 Show Low Creek near Show Low, AZ

Table 99. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09392500
Station: Show Low Creek at Show Low, AZ
Elevation: 6,309.22 feet above mean sea level
Latitude: +34d 15m 10s
Longitude: 110d 01m 40s
Drainage Area: * sq. mi.**
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1945	144	224	175	161	432	2,722	626	47	48	88	132	91	4,890
1946	118	13	89	42	75	66	6	3	1	126	161	4,137	4,836
1947	286	1,101	391	379	438	295	16	47	35	48	360	131	3,527
1948	1,267	362	363	187	1,357	3,905	1,258	16	16	215	22	22	8,990
1949	34	20	613	2,292	4,105	4,213	1,055	26	25	212	368	93	13,056
1950	85	71	99	289	209	715	15	8	12	49	38	10	1,600
1951	17	9	33	52	9	31	7	21	9	2	115	89	394
1952	9	24	1,118	13,744	406	5,287	4,280	231	85	128	110	89	25,511
1953	35	261	250	84	6	567	84	44	39	69	53	53	1,545
1954	44	33	12	15	2	934	31	27	23	50	47	49	1,267
1955	52	57	47	15	21	6	0	15	32				
Average	190	198	290	1,569	642	1,704	671	44	29	99	141	476	6,562
Maximum	1,267	1,101	1,118	13,744	4,105	5,287	4,280	231	85	215	368	4,137	25,511
Minimum	9	9	12	15	2	6	0	3	1	2	22	10	394

9.1.17 Show Low Creek above Jaques Reservoir

Table 100. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09392000
Station: Show Low Creek below Jaques Dam, AZ
Elevation: 6,350 feet above mean sea level
Latitude: +34d 11m 47s
Longitude: 110d 10m 13s
Drainage Area: * sq. mi.**
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1956	292	67	36	29	30	36	136	308	419	282	211	208	2,054
1957	48	35	31	31	6	22	144	246	359	313	133	257	1,625
1958	94	30	31	31	26	2	74	398	419	457	318	257	2,137
1959	127	112	49	49	38	37	134	360	372	341	115	302	2,036
1960	62	29	31	531	125	4,012	213	370	404	498	488	368	7,131
1961	187	38	80	43	38	0	4	379	395	395	139	178	1,876
1962	132	47	43	45	1,785	2,692	1,365	370	432	420	426	267	8,024
1963	56	14	14	12	15	69	190	326	396	430	175	99	1,796
1964	223	42	44	27	14	9	187	231	317	292	151	155	1,692
1965	167	47	32	28	19	47	3,012	292	333	326	269	242	4,814
1966	147	40	1,519	1,488	637	4,656	235	270	376	396	372	263	10,399
1967	164	12	12	48	8	23	153	281	300	281	166	246	1,694
1968	301	134	40	64	98	4,348	856	393	448	485	278	380	7,825
1969	102	54	15	29	45	53	307	261	442	311	262	361	2,242
1970	335	81	41	32	19	27	151	298	387	394	160	174	2,099
1971	33	49	53	31	27	60	208	276	325	367	90	260	1,779
1972	45	56	2,669	63	59	85	192	275	190	320	299	183	4,436
1973	56	7	7	7	5	4,603	11,683	4,429	359	343	311	417	22,228
1974	522	123	8	12	14	16	204	327	350	317	277	270	2,440
1975	62	2	30	29	29	717	2,674	327	363	330	370	142	5,075
1976	281	75	16	18	19	26	207	315	363	300	373	224	2,217
1977	50	35	42	31	11	12	105	421	410	249	224	240	1,830
1978	0	0	0	0	0	7,894	0	97	334	373	305	296	9,299
1979	50	2	10,245	2,638	3,650	7,379	3,064	1,016	385	368	228	326	29,351
1980	138	79	86	89	10,402	2,083	669	122	410	382	289	198	14,947
1981	412	179	184	186	177	201	208	356	391	392	387	357	3,430
1982	113	39	37	37	33	43	135	358	358	375	136	265	1,929
1983	255	52	25	53	57	5,691	1,873	363	391	429	426	422	10,037
1984	102	101	112	425	104	177	267	364	396	394	220	253	2,915
1985	126	125	14,468	2,642	4,879	7,759	1,950	1,018	521	409	324	244	34,465
1986	68	65	69	68	69	203	356	410	392	399	420	287	2,806
1987	144	139	148	169	169	5,158	1,122	419	419	483	263	384	9,017
1988	291	41	42	45	1,337	521	199	379	409	353	154	513	4,284
1989	254	227	262	263	271	655	261	316	366	377	266	310	3,828
1990	72	101	31	35	66	60	157	194	232	201	187	95	1,431
1991	149	0	30	56	157	3,691	1,800	359	316	324	307	227	7,416
1992	120	89	98	108	1,424	3,114	768	1,940	685	301	841	292	9,780
1993	316	144	4,445	12,119	9,346	2,898	1,292	518	296	358	315	310	32,357
Average	160	66	924	569	927	1,818	962	510	381	362	281	270	7,230
Maximum	522	227	14,468	12,119	10,402	7,894	11,683	4,429	685	498	841	513	34,465
Minimum	0	0	0	0	0	0	0	97	190	201	90	95	1,431

9.1.18 Show Low Creek near Lakeside

Table 101. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09390500
Station: Show Low Creek near Lakeside, AZ
Elevation: 6,610 feet above mean sea level
Latitude: +34d 10m 46s
Longitude: 109d 59m 14s
Drainage Area: 68.6 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1953								412	400	314	349	337	
1954	253	216	61	49	17	3,403	281	259	369	381	316	266	5,871
1955	202	110	147	77	139	53	95	385	346	229	665	361	2,809
1956	141	32	22	24	225	211	69	261	450	214	276	123	2,048
1957	130	41	32	100	413	171	58	311	361	266	294	133	2,310
1958	82	42	19	22	186	3,062	1,293	266	396	258	252	136	6,014
1959	111	53	14	15	83	92	144	528	492	67	196	105	1,900
1960	145	2,219	1,177	1,890	697	4,979	158	104	144	144	126	111	11,894
1961	97	70	126	101	93	237	243	205	161	459	322	214	2,328
1962	99	58	101	116	6,658	4,185	1,972	146	322	422	394	408	14,881
1963	71	69	82	129	1,094	649	248	273	322	535	299	459	4,230
1964	180	212	189	10	11	104	276	222	367	373	84	77	2,105
1965	45	171	12	3,705	1,452	2,872	4,578	271	333	299	181	277	14,196
1966	158	150	7,016	1,343	692	5,137	344	223	215	353	402	325	16,358
1967	214	96	91	143	100	133	101	294	475	214	251	293	2,405
1968	320	116	101	168	5,340	5,494	883	377	489	629	203	360	14,480
1969	326	156	142	576	478	3,521	483	438	482	319	166	250	7,337
1970	294	139	44	7	28	211	343	296	340	388	168	173	2,431
1971	92	17	134	6	26	96	199	284	317	371	345	217	2,104
1972	3,011	214	8,212	602	56	55	166	229	131	218	268	210	13,372
1973	734	455	932	742	2,189	7,012	11,744	4,426	411	470	470	305	29,890
1974	282	270	235	465	516	679	179	255	475	313	243	382	4,294
1975	427	121	38	108	2,026	5,960	4,015	249	338	424	331	325	14,362
1976	190	92	223	224	1,740	802	2,386	225	294	522	229	308	7,235
1977	54	38	61	351	68	220	378	350	489	322	148	204	2,683
1978	60	53	39	267	1,889	11,633	943	190	277	392	225		
1979	99	3,232	11,981	2,850	4,052	7,890	3,387	1,166	600	565	521	440	36,783
1980	323	376	303	1,572	12,944	4,629	2,819	629	481	516	470	398	25,460
1981	425	290	289	255	369	991	529	275	643	295	278	674	5,313
1982	269	96	124	198	1,068	3,371	241	269	396	299	297	225	6,853
1983	153	212	1,625	1,029	2,852	6,480	2,202	376	428	542	364	407	16,670
1984	1,058	418	2,050	960	441	365	333	305	283	381	677	444	7,715
1985	3,531	502	17,546	2,360	4,889	7,888	1,888	985	431	305	268	521	41,114
1986	809	657	810	314	1,486	1,757	569	294	266	536	505	253	8,256
1987	231	391	854	593	2,227	7,757	2,236	540	386	662	294	195	16,366
1988	183	178	233	610	2,737	812	1,661	464	465	600	1,235	1,102	10,280
1989	344	353	389	511	1,563	1,489	336	251	434	471	168	103	6,412
1990	80	48	53	71	78	125	90	122	108	73	95	224	1,167
1991	234	71	199	886	1,144	5,950	911	113	548	431	272	260	11,019
1992	97	159	593	589	2,981	3,126	727	2,068	783	150	1,150	143	12,566
1993	366	255	4,497	12,282	9,459	2,916	1,248	521	375	304	348	311	32,882
Average	398	311	1,520	908	1,863	2,913	1,269	484	386	366	345	301	10,933
Maximum	3,531	3,232	17,546	12,282	12,944	11,633	11,744	4,426	783	662	1,235	1,102	41,114
Minimum	45	17	12	6	11	53	58	104	108	67	84	77	1,167

9.1.19 Little Colorado River above Zuni River, AZ

Table 102. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09386500
Station: Little Colorado River above Zuni River near Hunt, AZ
Elevation: 5,399 feet above mean sea level
Latitude: +34d 38m 30s
Longitude: 109d 40m 35s
Drainage Area: 3,741 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1940						0	1	0	0	540	2,886	3,005	
1941	847	405	635	948	607	1,779	595	9,104	450	287	76	117	15,850
1942	940	401	522	524	307	294	84	58	28	6	3	2	3,170
1943	5	6	25	8	0	0	0	0	0	0	0	4	47
1944	2	0	5	7	25	44	11	0	0	1	28	130	253
1945	21	25	30	15	8	9	6	19	9	15	7,573	231	7,962
1946	60	57	106	377	618	208	61	38	19	119	3,217	2,235	7,115
1947	391	448	413	465	187	80	26	15	11	14	2,021	702	4,773
1948	110	123	432	327	516	554	144	36	5	9	87	57	2,401
1949	44	34	38	62	99	124	28	33	22	285	5,099	54	5,922
1950	68	117	215	314	180	111	68	34	6	45	0	2	1,160
1951	2	0	1	9	17	9	6	4	1	0	44	0	92
1952	6	0	4	8	0	0	25	1	8	20	3	16	91
1953	0	8	105	112	92	173	68	20	1	32	0	0	612
1954	0	6	12	43	38	3	0	0	0	1,230	800	122	2,254
1955	15	11	6	52	159	75	10	0	0	1	20,763	545	21,638
1956	17	31	337	468	801	113	15	6	0	11	1	0	1,799
1957	0	0	12	5	0	0	0	3	0	2	2,616	2,866	5,503
1958	44	282	323	383	349	288	6	6	16	60	794	386	2,937
1959	291	137	199	353	190	7	5	2	2	8	1,042	34	2,271
1960	87	286	352	650	487	242	9	0	1	1	0	0	2,115
1961	3	0	0	0	0	0	0	0	0	0	0	1	5
1962	3	4	0	18	95	0	0	0	0	0	0	10	130
1963	0	48	0	0	55	0	3	6	6	11	16	64	209
1964	9	22	133	80	216	63	0	6	4	4	890	817	2,243
1965	206	201	393	542	507	72	2	9	2	46	0	1,886	3,866
1966	306	281	455	539	410	411	514	248	22	99	79	34	3,398
1967	0	4	88	111	60	0	2	6	3	175	3,526	2,437	6,411
1968	489	236	158	517	661	687	391	74	77	69	174	31	3,564
1969	4	1	15	34	12	103	35	52	54	591	36	344	1,280
1970	18	137	286	98	41	271	143	5	25	53	36	41	1,154
1971	46	13	0	0	0	18	12	69	57	78	119	4,243	4,655
1972	2,522	555	984	351	87	49	23	20	16	74	63	48	4,792
Average	205	121	196	232	213	175	69	299	26	118	1,576	620	3,740
Maximum	2,522	555	984	948	801	1,779	595	9,104	450	1,230	20,763	4,243	21,638
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	5

9.1.20 Little Colorado River near Hunt, AZ

Table 103. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09388000
Station: Little Colorado River near Hunt, AZ
Elevation: 5,731.59 feet above mean sea level
Latitude: +34d 38m 50s
Longitude: 109d 42m 19s
Drainage Area: * sq. mi.**
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1929								0	0	12,954	26,705	23,314	
1930	3,648	327	597	768	559	805	254	133	119	2,043	4,455	298	14,006
1931	167	268	69	123	557	214	40	28	2	3,792	12,754	9,564	27,578
1932	5,232	480	543	458	8,582	11,542	10,078	924	117	1,866	7,670	1,214	48,706
1933	742	615	337	276	676	371	16	12	353	4,189	2,975	5,384	15,946
1934	3,568												
1940							39	10	9	2,804	6,191	6,325	
1941	922	534	899	2,029	1,390	13,741	18,744	14,723	541	1,220	1,008	1,673	57,424
1942	2,374	430	547	573	375	349	1,347	61	27	14	587	39	6,723
1943	106	21	135	50	43	33	7	7	6	68	423	212	1,111
1944	53	12	58	40	39	59	30	5	5	60	39	906	1,306
1945	54	29	45	24	16	15	9	23	14	458	13,199	338	14,224
1946	57	54	335	631	906	235	61	43	29	510	12,456	4,679	19,996
1947	524	502	472	572	221	98	30	37	33	26	7,662	2,036	12,213
1948	1,754	132	442	429	697	693	956	36	15	231	695	253	6,333
1949	102	46	45	66	102	127	29	35	24	1,520	12,926	769	15,791
1950	78	112	218	308	184	113	73	36	8	143	2	4	1,279
1951	7	6	7	15	27	21	16	10	3	61	1,234	16	1,423
1952	88	3	2	85	8	32	189	10	169	224	72	478	1,360
1953	3	89	276	110	92	188	42	16	5	89	29	0	939
1954	0	6	9	24	33	25	1	0	0	1,865	910	160	3,033
1955	5	0	0	47	134	36	18	0	131	27	32,194	696	33,288
1956	12	17	228	473	890	116	26	13	1	85	101	0	1,962
1957	0	0	11	10	0	2	0	4	40	3	3,610	3,857	7,537
1958	132	402	406	437	323	317	13	9	40	325	2,462	1,134	6,000
1959	336	141	205	425	227	15	19	3	1	142	1,888	71	3,473
1960	863	362	390	1,365	430	515	110	3	0	0	0	0	4,038
1961	134	0	0	0	0	13	1	0	0	0	164	79	391
1962	124	135	0	15	41	0	0	0	0	0	0	0	315
1963	43	142	0	48	37	0	0	3	2	0	509	1,410	2,195
1964	77	278	83	127	265	99	0	9	24	53	2,737	1,796	5,548
1965	190	224	438	590	469	83	8	18	2	606	307	3,092	6,027
1966	301	331	609	443	405	413	505	210	18	645	2,410	799	7,089
1967	55	2	118	183	105	0	0	1	0	746	10,296	4,923	16,429
1968	425	185	153	492	655	749	817	135	62	389	1,414	11	5,487
1969	71	16	3	223	25	177	31	129	74	2,644	331	1,098	4,822
1970	69	145	342	182	49	267	200	9	16	78	310	227	1,894
1971	155	17	0	26	0	11	7	72	63	73	1,174	10,130	11,728
1972	6,434	579	1,213	398	110	54	30	46	58	245	85	123	9,375
Average	781	184	257	335	519	876	912	454	54	736	3,926	1,724	10,472
Maximum	6,434	615	1,213	2,029	8,582	13,741	18,744	14,723	541	4,189	32,194	10,130	57,424
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	315

9.1.21 Little Colorado River below Lyman Reservoir, AZ

Table 104. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09385500
Station: Little Colorado River below Lyman Reservoir, AZ
Elevation: 6,480 feet above mean sea level
Latitude: +34d 22m 05s
Longitude: 109d 22m 56s
Drainage Area: 706 sq. mi.
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1941							54	11,117	1,380	1,456	645	400	
1942	112	40	15	11	8	9	163	791	574	468	434	167	2,793
1943	9	15	6	6	7	3	276	678	369	224	353	133	2,079
1944	10	7	12	11	6	7	185	388	329	52	232	221	1,458
1945	7	7	6	6	6	6	447	974	479	523	531	475	3,467
1946	20	11	12	12	9	11	113	244	193	74	186	255	1,140
1947	180	91	41	42	34	36	47	119	175	238	183	267	1,453
1948							91	443	543	302	278	163	
1949	21	13	7	9	6	27	282	905	435	438	339	269	2,751
1950	45	16	9	12	13	14	113	229	297	293	322	286	1,649
1951	51	12	8	6	6	6	10	75	154	119	388	108	943
1952	7	0	0	0	0	0	77	790	507	431	433	250	2,495
1953	58	53	18	6	6	6	133	302	259	204	462	124	1,631
1954	2	0	0	0	2	0	9	133	100				
1955							12	29	29	130	83	159	
1956	52	24	28	32	21	13	26	308	163	183	189	61	1,100
1957	12	5	6	2	6	6	8	386	246	220	240	117	1,253
1958	69	27	25	25	22	33	95	628	568	417	318	297	2,524
1959	15	15	17	19	14	5	57	119	153	95	112	202	823
1960	10	7	6	6	6	6	154	373	391	538	222	160	1,879
1961	13	9	6	6	6	6	6	151	96	53	114	83	549
1962	31	19	18	23	23	37	235	555	525	503	544	156	2,669
1963	50	39	22	23	28	21	58	95	62	63	54	28	543
1964	19	16	12	10	6	10	79	244	64	52	43	50	605
1965	17	9	6	6	6	6	349	852	292	297	358	157	2,355
1966	94	51	11	7	6	129	4,816	900	215	253	233	127	6,842
1967	15	14	11	6	9	9	87	134	286	274	146	99	1,091
1968	10	13	13	10	9	9	575	853	291	380	238	228	2,629
1969	91	132	66	88	29	6	140	284	367	347	348	138	2,036
1970	24	22	27	23	18	67	151	191	242	268	229	160	1,422
1971	6	13	35	20	12	11	33	109	194	248	180	43	904
1972	34	21	20	36	12	9	25	99	155	169	137	72	789
1973	22	20	16	12	12	25	1,769	16,681	212	295	317	179	19,560
1974	13	11	13	12	11	12	99	165	235	240	268	155	1,234
1975	35	25	17	10	12	13	16	179	245	321	275	103	1,251
1976	39	48	47	55	41	37	62	208	298	390	397	212	1,834
1977	94	84	44	45	41	35	47	311	280	323	236	52	1,592
1978	11	22	54	52	38	21	75	274	291	242	261	135	1,476
1979	47	50	28	29	32	33	6,475	6,242	1,508	313	217	106	15,080
1980	28	24	23	21	16	2,375	3,838	4,277	119	94	81	42	10,938
1981													
1982				12	12	636	437	157	308	357	336	176	
1983	34	27	28	22	18	21	164	331	359	463	353	165	1,985
1984	22	24											
Average	37	27	19	19	15	95	533	1,005	308	272	267	160	2,887
Maximum	180	132	66	88	41	2,375	6,475	16,681	1,508	538	544	475	19,560
Minimum	2	0	0	0	0	0	6	29	29	52	43	28	543

9.1.22 Little Colorado River above Lyman Reservoir, AZ

Table 105. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database
Station No. 09384000
Station: Little Colorado River above Lyman Reservoir, AZ
Elevation: 6,010 feet above mean sea level
Latitude: +34d 18m 52s
Longitude: 109d 21m 42s
Drainage Area: * sq. mi.**
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1940							579	238	651	6,229	1,406	643	
1941	305	353	478	728	1,486	4,532	12,700	22,990	2,440	1,868	1,553	573	50,006
1942	585	506	1,301	2,392	776	460	5,117	730	434	391	655	220	13,567
1943	122	157	383	462	470	460	2,817	589	280	169	2,830	992	9,731
1944	222	369	426	446	450	524	2,366	684	268	194	1,324	159	7,432
1945	662	480	339	397	424	452	3,527	1,398	482	799	1,857	498	11,315
1946	272	200	355	514	587	532	311	264	103	691	5,851	6,248	15,928
1947	2,025	714	847	583	589	313	127	198	222	303	1,933	460	8,314
1948	553	476	492	430	1,150	3,997	11,514	970	253	194	164	58	20,251
1949	135	160	540	762	601	3,009	13,260	2,450	1,094	1,222	2,626	843	26,702
1950	504	324	555	924	746	676	814	52	9	129	57	13	4,803
1951	16	53	97	178	326	278	104	350	82	464	1,231	133	3,312
1952	28	117	250	1,190	390	421	16,239	4,090	1,144	874	1,282	287	26,312
1953	233	204	315	363	307	486	560	401	378	616	645	97	4,605
1954	58	90	276	414	294	264	370	699	37	1,522	631	441	5,096
1955	142	127	216	193	289	153	77	45	26	327	8,797	641	11,033
1956	147	86	184	203	398	956	910	426	237	91	183	9	3,830
1957	5	19	51	128	158	263	217	384	478	809	4,540	820	7,872
1958	249	611	677	549	760	1,598	15,150	5,002	894	344	758	679	27,271
1959	338	498	750	781	588	439	257	69	1	952	1,721	54	6,448
1960	93	243	316	525	488	6,673	5,074	1,091	666	219	100	1	15,489
1961	73	63	187	237	181	224	555	157	26	8	333	85	2,129
1962	75	220	334	383	2,407	2,346	18,536	2,788	841	317	51	109	28,407
1963	282	393	316	404	746	906	868	117	9	0	1,632	2,241	7,914
1964	486	734	605	581	612	784	3,489	148	46	240	2,009	1,250	10,984
1965	484	415	451	1,217	1,267	2,138	12,278	3,469	668	2,016	1,652	660	26,715
1966	278	656	1,299	1,093	998	7,640	12,585	1,189	155	328	752	465	27,438
1967	324	305	365	276	577	395	84	53	81	2,480	7,432	2,444	14,816
1968	921	529	862	1,252	1,150	2,454	13,269	4,572	578	166	1,031	495	27,279
1969	306	411	527	474	470	702	5,919	908	213	646	2,676	2,733	15,985
1970	568	654	783	810	968	1,434	2,750	452	329	197	103	158	9,206
1971	165	237	326	277	240	268	222	204	168	79	560	681	3,427
1972	823	640	1,855	1,501	1,071	1,397	262	92	224	81	265	142	8,353
1973	1,550	602	154	332	482	2,579	19,140	19,162	5,679	1,583	480	124	51,867
1974	93	111	246	293	324	530	211	62	75	99	535	145	2,724
1975	278	311	288	182	417	2,097	8,610	5,387	1,145	1,229	553	1,541	22,038
1976	249	265	252	217	553	584	4,087	1,275	259	1,854	672	584	10,851
1977	1,180	575	326	483	415	602	903	186	91	417	1,119	729	7,026
1978	270	281	323	393	457	2,287	5,966	146	192	98	753	102	11,268
1979	48	285	2,864	1,348	1,698	4,009	23,617	10,370	4,306	675	693	483	50,396
1980	117	243	436	433	1,741	2,412	13,097	7,347	337	418	1,060	718	28,359
1981	636	952	701	551	402	509	1,806	284	146	1,221	615	310	8,133
1982	127	179	266	340	453	623	2,786	536	277	275	1,170	629	7,661
1983	117	227	530	839	740	3,261	9,090	7,591	1,934	1,678	2,497	1,081	29,585
1984	13,105	1,952	1,656	1,460	1,004	1,904	1,303	623	276	488	1,726	715	26,212
1985	687	1,484	2,452	1,890	1,273	11,209	13,630	6,274	1,245	1,183	790	403	42,520
1986	1,099	1,769	912	645	962	3,205	2,474	365	349	523	843	360	13,506
1987	627	2,249	2,475	1,732	1,821	3,959	18,627	4,627	834	500	1,669	436	39,556
1988	177	655	631	1,581	1,478	3,076	5,022	1,329	380	734	2,098	4,844	22,005
1989	792	928	1,140	998	811	2,245	347	109	56	114	282	205	8,027
1990	208	255	269	255	276	116	92	121	42	818	162	104	2,718
1991	186	360	356	286	372	627	6,990	1,180	430	352	473	301	11,913
1992	84	134	605	603	756	1,440	8,158	2,360	756	523	1,751	1,698	18,868
1993	319	331	664	1,077	1,174	5,883	15,368	4,401	996	85	1,210	574	32,082
Average	657	487	654	693	745	1,848	5,759	2,413	611	762	1,497	762	16,928
Maximum	13,105	2,249	2,864	2,392	2,407	11,209	23,617	22,990	5,679	6,229	8,797	6,248	51,867
Minimum	5	19	51	128	158	116	77	45	1	0	51	1	2,129

9.1.23 Puerco River at Gallup, NM

This gage is located within the city of Gallup along the Puerco River. The importance of this station is based upon the fact that much of the sediment transported by the Little Colorado River system originates in the Puerco River watershed.

Table 106. The Hopi Tribe
U. S. Geological Survey
Monthly Discharge Data
Station: Puerco River at Gallup
Elevation: 6480.00 feet above mean sea level
Latitude: +35d 31m 45s
Longitude: 108d 44m 41s
Drainage Area: 558 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1941	218	38	218	282	841	2900	3540	1230	46	805	760	3570	14,448
1942	1430	0	0	125	20	946	192	0	0	101	46	32	2,892
1943	40	0	0	0	0	264	0	0	14	1590	3420	415	5,743
1944	151	0	24	17	24	149	0	0	0	12	254	839	1,470
1945	139	1	39	19	1470	276	646	0	0	1210	2540	131	6,471
1946	101	0	16	75	1180	0	1	0	1				
1977												199	
1978	263	209	197	325	401	730	178	232	59	135	115	136	2,980
1979	256	357	884	277	3040	3480	1600	237	243	315	354	181	11,224
1980	453	343	351	886	731	2940	3350	532	198	226	316	507	10,833
1981	196	211	298	293	542	1310	554	229	535	331	246	618	5,363
1982	739	295	215	445	713	625	332	406	196	347	1930	589	6,832
Mean	307	112	172	211	689	1,048	799	220	99	423	832	555	5,688
Max	1,430	357	884	886	3,040	3,480	3,540	1,230	535	1,590	3,420	3,570	14,448
% Total	0.0539	0.0197	0.0303	0.0371	0.1212	0.1842	0.1406	0.0388	0.0175	0.0743	0.1462	0.0976	

Period of Record: 1940-46, 1977-82
Mean Discharge for period: 5,688 AF/YR

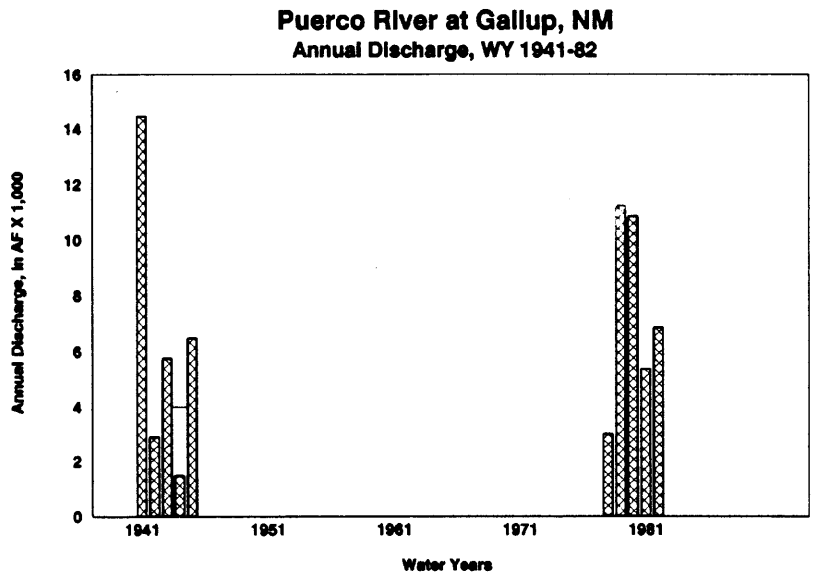


Figure 377. Puerco River near Gallup, Annual Discharge, WY 1941-82

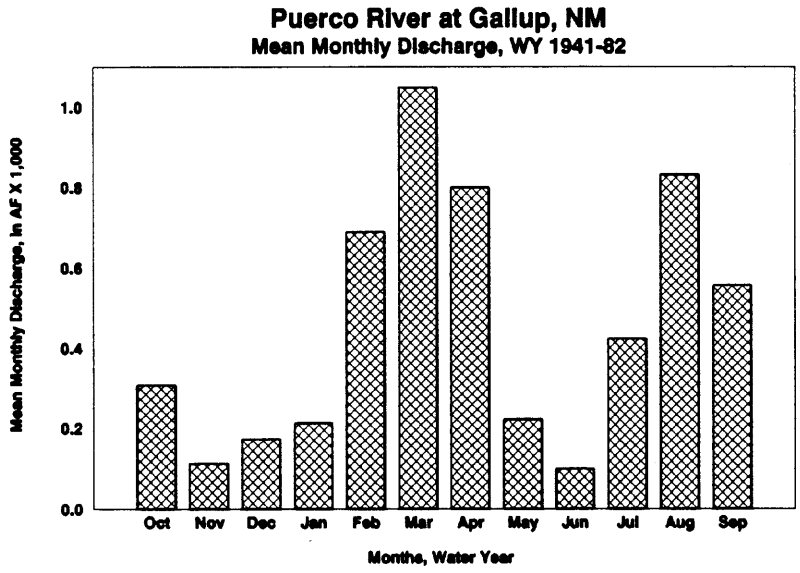


Figure 378. Puerco River near Gallup, Annual discharge, WY 1941-82

9.1.24 Puerco River near Church Rock, NM

This gage is located about 15 miles upstream of Gallup, near the community of Church Rock, New Mexico. Its historical record supplements the record of the Puerco River at Gallup gage.

Table 107. The Hopi Tribe
U. S. Geological Survey
Monthly Discharge Data
Station: Puerco River near Church Rock 09395350
Elevation: 6730.00 feet above mean sea level
Latitude: +35d 36m 41s
Longitude: 108d 33m 11s
Drainage Area: 193 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1978	417	452	509	266	648	752	648	412	428	407	423	683	6,045
1979	532	408	525	248	808	667	323	424	367	704	553	340	5,899
1980	438	390	509	621	358	670	1060	468	192	818	533	514	6,571
1981	730	405	589	349	474	763	510	656	343	743	442	351	6,355
1982	545	274	243	518	547	472	277	357	316	1060	3520	1240	9,369
1983	853	1120	5990										
1988									54	536	107	237	
1989													
1990										757	243	52	
1991	528										529		
1992										91			
Mean	444	322	396	334	473	554	470	386	274	622	912	521	5,707
Max	730	452	589	621	808	763	1,060	656	428	1,060	3,520	1,240	9,369
% Total	0.0777	0.0563	0.0694	0.0585	0.0828	0.0971	0.0823	0.0677	0.0481	0.1090	0.1598	0.0914	

Period of Record: 1977-82
Mean Discharge for period: 5,688 AF/YR

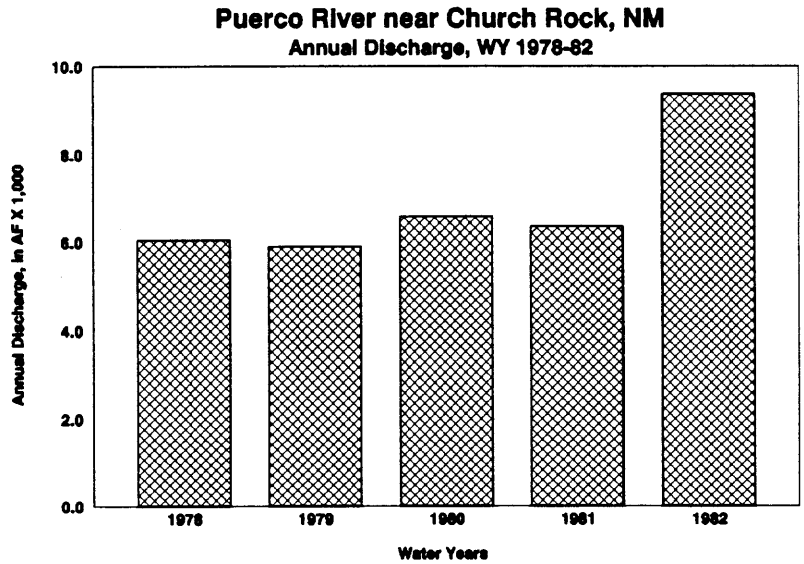


Figure 379. Puerco River near Church Rock, Annual Discharge, WY 1978-82

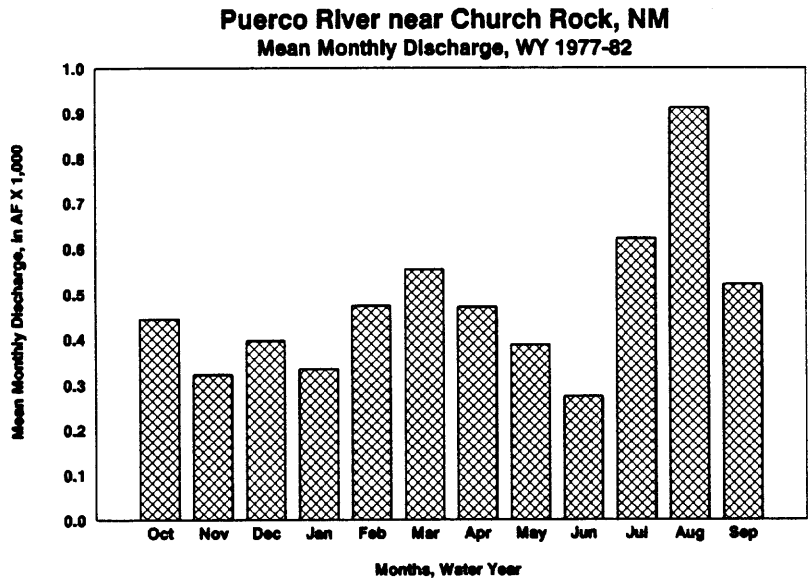


Figure 380. Puerco River near Church Rock, Mean Monthly Discharge, WY 1977-82

9.1.25 Black Creeek near Houk, AZ

Table 108. The Hopi Tribe
U. S. Geological Survey
Monthly Discharge Data
Station No. 09395990
Station: Black Creek near Houk, AZ
Elevation: 5,980 feet above mean sea level
Latitude: +35d 17m 05s
Longitude: 109d 12m 54s
Drainage Area: * sq. mi.**
Monthly Discharge in Acre-Feet

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1990	0	0	0	21	165	124	4	0	0	603	765	624	2,306
1991	62	38	30	322	315	1,224	671	5	7	267	742	169	3,852
Average	31	19	15	172	240	674	338	2	4	435	754	397	3,079
Maximum	62	38	30	322	315	1,224	671	5	7	603	765	624	3,852
Minimum	0	0	0	21	165	124	4	0	0	267	742	169	2,306

9.1.26 Black Creek near Lupton, AZ

Table 109. The Hopi Tribe
U. S. Geological Survey
Monthly Discharge Data
Station No. 09395900
Station: Black Creek near Lupton, AZ
Elevation: 6,550 feet above mean sea level
Latitude: +35d 27m 09s
Longitude: 109d 07m 33s
Drainage Area: 494 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1964												796	
1965	6	29	202	826	2,415	845	2,036	73	8	4,959	1,674	746	13,819
1966	9	285	690	312	1,759	1,213	15	0	1	1,564	1,304	2,165	9,316
1967	167	37	126	199	95	3	0	0	557	1,720	1,956	480	5,340
1968	5	5	6	71	744	190	43	4	0	124	2,307	8	3,508
1969	0	21	28	120	341	1,641	757	176	1	1,418	3,683	381	8,567
1970	713	111	66	19	12	33	167	49	1	109	690	3,149	5,119
1971	9	9	21	41	36	28	0	0	0	72	3,404	2,220	5,840
1972	741	38	224	173	36	0	0	0	7	2	304	330	1,855
1973	3,325	64	96										
1974								0	0	382	100	40	
1975	535	15	1	6	109	671	446	89	0	232	27	658	2,789
1976	3	0	4	2	33	11	3	2	0	441	14	0	513
1977	2	1	6	143	10	17	4	3	6	922	3,461	122	4,697
1978	58	53	61	56	133	425	7	95	0	47	56	57	1,048
1979	18	45	119	223	4,326	1,345	3,360	841	23	13	21	534	10,868
1980	14	7	61	94	121	206	137	47	24	1,364	79	447	2,601
1981	39	112	48	23	110	992	203	103	3	1,065	7,628	1,198	11,524
Average	353	52	110	154	685	508	479	93	39	902	1,669	784	5,827
Maximum	3,325	285	690	826	4,326	1,641	3,360	841	557	4,959	7,628	3,149	13,819
Minimum	0	0	1	2	10	0	0	0	0	2	14	0	513

9.1.27 Rio Nutria near Ramah, NM

Rio Nutria, along with the Zuni River, supplies source water for the Black Rock Reservoir near Zuni, New Mexico. It is located near the community of Ramah.

Table 110. The Hopi Tribe
U. S. Geological Survey
Monthly Discharge Data
Station: Rio Nutria near Ramah, NM 09386900
Latitude: +35d 16m 57s
Elevation: 7000.00 feet above mean sea level
Longitude: 108d 33m 10s
Drainage Area: 71.40 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1970	8	10	5	12	12	30	119	11	4	10	93	7	322
1971	6	8	6	5	5	44	8	6	5	3	2	73	170
1972	21	6	144	10	6	7	8	6	4	5	4	3	223
1973	149	156	59	57	175	1,340	11,130	2,080	79	11	23	7	15,266
1974	2	19	10	11	11	425	26	13	6	180	76	10	789
1975	36	10	12	5	6	1,540	1,830	64	7	31	7	7	3,555
1976	4	5	7	4	9	9	7	5	3	5	29	10	96
1977	4	5	7	6	10	44	18	10	7	19	39	7	176
1978	2	1	1	5	130	3,050	449	32	4	4	4	4	3,686
1979	4	18	199	46	364	3,230	8,630	561	64	4	82	2	13,204
1980	4	10	6	271	1,450	4,380	9,470	620	32	3	4	6	16,256
1981	9	12	18	21	19	120	173	6	6	18	144	25	571
1982	26	7	9	10	237	3,230	706	72	19	216	182	24	4,738
1983	7	24	90	38	462	5,880	8,160	543	67	82	138	2	15,493
1984	145	11	231	74	38	894	2,090	39	2	4	8	113	3,649
1985	65	15	220	115	535	6,150	1,860	875	70	25	18	12	9,960
1986	12	15	20	16	32	171	71	9	9	9	60	9	433
1987	65	241	46	27	171	2,290	4,790	369	23	21	294	49	8,386
1988	17	38	38	28	175	374	687	86	23	17	39	8	1,530
1989	10	12	11	14	162	287	15	9	12	185	16	48	780
1990	9	8	10	7	11	22	11	25	21	81	83	27	314
1991	7	11	9	70	161	1,520	2,340	24	5	5	5	107	4,264
1992	12	46	121	8	360	2,240	431	58	7	2	362		3,647
Mean	27	28	50	37	182	1,523	2,287	238	21	41	59	24	4,516
Max	149	241	231	271	1,450	6,150	11,130	2,080	79	216	294	113	
% Total	0.0059	0.0062	0.0111	0.0082	0.0402	0.3373	0.5064	0.0526	0.0045	0.0090	0.0130	0.0054	

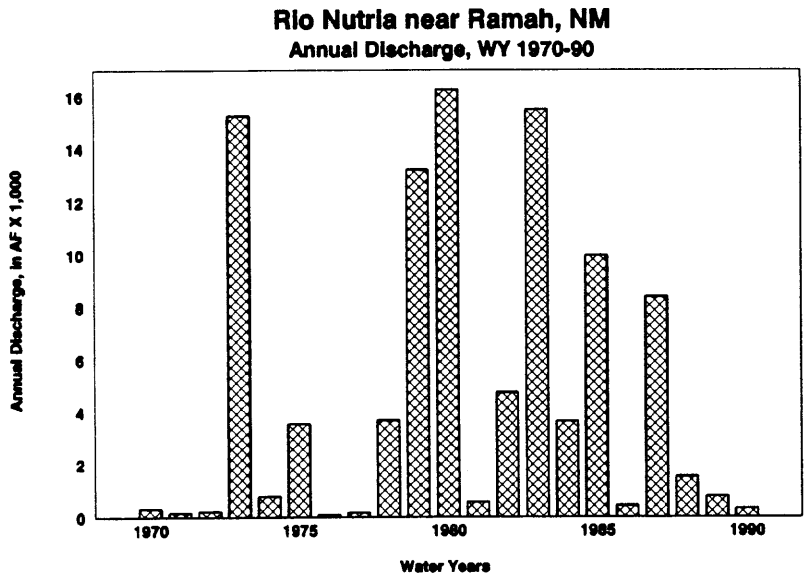


Figure 381. Rio Nutria near Ramah, Annual Discharge, WY 1970-90

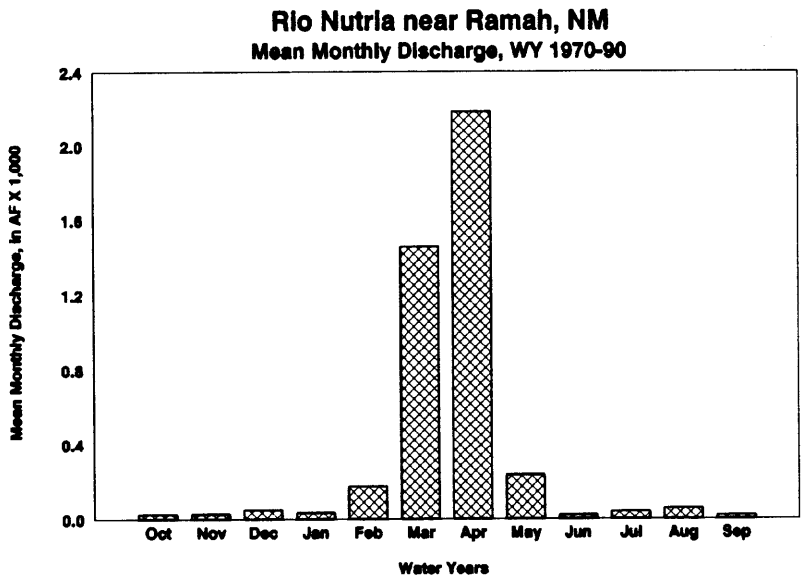


Figure 382. Rio Nutria near Ramah, Mean Monthly Discharge, WY 1970-90

9.1.28 Zuni River above Black Rock Reservoir, NM

This gage is one of the inflow gages to Black Rock Reservoir, near the community of Zuni in New Mexico.

Table 111. The Hopi Tribe
U. S. Geological Survey
Monthly Discharge Data
Station: Zuni River above Black Rock Res., NM
Station No: 09386950
Latitude: +35d 06m 03s
Elevation: 6450.00 feet above mean sea level
Longitude: 108d 45m 00s
Drainage Area: 848 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/ Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1970	74	66	79	68	57	59	77	17	0	219	413	33	1,162
1971	27	0	1	12	39	41	479	1	0	0	1,450	771	2,820
1972	153	47	87	23	19	109	1	15	3	23	139	392	1,011
1973	484	3	35	59	722	8,550	18,320	4,020	13	771	731	277	33,985
1974	0	17	35	84	82	115	121	55	0	98	1,040	6	1,653
1975	358	245	61	65	115	893	1,160	333	9	54	32	605	3,930
1976	45	26	34	50	92	170	121	5	0	610	1,280	3	2,436
1977	0	0	17	7	49	125	67	24	0	1,580	1,450	92	3,411
1978	40	74	25	67	138	924	744	34	0	47	34	36	2,163
1979	40	56	254	62	758	7,420	16,790	469	117	0	204	0	26,170
1980	104	84	50	290	4,220	9,180	17,970	482	16	123	104	195	32,818
1981	0	15	74	58	50	160	141	39	1	260	219	55	1,072
1982	127	27	44	53	502	862	952	249	20	15	1,430	228	4,509
1983	22	121	182	194	428	8,250	15,800	535	3	107	615	45	26,302
1984	774	814	361	231	132	156	274	45	0	286	316	1,040	4,429
1985	183	104	138	182	2,970	16,150	2,060	2,250	65	413	364	26	24,905
1986	33	65	66	74	75	123	123	46	5	18	0	9	636
1987	67	71	79	131	543	3,790	7,360	231	32	112	109	29	12,554
1988	27	128	124	185	1,200	345	195	122	25	22	140	138	2,651
1989	95	131	156	182	271	145	57	11	0	238	14	0	1,300
1990	7	9	10	57	82	97	38	7	0	0	39	14	359
1991	15	24	42	71	138	170	1,370	19	0	0	5	161	2,015
1992	15	90	138	97	164	195	398	55	4	49	48		
Mean	116	92	85	96	551	2,515	3,662	392	13	217	440	181	8,360
Max	774	814	361	290	4,220	16,150	18,320	4,020	117	1,580	1,450	1,040	
% Total	0.0139	0.0111	0.0102	0.0115	0.0660	0.3008	0.4380	0.0468	0.0016	0.0260	0.0527	0.0216	

Period of Record: 1969-92
Mean Discharge for period: 8,360 AF/YR

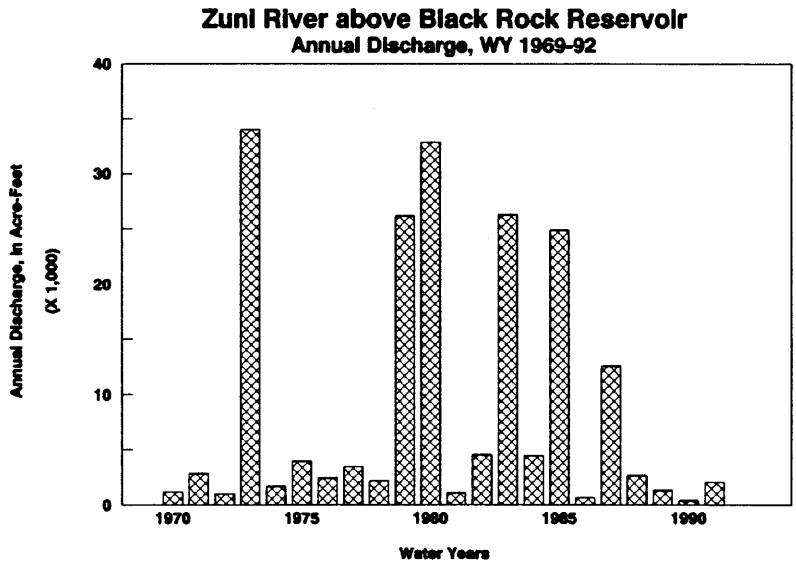


Figure 383. Zuni River above Black Rock Res., Annual Discharge, WY 1969-92

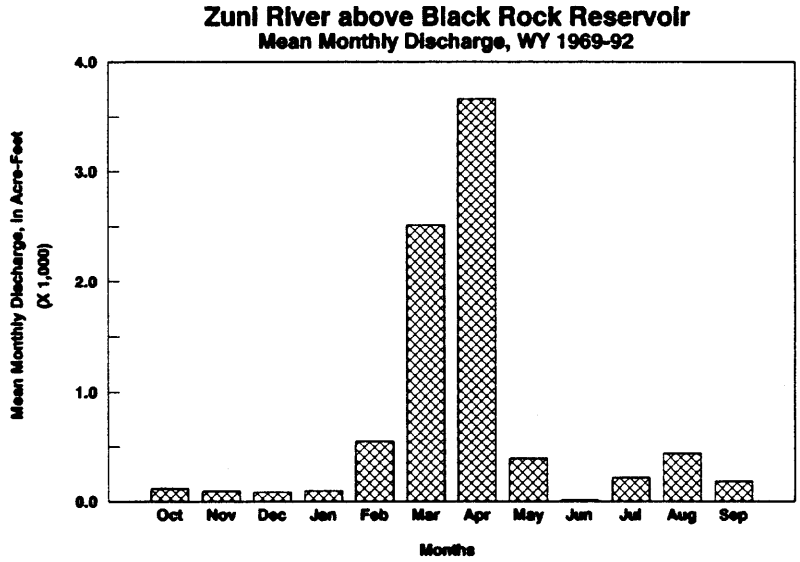


Figure 384. Zuni River above Black Rock Res., Mean Monthly Discharge, WY 1969-92

9.2 Reconstruction of Missing Records

It is obvious from the gaged records that the periods of record do not overlap sufficiently to properly characterize the temporal and spatial distribution of various flow conditions. In order to determine these effects, a statistical model was utilized to reconstruct missing records for Little Colorado River near Cameron and Little Colorado River at Grand Falls. An attempt was made to investigate Moenkopi Wash at Moenkopi, however, insufficient precipitation data was available for the effort. It is hoped that the recently reconstructed Little Colorado River Basin precipitation data will enable a better correlation with the model.

9.2.1 Method of Reconstruction

The statistical models employed by DBS&A are detailed in their report, "Little Colorado River Basin Progress Report, March 14, 1994." During this first phase of their portion of this study (Marley, 1994), interstation correlations were examined for LCR near Cameron and LCR at Grand Falls. The interstation discharge correlations were determined by deriving month-to-month linear regression equation which resulted in correlation coefficients of between $r^2 = 0.891$ and 0.981 for LCR at Grand Falls and between $r^2 = 0.968$ and 0.988 for LCR near Cameron. For this reason it can be assumed that the reconstructed records are quite accurate.

9.2.2 Reconstructed Records for Two Stations

The following tables and graphs illustrate the results of the linear regression reconstructions of the 1939-90 discharge records for LCR near Cameron and LCR at Grand Falls.

9.2.2.1 Little Colorado River near Cameron

This station is located upstream of the heavy vehicle bridge over the Little Colorado River above the community of Cameron. It was installed in 1947 to supplement the record of LCR at Grand Falls. In 1960 this gage replaced the Grand Falls gage until 1990. Since 1990, both gages have been in operation, which gives valuable information on Dinnebito Wash and local drainages between the two LCR gages. The annual average of LCR near Cameron is about 4,000 AF/YR less than that of Grand Falls. This fact indicates that considerable losses occur between Grand Falls and Cameron, since Dinnebito Wash generally contains significant amounts of water during the monsoon season in most years.

The histogram of annual flows is distinctly lognormal, with several extremely wet years outlying the main portion of the data. The monthly distribution shows that the highest flows occur during the melting of snow in the San Francisco Mountains and the Mogollon Rim during March and April. A secondary peak occurs in July through October during the monsoon months.

Table 112. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Little Colorado River near Cameron
Elevation: 3979.20 feet above mean sea level
Latitude: +35d 55m 35s
Longitude: 111d 34m 00s
Drainage Area: 26,091 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1939	635	0	0	202	1,365	34,408	40,287	112	102	635	3,892	5,429	87,065
1940	635	0	169	618	4,883	13,596	6,789	104	102	14,937	49,806	60,801	152,439
1941	25,954	8,522	28,601	53,271	70,449	137,018	107,925	86,637	4,071	5,100	31,951	36,897	596,396
1942	63,591	3,020	2,920	6,180	5,928	19,176	50,789	6,095	102	635	1,068	635	160,138
1943	1,411	556	0	122	6,190	53,310	12,905	102	102	635	20,201	14,761	110,294
1944	1,469	0	22	28	180	22,847	71,984	24,818	102	635	635	10,600	133,319
1945	3,209	983	1,078	326	4,468	16,947	67,514	19,718	102	11,888	42,507	1,414	170,153
1946	674	0	394	3,926	2,213	4,087	3,279	102	102	11,874	61,448	47,851	135,949
1947	1,404	14,439	4,866	3,179	7,781	6,735	918	525	0	0	104,261	20,168	164,277
1948	75,390	710	1,020	3,300	6,460	19,070	67,370	857	879	5,240	20,190	602	201,088
1949	4,440	2,180	2,070	18,340	13,640	97,140	77,890	6,010	1,690	11,760	41,370	10,750	287,280
1950	6,490	252	30	188	11,310	14,550	3,870	0	0	7,690	998	1,680	47,058
1951	0	22	94	152	14	0	454	1,310	0	3,970	26,270	17,910	50,196
1952	9,050	103	147	124,700	10,190	12,910	131,800	21,070	165	1,910	12,560	27,820	352,425
1953	114	486	3,920	1,640	1,420	15,310	5,730	0	0	14,890	15,050	227	58,789
1954	0	160	27	135	26	17,560	20,200	120	270	37,860	6,290	25,950	108,598
1955	4,160	68	63	113	176	473	22	0	35,380	12,320	139200	3,600	195,575
1956	0	0	69	121	2,030	5,170	1,230	37	0	1,980	8,690	0	19,327
1957	0	0	0	39,170	40,880	25,760	1,930	57	263	4,170	53,470	9,270	174,970
1958	12,830	12,420	1,260	307	4,900	31,260	44,540	1,620	165	444	23,090	34,420	167,256
1959	10,810	63	29	128	80	1,890	2,390	0	49	96	35,590	264	51,389
1960	6,580	34,720	19,010	18,200	8,220	88,480	18,560	24	13	0	0	382	194,189
1961	9,150	80	124	73	13	2,280	11,620	0	0	706	9,460	5,270	38,776
1962	510	3,710	6	93	46,290	14,010	85,640	1,200	0	0	167	6,130	157,756
1963	4,500	3,110	159	14	2,130	1,310	1,750	0	0	0	41,360	29,930	84,263
1964	1,850	680	0	0	0	0	27,190	3,080	60	9,940	101,900	26,200	170,900
1965	549	0	0	42,140	12,210	14,970	87,550	16,570	0	20,820	10,110	20,970	225,889
1966	416	3,920	24,490	55,820	4,330	66,880	16,950	77	0	976	17,510	11,110	202,479
1967	4,530	43	23,020	50	48	0	1,200	0	2,600	22,760	87,290	48,880	190,421
1968	450	0	117	3,940	40,260	49,080	67,110	12,310	0	6,570	33,950	1	213,788
1969	5,160	179	0	26,600	7,620	17,880	37,710	1,100	0	12,940	7,880	22,770	139,839
1970	5,650	1,160	48	63	0	5,280	4,630	0	0	729	13,590	49,520	80,670
1971	679	8	67	46	5	0	0	0	0	130	60,540	16,170	77,646
1972	75,450	6,060	28,210	6,900	322	0	0	0	182	8,780	5,200	1,480	132,584
1973	257,800	12,100	6,400	12,300	24,760	86,970	236,200	177,200	1,860	39	205	46	815,880
1974	0	0	0	656	62	8,060	4,000	0	0	6,640	6,040	2,800	28,258
1975	11,020	11,850	0	12	53	14,160	32,780	6,190	0	9,860	979	25,530	112,434
1976	177	0	892	142	12,490	17,820	35,500	9,730	0	19,120	4,020	7,670	107,561
1977	509	77	0	3,330	560	29	5,000	3	0	16,440	36,160	7,470	69,578
1978	6,020	605	168	603	5,260	115,200	47,070	2,280	202	0	243	1,210	178,861
1979	7,340	35,920	103,900	15,410	45,370	78,580	158,700	21,950	1,630	0	3,990	0	472,790
1980	267	1,870	388	8,260	121,300	45,730	104,200	36,850	94	14	4,670	9,680	333,323
1981	0	0	8	65	73	47	1,820	76	7	20,830	5,160	13,070	41,156
1982	26,010	33	1,330	3,290	21,820	71,120	32,310	3,150	0	200	42,490	25,840	227,593
1983	395	3,220	27,350	8,850	17,110	83,140	93,590	41,700	13	9,460	21,370	17,080	323,278
1984	42,350	2,510	14,080	9,610	513	4,050	1,450	0	0	17,500	75,600	44,830	212,493
1985	23,410	207	18,980	27,260	22,510	94,980	49,250	19,860	0	2,010	6,390	9,820	274,677
1986	3,000	10,890	6,700	172	9,530	20,330	10,050	0	0	15,570	8,170	12,420	96,832
1987	13,760	11,180	9,300	8,700	13,510	31,850	38,010	7,920	565	1,100	25,840	223	161,958
1988	901	44,810	15	2,130	32,400	18,580	28,250	4,190	868	1,920	30,520	15,540	180,124
1989	0	64	30	142	452	10,570	3,220	0	0	2,460	19,540	4	36,482
1990	155	0	0	21	515	14	135	2	0	7,640	8,720	18,930	36,132
1991	1,720	1,540	2,960	14,320	3,490	29,920	61,050	3,360	11	3	1,180	5,010	124,564
1992	0	425	9,949	3,523	17,567	51,969	48,264	14,050	3,808	14,148	37,354	15,233	216,291
Mean	13,566	4,351	6,379	9,794	12,322	29,491	38,344	10,225	1,029	7,000	26,410	14,857	173,768
Max	257,800	44,810	103,900	124,700	121,300	137,018	236,200	177,200	35,380	37,860	139,200	60,801	815,880
Min	0	0	0	0	0	0	0	0	0	0	0	0	19,327

Reconstructed Period of Record: 1939 to present
Mean Discharge for Period: 173,768 Acre-Feet per year

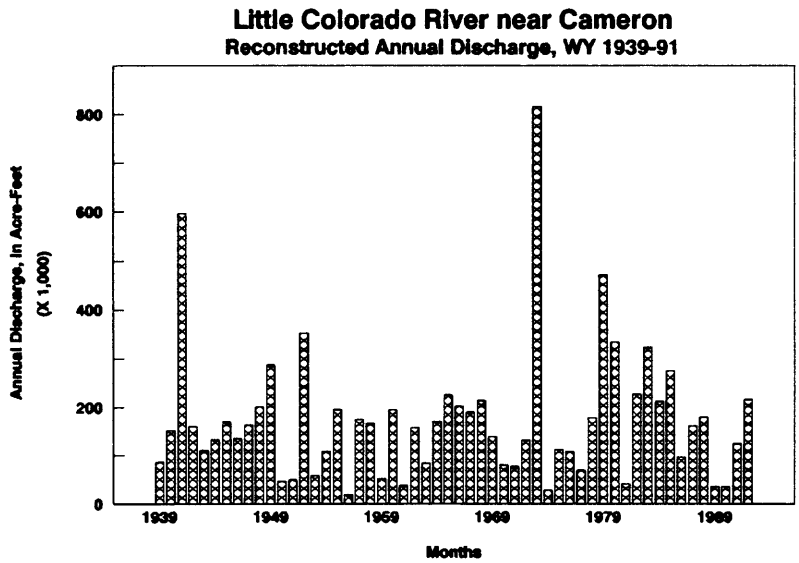


Figure 385. LCR near Cameron, Reconstructed Annual Discharge, WY 1939-90

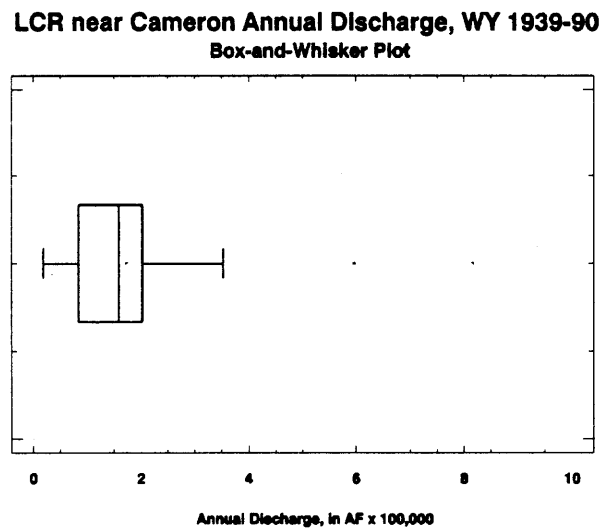


Figure 386. LCR near Cameron, Box Plot of Reconstructed Annual Discharge

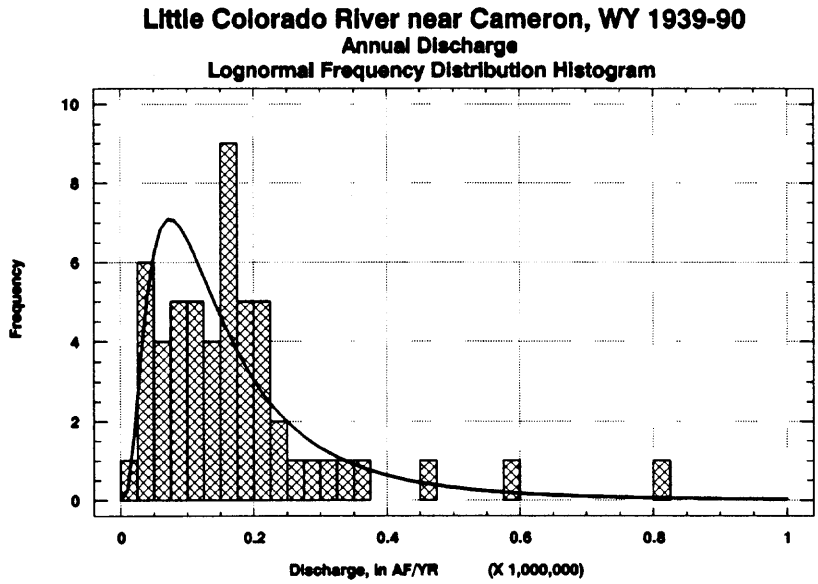


Figure 387. LCRA near Cameron, Histogram of Annual Discharge, WY 1939-90

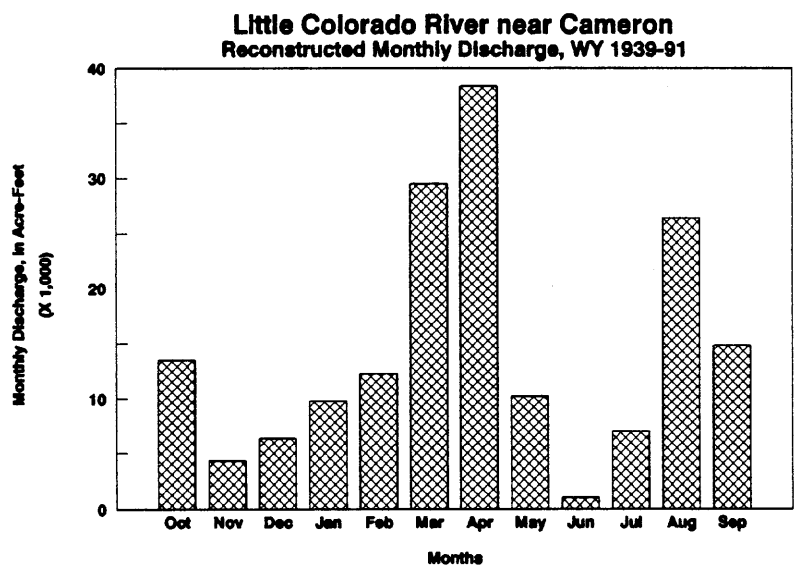


Figure 388. LCR near Cameron, Mean Monthly Discharge, WY 1939-90

9.2.2.2 Little Colorado River at Grand Falls

It is to be noted that the long-term (1939-90) trend of the reconstructed data shows a slight downward to flat incline. This fact is to be noted in spite of the increased precipitation in the same period for many stations. It is not known at this time whether consumptive use from the river or natural losses are responsible. Upon the conclusion of the detailed DBS&A model activity in 1995, it may be possible to identify the causes of this trend.

Table 113. U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Little Colorado River at Grand Falls
Elevation: 4438.90 feet above mean sea level
Latitude: +35d 26m 00s
Longitude: 111d 12m 00s
Drainage Area: 20,700 sq. mi.
Monthly Discharge in Acre-Feet

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1926			2,410	946	474	18,730	83,940	10,870	0	688	5,530	47,930	
1927	2,370	1,120	1,000	3,000	60,980	74,950	50,500	6,050	36,990	20,660	20,840	115,300	393,760
1928	643	0	153	464	17,210	50,460	7,600	125	0	2,490	5,250	3,170	87,565
1929	87	7,300	908	543	1,420	42,350	155,300	2,420	0	96,850	110,300	93,330	510,808
1930	12,090	496	468	655	1,420	22,310	27,040	1,000	0	50,540	67,650	5,640	189,309
1931	0	1,000	4,440	1,130	12,480	29,340	13,890	12,430	2	23,230	51,340	15,870	165,152
1932	14,090	17,060	7,060	9,420	153,700	146,800	77,710	9,410	0	3,330	24,170	3,090	465,840
1933	1,900	236	89	184	7,370	25,260	18,050	10,600	0	18,280	19,610	27,650	129,229
1934	31,120	1,030	1,230	712	778	1,690	1,500	6	1,500	2,060	20,890	8,460	70,976
1935	139	0	0	19,080	27,440	38,000	72,590	2,820	0	724	32,840	21,800	215,433
1936	1,720	99	827	631	4,040	22,680	49,250	752	0	3,830	45,630	35,610	165,069
1937	335	4,920	242	18	115,800	110,900	89,090	2,530	0	6,020	2,780	6,870	339,505
1938	6,280	95	538	93	1,250	128,100	4,440	44	0	171	11,220	17,950	170,181
1939	0	0	0	377	1,610	34,250	40,120	10	0	0	2,780	4,100	83,247
1940	0	0	206	817	5,350	13,470	6,670	2	0	12,230	42,050	51,450	132,245
1941	21,650	8,600	28,770	56,698	74,900	136,700	107,600	86,370	3,970	3,820	26,700	31,010	586,788
1942	53,830	3,070	2,970	6,720	6,450	19,040	50,610	5,980	0	0	371	0	149,041
1943	666	597	0	292	6,730	53,120	12,780	0	0	0	16,730	12,080	102,995
1944	711	29	58	192	354	22,710	71,770	24,680	0	0	0	8,520	129,024
1945	2,200	1,020	1,120	508	4,900	16,810	67,280	19,590	0	9,620	35,800	666	159,514
1946	34	0	432	4,330	2,510	3,980	3,170	0	0	9,610	52,000	40,380	116,446
1947	661	14,550	4,930	3,530	8,420	6,620	815	422	0	0	74,460	12,670	127,078
1948	57,000	702	1,020	3,510	7,920	19,870	68,300	996	63	4,960	16,170	1,730	182,241
1949	2,120	2,020	3,280	16,870	13,150	85,550	76,000	6,070	4	13,340	39,290	10,750	268,444
1950	163	445	78	462	12,115	14,433	3,982	197	197	6,249	686	1,250	40,256
1951	0	0	0	0	157	253	1,830	2,180	0	1,920	30,600	9,250	46,190
1952	7,377	201	245	130,990	10,947	12,827	129,160	20,807	358	1,447	10,293	22,982	347,634
1953	0	580	5,959	1,986	1,755	15,169	5,806	197	197	12,237	12,369	45	56,300
1954	0	0	0	0	0	20,840	19,980	0	0	39,310	5,400	21,990	107,520
1955	2,710	0	0	25	79	1,160	525	0	18,080	5,280	122,100	2,340	152,299
1956	0	0	121	0	3,710	7,380	2,070	47	0	0	5,340	0	18,668
1957	0	0	0	43,300	41,710	24,810	2,990	0	0	4,470	44,360	8,140	169,780
1958	12,860	9,590	2,080	228	6,500	29,940	43,160	1,170	778	987	22,310	31,470	161,073

U. S. Geological Survey
Monthly Discharge Data
Hopi Tribal Database

Station: Little Colorado River at Grand Falls
Elevation: 4438.90 feet above mean sea level
Latitude: +35d 26m 00s
Longitude: 111d 12m 00s
Drainage Area: 20,700 sq. mi.
Monthly Discharge in Acre-Feet; Peak Discharge in cfs

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1959	8,890	0	0	0	0	4,240	3,200	0	0	354	30,890	282	47,856
1960	12,310	33,200	22,830	22,050	8,890	89,750	18,210	99	2	0	0	174	207,515
1961	7,459	179	222	342	278	2,422	11,560	197	197	443	7,717	4,235	35,252
1962	281	3,753	106	362	48,779	13,900	83,967	1,367	197	0	0	4,952	157,663
1963	3,595	3,166	257	280	2,498	1,476	1,911	197	197	0	34,232	24,737	72,544
1964	1,396	769	100	265	265	197	26,792	3,210	255	8,123	84,555	21,636	147,562
1965	313	100	100	44,426	13,065	14,839	85,835	16,407	197	17,160	8,261	17,286	217,986
1966	202	3,956	24,217	58,758	4,807	65,611	16,777	272	197	668	14,410	9,094	198,966
1967	3,620	142	22,763	317	315	197	1,374	197	2,742	18,778	72,414	40,484	163,343
1968	231	100	215	4,395	42,456	48,208	65,842	12,237	197	5,320	28,076	0	207,275
1969	4,144	276	100	28,142	8,251	17,888	37,087	1,274	197	10,612	6,405	18,786	132,961
1970	4,555	1,213	147	331	265	5,359	4,724	197	197	463	11,150	41,021	69,620
1971	420	108	166	313	271	197	197	197	197	0	50,179	13,300	65,543
1972	62,572	6,069	27,874	7,500	603	197	197	197	374	7,152	4,175	1,083	117,992
1973	214,117	12,015	6,402	13,152	26,214	85,263	231,253	173,524	2,016	0	27	0	763,982
1974	0	100	100	952	330	8,081	4,108	197	197	5,379	4,878	2,185	26,506
1975	9,016	11,763	100	277	321	14,042	32,263	6,247	197	8,055	670	21,077	104,027
1976	3	100	978	413	13,352	17,631	34,925	9,713	197	15,752	3,200	6,230	102,494
1977	279	176	100	3,757	852	225	5,083	199	197	13,521	29,916	6,062	60,365
1978	4,864	695	265	696	5,773	112,846	46,240	2,432	394	0	58	864	175,328
1979	5,958	35,469	102,358	16,413	47,806	77,056	155,409	21,662	1,789	0	3,170	0	467,091
1980	78	1,941	482	8,920	127,357	44,923	102,146	36,241	289	0	3,739	7,905	334,021
1981	0	100	108	334	342	243	1,979	271	203	17,169	4,143	10,716	35,608
1982	21,476	133	1,408	3,711	23,129	69,761	31,798	3,280	197	23	35,172	21,333	211,419
1983	185	3,271	27,031	9,535	18,197	81,524	91,737	40,988	209	7,722	17,617	14,056	312,073
1984	35,060	2,573	13,966	10,340	802	4,155	1,614	197	197	14,400	62,692	37,119	183,113
1985	19,313	304	18,786	28,835	23,850	93,099	48,374	19,624	197	1,527	5,166	8,021	267,095
1986	2,354	10,821	6,695	445	10,253	20,081	10,030	197	197	12,799	6,647	10,182	90,700
1987	11,297	11,109	9,256	9,383	14,424	31,353	37,374	7,939	749	768	21,331	42	155,026
1988	605	44,221	115	2,501	34,216	18,366	28,806	4,297	1,046	1,454	25,226	12,774	173,629
1989	0	163	129	414	738	10,535	3,342	197	197	1,899	16,100	0	33,713
1990	0	0	0	0	0	0	646	0	0	5,760	6,760	8,690	21,856
1991	1,250	1,340	4,570	16,520	4,530	32,740	70,650	2,980	0	0	172	1,270	136,022
1992	0	541	8,731	6,930	16,054	60,099	46,265	11,062	2,041	8,996	36,211	6,998	203,928
Mean	10,130	4,009	5,589	9,212	16,855	34,516	39,747	9,003	1,179	8,151	24,359	15,124	177,874
Max	214,117	44,221	102,358	130,990	153,700	146,800	231,253	173,524	36,990	96,850	122,100	115,300	763,982
Min	0	0	0	0	0	0	197	0	0	0	0	0	18,668

Reconstructed Period of Record: 1926-present
Mean 177,874 Acre-Feet Discharge per Year for Period:

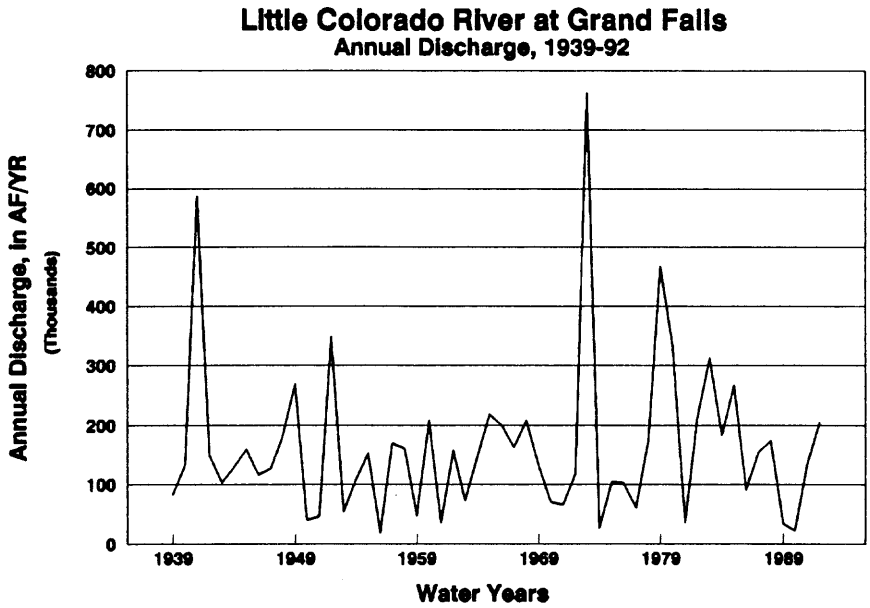


Figure 389. LCR at Grand Falls, Reconstructed Annual Discharge, WY 1939-90

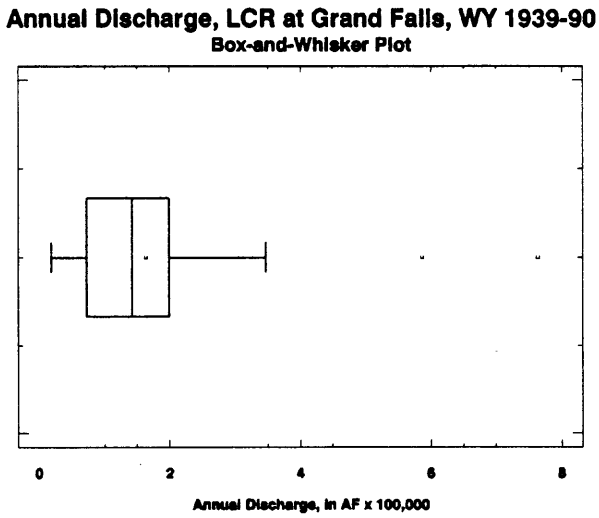


Figure 390. LCR at Grand Falls, Box Plot of Reconstructed Annual Discharge, WY 1939-90

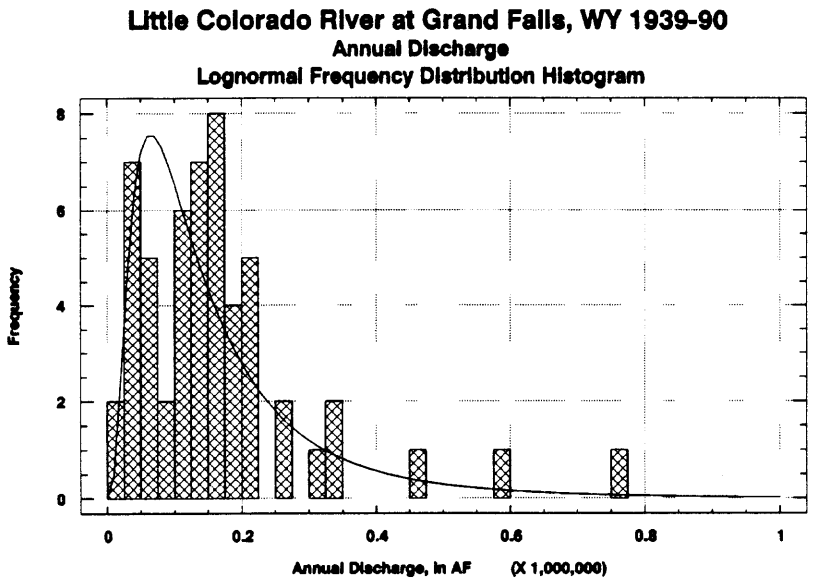


Figure 391. LCR at Grand Falls, Histogram of Reconstructed Annual Discharge, WY 1939-90

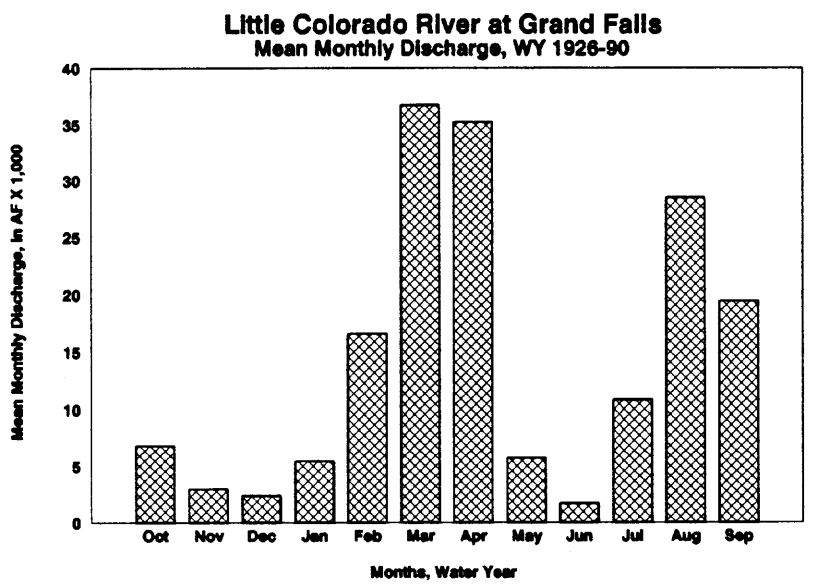


Figure 392. LCR at Grand Falls, Mean Monthly Reconstructed Discharge, WY 1939-90

9.3 Summary Statistics and Variability of Selected Streamflow Stations

The following summary statistics are presented in tabular form. The purpose of this analysis is to characterize the distributions of discharges at streamflow stations of interest in endangered species management and water supply development. The number of parameters assessed is fairly exhaustive, with the mean, mode, median, standard deviation, skewness, range, interquartile range, maximum, minimum, and kurtosis being the most important.

The sequential comparison of the statistics, station to station along the main stem of the Little Colorado River, and from month to month at the same station, reveals the relative contribution of the base flow at Blue Spring and the tributary flows to the resultant discharge at the mouth of the LCR, as well as the seasonal components of the discharge form snowmelt and monsoons.

Previous sections of this report have also addressed the time series analysis and the frequency domain analysis of the same data. The section on descriptive statistics under the climate section (Section 6.2.1) more fully describes the interpretive aspect of these separate statistical moments.

9.3.1 Little Colorado River at Mouth

This reach of the Little Colorado River from Blue Spring to the confluence with the main stem Colorado River constitutes the only significant perennial flows in the Little Colorado River Basin. It is within this reach that critical habitat for the endangered fish, the humpback chub, has been declared. It is hoped that these tabulated values will be of benefit to researchers who may desire to examine these statistics in light of the life cycle of the humpback chub.

The annual and seasonal variation in discharge is somewhat attenuated by the Blue Spring discharge. In addition, chemical and temperature parameters are somewhat smoothed by the addition of clear, slightly saline, Blue Spring waters.

The data analyzed is a reconstruction from statistical modeling of LCR near Cameron, Moenkopi Wash at Moenkopi, and LCR at Mouth 1990-93. In any reconstruction procedure, some error will occur. However, this data set represents the most reliable information presently available.

Table 114. Little Colorado River at Mouth
WY 1939-90 Summary Statistics

Variable:	Oct	Nov	Dec
Sample size	52.	52.	52.
Average	28425.451322	17761.052103	22913.542154
Median	15306.2	13599.	16650.666667
Mode	13008.567214	13040.	16411.566667
Geometric mean	19895.301243	16332.343715	20494.459377
Variance	1.99093E9	92264941.200501	264151039.862027
Standard deviation	44619.862867	9605.464132	16252.724075
Standard error	6187.661672	1332.03821	2253.847308
Minimum	12375.6	13040.	16297.666667
Maximum	312364.	59040.8	121027.666667
Range	299988.4	46000.8	104730.
Lower quartile	12930.95	13195.65	16467.591882
Upper quartile	23517.5	16867.9	21080.27813
Interquartile range	10586.55	3672.25	4612.686249
Skewness	5.416692	3.010799	4.663635
Standardized skewness	15.946309	8.86355	13.72937
Kurtosis	33.27749	9.290336	26.416606
Standardized kurtosis	48.983139	13.675004	38.884192
Coeff. of variation	156.97152	54.081617	70.930649
Sum	1478123.46876	923574.709338	1191504.191992

Little Colorado River at Mouth WY 1939-90 Summary Statistics			
Variable:	**Jan**	**Feb**	**Mar**
Sample size	52.	52.	52.
Average	24338.970454	19176.498868	37634.164163
Median	15094.	11557.503964	24616.435955
Mode	14970.176091	11182.716852	23431.5
Geometric mean	20331.439261	13562.475677	26096.401663
Variance	451383894.55148	467241944.949424	1.198112E9
Standard deviation	21245.797103	21615.779999	34613.759616
Standard error	2946.261956	2997.569352	4800.064813
Minimum	14390.5	6551.5	8356.5
Maximum	140031.5	128063.5	145794.090311
Range	125641.	121512.	137437.590311
Lower quartile	14547.6	6965.643949	12589.385685
Upper quartile	23365.5	19791.	48460.89214
Interquartile range	8817.9	12825.356051	35871.506455
Skewness	3.767401	3.202355	1.458339
Standardized skewness	11.090927	9.427478	4.293233
Kurtosis	17.330579	12.687883	1.251124
Standardized kurtosis	25.509922	18.676059	1.841604
Coeff. of variation	87.291273	112.720159	91.974302
Sum	1265626.463587	997177.941144	1956976.536475

Little Colorado River at Mouth WY 1939-90 Summary Statistics			
Variable:	**Apr**	**May**	**Jun**
Sample size	52.	52.	52.
Average	53702.145321	24010.817768	16088.194094
Median	35309.5	14070.429137	15086.166667
Mode	32855.5	13676.433333	15052.666667
Geometric mean	39335.826019	18994.37531	15750.821944
Variance	2.274449E9	776169874.299266	24232944.226271
Standard deviation	47691.180271	27859.825453	4922.696845
Standard error	6613.576764	3863.462661	682.655226
Minimum	15894.5	13676.433333	15052.666667
Maximum	252265.5	190943.433333	50432.666667
Range	236371.	177267.	35380.
Lower quartile	18758.871743	13702.033333	15052.666667
Upper quartile	74880.937882	20855.433333	15254.666667
Interquartile range	56122.066139	7153.4	202.
Skewness	2.006416	4.828072	6.923927
Standardized skewness	5.90673	14.213458	20.383488
Kurtosis	5.155513	26.55879	49.078789
Standardized kurtosis	7.58871	39.09348	72.242021
Coeff. of variation	88.806844	116.030307	30.598194
Sum	2792511.556703	1248562.523914	836586.092905

Little Colorado River at Mouth WY 1939-90 Summary Statistics			
Variable:	**Jul**	**Aug**	**Sep**
Sample size	52.	52.	52.
Average	19497.042433	42196.214237	27802.586056
Median	15833.851814	31088.	22506.5
Mode	12986.2	29941.	22264.5
Geometric mean	17782.780582	32937.434837	23571.139237
Variance	82892642.818117	1.072669E9	278522579.853926
Standard deviation	9104.539682	32751.626101	16688.995771
Standard error	1262.572487	4541.833356	2314.347307
Minimum	10998.3	12700.4	11144.5
Maximum	50846.2	157774.7	74813.25517
Range	39847.9	145074.3	63668.75517
Lower quartile	12378.3	18557.	12782.582904
Upper quartile	24864.206243	53941.2	37232.8
Interquartile range	12485.906243	35384.2	24450.217096
Skewness	1.284818	1.632822	1.077676
Standardized skewness	3.782402	4.806897	3.172593
Kurtosis	1.467689	2.587528	0.442398
Standardized kurtosis	2.16038	3.808739	0.651193
Coeff. of variation	46.69703	77.617451	60.026775
Sum	1013846.206538	2194203.140314	1445734.47492

Table 115. Little Colorado River at Mouth WY 1939-90 Summary Statistics	
Variable:	**Mean Annual Total**
Sample size	52.
Average	333546.678973
Median	316851.086264
Mode	314126.605
Geometric mean	311062.004406
Variance	2.176605E10
Standard deviation	147533.208649
Standard error	20459.17494
Minimum	175705.166667
Maximum	1010940.066667
Range	835234.9
Lower quartile	241768.816667
Upper quartile	362159.766667
Interquartile range	120390.95
Skewness	2.557308
Standardized skewness	7.52851
Kurtosis	8.92757
Standardized kurtosis	13.141028
Coeff. of variation	44.231653
Sum	17344427.306591

9.3.2 Little Colorado River near Cameron

This reach of the Little Colorado River contains all the surface water discharges from snowmelt and the monsoon precipitation, except Moenkopi Wash. Monthly variation depends on the phase of the annual rainfall and temperature patterns. By examining the individual parameters, it is possible to cut a slice through time to characterize the magnitudes of the flows.

Missing data from WY 1939-47 has been reconstructed by statistical modeling. The correlations of the results are in the 0.9 range, which could be described as excellent. Individual reconstructed monthly flows in the model may deviate from actual measured flows, if they were available. However, the analysis of the entire data set for the period likely enables a close correlation with the natural condition.

Table 116. Little Colorado River near Cameron WY 1939-90 Summary Statistics

Variable:	Oct	Nov	Dec
Sample size	52.	52.	52.
Average	14054.851322	4480.632872	6376.360102
Median	2425.	370.	153.
Mode	0.	0.	0.
Geometric mean			
Variance	1.498102E9	89009156.879443	261243200.147246
Standard deviation	38705.327071	9434.466433	16163.019524
Standard error	5367.46313	1308.325095	2241.407525
Minimum	0.	0.	0.
Maximum	257800.	44810.	103900.
Range	257800.	44810.	103900.
Lower quartile	433.	15.15	18.419751
Upper quartile	9100.	3465.	4393.111464
Interquartile range	8667.	3449.85	4374.691713
Skewness	5.281386	3.025967	4.658226
Standardized skewness	15.54798	8.908206	13.713447
Kurtosis	31.859296	9.326933	26.358649
Standardized kurtosis	46.895613	13.728873	38.798881
Coeff. of variation	275.387666	210.561023	253.483481
Sum	730852.26876	232992.909338	331570.725325

Little Colorado River near Cameron WY 1939-90 Summary Statistics			
Variable:	**Jan**	**Feb**	**Mar**
Sample size	52.	52.	52.
Average	9827.637761	12390.746945	29050.329548
Median	636.788045	4891.303964	16128.435955
Mode	142.	0.	0.
Geometric mean			
Variance	446699727.067062	461867050.881462	1.192033E9
Standard deviation	21135.272108	21491.092361	34525.832877
Standard error	2930.934896	2980.278287	4787.871568
Minimum	0.	0.	0.
Maximum	124700.	121300.	137017.590311
Range	124700.	121300.	137017.590311
Lower quartile	121.288911	251.143949	4068.385685
Upper quartile	8775.	13000.	40068.89214
Interquartile range	8653.711089	12748.856051	36000.506455
Skewness	3.755122	3.239694	1.457722
Standardized skewness	11.05478	9.5374	4.291417
Kurtosis	17.201557	12.997374	1.252542
Standardized kurtosis	25.320006	19.131616	1.843692
Coeff. of variation	215.059535	173.444688	118.848335
Sum	511037.163587	644318.841144	1510617.136475

Little Colorado River near Cameron WY 1939-90 Summary Statistics			
Variable:	**Apr**	**May**	**Jun**
Sample size	52.	52.	52.
Average	37716.549167	10283.753665	994.98512
Median	19380.	322.495804	13.
Mode	0.	0.	0.
Geometric mean			
Variance	2.269419E9	775950925.429979	24211327.934759
Standard deviation	47638.422374	27855.895703	4920.500781
Standard error	6606.26056	3862.917703	682.350687
Minimum	0.	0.	0.
Maximum	236200.	177200.	35380.
Range	236200.	177200.	35380.
Lower quartile	2805.	0.2	0.
Upper quartile	58949.437882	7055.	173.5
Interquartile range	56144.437882	7054.8	173.5
Skewness	2.007972	4.829279	6.958522
Standardized skewness	5.911311	14.217011	20.485333
Kurtosis	5.171496	26.566067	49.419709
Standardized kurtosis	7.612236	39.104192	72.743842
Coeff. of variation	126.306418	270.872841	494.530087
Sum	1961260.556703	534755.190581	51739.226238

Little Colorado River near Cameron WY 1939-90 Summary Statistics			
Variable:	**Jul**	**Aug**	**Sep**
Sample size	52.	52.	52.
Average	6996.573203	26684.623852	15038.962979
Median	4070.	16280.	10674.867481
Mode	0.	13590.	9820.
Geometric mean			
Variance	65153919.155304	932707017.662411	239628827.66523
Standard deviation	8071.797765	30540.252416	15479.949214
Standard error	1119.356951	4235.171002	2146.682717
Minimum	0.	0.	0.
Maximum	37860.	139200.	60801.35517
Range	37860.	139200.	60801.35517
Lower quartile	634.567214	5180.	1446.982904
Upper quartile	11881.103367	38760.	24150.
Interquartile range	11246.536153	33580.	22703.017096
Skewness	1.480637	1.795389	1.171711
Standardized skewness	4.358878	5.285481	3.449424
Kurtosis	2.759453	3.355669	0.773743
Standardized kurtosis	4.061805	4.939411	1.13892
Coeff. of variation	115.367874	114.448877	102.932292
Sum	363821.806538	1387600.440314	782026.07492

Table 117. Little Colorado River near Cameron WY 1838-90 Summary Statistics	
Variable:	**Annual Discharge**
Sample size	52.
Average	173896.006537
Median	158947.106774
Mode	157755.8
Geometric mean	131687.415453
Variance	2.052036E10
Standard deviation	143249.280938
Standard error	19865.101061
Minimum	19327.4
Maximum	815880.
Range	796552.6
Lower quartile	82466.5
Upper quartile	201783.5
Interquartile range	119317.
Skewness	2.446595
Standardized skewness	7.202582
Kurtosis	8.126613
Standardized kurtosis	11.962051
Coeff. of variation	82.376406
Sum	9042592.339924

9.3.3 Little Colorado River at Grand Falls

This gage represents the original Little Colorado River streamflow measurement station. It was operated from WY 1926-1950 and from WY 1990 to the present.

The discharges from this gage differ only slightly from that at Cameron, despite the introduction of flows from Dinnebito Wash and local minor drainages. For this reason, it can be deduced that significant losses occur in this reach of the LCR.

The data from WY 1951 to 1990 have been reconstructed by statistical modeling, with a correlation in the range of 0.9, which must be described as an excellent fit. Individual reconstructed monthly flows in the model may deviate from actual measured flows, if they were available. However, the analysis of the entire data set for the period likely enables a close correlation with the natural condition.

Table 118. Little Colorado River at Grand Falls WY 1939-90 Summary Statistics

Variable:	Oct	Nov	Dec
Sample size	52.	52.	52.
Average	11472.577496	4411.319977	6512.407565
Median	1053.516584	512.5	233.683148
Mode	0.	0.	0.
Geometric mean			
Variance	1.028636E9	84731960.837002	255730378.511005
Standard deviation	32072.353193	9204.996515	15991.572109
Standard error	4447.635152	1276.503343	2217.632047
Minimum	0.	0.	0.
Maximum	214117.204667	44221.241502	102358.000177
Range	214117.204667	44221.241502	102358.000177
Lower quartile	56.029242	99.917196	99.917196
Upper quartile	8174.325026	3512.282848	5444.5
Interquartile range	8118.295784	3412.365652	5344.582804
Skewness	5.314075	3.061868	4.574968
Standardized skewness	15.644214	9.013897	13.468342
Kurtosis	32.283613	9.598202	25.598036
Standardized kurtosis	47.520192	14.128171	37.679289
Coeff. of variation	279.556649	208.667622	245.555456
Sum	596574.0298	229388.63881	338645.193368

Little Colorado River at Grand Falls WY 1939-90 Summary Statistics			
Variable:	**Jan**	**Feb**	**Mar**
Sample size	52.	52.	52.
Average	10549.927808	13230.056304	28699.874325
Median	924.397392	5561.580609	15989.5
Mode	0.	0.	196.522219
Geometric mean			
Variance	495988961.7437135	7518341.705341	1.129425E9
Standard deviation	22270.809634	22528.16774	33606.924337
Standard error	3088.405618	3124.094766	4660.441881
Minimum	0.	0.	0.
Maximum	130990.	127356.524314	136700.
Range	130990.	127356.524314	136700.
Lower quartile	314.9632	347.940277	4197.702702
Upper quartile	9459.385457	13251.213325	39586.440915
Interquartile range	9144.422257	12903.273048	35388.738213
Skewness	3.716219	3.246969	1.479449
Standardized skewness	10.940253	9.558817	4.35538
Kurtosis	16.842291	13.030896	1.412892
Standardized kurtosis	24.791181	19.180959	2.079721
Coeff. of variation	211.099166	170.280211	117.09781
Sum	548596.246018	687962.927832	1492393.464913

Little Colorado River at Grand Falls WY 1939-90 Summary Statistics			
Variable:	**Apr**	**May**	**Jun**
Sample size	52.	52.	52.
Average	37296.466062	10230.081084	716.395013
Median	19095.	346.803086	196.522219
Mode	196.522219	196.522219	196.522219
Geometric mean	12643.048482		
Variance	2.176701E9	747974422.786064	6557608.035771
Standard deviation	46655.123122	27349.121061	2560.7827
Standard error	6469.901488	3792.640705	355.116667
Minimum	196.522219	0.	0.
Maximum	231253.290388	173524.014101	18080.
Range	231056.768169	173524.014101	18080.
Lower quartile	3185.	196.522219	0.
Upper quartile	58225.809054	7092.798105	231.833018
Interquartile range	55040.809054	6896.275886	231.833018
Skewness	1.997413	4.801935	6.401747
Standardized skewness	5.880224	14.136515	18.846232
Kurtosis	5.10508	26.241402	43.510724
Standardized kurtosis	7.514474	38.626298	64.046052
Coeff. of variation	125.092611	267.340218	357.45401
Sum	1939416.235241	531964.216348	37252.540689

Little Colorado River at Grand Falls WY 1939-90 Summary Statistics			
Variable:	**Jul**	**Aug**	**Sep**
Sample size	52.	52.	52.
Average	5784.243031	22284.321408	12214.417104
Median	2870.	13389.295532	8605.
Mode	0.	0.	0.
Geometric mean			
Variance	54878146.390808	650351801.660523	169679473.323045
Standard deviation	7407.978563	25501.996033	13026.107374
Standard error	1027.301791	3536.490551	1806.396079
Minimum	0.	0.	0.
Maximum	39310.	122100.	51450.
Range	39310.	122100.	51450.
Lower quartile	0.	4159.097466	1166.698375
Upper quartile	9615.	32560.984529	19931.351278
Interquartile range	9615.	28401.887063	18764.652903
Skewness	2.126192	1.82134	1.257127
Standardized skewness	6.25934	5.361881	3.700882
Kurtosis	6.901136	3.904759	0.93213
Standardized kurtosis	10.158197	5.74765	1.372058
Coeff. of variation	128.071703	114.439186	106.645346
Sum	300780.637632	1158784.713217	635149.689404

Table 119. Little Colorado River at Grand Falls WY 1939-90 Summary Statistics	
Variable:	**Annual Discharge**
Sample size	52.
Average	163402.087178
Median	140261.458427
Mode	132961.211804
Geometric mean	121045.410718
Variance	1.933185E10
Standard deviation	139039.018258
Standard error	19281.242678
Minimum	18668.
Maximum	763982.429886
Range	745314.429886
Lower quartile	71082.063773
Upper quartile	191039.716101
Interquartile range	119957.652328
Skewness	2.36001
Standardized skewness	6.947681
Kurtosis	7.24453
Standardized kurtosis	10.66366
Coeff. of variation	85.090112
Sum	8496908.533272

9.3.4 Little Colorado River at Woodruff

This gage is located near the bridge over the Little Colorado River in the community of Woodruff, about 20 miles upstream of Holbrook. This discharge does not include that of the Puerco River or the northern drainages which originate on the Hopi and Navajo Reservations. It will be noted that the discharges are greatly diminished when compared to Grand Falls and Cameron.

Table 120. Little Colorado River at Woodruff
WY 1939-90 Summary Statistics

Variable:	Oct	Nov	Dec
Sample size	52.	52.	52.
Average	2626.826923	992.519231	1788.865385
Median	762.5	421.	549.
Mode	728.	395.	490.
Geometric mean	984.959447	560.079667	775.128121
Variance	18100898.616516	3539138.450603	12847435.452112
Standard deviation	4254.515086	1881.259804	3584.331939
Standard error	589.995088	260.883796	497.057408
Minimum	65.	179.	139.
Maximum	18530.	12500.	21440.
Range	18465.	12321.	21301.
Lower quartile	415.	313.	392.
Upper quartile	1910.	936.5	931.
Interquartile range	1495.	623.5	539.
Skewness	2.262216	5.071276	3.986245
Standardized skewness	6.659782	14.929433	11.735188
Kurtosis	4.396955	28.89659	18.330079
Standardized kurtosis	6.472143	42.534628	26.981145
Coeff. of variation	161.964043	189.543915	200.369014
Sum	136595.	51611.	93021.

Little Colorado River at Woodruff
WY 1939-90 Summary Statistics

Variable:	Jan	Feb	Mar
Sample size	52.	52.	52.
Average	2244.596154	1986.038462	697.576923
Median	720.5	735.	1023.
Mode	707.	843.	278.
Geometric mean	1007.386281	920.851945	1131.063579
Variance	21387133.696456	16375098.978884	47895757.033184
Standard deviation	4624.622546	4046.615744	6920.676053
Standard error	641.319758	561.164637	959.725091
Minimum	184.	142.	160.
Maximum	30030.	27450.	37520.
Range	29846.	27308.	37360.
Lower quartile	443.	443.	291.
Upper quartile	1675.	1565.	4070.
Interquartile range Skewness	1232.	1122.	3779.
Standardized skewness	4.719922	5.201391	3.234709
Kurtosis	13.895075	15.31248	9.522726
Standardized kurtosis	26.174872	31.61201	11.848616
Coeff. of variation	38.528368	46.531619	17.44069
Sum	206.033613	203.753141	187.167872
	116719.	103274.	192274.

Little Colorado River at Woodruff
WY 1939-90 Summary Statistics

Variable:	Apr	May	Jun
Sample size	52.	52.	52.
Average	2297.005769	1532.755769	454.082692
Median	318.	247.5	211.5
Mode	286.	327.	0.
Geometric mean	449.389296		
Variance	26335893.514672	22382761.603692	712743.559891
Standard deviation	5131.850886	4731.042338	844.241411
Standard error	711.659673	656.077528	117.075219
Minimum	0.2	0.	0.
Maximum	24620.	30010.	5230.
Range	24619.8	30010.	5230.
Lower quartile	195.5	110.5	65.
Upper quartile	1245.	457.	407.
Interquartile range	1049.5	346.5	342.
Skewness	3.182627	5.000205	4.200563
Standardized skewness	9.369399	14.720204	12.366122
Kurtosis	10.177054	27.503493	20.827424
Standardized kurtosis	14.980219	40.484046	30.657138
Coeff. of variation	223.414802	308.662504	185.922394
Sum	119444.3	79703.3	23612.3

Little Colorado River at Woodruff
WY 1939-90 Summary Statistics

Variable:	Jul	Aug	Sep
Sample size	52.	52.	52.
Average	3379.826923	8294.826923	4480.269231
Median	2135.	3980.	2020.
Mode	8360.	3760.	1680.
Geometric mean	1839.600021	4388.484307	1872.871574
Variance	11729343.087104	103674771.596909	39957532.161389
Standard deviation	3424.812854	10182.080907	6321.197051
Standard error	474.936091	1412.000569	876.592311
Minimum	32.	219.	42.
Maximum	14640.	58500.	36390.
Range	14608.	58281.	36348.
Lower quartile	733.5	1845.	590.5
Upper quartile	4745.	13085.	5945.
Interquartile range	4011.5	11240.	5354.5
Skewness	1.430782	2.720143	3.126967
Standardized skewness	4.212108	8.007883	9.205541
Kurtosis	1.690968	10.601215	12.690346
Standardized kurtosis	2.489038	15.604567	18.679683
Coeff. of variation	101.331013	122.75218	141.08967
Sum	175751.	431331.	232974.

Table 121. Little Colorado River at Woodruff WY 1939-90 Summary Statistics	
Variable:	**Annual Discharge**
Sample size	52.
Average	31259.421154
Median	24377.5
Mode	24123.
Geometric mean	24642.301496
Variance	577078281.157389
Standard deviation	24022.453687
Standard error	3331.314944
Minimum	7051.
Maximum	110954.
Range	103903.
Lower quartile	13916.15
Upper quartile	37357.5
Interquartile range	23441.35
Skewness	1.789262
Standardized skewness	5.267445
Kurtosis	3.254425
Standardized kurtosis	4.790383
Coeff. of variation	76.848684
Sum	1625489.9

9.3.5 Moenkopi Wash at Moenkopi and Tuba City

The flows from this drainage must be added to the LCR near Cameron flows in order to get a clear representation of the flows from the entire basin due to runoff.

There is no ideal location to erect a gage for this stream, four sites having been attempted since 1941. The scatter in the low flow calibration measurements indicates that for the drier months, the data may be less accurate than the medium and high flows.

There is a diversion of this water at the Hopi village of Moenkopi downstream of the present gage, as well as discharges from an overflowing Tuba City sewage lagoon. These flows are unaccounted for at this time. In order to assess the data from the entire study period, both the Moenkopi Wash near Tuba City and the present gage, Moenkopi Wash at Moenkopi, were used. Missing data were filled in from the output from an uncalibrated model.

Table 122. Moenkopi Wash at Moenkopi and Tuba City WY 1940-90 Summary Statistics

Variable:	Oct	Nov	Dec
Sample size	50.	50.	50.
Average	2076.464	250.036	249.096
Median	354.5	178.5	154.
Mode	6.9	68.	113.9
Geometric mean			189.120444
Variance	40342295.452557	59596.182759	49309.054269
Standard deviation	6351.558506	244.123294	222.056421
Standard error	898.246018	34.524247	31.40352
Minimum	0.	0.	38.
Maximum	42190.	1190.8	1250.
Range	42190.	1190.8	1212.
Lower quartile	105.	121.	113.9
Upper quartile	1266.4	264.	317.
Interquartile range	1161.4	143.	203.1
Skewness	5.562728	2.480511	2.527579
Standardized skewness	16.058213	7.160618	7.296493
Kurtosis	33.978965	6.750156	8.098451
Standardized kurtosis	49.044411	9.743011	11.689107
Coeff. of variation	305.883391	97.635258	89.144917
Sum	103823.2	12501.8	12454.8

Moenkopi Wash at Moenkopi and Tuba City WY 1940-90 Summary Statistics			
Variable:	**Jan**	**Feb**	**Mar**
Sample size	51.	51.	51.
Average	254.731373	290.845098	258.301961
Median	213.	176.	167.
Mode	145.	165.7	272.
Geometric mean	215.399738	210.203448	
Variance	31586.944996	105017.298925	55202.598996
Standard deviation	177.727164	324.063727	234.952333
Standard error	24.886781	45.377998	32.899907
Minimum	62.	44.	0.
Maximum	1070.	1610.	1020.
Range	1008.	1566.	1020.
Lower quartile	146.	165.7	122.
Upper quartile	288.	272.	331.
Interquartile range	142.	106.3	209.
Skewness	2.537768	2.874017	1.619438
Standardized skewness	7.398802	8.379127	4.721432
Kurtosis	8.440219	7.890166	2.227745
Standardized kurtosis	12.303628	11.501794	3.247469
Coeff. of variation	69.770426	111.421416	90.960337
Sum	12991.3	14833.1	13173.4

Moenkopi Wash at Moenkopi and Tuba City WY 1940-90 Summary Statistics			
Variable:	**Apr**	**May**	**Jun**
Sample size	51.	51.	51.
Average	92.882353	51.623529	41.337255
Median	35.	26.	0.
Mode	35.	0.	0.
Geometric mean			
Variance	22582.505882	9497.157835	21582.775984
Standard deviation	150.274768	97.453362	146.910776
Standard error	21.042676	13.6462	20.571623
Minimum	0.	0.	0.
Maximum	857.	645.	715.
Range	857.	645.	715.
Lower quartile	25.	1.8	0.
Upper quartile	117.	64.	4.5
Interquartile range	92.	62.2	4.5
Skewness	3.554703	4.852972	3.945905
Standardized skewness	10.363652	14.148723	11.50419
Kurtosis	14.566294	28.190001	14.699505
Standardized kurtosis	21.23384	41.093635	21.428027
Coeff. of variation	161.79044	188.777024	355.395577
Sum	4737.	2632.8	2108.2

Moenkopi Wash at Moenkopi and Tuba City WY 1940-90 Summary Statistics			
Variable:	**Jul**	**Aug**	**Sep**
Sample size	51.	51.	51.
Average	1531.623529	3039.033333	1650.870588
Median	1330.	1770.	617.
Mode	1987.9	0.	0.
Geometric mean			
Variance	3393267.769835	9976213.357067	5299338.178918
Standard deviation	1842.082455	3158.514422	2302.029144
Standard error	257.943137	442.280484	322.348556
Minimum	0.	0.	0.
Maximum	10690.	13900.	11340.
Range	10690.	13900.	11340.
Lower quartile	130.	404.4	122.
Upper quartile	1987.9	4850.	2400.
Interquartile range	1857.9	4445.6	2278.
Skewness	2.760823	1.322522	2.330697
Standardized skewness	8.049112	3.855782	6.79509
Kurtosis	11.437806	1.820946	6.347139
Standardized kurtosis	16.673325	2.654462	9.252466
Coeff. of variation	120.269924	103.931549	139.443343
Sum	78112.8	154990.7	84194.4

Table 123. Moenkopi Wash at Moenkopi and Tuba City WY 1940-90 Summary Statistics	
Variable:	**Annual Discharge**
Sample size	51.
Average	9736.343137
Median	8496.6
Mode	8496.6
Geometric mean	7933.056607
Variance	48241766.100903
Standard deviation	6945.62928
Standard error	972.582635
Minimum	1558.
Maximum	44958.5
Range	43400.5
Lower quartile	5819.7
Upper quartile	12779.6
Interquartile range	6959.9
Skewness	2.74499
Standardized skewness	8.002951
Kurtosis	12.314575
Standardized kurtosis	17.951423
Coeff. of variation	71.337146
Sum	496553.5

9.4 Mean Velocities in Streams

The purposes of the examination of mean velocities in selected streams are: (1.) to compare the mean velocities with the particle settling velocities of the sizes of sediment particles found in distributions in the suspended sediment samples (See Section 11.3) and (2.) to compare the mean velocities in streams to swimming fatigue tolerances of various native Little Colorado River fishes for environmental management purposes.

The methodology employed consisted of retrieving the calibration current meter field sheets from USGS from measurements taken at selected gages of interest in terms of sediment and swimming velocity. The flows at LCR at Mouth, LCR at Cameron, LCR near Cameron, and Moenkopi Wash at Moenkopi have been previously reconstructed (see Section 9.2). The discharges in AF/Month were converted to mean cfs-day. From the USGS field sheets, the discharge in cfs and the cross-sectional area of the stream in square feet were used to determine mean velocity in the stream cross section. Calculated velocities were ploted against measured discharges and equations were fitted with the computer code Jandell Scientific TableCurve for Windows. These equations were entered into Lotus 1-2-3 formula cells and the mean monthly stream velocities were calculated from the previously derived mean daily discharges in cfs-days.

9.4.1 LCR at Mouth

The calculation of the velocities in this perennial reach of the Little Colorado River supplied by both upstream storm and snowmelt flows plus the continuous discharges of the Blue Spring complex is of importance to compare to the swimming fatigue measurements previously tabulated in this report from the humpback chub tolerance and preference study (Bulkley, 1981).

At 14°C, humpback chub fatigued from 116 to 2 minutes in water flowing at 0.27 to 0.51 m/s (0.9 to 1.7 ft/sec), respectively; at 20°C from 74 to 4 minutes at 0.45 to 0.72 m/s (1.5 to 2.4 ft/sec), respectively; and at 26°C from 120 to 2 minutes at 0.45 to 0.78 m/s (1.5 to 2.6 ft/sec, respectively. Thus, the chub would be able to swim in much of the deeper part of the stream in most months in most years. Those fish not protected in still water conditions or behind rocks and ledges during storm events would probably be swept out to the main stem of the Colorado River. This may be one of the reasons for the dramatic decrease in chub fry counts in the aftermath of the summer monsoons.

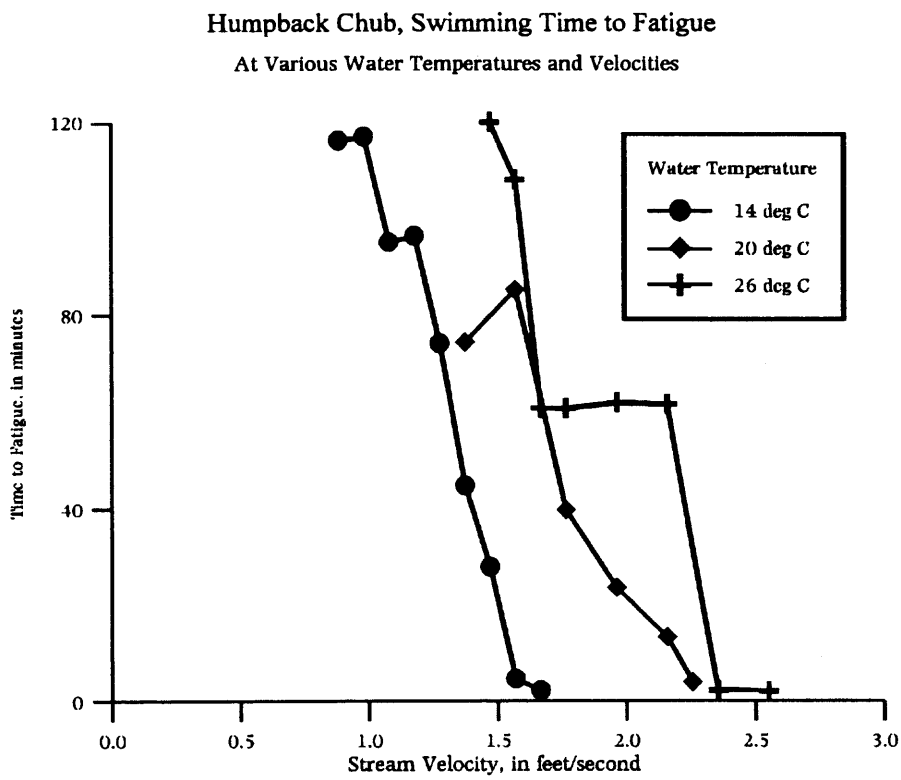


Figure 393. Humpback Chub, Swimming Time to Fatigue (Data from Bulkley, *et al*, 1981)

From the figure, it is apparent that swimming time to fatigue decreases rapidly from the point where fatigue begins; in other words, the curves slope steeply downward as velocity increases. It is also obvious that the strength of the fish is strongly dependent upon the water temperature. In the figures below, it is possible to determine the swimming speed in comparison to the mean monthly stream velocity.

The maximum monthly velocity of 6.53 fps occurred in October, 1973. The results were obtained utilizing the mean daily flow and the velocity-flow curve.

Table 124. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River at Colorado River Confluence (Mouth)

Stream Drainage Area: , sq. mi.
Elevation: in feet above mean sea level
Latitude: + d m s
Longitude: d m s

Velocity, in feet per second (fps)

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Mean
1939	1.33	1.37	1.60	1.45	0.94	3.15	3.74	1.39	1.55	1.21	1.61	1.66	1.75
1940	1.33	1.37	1.61	1.49	1.27	2.02	2.11	1.39	1.55	2.39	4.07	4.30	2.07
1941	3.18	2.05	3.27	4.06	4.51	5.47	5.26	4.80	1.85	1.60	3.42	3.71	3.60
1942	4.62	1.65	1.83	1.93	1.42	2.37	4.08	1.86	1.55	1.21	1.42	1.26	2.10
1943	1.41	1.43	1.69	1.48	1.45	3.87	2.50	1.39	1.55	1.25	2.95	2.37	1.94
1944	1.44	1.38	1.61	1.46	0.82	2.60	4.62	2.96	1.55	1.21	1.36	2.06	1.92
1945	1.55	1.47	1.70	1.49	1.27	2.24	4.51	2.70	1.55	2.35	3.95	1.34	2.18
1946	1.40	1.38	1.67	1.76	1.05	1.29	1.86	1.39	1.55	2.17	4.39	3.85	1.98
1947	1.40	2.44	1.98	1.70	1.57	1.50	1.68	1.43	1.54	1.15	5.19	2.67	2.02
1948	4.74	1.45	1.71	1.72	1.43	2.37	4.51	1.45	1.67	1.73	2.71	1.26	2.23
1949	1.72	1.57	1.78	2.69	2.13	4.91	4.74	1.85	1.71	2.08	3.66	2.10	2.58
1950	2.04	1.40	1.61	1.47	1.87	2.07	1.90	1.38	1.54	1.87	1.41	1.43	1.67
1951	1.28	1.38	1.62	1.46	0.80	0.91	1.65	1.49	1.54	1.52	3.01	2.72	1.62
1952	2.10	1.40	1.65	5.40	1.73	1.97	5.55	2.77	1.55	1.33	2.32	3.52	2.61
1953	1.29	1.43	1.92	1.59	0.97	2.13	2.03	1.38	1.54	2.86	2.61	1.22	1.75
1954	1.29	1.39	1.63	1.46	0.82	2.29	2.90	1.40	1.56	3.48	1.79	3.05	1.92
1955	1.64	1.37	1.61	1.46	0.83	0.95	1.61	1.39	3.53	2.23	5.60	1.51	1.98
1956	1.27	1.38	1.61	1.46	1.00	1.37	1.71	1.39	1.54	1.49	2.19	1.20	1.47
1957	1.28	1.37	1.60	3.59	3.55	2.75	1.76	1.40	1.56	1.66	4.15	1.95	2.22
1958	2.32	2.36	1.70	1.47	1.31	3.04	3.89	1.52	1.55	1.36	3.04	3.42	2.25
1959	2.13	1.38	1.61	1.45	0.82	1.08	1.79	1.39	1.54	1.33	3.53	1.23	1.61
1960	1.89	3.43	2.80	2.65	1.57	4.74	2.81	1.40	1.54	1.33	1.30	1.35	2.23
1961	2.13	1.39	1.61	1.45	0.81	1.20	2.42	1.39	1.54	1.39	2.26	1.74	1.61
1962	1.39	1.70	1.60	1.45	3.76	2.05	4.89	1.48	1.54	1.33	1.34	1.82	2.03
1963	1.75	1.67	1.62	1.44	1.04	1.04	1.75	1.39	1.54	1.33	3.96	3.16	1.81
1964	1.49	1.43	1.60	1.44	0.79	0.97	3.23	1.63	1.54	2.07	5.12	3.00	2.03
1965	1.32	1.39	1.60	3.69	1.93	2.11	4.92	2.53	1.54	2.77	2.07	2.81	2.39
1966	1.32	1.71	3.08	4.11	1.26	4.26	2.73	1.39	1.54	1.28	2.53	2.09	2.27
1967	1.72	1.38	3.00	1.44	0.81	0.91	1.70	1.38	1.74	2.95	4.90	4.06	2.17
1968	1.32	1.38	1.61	1.76	3.45	3.72	4.51	2.27	1.54	1.81	3.46	1.20	2.34
1969	1.69	1.38	1.60	3.07	1.56	2.29	3.65	1.48	1.54	2.28	1.96	2.80	2.11
1970	1.80	1.48	1.61	1.45	0.80	1.43	1.96	1.38	1.54	1.22	2.51	4.00	1.77
1971	1.35	1.38	1.61	1.45	0.81	0.91	1.61	1.38	1.54	1.18	4.53	2.43	1.68
1972	4.56	1.86	3.24	1.96	0.82	0.91	1.61	1.38	1.56	1.86	1.82	1.33	1.91
1973	6.53	2.28	2.07	2.32	2.81	4.72	6.32	5.89	1.69	1.16	1.32	1.21	3.19
1974	1.27	1.37	1.60	1.50	0.81	1.63	1.91	1.38	1.54	1.80	1.78	1.44	1.50
1975	2.13	2.26	1.60	1.44	0.81	2.05	3.46	1.87	1.54	2.17	1.37	3.02	1.98
1976	1.29	1.38	1.68	1.46	1.91	2.29	3.57	2.11	1.54	2.56	1.64	2.08	1.96
1977	1.34	1.39	1.61	1.71	0.88	0.92	1.98	1.38	1.54	2.64	3.45	2.05	1.74
1978	1.76	1.43	1.62	1.50	1.35	5.19	3.97	1.57	1.55	1.16	1.31	1.33	1.98
1979	1.86	3.50	5.15	2.51	3.78	4.53	5.81	2.82	1.67	1.15	1.62	1.20	2.97
1980	1.31	1.54	1.64	2.06	5.36	3.61	5.19	3.47	1.55	1.16	1.70	2.15	2.56
1981	1.27	1.37	1.60	1.45	0.82	0.92	1.76	1.40	1.54	2.81	1.76	2.29	1.58
1982	3.18	1.38	1.71	1.70	2.60	4.36	3.45	1.69	1.54	1.18	3.72	3.02	2.46
1983	1.32	1.65	3.19	2.10	2.29	4.63	5.03	3.65	1.54	2.00	2.87	2.90	2.76
1984	3.65	1.60	2.55	2.15	0.85	1.29	1.73	1.39	1.54	2.49	4.72	3.81	2.31
1985	2.84	1.40	2.80	3.10	2.64	4.87	4.04	2.71	1.54	1.33	1.81	2.03	2.59
1986	1.53	2.23	2.10	1.47	1.72	2.44	2.33	1.39	1.54	2.37	2.03	2.42	1.96
1987	2.36	2.25	2.27	2.11	2.05	3.05	3.66	2.00	1.58	1.27	3.10	1.23	2.24
1988	1.50	3.84	1.61	1.65	3.15	2.34	3.29	1.72	1.66	1.33	3.37	2.39	2.32
1989	1.28	1.39	1.61	1.46	0.87	1.81	1.86	1.39	1.54	1.38	2.72	1.20	1.54
1990	1.30	1.38	1.61	1.45	0.88	0.92	1.63	1.39	1.54	1.90	2.03	2.73	1.56
Average	1.97	1.69	1.95	1.97	1.66	2.47	3.14	1.88	1.60	1.77	2.78	2.27	2.10
Maximum	6.53	3.84	5.15	5.40	5.36	5.47	6.32	5.89	3.53	3.48	5.60	4.30	3.60
Minimum	1.27	1.37	1.60	1.44	0.79	0.91	1.61	1.38	1.54	1.15	1.30	1.20	1.47
Std. Dev.	1.08	0.56	0.67	0.85	1.07	1.36	1.36	0.91	0.28	0.59	1.19	0.90	0.43

Table 125. The Hopi Tribe
U.S. Geological Survey Data
Glen Canyon Environmental Studies - Little Colorado River Hydrology Study
Little Colorado River at Mouth

Current Meter Measurements for Calibration of Continuous Record Gage

Date	Q, cfs	Stream Width, ft	Gage Height, ft	Area, sq ft	Velocity, fps
01/20/90	199	106.0	10.71	108.0	1.17
05/04/90	217	112.0	48.18	167.0	1.30
07/05/90	216	83.9	48.23	156.0	1.38
07/27/90	248	133.0	48.19	174.4	1.42
07/31/90	188	101.0	48.14	141.0	1.33
10/22/90	212	88.0	48.24	188.4	1.13
11/05/90	219	93.0		195.0	1.12
02/01/90	218	96.0	48.16	196.0	1.11
03/21/91	318	136.0	48.69	211.1	1.51
05/23/91	215	117.0	48.34	156.0	1.38
06/17/91	213	92.0	48.33	170.6	1.25
06/19/91	234	92.0	48.34	185.4	1.26
07/05/91	228	98.0	48.31	165.7	1.37
09/13/91	254	114.0	48.46	156.7	1.62
09/15/91	241	91.0	48.26	149.4	1.62
11/10/91	219	93.0	48.33	166.0	1.32
01/14/92	252	90.0	48.81	145.8	1.73
05/24/92	280	104.0	48.42	157.0	1.70
07/24/92	2,746	100.0		462.0	5.94
07/24/92	3,600	135.0		616.0	5.84
10/11/92	228	85.0	48.22	151.0	1.51

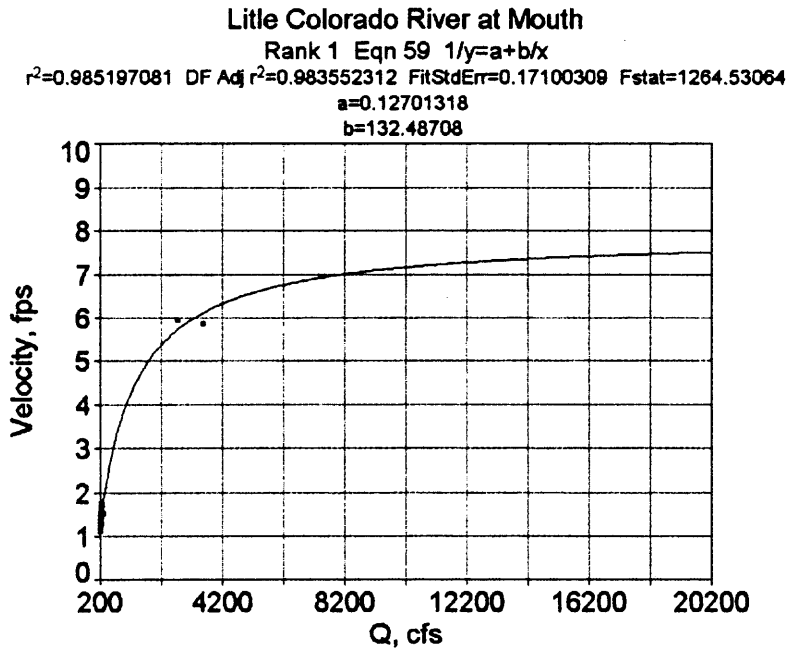


Figure 394. Flow-Velocity Curve, Little Colorado River at Mouth

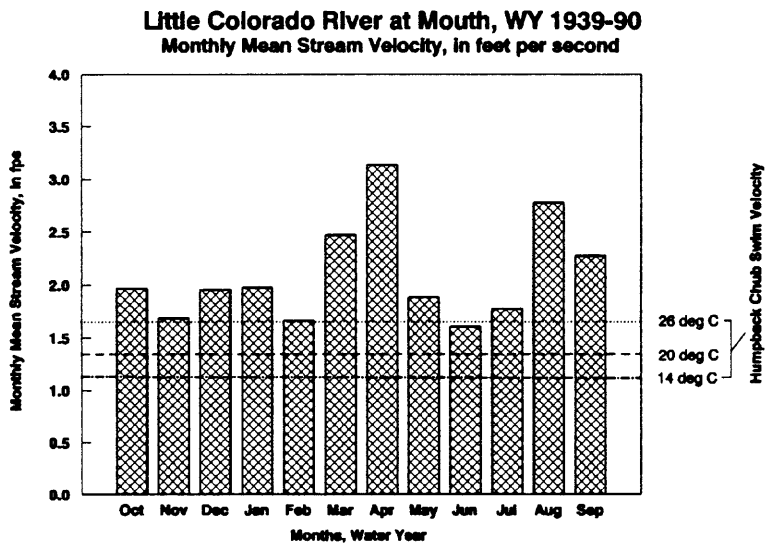


Figure 395. Mean Monthly Flow Velocity, Little Colorado River at Mouth

9.4.2 LCR near Cameron

This gage, following reconstruction of the missing record, has a long period of record. When the mean velocity in stream exceeds the particle settling velocity of a given size and shape of particle, the sediment of that size is suspended. This station and the LCR Grand Falls station contain sediment transport conditions conducive to the movement of sand, silt, and clay to the Colorado River main stem, where some of the material is deposited on the beaches in the Grand Canyon. It will be noted in the sediment transport analysis (see Section 11.2) that sufficient velocity and conditions capable of transporting heavier sand particles are reached only occasionally.

The equation relating velocity to discharge which follows will enable other analyses of the sediment relationships at this site. The equation was derived from current meter measurements used for calibration of the continuous record gage.

The maximum mean monthly velocity of 4.85 fps was obtained from utilizing the mean daily flow rate and the velocity-flow curve. This flow occurred in October, 1973.

Table 126. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River near Cameron
Elevation: 3979.20 feet above mean sea level
Mean Daily Stream Velocity, in feet per second

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Average
1939	0.12	0.00	0.00	0.04	0.22	1.49	1.67	0.02	0.02	0.12	0.40	0.50	0.38
1940	0.12	0.00	0.04	0.11	0.48	0.86	0.57	0.02	0.02	0.91	1.85	2.13	0.59
1941	1.26	0.66	1.34	1.93	2.41	3.36	2.98	2.57	0.42	0.47	1.43	1.58	1.70
1942	2.14	0.35	0.33	0.53	0.55	1.05	1.91	0.53	0.02	0.12	0.17	0.12	0.65
1943	0.21	0.11	0.00	0.02	0.57	1.93	0.85	0.02	0.02	0.12	1.09	0.92	0.49
1944	0.21	0.00	0.00	0.00	0.04	1.17	2.35	1.23	0.02	0.12	0.12	0.75	0.50
1945	0.35	0.16	0.17	0.07	0.46	0.98	2.26	1.07	0.02	0.79	1.69	0.21	0.69
1946	0.12	0.00	0.08	0.40	0.30	0.41	0.36	0.02	0.02	0.79	2.10	1.85	0.54
1947	0.20	0.91	0.46	0.35	0.65	0.56	0.16	0.10	0.00	0.00	2.86	1.11	0.61
1948	2.37	0.13	0.16	0.36	0.57	1.05	2.26	0.15	0.15	0.48	1.09	0.11	0.74
1949	0.43	0.28	0.27	1.03	0.91	2.75	2.46	0.52	0.24	0.79	1.66	0.76	1.01
1950	0.55	0.06	0.00	0.04	0.82	0.89	0.40	0.00	0.00	0.61	0.16	0.24	0.31
1951	0.00	0.00	0.02	0.03	0.00	0.00	0.09	0.20	0.00	0.40	1.27	1.03	0.25
1952	0.67	0.02	0.03	3.18	0.75	0.83	3.35	1.11	0.04	0.25	0.82	1.34	1.03
1953	0.02	0.10	0.40	0.23	0.22	0.92	0.52	0.00	0.00	0.91	0.91	0.05	0.36
1954	0.00	0.03	0.00	0.03	0.00	1.00	1.11	0.02	0.06	1.58	0.54	1.29	0.47
1955	0.41	0.01	0.00	0.02	0.04	0.09	0.00	0.00	1.55	0.81	3.39	0.39	0.56
1956	0.00	0.00	0.01	0.02	0.27	0.47	0.19	0.00	0.00	0.26	0.65	0.00	0.16
1957	0.00	0.00	0.00	1.61	1.75	1.26	0.26	0.00	0.06	0.42	1.93	0.69	0.66
1958	0.83	0.83	0.19	0.06	0.49	1.41	1.77	0.23	0.04	0.09	1.18	1.52	0.72
1959	0.75	0.01	0.00	0.02	0.01	0.25	0.30	0.00	0.00	0.02	1.52	0.06	0.24
1960	0.55	1.53	1.05	1.02	0.66	2.60	1.05	0.00	0.00	0.00	0.00	0.08	0.71
1961	0.67	0.01	0.02	0.01	0.00	0.28	0.80	0.00	0.00	0.13	0.69	0.49	0.26
1962	0.10	0.39	0.00	0.01	1.89	0.87	2.60	0.18	0.00	0.00	0.03	0.54	0.55
1963	0.44	0.35	0.03	0.00	0.29	0.20	0.24	0.00	0.00	0.00	1.66	1.40	0.38
1964	0.25	0.13	0.00	0.00	0.00	0.00	1.32	0.34	0.00	0.71	2.82	1.29	0.57
1965	0.10	0.00	0.00	1.68	0.85	0.91	2.63	0.96	0.00	1.11	0.72	1.13	0.84
1966	0.08	0.41	1.22	1.98	0.45	2.21	1.00	0.01	0.00	0.16	1.00	0.77	0.77
1967	0.44	0.00	1.17	0.00	0.00	0.00	0.19	0.00	0.31	1.17	2.58	1.87	0.64
1968	0.09	0.00	0.02	0.40	1.70	1.84	2.25	0.81	0.00	0.55	1.48	0.00	0.76
1969	0.47	0.04	0.00	1.28	0.64	1.01	1.60	0.17	0.00	0.83	0.62	1.19	0.65
1970	0.50	0.18	0.00	0.00	0.00	0.48	0.45	0.00	0.00	0.13	0.86	1.88	0.37
1971	0.12	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	2.08	0.97	0.27
1972	2.37	0.53	1.33	0.57	0.07	0.00	0.00	0.00	0.04	0.66	0.48	0.22	0.52
1973	4.85	0.81	0.54	0.81	1.30	2.57	4.70	3.90	0.25	0.00	0.04	0.00	1.65
1974	0.00	0.00	0.00	0.12	0.01	0.62	0.41	0.00	0.00	0.55	0.52	0.33	0.21
1975	0.75	0.80	0.00	0.00	0.00	0.88	1.48	0.53	0.00	0.71	0.16	1.27	0.55
1976	0.04	0.00	0.15	0.03	0.85	1.01	1.55	0.70	0.00	1.05	0.41	0.62	0.53
1977	0.10	0.01	0.00	0.36	0.11	0.00	0.47	0.00	0.00	0.96	1.54	0.61	0.35
1978	0.52	0.12	0.04	0.11	0.51	3.03	1.83	0.28	0.04	0.00	0.05	0.19	0.56
1979	0.59	1.56	2.86	0.92	1.86	2.42	3.73	1.14	0.23	0.00	0.40	0.00	1.31
1980	0.06	0.25	0.08	0.63	3.25	1.76	2.92	1.55	0.02	0.00	0.45	0.71	0.97
1981	0.00	0.00	0.00	0.01	0.01	0.00	0.25	0.01	0.00	1.11	0.47	0.85	0.23
1982	1.26	0.00	0.20	0.36	1.21	2.29	1.46	0.35	0.00	0.04	1.69	1.28	0.84
1983	0.08	0.36	1.30	0.66	1.05	2.51	2.74	1.67	0.00	0.69	1.12	1.00	1.10
1984	1.69	0.31	0.88	0.69	0.10	0.41	0.21	0.00	0.00	1.00	2.37	1.78	0.79
1985	1.19	0.05	1.05	1.30	1.23	2.71	1.88	1.08	0.00	0.26	0.54	0.72	1.00
1986	0.34	0.76	0.56	0.04	0.74	1.09	0.73	0.00	0.00	0.93	0.63	0.83	0.55
1987	0.86	0.78	0.68	0.65	0.91	1.42	1.61	0.62	0.11	0.17	1.26	0.05	0.76
1988	0.15	1.78	0.00	0.27	1.50	1.03	1.35	0.42	0.15	0.25	1.39	0.95	0.77
1989	0.00	0.01	0.00	0.03	0.10	0.74	0.36	0.00	0.00	0.30	1.06	0.00	0.22
1990	0.03	0.00	0.00	0.00	0.11	0.00	0.03	0.00	0.00	0.60	0.65	1.07	0.21
Mean	0.55	0.28	0.33	0.47	0.64	1.13	1.33	0.44	0.08	0.46	1.08	0.78	0.63
Max	4.85	1.78	2.86	3.18	3.25	3.36	4.70	3.90	1.55	1.58	3.39	2.13	1.70
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Std Dev	0.83	0.42	0.54	0.65	0.69	0.90	1.09	0.72	0.23	0.40	0.80	0.58	0.33

Table 127. The Hopi Tribe
U.S. Geological Survey Data
Glen Canyon Environmental Studies - Little Colorado River Hydrology Study
Little Colorado River near Cameron

Current Meter Measurements for Calibration of Continuous Record Gage

Date	Flow, cfs	Strm Width, ft	Gage Ht, ft	Area, sq ft	Velocity, fps
02/22/90	42	55.0	2.81	154.55	0.27
03/13/90	16	36.0	2.64	95.04	0.17
07/12/90	100	64.0	3.29	210.56	0.47
08/19/90	657	90.0	4.70	423.00	1.55
08/21/90	167	60.0	3.51	210.60	0.79
08/23/90	36	54.5	3.87	210.92	0.17
01/08/91	2,210	100.0	6.68	668.00	3.31
03/07/91	1,180	90.0	5.43	488.70	2.41
05/08/91	213	98.0	2.54	248.92	0.86
09/05/91	20	24.0	2.73	65.52	0.31

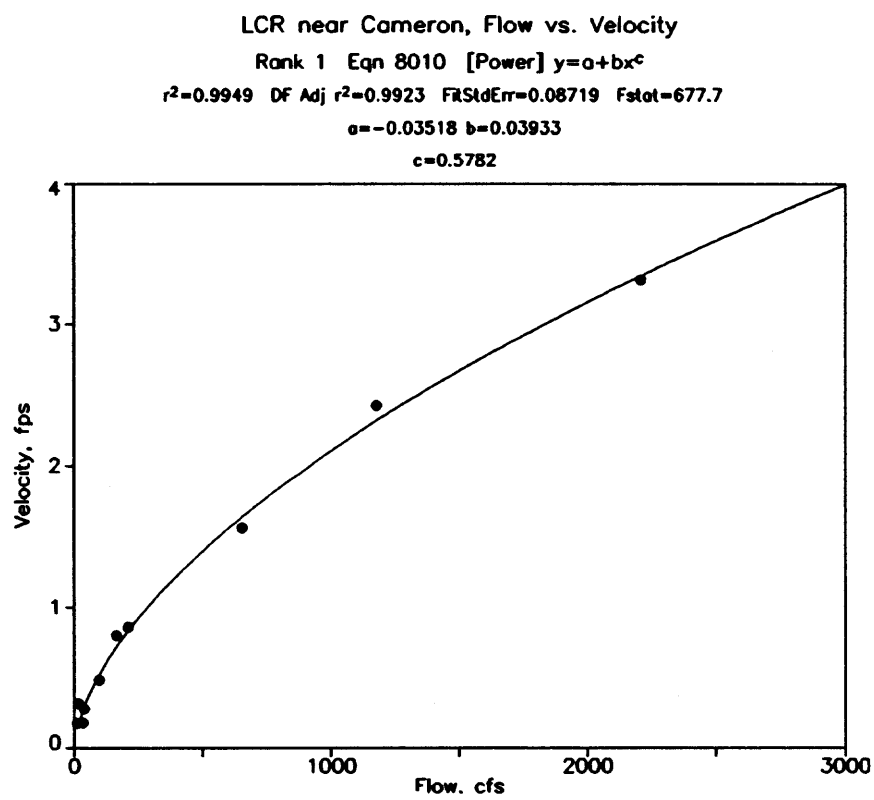


Figure 396. Flow-Velocity Curve, LCR near Cameron

9.4.3 LCR at Grand Falls

The Grand Falls streamflow station has a record which extends from WY 1926-1960 and 1990 to the present. The existing gage has been calibrated by occasional current meter readings. These have been tabulated and a velocity-flow curve fitted from the data.

The maximum mean monthly velocity of 6.05 fps occurred in October, 1973, based upon mean daily flow rates and the velocity-flow curve.

Table 128. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River at Grand Falls
Elevation: 4438.90 feet above mean sea level
Drainage Area: 20,700 sq. mi.

Mean Monthly Stream Velocity, in feet per second

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Ave
1939	0.00	0.00	0.00	0.25	0.61	3.55	3.85	0.00	0.00	0.00	0.82	1.08	0.85
1940	0.00	0.00	0.21	0.38	1.31	2.21	1.47	0.00	0.00	2.09	3.87	4.24	1.31
1941	2.86	1.72	3.28	4.34	4.90	5.56	5.30	4.96	1.05	1.01	3.17	3.45	3.47
1942	4.26	0.89	0.85	1.45	1.51	2.67	4.21	1.35	0.00	0.00	0.25	0.00	1.45
1943	0.34	0.32	0.00	0.23	1.55	4.24	2.18	0.00	0.00	0.00	2.49	2.11	1.12
1944	0.35	0.00	0.00	0.21	0.25	2.93	4.74	3.05	0.00	0.00	0.00	1.71	1.10
1945	0.70	0.44	0.46	0.29	1.26	2.50	4.64	2.71	0.00	1.81	3.62	0.34	1.56
1946	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1947	0.33	2.35	1.19	0.96	1.78	1.44	0.38	0.27	0.00	0.00	4.75	2.17	1.30
1948	4.34	0.35	0.43	0.95	1.67	2.73	4.67	0.42	1.20	1.19	2.45	0.61	1.75
1949	0.68	0.68	0.91	2.50	2.31	4.95	4.82	1.36	0.00	2.20	3.76	1.97	2.18
1950	0.20	0.28	0.39	0.28	2.20	2.30	1.06	0.21	0.21	1.38	0.34	0.50	0.78
1951	0.00	0.00	0.00	0.00	0.20	0.22	0.63	0.70	0.00	0.64	3.38	1.80	0.63
1952	1.54	0.21	0.22	5.51	2.03	2.15	5.54	2.80	0.25	0.53	1.89	2.99	2.14
1953	0.00	0.32	1.34	0.66	0.65	2.36	1.35	0.21	0.21	2.09	2.10	0.00	0.94
1954	0.00	0.00	0.00	0.00	0.00	2.80	2.79	0.00	0.00	3.77	1.26	2.93	1.13
1955	0.80	0.00	0.00	0.00	0.30	0.47	0.30	0.00	2.64	1.24	5.42	0.75	0.99
1956	0.00	0.00	0.22	0.00	1.03	1.54	0.69	0.00	0.00	0.00	1.25	0.00	0.39
1957	0.00	0.00	0.00	3.92	4.02	3.06	0.88	0.00	0.00	1.11	3.95	1.67	1.55
1958	2.15	1.84	0.68	0.21	1.51	3.34	3.96	0.47	0.37	0.42	2.90	3.47	1.78
1959	1.72	0.00	0.00	0.00	0.00	1.08	0.91	0.00	0.00	0.25	3.39	0.23	0.63
1960	2.10	3.55	2.93	2.88	1.80	5.01	2.65	0.25	0.00	0.00	0.00	0.20	1.78
1961	1.55	0.21	0.21	0.24	0.23	0.75	2.06	0.21	0.21	0.27	1.58	1.10	0.72
1962	0.23	1.02	0.24	0.25	4.26	2.25	4.97	0.52	0.21	0.00	0.00	1.22	1.26
1963	0.97	0.91	0.22	0.23	0.81	0.54	0.65	0.21	0.21	0.00	3.55	3.10	0.95
1964	0.52	0.37	0.25	0.22	0.23	0.21	3.22	0.90	0.22	1.63	4.93	2.90	1.30
1965	0.23	0.24	0.25	3.96	2.30	2.33	5.00	2.47	0.21	2.53	1.65	2.58	1.98
1966	0.21	1.05	3.02	4.39	1.25	4.56	2.54	0.22	0.21	0.34	2.29	1.78	1.82
1967	0.97	0.21	2.93	0.24	0.24	0.21	0.53	0.21	0.83	2.65	4.71	3.86	1.46
1968	0.21	0.24	0.21	1.10	3.99	4.08	4.61	2.09	0.21	1.25	3.24	0.00	1.77
1969	1.06	0.23	0.25	3.25	1.75	2.57	3.73	0.49	0.21	1.92	1.41	2.70	1.63
1970	1.13	0.49	0.21	0.24	0.23	1.25	1.18	0.21	0.21	0.28	1.98	3.88	0.94
1971	0.27	0.23	0.20	0.23	0.23	0.21	0.21	0.21	0.21	0.00	4.15	2.23	0.70
1972	4.49	1.39	3.23	1.55	0.33	0.21	0.21	0.21	0.26	1.51	1.07	0.46	1.24
1973	6.05	2.11	1.40	2.18	3.29	4.94	6.16	5.84	0.68	0.00	0.00	0.00	2.72
1974	0.00	0.24	0.25	0.41	0.25	1.63	1.08	0.21	0.21	1.26	1.18	0.71	0.62
1975	1.74	2.08	0.25	0.22	0.25	2.26	3.51	1.38	0.21	1.62	0.34	2.86	1.39
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.23	0.21	0.25	0.99	0.41	0.21	1.24	0.21	0.21	2.21	3.34	1.39	0.91
1978	1.18	0.35	0.22	0.40	1.40	5.32	4.07	0.75	0.26	0.00	0.00	0.40	1.20
1979	1.34	3.66	5.19	2.47	4.23	4.80	5.75	2.86	0.63	0.00	0.89	0.00	2.65
1980	0.39	0.66	0.28	1.73	5.56	3.97	5.24	3.64	0.23	0.00	0.99	1.64	2.03
1981	0.00	0.24	0.23	0.24	0.25	0.22	0.67	0.22	0.21	2.53	1.06	1.97	0.65
1982	2.84	0.21	0.53	0.99	3.10	4.65	3.49	0.91	0.21	0.00	3.59	2.88	1.95
1983	0.21	0.93	3.19	1.80	2.75	4.88	5.09	3.83	0.21	1.58	2.56	2.30	2.44
1984	3.59	0.79	2.25	1.89	0.39	1.06	0.59	0.21	0.21	2.29	4.49	3.73	1.79
1985	2.69	0.23	2.65	3.28	3.15	5.07	4.14	2.71	0.21	0.55	1.22	1.65	2.30
1986	0.73	1.98	1.45	0.27	2.00	2.75	1.89	0.21	0.21	2.14	1.44	1.91	1.41
1987	1.99	2.01	1.77	1.78	2.43	3.41	3.74	1.61	0.37	0.36	2.83	0.00	1.86
1988	0.32	4.00	0.22	0.76	3.65	2.62	3.33	1.09	0.45	0.54	3.08	2.18	1.85
1989	0.00	0.20	0.21	0.26	0.38	1.91	0.94	0.21	0.21	0.64	2.44	0.00	0.62
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	1.31	1.45	1.74	0.40
Average	1.11	0.76	0.86	1.17	1.54	2.42	2.64	1.01	0.27	0.94	2.16	1.60	1.37
Maximum	6.05	4.00	5.19	5.51	5.56	5.56	6.16	5.84	2.64	3.77	5.42	4.24	3.47
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Std. Dev.	1.39	0.99	1.18	1.39	1.45	1.69	1.89	1.37	0.42	0.95	1.52	1.26	0.69

Table 129. The Hopi Tribe
U.S. Geological Survey Data
Glen Canyon Environmental Studies - Little Colorado River Hydrology Study
Little Colorado River at Grand Falls

Current Meter Measurements for Calibration of Continuous Record Gage

Date	Flow, cfs	Strm Width,ft	Gage Ht, ft	Area, sq ft	Velocity, fps
05/01/91	241	70.0	6.62	136.00	1.77
05/09/91	69	54.0	5.86	71.80	0.96
02/24/92	127	55.0	6.25	84.60	1.50
03/19/92	1,210	80.0	8.36	237.00	5.11
04/02/92	1,330	93.0	8.62	269.00	4.94
05/06/92	19	44.0	5.41	35.00	0.54
08/10/92	149	54.0	6.31	84.40	1.77
08/28/92	2,787	127.0	10.93	510.00	5.46

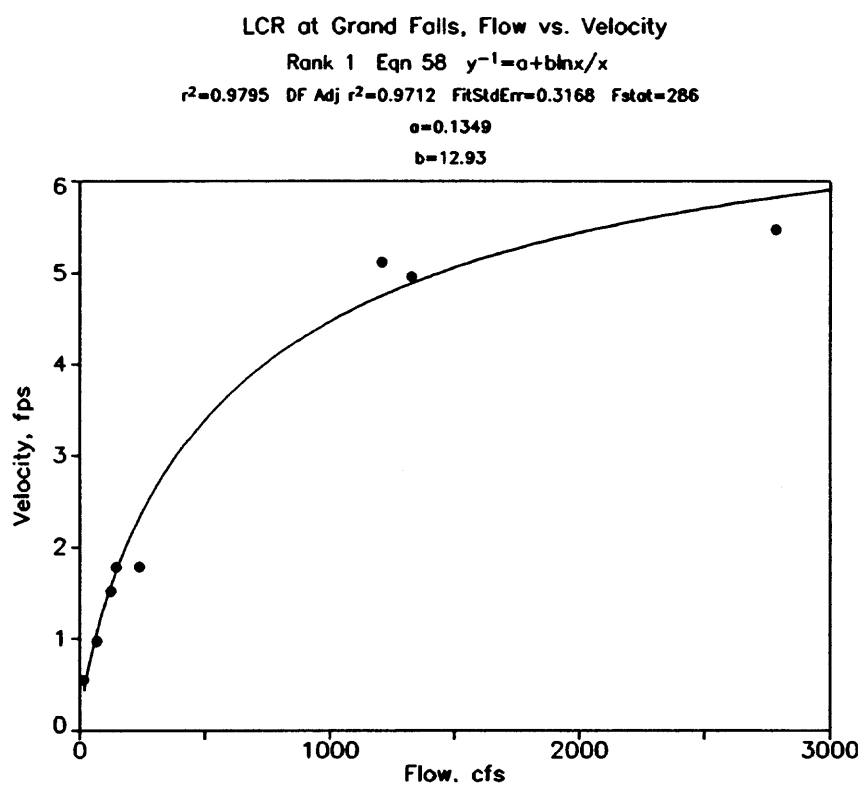


Figure 397. Flow-Velocity Curve, Little Colorado River at Grand Falls

9.4.4 Moenkopi Wash at Moenkopi

This gage has operated since 1976 as a replacement gage for the original Moenkopi Wash near Tuba City station. Velocities for 1939-76 were reconstructed utilizing modified LCR model output (Marley and Blandford, 1995).

The maximum mean monthly velocity of 6.26 fps occured in October, 1973 and is based upon the mean daily flow rates and the velocity-flow curve.

Table 130. U. S. Geological Survey
Hopi Tribal Database
Station: Moenkopi Wash near Tuba City and at Moenkopi
Elevation: 4309.00 feet above mean sea level
Drainage Area: 2,492 sq. mi.
Mean Monthly Velocity, in feet per second

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1939													
1940	0.45	0.45	0.45	0.50	0.52	0.52	0.47	0.47	0.45	0.95	1.70	1.14	0.67
1941	1.51	0.57	0.66	0.64	0.73	0.60	0.71	0.47	0.45	0.54	1.47	1.89	0.85
1942	3.01	0.59	0.54	0.59	0.56	0.50	0.48	0.45	0.45	0.49	0.63	0.46	0.73
1943	0.53	0.52	0.80	0.62	0.58	0.55	0.45	0.45	0.45	0.62	1.60	0.70	0.66
1944	0.63	0.52	0.53	0.56	0.57	0.59	0.49	0.48	0.45	0.45	0.52	0.54	0.53
1945	0.52	0.54	0.56	0.58	0.54	0.52	0.47	0.45	0.45	1.41	2.22	0.51	0.73
1946	0.70	0.53	0.64	0.56	0.52	0.52	0.47	0.45	0.45	0.86	1.82	0.59	0.68
1947	0.51	0.61	0.57	0.54	0.53	0.49	0.45	0.46	0.45	0.45	1.83	0.65	0.63
1948	2.19	0.54	0.63	0.56	0.57	0.51	0.45	0.45	0.68	0.93	0.74	0.50	0.73
1949	0.76	0.55	0.58	0.67	0.83	0.74	0.45	0.45	0.62	0.56	0.90	0.65	0.65
1950	1.26	0.52	0.53	0.54	0.55	0.47	0.45	0.45	0.45	0.81	0.60	0.74	0.62
1951	0.50	0.52	0.52	0.54	0.48	0.47	0.52	0.48	0.45	0.58	0.71	1.30	0.59
1952	0.93	0.56	0.63	0.76	0.54	0.53	0.62	0.47	0.47	0.53	0.91	2.53	0.79
1953	0.50	0.54	0.61	0.55	0.53	0.52	0.45	0.45	0.45	2.38	1.37	0.48	0.74
1954	0.54	0.51	0.58	0.54	0.52	0.62	0.47	0.48	0.45	0.95	0.45	1.00	0.59
1955	0.58	0.47	0.50	0.52	0.52	0.48	0.47	0.47	0.45	0.95	1.67	0.45	0.63
1956	0.46	0.51	0.50	0.53	0.52	0.48	0.47	0.47	0.45	0.95	1.24	0.47	0.59
1957	0.50	0.45	0.50	0.58	0.52	0.58	0.47	0.50	0.45	0.95	1.59	0.45	0.63
1958	0.88	0.78	0.50	0.50	0.52	0.66	0.47	0.47	0.45	0.95	1.46	0.98	0.72
1959	0.63	0.49	0.50	0.50	0.52	0.45	0.47	0.47	0.45	0.95	1.35	0.48	0.61
1960	0.80	0.55	0.50	0.52	0.52	0.52	0.47	0.54	0.45	0.95	0.52	0.83	0.60
1961	1.01	0.54	0.50	0.52	0.52	0.73	0.47	0.47	0.45	0.95	1.30	0.78	0.69
1962	0.72	0.56	0.50	0.52	0.52	0.52	0.47	0.47	0.45	0.95	0.59	0.83	0.59
1963	0.83	0.63	0.50	0.51	0.52	0.52	0.47	0.46	0.45	0.95	2.40	0.62	0.74
1964	0.68	0.48	0.50	0.51	0.52	0.67	0.47	0.47	0.45	0.95	1.52	0.73	0.66
1965	0.46	0.54	0.50	0.54	0.52	0.51	0.53	0.51	0.45	1.13	0.55	1.05	0.61
1966	0.51	0.55	0.58	0.48	0.53	0.60	0.46	0.45	0.45	0.61	0.57	0.55	0.53
1967	0.75	0.51	0.51	0.49	0.49	0.47	0.45	0.46	0.47	1.46	1.64	1.68	0.78
1968	0.50	0.51	0.49	0.56	0.52	0.51	0.47	0.45	0.45	0.86	1.29	0.45	0.59
1969	0.45	0.47	0.50	0.51	0.52	0.52	0.46	0.48	0.47	1.00	0.70	0.59	0.56
1970	0.75	0.53	0.51	0.51	0.48	0.66	0.50	0.46	0.45	0.47	1.29	1.26	0.66
1971	0.55	0.51	0.52	0.51	0.51	0.50	0.47	0.46	0.45	0.51	2.83	0.60	0.70
1972	0.59	0.52	0.56	0.52	0.51	0.47	0.45	0.45	0.48	0.48	0.86	0.46	0.53
1973	6.26	0.53	0.54	0.53	0.74	0.67	0.52	0.49	0.46	0.46	0.51	0.51	1.02
1974	0.46	0.49	0.48	0.52	0.48	0.57	0.47	0.45	0.45	0.84	0.51	0.45	0.51
1975	0.57	0.51	0.48	0.50	0.50	0.51	0.47	0.48	0.45	1.25	0.48	0.96	0.60
1976	0.48	0.51	0.52	0.51	0.53	0.49	0.48	0.46	0.45	0.69	0.56	1.25	0.58
1977	0.54	0.52	0.53	0.54	0.54	0.50	0.45	0.46	0.45	1.47	0.82	1.22	0.67
1978	0.49	0.51	0.52	0.54	0.55	0.57	0.50	0.48	0.46	0.47	0.45	0.54	0.51
1979	0.51	0.67	0.70	0.58	0.88	0.53	0.48	0.50	0.46	0.45	0.50	0.45	0.56
1980	0.54	0.54	0.54	0.54	0.55	0.51	0.51	0.50	0.46	0.46	0.60	1.08	0.57
1981	0.46	0.49	0.47	0.52	0.51	0.51	0.51	0.49	0.46	1.28	0.68	0.80	0.60
1982	1.50	0.49	0.53	0.51	0.56	0.55	0.51	0.65	0.46	0.51	1.02	0.88	0.68
1983	0.53	0.54	0.51	0.53	0.53	0.52	0.49	0.49	0.45	0.81	1.12	2.01	0.71
1984	0.66	0.56	0.58	0.55	0.56	0.54	0.52	0.47	0.45	0.78	1.96	1.01	0.72
1985	0.58	0.52	0.52	0.53	0.56	0.65	0.52	0.49	0.46	0.47	0.53	0.64	0.54
1986	0.49	0.66	0.56	0.54	0.53	0.52	0.52	0.49	0.46	0.76	0.87	1.35	0.65
1987	0.81	0.67	0.57	0.61	0.59	0.57	0.49	0.53	0.46	0.54	1.21	0.52	0.63
1988	0.93	0.79	0.50	0.63	0.79	0.53	0.62	0.48	0.66	0.51	1.47	0.61	0.71
1989	0.49	0.53	0.51	0.54	0.56	0.53	0.50	0.47	0.45	0.53	0.92	0.47	0.54
1990	0.51	0.50	0.51	0.54	0.55	0.52	0.52	0.49	0.50	0.92	0.74	1.16	0.62
Mean	0.84	0.54	0.54	0.55	0.56	0.54	0.49	0.48	0.47	0.82	1.09	0.84	0.65
Minimum	0.45	0.45	0.45	0.48	0.48	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.51
Maximum	6.26	0.79	0.80	0.76	0.88	0.74	0.71	0.65	0.68	2.38	2.83	2.53	1.02
Std Dev	0.89	0.07	0.06	0.05	0.08	0.07	0.05	0.03	0.05	0.36	0.56	0.44	0.09

Table 131. The Hopi Tribe
U.S. Geological Survey Data
Glen Canyon Environmental Studies - Little Colorado River Hydrology Study
Moenkopi Wash at Moenkopi

Current Meter Measurements for Calibration of Continuous Record Gage

Date	Flow, cfs	Strm Width, ft	Gage Ht, ft	Area, sq ft	Velocity, fps
10/11/77	1.09	7.6	4.04	3.26	0.33
11/21/77	2.32	9.0	4.08	4.60	0.50
01/04/78	2.75	7.8	4.10	3.79	0.73
03/02/78	20.80	39.0	4.20	27.70	0.75
09/25/78	75.60	44.0	4.52	52.20	1.45

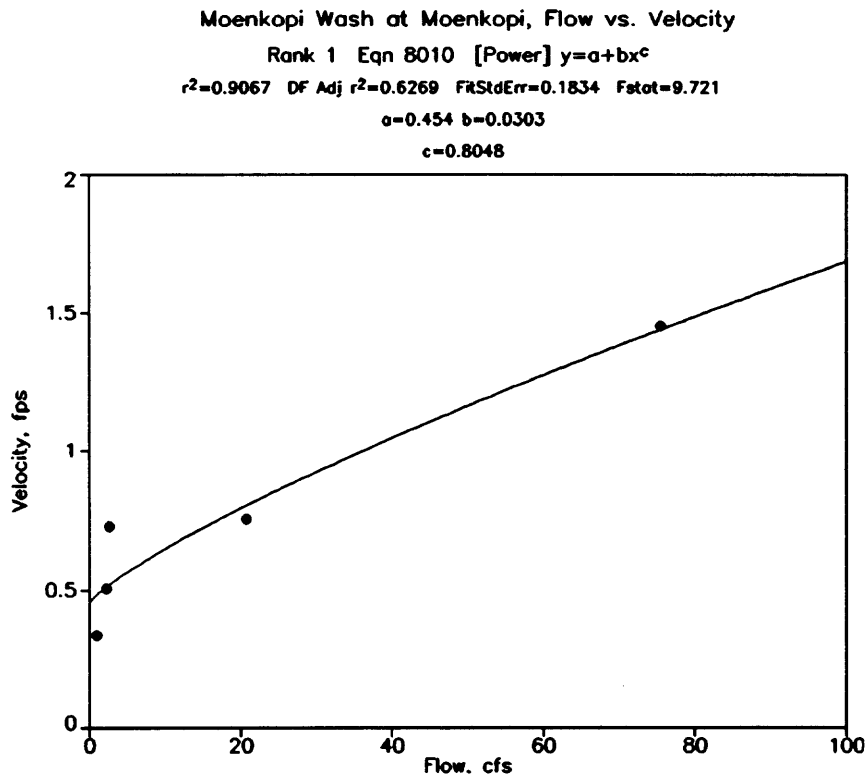


Figure 398. Flow-Velocity Curve, Moenkopi Wash at Moenkopi

9.5 Historical Trends of Annual Flows

TO BE COMPLETED IN FINAL REPORT, 9/30/95

9.6 Frequency Analysis of Annual Flows

TO BE COMPLETED IN FINAL REPORT, 9/30/95

9.7 Frequency Analysis of Peak Discharges

During 1963-65, the USGS, the Arizona Department of Transportation, and the Federal Highway Administration cooperatively operated a series of partial-record stream flow gages throughout Arizona. The purpose of this study was to enable the design of safe bridges and culverts over selected streams. Partial-record gages are normally utilized to examine peak flows from drainages and to define floods of various recurrence periods, principally the 100 year flood.

The usual method of estimating a flood is to utilize the Log-Pearson Type III distribution to determine the 100 year recurrence. In the present report, the normal distribution graphs are used for illustrative purposes. At this time, there is a difficulty in converting Log-Pearson III graphics for insertion into a word processor.

The following thematic map illustrates projected peak flows from drainages throughout the basin.

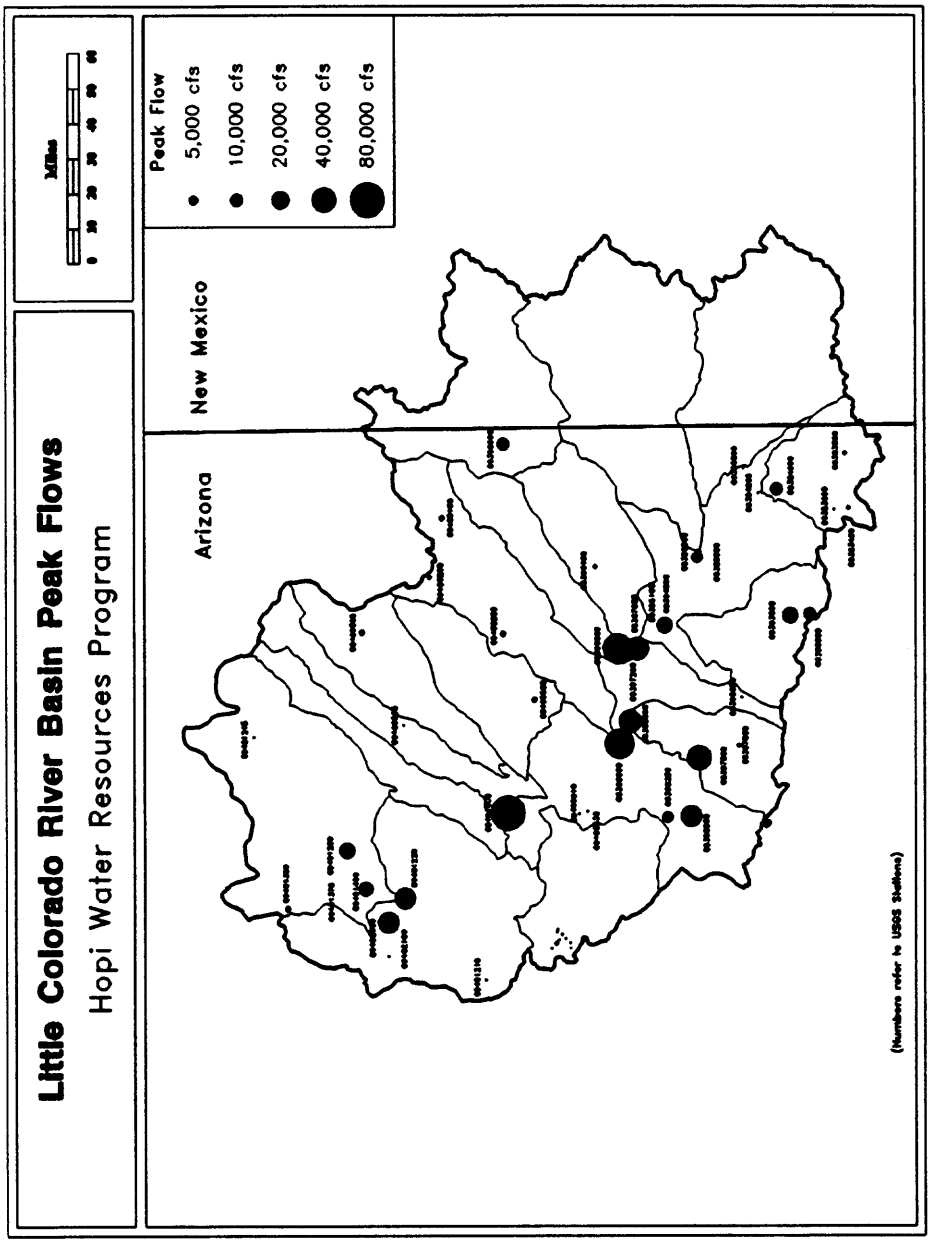


Figure 399. LCR Basin, Map of Peak Discharges

Table 132. The Hopi Tribe
Cumulative Peak Discharge Projections
Selected Little Colorado River Basin Streamflow Stations
Projected Peak Discharges in cfs

Station	Drainage Area, sq mi	100 Year Event	Max Recorded Event
Little Colorado River near Cameron	26,091	28,900	50,000
Little Colorado River at Grand Falls	20,700	80,600	120,000
Little Colorado River at Holbrook	11,115	37,200	60,000
Little Colorado River at Woodruff	7,775	17,900	25,000
Moenkopi Wash near Tuba City	2,492	14,500	12,100
Moenkopi Wash at Moenkopi	1,629	17,300	10,100
Dinnebito Wash near Oraibi		49,500	29,000
Oraibi Wash near Oraibi	2	770	383
Polacca Wash Tributary near Chinle	6	2,150	1,130
Clear Creek near Winslow	621	60,900	50,000
Chevelon Creek near Winslow	781	33,800	33,600
Puerco River near Adamana	2,604	57,900	30,000
Silver Creek near Snowflake	846	17,900	25,000
Nutrioso Creek above Nelson Reservoir	83	1,100	439

9.7.1 Little Colorado River near Cameron

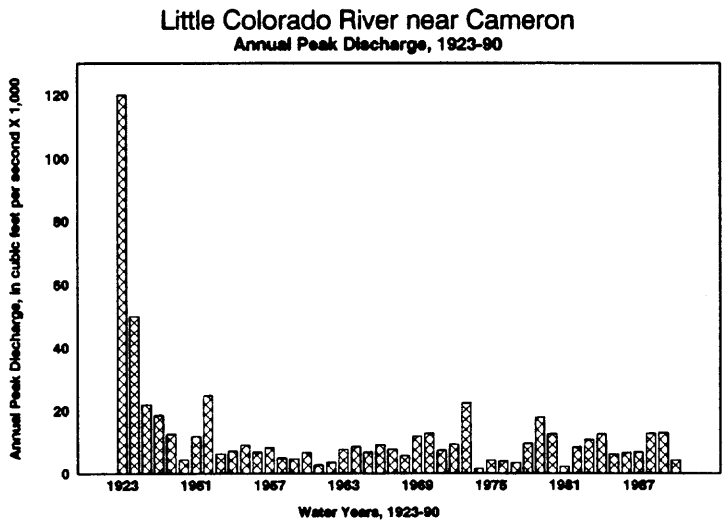


Figure 400. LCR near Cameron, Annual Peak Discharge, WY 1921-90

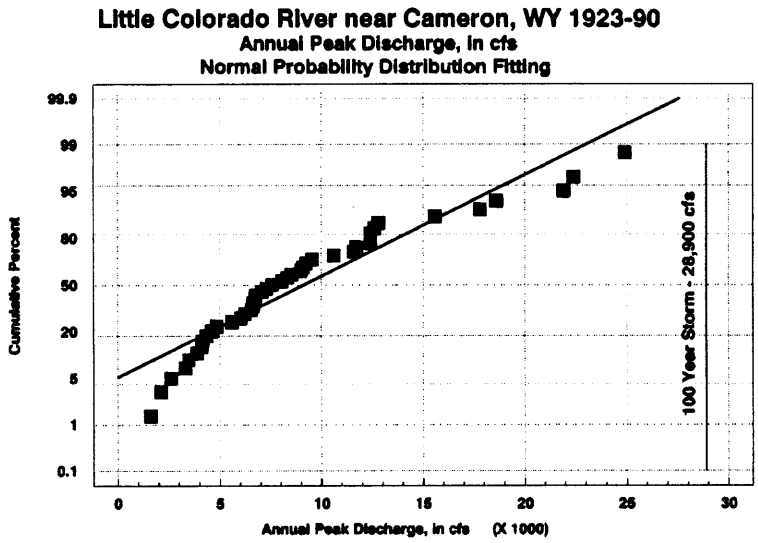


Figure 401. LCR near Cameron, Cumulative Probability Fitting, Peak Discharge

9.7.2 Little Colorado River at Grand Falls

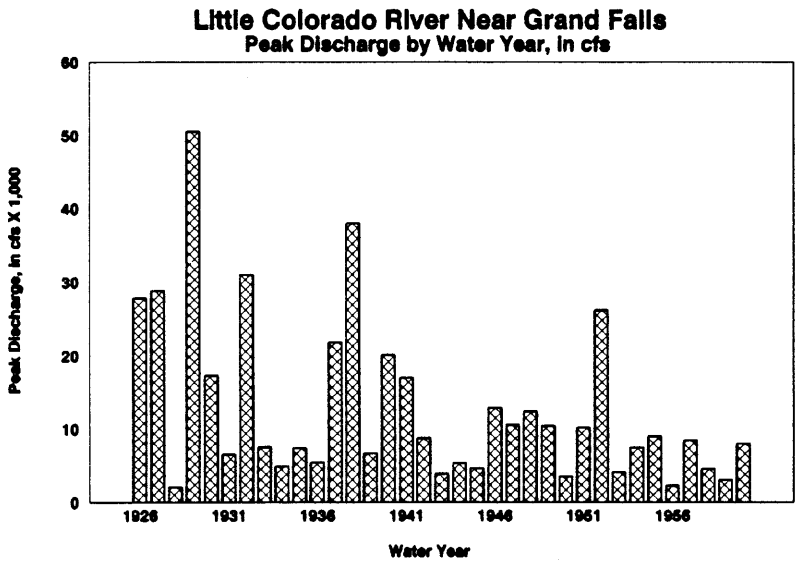


Figure 402. LCR at Grand Falls, Annual Peak Discharge, WY 1926-70

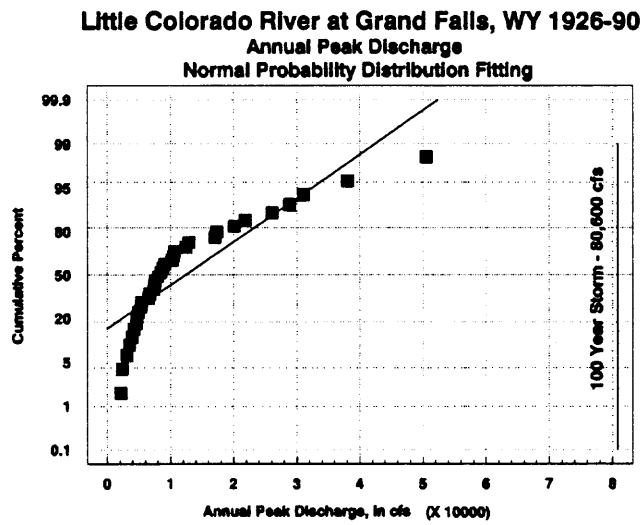


Figure 403. LCR at Grand Falls, Cumulative Probability Fitting, Peak Discharge

9.7.3 Little Colorado River at Holbrook

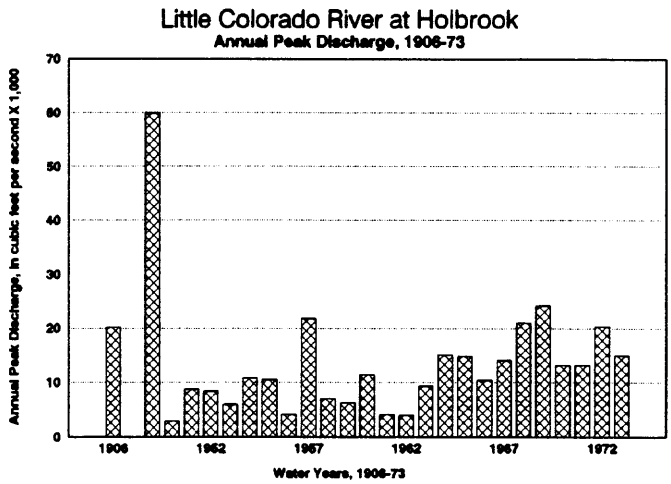


Figure 404. LCR at Holbrook, Annual Peak Discharge, WY 1906-73

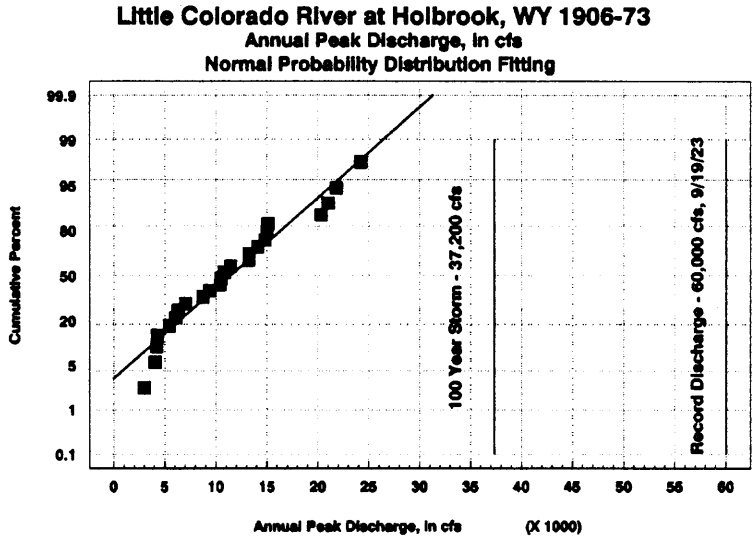


Figure 405. LCR at Holbrook, Cumulative Probability Fitting, Peak Discharge

9.7.4 Little Colorado River at Woodruff

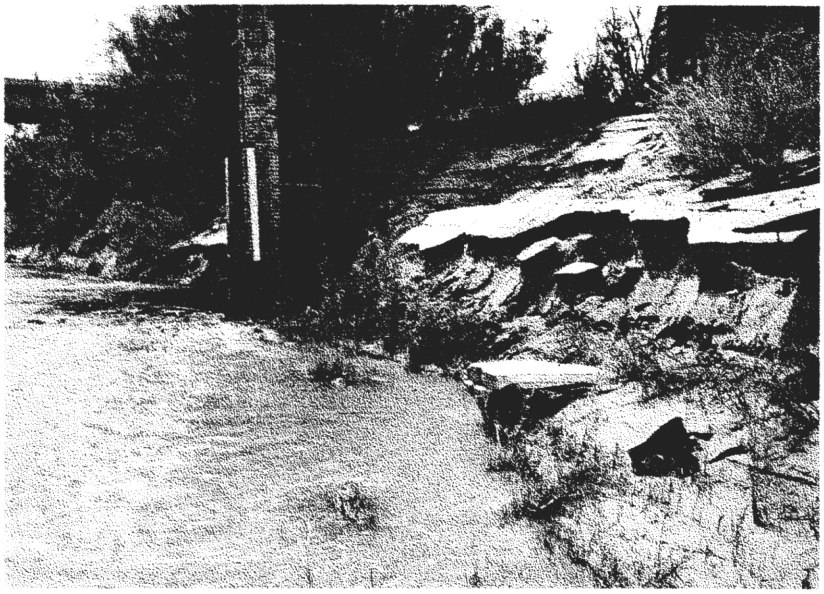


Figure 406. Steam Gage, LCR at Woodruff

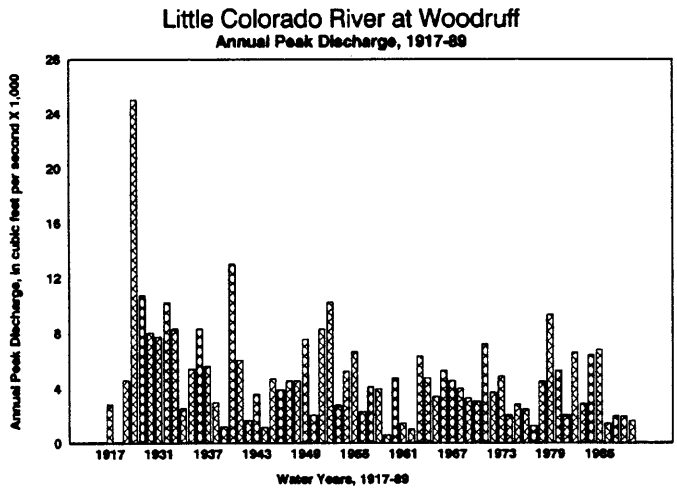


Figure 407. LCR at Woodruff, Annual Peak Discharge, WY 1917-89

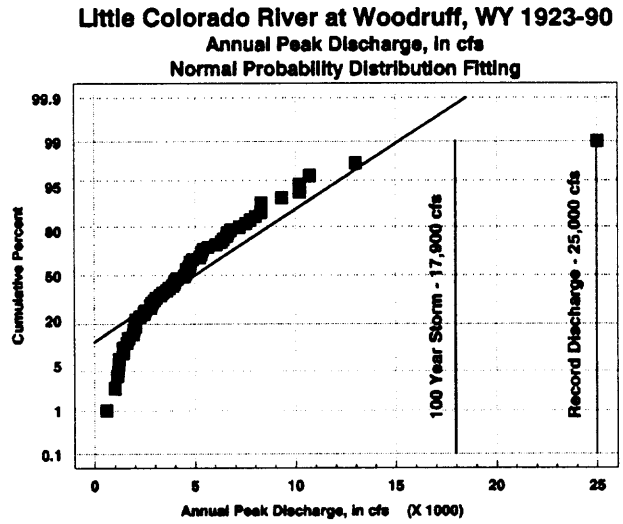


Figure 408. LCR at Woodruff, Cumulative Peak Discharge Probability Fitting

9.7.5 Moenkopi Wash near Tuba City

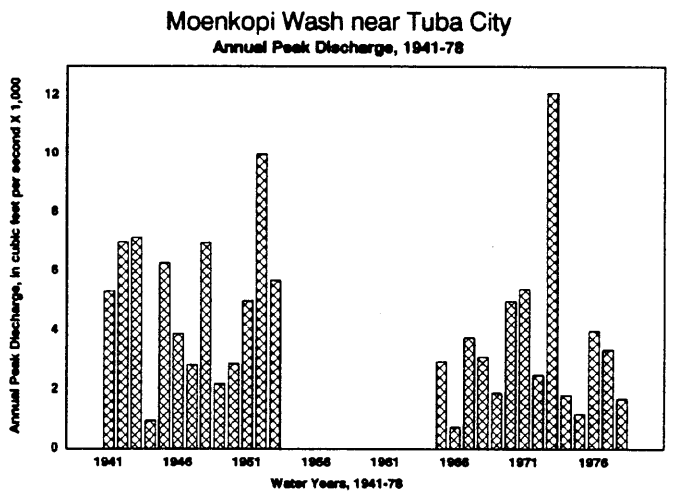


Figure 409. Moenkopi Wash near Tuba City, Annual Peak Discharge, WY 1976-90

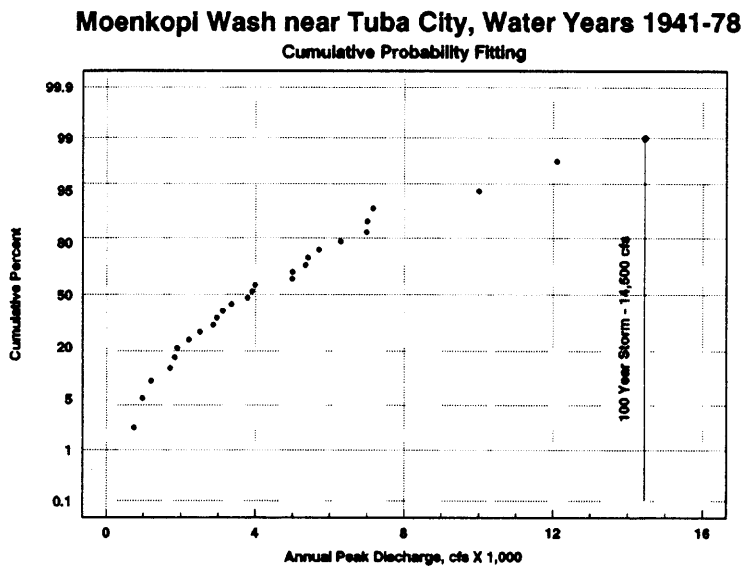


Figure 410. Moenkopi Wash near Tuba City, Cumulative Peak Discharge Probability Fitting

9.7.6 Moenkopi Wash at Moenkopi

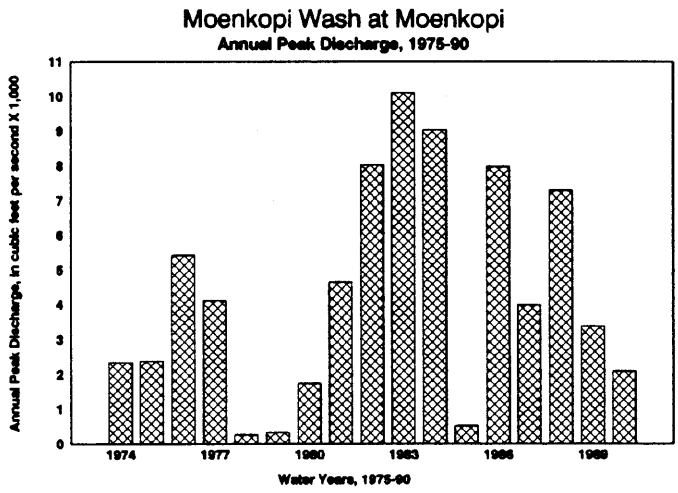


Figure 411. Moenkopi Wash at Moenkopi, Annual Peak Discharge, WY 1975-90

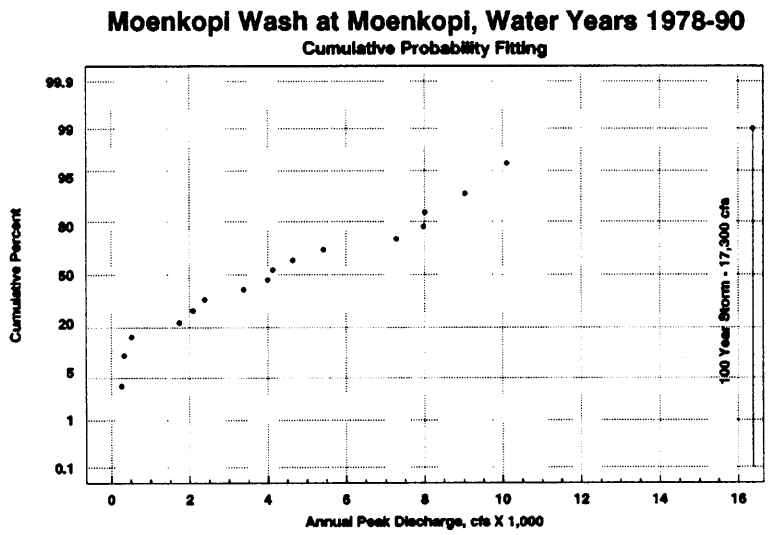


Figure 412. Moenkopi Wash at Moenkopi, Cumulative Peak Discharge Probability Fitting

9.7.7 Dinnebito Wash near Oraibi

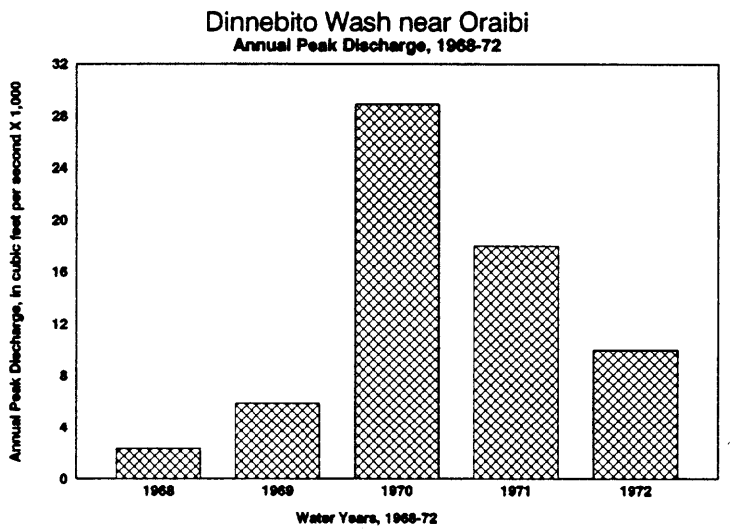


Figure 413. Dinnebito Wash near Oraibi, Annual Peak Discharge, 1968-72

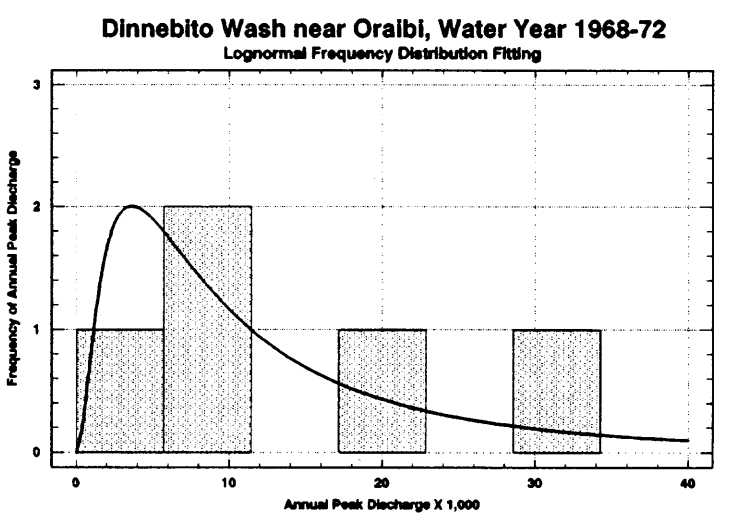


Figure 414. Dinnebito Wash near Oraibi, Peak Discharge Frequency Histogram

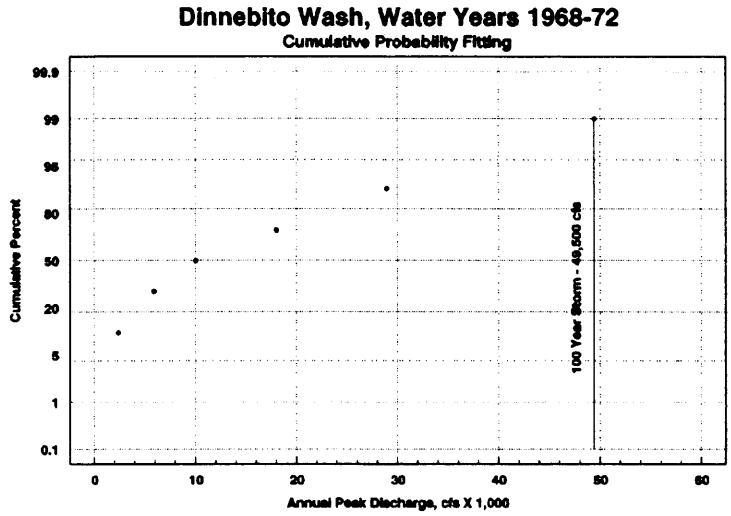


Figure 415. Dinnebito Wash near Oraibi, Cumulative Peak Discharge Probability Fitting

9.7.8 Oraibi Wash near Oraibi

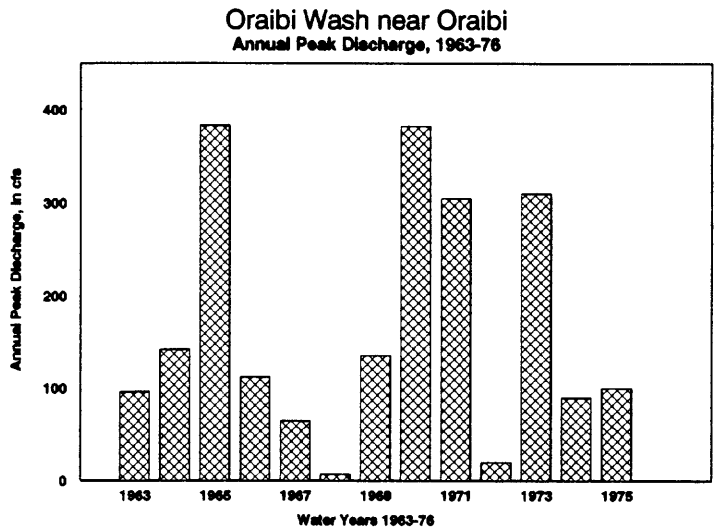


Figure 416. Oraibi Wash near Oraibi, Annual Peak Discharge, WY 1963-76

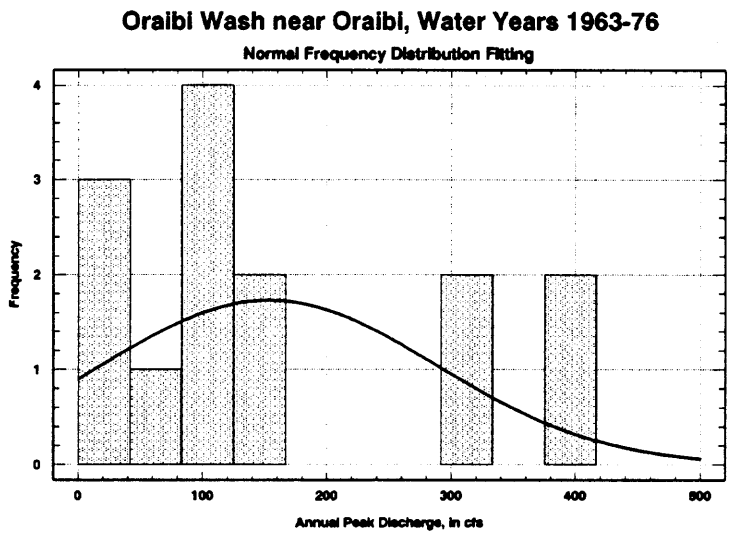


Figure 417. Oraibi Wash near Oraibi, Peak Discharge Frequency Histogram

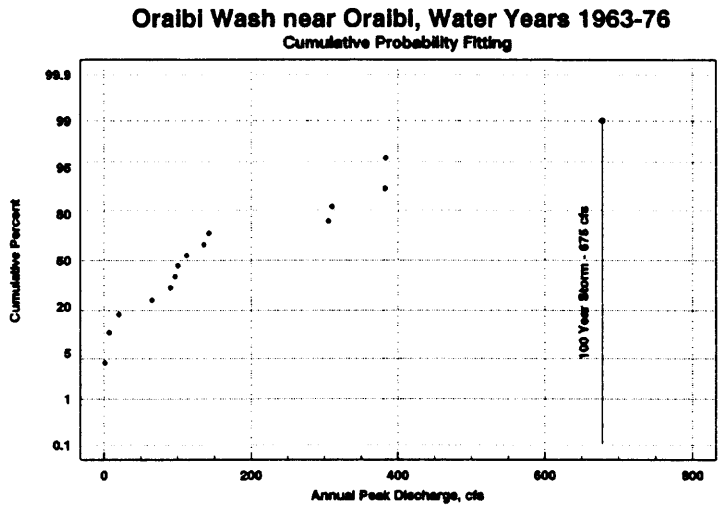


Figure 418. Oraibi Wash near Oraibi, Cumulative Peak Discharge Probability Fitting

9.7.9 Polacca Wash

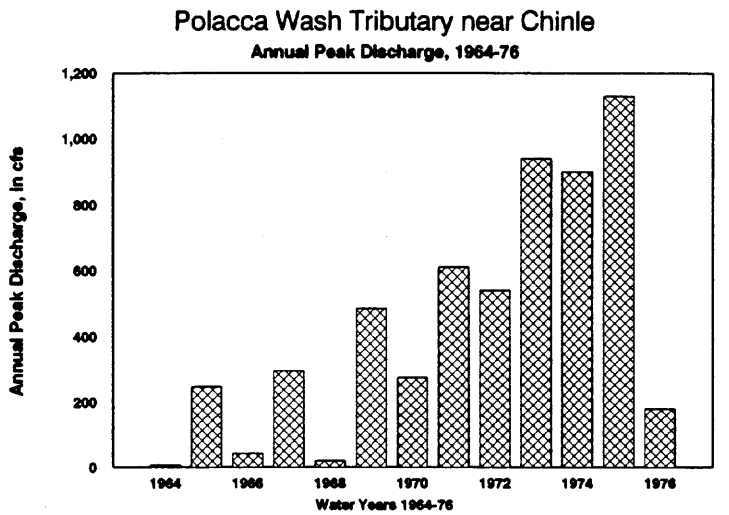


Figure 419. Polacca Wash Trib near Chinle, Annual Peak Discharge, WY 1964-76

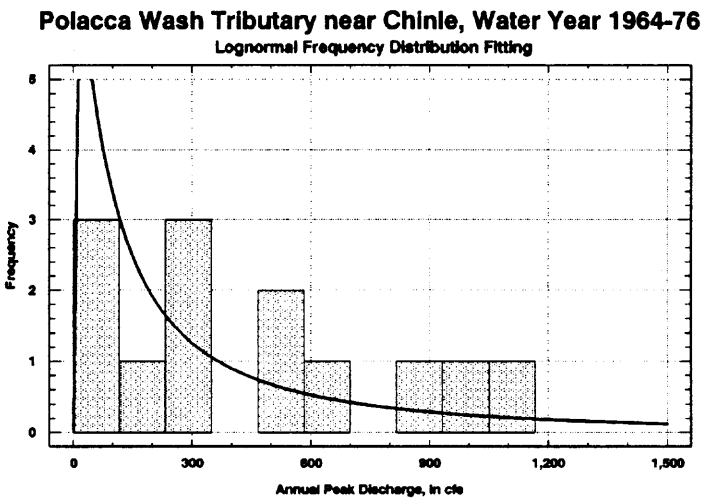


Figure 420. Polacca Wash Trib near Chinle, Peak Discharge Frequency Histogram

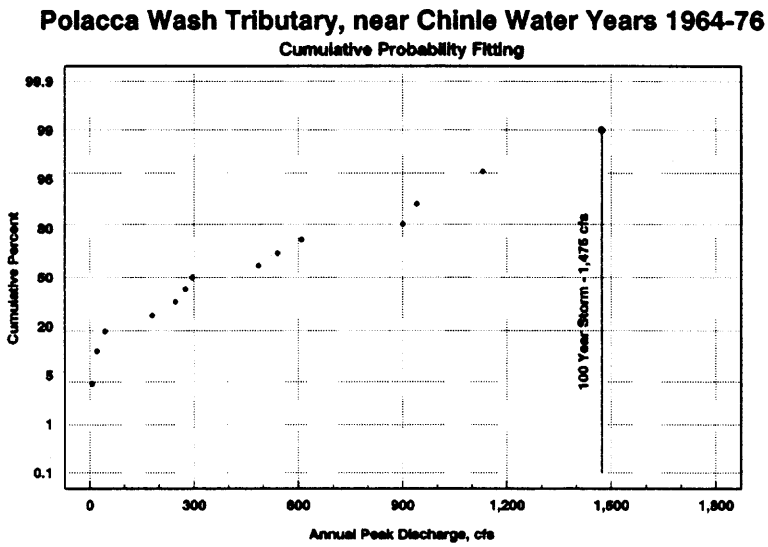


Figure 421. Polacca Wash Trib near Chinle, Cumulative Peak Discharge Probability Fitting

9.8 Base Flows and Spring Discharges

Base flows are those flows in a stream bed due to groundwater discharges from springs and seeps, and from rising water table underflow from beneath the stream bed. In the present case, there is concern over the long-term fate of Blue Springs, near the confluence of the Little Colorado River with the main stem Colorado River. It is this spring flow which results in the perennial reach of the Little Colorado in which the endangered humpback chub dwells.

9.8.1 Blue Spring Calculated Discharges, WY 1990-93

Blue Spring is located about eleven miles upstream of the Colorado River confluence along the Little Colorado River. The spring provides the Little Colorado with its only perennial reach. The discharge has been measured over the years at about 230 cfs. Generally, the spring discharge is measured by the USGS in the summer months, when the main stem Little Colordo River is dry (has zero flow). The discharge is measured at this time because, when the river is flowing, it is impossible to distinguish between LCR and Blue Spring discharges.

In 1990, the USGS installed a gage (Station Number 09402300) on the Little Colorado River near the confluence (mouth) with the main stem Colorado River. This gaging station became operational in May, 1990, and was washed out by the intense Arizona flood flows of January, 1993 (unpublished USGS records, as of 6/94). During its brief period of record, the gage provided an opportunity to indirectly measure Blue Spring flows for any variation in discharge.

The gage at Little Colorado River near Cameron is located upstream of the confluence of the Little Colorado and Moenkopi Wash. The LCR near Cameron gage has operated since June, 1947; the Moenkopi Wash gage has operated (at three different locations) since October, 1940. The missing records for LCR Cameron were reconstructed for the 1939-47 period by DBS&A (Marley, 1994). The missing records for Moenkopi Wash have also been reconstructed by DBS&A (Marley and Blandford, 1995). The point on the Little Colordo River sampled for sediment and water chemistry is located downstream of the confluence with Moenkopi Wash (Little Colorado River at Cameron). The discharge at the latter sampling point, representing almost all LCR main stem flows, is found by adding LCR Cameron flows to Moenkopi Wash flows.

The discharge at Blue Spring may be calculated by subtracting the sum of the LCR near Cameron and Moenkopi Wash flows from the LCR above Mouth record.

Blue Springs = LCR above Mouth - (LCR nr Cameron + Moenkopi Wash)

The following table enumerates the monthly discharges of LCR above Mouth for the 1990-93 period. This represents the total discharge from the Little Colorado River into the main stem Colorado River.

Table 133. The Hopi Tribe
Glen Canyon Environmental Studies Group - Little Colorado River Basin Hydrology Study
Little Colorado River above Mouth
Elevation: 2760 ft amsl
Latitude: 36d 11m 43s N
Longitude: 111d 46m 35s W

Discharges in Ac-FT

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann Total
1990								12,580	12,300	18,130	22,320	33,350	
1991	15,970	14,790	17,070	30,950	13,240	42,380	78,020	15,810	11,810	13,340	13,940	16,020	283,340
1992	11,090	11,680	29,060	15,880	21,260	56,596	63,290	31,120	25,040				
1993		18,590	26,680										
Average	13,530	15,020	24,270	23,415	17,250	49,488	70,655	19,837	16,383	15,735	18,130	24,685	

The succeeding table tabulates the flows measured at Little Colorado River near Cameron for the period of operation of the LCR at Mouth gage for the 1990-93 period of record of LCR above Mouth.

Table 134. The Hopi Tribe
Glen Canyon Environmental Studies Group - Little Colorado River Basin Hydrology Study
Little Colorado River near Cameron, AZ
Elevation: 3979.2 ft amsl
Latitude: 35d 55m 35s N
Longitude: 111d 34m 00s W

Discharges in Ac-FT

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann Total
1990	155	0	0	21	515	14	135	2	0	7,640	8,720	18,930	36,132
1991	1,720	1,540	2,960	14,320	3,490	29,920	61,050	3,360	11	3	1,180	5,010	124,564
1992	0	425	9,950	3,520	17,570	51,970	48,270	14,050	3,810	14,150	37,360	15,230	216,305
1993	3,080	3,610	10,490	288,500	151,200	84,930	38,210	1,800	0	0	5,650	7,050	594,520
Average	1,239	1,394	5,850	76,590	43,194	41,709	36,916	4,803	955	5,448	13,228	11,555	242,880

This table shows flows from Moenkopi Wash at Moenkopi for the 1990-93 period of the LCR above Mouth gage.

Table 135. The Hopi Tribe
Glen Canyon Environmental Studies Group - Little Colorado River Basin Hydrology
Moenkopi Wash at Moenkopi
Elevation: 4610 ft amsl
Latitude: 36d 06m 18s N
Longitude: 111d 12m 04s W

Discharges in Ac-FT

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann Total
1990	145	100	133	211	254	150	165	64	88	1,830	989	2,950	7,079
1991	577	146	195	263	210	230	68	51	12	0	309	191	2,252
1992	15	145	260	204	229	195	133	954	71	382	188	1,210	3,986
1993	116	74	62	1,730	2,640	646	142	74	1	0	580	90	6,155
Average	213	116	163	602	833	305	127	286	43	553	517	1,110	4,868

The final table enumerates discharges at Blue Springs for 1990-93 calculated from the difference of LCR above Mouth and the sum of LCR near Cameron and Moenkopi Wash at Moenkopi.

Table 136. The Hopi Tribe
Glen Canyon Environmental Studies Group - Little Colorado River Basin Hydrology
Blue Spring, AZ
Elevation:
Latitude:
Longitude:

Discharges in Ac-FT

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann Total
1990								12,514	12,212	8,660	12,611	11,470	
1991	13,673	13,104	13,915	16,367	9,540	12,230	16,902	12,399	11,787	13,337	12,451	10,819	156,524
1992	11,075	11,110	18,850	12,156	3,461	4,431	14,887	16,116	21,159				
1993		14,906	16,128										
Average	12,374	13,040	16,298	14,262	6,501	8,331	15,895	13,676	15,053	10,998	12,531	11,145	156,524
AF/DAY	399	435	526	460	232	269	530	441	502	355	404	371	429
Mn Q, cfs	201	219	265	232	117	135	267	222	253	179	204	187	216

It is apparent from the above tables and the subsequent graph that there is a seasonal component to Blue Spring discharges. Note that the maximum discharge occurs in December and April, with a secondary maximum in June. The minimum discharge is in February and March, when snow melt is beginning in the Mogollon Rim and San Francisco Mountains, and when LCR discharge is at its maximum. One of the months of maximum Blue Spring discharge occurs in June, when LCR flows are at a minimum.

Blue Spring flows are not from a singular discharge, but from a number of fractures and solution channels in the Mauve and Redwall Limestone formations. Cooley (Cooley, 1976) enumerates the flows which combine to give Blue Spring its approximately 230 cfs discharge. (Additional data is to be found in Johnson and Sanderson, 1968). These springs tend to be present near fractures and faults. Among the faults responsible for this flow are the Big Canyon Fault and the Blue Spring fault. Cooley deduces from structural evidence that the water discharged into the LCR from the Mauve and Redwall Limestone at Blue Spring originates in the vast Coconino

Sandstone Aquifer (C multiple-aquifer system) which spreads eastward and south-eastward from the Little Colorado River to the Navajo and Hopi Reservations and the communities of Flagstaff, Winslow, and Holbrook. Undoubtedly, some point of communication between the limestones and the Coconino formation must occur subsurface in order for the water to discharge from such deep formations. Evidently, the variations in discharge indirectly calculated for the Blue Spring flows must originate in the hydraulics of this aquifer.

Several cities and villages draw water from the Coconino Aquifer, including Winslow, Holbrook, Leupp, and Cameron. Although this aquifer's areal extent covers thousands of square miles, it is a confined fractured rock aquifer throughout most of its area, and may be responding to slight variations in recharge, withdrawal, and discharge at great distances from Blue Spring.

The Blue Spring flows are important to the survival of remnant fish species which inhabit the lower Little Colorado. Examination of this seasonal and temporal variation in discharge may reveal an insecure future for these species, especially if the Blue Spring discharges diminish over time from overdrafting of the Coconino Aquifer. The notion that Blue Spring may be a useful source of industrial water is seriously proposed in a 1972 Bureau of Reclamation Report in which several dams below Blue Spring and a pipeline to the plateau above the Little Colorado River Gorge are evaluated.

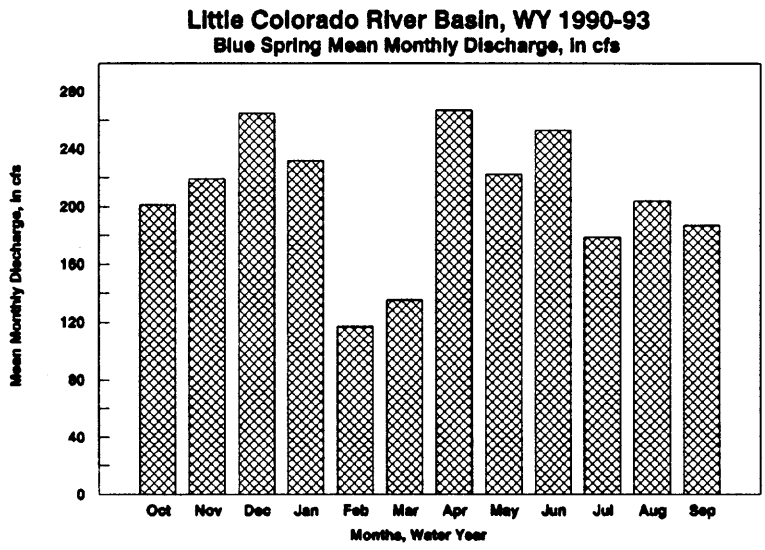


Figure 422. Blue Spring Mean Monthly Discharge, WY 1990-93

9.8.2 Navajo Sandstone Spring Discharges

Flows from the Navajo Sandstone Aquifer provide perennial flow for endangered plant species, such as the Parrish Alkali Grass. In the Little Colorado River Basin, this plant is limited to a small habitat around Pasture Canyon Spring northeast of Tuba City, which in turn discharges to Moenkopi Wash. Groundwater modeling by USGS predicts that the Navajo Aquifer near Tuba City will be dry around the year 2012. It is expected that Pasture Canyon Spring will suffer severe depletions in discharge at that time.

However, historical discharge measurements of Navajo Aquifer springs do not demonstrate a definitive long-term downward trend at present. This factor could be due to the difficulty of measuring spring flows at the same discharge point year to year. The following graph illustrates recent discharge trends from significant Navajo Aquifer springs.

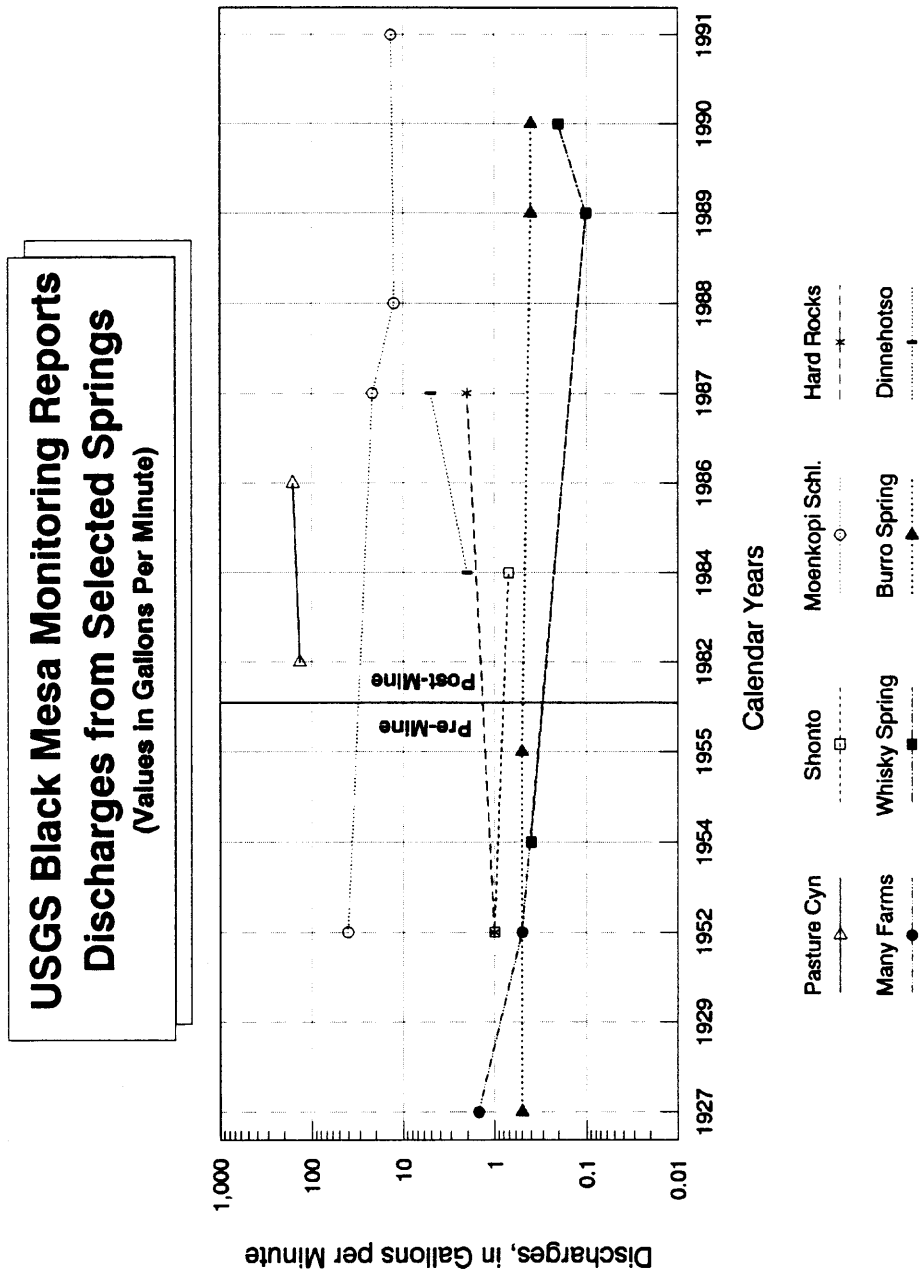


Figure 423. Selected Navajo Aquifer Springs, Discharge in cfs, 1927-91

9.9 Regionalized Hydrology

The purpose of this section is to determine whether precipitation-discharge and area-peak discharge relationships exist to enable reconstruction of discharges from precipitation-runoff coefficients and watershed areas.

Table 137. The Hopi Tribe
Little Colorado River Study - Peak Flow Data
Station Name: Little Colorado River Basin, Various Drainages
Peak Discharges, in cfs

Year	Dinnebito	Oraibi	Polacca	Moenkopi at Moenkopi	Castle Butte	Rio de Flag at Hdn Hol	Schultz Cyn	Rio de Flag at Flagstaff	Sinclair Wash at Flagstaff	Rio de Flag at I-40	Bow and Arrow at Flagstaff	Switzer Cyn at Flagstaff	Switz Cyn Trib at Flagstaff	Lockett Div at Flagstaff
1940														
1941														
1942														
1943														
1944														
1945														
1946														
1947														
1948														
1949														
1950														
1951														
1952														
1953														
1954														
1955														
1956								0						
1957								0						
1958								56						
1959								0						
1960								11						
1961														
1962														
1963		96												
1964		142	7		101									
1965		383	247		707									
1966		112	43		5									
1967		65	295		0									
1968	2,360	7	20		0								262	
1969	5,890	135	485		1						45	112	70	85
1970	28,900	382	275		117	2	0	10	401	350	42	61	178	65
1971	18,000	305	610		127	0.1	0	10	62	50	73	12	42	66
1972	10,000	20	540		280	11	0	0	105	100	26	15	15	0
1973		310	940		215	153	48	235	135	300	10	79	73	17
1974		90	900	2,340	2	0	0	3	1	0	12	18	100	2
1975		100	1,130	2,380	860	0	0	10	74	70	13	10	65	0
1976		1	180	5,420	58	1	0	35	44	134	7	51	45	46
1977				4,120		1	3	8.5	23	3	24	5	47	1
1978				262		144	17	128	37	153	20	90	76	54
1979				330		93	41	90	295	421	17	135	103	46
1980				1,740		110	35	104	70	165	40	107	84	0
1981				4,640		1		14		150				
1982				8,010		133		240		370				
1983				10,100										
1984				9,030										
1985				520										
1986				7,970										
1987				3,990										
1988				7,280										
1989				3,380										
1990				2,090										
Drain. Area In Sq. Mi.		1.78	6.45	1,629	5.57	31.5	6.09	51	8.11	82.4	2.06	1.87	7.02	1.05
100 Year Recurrence	31,300	339	995	9,330	536			167	260		54	151	163	
Average Annl Flow	24,352	264	774	7,259	417			130	202		42	117	127	

The Hopi Tribe
Little Colorado River Study - Peak Flow Data
Station Name: Little Colorado River Basin, Various Drainages
Peak Flows in cfs

Year	Cow Cyn near Winslow	Teshibito W near Holbrook	Steamboat W near Ganado	Ganado W near Ganado	Clear Ck near Winslow	Clear Ck below Willow Ck	Chevelon Ck near Winslow	Chevelon Ck bl Wldct Cyn	Penzan W near Jos. City	Puerco R. nr Adamana	Dead Wash Tr. near Holbrook	Black Ck near Lupton	Black Ck Trib nr Wind Rk	Decker W near Snowflk	Carr Lk Dr nr Holbrk
1940										7,500					
1941										22,600					
1942										19,400					
1943										4,800					
1944										4,700					
1945										5,740					
1946										30,000					
1947										22,000					
1948										17,100					
1949										8,040					
1950															
1951															
1952															
1953															
1954															
1955															
1956					173	198	562	227							
1957					9,150	8,880	8,680	11,300							
1958					2,920	2,920	2,140	4,080							
1959					542	296	1,320	479							
1960					2,440	2,770	2,640	2,630							
1961					925	1,080	500	476							
1962	90				2,330	2,240	1,540	1,920							
1963	140	1220	1	231	881	403	1,620	950	106		210		134	1	
1964	253	514	383	620	1,060	1,210	1,680	1,240	120		130	5,470	145	74	129
1965	0	374	1	1680	5,930	5,600	13,100	9,100	3		307	3,370	125	135	0
1966	0.1	1080	35	150	18,500	13,100	13,300	9,560	36		142	2,860	12	1,170	140
1967	192	1580	5	456	12,500	9,970	8,890	9,920	116		743	1,630	141	152	35
1968	82	540	130	280	1,840	1,840	1,640	1,600	0		73	3,750	171	60	102
1969	1	550	49	10	5,700	5,550	5,120	6,340	1		94	4,280	134	2	39
1970	55	950	360	1	9,650	15,800	8,020	11,100	95		340	3,720	102	1	52
1971	102	1280	55	35	1,460	1,180	4,150		24		526	3,090	55	349	45
1972	20	68	35	2	4,580	5,840	9,040		40		377	3,160	124		0
1973	61	628	380	287	9,350	8,190			5		180	2,420	106		5
1974	0	256	5	548	538	589			20		30	1,600	109	0	0
1975	8	700	28	418	3,940	920			35		138	865	156	2	4
1976	122	100		0	2,120	4,170			96			830	81		1
1977					372	353						7,160			
1978					12,900	10,500	33,600					72			
1979					36,300	19,700		19,900				1,340			
1980					10,800	8,140						1,740			
1981						250						2,220			
1982					570	5,230		6,440				7,680			
1983						2,020		1,950							
1984						2,130		2,360							
1985						4,750		5,250							
1986						2,570		3,490							
1987						1,070		417							
1988						1,270		1,170							
1989						602		525							
1990															
Drain. Area in Sq. Mi.	7.53	49.6	0.32	7.85	621	317	785	271	0.17	2,604	1.22	493.44	0.33	16.5	1.28
10 Year Recurrence	181	1,720	322	819	13,600	10,800	9,670	11,500	126	28,400	522	5,880			120
Average Ann. Flow	141	1,338	251	637	10,581	8,403	7,524	8,947	98	22,096	406	4,575			93

Table 138. The Hopi Tribe
Little Colorado River Study - Peak Flow Data
Station Name: Various Sub-Drainages, LCR Basin

Area, Sq. Mi.	100 Yr. Peak Q, in cfs
0.17	126
0.24	74.9
0.32	322
1.22	522
1.28	120
1.78	339
1.87	151
2.06	54
5.22	524
5.57	536
6.45	995
7.02	163
7.53	181
7.85	819
8.11	260
14.4	227
29.1	425
49.6	1,720
51	167
68.6	2,830
83.3	403
271	11,500
317	10,800
493.44	5,880
621	13,600
706	3,150
785	9,670
846	7,810
1,629	9,330
2,604	28,400
3,741	819
6,383	3,040
8,072	9,160
11,462	21,400
21,068	28,000
26,459	16,000

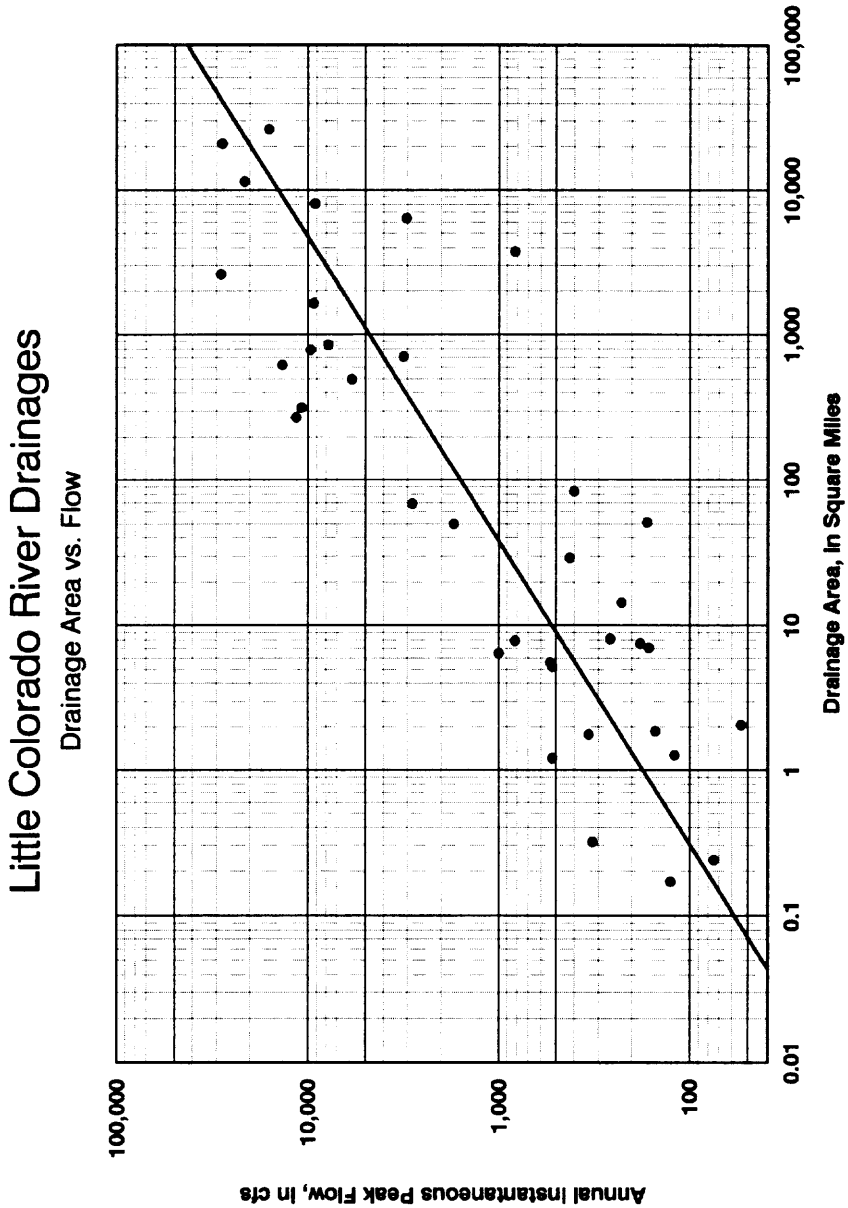


Figure 424. Regionalized Peak Flows, Little Colorado River Basin

9.10 Paleohydrology

To be completed in Final Report

9.10.1 Reconstruction of Flows from Treering Retrodictions

To be completed in Final Report

10 Generalized Geology of the Little Colorado River Basin

TO BE COMPLETED IN FINAL REPORT, 9/30/95

10.1 Historical Geology

TO BE COMPLETED IN FINAL REPORT, 9/30/95

10.2 Structural Geology

TO BE COMPLETED IN FINAL REPORT, 9/30/95

10.3 Faulting and Seismicity

TO BE COMPLETED IN FINAL REPORT, 9/30/95

10.4 Gravity Studies

TO BE COMPLETED IN FINAL REPORT, 9/30/95

10.5 Mineral Deposits

TO BE COMPLETED IN FINAL REPORT, 9/30/95

11 Sediment Discharges at Selected Stations

One of the major concerns to be addressed in this investigation relates to the amount of sediment carried by the Little Colorado River system to replenish Colorado River beaches

in Grand Canyon and to provide such light extinction and visibility depletion as may be required for the survival of native Colorado River fishes. Sediment sampling is labor intensive and expensive for the relatively inaccessible locations required for a meaningful analysis of the sediment transport regime. Consequently, the volume of available data is sparse compared to other southwest desert drainages, such as the main stem Colorado River.

The conclusion to be drawn from the analysis of available data and reconstruction of missing data is that the Little Colorado River sediment largely originates in the Puerco River watershed (Graf, et al, 1993) and is transported downstream by the high intensity summer monsoon events in the northern tributary watersheds and by the substantial spring snowmelt flows from the southern tributaries which originate along the high elevation Mogollon Rim. An examination of the stream bed morphology of the main stem LCR indicates that a considerable amount of sandy sediment is stored in reaches of the LCR with gentle slopes and wide channels, such as the reach from Holbrook to Leupp (Marley and Blandford, 1995). This material is transported past the Grand Falls reach through Cameron to the confluence with the Colorado River. A substantial stream velocity is required to transport the heavier stored sediment, which is reached only several times in an average year from heavy flows.

11.1 Measurement of Suspended Sediment and Bed Load

The purpose of this section is to provide some background for understanding the data presented in subsequent sections, to illustrate some of the concepts involved, and to relate these concepts to conditions found in the Little Colorado River and its tributaries. The subject is exhaustively covered in Edwards and Glysson (1988), Guy (1969 and 1970), and Porterfield (1972).

As a stream discharge hydrograph rises, the concentration of sediment in the stream increases, with the lighter particles becoming suspended at a lower flow rate than the heavier particles. The sediment-laden water is sampled from a lateral cross-section of the stream by one of several methods. A sediment sampler is utilized which is constructed to preserve the velocity relationships in the stream. Due to the necessity to insure that water flowing into the sampler does not flow out again, the sampler is tilted upward. For this reason, a small segment of the cross section, near the stream bed, is not sampled. This is called the unsampled zone.

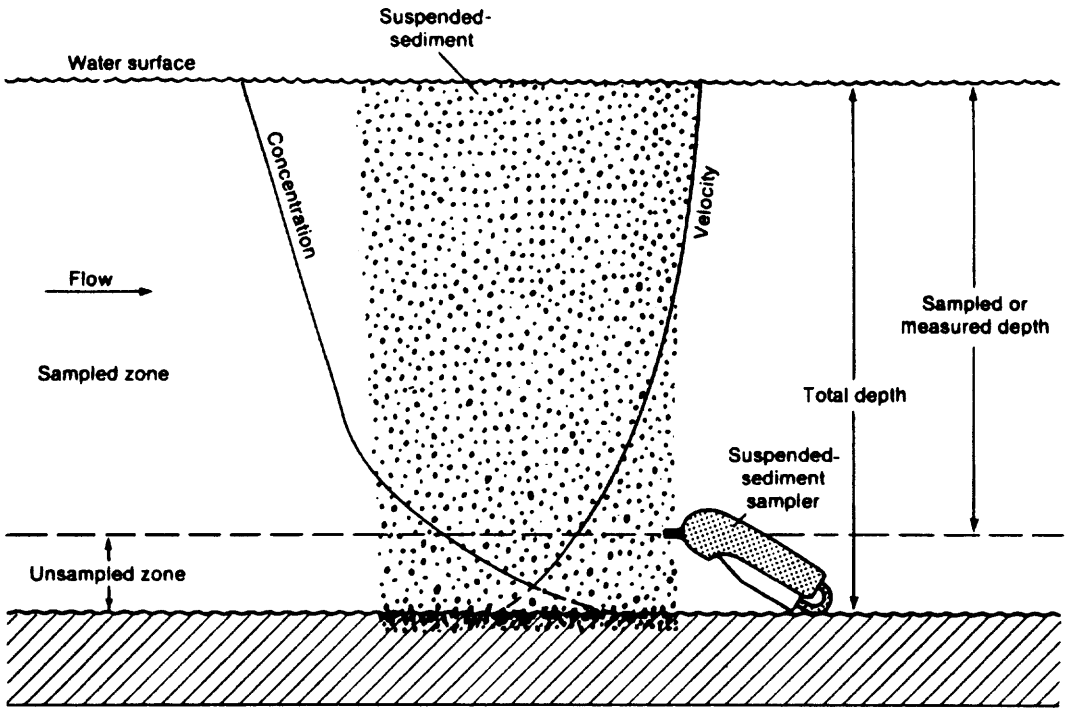


Figure 425. Sampled and Unsampled Zones in a Stream (From Edwards and Glysson, 1988)

One such sampler is the US DH-81 hand-held suspended sediment sampler. This sampler is convenient for wading in small streams when the velocity is not too great. A variety of glass, plastic, and teflon sample containers are available to fit into the sampler head. This particular sampler is specific for the depth-integrated method of sampling (See Edwards and Glysson, 1988).

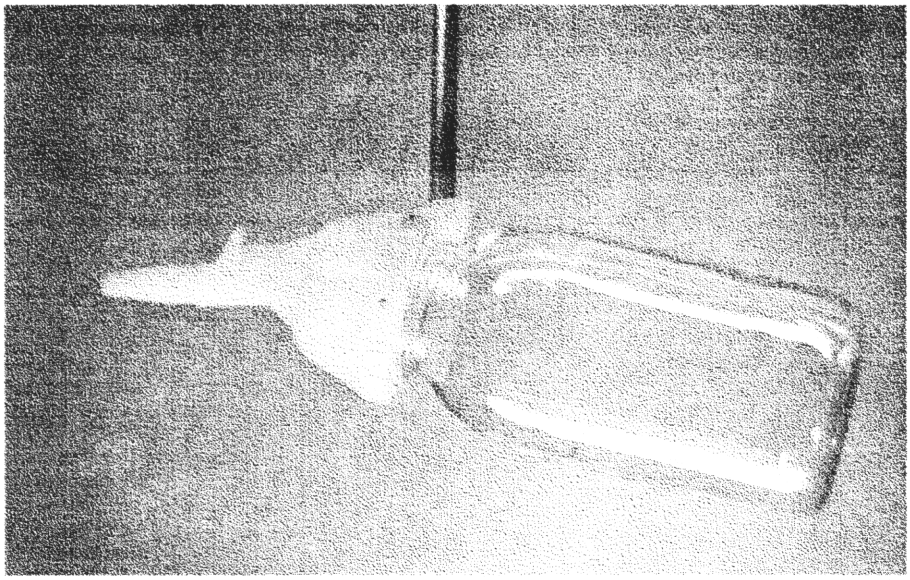
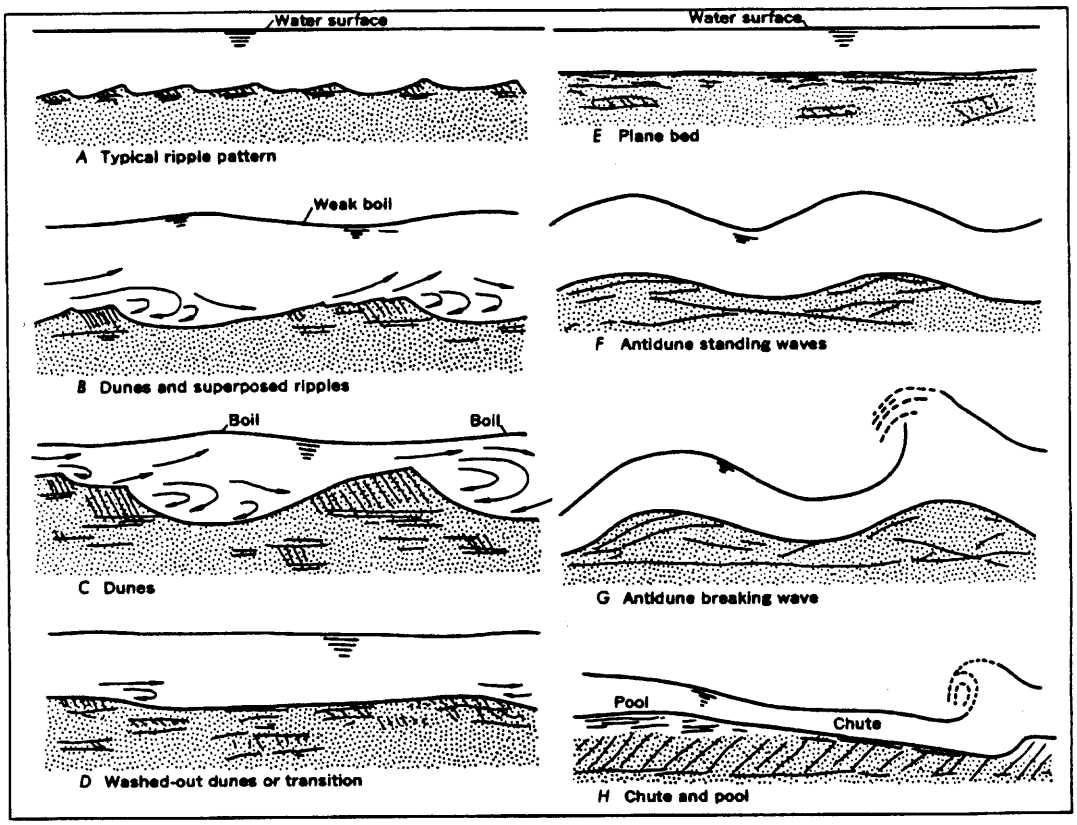


Figure 426. US DH-81 Suspended-Sediment Sampler (From Edwards and Glysson, 1988)

As the velocity of the stream increases, the bed material assumes various configurations, depending upon the hydraulic conditions within the stream (See Guy, 1970).



Schematic diagrams of eight types of roughness found in sand-bed channels. Types A through C are representative of the lower flow regime where the Froude number is usually <0.4, E through H are representative of the upper flow regime where the Froude number is usually >0.7, and D represents the transition regime. Modified from Simons and Richardson (1966, p. J5).

Figure 427. Shapes of Streambed Dunes under Varying Stream Velocities (From Guy, 1970)

All the hydraulic conditions are present at some time or reach in the Little Colorado River and its tributaries, from laminar flow through turbulent flow regimes. These stream flows are driven by the highly variable precipitation or snowmelt events which accompany an arid region with a highly variable topography. For example, note the following illustration from a single convective storm in the Dinnebito Wash watershed on the Hopi Indian Reservation.

Figure 428. Standing Waves in Dinnebito Wash, September, 1992

The sampling of the largely heavier sediment which is transported along the stream bed requires a different type of sampler. Bed material sampling requires a great weight to depress the mechanism deeply enough into the sediments to enable the capture and retrieval of the material. One such sampler is the US BMH-80, which features a spring-loaded clamshell covered sampling chamber. The mechanism is allowed to settle into the stream bed and the clamshell trap is sprung, capturing the bed material in the sample chamber.

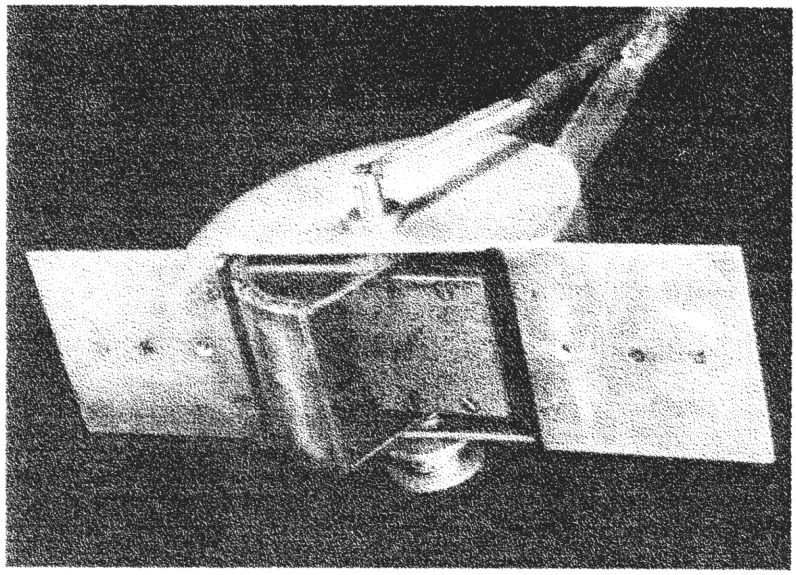


Figure 429. US BMH-80 Bed-Material Sampler (From Edwards and Glysson, 1988)

Ultimately, the presence and composition of sediment in a stream is due to erosion of the material in the watershed and the transport regime of the material is due to the local hydraulics of the stream.

11.2 Settling Velocity (Falling Velocity, USGS) of Particles

The rate at which particles settle from a liquid medium is a function of their size, specific gravity, and shape, and the viscosity of the medium in which they are suspended. The specific gravity of sand, silt, and clay are basically that of quartz, approximately 2.65 gm/cc. The specific gravity and viscosity of water vary with temperature. The size generally taken is the nominal diameter, which is the diameter of that sphere which is the same weight as the particle. The shape factor is the ratio of the length to the square root of the product of the other two dimensions, width and breadth. This assumes that the particle can be roughly approximated by a rectangular prism. Sand generally has a high shape factor, or nearly the same as a sphere, which would have a shape factor of 1.0. Silt and clay have lower shape factors, down to about 0.5.

As the velocity of the stream increases, the falling velocity (the effects of gravity, essentially) is overcome by the stream velocity, and the particles become suspended. Obviously, the smaller particles are suspended at a lower velocity than the heavier particles. As the stream loses velocity on the receeding limb of the hydrograph, the heavier particles settle first and the lighter particles settle later. This process is called deposition.

The velocity in the middle of the stream is greater than that of the water near the banks. In the Little Colorado River above Grand Falls, for example, the dry stream bed consists mostly of sand, which the bed near the bank has cracked plates of clay on the top.

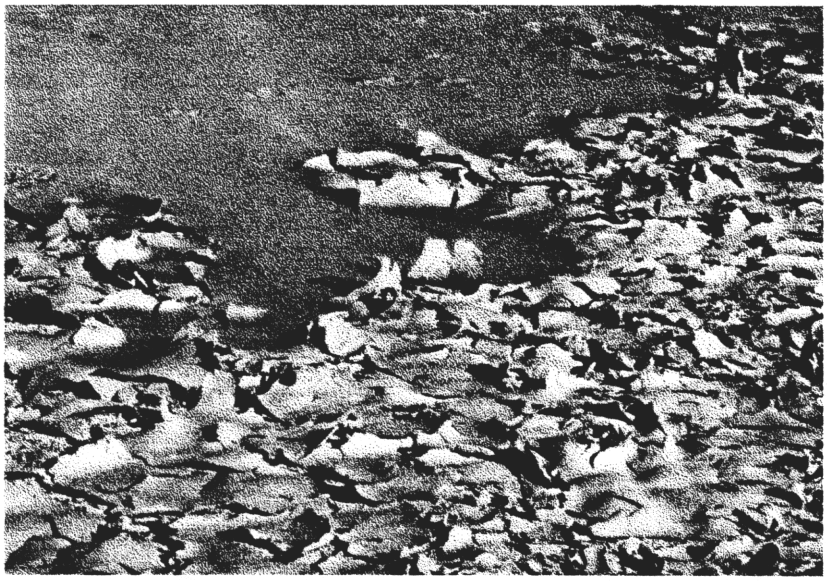


Figure 430. Clay Deposits near the bank of the LCR above Grand Falls

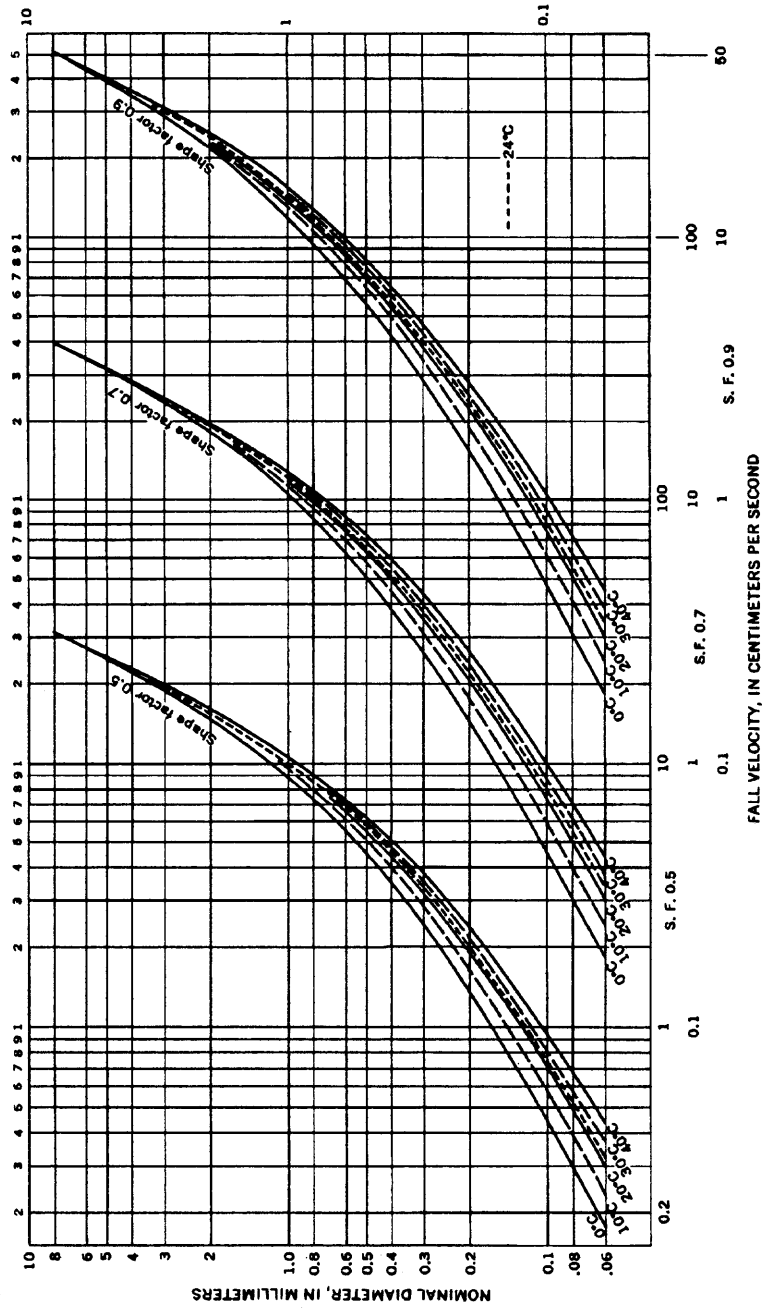


Figure 431. Falling Velocity of Particles (From Guy, 1969)

In the following section, particle size distributions of suspended sediment at various Little Colorado River sampling locations indicate the relationship of suspended sediment particle sizes at different flow rates (velocities).

11.3 Particle Size Distribution Analyses

In this section, various stations are examined for particle size distributions at diverse flow rates and velocities. It will be noted that, as the flow rate increases, a larger proportion of larger particles are suspended.

11.3.1 Little Colorado River near Cameron

This reach of the Little Colorado River contains the waters of all the major tributaries and the main stem, with the exception of Moenkopi Wash and Hamblin Wash.

It will be noted that at 0.7 and 23 cfs, the sediment is of 0.002-0.004 mm in size. At 600 and 628 cfs, the sediment is from 0.125 to 0.002 mm in size. At 1,070, 1,660, and 2,110 cfs, the sediment is from 0.250 to 0.002 mm in size, with a larger fraction between 0.031 and 0.004 mm in size. In other words, as the flow rate increases, heavier and heavier particles are suspended.

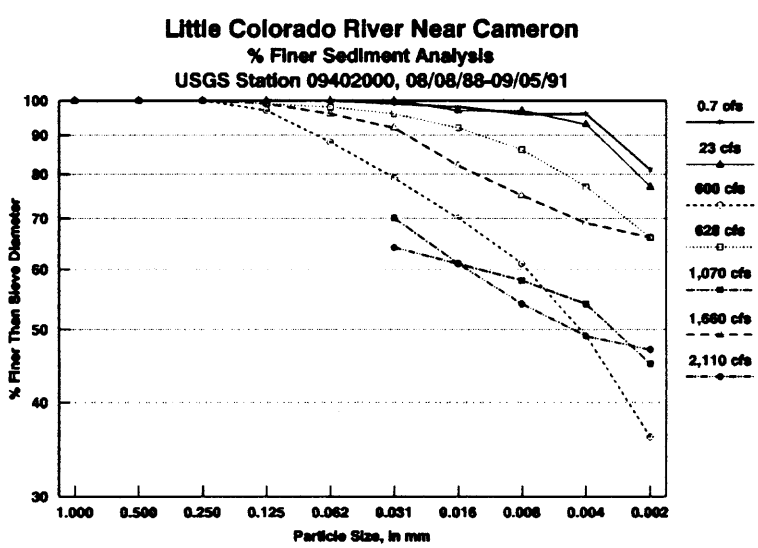


Figure 432. LCR near Cameron, Particle Size Analysis, Suspended Sediment

11.3.2 Little Colorado River at Grand Falls

This reach of the Little Colorado River contains all the major flows except Dinnebito Wash, Moenkopi Wash, and Hamblin Wash. Flow rates from 4.1 to 3,120 cfs are examined. At 4.1 to 138 cfs, almost all the suspended particles are less than 0.016 mm in size. From 278 to 1,110 cfs, all particles are less than 0.031 mm in size. At 1,590 and 3,120 cfs particles from 0.125 to 0.250 mm are also suspended. The proportion of heavy particles is somewhat higher at Grand Falls than near Cameron. The Cameron distribution seems about equal to Grand Falls in the content of fines.

As with the LCR near Cameron, the LCR at Grand Falls demonstrates that the heavier particles are suspended as the flow rate increases.

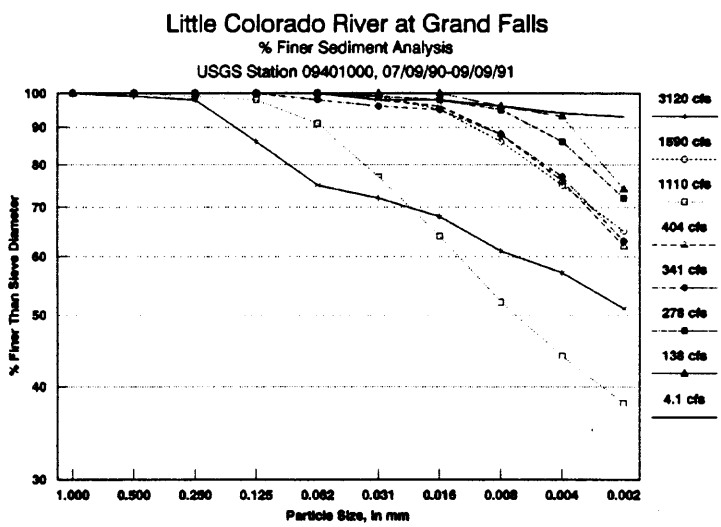


Figure 433. LCR at Grand Falls, Particle Size Analysis, Suspended Sediment

11.3.3 Moenkopi Wash at Moenkopi

Discharge rates from 2 to 238 cfs are examined. At 2 cfs, Moenkopi Wash transports a larger proportion of fines (<0.004 mm) than the main stem Little Colorado River sampling points near Cameron and at Grand Falls.

From 2 to 5 cfs, Moenkopi Wash sediment is finer than 0.016 mm. From 26 to 46 cfs, the sediment is finer than 0.031 mm. From 46 to 238 cfs, the sediment contains particles up to 0.125 mm. Heavier particles present in the main stem Little Colorado River appear to be absent in Moenkopi Wash.

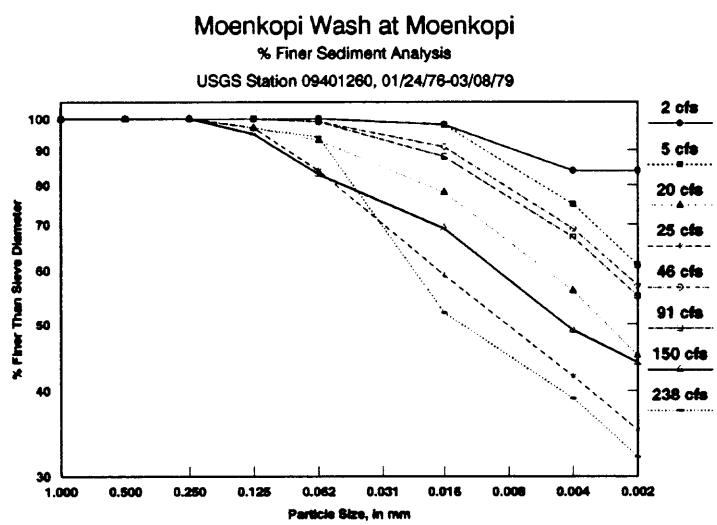


Figure 434. Moenkopi Wash at Moenkopi, Particle Size Analysis, Suspended Sediment

11.4 Discharge-Suspended Solids Relationships (Transport Curves)

Sediment transport curves are utilized at gaging stations to estimate the sediment discharge of the stream at that point. These curves are calibrated from irregularly discretized samples for which the flow is known. The total suspended sediment and the flow define the curve.

The curve has three distinct slopes. The first slow rise in sediment occurs as the stream velocity exceeds the settling (falling) velocity of the particles. Finer particles, such as clay and silt, go into suspension at a lower flow (velocity) than heavier particles, such as sand. The next rapid rise in sediment with flow is due to changes in the shape factor of the particles (going from clay to silt and sand). The final low slope is due to channel geometry, in which an increase in flow does not result in as great an increase in velocity; the heavier particles also contribute to this section of the curve.

A typical transport curve is presented for comparison to curves for streams in the Little Colorado Basin.

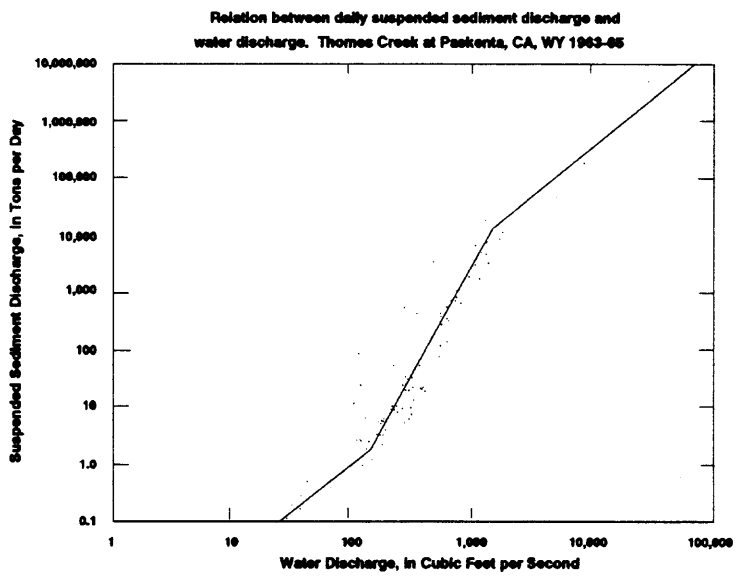


Figure 435. Typical USGS Sediment Transport Curve, Thomas Wash at Paskenta, CA (From Porterfield, 1972)

Generally, it is only possible to define a transport curve for a particular event. This is because of seasonal effects of the origin of flows through the parent material of the sediment and the spatial origin of the storm events which give rise to the flows. In

general, there are two populations of sediments in the Little Colorado River. It is not possible to speculate on the causes of these divergent curves until the Little Colorado River model is completed.

It is apparent from the foregoing that the transport curves of the main stem Little Colorado and the tributaries differ significantly. This is probably due to the nature of the sediment and the hydraulics of the stream channels.

A thorough treatment of the methodology of translating continuous record discharge data to sediment discharge data is to be found in Porterfield (1972).

11.4.1 Little Colorado River at Cameron

The following curve defines the sediment-discharge relationships for the Little Colorado River at Cameron sampling point for the period of 7/30/66 to 9/3/66. It will be noted that the data points are greatly scattered. This period was used because of the large number of samples collected at various flow rates, obviously taken for purposes of calibrating the sediment-discharge curve for that time of year.

It is to be noted that the break in the curve from the lower discharge rates to the mid-level rates is less pronounced than with the example curve for Thomas Wash, above.

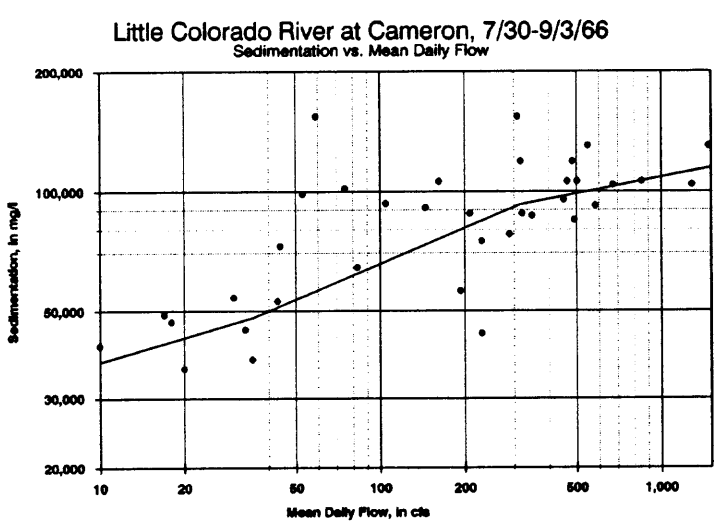


Figure 436. LCR at Cameron, Sediment-Discharge Curve

The following graph of sediment vs. discharge for the study period seems to indicate two populations of data. The higher curve is for the summer monsoon discharges, and the lower curve for the spring snowmelt period. It is likely that the USGS develops separate calibration curves for the two disparate discharge seasons.

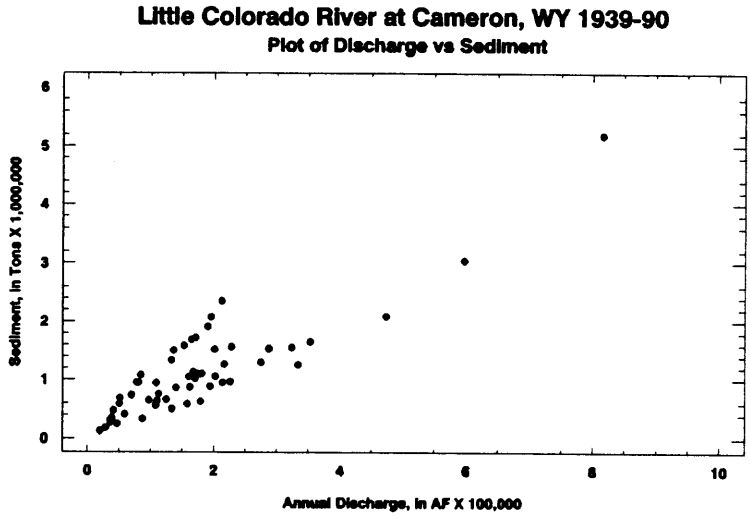


Figure 437. LCR at Cameron, Plot of Sediment vs Discharge, WY 1939-90

11.4.2 Little Colorado River at Grand Falls

As with the Little Colorado River at Cameron sampling point, the Little Colorado River at Grand Falls seems to exhibit two seasonal transport curves. Insufficient data exists to derive seasonal transport curves for this station from information available at this time to the project investigator.

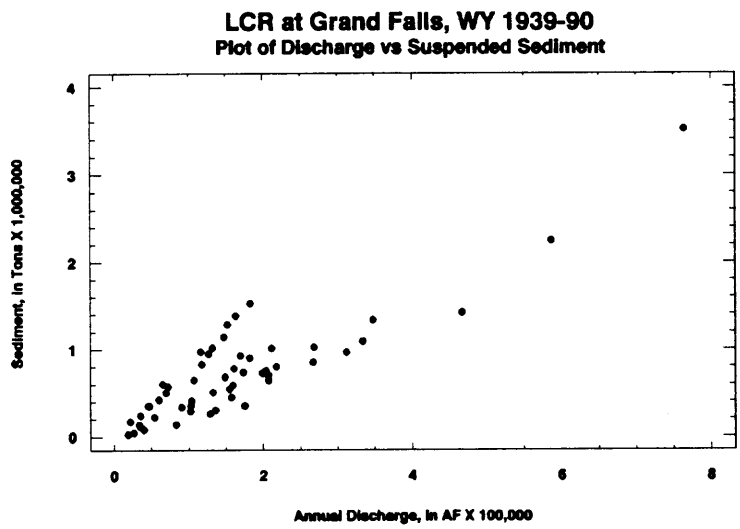


Figure 438. Little Colorado River at Grand Falls, Sediment Discharge Curve

11.4.3 Little Colorado River at Woodruff

The breaks in the curves between low and mid-range discharges is more pronounced at this station than at LCR at Cameron. Also, the break between mid to high-level discharges is quite pronounced. This station is upstream of the Puerco River confluence and the mouths of the northern washes from the Hopi and Navajo Reservations, and the mixture of particle sizes and shape factors differs.

Most of the sediment at this station originates in the upper Little Colorado River, with a large proportion of volcanic material in the parent material of the sediment.

The transport curve illustrated below is taken from a series of events from 7/8/50 to 9/29/50. Also included is an illustration of the time series relation between discharge and sediment concentration for these events. The lag or advance of sediment with respect to discharge is not evident in the series. It is assumed from this example that discharge and sediment are simultaneous for this reach of the river (See Porterfield, 1972).

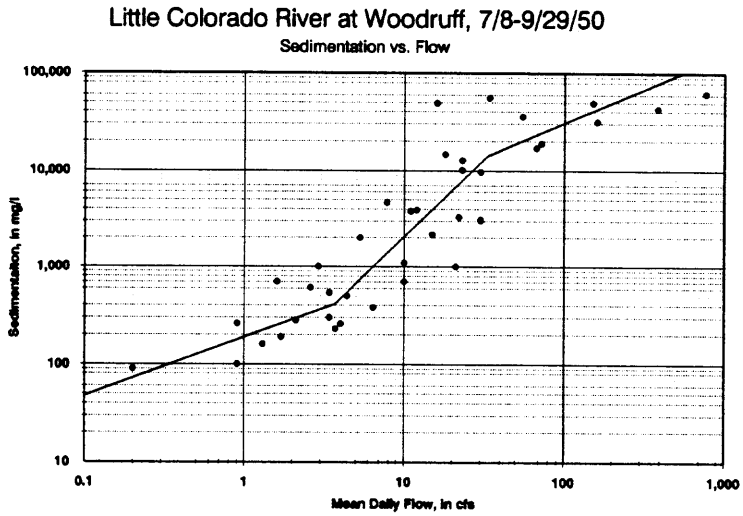


Figure 439. Little Colorado River at Woodruff, Sediment Discharge Curve

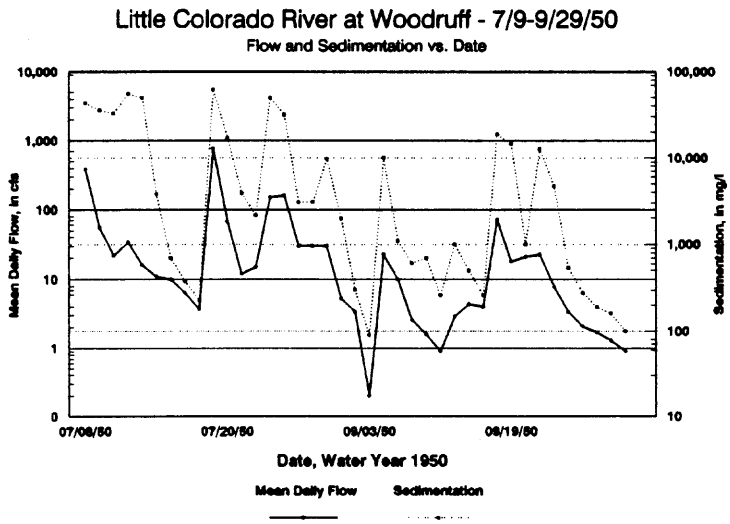
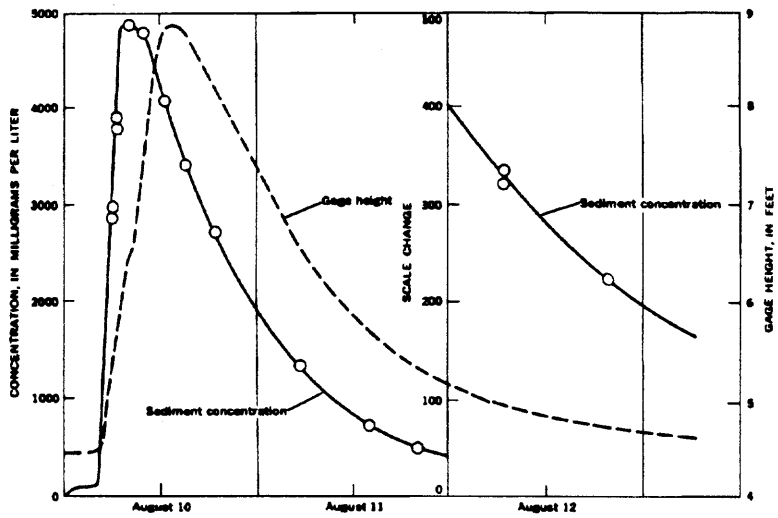


Figure 440. Time Series, Sediment vs. Discharge, LCR Woodruff

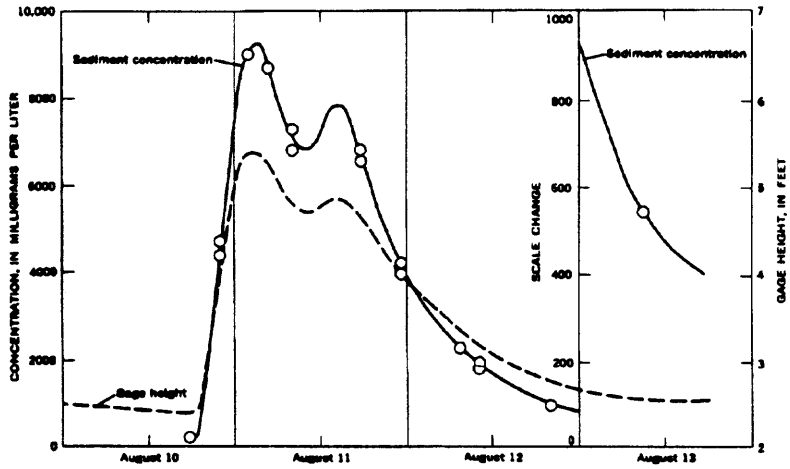
In the figure above, the rise and fall of both discharge and sediment concentration occur simultaneously. On the other hand, the following graph illustrates an advance in time such that the sediment concentration rises ahead of the flow rate.



Advanced concentration during excess runoff periods.

Figure 441. Advance sediment concentration during excess runoff periods (From Porterfield, 1972)

In the next figure, the rise in sediment concentration concides with the rise in discharge, as in the LCR at Woodruff example.



Simultaneous concentration during excess runoff periods.

Figure 442. Simulataneous sediment concentration during excess runoff periods (From Porterfield, 1972)

On the other hand, the following figure demonstrates a condition in which the sediment concentration temporally lags behind the discharge.

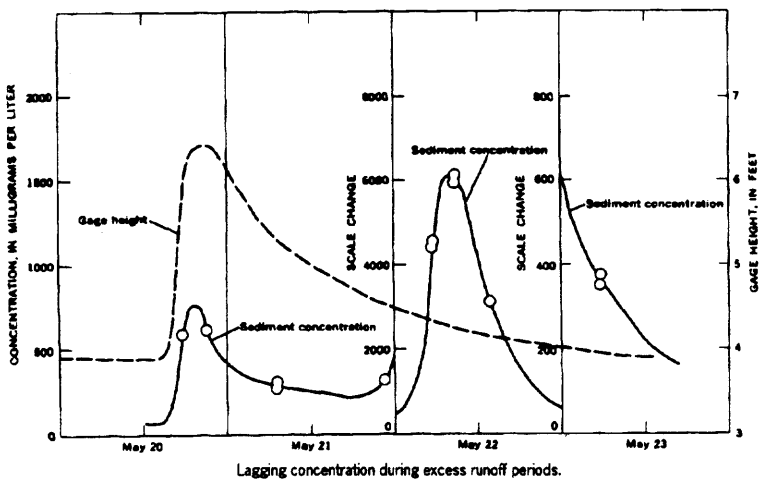


Figure 443. Lagging sediment concentration during excess runoff periods (From Porterfield, 1972)

In the preceeding graphs, it is apparent that, for the period of 7/9-9/29/50, the sediment concentration and discharge are simultaneous. The sampling was not continuous, resulting in an irregularly discretized series, with respect to time. It is to be noted that this example is from a singular period of time which may not be representative of all storms. This time series of samples and discharge gagings was evidently utilized to derive a sediment transport curve during the period of record of sediment discharge measurements at the Woodruff gaging station.

11.4.4 Moenkopi Wash at Moenkopi

The transport curve illustrated here is from a series of sediment samples taken from 7/20/76 to 9/30/76. It will be noted that the breaks in the curve are much more pronounced than in the main stem transport curves. The data are from a series of events during the monsoon season of WY 1976. There is a considerable spread in the data from the curve.

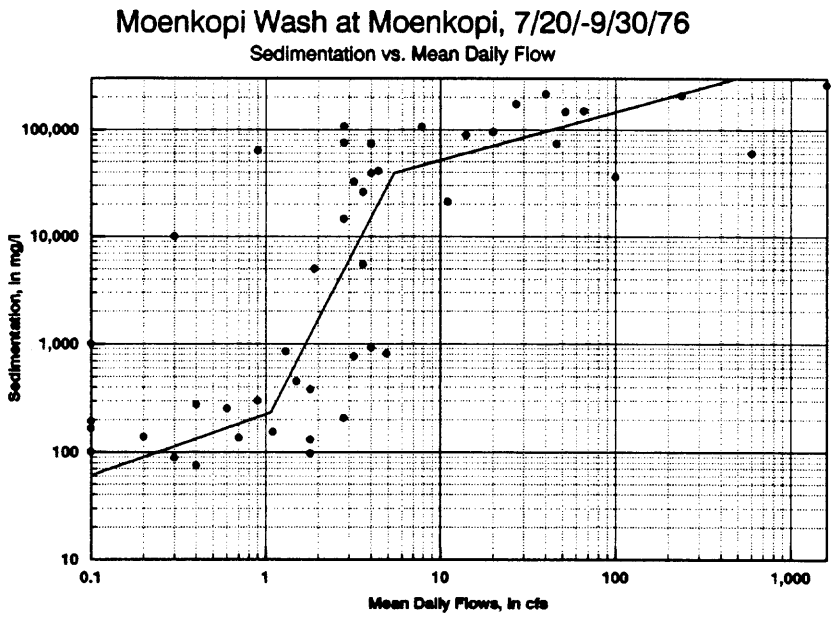


Figure 444. Moenkopi Wash at Moenkopi, Sediment Discharge Curve

11.5 Frequency of Sediment Discharges

Since the sediment transported to the main stem Colorado River by the Little Colorado River contributes (along with Paria and Bright Angel Creeks) to the sediment load which replenishes beaches in the Grand Canyon, it is of importance to note the frequency with which heavy sediment loads occur. In addition, the clays and silts provide light extinction and turbidity in the Little Colorado, which is reported to be favorable to the humpback chub at various phases of its life cycle (Wegner, 1992).

It is apparent in the following graphs that the Little Colorado River transports great volumes of sediment infrequently. While the minor drainages contribute material to the Little Colorado, it requires great velocity to move the sand from the LCR bed to the main stem.

It will be noted later that although various tributaries, such as the northern washes, contribute fines to the LCR sediment mixture, all but Moenkopi and Dinnebito are detained in the natural depression, Tolani Lake (Morgan, Hopi WRP observation, 1993). It will also be noted that the minerology of the sediments point toward an upstream origin for most of the sediment material, such as Puerco River and the Upper Little Colorado River. Finally, the high velocity and volume of flow occurs during snow melt in the spring, rather than during the monsoons. Little snow is deposited or melts in the northern areas of the basin.

The issue of the sediment required for environmental management of the Little Colorado and main stem Colorado habitats is probably far too complex to estimate in a simplistic manner. For this reason, a sediment discharge model is requred for assessment of quantities and for evaluation of management alternatives.

11.5.1 Little Colorado River at Cameron

The sediment load for the 1939-90 study period has been reconstructed by D.B. Stephens and Associates (Marley and Blandford, 1995). The data has been smoothed by Brown's Exponential Smoothing, Quadratic Form, alpha factor = 0.1. This enables the examination of annual trends for the study period. The peak sediment discharge occurred during the storm of October, 1973. The smoothed data indicates that the annual sediment load varies between 900,000 and 2,500,000 tons/year. The box plot and histogram demonstrate the lognormal distribution of the sediment load, which corresponds to the discharge distribution.

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Little Colorado River Hydrology Study

Suspended Sediment, in Tons/Month

Modeled Data Output

LCR near Cameron

Mo/Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	93,323	0	0	0	31,202	973,226	1,144,712	0	0	93,323	489,439	676,369	3,501,594
1940	93,323	0	16,155	5,472	152,358	366,184	187,607	0	0	1,832,581	6,072,664	7,409,749	16,116,052
1941	3,172,186	478,266	1,589,064	1,818,832	2,410,417	3,966,321	3,117,700	2,498,722	88,326	636,343	3,901,458	4,602,980	28,178,624
1942	7,748,943	173,886	168,349	197,046	186,374	526,933	1,451,058	147,341	0	93,323	146,061	93,323	10,936,626
1943	187,761	37,578	0	0	197,386	1,524,595	346,990	0	0	93,323	2,472,642	1,811,161	6,870,427
1944	194,766	0	8,022	0	0	636,009	2,069,311	693,500	0	93,323	93,323	1,305,111	5,093,366
1945	405,368	61,170	66,435	0	138,088	463,897	1,936,915	544,743	0	1,461,803	5,186,119	188,100	10,454,836
1946	98,115	0	28,615	119,418	60,401	88,772	65,203	0	0	1,460,064	7,488,363	5,834,932	15,243,873
1947	186,887	806,622	276,019	93,678	262,180	186,025	0	0	0	0	12,694,568	2,488,627	16,943,602
1948	9,183,733	46,074	63,181	98,007	206,743	526,802	1,934,567	0	0	653,836	2,470,918	88,360	15,272,022
1949	556,458	127,196	121,381	615,727	453,969	2,903,177	2,241,498	144,893	18,747	1,446,861	5,047,121	1,322,807	14,896,837
1950	805,154	20,760	8,471	0	373,837	394,119	82,454	0	0	961,270	137,551	220,018	2,993,432
1951	0	8,010	12,037	0	0	0	0	7,847	0	498,064	3,210,519	2,194,606	5,932,072
1952	1,116,368	12,487	14,955	4,280,410	336,247	346,213	3,815,331	584,174	0	248,839	1,543,018	3,399,229	15,696,271
1953	30,051	33,807	223,636	40,764	33,167	416,047	136,839	0	0	1,827,290	1,846,706	43,799	4,632,106
1954	0	14,023	8,306	0	0	481,657	568,780	0	0	4,620,278	760,601	3,171,155	9,634,801
1955	521,823	10,599	10,325	0	0	0	0	0	1,001,590	1,513,976	16,942,972	463,686	20,454,973
1956	0	0	10,654	0	54,262	120,448	5,567	0	0	256,894	1,073,338	16,206	1,537,371
1957	0	0	0	1,276,580	714,938	227,638	2,702	1,905	28,202	687,234	7,246,700		10,186,799
1958	1,632,257	874,157	2,698	161	65,081	990,326	770,220	14,042	16,710	55,290	3,660,938	3,254,557	11,336,436
1959	400,503	140	50	300	120	10,408	11,305	0	3,823	14,042	6,389,120	20,778	6,850,688
1960	848,423	2,203,112	1,088,968	533,016	99,708	3,836,211	182,926	9	300	0	0	41,525	8,834,186
1961	686,400	500	360	200	40	39,060	175,341	0	0	100,000	1,374,890	1,121,390	3,498,271
1962	61,818	477,878	50	6,000	2,628,890	226,377	1,594,500	2,631	0	0	21,000	829,112	5,847,256
1963	725,390	341,974	1,073	18	74,710	11,642	17,791	0	0	0	6,181,000	3,454,900	10,808,498
1964	172,109	47,038	0	0	0	0	784,980	84,241	1,000	1,530,850	12,976,300	1,667,640	17,163,958
1965	20,446	0	0	1,317,200	65,730	99,590	1,364,000	191,139	0	3,270,000	1,331,433	1,967,459	9,636,998
1966	36,384	146,447	1,514,480	1,450,400	6,148	2,991,760	147,998	28	0	174,000	2,620,100	1,464,000	10,552,746
1967	594,763	617	532,002	36	34	0	2,954	0	296,106	3,618,779	9,343,100	4,791,980	19,080,359
1968	20,636	0	2,600	71,400	1,287,500	1,074,100	1,546,400	113,102	0	893,442	4,509,200	80	9,518,459
1969	490,123	13,019	0	1,581,989	122,991	676,198	926,136	17,158	0	1,532,684	968,823	2,273,693	8,595,795
1970	717,219	57,807	115	2,002	0	210,281	82,348	0	0	90,443	2,149,947	6,186,902	9,497,065
1971	98,671	7,276	10,533	0	0	0	0	0	0	31,908	7,378,004	1,982,861	9,509,261
1972	9,190,970	342,187	1,567,344	221,989	0	0	0	0	0	1,093,469	647,944	196,656	13,249,558
1973	31,361,117	676,266	360,906	407,724	836,962	2,506,312	6,869,892	5,138,361	23,916	20,934	41,097	21,778	48,265,173
1974	0	0	0	6,793	0	204,671	86,203	0	0	824,016	750,837	356,821	2,229,342
1975	1,366,092	662,099	0	0	0	392,456	926,826	149,986	0	1,215,572	136,163	3,120,577	7,947,768
1976	37,648	0	56,169	0	414,309	489,467	1,005,207	263,362	0	2,341,518	505,301	948,497	6,061,488
1977	78,024	11,071	0	98,967	3,487	0	115,270	0	0	2,015,263	4,413,823	923,943	7,659,628
1978	748,763	40,270	16,097	4,958	165,224	3,328,867	1,342,630	36,214	0	0	46,956	163,528	5,892,204
1979	908,820	1,994,098	5,752,307	514,902	1,546,586	2,261,576	4,598,139	609,696	17,063	0	500,839	0	18,704,013
1980	48,574	110,276	28,298	268,652	4,160,937	1,303,345	3,009,786	1,044,434	0	17,870	584,075	1,193,647	11,769,894
1981	0	0	7,276	0	0	0	22,716	0	0	2,548,897	843,264	1,604,908	4,827,060
1982	3,178,946	8,646	80,331	97,447	736,611	2,044,033	911,941	61,509	0	40,470	5,182,552	3,157,962	15,499,448
1983	64,228	196,001	1,519,964	288,865	573,512	2,394,821	2,693,381	1,186,010	0	1,168,899	2,614,957	2,093,497	14,786,534
1984	5,166,160	146,754	786,883	316,301	1,868	87,620	11,827	0	0	2,143,782	9,208,576	5,467,403	23,334,143
1985	2,862,498	18,291	1,056,692	923,121	759,314	2,739,997	1,406,273	548,698	0	260,488	792,952	1,210,579	12,579,104
1986	361,472	609,178	377,343	0	312,455	582,541	262,808	0	0	1,908,636	1,009,514	1,526,781	6,951,704
1987	1,889,775	625,380	521,277	283,871	449,529	898,692	1,078,222	200,448	0	149,539	3,157,798	43,237	9,097,788
1988	125,684	2,486,823	7,648	57,697	1,099,975	511,407	822,731	91,860	0	249,827	3,727,592	1,906,968	11,086,203
1989	0	10,368	8,460	0	0	277,866	63,349	0	0	314,998	2,392,482	16,640	3,084,154
1990	569	0	0	0	28,590	0	0	0	0	394,141	805,380	1,972,580	3,201,260
Average	1,694,264	267,755	344,702	326,883	404,646	849,782	998,641	276,236	28,763	891,865	3,361,479	1,768,080	11,179,093
Maximum	31,361,117	2,486,823	5,752,307	4,280,410	4,160,937	3,966,321	6,869,892	5,138,361	1,001,590	4,620,278	16,942,972	7,409,749	48,265,173
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	1,537,371
Std. Dev.	4,667,593	540,588	881,803	713,568	767,944	1,086,427	1,362,367	799,012	142,636	1,037,366	3,701,719	1,796,761	7,862,102

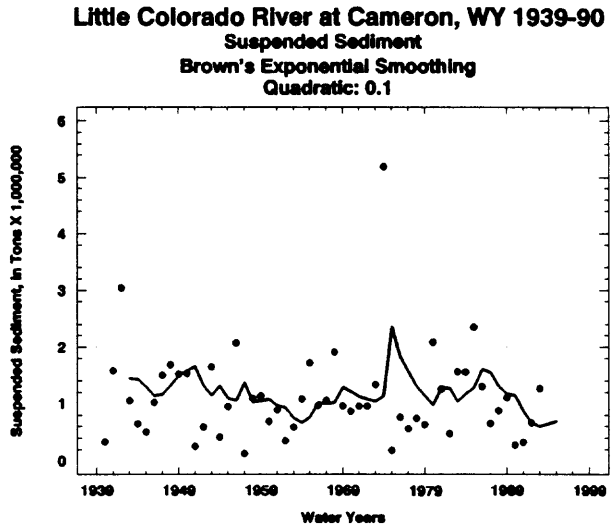


Figure 445. LCR at Cameron, Smoothed Annual Sediment Load, WY 1939-90

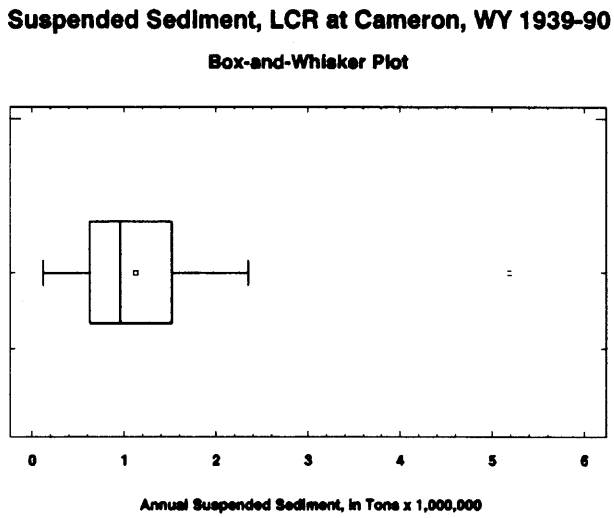


Figure 446. LCR at Cameron, Annual Sediment Load Box and Whisker Plot

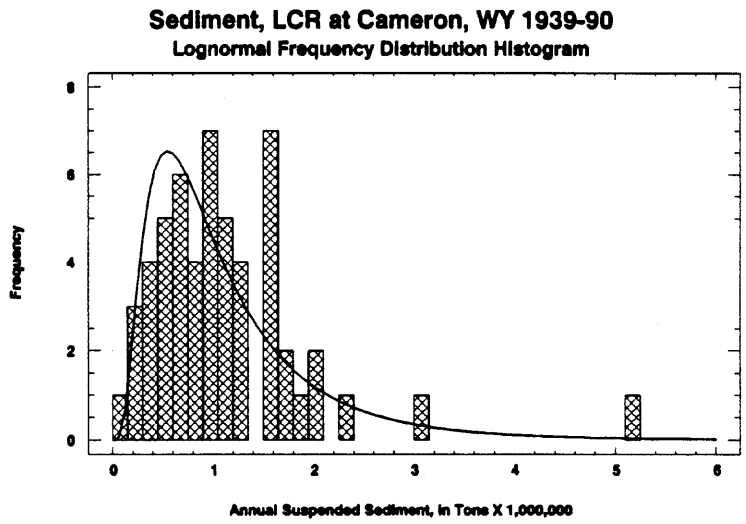


Figure 447. LCR at Cameron, Annual Sediment Load Frequency Histogram

11.5.2 Little Colorado River at Grand Falls

The sediment load in the data smoothed by Brown's exponential smoothing, quadratic form, alpha factor at 0.1, indicates an annual sediment load between 400,000 and 1,600,000 tons/year. Evidently, about 500,000 to 900,000 tons/year are added between Grand Falls and Cameron through Dinnebito and Moenkopi Washes and the local drainages from the Ward Terrace to the north and east of the Little Colorado River.

The Hopi Tribe
Glen Canyon Environmental Studies
Little Colorado River Basin Hydrology Study

Little Colorado River at Grand Falls

Suspended Sediment in Tons/Month

Modeled Data Output

Mo/Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1939	0	0	0	0	0	552,507	700,105	0	0	0	0	0	1,252,612
1940	0	0	6,874	0	13,967	59,694	0	0	0	800,008	3,910,989	4,907,372	9,698,893
1941	1,782,896	359,296	1,206,183	2,698,280	3,690,167	2,982,347	2,301,807	1,789,304	0	0	2,317,966	2,774,683	21,902,922
1942	5,140,882	127,199	122,919	57,965	72,603	191,923	948,801	0	0	0	0	0	6,662,191
1943	0	23,268	0	0	87,275	1,000,117	51,690	0	0	0	1,269,638	799,657	3,231,643
1944	0	0	673	0	0	278,749	1,450,708	325,420	0	0	0	428,373	2,483,923
1945	0	41,255	45,211	0	0	139,026	1,344,861	204,658	0	527,981	3,259,794	0	5,562,775
1946	0	0	16,374	0	0	0	0	0	0	526,698	4,949,694	3,751,922	9,244,688
1947	0	608,886	205,016	0	176,482	0	0	0	0	0	7,293,355	861,124	9,144,863
1948	5,471,291	27,763	41,081	0	149,820	211,367	1,368,845	0	0	41,670	1,211,256		8,523,092
1949	0	82,977	136,828	594,347	426,201	1,768,886	1,560,921	0	0	915,491	3,623,586	660,581	9,758,798
1950	0	16,970	1,478	0	371,727	82,484	0	0	0	175,891	0	0	648,561
1951	0	0	0	0	0	0	0	0	0	0	2,716,382	504,741	3,221,123
1952	293,643	6,717	8,504	6,624,011	310,007	44,380	2,812,112	233,656	0	0	597,940	1,937,192	12,868,159
1953	0	22,649	164,444	0	0	99,326	0	0	0	800,690	814,538	0	1,902,248
1954	0	0	0	0	0	234,411	222,333	0	0	3,625,490	87,222	1,833,415	6,002,870
1955	0	0	0	0	0	0	0	0	177,308	74,390	12,265,536	0	12,517,234
1956	0	0	3,311	0	0	0	0	0	0	0	80,806	0	84,117
1957	0	0	0	1,990,695	1,936,672	326,629	0	0	0	0	4,152,220	398,016	8,795,232
1958	865,448	401,021	85,485	0	74,950	460,267	772,068	0	0	0	1,861,544	2,823,091	7,323,895
1959	460,993	0	0	0	0	0	0	0	0	0	2,747,178	0	3,198,171
1960	808,348	1,392,378	958,537	867,574	201,487	1,869,521	180,413	0	0	0	0	0	6,278,258
1961	302,168	5,790	7,561	0	0	0	22,721	0	0	0	329,166	0	667,397
1962	0	155,868	2,658	0	2,308,908	69,629	1,740,172	0	0	0	0	56,019	4,333,453
1963	0	131,228	9,013	0	0	0	0	0	0	3,095,689	2,120,348	0	5,356,278
1964	0	30,569	2,420	0	0	0	384,013	0	0	371,450	8,346,441	1,796,750	10,931,644
1965	0	2,478	2,420	2,050,183	421,917	92,102	1,784,489	129,287	0	1,314,369	386,831	1,342,911	7,525,977
1966	0	164,379	1,014,990	2,807,417	0	1,296,396	146,469	0	0	0	1,027,420	488,131	6,946,190
1967	0	4,267	953,952	0	0	0	0	0	0	1,483,198	7,078,641	3,763,370	13,284,406
1968	0	2,478	7,268	0	1,974,824	883,597	1,310,264	30,390	0	79,057	2,453,344	0	6,741,203
1969	0	9,867	2,420	1,189,801	167,586	159,687	628,196	0	0	631,227	192,251	1,499,368	4,480,389
1970	0	49,181	4,406	0	0	0	0	0	0	0	687,307	3,819,398	4,560,300
1971	0	2,822	5,200	0	0	0	0	0	0	0	4,759,594	927,004	5,694,619
1972	6,052,646	253,090	1,168,552	99,164	0	0	0	0	0	270,178	0	0	7,843,630
1973	21,864,936	502,736	267,022	397,776	1,116,662	1,762,530	5,233,767	3,858,064	0	0	0	0	35,001,489
1974	0	2,478	2,420	0	0	0	0	0	0	85,130	32,937	0	122,965
1975	464,619	492,150	2,420	0	0	73,207	513,789	0	0	364,337	0	1,738,461	3,648,033
1976	0	2,478	39,302	0	437,116	158,325	578,928	0	0	1,167,449	0	189,270	2,570,869
1977	0	5,659	2,420	0	0	0	0	0	0	934,749	2,645,325	171,768	3,759,911
1978	31,468	27,478	9,367	0	36,655	2,416,794	845,316	0	0	0	0	0	3,367,058
1979	145,614	1,487,500	4,295,832	570,088	2,257,511	1,567,886	3,434,760	253,954	0	0	0	0	14,013,126
1980	0	79,792	18,476	174,185	6,460,884	806,886	2,171,377	599,747	0	0	0	364,117	10,674,063
1981	0	2,478	2,765	0	0	0	0	0	0	1,316,357	0	657,439	1,978,038
1982	1,764,724	3,847	57,368	0	963,683	1,394,832	502,745	0	0	0	3,193,744	1,765,115	9,636,046
1983	0	136,631	1,133,146	206,681	693,072	1,673,860	1,924,481	712,368	0	329,682	1,362,046	1,005,912	9,176,858
1984	3,182,046	106,303	584,592	249,183	0	0	0	0	0	1,028,405	6,065,203	3,412,264	14,625,996
1985	1,639,026	11,064	798,959	1,226,395	991,782	1,948,404	895,938	205,596	0	0	62,975	376,194	8,044,332
1986	0	452,602	279,305	0	273,363	216,448	0	0	0	869,421	217,432	601,702	2,900,273
1987	702,611	464,711	398,861	198,653	493,742	483,623	835,005	0	0	0	1,749,840	0	5,115,047
1988	0	1,864,957	3,043	0	1,539,483	175,778	431,787	0	0	0	2,156,031	872,162	7,033,239
1989	0	5,126	3,650	0	0	0	0	0	0	0	1,203,798	0	1,212,574
1990	0	0	0	0	0	0	1,152	0	0	518,850	687,010	539,210	1,726,222
Average	978,141	183,834	270,302	423,123	531,487	489,871	709,386	160,393	3,410	350,754	1,939,662	964,256	6,986,075
Maximum	21,864,936	1,864,957	4,295,832	6,624,011	6,460,884	2,982,347	5,233,767	3,858,064	177,308	3,625,490	12,265,536	4,907,372	35,001,489
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	84,117
Std. Dev.	3,230,337	382,587	664,978	1,097,137	1,126,426	738,407	1,041,081	587,154	24,361	624,504	2,564,511	1,240,924	5,846,950

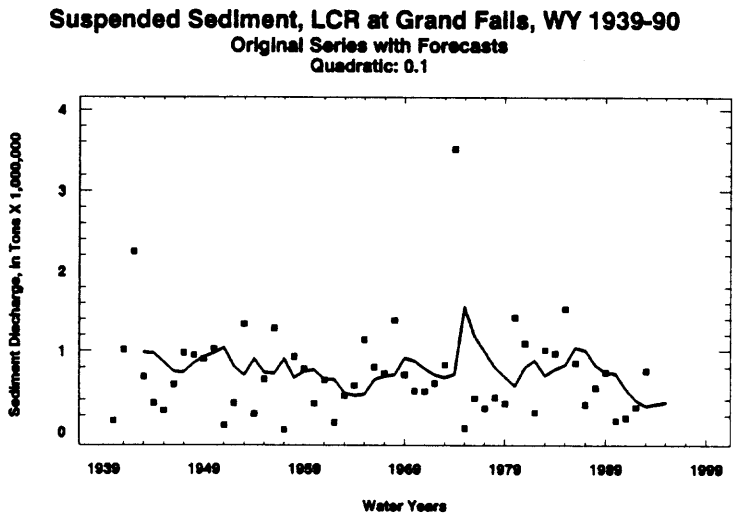


Figure 448. LCR at Grand Falls, Smoothed Annual Sediment Load, WY 1939-90

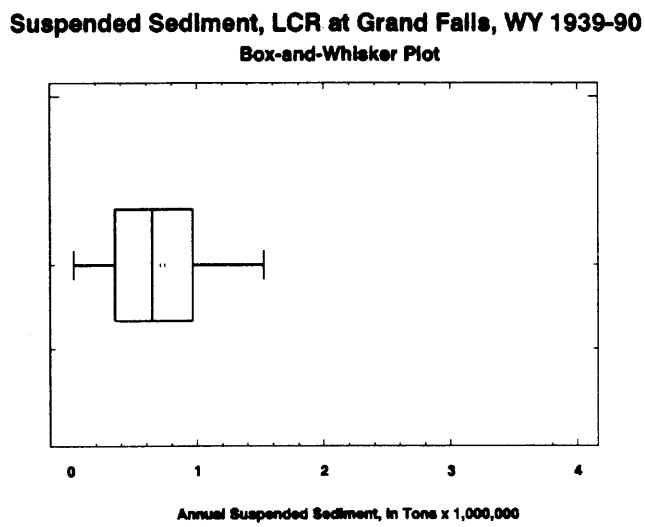


Figure 449. LCR at Grand Falls, Annual Sediment Load Box and Whisker Plot

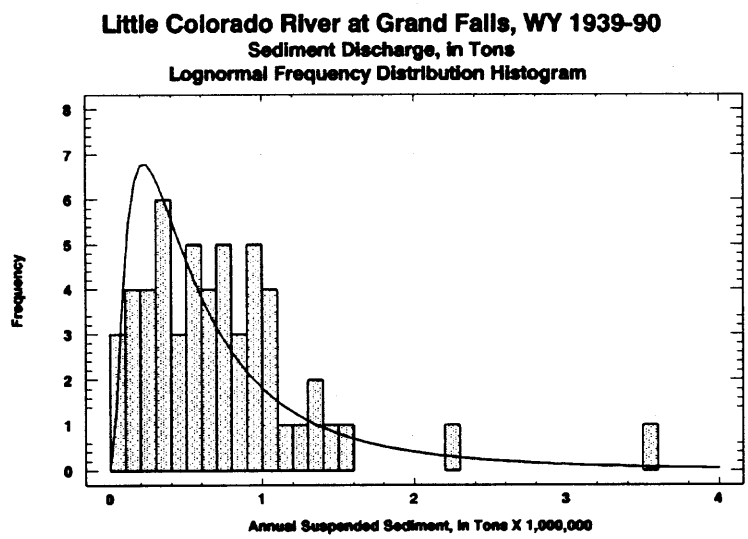


Figure 450. LCR at Cameron, Annual Sediment Load Frequency Histogram

11.6 Bed Load Movement

To be included in the Final Report

11.7 Dry Bed Sampling

Dry bed samples were taken from numerous LCR and tributary stream bed locations in the summer of 1993. The samples were analyzed for particle size distribution and minerals (by acid digestion). Although dry bed sampling is not a quantitative procedure sanctioned by USGS or EPA, it does give a qualitative indication of sediment origins (See Graf, *et al*, 1993, for mention of one example of the method, and Marley and Blandford, 1995, for an estimate of the proportion of suspended fines remaining in the dry bed). It may also provide useful data for any geochemical study of mixtures of waters of different sources as an indication of water quality in the lower Little Colorado.

The procedure followed in taking the samples was as follows: (1.) Find a reach of the stream in which there is a gentle slope and a wide bed, but no depressions for ponding of water. (2.) Take a sample about six inches deep with a round bladed shovel and transfer to a suitable plastic sample bag (about a 1 quart Ziploc). (3.) Document the location, time and date of the sample. (4.) Send the sample to the laboratory (in this case DBS&A and USGS) and await the results.

The following map shows the locations of the samples taken.

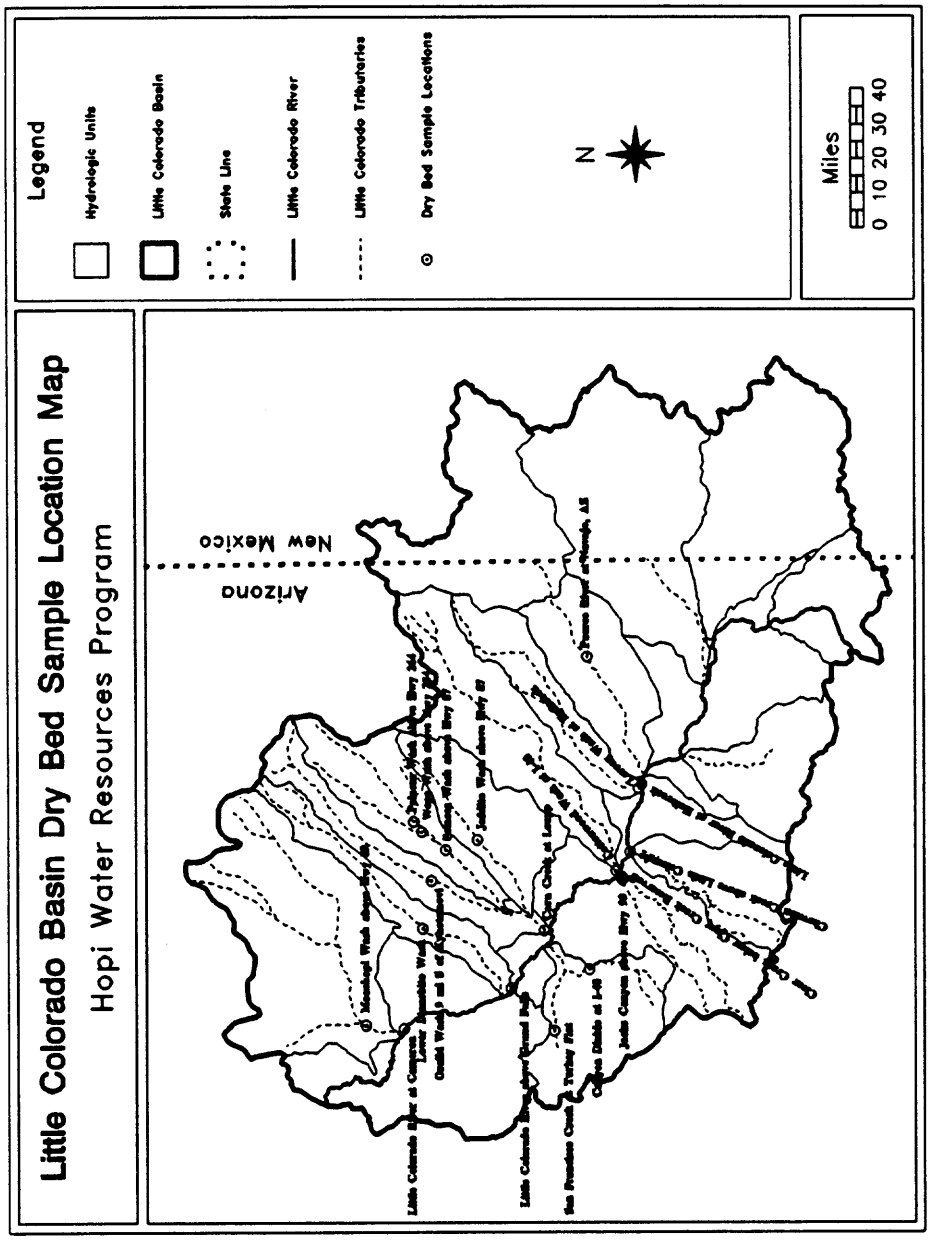


Figure 451. LCR Dry Bed Sample Location Map

Table 139. Dry Bed Samples, Little Colorado Basin, 1993
Hopi Tribe/D. B. Stephens Program for
Glen Canyon Environmental Studies

% Finer Analysis

			Cobbles				Gravel				Sand			Silt			Clay		
Stream	Date	Time	256	128	64	32	16	8	4	2	1	0.5	0.25	0.125	0.0625	0.031	0.016	0.008	0.004
LCR Grand Falls	07/27/93	0800	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	85.0	54.7	23.3	8.6	4.2	2.9	2.2
San Francisco Ck.	07/29/93	0900	100.0	100.0	100.0	100.0	100.0	99.7	99.4	98.0	88.7	54.5	14.3	8.3	1.3	0.0	0.0	0.0	0.0
Canyon Diablo	07/28/93	1905	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.7	95.0	75.9	33.1	9.4	6.8	4.1	2.4	1.4
Jacks Canyon	07/28/93	0745	100.0	100.0	100.0	100.0	100.0	99.8	97.1	89.4	73.4	49.1	27.8	13.7	2.9	0.0	0.0	0.0	0.0
Clear Creek	07/28/93	0840	100.0	100.0	100.0	97.3	97.0	93.5	88.3	87.1	76.6	71.2	67.3	45.5	12.5	5.6	3.4	2.8	2.2
Chevelon Creek	07/28/93	1010	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.1	97.5	92.8	68.7	9.7	4.7	2.6	1.7	1.2
Leroux Wash	07/28/93	1350	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.3	94.5	55.1	5.9	0.6	0.0	0.0	0.0	0.0
Cottonwood Wash	07/28/93	0700	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	88.2	30.9	20.0	10.7	8.7	7.6	6.2
Oraibi Wash	07/29/93	1350	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	96.0	71.1	17.7	5.1	0.0	0.0	0.0	0.0
Polacca W. @ 87	07/27/93	1425	100.0	100.0	100.0	80.3	72.3	69.8	67.7	67.1	65.7	63.6	55.1	50.4	50.0	35.6	32.4	29.5	25.2
Polacca W. @ 264	07/27/93	1300	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.6	99.1	97.7	56.4	8.3	2.3	0.0	0.0	0.0	0.0
Wepo Wash	07/27/93	1345	100.0	100.0	100.0	98.8	98.4	98.2	97.9	97.1	93.5	70.5	39.1	27.8	26.0	21.1	18.0	14.8	11.3
Jeddito Wash	07/27/93	1610	100.0	100.0	100.0	100.0	100.0	99.9	99.6	99.0	95.3	82.8	54.7	17.8	2.6	0.0	0.0	0.0	0.0
LCR Holbrook	07/28/93	1420	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.3	83.3	16.7	5.6	0.0	0.0	0.0	0.0
Puerco River	07/28/93	1610	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	97.3	87.7	71.2	49.7	31.6	12.5	6.3	4.3	3.1
LCR Cameron			100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	95.1	41.5	10.6	3.8	1.9	1.1	0.8
Moenkopi Wash @ 89			100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.2	87.7	50.1	10.8	3.0	2.7	1.8	1.1
Corn Creek @ Leupp			100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	93.6	66.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Lower Dinnebito			100.0	100.0	100.0	100.0	99.5	97.2	92.9	87.6	82.7	74.1	41.4	9.2	1.8	0.7	0.5	0.4	0.3

The following subsections graphically present the particle size data for each drainage sampled. Note that Puerco River, Wepo Wash, and Polacca Wash below the confluence with Wepo Wash contain fines (such as silt and clay). At Corn Creek below Tolani Lake, the fines are no longer present in the dry stream bed. The rest of the drainages are basically sand channels.

11.7.1 Little Colorado River near Cameron

The Little Colorado River near Cameron strean gage has a continuous period of record since WY 1948. As a consequence of the importance of this gage, the flows from 1939 to 1948 were reconstructed by DBS&A (Marley, 1994) at the request of the Hopi Tribe to facilitate the analyses contracted by the Tribe with Glen Canyon Environmental Studies group.

The dry bed sample from LCR near Cameron represents all major LCR flows except Moenkopi Wash and Blue Spring. The analyzed sample indicates that the LCR near Cameron is primarily a sand channel with little silt and clay present. In fact, the sand present in the dry bed is relatively fine, about 0.2 to 0.5 mm in size.

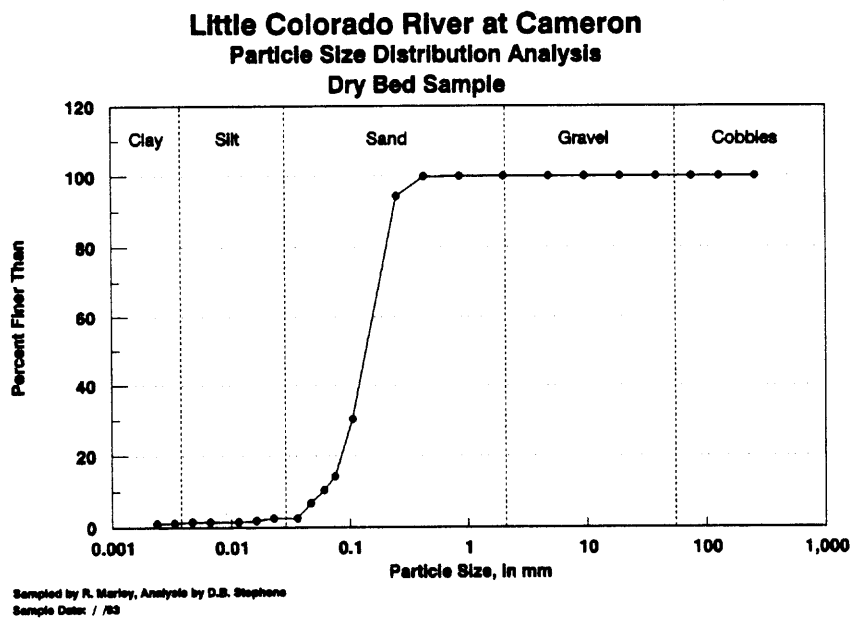


Figure 452. LCR at Cameron, Particle Size Analysis, Dry Bed Sample

11.7.2 Little Colorado River at Grand Falls

The Little Colorado River at Grand Falls stream gage has a period of record from 1926 to 1960 and from 1990 to the present. The WY 1939-90 study period data has been reconstructed by DBS&A (Marley, 1994) at the request of the Hopi Tribe to facilitate the analyses contracted by the Tribe with Glen Canyon Environmental Studies group.

The dry bed sample from LCR at Grand Falls represents all major LCR flows except Dinnebito Wash, Moenkopi Wash, and Blue Spring. A comparison of the sediment differences between Grand Falls and Cameron indicates the particle size distribution difference due to the contribution of Dinnebito Wash plus minor local drainages. However, there appears to be more fines present at Grand Falls than at Cameron, indicating that a detention area exists between the Dinnebito confluence and Cameron. There is slightly more coarse sand present, perhaps indicating a greater transport velocity at Grand Falls, or indicating the presence of a detention area.

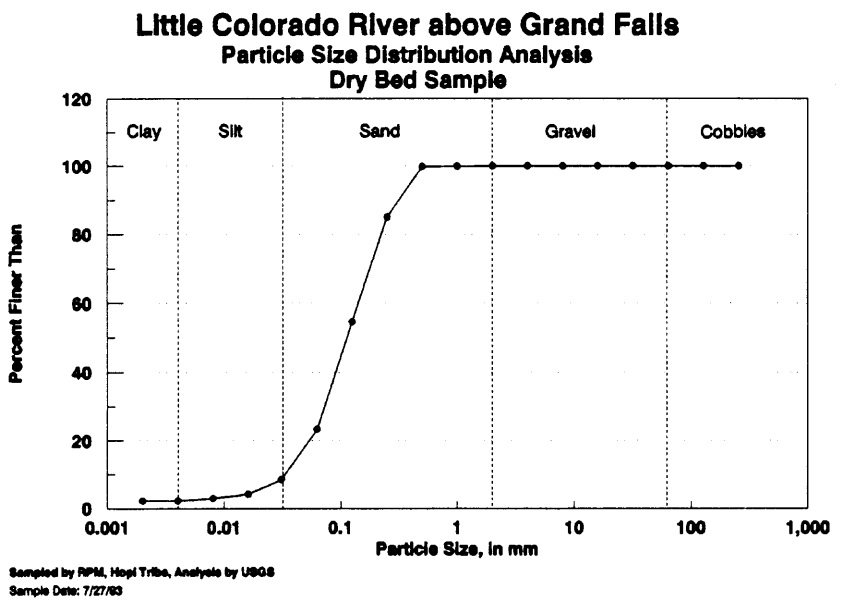


Figure 453. LCR at Grand Falls, Particle Size Analysis, Dry Bed Sample

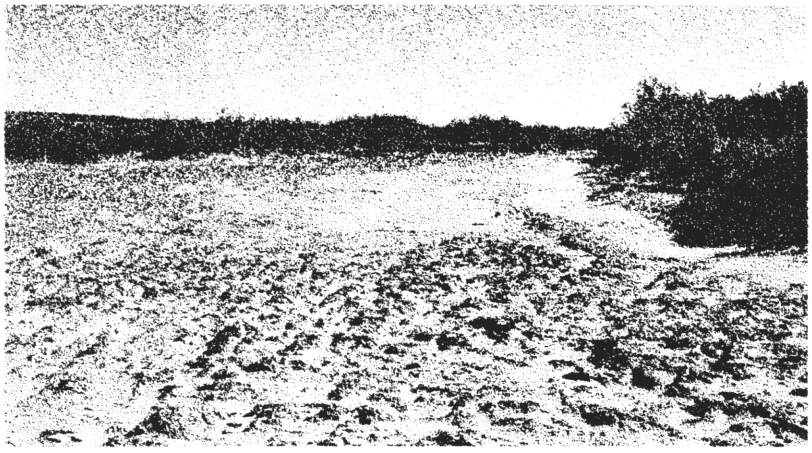


Figure 454. LCR above Grand Falls, Dry Bed Sample Location

11.7.3 San Francisco Creek at Turkey Flat Dam

San Francisco Creek is an ungaged drainage which contains all the waters of Rio de Flag (which transports treated wastewater from Flagstaff), Shultz Wash, and other drainages between Flagstaff and Turkey Flat. Turkey flat is an impoundment structure which has been completely infilled with sediment, located about ten miles east along Leupp Road from Townsend-Winnona Road in the Flagstaff area.

The dry bed sample from San Francisco Creek represents only local flows. The particle size distribution shows only sand from the sieve analysis. The sand contains more coarse sand and more fine sand than the LCR stream bed. The material is fairly dark, being a mixture of light sand sprinkled with dark volcanic material.

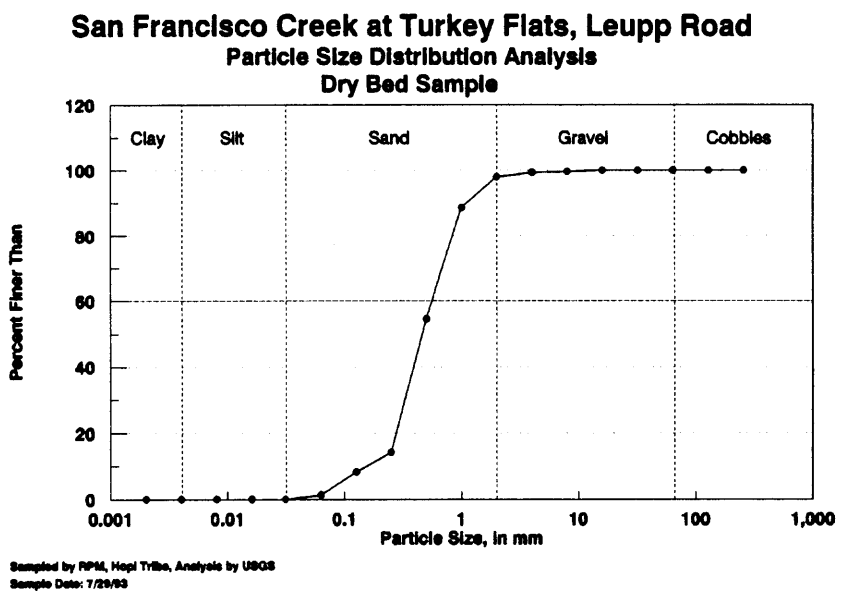


Figure 455. San Francisco Creek, Particle Size Analysis, Dry Bed Sample

11.7.4 Little Colorado River at Holbrook

The Little Colorado River at Holbrook dry bed sample was taken from a reach of the stream located approximately where there was a stream flow gaging station from 1905 to 1907 and from 1950 to 1974. The station record is tabulated in Section 9.1.3. This reach of the LCR is identified by DBS&A (Marley and Blandford, 1995) as having considerable sediment in storage.

The particle size analysis shows this part of the LCR bed to be entirely a sand channel, with no evident silt or clay present. In this way the analysis closely resembles that of the dry bed sample taken at LCR near Cameron.

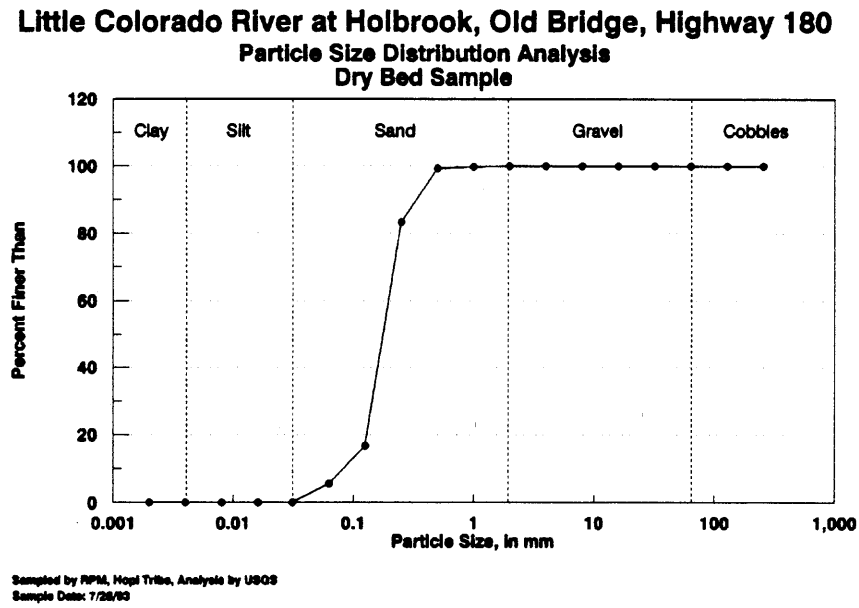


Figure 456. LCR at Holbrook, Particle Size Analysis, Dry Bed Sample

11.7.5 Moenkopi Wash at Highway 89

This sample was taken by DBS&A (Marley, 1993) in the middle of the Moenkopi Wash bed just upstream of Highway 89. No gaging station on the wash is located near here.

The particle size analysis is very similar to the LCR near Cameron with the exception of a few silt and clay size particles.

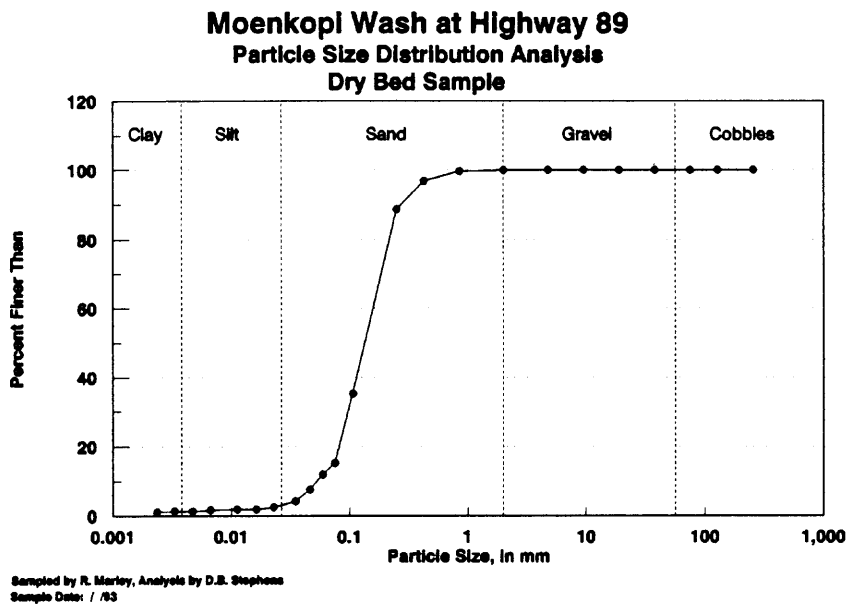


Figure 457. Moenkopi Wash at Highway 89, Particle Size Analysis, Dry Bed Sample

11.7.6 Canyon Diablo at Two Guns

Canyon Diablo was well known as a stagecoach stop during the late 1800's. The buildings now lie in ruins near Two Guns Trading Post along Interstate Highway 40. Additionally, meteorite from the nearby Meteor Crater was first recognized from samples taken from the canyon, hence the name "Canyon Diablo Iron" for this rare form of nickel-iron alloy.

The dry bed sample was taken from the wash bed within the canyon just north of Two Guns and just south of I-40 highway. The creek is slightly sinuous throughout the reach, but the incline (slope) of the bed is even and slight. The particle size analysis is typical of the LCR main stem bed, except for a number of silt-sized particles. The color was a normal brownish shade.

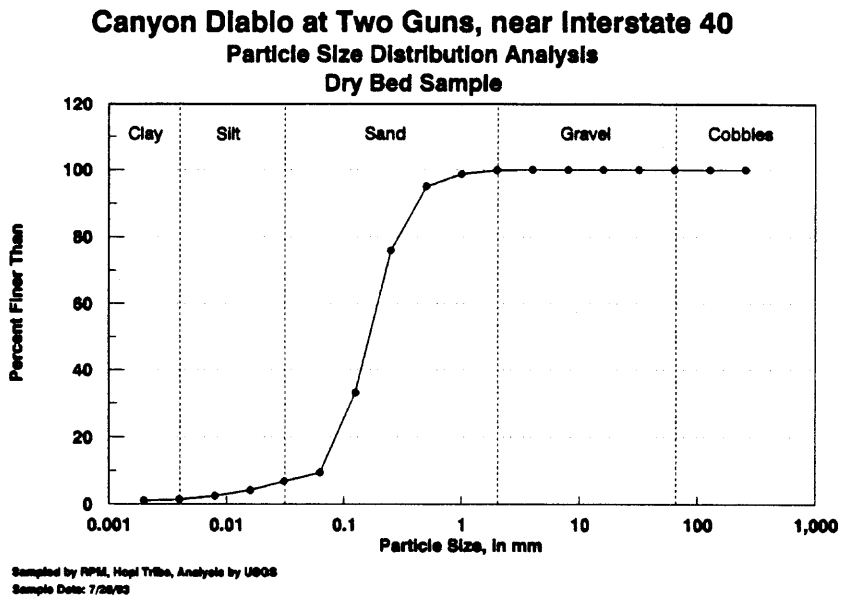


Figure 458. Canyon Diablo at Two Guns, Particle Size Analysis, Dry Bed Sample

11.7.7 Dinnebito Wash near Sand Springs

Dinnebito Wash is the major northern drainage with a confluence between Grand Falls and Cameron. The wash lies in a southwesterly to northeasterly valley, east of Moenkopi Wash. This sample was taken by DBS&A (Marley, 1993) near the center of the steam bed just north of Sand Spring on Dinnebito Wash.

The dry bed sample particle size analysis shows that Dinnebito Wash differs from the main stem Little Colorado River bed in that a greater percentage of coarse sand and fine gravel is present. Particles finer than medium sand are found in a very low percentage.

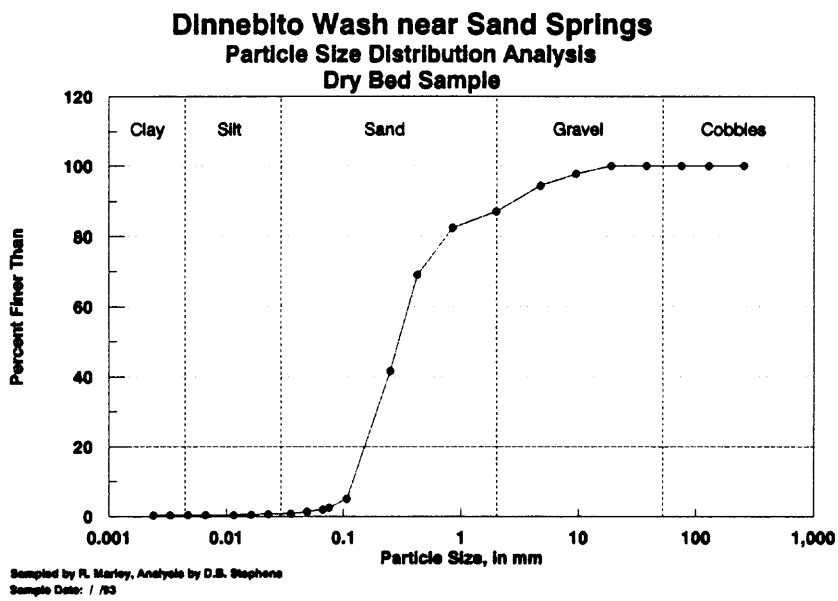


Figure 459. Dinnebito Wash near Sand Springs, Particle Size Analysis, Dry Bed Sample

11.7.8 Oraibi Wash, Highway 264, Ten (10) miles south of Kykotsmovi

Oraibi Wash lies just to the east of Dinnebito Wash in a southwesterly to northeasterly valley parallel to Dinnebito and Polacca Valleys. Oraibi Wash has a confluence with Polacca Wash just upstream of Tolani Lake, north of Leupp. Jeddito Wash joins the two others just downstream of Tolani Lake. Thereafter, the combined drainage is known as Corn Creek, which joins the Little Colorado River within two miles east of Leupp.

The particle size analysis from the dry bed sample taken 10 miles south of Kykotsmovi, is indicative of a typical sand channel such as the LCR near Cameron, which it resembles.

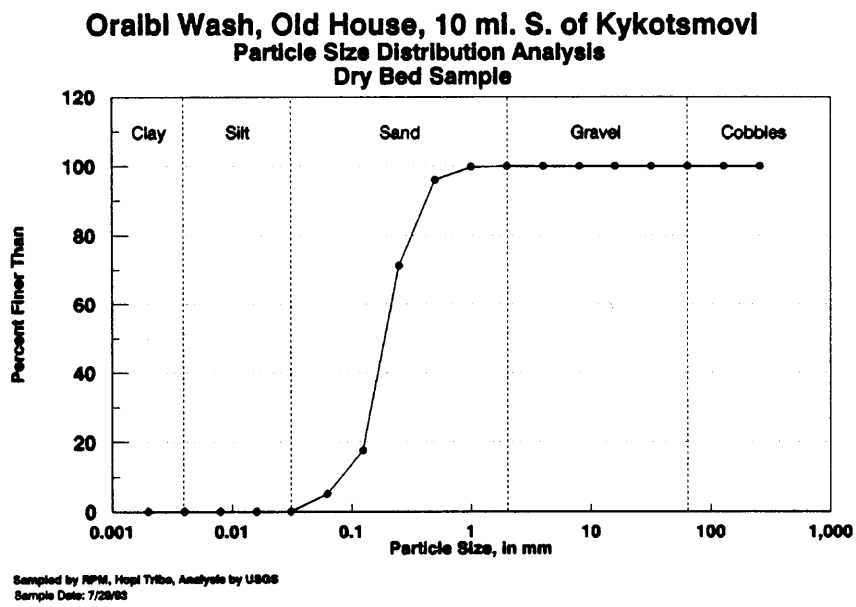


Figure 460. Oraibi Wash, 10 mi. S of Kykotsmovi, Particle Size Analysis, Dry Bed Sample

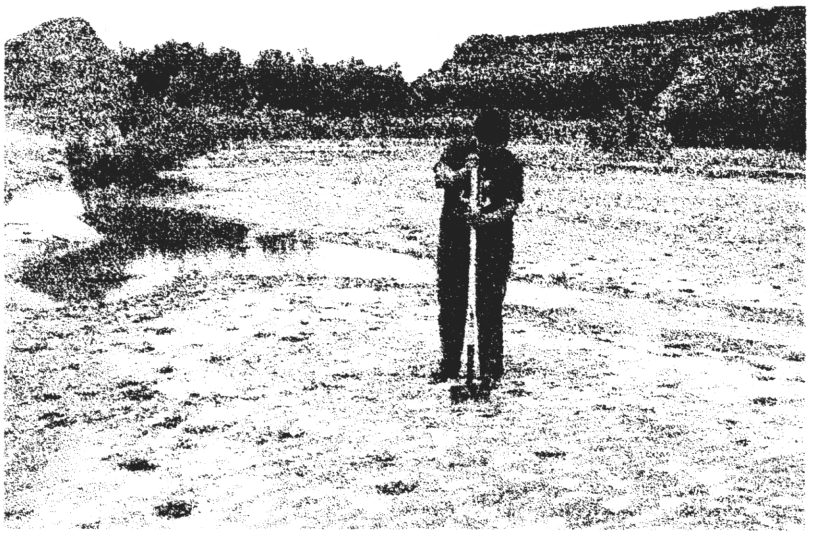


Figure 461. Oraibi Wash, Dry Bed Sample Location

11.7.9 Wepo Wash at Highway 264

Wepo Wash is a western tributary of Polacca Wash. The Wepo Valley is noted for its deposits of fine, pottery quality clay, from which residents of the First Mesa at Hopi make world renowned fired clay bowls and pots. The confluence of Wepo Wash and Polacca Wash, the next major drainage to the east of Oraibi Wash, is just south and downstream of the east-west coursing Highway 264.

The dry bed sample was taken just upstream of the highway in the center of the wash, in an area where the slope is slight and the stream course is straight. The particle size analysis shows a considerable portion of silt and clay fines, along with some gravel. This is the most silty dry bed sample taken during the project.

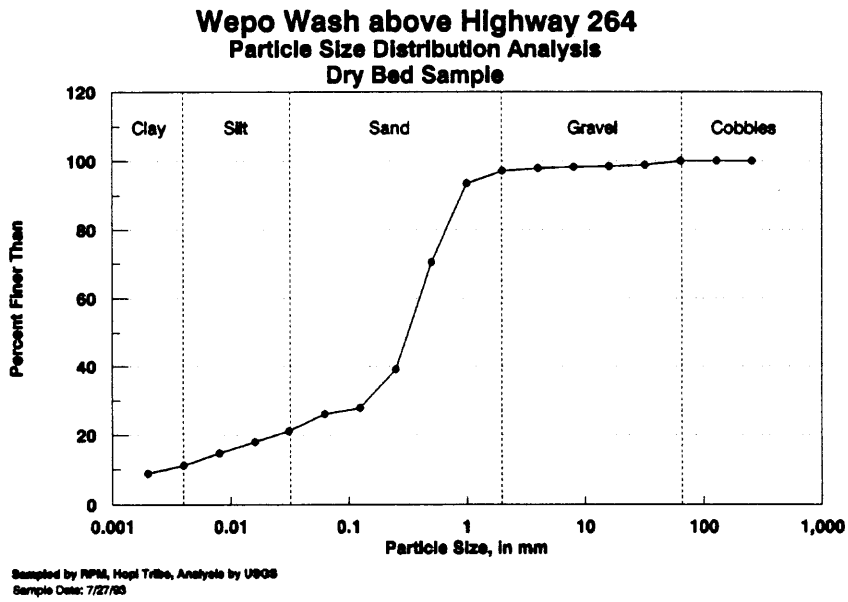


Figure 462. Wepo Wash at Hwy 264, Particle Size Analysis, Dry Bed Sample

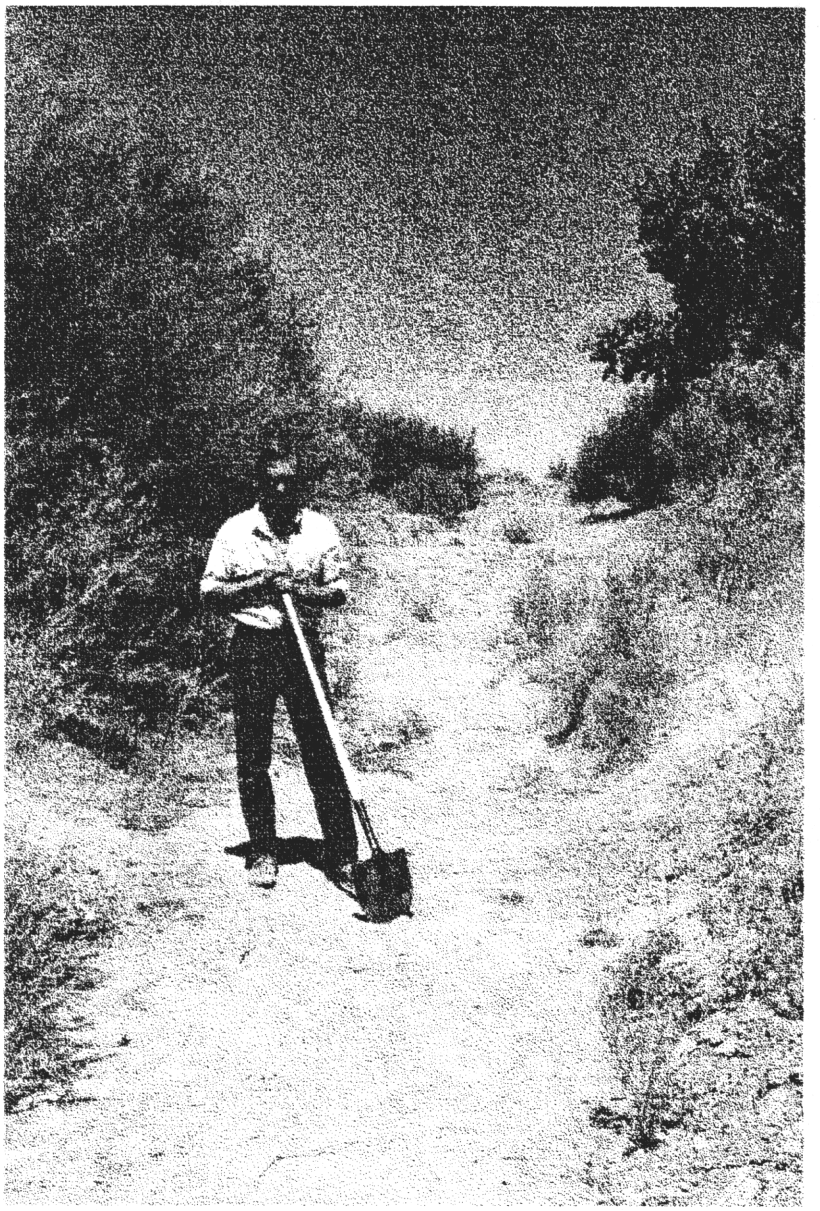


Figure 463. Wepo Wash at Hwy 264, Dry Bed Sample Location

11.7.10 Polacca Wash at Highway 264

Just east of Wepo Wash, Polacca Wash crosses Highway 264. The two washes run more or less parallel for about four miles, where they meet in an arroyo cut into the alluvium. The dry bed sample was taken just upstream of the bridge at Highway 264.

The particle size analysis from the sample indicates that Polacca Wash is a sand channel with few fines. The sand, however, is somewhat finer than that of the main stem LCR bed.

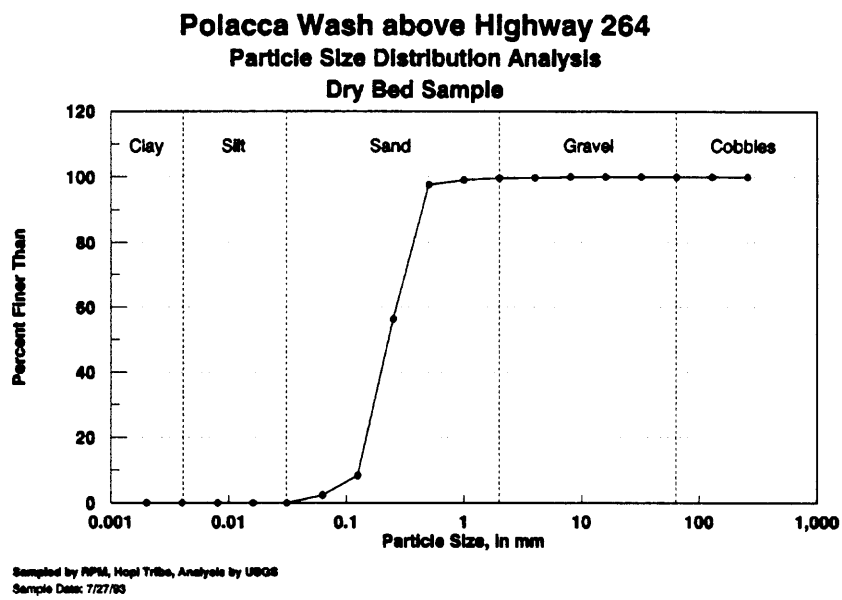


Figure 464. Polacca Wash at Hwy 264, Particle Size Analysis, Dry Bed Sample

Figure 465. Poacca Wash at Hwy 264, Dry Bed Sample Location

11.7.11 Polacca Wash at Highway 87

Polacca Wash meets Wepo Wash just upstream of the Highway 87 crossing. At the bridge crossing, Polacca Wash is a deeply incised channel, with brush and tumbleweed growing along its banks. The dry bed sample was taken just downstream of the crossing in a moderately sloping straight reach of the channel.

The dry bed sample particle analysis shows more fines than Polacca Wash at the Highway 264 bridge, upstream of the confluence with Wepo Wash (see preceeding subsection). The distribution differs from Wepo Wash in that there are a number of gravel sized particles present. This material represents the combined sediment load of both Wepo and Polacca Wash, plus material from the intervening alluvium, which must contain a certain amount of fine gravel.

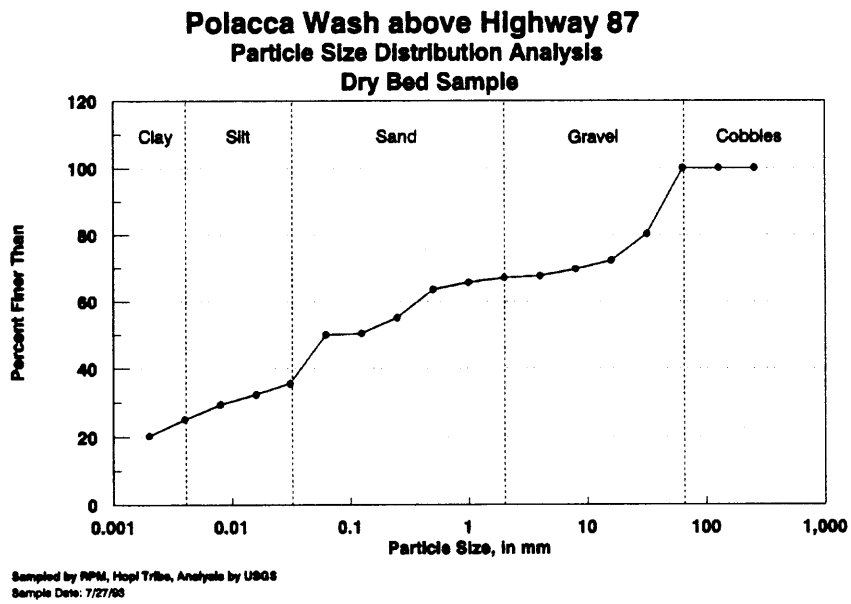


Figure 466. Polacca Wash at Hwy 87, Particle Size Analysis, Dry Bed Sample

11.7.12 Jeddito Wash at Highway 87

Jeddito Wash at Highway 87 on the Hopi Reservation south of Polacca contains waters from the Navajo Partitioned land and local sub-watersheds from the Hopi Reservation. At the Highway 87 bridge, Jeddito Wash is a deeply incised channel. The wash runs from northeast to southwest. Jeddito Wash joins Corn Creek downstream of Tolani Lake, and probably provides much of the sediment carried by Corn Creek to the main stem Little Colorado River from the northern tributaries. Despite the relatively large watershed, roughly equal in area to that of Oraibi and Polacca Washes, Jeddito peak flow projections indicate that the amount of water carried is substantially less than that of the other northern washes. This is possibly due to the lower elevation of most of the Jeddito watershed.

The particle size analysis of the dry bed sample, which was taken just downstream of the Highway 87 bridge, provides evidence that Jeddito Wash is basically a sand channel. The sample was deficient in gravel, silt, and clay.

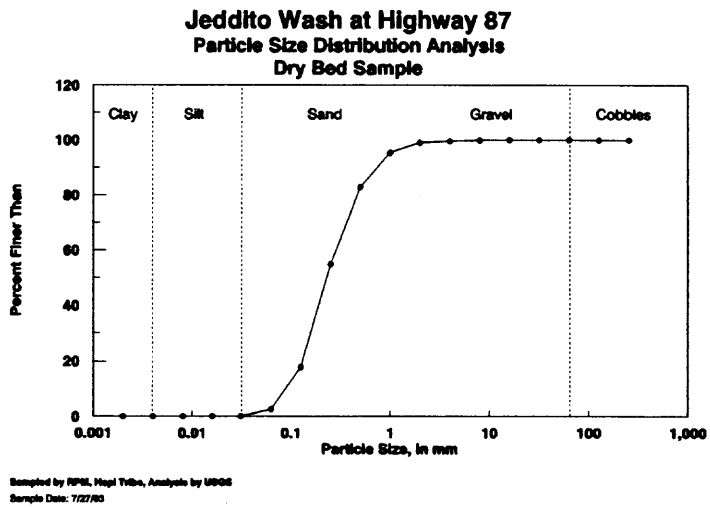


Figure 467. Jeddito Wash at Hwy 87, Particle Size Analysis, Dry Bed Sample

Figure 468. Jeddito Wash, Dry Bed Sample Location

11.7.13 Corn Creek near Leupp

Corn Creek near Leupp contains flows from Oraibi, Wepo, Polacca, and Jeddito Washes which run from northeast to southwest, originating in the northern portion of Black Mesa on the Hopi and Navajo Reservations. Prior to its arrival in Leupp, Corn Creek tributaries flow into Tolani Lake, which is a natural depression in the Little Colorado River Valley. This lake detains all but the highest flows from the tributaries, allowing much of the sediment to settle before the water reaches Leupp.

The particle size analysis from the dry bed sample taken by DBS&A, Robert Marley, indicates that the sediment once again resembles the sand channel deposits of the main stem Little Colorado River. The sand is somewhat more coarse than the main stem sediment.

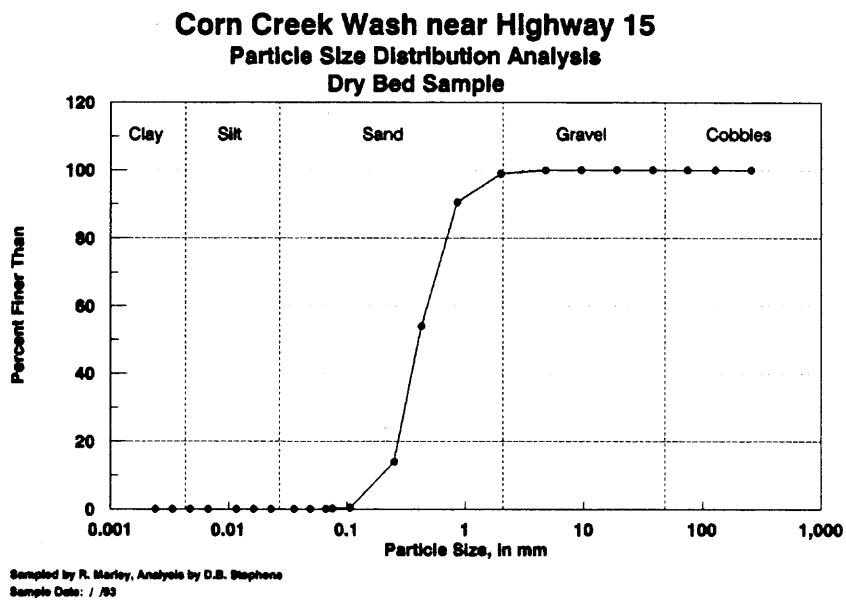


Figure 469. Corn Creek near Leupp, Particle Size Analysis, Dry Bed Sample

11.7.14 Cottonwood Wash near I 40

Cottonwood Wash flows from northeast to southwest through the Navajo Reservation, joining the Little Colorado River just east of Winslow. The dry bed sample was taken from the north side of I-40 in the deeper of the two divided channels. The bed and the banks are heavily infested with salt cedar trees of considerable size and density.

The analysis of the dry bed sample is similar to the main stem LCR bed, except that a certain amount of silt and clay fines are present. The wash is not detained upstream by impoundments or natural depressions to allow the settling of sediment from the water.

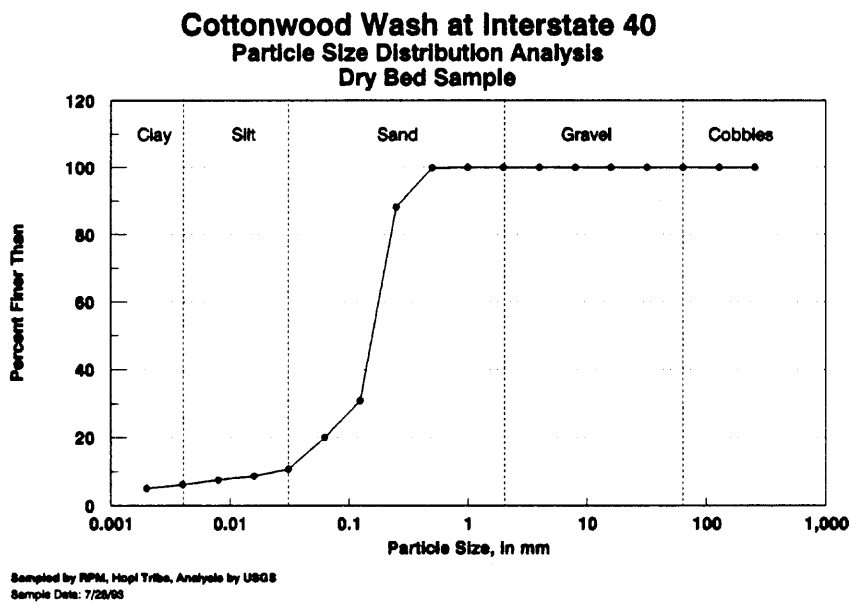


Figure 470. Cottonwood Wash near I 40, Particle Size Analysis, Dry Bed Sample

11.7.15 Jacks Canyon near Winslow

Jacks Canyon Wash originates in the Mogollon Plateau to the southwest of Winslow. The narrow, sinuous canyon probably does not have a high flow, judging from the morphology of the canyon and stream bed. The dry bed sample was taken just upstream of the Highway 99 crossing in a winding, narrow slightly sloped reach of the stream.

The particle size analysis of the dry bed sample indicates a sand channel, with some pea gravel sized particles. Otherwise, the material is not noticeably different from the main stem LCR bed.

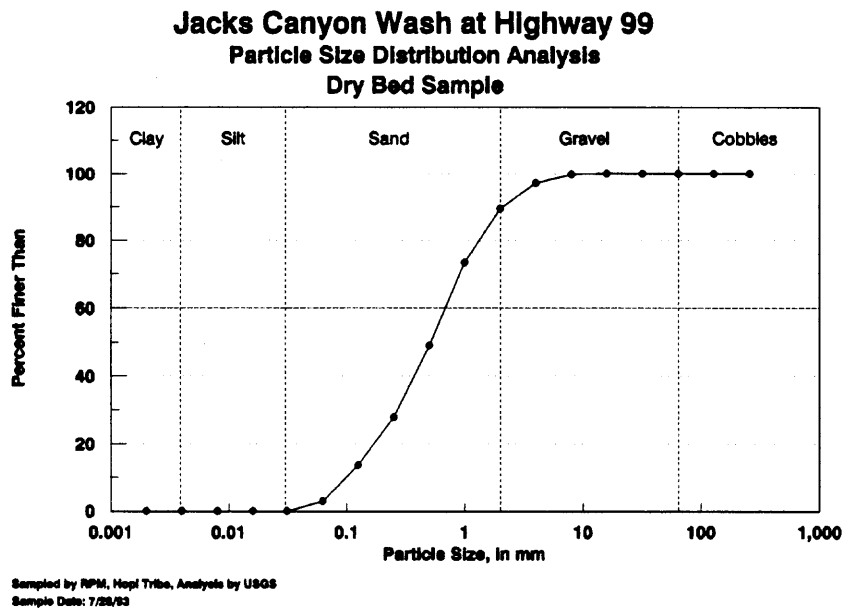


Figure 471. Jacks Canyon near Winslow, Particle Size Analysis, Dry Bed Sample

11.7.16 Chevelon Creek near Winslow

Chevelon Creek originates high on the Mogollon Plateau, near the Mogollon Rim. Heavy snowfalls give the stream a considerable flow during the spring snowmelt. Thunderstorms during the fall monsoons bring brief heavy flows. This high velocity stream cuts a scenic, narrow and sinuous canyon some 200 feet deep into the plateau several miles upstream of its entry upon the floor of the Little Colorado River Valley. The dry bed sample was taken from the bed just downstream of the canyon mouth, after a considerable hike from the highway bridge.

The particle size analysis shows basically a sand channel with few silt sized particles. Most of the sand is finer than that of the main stem channel.

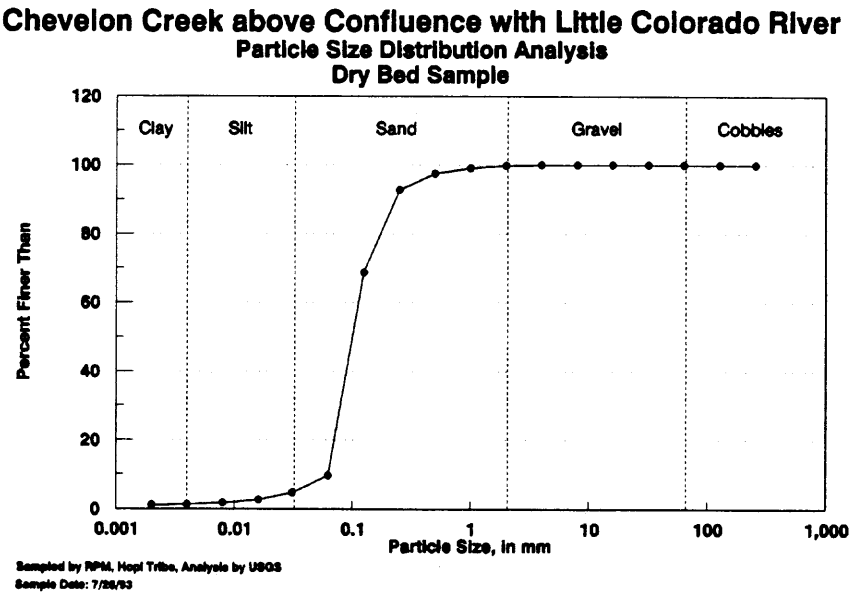


Figure 472. Chevelon Creek near Winslow, Particle Size Analysis, Dry Bed Sample

11.7.17 Leroux Wash near Broadcast Avenue at Holbrook

Leroux Wash joins the Little Colorado River just west of Holbrook, near the transmitter of the local radio station. During the floods of January, 1993, the transmitter and studio were inundated by Leroux Wash flows. The bed is deep with sand, and the banks are lined with dense and extensive growths of salt cedar. The dry bed sample was taken about 1/4 mile upstream of the Broadcast Avenue crossing, to avoid a disturbance caused by a water works construction project. The wash flows from northeast to southwest, originating in the southeast corner of the Navajo Reservation.

The analysis of the dry bed sample shows Leroux Wash to be basically a sand channel, not unlike the LCR at Holbrook.

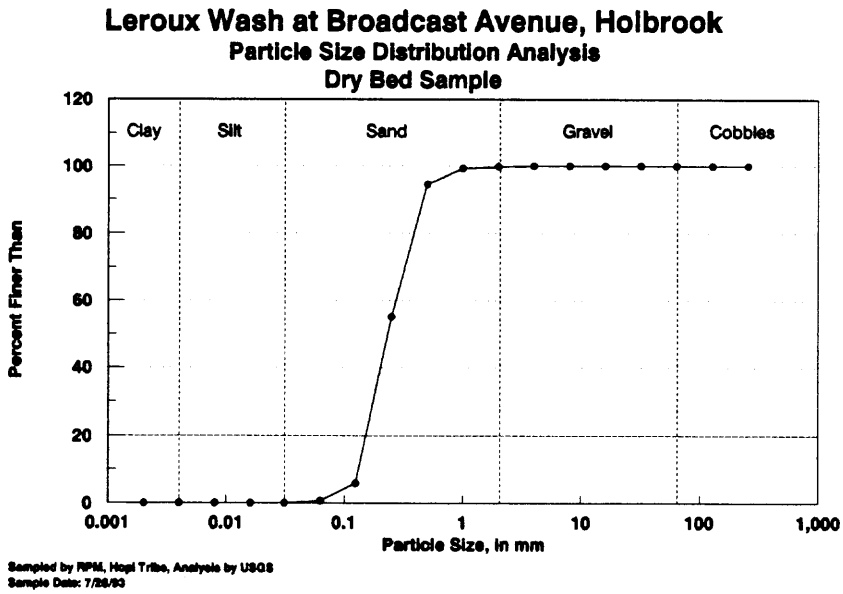


Figure 473. Leroux Wash near Broadcast Ave. at Holbrook, Particle Size Analysis, Dry Bed Sample

11.7.18 Puerco River at Navajo, AZ

Puerco River originates in the mountains of eastern New Mexico. The river runs mostly from east to west in its sinuous, mostly broad valley. In the long, gently sloping reach between just east of Gallup to Holbrook, many desert drainages join the main stem Puerco. According to DBS&A (Marley and Blandford, 1995), much of the flow and sediment in the Little Colorado River originates in the Puerco River system. The dry bed sample was taken at Navajo, Arizona, some 35 miles east of Holbrook, where the stream bed was easily accessible.

The dry bed sample resembles the main stem LCR at Grand Falls, with slightly more fines. This is again a basic sand channel with a broadly distributed selection of sand particle sizes.

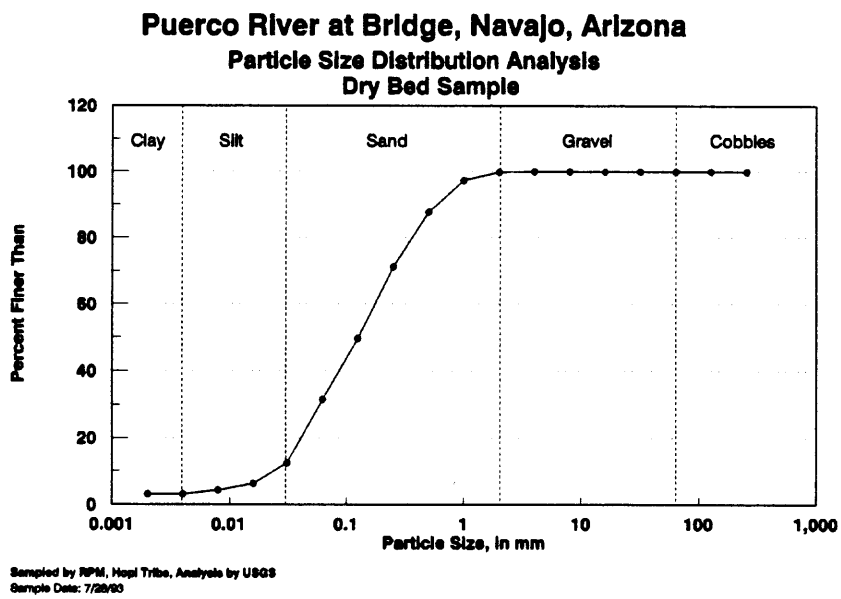


Figure 474. Puerco River at Navajo, Particle Size Analysis, Dry Bed Sample

11.7.19 Sand, Silt, and Clay Fractions in the Little Colorado Basin

A trilinear graph of the sand, silt, and clay fractions from the dry bed samples from the streams enumerated above. It will be noted that most of the samples lie along the sand-silt axis, with only Wepo, Polacca, and Cottonwood Washes containing any tendency toward clay sized particles. This dry bed sampling and analysis procedure has yielded results which are supportive of the central sediment transport thesis for the LCR contained in the DBS&A report (Marley and Blandford, 1995) that the sediment originates in the Puerco River system and is transported downstream by the additional flows of the LCR and its tributaries. The tributaries, of course, add their own sediment load to the stream, but the dynamics of the sediment system are driven by Puerco River loads.

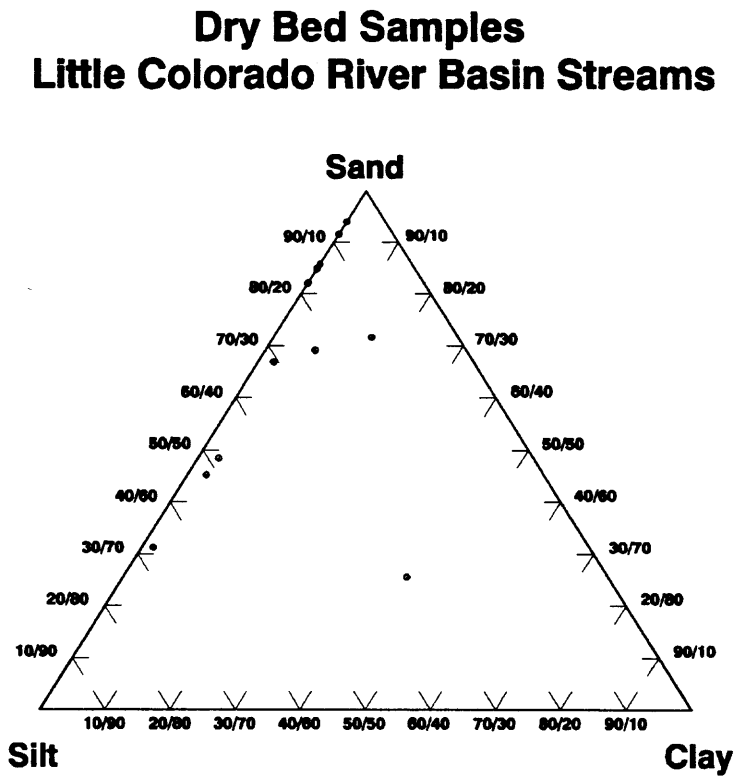


Figure 475. Sand, Silt, and Clay Fractions, Dry Bed Samples, LCR and Tributaries

11.8 Mineral Analyses of Dry Bed Samples

The mineral analyses were standardized due to the great difference in scale between the various component elements. The following star plots demonstrate which tributary beds are enriched or deficient in various mineral ions. Note that the Little Colorado main stem bed shows continuity at the various sampling points, whereas there is a greater variety in the tributary values. It would appear that much of the material in the Little Colorado comes from Puerco River, Dinnebito Wash, and the upper Little Colorado River. The material from most of the northern washes have unique chemical signatures not apparent in the main stem.

The values from the mineral analyses were converted to standard deviations in order to enable comparison between constituents on the same scale. The analyses were performed by acid digestion in the US Geological Survey laboratory in accordance with the procedures indicated in Fishman and Friedman (1989, pp. 45-50 and 515-545).

The following illustration is the key to the major ions in the star plot. The star plot shows a tendency of the Puerco sediment star shape to Holbrook. After Holbrook, the sediment gains manganese from Cottonwood Wash, Leroux Wash, and Corn Creek. The star shape for LCR at Grand Falls shows the additional manganese. LCR at Cameron is not noticeably different from Grand Falls, even though Dinnebito Wash joins the main stem in that reach. Most interesting, however, are the sediments from Wepo, Oraibi, Polacca and Jeddito Washes. Wepo and Polacca add Mn to the Corn Creek system, whereas Oraibi and Jeddito are deficient in Mn. Corn Creek acquires highly mineralized sediment between the Jeddito confluence and the Leupp Highway bridge.

Like the particle size distribution analyses in the previous sections, the mineral analyses are supportive of the central thesis of the sediment modeling activities of DBS&A (Marley and Blandford, 1995).

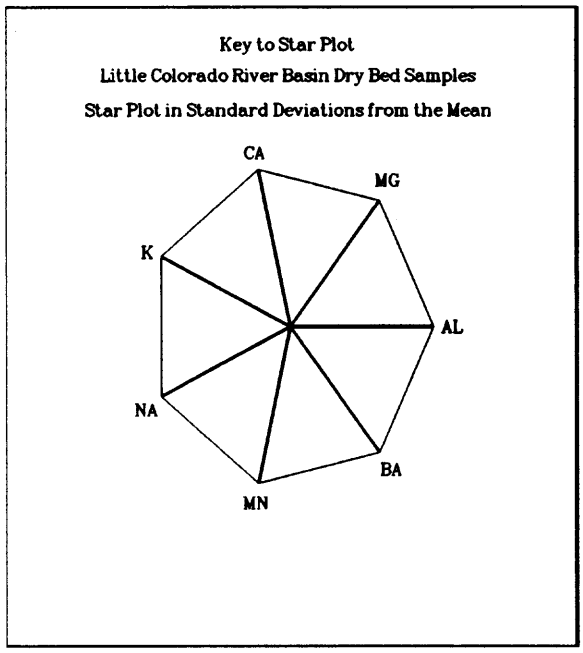


Figure 476. Key Diagram to Star Plot of Dry Bed Sample Mineral Analyses

Where: Mg = magnesium

Al = aluminum

Ba = barium

Mn = manganese

Na = sodium

K = potassium

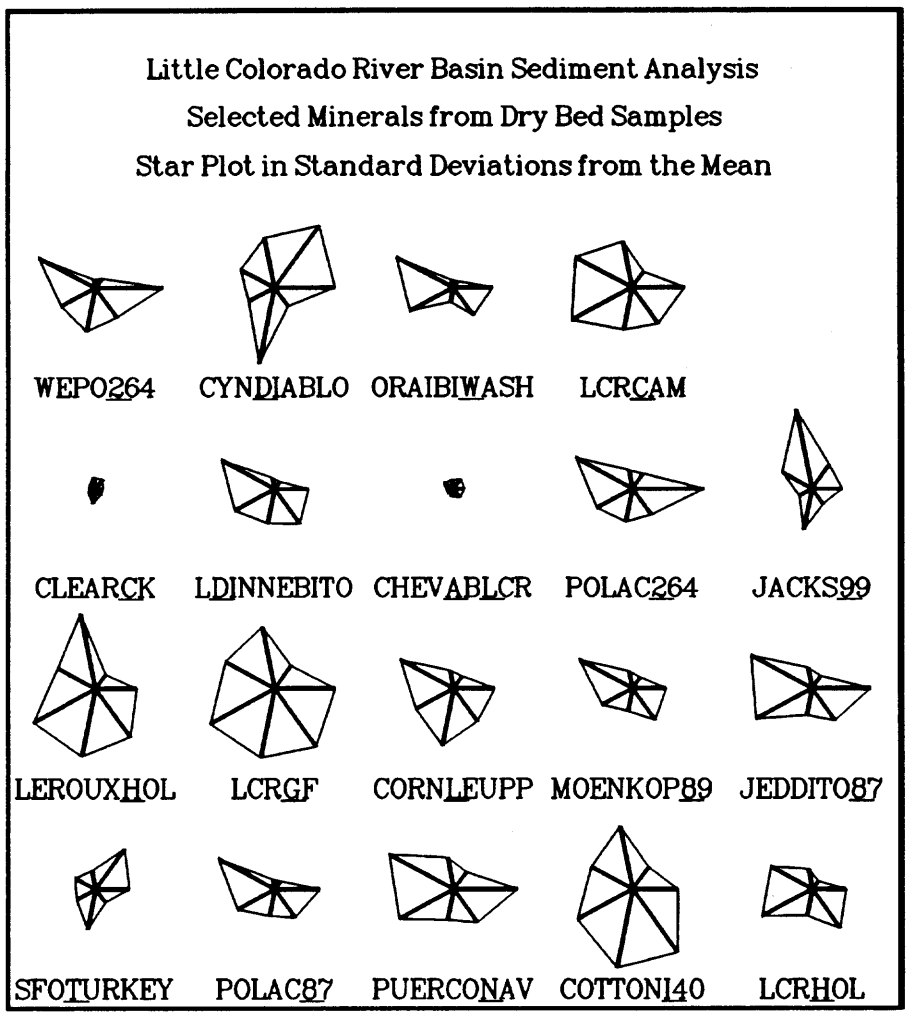


Figure 477. Star Plot, Standardized Dry Bed Sample Mineral Analyses, LCR and Tributaries

12 Water Quality within the Little Colorado River Basin

The quality of water determines the support status of the designated uses. For example, a drinking water source must meet Safe Drinking Water Act water quality standards.

The following sections examine available water quality data within the Little Colorado River to estimate the uses supported by the quality of water for the various sources. Environmental, traditional, and modern uses are discussed.

12.1 Groundwater Basins and Water Quality

TO BE COMPLETED IN FINAL REPORT, 9/30/95

12.2 Base Flow and Spring Discharge Quality Data

The spring of primary environmental interest is Blue Spring, located near mile 3.1 of the Little Colorado, as measured from the mouth. It is to be noted in the following Piper diagram that the discharges from the various springs and the mean of the LCR main stem vary widely. Although there is a paucity of water quality data on the Little Colorado and the springs which feed the perennial reach, it is obvious that the quality of water in the critical habitat area for the humpback chub must vary greatly with the seasons, such as when storm flows mix with the spring discharges. In the upper Little Colorado, percolation and evaporation losses are too great for the tributary base flows to contribute significantly to main stem water quality. The existence of a long period of zero (0) flows in the Little Colorado River indicate that a small portion of storm and snowmelt flows are available to influence water quality during the spawning period of the humpback chub.

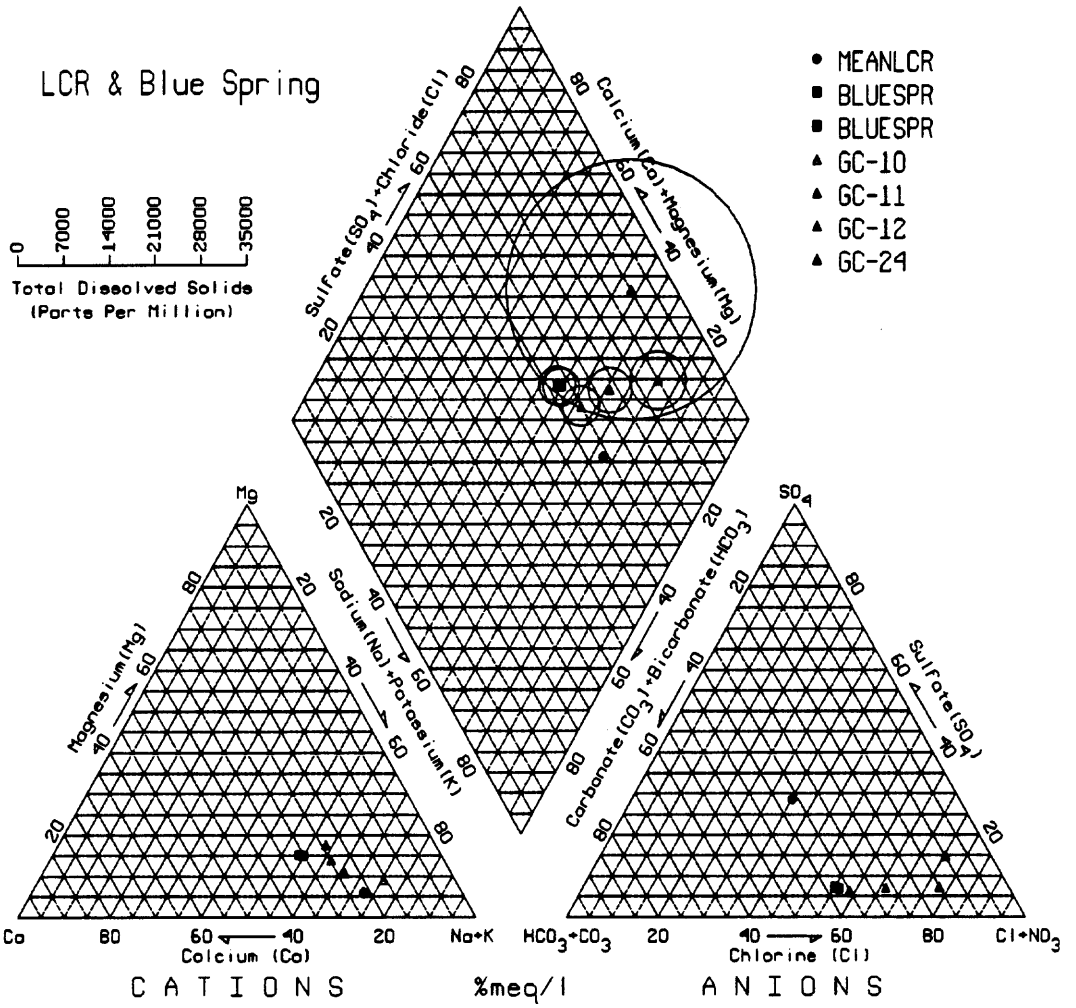


Figure 478. Piper Diagram, LCR at Cameron and Blue Spring

12.3 Water Quality in the lower Little Colorado River

The humpback chub is thought to be sensistive to various water quality parameters. Historical water quality data is available at Blue Spring (in June) and at Little Colorado River at Cameron. The Cameron data is taken from chemical analyses of suspended sediment samples analyzed as a part of the Little Colorado River sediment program in 1974-86. The data have been averaged for the several published water quality samples for the purpose of estimating a mean value from which to calculate the water quality of the LCR at Mouth for the parameters of interest. The Blue Spring water quality data is from Cooley (Cooley, 1976, p. F10) (For additional data, see also, Johnson and Sanderson, 1968.) The mean monthly flow of Blue Spring is derived above in Section 9.7.1.

In turn, the Little Colorado River at Cameron discharges were calculated by adding Little Colorado River near Cameron flows to Moenkopi Wash at Moenkopi flows. Missing data for Moenkopi Wash were supplied by the modeling efforts of DBS&A (Marley and Blandford, 1995). The LCR at Cameron flows and the Blue Spring discharges were converted to cfs-days. Water quality parameter data for Little Colorado River at Mouth, including temperature and suspended sediment, were calculated from the following formula:

$$C_m = \frac{C_1 Q_1 + C_2 Q_2}{Q_1 + Q_2}$$

Where: C_m = concentration of parameter in mixture
C_1 = concentration of parameter in first flow
C_2 = concentration of parameter in second flow
Q_1 = rate of first flow

and Q_2 =
rate of second flow

Complete mixture of two flows under laminar flow conditions may not be adequately represented by the above formula. Indeed, the muddy Little Colorado River water and the clear Blue Spring water do not seem to mix substantially for some distance downstream. However, the mixtures in the following subsections will be present at some point on the cross section of the LCR at Mouth.

Figure 479. Laminar Flow Conditions, Paria River Silt in Colorado River at Lees Ferry

The following piper diagram reveals that the water of the Little Colorado River differs greatly from that of the various springs which contribute to the Blue Spring flow. Cooley (Cooley, 1976, pp. F5 and F6) identifies no fewer than 29 springs which he considers to be components of the Blue Spring complex. These range in discharge from 0.02 cfs to 99 cfs. Together, the flows amount to about 230 cfs. The electroconductivity of these discharges range from 3,900 to 33,000 mmhos. These waters all have high proportions of sodium+potassium, chloride, and carbonate. The small squares denote Blue Spring mean concentrations, and the solid round dot represents mean LCR at Cameron. All these waters have some aspects in common chemically, although the absolute concentrations differ widely. The identifying numbers for the springs are from Cooley.

In order to calculate possible mixtures of the LCR and Blue Spring water in the lower LCR, it is first necessary to convert the flows of LCR at Cameron and Blue Spring from acre-feet per month to cubic feet per second (cfs).

Table 140. U.S. Geological Survey
The Hopi Tribe
Glen Canyon Environmental Studies - Little Colorado River Hydrology

Station: Blue Spring

Monthly Discharges in Acre-Feet
Mean Daily Discharges in cfs-days

Months	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Ave AF	12,374	13,040	16,298	14,262	6,501	8,331	15,895	13,676	15,053	10,998	12,531	11,145
cfs-days	201.2	219.1	265.1	231.9	117.0	135.5	267.1	222.4	253.0	178.9	203.8	187.3

The Little Colorado River at Cameron flows are derived by adding the flows at Moenkopi Wash at Moenkopi to the Little Colorado River near Cameron. The discharges are converted from AF/mo to cfs.

Table 141. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River at Cameron 09401200
Elevation: feet above mean sea level
Longitude: d m s
Latitude: + d m s
Drainage Area: , sq. mi.
Calculated Mean Daily Discharge in cfs-days

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1939	10.3	0.0	0.0	3.3	24.6	559.6	677.0	1.8	1.7	10.3	63.3	91.2
1940	10.3	0.0	2.7	11.5	87.8	223.6	114.7	2.2	1.7	275.3	911.7	1,070.0
1941	505.0	148.3	475.9	876.0	1,284.9	2,235.6	1,828.1	1,409.3	68.4	86.7	598.2	741.1
1942	1,281.9	57.4	51.4	107.1	111.9	313.8	854.5	99.1	1.7	11.4	26.3	10.8
1943	26.1	12.1	20.3	10.3	117.9	871.4	216.9	1.7	1.7	18.8	419.8	261.4
1944	32.7	2.8	3.7	5.3	8.4	377.8	1,210.9	404.5	1.7	10.3	13.2	181.9
1945	54.8	20.4	22.4	10.9	84.3	278.3	1,135.1	320.7	1.7	265.9	847.4	25.8
1946	24.1	3.0	16.2	68.4	42.9	69.0	55.5	1.7	1.7	218.3	1,112.7	810.5
1947	25.0	250.5	84.3	55.3	143.6	110.9	15.4	8.8	0.0	0.0	1,810.3	349.2
1948	1,379.0	15.7	25.2	58.6	117.7	312.5	1,132.2	13.9	26.8	115.6	344.6	11.8
1949	89.6	41.0	39.5	309.5	270.4	1,596.4	1,309.0	97.7	36.7	196.0	700.8	191.0
1950	164.4	7.1	3.5	6.7	208.1	237.2	65.0	0.0	0.0	146.7	23.4	44.7
1951	1.7	2.9	4.2	6.3	1.3	0.4	10.0	22.0	0.0	70.6	441.4	363.2
1952	177.8	6.2	11.2	2,045.5	180.8	213.3	2,223.5	343.1	3.2	34.0	233.1	658.1
1953	3.5	11.7	71.3	31.0	28.9	251.4	96.3	0.0	0.0	416.0	313.7	4.8
1954	3.6	4.7	6.2	5.8	3.5	293.6	340.1	2.9	4.5	648.1	102.3	472.4
1955	73.8	1.5	2.9	4.6	6.2	8.4	1.0	0.3	594.6	232.7	2,362.2	60.5
1956	0.1	2.0	3.0	5.2	38.2	84.9	21.3	1.2	0.0	64.5	198.7	0.5
1957	1.5	0.0	1.9	642.9	739.1	425.1	33.0	2.6	4.4	100.1	959.5	155.8
1958	235.4	227.9	22.3	6.9	91.2	519.3	749.1	26.9	2.8	39.6	453.6	613.4
1959	184.7	2.3	2.3	3.9	4.4	30.7	40.8	0.3	0.8	33.9	646.2	5.1
1960	127.6	587.9	311.0	298.4	145.8	1,441.6	312.5	4.0	0.2	32.3	2.8	29.2
1961	186.0	4.9	3.9	3.7	3.2	52.5	195.9	0.4	0.0	43.8	216.2	107.7
1962	23.1	67.2	1.9	4.2	836.5	230.7	1,439.8	19.9	0.0	32.3	9.3	125.8
1963	96.0	61.4	4.4	2.3	41.3	24.0	30.0	0.3	0.0	32.3	849.3	511.2
1964	42.3	12.2	1.9	2.1	2.9	11.4	457.5	50.5	1.0	194.0	1,741.0	456.2
1965	9.0	3.9	1.9	689.1	222.8	245.6	1,474.4	271.8	0.0	385.9	168.5	392.7
1966	9.1	69.9	404.3	908.8	81.4	1,094.6	285.0	1.3	0.0	23.4	289.9	190.9
1967	90.6	2.8	376.7	2.2	2.0	0.6	20.2	0.1	44.0	447.7	1,514.5	920.6
1968	9.0	2.0	3.1	68.8	702.6	800.4	1,128.1	200.2	0.0	131.9	613.8	0.0
1969	83.9	3.3	1.9	435.0	139.8	293.6	633.9	18.7	0.3	246.9	141.9	389.3
1970	108.6	22.5	3.1	3.0	0.9	96.4	79.7	0.0	0.0	12.4	283.1	891.4
1971	15.0	2.5	3.5	3.1	2.2	1.5	0.6	0.0	0.0	4.2	1,210.7	278.6
1972	1,233.7	104.3	463.4	114.7	7.8	0.6	0.0	0.0	4.1	143.7	109.6	25.1
1973	4,878.9	206.4	107.7	203.3	463.0	1,425.7	3,972.3	2,883.0	31.3	0.8	5.6	2.9
1974	0.0	1.1	0.9	13.5	1.9	136.3	67.8	0.0	0.0	131.2	100.2	47.1
1975	184.7	201.1	0.7	2.1	2.7	232.3	551.3	101.5	0.0	218.3	16.6	462.2
1976	3.8	2.4	16.9	4.7	220.4	291.1	597.6	158.4	0.0	323.8	70.3	186.9
1977	12.1	3.9	3.3	57.6	14.1	2.2	84.0	0.1	0.0	346.4	609.9	181.0
1978	99.0	12.3	5.2	13.6	99.0	1,878.6	792.9	37.8	3.6	0.6	4.0	24.1
1979	121.7	614.9	1,703.3	256.7	845.9	1,281.2	2,668.0	358.6	27.7	0.0	66.5	0.0
1980	7.9	34.9	9.8	138.0	2,113.4	745.7	1,753.3	600.9	1.7	0.5	83.1	205.7
1981	0.2	1.1	0.8	3.9	3.5	2.8	32.7	2.3	0.3	399.3	95.8	240.0
1982	504.8	1.9	25.0	55.5	397.8	1,161.1	545.0	61.7	0.0	5.3	729.3	460.6
1983	9.6	57.7	447.0	146.9	311.2	1,354.8	1,574.2	679.3	0.2	175.3	394.4	420.6
1984	699.4	47.0	234.6	160.4	14.0	69.5	27.1	0.3	0.0	303.6	1,358.2	790.7
1985	386.8	6.0	311.2	446.6	410.2	1,554.7	830.3	324.0	0.0	33.0	107.2	174.6
1986	50.2	193.6	113.6	6.6	174.8	333.2	171.6	1.4	0.0	271.3	158.4	275.9
1987	245.1	199.5	156.5	149.2	250.4	523.4	640.2	132.0	9.5	21.5	474.6	6.3
1988	45.2	773.1	2.1	43.8	583.8	305.4	483.3	68.9	25.2	33.3	575.2	268.6
1989	1.3	4.4	2.8	6.0	12.9	174.8	55.9	0.5	0.0	43.3	347.9	0.5
1990	4.9	1.7	2.2	3.8	13.8	2.7	5.0	1.1	1.5	154.0	157.9	367.7
Average	261.1	79.3	107.6	163.9	225.3	476.6	635.4	168.1	17.4	138.2	482.5	279.9

12.3.1 Little Colorado River at Mouth Total Dissolved Solids

Total dissolved solids (TDS) is one of two water quality parameters identified in the humpback chub preference study (Bulkley, et al, 1981, p. 220) for which the chub has an inclination. TDS is also a universally accepted measure of the relative salinity of waters. According to Bulkley, the humpback chub moderately prefers waters with a TDS of 1,000-3,500 mg/l. The mean TDS of the Little Colorado River at Cameron, taken from analyses of suspended solids samples, is about 470 mg/l.

Table 142. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River at Mouth
Elevation: feet above mean sea level
Drainage Area: , sq. mi.
Latitude: + d m s
Longitude: d m s

Calculated Mean Monthly TDS, in mg/l

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann. Mean
1939	2,271	2,363	2,363	2,337	2,035	840	1,006	2,348	2,351	2,260	1,915	1,743	1,986
1940	2,271	2,363	2,344	2,274	1,552	1,185	1,795	2,345	2,351	1,216	816	753	1,772
1941	1,010	1,599	1,148	867	629	579	712	729	1,960	1,745	952	852	1,065
1942	727	1,970	2,056	1,766	1,438	1,041	921	1,780	2,351	2,250	2,147	2,260	1,726
1943	2,146	2,265	2,229	2,283	1,414	725	1,515	2,349	2,351	2,183	1,089	1,261	1,817
1944	2,099	2,340	2,337	2,321	2,237	970	813	1,142	2,351	2,260	2,248	1,431	1,879
1945	1,958	2,202	2,216	2,278	1,571	1,090	831	1,246	2,351	1,232	838	2,134	1,662
1946	2,161	2,338	2,255	1,932	1,856	1,724	2,038	2,349	2,351	1,323	764	826	1,826
1947	2,154	1,354	1,907	1,999	1,321	1,512	2,260	2,291	2,363	2,363	662	1,131	1,776
1948	712	2,237	2,199	1,981	1,415	1,043	832	2,252	2,182	1,620	1,174	2,251	1,658
1949	1,780	2,065	2,118	1,281	1,042	619	791	1,786	2,124	1,374	897	1,408	1,440
1950	1,512	2,304	2,339	2,310	1,152	1,159	1,993	2,363	2,363	1,511	2,168	1,999	1,931
1951	2,348	2,339	2,334	2,313	2,342	2,357	2,295	2,193	2,363	1,828	1,069	1,115	2,075
1952	1,476	2,311	2,287	663	1,214	1,206	674	1,215	2,339	2,061	1,354	890	1,474
1953	2,331	2,267	1,962	2,140	1,988	1,133	1,862	2,363	2,363	1,040	1,216	2,316	1,915
1954	2,330	2,324	2,320	2,317	2,309	1,068	1,303	2,339	2,330	880	1,731	1,008	1,855
1955	1,856	2,350	2,343	2,326	2,269	2,253	2,357	2,361	1,036	1,293	621	1,901	1,914
1956	2,362	2,346	2,342	2,322	1,898	1,634	2,224	2,353	2,363	1,862	1,429	2,359	2,124
1957	2,349	2,363	2,350	972	729	928	2,155	2,341	2,331	1,684	802	1,504	1,709
1958	1,343	1,398	2,216	2,309	1,534	862	968	2,159	2,343	2,021	1,057	913	1,594
1959	1,457	2,343	2,347	2,332	2,294	2,013	2,113	2,361	2,357	2,062	924	2,313	2,076
1960	1,629	985	1,341	1,298	1,314	633	1,343	2,330	2,362	2,074	2,338	2,108	1,646
1961	1,454	2,322	2,336	2,334	2,313	1,835	1,563	2,360	2,363	1,991	1,389	1,672	1,994
1962	2,169	1,919	2,350	2,330	703	1,171	767	2,208	2,363	2,074	2,281	1,603	1,828
1963	1,752	1,949	2,332	2,345	1,869	2,078	2,172	2,361	2,363	2,074	837	978	1,926
1964	2,034	2,263	2,350	2,346	2,318	2,216	1,168	2,013	2,356	1,379	669	1,022	1,845
1965	2,282	2,331	2,350	947	1,122	1,144	761	1,322	2,363	1,070	1,507	1,082	1,523
1966	2,282	1,905	1,220	855	1,587	679	1,386	2,353	2,363	2,144	1,252	1,408	1,620
1967	1,776	2,340	1,252	2,346	2,332	2,355	2,230	2,363	2,083	1,011	695	791	1,798
1968	2,282	2,346	2,342	1,931	741	745	833	1,467	2,363	1,560	942	2,363	1,660
1969	1,806	2,335	2,350	1,129	1,333	1,068	1,032	2,217	2,361	1,266	1,586	1,085	1,631
1970	1,700	2,187	2,341	2,339	2,349	1,576	1,928	2,363	2,363	2,241	1,263	799	1,954
1971	2,232	2,342	2,338	2,338	2,329	2,343	2,359	2,363	2,363	2,320	743	1,232	2,109
1972	736	1,753	1,159	1,737	2,245	2,355	2,363	2,363	2,333	1,520	1,701	2,139	1,867
1973	546	1,445	1,816	1,479	853	635	590	606	2,155	2,354	2,312	2,335	1,427
1974	2,363	2,354	2,357	2,259	2,333	1,414	1,980	2,363	2,363	1,562	1,739	1,983	2,089
1975	1,458	1,458	2,358	2,346	2,320	1,168	1,088	1,770	2,363	1,323	2,221	1,016	1,741
1976	2,328	2,343	2,250	2,326	1,127	1,072	1,055	1,576	2,363	1,144	1,878	1,418	1,740
1977	2,256	2,330	2,340	1,987	2,160	2,333	1,910	2,362	2,363	1,115	945	1,433	1,961
1978	1,739	2,262	2,327	2,259	1,496	598	948	2,088	2,337	2,357	2,327	2,148	1,907
1979	1,650	968	726	1,369	701	652	643	1,195	2,177	2,363	1,898	2,363	1,392
1980	2,292	2,103	2,296	1,657	570	762	721	982	2,350	2,358	1,815	1,373	1,607
1981	2,361	2,354	2,358	2,332	2,309	2,325	2,157	2,344	2,361	1,056	1,758	1,300	2,085
1982	1,010	2,347	2,200	1,998	901	668	1,093	1,952	2,363	2,309	884	1,018	1,562
1983	2,277	1,969	1,175	1,629	988	643	745	938	2,362	1,426	1,115	1,054	1,360
1984	894	2,029	1,475	1,590	2,162	1,722	2,189	2,361	2,363	1,172	718	833	1,626
1985	1,118	2,313	1,341	1,118	891	622	931	1,241	2,363	2,068	1,711	1,450	1,431
1986	1,986	1,476	1,796	2,311	1,230	1,018	1,623	2,352	2,363	1,223	1,536	1,236	1,679
1987	1,324	1,461	1,661	1,622	1,074	860	1,028	1,658	2,295	2,160	1,039	2,302	1,540
1988	2,016	889	2,348	2,063	787	1,052	1,144	1,916	2,192	2,066	966	1,248	1,557
1989	2,351	2,326	2,344	2,316	2,175	1,297	2,036	2,359	2,363	1,994	1,170	2,358	2,091
1990	2,319	2,349	2,348	2,333	2,163	2,327	2,328	2,354	2,352	1,488	1,537	1,109	2,084
Average	1,828	2,061	2,069	1,934	1,597	1,294	1,453	1,984	2,299	1,737	1,359	1,512	
Maximum	2,363	2,363	2,363	2,346	2,349	2,357	2,363	2,363	2,363	2,363	2,338	2,363	
Minimum	546	889	726	663	570	579	590	606	1,036	880	621	753	
Std. Dev.	524.7	410.1	432.8	500.1	595.3	591.5	605.7	512.1	195.9	461.5	526.6	541.4	

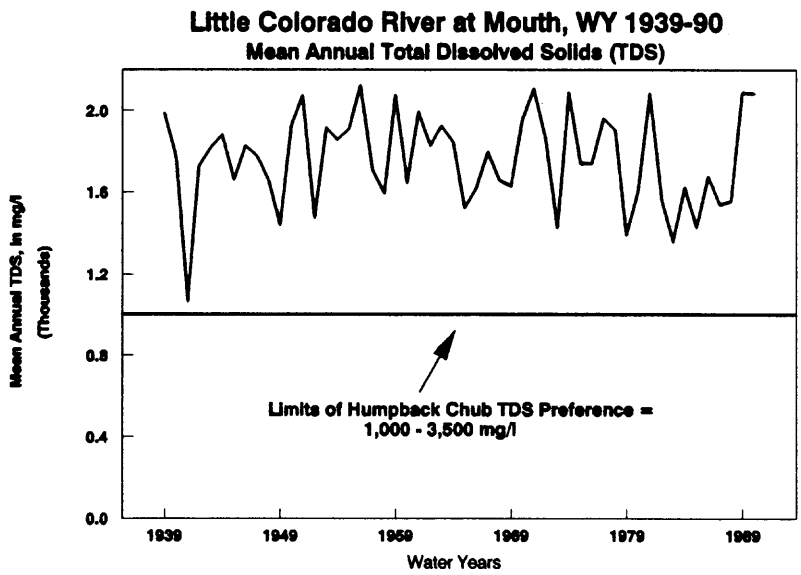


Figure 480. LCR at Mouth, Mean Annual TDS, WY 1939-90

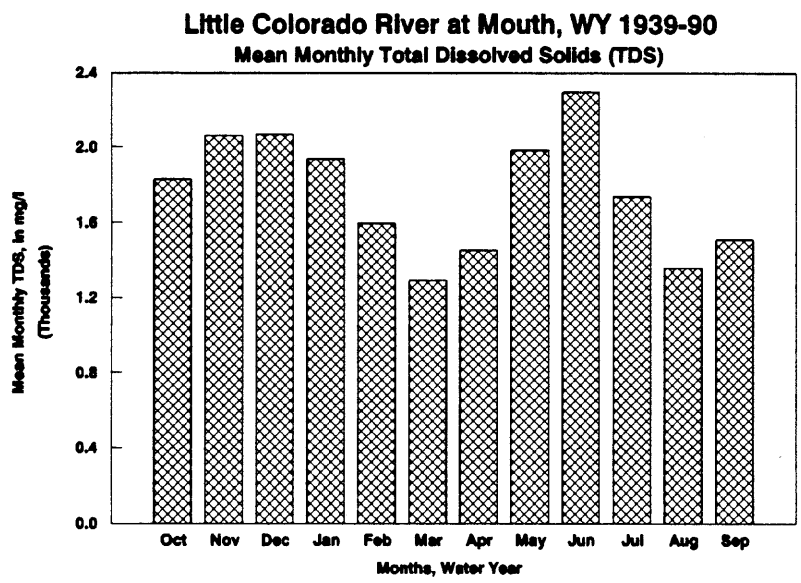


Figure 481. LCR at Mouth, WY 1939-90, Mean Monthly TDS

12.3.2 Little Colorado River at Mouth Temperature

Temperature plays two roles in the life cycle of the humpback chub. First, the temperature should be between 20° and 26° C for hatching of the eggs. Second, the chub preference is for water between 17° and 23° C, depending on their acclimatization temperature. Third, the velocity at which the fish can swim without exhaustion is dependent upon the temperature (see Bulkley, et al, 1981).

The water temperature in the Little Colorado River at Cameron can be approximately characterized by taking of monthly means of the temperatures of suspended sediment samples from that location during the 1975-86 water years.

It will be noted in the graph of LCR at Cameron water temperatures for 1975-86 that the range during that period of time is from nearly zero (0) to 27 C°. The graph of the monthly average temperatures at Cameron demonstrate that during the winter and spring the water temperature fall far below the preference range for the humpback chub.

Table 143. The Hopi Tribe
U.S. Geological Survey
Little Colorado River at Cameron 09401200
Temperature Variation
Temperatures in C°
WY 1975-86

Date	Temperature in C°
10/17/74	12.0
11/26/74	8.0
03/26/75	11.0
04/30/75	7.0
07/29/75	27.0
09/12/75	22.0
02/14/76	9.0
03/24/76	10.0
07/29/76	24.0
08/28/76	24.0
09/27/76	22.0
02/04/77	5.0
04/13/77	18.0
07/27/77	28.5
08/10/77	25.0
09/06/77	25.5
10/07/77	21.0
11/21/77	7.5
02/06/78	6.0
03/09/78	12.0
04/05/78	17.0
05/05/78	14.0
10/30/78	15.0
12/11/78	0.5
01/16/79	6.0
02/20/79	7.5
03/19/79	9.0
04/17/79	16.0
05/23/79	25.0
11/14/79	6.0
12/12/79	1.5
01/15/80	5.0
02/13/80	4.0
02/26/80	9.5
03/26/80	10.5
04/18/80	18.5
05/06/80	20.0
06/06/80	26.0
02/24/81	10.0
04/22/81	22.0
07/15/81	24.0
09/08/81	26.0
03/01/82	11.0
04/07/82	11.0
08/03/82	24.0
09/02/82	26.0
01/13/83	3.5
03/31/83	15.0
05/20/83	17.5
08/04/83	22.5
11/30/83	4.5
01/24/84	2.5
04/09/84	15.0
07/31/84	24.5
03/07/85	9.0
03/25/85	11.0
04/19/85	11.0
03/14/86	12.0
04/08/86	20.0
07/31/86	20.0

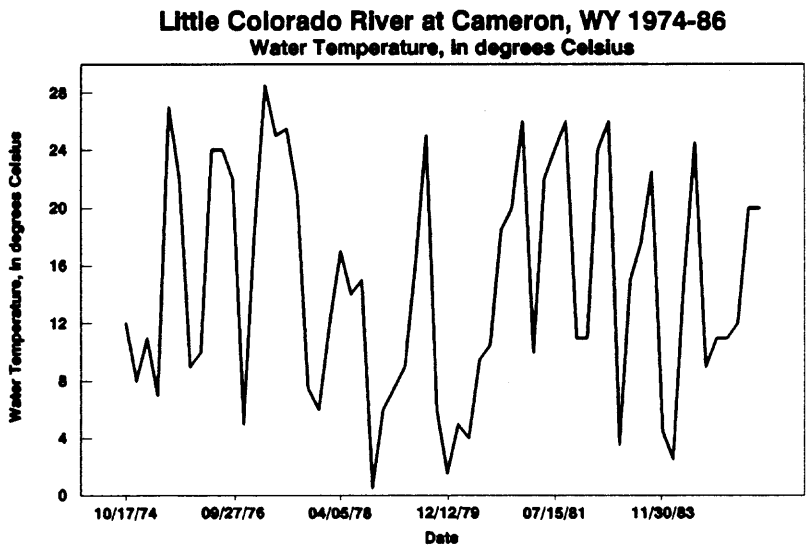


Figure 482. LCR at Cameron, WY 1974-86, Water Temperature, in C°

Table 144. Little Colorado River at Cameron 09401200
Temperature Variation
Temperatures in C°

Date	Temperature C°	Monthly Ave	Month
10/17/74	12.0		
10/07/77	21.0		
10/30/78	15.0	16.0	Oct
11/26/74	8.0		
11/21/77	7.5		
11/14/79	6.0		
11/30/83	4.5	6.5	Nov
12/11/78	0.5		
12/12/79	1.5	1.0	Dec
01/16/79	6.0		
01/15/80	5.0		
01/13/83	3.5		
01/24/84	2.5	4.3	Jan
02/14/76	9.0		
02/04/77	5.0		
02/06/78	6.0		
02/20/79	7.5		
02/13/80	4.0		
02/26/80	9.5		
02/24/81	10.0	7.3	Feb
03/26/75	11.0		
03/24/76	10.0		
03/09/78	12.0		
03/26/80	10.5		
03/01/82	11.0		
03/31/83	15.0		
03/07/85	9.0		
03/25/85	11.0		
03/14/86	12.0	11.3	Mar
04/30/75	7.0		
04/13/77	18.0		
04/05/78	17.0		
04/17/79	16.0		
04/18/80	18.5		
04/22/81	22.0		
04/07/82	11.0		
04/09/84	15.0		
04/19/85	11.0		
04/08/86	20.0	15.6	Apr
05/05/78	14.0		
05/23/79	25.0		
05/06/80	20.0		
05/20/83	17.5	19.1	May
06/06/80	26.0	26.0	Jun
07/29/75	27.0		
07/29/76	24.0		
07/27/77	28.5		
07/15/81	24.0		
07/31/84	24.5		
07/31/86	20.0	24.7	Jul
08/28/76	24.0		
08/10/77	25.0		
08/03/82	24.0		
08/04/83	22.5	23.9	Aug
09/12/75	22.0		
09/27/76	22.0		
09/06/77	25.5		
09/08/81	26.0		
09/02/82	26.0	24.3	Sep

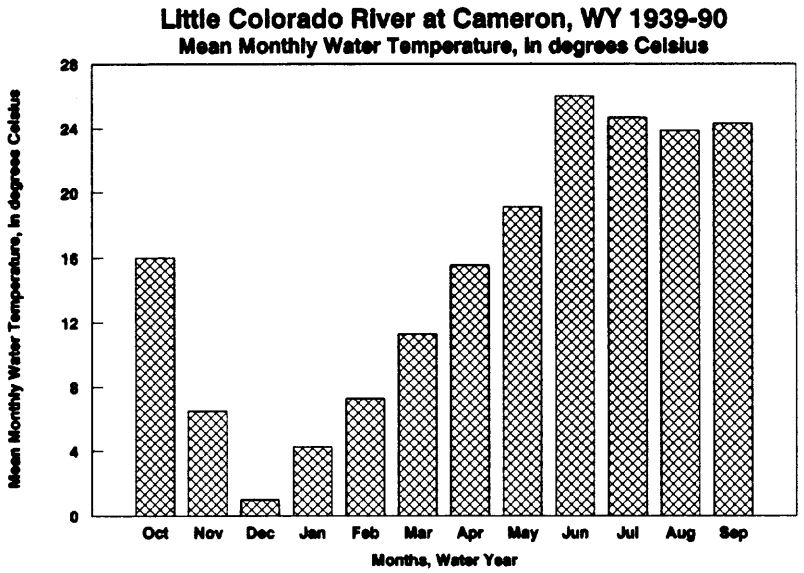


Figure 483. LCR at Cameron, WY 1939-90, Mean Monthly Water Temperature, in C°

The mixture formula given in Section 12.3 is used to calculate the water temperature at Little Colorado River at Mouth. It will be noted that the range of temperatures is significantly less than the Little Colorado River at Cameron. The range of LCR at Mouth is from 15.0° to 22.2° C, on average. Thus, Blue Spring, with its constant, relatively warm water, evens out the temperature range to more closely correspond with the temperature preference of the humpback chub. Even more importantly, the temperature range for LCR at Mouth is suitable for the hatching of the eggs. Without Blue Spring, the temperature of the LCR would be inhospitable to the humpback chub except for a very few months out of the year. In addition, the availability of water in the LCR in insufficient during critical stages of the chub life cycle.

Table 145. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River at Mouth
Elevation: feet above mean sea level
Drainage Area: , sq. mi.
Latitude: + d m s
Longitude: d m s
Calculated Mean Monthly Water Temperature, in C°

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann. Mean
1939	20.1	20.3	20.3	20.1	18.0	13.0	16.9	20.3	20.3	20.5	21.1	21.6	19.4
1940	20.1	20.3	20.1	19.5	14.7	14.7	18.9	20.3	20.3	22.9	23.2	23.7	19.9
1941	17.2	14.7	7.9	7.6	8.4	11.8	16.2	19.3	21.5	21.7	23.0	23.5	16.1
1942	16.6	17.4	17.1	15.2	13.9	14.0	16.7	19.9	20.3	20.5	20.7	20.5	17.7
1943	19.8	19.6	18.9	19.6	13.8	12.5	18.2	20.3	20.3	20.7	22.7	22.6	19.1
1944	19.7	20.1	20.0	19.9	19.4	13.7	16.4	19.5	20.3	20.5	20.5	22.3	19.4
1945	19.4	19.1	18.8	19.6	14.8	14.2	16.5	19.6	20.3	22.9	23.2	20.8	19.1
1946	19.8	20.1	19.2	16.6	16.8	17.2	19.5	20.3	20.3	22.7	23.3	23.5	19.9
1947	19.8	12.9	15.6	17.2	13.1	16.2	20.0	20.2	20.3	20.3	23.5	22.9	18.5
1948	16.5	19.4	18.6	17.0	13.8	14.0	16.5	20.2	20.8	22.0	22.5	20.5	18.5
1949	19.0	18.1	17.8	11.1	11.2	12.0	16.4	19.9	21.0	22.6	23.1	22.3	17.9
1950	18.4	19.8	20.0	19.8	12.0	14.5	19.4	20.3	20.3	22.3	20.6	21.1	19.0
1951	20.2	20.1	20.0	19.9	20.1	20.2	20.1	20.2	20.3	21.5	22.7	22.9	20.7
1952	18.3	19.9	19.5	5.9	12.4	14.8	16.1	19.6	20.3	21.0	22.2	23.4	17.8
1953	20.2	19.6	16.2	18.4	17.7	14.4	19.0	20.3	20.3	23.3	22.5	20.4	19.4
1954	20.2	20.0	19.8	19.9	19.9	14.1	17.6	20.3	20.4	23.7	21.5	23.2	20.0
1955	19.1	20.2	20.1	20.0	19.6	19.8	20.3	20.3	24.3	22.8	23.6	21.3	20.9
1956	20.3	20.2	20.1	19.9	17.1	16.8	19.9	20.3	20.3	21.4	22.1	20.3	19.9
1957	20.2	20.3	20.1	8.5	9.1	13.5	19.8	20.3	20.4	21.9	23.2	22.1	18.3
1958	18.0	13.3	18.8	19.8	14.6	13.1	16.8	20.2	20.3	21.1	22.8	23.4	18.5
1959	18.2	20.1	20.1	20.0	19.8	18.6	19.7	20.3	20.3	21.0	23.0	20.4	20.1
1960	18.6	10.2	9.9	11.3	13.1	12.1	17.7	20.3	20.3	20.9	20.3	20.8	16.3
1961	18.2	20.0	20.0	20.0	19.9	17.8	18.3	20.3	20.3	21.1	22.1	21.7	20.0
1962	19.8	17.0	20.1	20.0	8.9	14.6	16.3	20.2	20.3	20.9	20.4	21.9	18.4
1963	18.9	17.3	20.0	20.1	16.9	18.9	19.8	20.3	20.3	20.9	23.2	23.2	20.0
1964	19.5	19.5	20.1	20.1	20.0	19.6	17.3	20.1	20.3	22.6	23.5	23.1	20.5
1965	20.1	20.0	20.1	8.3	11.8	14.5	16.3	19.6	20.3	23.3	21.9	23.0	18.3
1966	20.1	16.9	8.6	7.5	14.9	12.3	17.8	20.3	20.3	20.8	22.4	22.3	17.0
1967	18.9	20.1	9.0	20.1	20.1	20.2	19.9	20.3	21.1	23.4	23.4	23.6	20.0
1968	20.1	20.2	20.1	16.6	9.1	12.6	16.5	19.7	20.3	22.1	23.0	20.3	18.4
1969	19.0	20.1	20.1	9.8	13.2	14.1	17.0	20.2	20.3	22.8	21.8	23.0	18.4
1970	18.8	19.0	20.1	20.1	20.2	16.5	19.2	20.3	20.3	20.6	22.4	23.6	20.1
1971	20.0	20.1	20.0	20.1	20.0	20.2	20.3	20.3	20.3	20.4	23.4	22.7	20.6
1972	16.6	15.8	8.0	15.0	19.5	20.2	20.3	20.3	20.4	22.2	21.5	20.8	18.4
1973	16.2	13.6	14.7	12.8	9.9	12.1	15.8	19.2	20.9	20.3	20.4	20.3	16.4
1974	20.3	20.2	20.2	19.4	20.1	15.8	19.3	20.3	20.3	22.1	21.5	21.1	20.0
1975	18.2	13.7	20.2	20.1	20.0	14.6	17.1	19.9	20.3	22.7	20.5	23.1	19.2
1976	20.2	20.1	19.1	20.0	11.8	14.1	17.0	19.8	20.3	23.1	21.2	22.3	19.1
1977	20.0	20.0	20.0	17.1	18.9	20.1	19.1	20.3	20.3	23.2	23.0	22.3	20.4
1978	18.9	19.5	19.9	19.4	14.3	11.9	16.7	20.1	20.4	20.3	20.3	20.7	18.5
1979	18.7	10.1	3.6	11.9	8.9	12.1	16.0	19.6	20.8	20.3	21.2	20.3	15.3
1980	20.1	18.4	19.6	14.3	8.0	12.7	16.2	19.4	20.3	20.3	21.3	22.4	17.7
1981	20.3	20.2	20.2	20.0	19.9	20.1	19.8	20.3	20.3	23.3	21.4	22.5	20.7
1982	17.2	20.2	18.6	17.2	10.2	12.2	17.1	20.0	20.3	20.4	23.1	23.1	18.3
1983	20.1	17.4	8.2	14.1	10.8	12.1	16.2	19.4	20.3	22.5	22.6	23.1	17.2
1984	17.0	17.8	11.2	13.7	18.9	17.2	19.8	20.3	20.3	23.0	23.4	23.5	18.9
1985	17.5	19.9	9.9	9.7	10.2	12.0	16.7	19.6	20.3	21.0	21.5	22.2	16.7
1986	19.4	13.8	14.5	19.8	12.5	13.9	18.4	20.3	20.3	22.9	21.9	22.7	18.4
1987	17.9	13.7	13.1	14.0	11.4	13.1	16.9	19.8	20.5	20.7	22.8	20.4	17.0
1988	19.5	9.5	20.1	17.7	9.5	14.0	17.2	20.0	20.8	21.0	22.9	22.6	17.9
1989	20.3	20.0	20.1	19.9	19.0	15.2	19.5	20.3	20.3	21.1	22.5	20.3	19.9
1990	20.2	20.2	20.1	20.0	18.9	20.1	20.2	20.3	20.3	22.3	21.8	22.9	20.6
Average	19.1	18.1	17.3	16.6	15.0	15.2	18.0	20.0	20.5	21.7	22.2	22.1	18.8
Maximum	20.3	20.3	20.3	20.1	20.2	20.2	20.3	20.3	24.3	23.7	23.6	23.7	20.9
Minimum	16.2	9.5	3.6	5.9	8.0	11.8	15.8	19.2	20.3	20.3	20.3	20.3	15.3
Std. Dev.	1.19	2.99	4.41	4.23	4.09	2.81	1.51	0.31	0.59	1.07	1.00	1.15	1.34

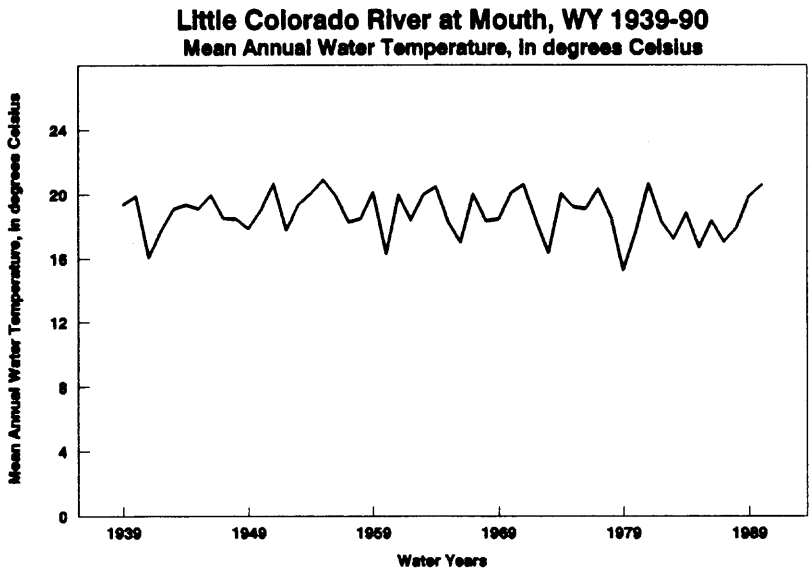


Figure 484. LCR at Mouth, WY 1939-90, Mean Annual Water Temperature, in C°

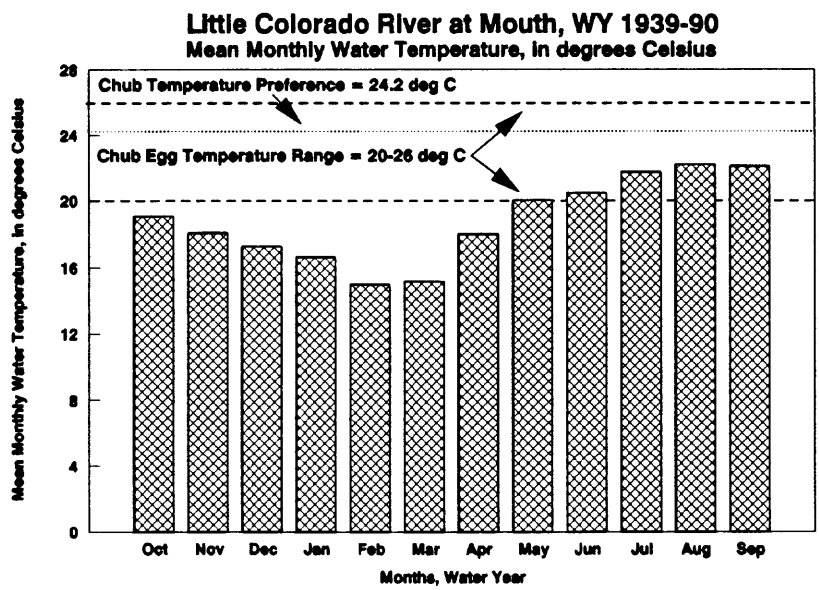


Figure 485. LCR at Mouth, WY 1939-90, Mean Monthly Water Temperature, in C°

12.3.3 Little Colorado River at Mouth Sodium

Sodium is considered to be one of the major consituents of saline input from oil shale processing. Evidently, Bulkley (1981) felt that it was worth doubling the concentration of sodium in the TDS preference test water due to the potential of processing oil shale upstream. Although the oil shale factor is not known to be a problem in the Little Colorado River, this ion was included in the estimation of concentrations at LCR at Mouth in the event that some future need would be found for this relationship.

Due to the fact that sodium is more prevalent in Blue Spring than in LCR at Cameron, the concentration varies widely from year to year and from month to month, even considering the mixture of the sources.

Table 146. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River at Mouth
Elevation: feet above mean sea level
Drainage Area: , sq. mi.
Latitude: + d m s
Longitude: d m s
Calculated Mean Monthly Sodium, in mg/l

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann. Mean
1939	535.2	556.0	556.0	550.0	481.9	212.2	249.8	552.5	553.1	532.7	454.8	416.1	470.9
1940	535.2	556.0	551.6	535.8	373.0	290.1	427.7	551.9	553.1	297.1	207.0	192.6	422.6
1941	250.6	383.6	281.7	218.3	164.6	153.3	183.4	187.2	465.1	416.6	237.5	215.1	263.1
1942	186.9	467.3	486.7	421.1	347.2	257.7	230.6	424.4	553.1	530.4	507.1	532.7	412.1
1943	507.0	533.7	525.6	537.8	341.7	186.4	364.6	552.8	553.1	515.3	268.5	307.2	432.8
1944	496.3	550.7	550.1	546.4	527.5	241.7	206.1	280.5	553.1	532.7	530.1	345.6	446.7
1945	464.6	519.7	522.7	536.8	377.2	268.8	210.3	303.8	553.1	300.7	211.7	504.3	397.8
1946	510.3	550.2	531.5	458.7	441.5	411.8	482.5	552.8	553.1	321.3	195.1	209.1	434.8
1947	508.8	328.2	453.0	473.8	320.7	363.8	532.7	539.7	556.0	556.0	172.2	278.0	423.6
1948	183.3	527.4	518.9	469.8	341.9	258.1	210.5	530.8	515.1	388.3	287.6	530.7	396.9
1949	424.4	488.8	500.7	311.9	257.9	162.3	201.3	425.6	502.0	332.7	225.2	340.4	347.8
1950	364.0	542.6	550.4	544.0	282.7	284.2	472.4	556.0	556.0	363.6	512.0	473.8	458.5
1951	552.5	550.5	549.3	544.6	551.3	554.7	540.5	517.6	556.0	435.2	263.8	274.2	490.9
1952	355.7	544.2	538.7	172.4	296.8	294.8	174.7	296.9	550.6	487.7	328.2	223.6	355.4
1953	548.7	534.4	465.5	505.7	471.4	278.5	442.8	556.0	556.0	257.3	297.1	545.2	454.9
1954	548.5	547.0	546.2	545.6	543.8	263.8	316.8	550.4	548.5	221.3	413.3	250.2	441.3
1955	441.4	553.1	551.4	547.6	534.7	531.1	554.5	555.4	256.4	314.5	162.9	451.7	454.6
1956	555.8	552.0	551.3	546.6	451.0	391.4	524.5	553.7	556.0	442.8	345.2	554.9	502.1
1957	552.8	556.0	553.0	242.2	187.3	232.2	509.0	551.1	548.7	402.7	203.8	362.1	408.4
1958	325.8	338.3	522.8	543.7	369.0	217.3	241.2	509.9	551.4	478.7	261.3	228.8	382.3
1959	351.6	551.5	552.3	548.9	540.4	477.0	499.5	555.4	554.6	488.0	231.3	544.6	491.3
1960	390.3	244.9	325.4	315.7	319.1	165.6	325.8	548.4	555.6	490.6	550.3	498.3	394.2
1961	350.9	546.6	549.9	549.3	544.6	436.8	375.3	555.3	556.0	472.0	336.2	400.1	472.7
1962	512.1	455.7	552.9	548.5	181.4	286.9	195.8	520.9	556.0	490.6	537.4	384.4	435.2
1963	418.0	462.5	549.0	551.9	444.5	491.7	512.9	555.5	556.0	490.6	211.6	243.5	457.3
1964	481.8	533.4	553.0	552.1	545.7	522.8	286.4	476.9	554.3	333.8	173.7	253.2	438.9
1965	537.6	548.6	553.0	236.5	276.0	280.8	194.4	321.1	556.0	264.2	362.7	266.8	366.5
1966	537.6	452.7	298.1	215.8	380.8	176.0	335.5	553.6	556.0	506.6	305.2	340.5	388.2
1967	423.4	550.7	305.3	552.0	548.9	554.1	526.0	555.8	492.7	250.8	179.6	201.1	428.4
1968	537.7	552.1	551.1	458.3	189.9	190.8	210.7	353.7	556.0	374.7	235.4	555.9	397.2
1969	430.3	549.6	553.0	277.5	323.5	263.8	255.5	522.9	555.5	308.4	380.7	267.7	390.7
1970	406.3	516.3	551.1	550.5	552.7	378.4	457.9	555.9	556.0	528.4	307.7	203.1	463.7
1971	526.4	551.2	550.4	550.3	548.2	551.4	555.0	555.9	556.0	546.1	190.5	300.6	498.5
1972	188.8	418.3	284.3	414.7	529.3	554.1	556.0	556.0	549.2	365.8	406.6	505.5	444.1
1973	145.9	348.9	432.6	356.5	215.1	166.0	155.8	159.5	508.9	554.0	544.5	549.5	344.8
1974	555.9	553.8	554.5	532.5	549.1	341.8	469.5	556.0	556.0	375.3	415.2	470.2	494.2
1975	351.6	351.6	554.9	552.2	546.3	286.3	268.3	422.2	556.0	321.3	523.8	252.1	415.5
1976	548.0	551.5	530.4	547.6	277.1	264.6	260.9	378.3	556.0	280.9	446.4	342.7	415.4
1977	531.9	548.4	550.7	471.0	510.1	549.2	453.8	555.8	556.0	274.4	235.9	346.1	465.3
1978	415.2	533.2	547.7	532.4	360.3	157.7	236.6	493.9	550.1	554.6	547.9	507.4	453.1
1979	395.1	241.1	186.4	331.7	180.8	169.8	167.8	292.4	513.9	556.0	451.0	556.0	336.8
1980	540.0	497.3	540.8	396.7	151.4	194.6	185.4	244.3	553.1	554.9	432.3	332.5	385.3
1981	555.5	553.8	554.8	548.9	543.7	547.5	509.5	551.6	555.5	261.1	419.5	316.1	493.1
1982	250.7	552.2	519.2	473.6	226.0	173.6	269.4	463.2	556.0	543.7	222.2	252.4	375.2
1983	536.6	467.0	287.9	390.4	245.7	167.8	190.9	234.3	555.6	344.6	274.4	260.5	329.6
1984	224.4	480.6	355.5	381.4	510.5	411.2	516.7	555.4	556.0	287.3	184.7	210.7	389.5
1985	275.1	544.6	325.4	274.9	223.7	163.2	232.9	302.8	555.9	489.4	408.8	350.0	345.6
1986	470.8	355.7	427.9	544.2	300.2	252.4	388.9	553.3	555.9	298.6	369.2	301.6	401.6
1987	321.5	352.5	397.4	388.8	265.0	216.8	254.7	396.9	540.5	510.2	257.2	542.2	370.3
1988	477.7	223.3	552.6	488.1	200.3	260.2	281.0	455.0	517.3	488.9	240.7	304.4	374.1
1989	553.3	547.5	551.6	545.3	513.5	315.4	482.1	555.1	556.0	472.7	286.7	554.8	494.5
1990	545.9	552.7	552.5	549.2	510.8	547.8	548.1	554.0	553.5	358.4	369.6	273.1	493.0
Average	535.2	556.0	556.0	550.0	481.9	212.2	249.8	552.5	553.1	532.7	454.8	416.1	470.9
Maximum	555.9	556.0	556.0	552.2	552.7	554.7	556.0	556.0	556.0	556.0	550.3	556.0	
Minimum	145.9	223.3	186.4	172.4	151.4	153.3	155.8	159.5	256.4	221.3	162.9	192.6	
Std. Dev.	118.4	92.5	97.6	112.8	134.3	133.5	136.7	115.5	44.2	104.1	118.8	122.2	

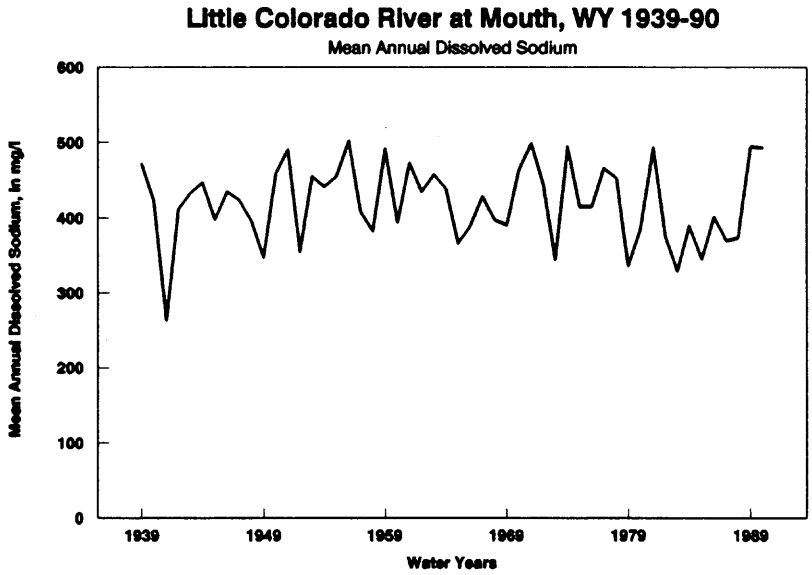


Figure 486. LCR at Mouth, WY 1939-90, Mean Annual Sodium, in mg/l

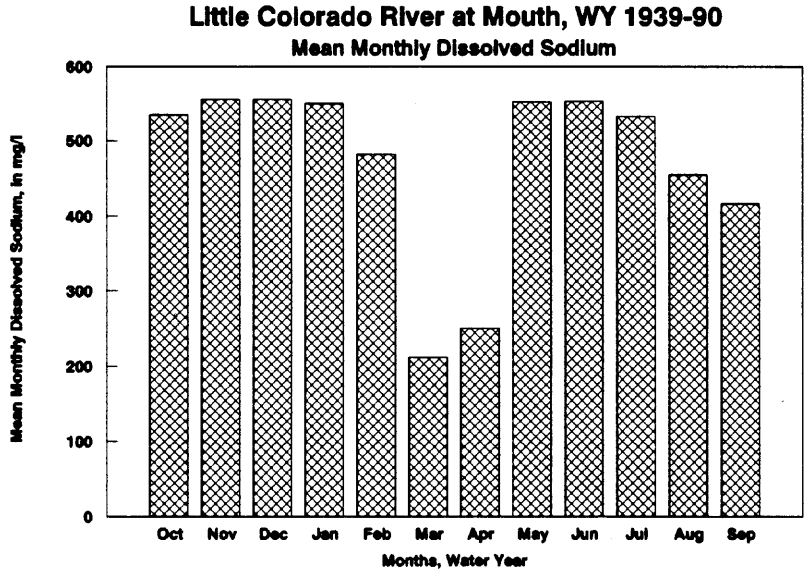


Figure 487. LCR at Mouth, WY 1939-90, Mean Monthly Sodium, in mg/l

12.3.4 Little Colorado River at Mouth Magnesium

Magnesium is considered to be one of the major consituents of saline input from oil shale processing. Evidently, Bulkley (1981) felt that it was worth doubling the concentration of magnesium in the TDS preference test water due to the potential of processing oil shale upstream. Although the oil shale factor is not known to be a problem in the Little Colorado River, this ion was included in the estimation of concentrations at LCR at Mouth in the event that some future need would be found for this relationship.

Due to the fact that magnesium is more prevalent in Blue Spring than in LCR at Cameron, the concentration varies widely from year to year and from month to month, even considering the mixture of the sources.

Table 147. U. S. Geological Survey
Hopi Tribal Database
Station: Little Colorado River at Mouth
Elevation: feet above mean sea level
Latitude: + d m s
Longitude: d m s
Drainage Area: , sq. mi.
Calculated Mean Monthly Magnesium, in mg/l

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann. Mean
1939	72.6	76.0	76.0	75.0	63.8	19.4	25.6	75.4	75.5	72.2	59.3	53.0	62.0
1940	72.6	76.0	75.3	72.7	45.9	32.2	54.9	75.3	75.5	33.4	18.6	16.2	54.0
1941	25.8	47.6	30.9	20.4	11.6	9.7	14.7	15.3	61.0	53.1	23.6	19.9	27.8
1942	15.3	61.4	64.6	53.8	41.6	26.9	22.5	54.3	75.5	71.8	68.0	72.2	52.3
1943	67.9	72.3	71.0	73.0	40.7	15.2	44.5	75.5	75.5	69.3	28.7	35.1	55.7
1944	66.2	75.1	75.0	74.4	71.3	24.3	18.4	30.7	75.5	72.2	71.7	41.4	58.0
1945	61.0	70.0	70.5	72.8	46.6	28.7	19.1	34.5	75.5	34.0	19.4	67.5	50.0
1946	68.5	75.0	72.0	60.0	57.2	52.3	63.9	75.5	75.5	37.4	16.6	18.9	56.1
1947	68.2	38.5	59.0	62.5	37.3	44.4	72.2	73.3	76.0	76.0	12.8	30.3	54.2
1948	14.7	71.3	69.9	61.8	40.8	27.0	19.1	71.9	69.3	48.4	31.8	71.8	49.8
1949	54.3	64.9	66.9	35.8	27.0	11.2	17.6	54.5	67.1	39.3	21.6	40.5	41.7
1950	44.4	73.8	75.1	74.0	31.0	31.3	62.2	76.0	76.0	44.3	68.8	62.5	60.0
1951	75.4	75.1	74.9	74.1	75.2	75.8	73.5	69.7	76.0	56.1	27.9	29.6	65.3
1952	43.0	74.1	73.1	12.9	33.3	33.0	13.3	33.4	75.1	64.8	38.5	21.3	43.0
1953	74.8	72.4	61.1	67.7	62.1	30.3	57.4	76.0	76.0	26.9	33.4	74.2	59.4
1954	74.8	74.5	74.4	74.3	74.0	27.9	36.6	75.1	74.8	20.9	52.5	25.7	57.1
1955	57.1	75.5	75.2	74.6	72.5	71.9	75.7	75.9	26.7	36.3	11.3	58.8	59.3
1956	76.0	75.3	75.2	74.5	58.7	48.9	70.8	75.6	76.0	57.4	41.3	75.8	67.1
1957	75.5	76.0	75.5	24.4	15.3	22.7	68.3	75.2	74.8	50.8	18.0	44.1	51.7
1958	38.1	40.2	70.5	74.0	45.2	20.3	24.2	68.4	75.2	63.3	27.5	22.2	47.4
1959	42.4	75.3	75.4	74.8	73.4	63.0	66.7	75.9	75.8	64.8	22.6	74.1	65.3
1960	48.7	24.8	38.1	36.5	37.0	11.8	38.1	74.8	75.9	65.2	75.1	66.5	49.4
1961	42.3	74.5	75.0	74.9	74.1	56.4	46.3	75.9	76.0	62.2	39.8	50.3	62.3
1962	68.8	59.5	75.5	74.8	14.4	31.7	16.7	70.2	76.0	65.2	72.9	47.8	56.1
1963	53.3	60.6	74.8	75.3	57.7	65.4	68.9	75.9	76.0	65.2	19.3	24.6	59.8
1964	63.8	72.3	75.5	75.4	74.3	70.5	31.6	63.0	75.7	39.4	13.1	26.2	56.7
1965	73.0	74.8	75.5	23.4	29.9	30.7	16.5	37.4	76.0	28.0	44.2	28.4	44.8
1966	73.0	59.0	33.6	20.0	47.2	13.5	39.7	75.6	76.0	67.9	34.7	40.5	48.4
1967	54.2	75.1	34.8	75.3	74.8	75.7	71.1	76.0	65.6	25.8	14.1	17.6	55.0
1968	73.0	75.4	75.2	59.9	15.8	15.9	19.2	42.7	76.0	46.2	23.2	76.0	49.9
1969	55.3	74.9	75.5	30.2	37.8	27.9	26.6	70.6	75.9	35.3	47.2	28.6	48.8
1970	51.4	69.5	75.2	75.1	75.5	46.8	59.9	76.0	76.0	71.5	35.1	17.9	60.8
1971	71.1	75.2	75.1	75.1	74.7	75.2	75.8	76.0	76.0	74.4	15.9	34.0	66.5
1972	15.6	53.3	31.3	52.7	71.6	75.7	76.0	76.0	74.9	44.7	51.4	67.7	57.6
1973	8.5	41.9	55.7	43.2	19.9	11.8	10.2	10.8	68.3	75.7	74.1	74.9	41.2
1974	76.0	75.6	75.8	72.1	74.9	40.8	61.8	76.0	76.0	46.3	52.8	61.9	65.8
1975	42.4	42.4	75.8	75.4	74.4	31.6	28.7	54.0	76.0	37.4	70.7	26.0	52.9
1976	74.7	75.3	71.8	74.6	30.1	28.0	27.4	46.8	76.0	30.7	58.0	40.9	52.9
1977	72.0	74.8	75.1	62.0	68.4	74.9	59.2	76.0	76.0	29.7	23.3	41.5	61.1
1978	52.8	72.3	74.6	72.1	43.8	10.5	23.4	65.8	75.0	75.8	74.7	68.0	59.1
1979	49.5	24.2	15.2	39.1	14.3	12.4	12.1	32.6	69.1	76.0	58.7	76.0	39.9
1980	73.4	66.3	73.5	49.8	9.4	16.5	15.0	24.7	75.5	75.8	55.7	39.2	47.9
1981	75.9	75.6	75.8	74.8	74.0	74.6	68.3	75.3	75.9	27.5	53.5	36.5	65.7
1982	25.8	75.4	70.0	62.4	21.7	13.1	28.8	60.7	76.0	74.0	21.1	26.0	46.2
1983	72.8	61.4	31.9	48.7	24.9	12.1	15.9	23.1	75.9	41.2	29.7	27.4	38.8
1984	21.4	63.6	43.0	47.3	68.5	52.2	69.5	75.9	76.0	31.8	14.9	19.2	48.6
1985	29.8	74.1	38.1	29.7	21.3	11.4	22.8	34.3	76.0	65.0	51.8	42.1	41.4
1986	62.0	43.0	54.9	74.1	33.9	26.0	48.5	75.6	76.0	33.7	45.3	34.1	50.6
1987	37.4	42.5	49.9	48.5	28.1	20.2	26.4	49.8	73.4	68.5	26.8	73.7	45.4
1988	63.1	21.2	75.4	64.8	17.5	27.3	30.7	59.4	69.6	65.0	24.1	34.6	46.1
1989	75.5	74.6	75.3	74.2	69.0	36.4	63.8	75.9	76.0	62.3	31.7	75.8	65.9
1990	74.3	75.5	75.4	74.9	68.6	74.6	74.7	75.7	75.6	43.5	45.3	29.4	65.6
Average	56.1	64.8	65.1	60.1	47.5	36.3	42.2	61.9	73.6	52.8	38.7	44.4	53.6
Maximum	76.0	76.0	76.0	75.4	75.5	75.8	76.0	76.0	76.0	76.0	75.1	76.0	
Minimum	8.5	21.2	15.2	12.9	9.4	9.7	10.2	10.8	26.7	20.9	11.3	16.2	
Std. Dev.	19.5	15.2	16.1	18.6	22.1	22.0	22.5	19.0	7.3	17.1	19.6	20.1	

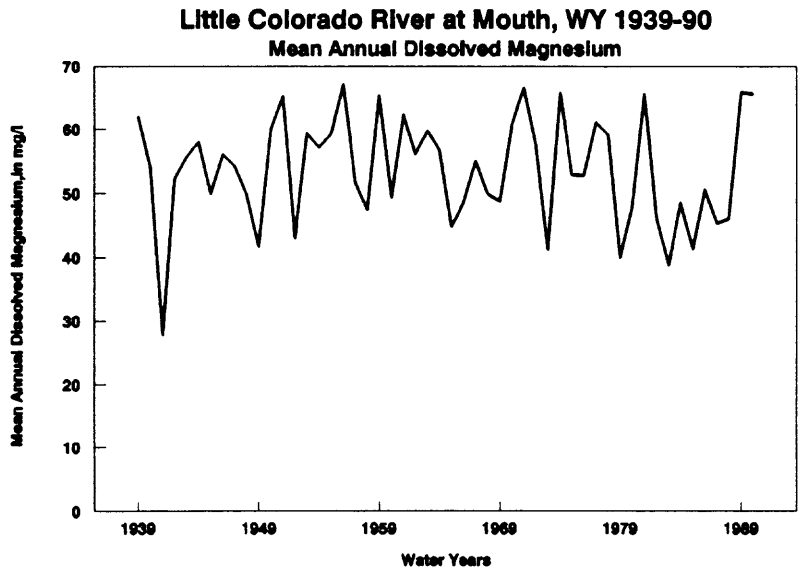


Figure 488. LCR at Mouth, WY 1939-90, Mean Annual Magnesium, in mg/l

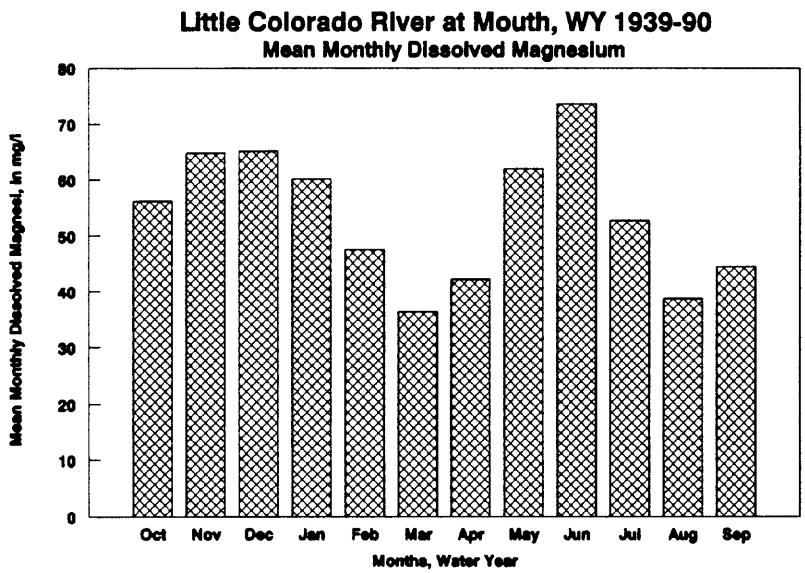


Figure 489. LCR at Mouth, WY 1939-90, Mean Monthly Magnesium, in mg/l

12.3.5 Little Colorado River at Mouth Sulfate

Sulfate is considered to be one of the major consituents of saline input from oil shale processing. Evidently, Bulkley (1981) felt that it was worth doubling the concentration of sulfate in the TDS preference test water due to the potential of processing oil shale upstream. Although the oil shale factor is not known to be a problem in the Little Colorado River, this ion was included in the estimation of concentrations at LCR at Mouth in the event that some future need would be found for this relationship.

Due to the fact that sulfate is approximately equal in Blue Spring and in LCR at Cameron, the concentration does not vary widely from year to year and from month to month.

Table 148. U. S. Geological Survey
Hopi Tribal Database

Station: Little Colorado River at Mouth
Elevation: feet above mean sea level
Drainage Area: , sq. mi.

Latitude: + d m s
Longitude: d m s

Calculated Mean Monthly SO4, in mg/l

Year/Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann. Mean
1939	137.3	139.0	139.0	138.5	133.0	111.0	114.1	138.7	138.8	137.1	130.8	127.6	132.1
1940	137.3	139.0	138.6	137.4	124.1	117.4	128.6	138.7	138.8	117.9	110.6	109.4	128.1
1941	114.2	125.0	116.7	111.5	107.2	106.2	108.7	109.0	131.6	127.7	113.1	111.3	115.2
1942	109.0	131.8	133.4	128.0	122.0	114.7	112.5	128.3	138.8	136.9	135.0	137.1	127.3
1943	135.0	137.2	136.5	137.5	121.6	108.9	123.4	138.7	138.8	135.7	115.6	118.8	129.0
1944	134.1	138.6	138.5	138.2	136.7	113.4	110.5	116.6	138.8	137.1	136.9	121.9	130.1
1945	131.6	136.0	136.3	137.4	124.5	115.6	110.9	118.5	138.8	118.2	111.0	134.8	126.1
1946	135.3	138.5	137.0	131.1	129.7	127.3	133.0	138.7	138.8	119.9	109.6	110.8	129.1
1947	135.2	120.5	130.6	132.3	119.9	123.4	137.1	137.7	139.0	139.0	107.8	116.4	128.2
1948	108.7	136.7	136.0	132.0	121.6	114.8	110.9	137.0	135.7	125.4	117.2	136.9	126.1
1949	128.3	133.5	134.5	119.1	114.8	107.0	110.2	128.4	134.6	120.8	112.1	121.5	122.1
1950	123.4	137.9	138.5	138.0	116.8	116.9	132.2	139.0	139.0	123.3	135.4	132.3	131.1
1951	138.7	138.6	138.5	138.1	138.6	138.9	137.7	135.9	139.0	129.2	115.2	116.1	133.7
1952	122.7	138.0	137.6	107.8	117.9	117.8	108.0	117.9	138.6	133.4	120.5	112.0	122.7
1953	138.4	137.2	131.6	134.9	132.1	116.4	129.8	139.0	139.0	114.7	117.9	138.1	130.8
1954	138.4	138.3	138.2	138.2	138.0	115.2	119.5	138.5	138.4	111.8	127.4	114.1	129.7
1955	129.7	138.8	138.6	138.3	137.3	137.0	138.9	139.0	114.6	119.4	107.0	130.5	130.7
1956	139.0	138.7	138.6	138.2	130.5	125.6	136.4	138.8	139.0	129.8	121.9	138.9	134.6
1957	138.7	139.0	138.8	113.5	109.0	112.7	135.2	138.6	138.4	126.5	110.4	123.2	127.0
1958	120.3	121.3	136.3	138.0	123.8	111.5	113.4	135.3	138.6	132.7	115.0	112.4	124.9
1959	122.4	138.6	138.7	138.4	137.7	132.6	134.4	139.0	138.9	133.5	112.6	138.1	133.7
1960	125.5	113.7	120.2	119.5	119.7	107.2	120.3	138.4	139.0	133.7	138.5	134.3	125.8
1961	122.3	138.2	138.5	138.5	138.1	129.3	124.3	138.9	139.0	132.2	121.1	126.3	132.2
1962	135.4	130.8	138.7	138.4	108.5	117.1	109.7	136.1	139.0	133.7	137.5	125.0	129.2
1963	127.8	131.4	138.4	138.7	129.9	133.8	135.5	139.0	139.0	133.7	111.0	113.6	131.0
1964	133.0	137.2	138.8	138.7	138.2	136.3	117.1	132.6	138.9	120.9	107.9	114.4	129.5
1965	137.5	138.4	138.8	113.0	116.2	116.6	109.6	119.9	139.0	115.3	123.3	115.5	123.6
1966	137.5	130.6	118.0	111.3	124.8	108.1	121.1	138.8	139.0	135.0	118.6	121.5	125.4
1967	128.2	138.6	118.6	138.7	138.4	138.8	136.6	139.0	133.9	114.2	108.4	110.1	128.6
1968	137.5	138.7	138.6	131.1	109.2	109.3	110.9	122.5	139.0	124.3	112.9	139.0	126.1
1969	128.8	138.5	138.8	116.3	120.1	115.2	114.6	136.3	139.0	118.9	124.7	115.5	125.6
1970	126.8	135.8	138.6	138.6	138.7	124.6	131.0	139.0	139.0	136.8	118.8	110.3	131.5
1971	136.6	138.6	138.5	138.5	138.4	138.6	138.9	139.0	139.0	138.2	109.3	118.2	134.3
1972	109.1	127.8	116.9	127.5	136.8	138.8	139.0	139.0	138.5	123.5	126.9	134.9	129.9
1973	105.6	122.2	129.0	122.8	111.3	107.3	106.5	106.8	135.2	138.8	138.1	138.5	121.8
1974	139.0	138.8	138.9	137.1	138.4	121.6	132.0	139.0	139.0	124.3	127.5	132.0	134.0
1975	122.4	122.4	138.9	138.7	138.2	117.1	115.6	128.1	139.0	119.9	136.4	114.3	127.6
1976	138.4	138.6	136.9	138.3	116.3	115.3	115.0	124.6	139.0	116.6	130.1	121.7	127.6
1977	137.0	138.4	138.6	132.1	135.3	138.4	130.7	139.0	139.0	116.1	113.0	121.9	131.6
1978	127.5	137.1	138.3	137.1	123.1	106.6	113.0	134.0	138.5	138.9	138.3	135.0	130.6
1979	125.9	113.4	108.9	120.8	108.5	107.6	107.4	117.6	135.6	139.0	130.5	139.0	121.2
1980	137.7	134.2	137.8	126.0	106.1	109.6	108.9	113.6	138.8	138.9	128.9	120.8	125.1
1981	139.0	138.8	138.9	138.4	138.0	138.3	135.2	138.6	139.0	115.0	127.9	119.5	133.9
1982	114.2	138.7	136.0	132.3	112.2	107.9	115.7	131.5	139.0	138.0	111.9	114.3	124.3
1983	137.4	131.8	117.2	125.5	113.8	107.4	109.3	112.8	139.0	121.8	116.1	115.0	120.6
1984	112.0	132.9	122.7	124.8	135.3	127.2	135.8	139.0	139.0	117.1	108.8	110.9	125.5
1985	116.2	138.1	120.2	116.1	112.0	107.0	112.7	118.4	139.0	133.6	127.0	122.2	121.9
1986	132.1	122.7	128.6	138.0	118.2	114.3	125.4	138.8	139.0	118.1	123.8	118.3	126.4
1987	119.9	122.4	126.1	125.4	115.3	111.4	114.5	126.1	137.7	135.3	114.7	137.9	123.9
1988	132.6	111.9	138.7	133.5	110.1	114.9	116.6	130.8	135.9	133.5	113.4	118.5	124.2
1989	138.8	138.3	138.6	138.1	135.5	119.4	133.0	138.9	139.0	132.2	117.1	138.9	134.0
1990	138.2	138.7	138.7	138.4	135.3	138.3	138.4	138.8	138.8	122.9	123.8	116.0	133.9
Average	129.2	133.5	133.6	131.1	124.9	119.4	122.3	132.0	137.8	127.5	20.6	123.4	127.9
Maximum	139.0	139.0	139.0	138.7	138.7	138.9	139.0	139.0	139.0	139.0	38.5	139.0	139.0
Minimum	105.6	111.9	108.9	107.8	106.1	106.2	106.5	106.8	114.6	111.8	107.0	109.4	105.6
Std. Dev.	9.63	7.53	7.94	9.18	10.93	10.86	11.12	9.40	3.59	8.47	9.66	9.94	4.24

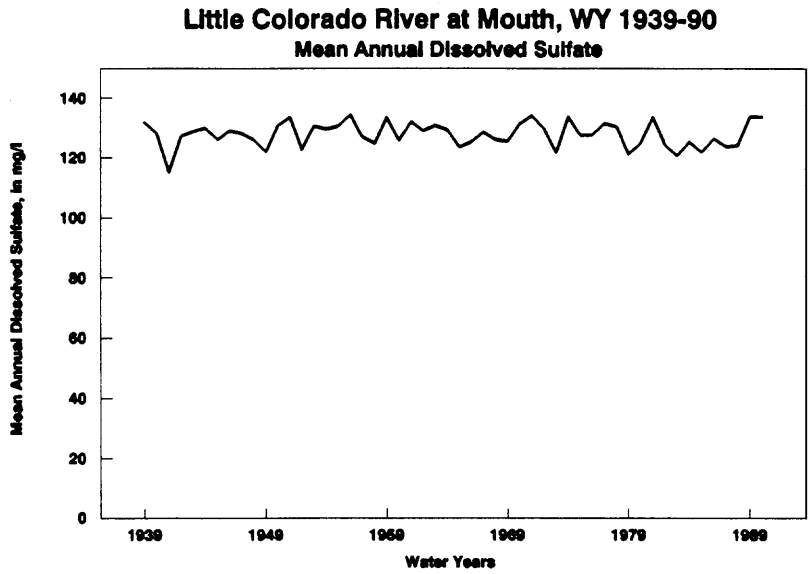


Figure 490. LCR at Mouth, WY 1939-90, Mean Annual Sulfate, in mg/l

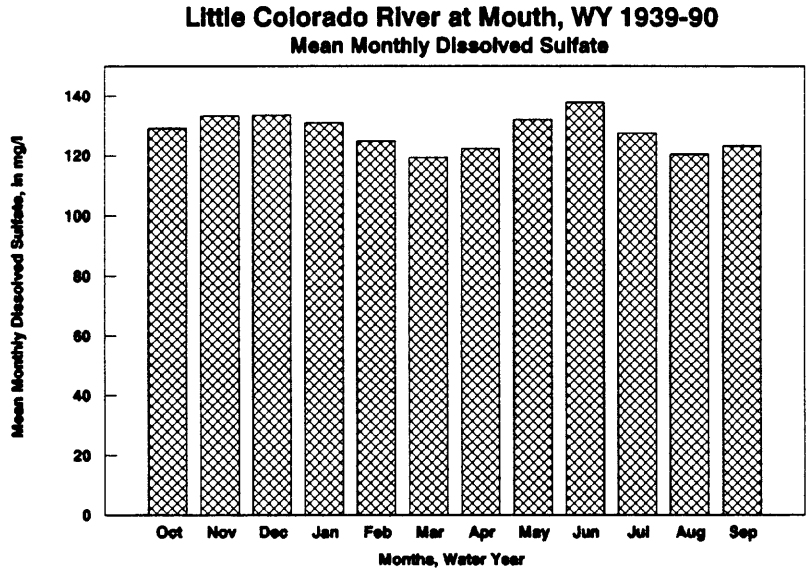


Figure 491. LCR at Mouth, WY 1939-90, Mean Monthly Sulfate, in mg/l

12.3.6 Suspended Sediment Concentration, Little Colorado River at Mouth

The humpback chub is presumably negatively phototrophic through a portion of its life cycle; that is, it requires "muddy" water at certain times in order to survive and reproduce (Wegner, 1992). Suspended load in a stream consists of lighter particles than bed load. Although there is a relationship between suspended load and bed load, the process of transforming the suspended load data to total load is lengthy and complex, and lies outside the scope of work for this project. While suspended load gives the water a muddy appearance and produces opacity in the water (reduces transmitted light, like a shadow), it is the bed load which contains the heavier sand and gravel particles which replenish the beaches in the Grand Canyon.

Missing records for the suspended sediment load for the Little Colorado River at Cameron has been reconstructed by DBS&A (Marley, 1994) by use of a routing model and regression analysis. This data is given in tons per month. Of more importance to the endangered species management issue related to the humpback chub is sediment concentration in mg/l. The conversion of the data from tons to mg/l is calculated by the following formula (Guy, 1977).

$$Q_s = Q_w C_s k$$

transposing, this equation becomes:

$$C_s = \frac{Q_s}{Q_w k}$$

where Q_s = Sediment discharge rate (in tons)

C_s = sediment concentration, in mg/l

Q_w = stream flow rate, in cubic feet per second

and k = conversion factor of 0.0027

The historical and modeled stream flow rate and sediment discharge are placed in a Lotus 1-2-3 spreadsheet. Along with the conversion factor, the sediment concentration calculated results are placed in another spreadsheet. The suspended sediment concentration for LCR at Mouth is calculated utilizing the formula in Section 12.2, assuming that discharges from Blue Spring do not carry any sediment; in other words, the concentration from Blue Spring is assumed to be zero (0). As in the previous calculations for TDS, etc., the calculation procedure assumes perfect mixing; the reality is that, due to laminar flow conditions, perfect mixture between LCR at

Cameron and Blue Spring does not occur for some distance downstream. However, there is no other simple way to characterize the sediment concentration for LCR at Mouth in the reach in which the humpback chub critical habitat lies. The calculations are conducted on a monthly basis from WY 1939-90, resulting in the following table:

Table 149. Little Colorado River
The Hopi Tribe
Glen Canyon Environmental Studies - Hydrology Study
Little Colorado River at Mouth, Calculated Suspended Sediment, in mg/l

Month/Yr	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Average
1939	0	0	0	0	0	17,350	15,710	0	0	1,933	20,178	28,863	7,003
1940	0	0	0	0	3,913	7,442	0	0	0	55,947	76,884	77,603	18,482
1941	66,768	16,612	29,841	21,986	23,544	24,748	21,859	21,879	0	28,549	69,849	72,490	33,177
1942	81,447	6,463	5,042	3,972	5,998	11,572	17,481	0	0	2,125	6,814	1,975	11,907
1943	7,814	0	0	0	6,467	20,576	5,047	0	0	3,378	62,579	52,069	13,161
1944	9,673	0	0	0	0	13,526	19,759	12,341	0	1,933	2,153	43,569	8,580
1945	17,775	0	136	0	3,132	10,148	19,373	9,966	0	54,794	75,728	8,092	16,595
1946	4,165	0	0	612	0	0	0	0	0	50,377	79,628	73,943	17,394
1947	7,507	23,154	9,150	0	8,681	0	0	0	0	0	84,906	58,594	15,999
1948	82,313	0	0	0	6,757	11,513	19,358	0	0	34,410	58,414	1,961	17,894
1949	26,603	3,953	3,114	13,719	14,345	23,599	20,207	0	0	47,903	72,756	44,678	22,573
1950	40,027	0	0	0	12,313	8,271	0	0	0	40,519	5,883	13,618	10,053
1951	0	0	0	0	0	0	0	0	0	24,142	63,891	59,244	12,273
1952	42,522	0	0	26,004	11,169	6,793	22,669	10,666	0	12,012	48,987	70,449	20,939
1953	0	0	7,509	0	0	8,917	0	0	0	64,544	55,966	0	11,411
1954	0	0	0	0	0	10,626	9,478	0	0	73,534	29,688	64,740	15,672
1955	23,008	0	0	0	0	0	0	0	14,882	51,884	87,045	20,011	16,402
1956	0	0	0	0	0	0	0	0	0	20,094	44,676	0	5,398
1957	0	0	0	18,180	10,351	5,088	113	293	1,351	44,927	84,853	26,809	15,997
1958	52,074	26,353	126	11	3,985	19,075	9,365	711	807	17,106	83,050	53,218	22,157
1959	13,457	17	11	30	37	773	459	0	186	17,760	103,607	1,543	11,490
1960	37,973	33,962	23,481	12,511	4,616	30,087	3,904	5	15	0	0	10,785	13,112
1961	27,362	121	31	32	57	3,638	4,691	0	0	21,151	56,812	57,092	14,249
1962	9,449	22,214	48	719	34,156	7,728	11,537	137	0	0	4,153	39,927	10,839
1963	39,555	17,659	84	9	6,279	1,018	753	0	0	0	91,500	62,055	18,243
1964	12,255	2,691	0	0	0	0	13,391	3,844	49	60,788	85,873	33,148	17,670
1965	1,216	0	0	17,753	2,419	3,255	9,832	4,815	0	81,481	45,249	46,435	17,705
1966	3,024	6,600	28,349	15,715	399	30,220	3,311	2	0	15,660	66,705	48,845	18,236
1967	30,954	131	10,299	5	8	0	127	0	12,383	83,847	71,614	59,848	22,435
1968	1,493	0	193	3,145	18,795	14,207	13,687	3,304	0	43,790	75,693	5	14,526
1969	21,226	805	0	29,443	6,023	19,640	12,720	916	0	52,137	37,966	49,522	19,200
1970	33,764	3,497	21	312	0	12,574	3,004	0	0	6,092	69,848	75,841	17,079
1971	2,727	0	0	0	0	0	0	0	0	0	80,630	53,569	11,411
1972	81,097	12,550	29,540	4,761	0	0	0	0	0	40,329	30,628	8,026	17,244
1973	90,929	20,747	11,671	9,877	18,688	23,143	24,428	24,700	0	0	0	0	18,682
1974	0	0	0	0	0	525	0	0	0	37,731	29,203	15,897	6,946
1975	43,744	20,433	0	0	0	7,943	13,985	0	0	50,015	4,247	64,319	17,057
1976	0	0	0	0	13,040	10,723	14,674	2,346	0	59,811	21,927	43,534	13,838
1977	1,173	0	0	0	0	0	0	0	0	61,024	70,294	42,776	14,606
1978	29,201	0	0	0	4,764	24,204	16,929	0	0	0	0	7,133	6,853
1979	23,604	66,127	39,243	25,071	20,113	22,615	22,795	15,832	1,773	0	0	0	19,765
1980	0	2,966	0	6,309	24,830	19,551	21,683	16,032	0	0	25,124	46,125	13,552
1981	0	0	0	0	0	0	0	0	0	64,238	27,984	50,025	11,854
1982	66,762	0	907	0	17,725	22,198	13,871	0	0	0	73,421	64,270	21,596
1983	0	6,690	29,115	6,891	15,874	22,934	21,173	17,062	0	44,967	61,356	62,066	24,011
1984	72,947	4,938	20,969	7,657	0	0	0	0	0	58,318	82,020	73,556	26,700
1985	61,314	0	24,610	17,048	17,943	23,503	17,267	10,055	0	11,858	30,648	42,542	21,399
1986	16,425	19,864	12,217	0	10,665	12,233	2,668	0	0	55,687	39,454	52,973	18,515
1987	50,567	20,234	15,900	6,878	13,964	16,720	15,246	207	0	6,484	65,317	0	17,626
1988	9,718	35,536	0	0	20,192	11,225	12,891	0	0	11,812	69,107	52,728	18,601
1989	0	0	0	0	0	4,171	0	0	0	15,500	58,579	0	6,521
1990	66	0	0	0	4,028	0	0	0	0	18,109	30,598	50,727	8,627
Average	23,917	7,198	5,800	4,782	7,024	10,463	8,759	2,983	605	29,783	50,452	38,216	15,832
Maximum	90,929	66,127	39,243	29,443	34,156	30,220	24,428	24,700	14,882	83,847	103,607	77,603	33,177
Minimum													5,398

The following graphics illustrate the relationship between mean suspended sediment concentration on an annual and a monthly basis for the study period of WY 1939-90. The annualized concentration is approximately proportional to the annual flow. The mean monthly load examines the probable seasonality of sediment concentration.

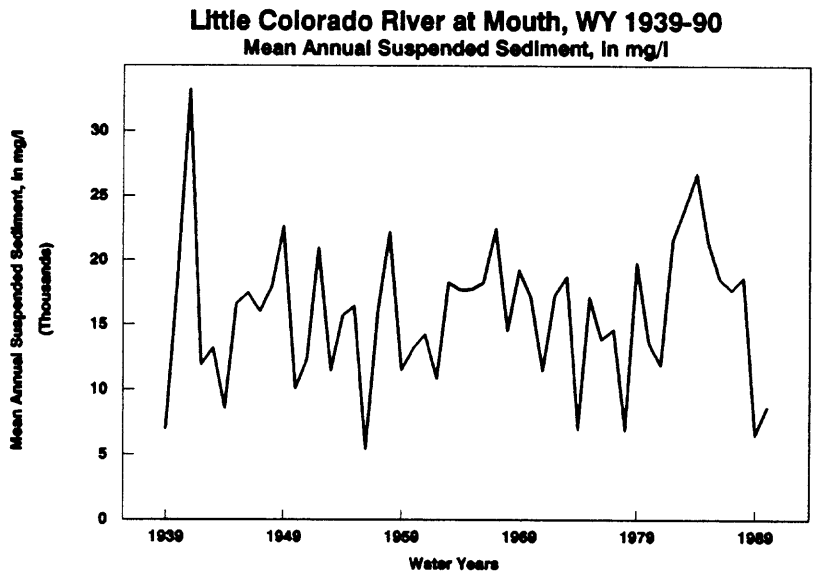


Figure 492. LCR at Mouth, WY 1939-90, Mean Annual Suspended Solids, in mg/l

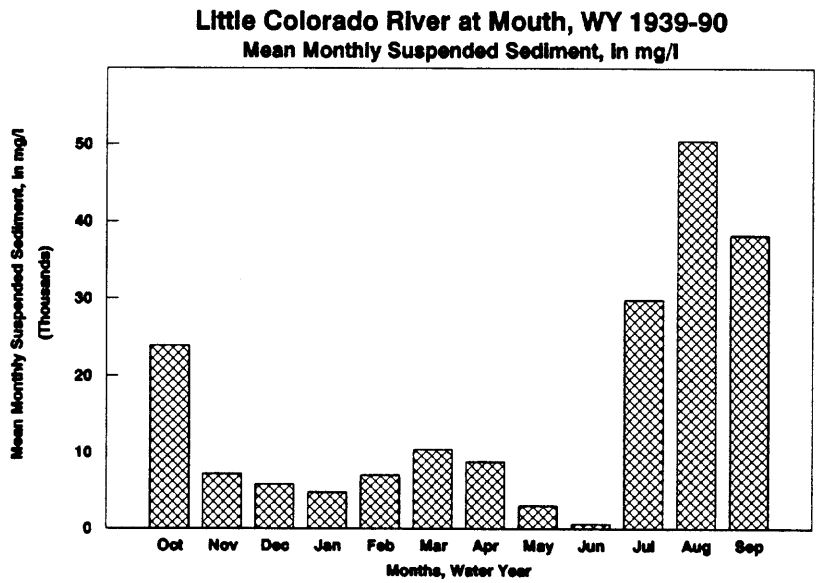


Figure 493. LCR at Mouth, WY 1939-90, Mean Monthly Suspended Solids, in mg/l

12.3.7 Sediment Concentration, Turbidity, Transmittance, and Opacity

Both the humpback chub and the spinedace are thought to require sediment in their habitat waters for a portion of their life cycle. This requirement indicates that these species are, at least for a portion of their lives, negatively phototrophic. This may indicate that a major defense against competitors is to "hide" in muddy water so they are less visible to predators. In order to examine the importance of the foregoing sediment concentration analyses, it is necessary to examine the relationship between sediment concentration, turbidity, transmittance, and opacity.

Fine particles have a greater surface to volume ratio than large particles. Therefore, at a given concentration, fines will scatter light more than larger particles, such as sand. As the velocity of the stream increases, larger particles are brought into suspension in the water of the stream. In addition, the sand, silt, and clay fractions in suspended load may vary according to the parent material for the watershed, which in turn, may effect the light scattering capability of flows from different watersheds.

Turbidity is a measure of the ability of particles suspended in a medium (such as water) to scatter light. Typically, this water quality parameter is measured with a Jackson or surface-scatter turbidimeter or with a nephelometer. The conversion of turbidity in continuous record water quality monitoring stations to sediment concentration requires the development of a transfer function (similar to a stream flow rating curve or function) (Pickering, 1976, p. 7).

Normally, rangers and naturalists from the US Forest Service and the US National Park Service measure the "cloudiness" of water by means of a Secchi disk. This procedure consists of lowering a long rod to which a high contrast visual target is connected into the water to be tested, such as from a boat floating in the water. The disk is submerged, by means of the rod, until the target in no longer clearly discernable. This technique is dependent on both observational accuracy and precision, and ambient light conditions. The disk can be seen deeper at mid-day than during twilight, due to the light threshold of the eye. The Secchi disk procedure measures neither turbidity nor sediment concentration; rather, it measures transmittance of light through the medium (water).

The humpback chub or the spinedace may rely on the ability of sediment to veil their presence from predator fish species. For this reason, the ability of sediment to retard or scatter light may be the major impact of sediment on native aquatic species. In other words, the fish may require less light or hazy light at times in their life cycle. In that case, the parameter of interest is no longer sediment concentration, turbidity, or transmittance, but rather, opacity. Opacity is the inverse of transmittance on a logarithmic scale.

In a study of available photosynthetic radiation, Yard *et al* (1993), discusses the relationship between light attenuation and suspended sediment for a narrow range of discharge (5,000 and 15,000 cfs. This study was undertaken to determine impacts on aquatic algae by suspended sediment. It was postulated that light attenuation by sediment is a limiting factor on productivity and growth of aquatic algae in the main stem Colorado River. Vertical and longitudinal attenuation was investigated and a methodology developed to relate attenuated light quantities to suspended sediment utilizing spherical light sensors. However, this experiment does not constitute relating turbidity to sediment concentration. It does provide a means to determine photosynthetically available radiation to sediment concentration. This measure is related to the growth of algae known to be found in the stomachs of native Colorado River fishes.

The issue of sediment tolerance for rainbow and brown trout (and other salmonids) has been investigated by Newcombe and MacDonald (1991). It has been determined that suspended sediment concentrations in excess of 1,000 mg/l result in a 100% mortality for the trout eggs. Related to the concentration is duration of exposure by the following formula:

$$StressIndex = \log_e(C X D)$$

Where:

C = Concentration of suspended sediment, in mg/l

D = Duration of exposure, in hours

The suspended sediment concentration in the Little Colorado River frequently exceeds the maxima in Newcombe and MacDonald by an order of magnitude. It is noted that the seventy (70) investigations reviewed in their study included only salmonids. No spinedace or humpback chub were included. The infant mortality and even the adult mortality was significant at high concentrations of sediments. As the silt-laden flows in the Little Colorado River persist for days, or even months, one can conclude that the duration of exposure for chub in the Little Colorado River designated critical habitat greatly exceeds that of the trout experiments. Although it is possible that the chub are more capable of sustaining sediment exposure than trout, in which case, the LCR may provide an opportunity for the chub to propogate and grow at various seasons without trout present in the habitat. Unfortunately, there is no experimental research to support this conclusion.

For the above stated reasons, it would be difficult to quantify the relationship between suspended sediment and the survival requirements of endangered species of fish. The sediment concentration data is presented in the present report to enable aquatic biologists to relate fish counts to sediment, if that is helpful.

12.4 Surface Water Quality and Discharge Relationships

Water quality parameters are examined in the literature in preference studies related to endangered species of aquatic wildlife. It was hoped that seasonal relationships with respect to water quality and relationships related to flow rate could be developed with available historical data. Unfortunately, the water quality data is so scarce that these relationships depend on two or three samples per location, in many cases. The low flows have been sampled more than the storm flows, obviously due to a greater interest in spring discharge and base flow quality. Lamentably, these flows have little impact on riparian wildlife, since the losses in the stream far outweigh low flow contributions. Only if highly toxic soluble matter were found in significant concentrations would there be a liklihood of environmental impairment from low flow quality. In addition, there seems to be an unusual direct positive correlation between flow rate and certain ions. It would appear that turbulent mixing with soils in sheet flows and in turbulent stream flows degrades water quality. Most drainages exhibit a negative correlation - the opposite effect.

The data is presented in the form of Piper diagrams, draftsman plots, and regression plots to illustrate differences in water quality between drainages. A comparison between the main stem Little Colorado River water and Moenkopi Wash water demonstrates the higher degree of mineralization, salination, and alkalinity present in the wash. Similarly, a comparison with the Piper diagram of waters near Blue Springs illustrates the superior quality of main stem waters.

12.4.1 Little Colorado River at Cameron

The water quality data for the piper diagram which follows was taken from suspended sediment samples which were also analyzed for sufficient water quality parameters to enable their inclusion in the diagram. This sampling location is particularly interesting for the reason that the sampled flows include both LCR main stem water and Moenkopi Wash water. The LCR near Cameron station includes only main stem Little Colorado River water less the Moenkopi flows. The analyses from both stations are included for comparison.

The diagram shows that the Total Dissolved Solids (TDS) is generally less than 1,500 mg/l. The diagram illustrates the heavy sodium+potassium and carbonate+bi-carbonate concentrations with moderate amounts of chloride and sulfate.

Piper Diagram

Little Colorado River at Cameron

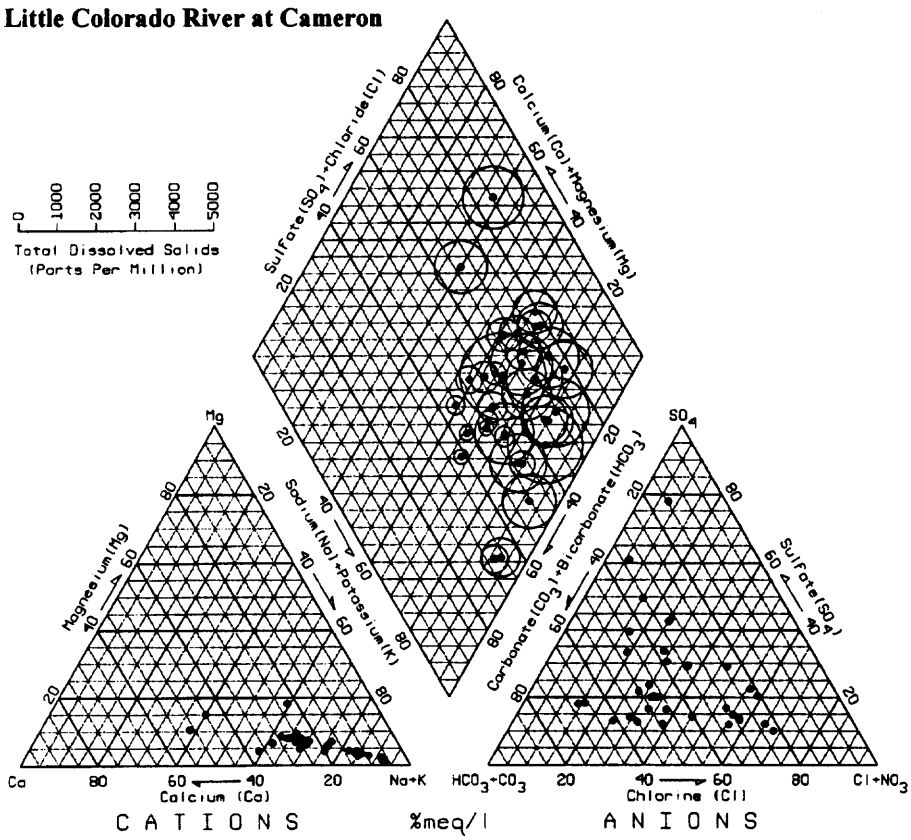


Figure 494. Piper Diagram, LCR at Cameron

12.4.2 Little Colorado River near Cameron

This sampling location is upstream of the confluence of the Little Colorado with Moenkopi Wash.

The TDS is fairly low, in the 1,500 mg/l range. The scatter in the data points is tighter, and when compared with Little Colorado River at Cameron, it is apparent that Moenkopi Wash flows add a certain amount of variability to the water quality of the Little Colorado. Sodium+potassium are quite high, as is chloride. The carbonate+bicarbonate hardness is lower than LCR at Cameron, indicating that a great deal of salinity and alkalinity is added by Moenkopi Wash.

Generally lower salinity indicates that the addition of water from the lower basin large snowmelt and thunderstorm flows, generally from Clear Creek and Chevelon Creek have a water quality benefit for the Little Colorado River.

Piper Diagram

Little Colorado River near Cameron

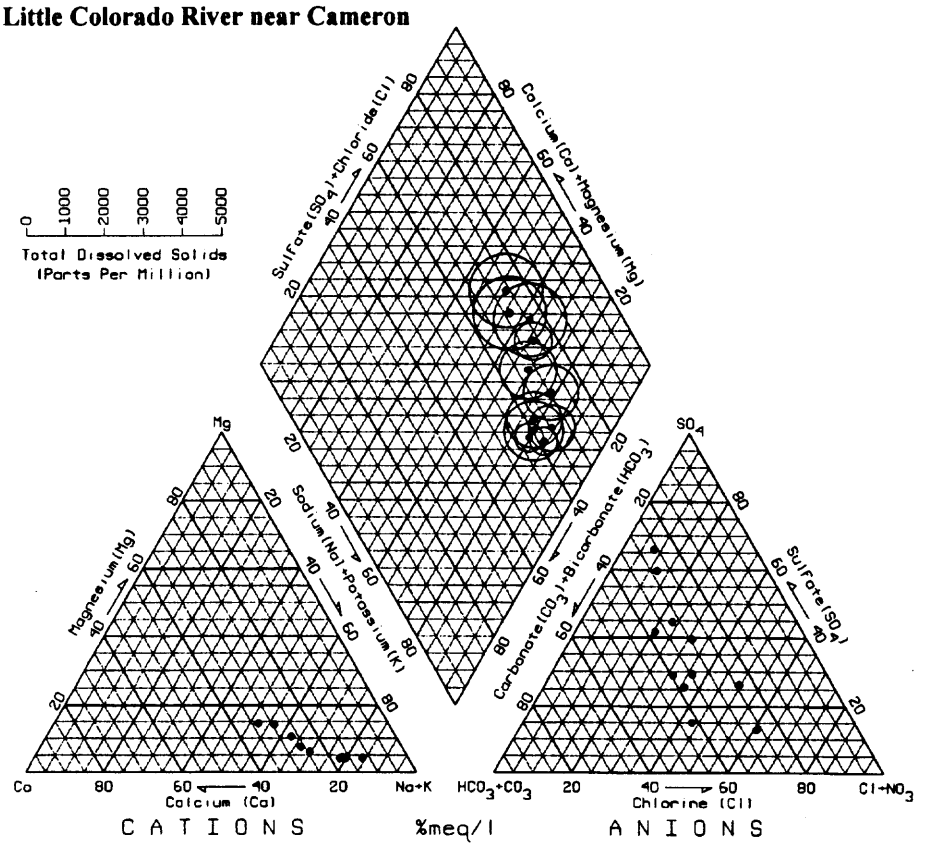


Figure 495. Piper Diagram, LCR near Cameron

The following draftsman plot of TDS, chloride, magnesium, calcium, sodium, and stream flow rate illustrate the various correlations between water quality parameters and flow. Flow (Q) is not a significant factor in the water quality of the main stem LCR. On the other hand, strong correlations are noted between TDS and sodium, TDS and calcium, TDS and magnesium, TDS and chloride, and calcium and magnesium.

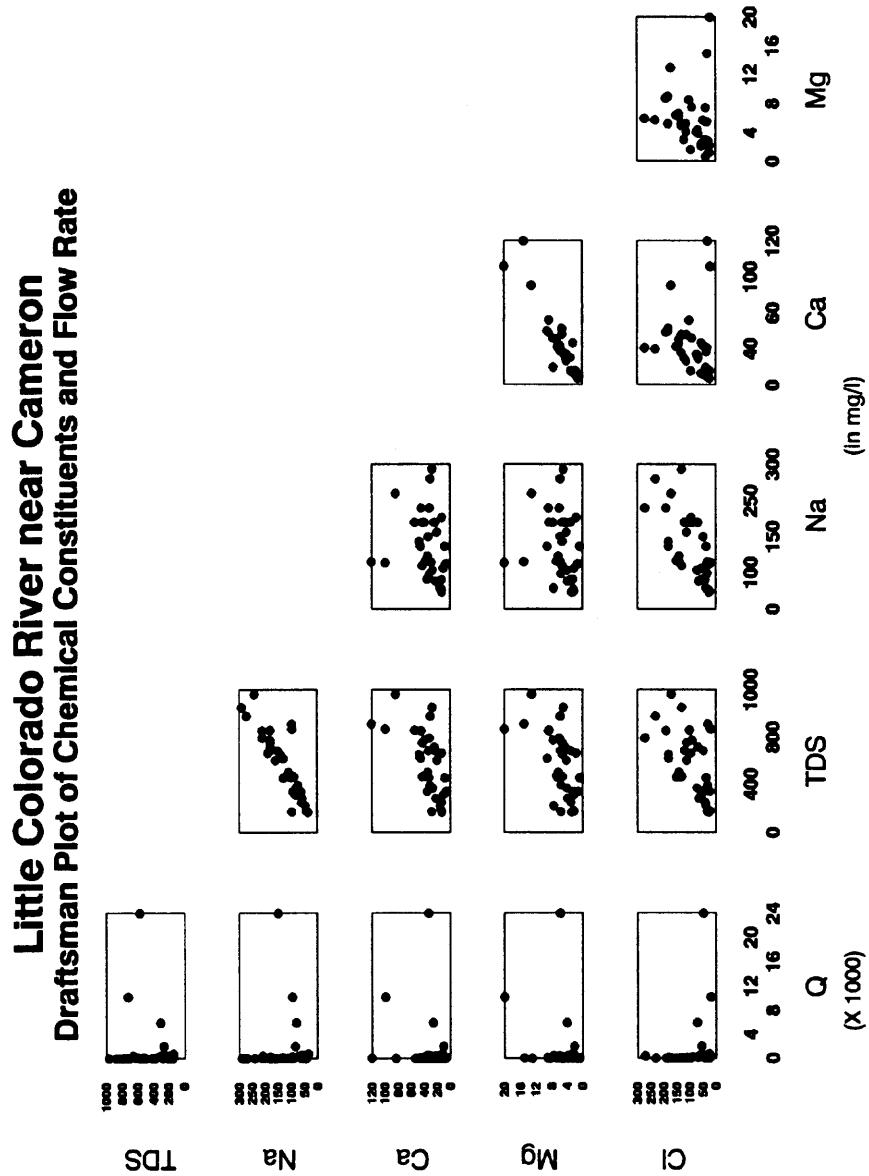


Figure 496. Draftsman Plot, LCR near Cameron

The following probability plot shows that the 100 year exceedance for TDS in the main stem Little Colorado is about 1,000 mg/l. The LCR upstream of Moenkopi Wash is fairly low in inorganic chemicals. This is probably due to the contribution of Clear Creek, Chevelon Creek, and other southerly drainages in both the spring snow melt and the monsoon seasons.

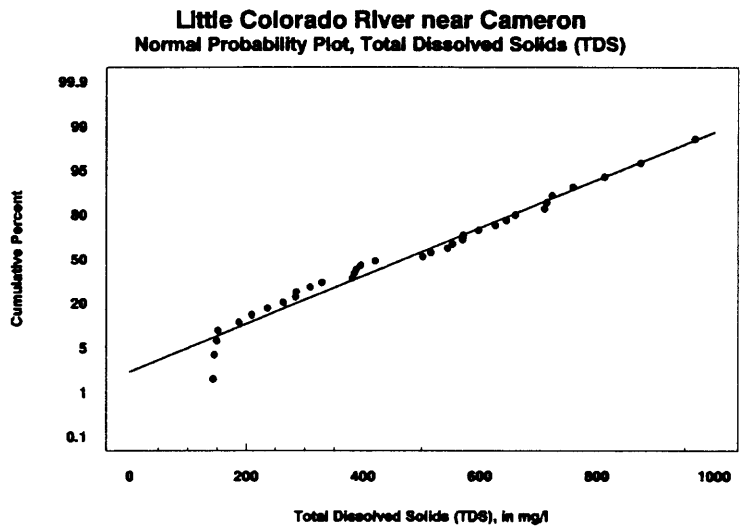


Figure 497. LCR near Cameron, Normal Probability Plot, TDS

The following linear regression plot demonstrates the strong positive correlation between calcium and magnesium in the main stem Little Colorado above Moenkopi Wash. These cations are present in most analyses at a fairly low concentration.

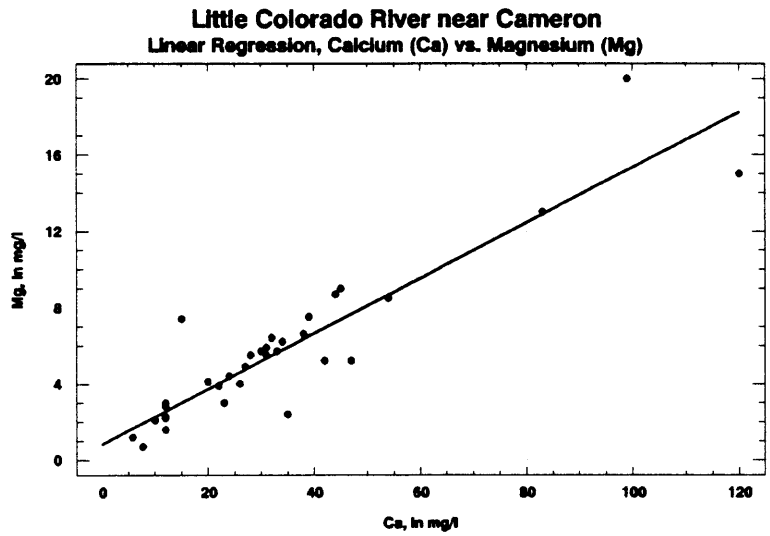


Figure 498. LCR near Cameron, Linear Regression, Calcium vs. Magnesium

The following linear regression plot shows a strong positive correlation between sodium and TDS. Obviously, solutes such as sodium chloride and sodium sulfate contribute a great deal to the salinity of the LCR.

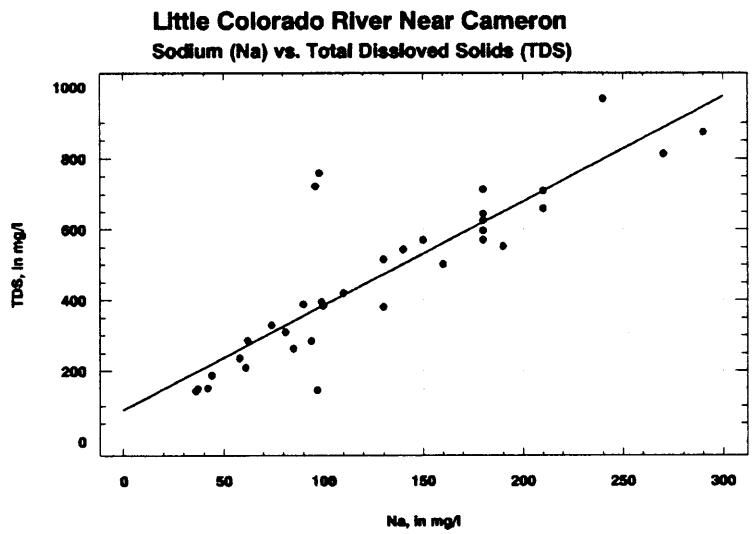


Figure 499. LCR near Cameron, Linear Regression of Sodium vs. TDS

In the frequency domain, it appears that relatively low sodium and moderate TDS are most probable conditions for the LCR. This histogram may be somewhat misleading, since most of the analyzed samples were taken in low flow conditions.

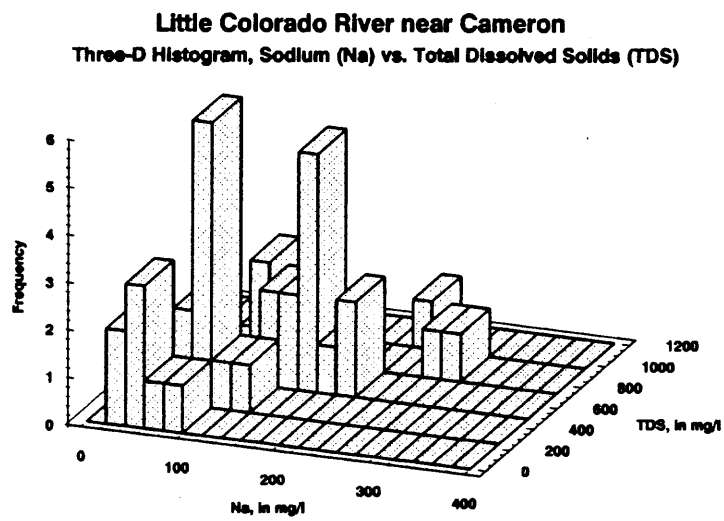


Figure 500. LCR near Cameron, 3D Histogram, Sodium vs. TDS

The following three dimensional plot demonstrates the strong correlation between TDS, sulfate, and sodium. Evidently, dissolved sodium sulfate contributes strongly to the salinity of the LCR system.

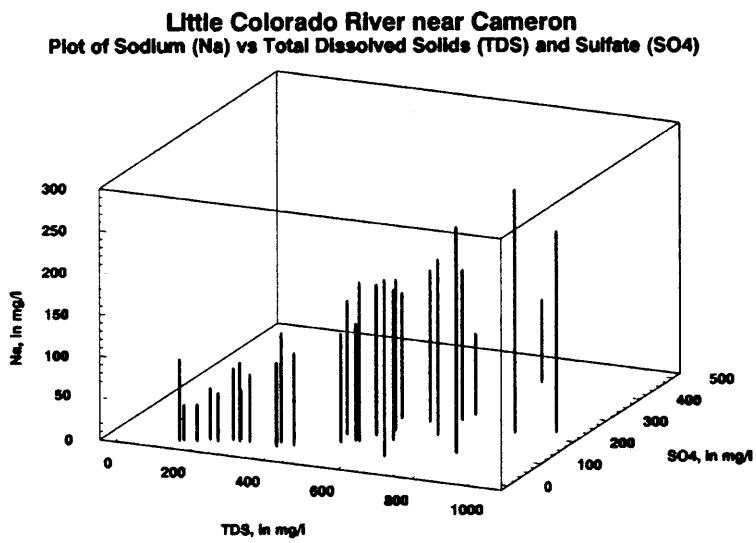


Figure 501. LCR near Cameron, Plot of Sodium vs. TDS and Sulfate

12.4.3 Moenkopi Wash at Moenkopi

Moenkopi Wash has been gaged since 1941. The gage has been moved several times in an attempt to gain better control for low flow accuracy. The present gage has operated since 1977.

It will be noted in the following piper diagram that the waters of the main stem Little Colorado differ considerably from that of Moenkopi Wash.

The usual TDS of Moenkopi Wash is considerably higher than that of the main stem LCR. TDS of up to 5,000 mg/l is noted. Moenkopi Wash is generally higher in calcium and magnesium than the LCR. Moenkopi is much higher in sulfate, but lower in carbonate+bicarbonate hardness and chloride than that of the main stem Little Colorado River. Note the shift in the distribution on the parallelogram plot from to the middle right to the top of the diagram. Although Moenkopi Wash contributes a certain amount of dissolved solids to the main stem, it moderates the sodium and hardness content.

Piper Diagram

Moenkopi Wash near Moenkopi

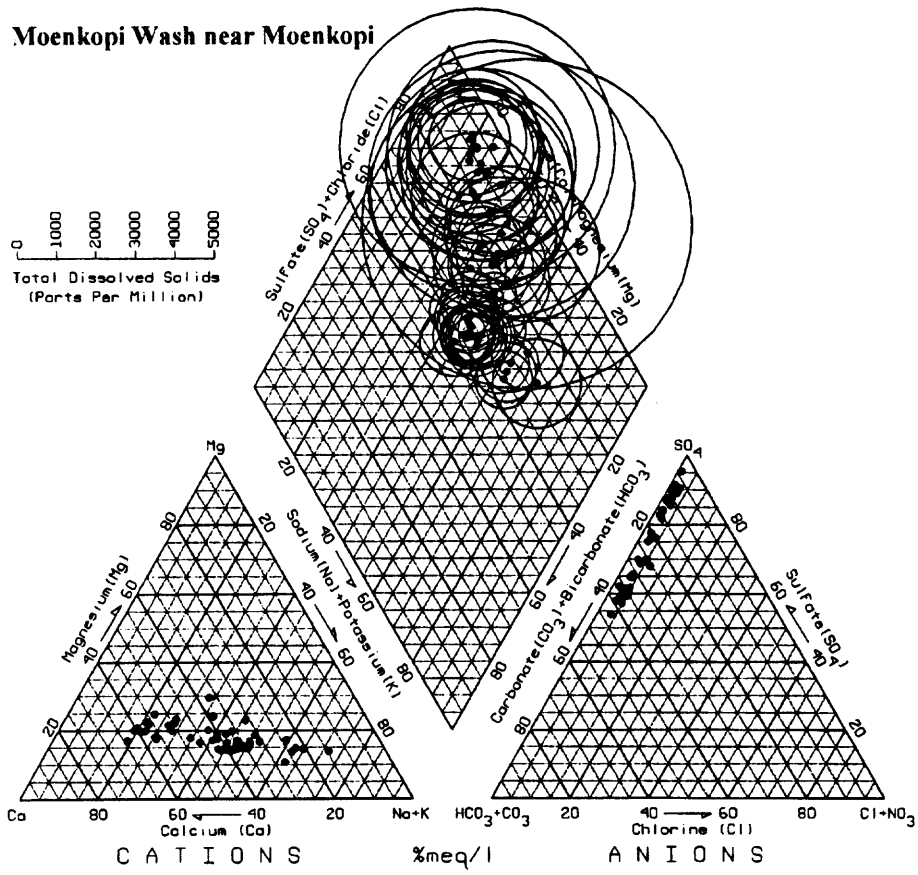


Figure 502. Piper Diagram, Moenkopi Wash at Moenkopi

The draftsman plot shows generally greater correlation between water quality constituents than the LCR. There appears to be a stronger correlation between flow (Q) and TDS, sodium, potassium, calcium, magnesium, and sulfate than in the main stem LCR. TDS and sulfate reveal a strong linear relationship, with little scatter. Sulfate shows a fairly strong correlationship with all the other constituents.

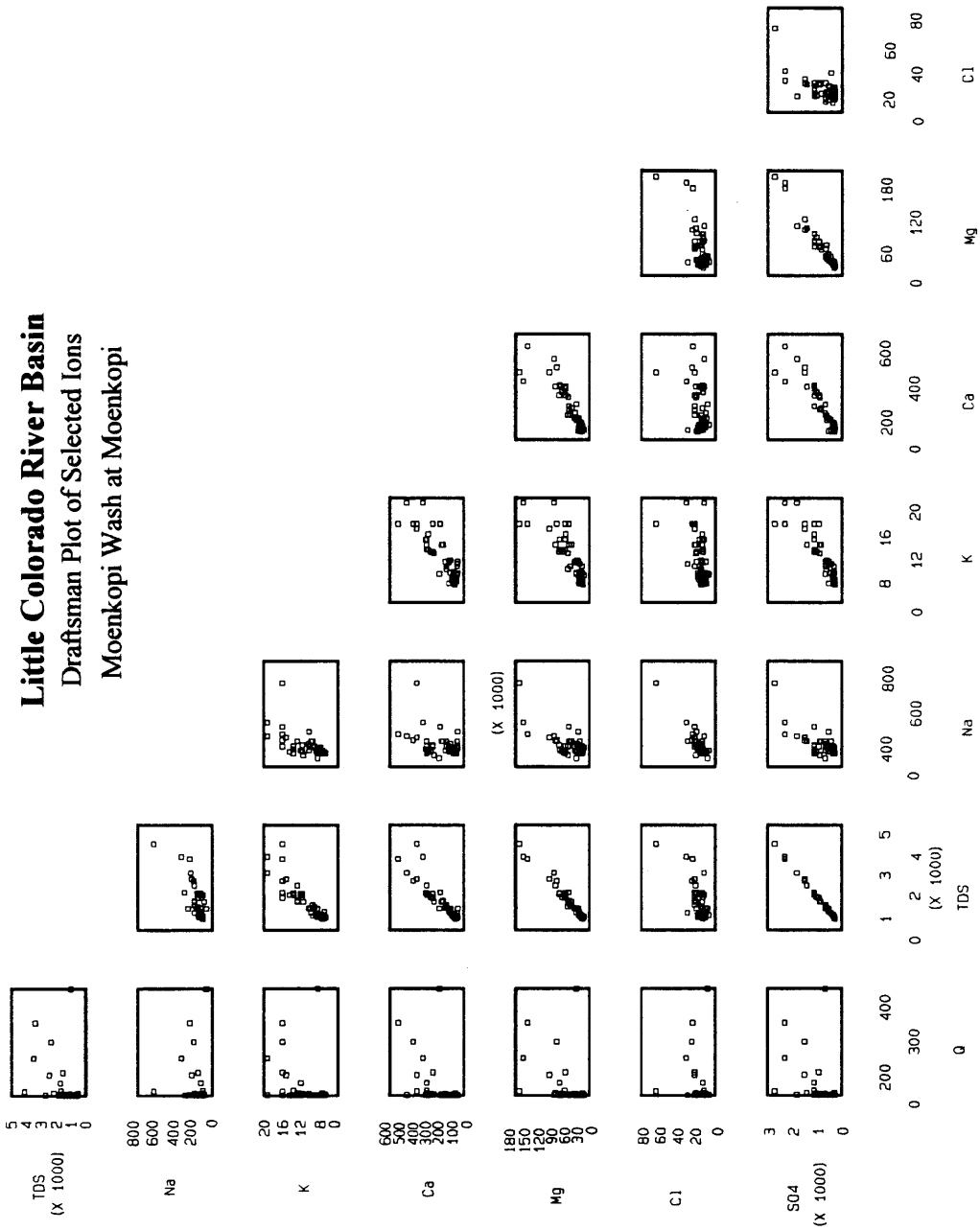


Figure 503. Moenkopi Wash at Moenkopi, Draftsman Plot

The following plot demonstrates a certain positive correlation between flow (Q) and TDS. This may be due to strong turbulent mixing of water with soluble ions adsorbed on the suspended fines of the sediment flow. This relationship is inverse to what is to be expected, namely, that storm flows in most drainages is much lower in dissolved ions than base flows, which generally originate in groundwater discharges.

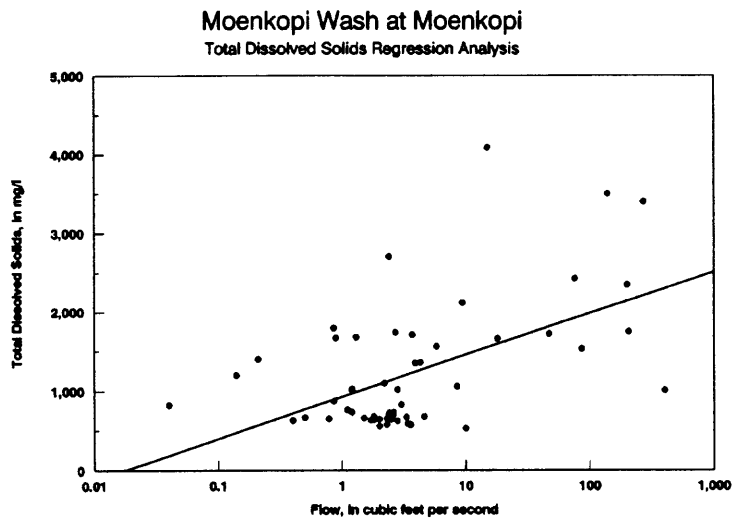


Figure 504. Moenkopi Wash at Moenkopi, Linear Regression of TDS vs. Flow

It is notable that sodium is not strongly correlated with flow (Q) in Moenkopi Wash. Evidently, the sodium content is relatively constant, regardless of the flow.

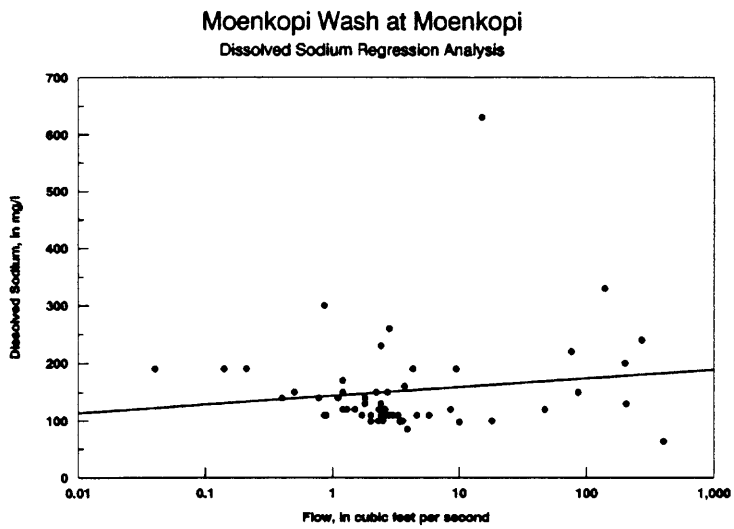


Figure 505. Moenkopi Wash at Moenkopi, Linear Regression of Sodium vs. Flow

There is, however, a strong correlation between flow and sulfate. This is surprising, since sulfate generally occurs in combination with sodium. However, the parent material may be oriented to calcium and magnesium, rather than sodium, in Moenkopi Wash.

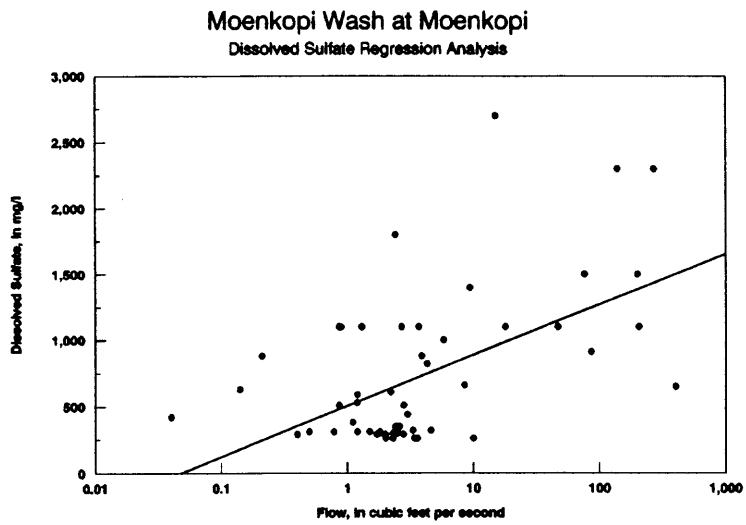
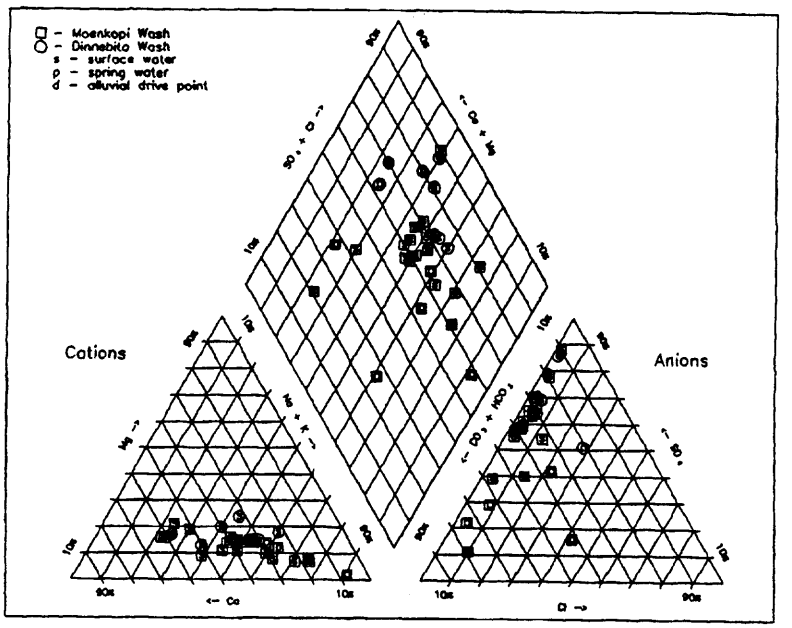


Figure 506. Moenkopi Wash at Moenkopi, Linear Regression of Sulfate vs. Flow

12.4.4 Moenkopi and Dinnebito Washes, with Spring Discharges

The following piper diagram of flows from springs and base flows in Moenkopi and Dinnebito Washes exhibits similar characteristics to flows in Moenkopi Wash. The water quality is not concentrated as much in the upper portion of the parallelogram portion of the piper diagram as in Moenkopi Wash flows, including storm flows. This is further evidence that storm flows in Moenkopi Wash are of lesser quality than the base flows and spring discharges.

This data was provided by Wickham (1992) as part of the research for his masters thesis in groundwater geochemistry of the Navajo Sandstone Aquifer (N-Aquifer) of the Hopi and Navajo Reservations.



Trilinear diagram for wash samples.

Figure 507. Piper Diagram, Moenkopi and Dinnebito Washes, and Springs

13 Geochemical Analyses of Surface and Ground Water Interactions

TO BE COMPLETED IN FINAL REPORT, 9/30/95

13.1 Geochemical Processes within Selected Aquifers

TO BE COMPLETED IN FINAL REPORT, 9/30/95

13.2 Geochemical Processes in Base Flows/Storm Flows

TO BE COMPLETED IN FINAL REPORT, 9/30/95

13.3 Geochemical Mixing of Tributaries with the Main Stem

TO BE COMPLETED IN FINAL REPORT, 9/30/95

14 Hydrologic Controls in the Little Colorado River System

For the purposes of this report, the term control is defined as that input hydrologic parameter to which the output is most sensitive. In other words, a control is the input parameter which most effects the outcome of the system.

14.1 Discharge Controls

There are two discharges of interest in the Little Colorado River. The first of these is the discharge from the LCR at its mouth into the main stem Colorado River. The second is the discharge in the main stem Little Colorado River as a response to precipitation and other sources of surface water.

14.1.1 Lower Little Colorado River (LCR at Mouth)

The principal control on discharges from the Little Colorado River at the mouth to the main stem Colorado River is the base flow discharge from Blue Spring, which provides

the continuous discharge necessary to make this reach of the Little Colorado River a perennial reach. The discharge from Blue Spring constitutes 48% of the annual flows from the Little Colorado River in an average year.

14.1.2 Main Stem Little Colorado River (LCR near Cameron)

The principal control on discharges within the Little Colorado River near Cameron is precipitation. The volume and intensity of the summer monsoon storms comprise the principal source of water from the Puerco River and the northern tributary washes from the Hopi and Navajo Indian Reservations. The snowmelt discharges from the southern tributaries and the upper Little Colorado River constitute the principal source of water for the spring peak in the LCR discharge.

Both the snowpack which melts to provide spring discharges and the variable, convective storms which provide the monsoon flows are orographic in nature, with the San Francisco Mountains, the Mogollon Rim, and the White Mountains elevate the flow of moist air from the Gulf of Mexico, the Gulf of California, and the Pacific Ocean to lower the dew point of the air and producing precipitation. The central Little Colorado River valley and the northern mesas and plateaus lie in a rain shadow cast by the higher elevations.

The variability of the precipitation in the higher elevations is greater than that of the low elevations. Consequently, the flows in the Little Colorado River main stem are highly variable.

14.2 Principal Losses

The disparity between the Little Colorado River at Grand Falls plus the Dinnebito Wash flows and LCR near Cameron flows indicates considerable loss between the two main stem stations. In order to account for this and other losses the flows from the tributaries would have to be gaged. However, it is possible, in a qualitative sense, to estimate the relative magnitude of these losses.

14.2.1 Percolation Losses

The principal loss of discharge in the main stem Little Colorado River is from percolation through the sandy beds into the alluvium. The losing reach of the stream between Grand Falls and Cameron cannot be accounted for by other losses. There are no consumptive uses of water in that reach of the main stem to account for this loss.

14.2.2 Evaporation Losses

Evaporation in the Little Colorado River basin is as much as 40 inches per year. However, the water does usually not pool into lakes, except at high altitudes, such as Silver Creek, Chevelon Creek, and the upper LCR basin. Evaporation will occur from bare rock and soil, but this is probably not as much as the percolation loss.

14.2.3 Evapotranspiration Losses

Phreatophytic plant colonies have established their presence along most of the tributaries and the main stem of the Little Colorado River. Tamarisk (salt cedar) has rapidly overcome cottonwood as the common wetlands plant species. These plants have root systems situated at great depth in the alluvium adjacent to the river and tributaries, and per acre of plant, have a very high demand for water. However, the acreage covered by these plants is quite small and probably they consititute a small fraction of the evapotranspiration losses from the native plant species which occupy the majority of acreage in the basin.

14.2.4 Consumptive Uses

Consumptive uses occur in the Little Colorado River system from a diversion in New Mexico on the Puerco River and several small diversions to irrigation in the Silver Creek drainage. The upper LCR basin has a major impoundment, and smaller ones exist on Silver Creek, Chevelon Creek, and Clear Creek. The electricity generating plant at Joseph City utilizes water from the alluvium, which in turn increases percolation in the vicinity. The City of Winslow derives a portion of its water supply from a dam on Chevelon Creek. At this time, consumptive use of tributary surface water does not deplete the main stem LCR to the point of environmental concern. It is possible that future water supply development projects in the spinedace habitats could further deplete the existing river lengths. It is also possible that developments on the southern tributaries could upset the temperature changes which are in synch with the spawning cycle of the humpback chub.

14.3 Sediment Transport Controls

The transport of sediment is governed by the velocity of water in the channels of the main stem Little Colorado River and its tributaries. Most of the sediment is input to the system by the Puerco River and the tributaries which flow through the Hopi and Navajo Indian Reservations.

14.3.1 Origins and Parent Material of Sediment

Aeolian and fluvial erosion break down and transport quartzic sand from the sandstone cliffs in northwestern New Mexico and on the Hopi and Navajo Reservations in northeastern Arizona. The highly erosible shales which interbed between successive sandstone units in the sedimentary formations in the same area are eroded and transported by sheet erosion from precipitation. The events of great magnitude and intensity which occasionally occur in this area transports fines and sand to the LCR between the Puerco River confluence and Grand Falls, where a considerable amount of sediment is stored until velocities are achieved in the main stem of sufficient magnitude to transport the sediment to the lower Little Colorado River.

14.3.2 Lower Little Colorado River

The principal control on the transport of sediment in the lower Little Colorado River is precipitation. The snowmelt in the spring provides the greatest discharges and velocities of the average year, and the material stored in the reach between the Puerco River and Grand Falls is transported to the lower LCR. The source of the sediment is sheet erosion in the northern tributary and Puerco River watersheds driven by the intense convective storms of the monsoon season. The base flow discharges from Blue Spring, when added to the snowmelt flows in the main stem, may increase the velocity to enable efficient transport of sediment to the main stem Colorado River.

14.3.3 Main Stem Little Colorado River

The principal control of sediment transport in the main stem Little Colorado River is precipitation. The origin, storage, and transport of the sediment in the main stem is exactly the same as that of the lower LCR, above.

14.3.4 Upper Little Colorado River

Sediment is discharged in a lesser quantity from the upper Little Colorado River due to the lack of fine material to transport, and due to the existence of impoundments on the upper tributaries.

14.4 Water Quality Controls

The quality of surface water in the Little Colorado River is a result of the interaction between the water falling on the surface of the ground in the basin and the mineral deposits and sediments with which it comes in contact.

14.4.1 Lower Little Colorado River

The principal control on water quality in the lower Little Colorado River is the sedimentary structure which defines the Coconino sandstone, the Mauve limestone, and the Redwall limestone through which the water is discharged to the Little Colorado River at Blue Spring. Slightly to highly saline water combine from a variety of springs to comprise this base flow discharge. Since the annual discharge of Blue Spring is as great in an average year than the discharge in the main stem, the quality of water at Blue Spring generally defines the quality of water at the mouth of the Little Colorado River.

14.4.2 Main Stem Little Colorado River

The principal control on water quality in the main stem Little Colorado River above Blue Spring is the soil through which the water passes. Heavy flows from snowmelt in the spring typically passes through volcanic and sedimentary formations on the way to the river. The convective storms on the Reservations contact saline members of sandstones and shales at a velocity proportional to the volume and intensity of the storm. The quality of water in some of the northern tributary washes has a higher quantity of dissolved ions at high flows than at low flows. However, the base flow discharges in some of the washes are highly mineralized, due to halite and other soluble minerals in the formations from which they drain, but the base flows percolate before reaching the main stem Little Colorado River.

15 Future Monitoring Recommendations

15.1 Glen Canyon Long-Term Monitoring Program

The Little Colorado River Basin, its climate, flows, sediments, and water quality, has never been systematically studied by means of gaging and sampling locations over a long period of time and over a wide range of flow conditions. As a result, most of the information about the watershed must be modeled with uncalibrated and estimated information for input. The future importance of the Little Colorado River, economically, environmentally, and for the sustenance of human life, suggests that the time is at hand when a long-term program of data collection and analysis is warranted. Environmental

management of the basin is handicapped as a result of the poor and sparse records. The following list of sampling/gaging locations is presented in an effort to jump start the process of understanding the drainage.

15.1.1 Discharge Measurements

Discharge measurements from springs and tributaries quantify not only the availability of water, but also the quantity of water of a certain quality which ends up in the environmentally sensitive reaches of the main stem. Such records as exist are not from coherent periods of record. For this reason, missing record must be filled in by modeling. As a result, losses and gains are unaccounted for, since these quantities are generally inferred from differences between adjacent gages.

Although this list may seem ambitious, the need for a medium-term, 7 to 10 year period of record would greatly enhance the accuracy of quantity, quality, and sediment transport models. These quantities can then be input into main stem Colorado River models as a decision making tool for managing the river environment for the benefit of man and nature. Without reliable data, the potential for error is great.

15.1.1.1 Little Colorado River near the Mouth

This gage operated from May 1990 until it was washed out in the storms of January/February 1993. The gage was not replaced due to environmental and aesthetic concerns. Unfortunately, there is no other way to monitor the Blue Spring discharges critical to the maintenance of the perennial reach near the mouth of the Little Colorado. Some environmentally acceptable means of gaging that flow is worthy of consideration.

15.1.1.2 Blue Springs

As noted above, flows from this series of groundwater discharges are perhaps best monitored by calculation from other gages. On the other hand, occasional visits to estimate flows and to acquire samples should be made.

15.1.1.3 Little Colorado River near Cameron

This station is the current continuous long-term record of discharges from the basin. When added to Moenkopi Wash flows, virtually the entire basin outflow is monitored, excluding Blue Spring. This record should continue to be monitored.

15.1.1.4 Little Colorado River at Grand Falls

This gage is easily calibrated with the LCR near Cameron gage. In the short term it is valuable for estimating losses, after the Dinnebito record is firmly established. It is also useful for determining attenuation of peak flows in the reach between Grand Falls and Cameron. Ultimately, a crest gage at Grand Falls would suffice.

15.1.1.5 Moenkopi Wash at Moenkopi

This gage is utilized in monitoring possible stream depletions by Peabody Western Coal Company impoundments. It is maintained by USGS as a part of the Black Mesa Monitoring Program and the data is utilized by Office of Surface Mining to monitor mine-related impacts.

15.1.1.6 Dinnebito Wash near Sand Springs

This drainage is a major contributor of surface water discharge and sediment during high flow storms. It has had no continuous discharge record until the gaging station was established by USGS in 1993 through funding provided by the Hopi Tribe. This gage should continue operation until knowledge is gained to understand this small but high flow drainage. Minimal crest gage records indicate that this wash could have one of the highest peak flows in the LCR Basin.

15.1.1.7 Oraibi Wash near District 6 Border

After a long search upstream and downstream along the wash, a site on the Hopi Partitioned Lands border was selected for the installation of a continuous record gage. Early crest gage records were taken from State Highway 264 and it is unlikely that the data is applicable for hydrologic and environmental study. A period of record of 7 to 10 years is recommended to insure that various flow regimes are explored.

15.1.1.8 Polacca Wash near Coyote Springs

This gage is located below State Highway 87, downstream of the confluence with Wepo Wash. The flows which move the fine sediments to Tolani Lake, and

at flood stage, to the main stem Little Colorado River need a period of record of seven years or more to fully understand the transport of turbidity-causing material to the mouth of the Little Colorado River and to the main stem Colorado River.

15.1.1.9 Jeddito Wash at Highway 87

This is a minor drainage which empties into Corn Creek just below Tolani Lake. Jeddito may be capable of transporting sediments to the Little Colorado which bypass the detention area. A period of record of 7 to 10 years is suggested.

15.1.1.10 Jacks Canyon near Winslow

There are indications that this drainage will be proposed as a significant water source in the near future. High quality water from the Mogollon Rim is transported in this drainage to the Little Colorado River. This wash has never been adequately gaged for water resource availability.

15.1.1.11 Clear Creek below Willow Creek near Winslow

This is another major drainage, utilized as water supply by the City of Winslow. Other users may also utilize this source. An adequate period of record is required to evaluate impacts of water supply development of this drainage on the main stem Little Colorado.

15.1.1.12 Chevelon Creek near Winslow

Several gages have operated here in the past, but never with concurrent record with other important gages. At least a five year record would be recommended for model calibration.

15.1.1.13 Black Creek near Lupton

This is a significant drainage in the southern Navajo Reservation. The flow contributions from this wash need to be quantified to monitor the effects of potential water resource developments which will be needed for a rapidly increasing population.

15.1.1.14 Little Colorado River at Woodruff

This is a long-term gage with a good record. This record is utilized to monitor the impacts of reservoirs and diversions on the long-term flow in the main stem. This gage should continue operation.

15.1.1.15 Puerco River near Navajo, AZ

Puerco River is a major source of sediment, particularly sand, for transport to the main stem Little Colorado River. It is one of the largest ungaged drainages in the basin. Its environmental importance indicates that a reliable gaging record would provide sediment transport, water quality, and flow data from the New Mexico portion of the watershed.

15.1.2 Water Quality Monitoring

15.1.2.1 Little Colorado River near the Mouth

This is the water which feeds the downstream critical habitat area and discharges into the main stem Colorado River. Only three or four samples have been taken in this reach of the Little Colorado (per USGS records). This sparse data set is insufficient to provide any useful background on the water quality at various flow rates. Quarterly sampling would be helpful until a baseline of information is established.

15.1.2.2 Blue Spring

This spring nurtures the critical habitat of the humpback chub in the lower Little Colorado River during the long summer periods of May through early July when the stream is dry. An examination of the graph of LCR near Cameron flows in Section 9.1.1 demonstrates that the number of zero (0) flow days during the dry season is increasing during the same period in which the precipitation is increasing. Blue Spring discharges alone provide most of the flow during humpback chub spawning. Due to the fact that the spring may lie on the Navajo Indian Reservationm it is likely that the Tribe may claim the beneficial uses of Blue Spring waters as part of the ongoing Little Colorado River General Stream Adjudication now before the Arizona Supreme Court. Should that occur, the U.S.

Fish and Wildlife Service may wish to intervene on behalf of the humpback chub, as the reduction of flows from the spring would certainly threaten the integrity of the Little Colorado River critical habitat area for the fish.

15.1.2.3 Little Colorado River near Cameron

This sampling location has a long period of record. Unfortunately, the sampling record is sparse during high flows. As a result, regression analyses for water quality vs. flow depend on relatively few data points.

15.1.2.4 Little Colorado River at Grand Falls

There is little historical record of water quality at Grand Falls. Water quality sampling at this location may duplicate the Little Colorado River near Cameron record.

15.1.2.5 Moenkopi Wash at Moenkopi

As with the Little Colorado River near Cameron, water quality data at Moenkopi is primarily low flow data. Storm water quality should be examined more thoroughly, because this water migrates fully to the main stem Little Colorado River.

15.1.2.6 Dinnebito Wash near Sand Springs

The only water quality data at Dinnebito is low flow and base flow data. No other data is available on storm flows. The Dinnebito Wash water quality contribution to the main stem LCR could be significant.

15.1.2.7 Oraibi Wash near District 6 Border

No water quality data is currently available from Oraibi Wash. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling.

15.1.2.8 Polacca Wash near Coyote Springs

No water quality data is currently available from Polacca Wash. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling.

15.1.2.9 Jeddito Wash at State Highway 87

No water quality data is currently available from Jeddito Wash. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling.

15.1.2.10 Jacks Canyon near Winslow

No water quality data is currently available from Jacks Canyon Wash. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling. The possibility of water supply development from Jacks Canyon Wash makes it a useful data point.

15.1.2.11 Clear Creek below Willow Creek near Winslow

Little water quality data is currently available from this reach of Clear Creek. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling. The possibility of water supply development from Clear Creek makes it a useful data point.

15.1.2.12 Black Creek near Lupton

Little water quality data is currently available from Black Creek. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling. The possibility of future water supply development from Black Creek makes it a useful data point.

15.1.2.13 Chevelon Creek near Winslow

No water quality data is currently available from this reach of Chevelon Creek. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling. The possibility of water supply development from Chevelon Creek makes it a useful data point.

15.1.2.14 Little Colorado River at Woodruff

Little water quality data is available at LCR Woodruff. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling. The possibility of additional upstream water supply development from the upper Little Colorado River makes it a useful point for data collection.

15.1.2.15 Puerco River near Navajo, AZ

Little water quality data is currently available from the Puerco River in Arizona. Sampling a wide range of flows would be helpful in establishing a baseline for water quality modeling. The possibility of water supply development for Gallup makes it a useful point for data collection.

15.1.3 Sediment Discharge Monitoring

15.1.3.1 Little Colorado River near the Mouth

Occasional sediment sampling at the mouth of the LCR would demonstrate the existing suspended sediment load available to the humpback chub. Measurements with a Secchi disk or turbidimeter cannot easily be correlated with suspended sediment unless a transfer function is calibrated for a wide range of conditions.

15.1.3.2 Little Colorado River at Cameron

This sediment sampling station has a long period of record. It is recommended that this sampling continue.

15.1.3.3 Moenkopi Wash at Moenkopi

Sediment sampling from this drainage has been sparse. The period of record is not continuous. The waters of this wash have been used by Hopi farmers for irrigated agriculture for centuries. As a significant source of sediment, the sediment supply must be monitored on an ongoing basis. Impoundments by Peabody Western Coal Company and others may eventually deplete the sediment supply to the Little Colorado River from this drainage.

15.1.3.4 Dinnebito Wash near Sand Springs

This wash exhibits a high velocity of discharge and potentially could carry a high volume of sediment during peak flow events. However, these flood flows are very intermittent and unpredictable, and require baseline monitoring to insure completeness of the record.

15.1.3.5 Oraibi Wash near District Six Reservation Border

This watershed is to be monitored for sediment, water quality, and discharge in the near future. A long period of record will be required to demonstrate the sediment contribution of this wash, if any, to the Little Colorado River main stem.

15.1.3.6 Polacca Wash near Coyote Springs

This watershed is being monitored for sediment, water quality, and discharge for the next several years. A long period of record will be required to demonstrate the sediment contribution of this wash, if any, to the Little Colorado main stem.

15.1.3.7 Jeddito Wash at State Highway 87

This watershed is being monitored for sediment, water quality, and discharge for the next several years. A long period of record will be required to demonstrate the sediment contribution of this wash, if any, to the Little Colorado River main stem.

15.1.3.8 Jacks Canyon near Winslow

The dry bed sample obtained from this stream contained some fine sediment. The sediment contribution of this wash to the Little Colorado River suspended sediment transport regime should be documented.

15.1.3.9 Chevelon Creek near Winslow

Due to the potential of water supply development from this drainage, periodic sampling for suspended sediment would be helpful to monitor the stream for future sediment depletions.

15.1.3.10 Black Creek near Lupton

Due to the potential for water supply development from this drainage, periodic sampling for suspended sediment would be helpful to monitor the stream for future suspended sediment depletions.

15.1.3.11 Little Colorado River at Woodruff

This gage has a long period discharge record. Additional suspended sediment sampling would be valuable to determine the suspended sediment contributions by the upper main stem to the Lower Little Colorado River system.

15.1.3.12 Puerco River near Navajo, AZ

Puerco River has a high sediment load. Seasonal snow melt and monsoon storm events both contribute to the flows. There is a large, gently sloping drainage area conducive to sheet erosion. The dry bed sample indicates that a considerable portion of Little Colorado River suspended sediment comes from the Puerco River drainage. Gallup has occasionally considered further water supply developments on the Puerco River.

15.1.4 Climatic Monitoring

Long-term climate monitoring has been accomplished in the cities, the national parks, and the national monuments. The Indian reservations have sparse and

inconsistent climate records. Significant thunderstorms originate on these lands. More emphasis should be given to monitoring the remote areas of the Little Colorado River Basin.

15.1.4.1 Leupp, AZ

This is a long-term station which has been out of service since the late 1970's. The importance of the station is that it lies on the north side of a small divide, which separates it from Winslow, 30 miles to the southeast.

15.1.4.2 Cameron, AZ

This station has had sporadic periods of inactivity. It is important to continue operation of this station to offset the impacts of nearby high altitude stations on regional climate modeling and analysis.

15.1.4.3 Tuba City, AZ

This station has had sporadic periods of inactivity. It is important to continue operation of this station to offset the impacts of nearby high altitude stations on regional climate modeling and analysis.

15.1.4.4 Keams Canyon, AZ

This station has had sporadic periods of inactivity. It is important to continue operation of this station to offset the impacts of nearby high altitude stations on regional climate modeling and analysis.

15.1.4.5 Kayenta, AZ

This climatological station went out of service during the 1980's. This gage was moved to a new location in Monument Valley. It is important to note that this station was located within the Navajo aquifer recharge area. The new Monument Valley station does not correlate well with Kayenta station records.

15.1.4.6 HPL Line near Hwy 264 and Coal Mine Mesa

This is a climatological station which will be constructed by the Hopi Tribe to enhance modeling of the stream flows on the Hopi Reservation.

15.1.4.7 Kykotsmovi near BIA Highway 2

This is a manual station with a standard rain gage, a thermometer, an anemometer, and a standard evaporation pan which has been recently placed into service.

15.1.4.8 Kachina Station 20 miles south of Kykotsmovi

This is a three year old automated climate station installed and operated by the Hopi Tribe with the BIA to enhance modeling of the stream flows on the Hopi Reservation.

15.1.4.9 Turqoise Trail Station

This climatological station will be constructed by the Hopi Tribe to enhance modeling of the stream flows on the Hopi Reservation.

15.1.4.10 Hohnani Station near Jeddito Island on State Highway 264

This climate station will be constructed by the Hopi Tribe to enhance modeling of the stream flows on the Hopi Reservation.

15.2 Black Mesa Monitoring Program

15.2.1 Water Level Monitoring Program and Groundwater Modeling

This is a long-term U.S. Geological Survey program designed to monitor potential impacts to Hopi and Navajo water resources by Peabody Western Coal

Company operations. Water levels and production meter readings are taken annually, and a report is issued after the end of the year to the USGS cooperators - Hopi, Navajo, and Peabody.

15.2.2 Spring Discharge, Base Flow, and Stream Flow Monitoring

This is a long-term program to monitor potential impacts to Hopi and Navajo water resources by Peabody Coal Company operations. Spring discharges, stream gagings, and water quality samples are taken annually, and a report is issued after the end of the year to the USGS cooperators - Hopi, Navajo, and Peabody.

In addition, the Hopi Tribe - USGS Joint Funding Agreement for Hopi Reservation surface water evaluation includes an annual work plan task to conduct a well and spring inventory. This task includes precise locations utilizing geopositioning satellite units (GPS), sampling of wells and springs for water quality, and measurement of water levels and discharges. The USGS will publish the results in FY 1996.

15.3 Office of Surface Mining Black Mesa Monitoring

The U.S. Office of Surface Mining evaluates Black Mesa and Peabody monitoring data to determine whether significant hydrologic impacts to tribal water resources are occurring.

16 Environmental Management Implications for the Little Colorado River Basin

Of all environmental concerns, water quality and availbility are paramount for all species. In particular, native aquatic wildlife is dependent upon a reliable supply of water of a quality preferred by those species. In addition, mankind is also a natural phenomenon. The drinking water requirements of an expanding human population, primarily Native American populations, which are concentrated on federally reserved lands set aside as Indian reservations, should be taken into account in developing environmental management scenarios.

The lack of significant biological information for endangered aquatic wildlife requirements in the lower Little Colorado main stem, and in various southerly drainages, renders it impossible to evaluate the environmental impacts of human water supply developments on those species. The environmental/wildlife community is dedicated to preserving the relevant endangered species. It would be incumbent upon them to devote time and financial resources to determine the water quality conditions in which the species will survive.

Otherwise, there will be a tendency to overreact to benign developments with a panic mentality. This would disrupt the cooperative and resource sharing atmosphere required for decision making to benefit man and nature.

Hydrologists share in the responsibility to acquire adequate data and information to assist in environmental management decisions. Unfortunately, the majority of hydrological research has investigated water resources of heavily populated areas, such as Phoenix and Tucson. As a result, inadequate sampling for water quality, sediment, and flows have created a situation for the Little Colorado River Basin, so that only reconstructed, synthetic data are available to evaluate the environmental condition of the Basin. It is regrettable that government agencies have dedicated money to water sampling and analysis over the years, but few analyses of samples taken of stream discharges have included all the constituents required to fully evaluate the chemistry of the riverine system, especially during high flow events. The labor and transportation costs of collecting samples amount to thousands of dollars annually while only hundreds of dollars are saved by minimizing the number of chemical components analyzed. In order to rectify the lack of hard information on water quantity and quality in the LCR Basin, this report recommends that a comprehensive seven year Little Colorado Basin monitoring program be included in the Long Term Monitoring Program of the Glen Canyon Environmental Studies activities. This should serve to ensure adequate review of proposed water supply and flood control developments for environmental impacts to the endangered Colorado River aquatic species now inhabiting the Little Colorado River and its tributaries.

16.1 Survival Requirements of Endangered Species

The research regarding the relationship between water quantity, quality, and sediment with regard to endangered species survival has been inadequate. Fish toxicity studies, preference studies, and sediment studies should be undertaken and published as a component of Little Colorado River management objectives. These studies should identify the environmental requirement ranges for a wide variety of water quality components.

16.1.1 Humpback chub

It is clear that the survival of the humpback chub is dependent almost entirely upon flows from Blue Spring in the lower Little Colorado River. That spring provides a constant supply of water at a rate of about 230 cfs year round, of a quality and temperature ideal for the propogation and subsequent nurture of the species. While the LCR adds sediment and velocity to the flows at the LCR Mouth, the wide ranges of temperature and TDS are moderated by the Blue Spring discharges to provide a comfortable environment for the hatching of eggs and the nurture of the fry. For this

reason, it is imperative that the integrity of the Blue Spring flows be unimpaired by groundwater withdrawals or diversions to consumptive use if the humpback chub is to survive in the Grand Canyon portion of the Colorado River system.

The spring snowmelt from the southern tributaries which originate in the Mogollon Rim area provide cold water in the spring which substantially reduces the temperature of the LCR at Mouth. It is possible that the humpback chub, like the Little Colorado Spinedace receives a biological signal from this drop and subsequent rise in water temperature to trigger its reproductive cycle. Extensive development of surface water impoundments and diversions from the southern tributaries could interrupt the temperature cycle in the LCR at Mouth and inhibit the breeding cycle of the humpback chub. For this reason, additional water supply developments in the southern trubutaries should be discouraged until such time as more information is available on the water temperature relationships with the life cycle of the humpback chub.

16.1.2 Little Colorado River Spinedace

It is equally clear that minimum flow requirements need to be developed for the southern LCR tributraries identified in the critical habitat designation for the Little Colorado River spinedace. It is also obvious that small scale water supply developments could coexist with the spinedace, providing that the pools of water frequented by these fish were maintained, along with the minimum sedimentation required.

The most devastating impact on the spinedace was the use of piscides in the 1960's in their habitat streams, and the frequent introduction of game fish for sport fishermen. Piscides should be legally discouraged in the habitat areas. Fish and wildlife agencies should be prohibited from additional game fish plantings.

Due to the lobbying strength of the sport fishing industry, it is likely that fish plantings will continue. If this occurs, the best hope for the survival of the spinedace is in the pool located at the Flagstaff Arboretum.

16.1.3 Parish Alkali Grass

Depletion of the base flows from the Navajo sandstone aquifer near Tuba City by intensive municipal pumping will occur by the year 2011, according to projections made by the USGS N-Aquifer model. As a result of this depletion, the saline marsh habitat of the Parrish alkali grass will dewater. Although an additional Parrish alkali grass habitat exists around Shonto, to the north of the LCR Basin, it would be unfortunate to allow the species to become extinct in the Tuba City/Moenkopi vicinity.

The Hopi Tribe has supported the concept of a pipeline from Lake Powell to the reservations to supplement the scarce groundwater supply. Should this pipeline be constructed in the near future, the discharges from Pasture Canyon Spring should continue to nourish the alkali grass and reservation farming activities for years.

16.2 Water Pollution Control

Tribes inhabiting the northerly watersheds are participating in the Clean Water Act Section 106 program. Activities of the Hopi Tribe include: building an environmental database for the LCR Basin, investigation of sewage lagoon contamination, water supply wells which may be leaking saline aquifer water into the Navajo Aquifer, and microbiological and radiological quality are being examined.

Accidental spills of hazardous material anywhere in the LCR Basin could potentially threaten the humpback chub, and spills in the watersheds of the tributary drainages to the south along the Mogollon Rim could threaten the spinedace. At present, emergency action response plans are either undeveloped (particularly on the reservations) or do not adequately address the isolation of the critical habitats from accidental or industrial pollution events.

For these reasons, the environmental community needs to focus on toxicity studies to determine those potential contaminants which most severely threaten native LCR aquatic wildlife. Armed with this information, adequate emergency response alternatives could be studied and implemented on a broad scale within the basin.

16.3 Clean Lakes Program

The Clean Water Act contains a section to protect the quality of water in natural lakes and man-made reservoirs. Reservoirs have been constructed in the upper Little Colrado River, Silver Creek, Clear Creek, San Francisco Creek, Polacca Wash, Moenkopi Wash, Dinnebito Wash, Pasture Canyon Wash, and Chevelon Creek. These reservoirs deplete the natural flows of the affected tributaries and the main stem Little Colorado River by an unquantified amount. There is at least one natural lake at Tolani Lake near Leupp, which detains most of the flows from Oraibi Wash, Polacca Wash and Jeddito Wash. The quality of water in these reservoirs and lakes is generally unknown.

Under the EPA 106 Pollution Control Program and a joint project with the Bureau of Reclamation, the Hopi Tribe is beginning to assess the quality of water in its reservoirs. If pollution or contamination is found in these waterbodies, the Hopi Tribe will participate in mitigation measures, to the extent that it is financially feasible.

Occasionally, all lakes and reservoirs spill during high flow events. At this time, it is possible that the quality of water in the reservoirs and lakes could have an impact on surface water quality downstream. For this reason, it is important to assess the quality of water in these waterbodies and to periodically monitor them for water constituents which may be harmful to human health and the natural inhabitants of the environment.

Unfortunately, the EPA grant programs are very competitive and inadequately not funded. Only when the funds are available will it be possible to initiate the type of investigation required to adequately insure the integrity of the environment.

16.4 Wetlands Protection Program

A recently acquired relationship between the Hopi Tribe and the Bureau of Reclamation has yielded several water quality samples and analyses for the several reservoirs on the Hopi Reservation. An EPA General Assistance Grant is being utilized to inventory and evaluate the condition of various wetlands habitats on the Hopi Reservation.

Other natural and artificial wetlands exist within the LCR Basin, however. The status or extent of investigations of these waterbodies is not known and recommendations for the LCR Basin as a whole have not been considered. At the present time, no synthesis of data and information is planned. The Hopi EPA CWA Section 106 program included sampling of algae and wastewater discharges on the Reservation. Such information needs to be collected from a broad area of the LCR Basin to evaluate the health of the sparse wetlands in the basin.

It should be noted that the Parrish alkali grass grows in the alluvium downstream from the Pasture Canyon Spring source. Little is known about the water quality of this source, or of the environmental requirements of the species. The US Geological Survey model of the N-Aquifer suggests that groundwater withdrawals in the Tuba City/Moenkopi Village area could deplete the groundwater by the year 2012, thus depleting the source of the Pasture Canyon Spring discharges. In that event, yet another endangered species would be placed at risk. The Hopi proposal to develop an alternative renewable supply of water for areas of the Hopi and Navajo Reservations dependent upon the N-Aquifer for drinking water supply by implementing a pipeline from Lake Powell deserves consideration on environmental grounds to preserve the Parrish Alkali Grass.

16.5 Wastewater Disposal and Treatment

This potential source of contamination of the streams and the alluvial environment poses a threat to all riverine species. Many of the Indian Health Service facilities on reservation land are discharging to the environment due to undersizing. Moenkopi Wash receives about 5 cfs discharge continuously from the Tuba City lagoon. The Hopi Tribe

is investigating the upgrade of several of its facilities. Human health considerations, as well as environmental considerations, are involved. Due to the lack of money, improvements are slow to be implemented.

Tolerance levels of native aquatic wildlife to elevated inorganic and organic contamination is not known at this time, making it difficult to determine the impacts of untreated wastewater discharges on endangered species.

16.6 Contaminant Discharges

In addition to sewage contamination, there are many abandoned underground storage tanks in the Little Colorado Basin. Not only tribal facilities are involved, but Route 66 and I-40 have many abandoned gasoline stations along the right-of-way. Informal solid waste disposal sites dot the reservations, as well as non-Indian land. The chemical content of these illegal dumps is unknown. The Hopi Tribe is developing a chemical emergency response plan as a part of its EPA activities. However, with toxic chemicals, an ounce of prevention is worth a pound of cure.

16.7 Livestock and Game

Cryptosporidium and *giardia lambdia* are carried by wildlife and domestic animals. The washes and springs on reservation lands contain a high concentration of fecal coliform and fecal streptococcus. Game animals and range animals, as well as single family septic facilities may be to blame.

16.8 Cloud Seeding

Cloud seeeding is a mass balance problem. For every drop of rain which falls in a climatically modified watershed as a result of seeding, downstream watersheds receive less rain. There exists a proposal to seed clouds in northern Arizona to increase surface water flows to southern Arizona, which could have a negative inpact on the Little Colorado Basin, reducing the inflow from precipitation. This activity must be closely watched to prevent out of basin transfer of water from an environmentally sensitive, water-short region.

16.9 Little Colorado River Management Plan

A Little Colorado River Management Plan has been mentioned as a next-stage activity for GCES. An intertribal groundwater management agency has been proposed by Secretary of the Interior Babbitt as a potential incentive for a portion of a Little Colorado River Adjudication settlement. Such activities would require coordination and cooperation among participants to avoid duplication of effort.

It is expected that the Hopi Tribe will continue in its efforts to support the development of any management planning activities undertaken by federal agencies and the Tribes. In this way, valuable data collection and analysis activities will continue to refine the knowledge of this vast, water-short riverine system.

Unfortunately, it must be noted that management plans require the mutual agreement of entities with divergent and competing interests. Such plans generally contain "pressure relief valve" mechanisms in the form of variances and exclusions. As a result, management plans tend to be unenforceable except in the broadest sense. The interagency commisions and committees usually appointed to oversee compliance with management plans do sometimes provide a valuable forum for the exchange of opinion.

17 Conclusions and Recommendations

The Little Colorado River Basin is a highly complex hydrologic, climatologic, and ecological wonder. The fragile interactions of plants, animals, water, geology, and meteorology have been in balance for eons. The recent desirability of the region for economic development and tribal population growth will stress the meager resources. It is imperative that equitable plans be developed to avert an environmental nightmare.

The state of current research is inadequate, in part, due to a lack of data and information. It is hoped that prudent and rational decion making will result in making an effort in the near term to acquire the knowledge and experience to wisely manage the sensitive resources of the LCR area. This effort will save many dollars which would otherwise be expended for mitigation later. The long-term monitoring plan for the Glen Canyon Environmental Studies is an ideal vehicle to further that knowledge.

Conclusions regarding the LCR hydrology still contain uncertainties. This uncertainty will continue until the LCR modeling project presently underway is concluded. Patience will bring rewards in the form of a successful contribution to environmental science and policy which will result from true scientific knowledge. The following general principles need to be stated:

(1.) The principal hydrologic input to surface water discharge upstream of Blue Spring is precipitation. This input is limited and highly variable. Wet years and drouths do not occur evenly throughout the basin, leading to variability of flows and surface water quality. The water quality of the spring snowmelt flows is lower in dissolved ion concentration than the flood flows of the monsoon season.

(2.) The principal hydrologic input to surface water discharge in the critical habitat area of the humpback chub is the perennial base flow of Blue Spring. This base flow combines with natural snowmelt runoff and may trigger the reproductive cycle of the chub.

(3.) The Little Colorado River is essentially an intermittent stream for all but the last 18 km of its length. The stream bed of the main stem and its tributaries are sand bedded, with a large amount of sediment in storage in its more quiescent reaches.

(4.) The principal input to annual flows in most of the Little Colorado River is from snowmelt in the higher elevations. This leads to a seasonal phase shift from winter snowfalls and spring runoff.

(5.) The principal mechanism for the transport of sediment within the Little Colorado River system are the high intensity monsoon precipitation events. Flows from Puerco River and the northern tributaries of the main stem drive the stored sediment from the quiescent reaches toward the Colorado River.

(6.) The principal contribution of water quality is from precipitation events and the resulting runoff. Northern tributaries are higher in dissolved solids when the flow is greater. This effect is moderated by dilution in the main stem Little Colorado River. Base flow discharges, with the exception of Blue Spring, normally do not reach the main stem Little Colorado River due to instream percolation and evapotranspiration.

(7.) Limited water supply development in the northern tributraries of the Little Colorado River by the Tribes and other water consumers is possible without undue environmental consequences. Such developments should be tested by modeling on a case-by-case basis to determine potential environmental impacts. Complete depletion of the Little Colorado River would lead to a constant temperature stream in the humpback chub critical habitat area which would impact the reproductive cycle of the fish.

(8.) Water supply developments in the southern, snowmelt-fed mountain tributaries could modify the existing temperature fluctuations in the critical habitat area of the humpback chub. This modification could adversely affect the breeding cycle of this endangered species of fish.

(9.) A comprehensive monitoring plan in the Little Colorado River system is necessary to the development of any management plan, since the available data are sparse and inconsistent.

The calibrated model of the Little Colorado River undertaken by D.B. Stephens & Associates as a subcontractor under Hopi Water Resources Program will be completed by September 30, 1995. At that time, this report will be finalized and copies of all the data and supporting documentation will be delivered to the Bureau of Reclamation Glen Canyon Environmental Studies Group.

References and Bibliography

Bedient, Philip B., and Huber, Wayne C., Hydrology and Floodplain Analysis, Reading, MA, Addison-Wesley Publishing Company, 1988.

Blinn, Dean W., Czarnecki, D. B., Griffith, G., McCall, T., and Minckley, C. O., An Aquatic Survey of Chevelon Creek, Arizona, First Progress Report to Arizona Public Service, 1977.

Blinn, Dean W., and Runck, Clay, Annual Report on Predation, Diet, Habitat, and Distribution of Little Colorado Spinedace (Lepidomeda vittata), Report to Coconino National Forest, Flagstaff, AZ, 1993.

Blinn, Dean W., and Runck, Clay, Effects of Rainbow Trout (Oncorhynchus mykiss) Predation on Little Colorado Spinedace (Lepidomeda vittata), Report to Coconino National Forest, Flagstaff, AZ, 1992.

Blinn, Dean W., Pradetto, Tom, and Runck, Clay, Annual Report on Spawning, Reproduction, Growth and Development, Diet, and Behavior of Little Colorado Spinedace (*Lepidomeda vittata*) in the Arboretum Pond at Flagstaff, AZ, Report to the Coconino National Forest, Flagstaff, AZ, 1994.

Bulkley, R. V., Berry, C. R., Pimentel, R., and Black, T., Tolerance and Preferences of Endangered Fishes to Selected Habitat Parameters, Logan, UT, Utah State University, Utah Cooperative Fishery Research Unit, Report No. 5, 1981.

Bureau of Reclamation, Memorandum Report: Little Colorado River Basin, Arizona, Part 1, Water Resources and Potential Developments, Blue Spring Area, Boulder City, Lower Colorado River Region, 1972.

Carothers, Steven W., and Minckley, C. O., A Survey of the Fishes, Aquatic Invertebrates and Aquatic Plants of the Colorado River and Selected Tributaries from Lees Ferry to Separation Rapids, Report to Water and Power Resources Services, Boulder City, NV, 1981.

Cooley, M. E., Spring Flow from Pre-Pennsylvanian Rocks in the Southwestern Part of the Navajo Indian Reservation, Arizona, Washington, U. S. Government Printing Office, U. S. Geological Survey Professional Paper 521-F, 1976.

Cope, E. D., On the Plagopterinae and the Ichthyology of Utah, Proceedings of the American Philosophical Society, 14: 129-140, 1874

Cressie, Noel, "Geostatistical Analysis of Spatial Data," in Spatial Statistics and Digital Image Analysis, Chapter 5, Washington, National Academy Press, 1991.

Cressie, Noel A. C., Statistics for Spatial Data, New York, John Wiley and Sons, Inc., 1991.

References and Bibliography

Denova, Bruce P. and Abarca, Francisco J., Distribution, Abundance and Habitat for the Little Colorado Spinedace (*Lepidomeda vittata*) in the Coconino and Apache-Sitgreaves National Forests along East Clear Creek and its Tributaries, Report to Arizona Game and Fish Department, Phoenix, 1992.

Edwards, Thomas K., and Glysson, G. Douglas, Field Methods for Measurement of Fluvial Sediments, Reston, U.S. Geological Survey Open-File Report 86-531, 1988.

Englund, Evan, GEO-EAS 1.2.1, Geostatistical Environmental Assessment Software, User's Guide, Las Vegas, U. S. Environmental Protection Agency, Office of Research and Development, 1991.

Englund, Evan J., "Spatial Simulation: Environmental Applications," in Goodchild, M. F., *et al*, eds, Environmental Modeling with GIS, New York, Oxford University Press, 1993.

Fishman, Marvin J., and Friedman, Linda C., eds., Methods for Determination of Inorganic Substances in Water and Fluvial Sediments, Washington, U. S. Geological Survey, Techniques or Water-Resources Investigations, Cahpeter A1, 1989.

Gabin, Vickie L., and Lesperance, Lee E., New Mexico Climatological Data - Precipitation, Temperature, Evaporation, and Wind - Monthly and Annual means, 1850-1975, Socorro, W. K. Summers and Associates, 1977.

Graf, Julia B., Wirt, Laurie, Swanson, Edwin K., Fisk, Gregory G, and Gray, John R., Transport of Radionuclides and Other Chemical Constituents in the Little Colorado River Basin, Arizona and New Mexico, U.S. Geological Survey Open-File Report 93- (unpublished draft report), Tucson, 1993.

Guttorp, Peter, "Spatial Statistics in Environmental Science," in Spatial Statistics and Digital Image Analysis, Washington, National Academy Press, 1991.

Guy, Harold P., Fluvial Sediment Concepts, Techniques of Water-Resources Investigations, Chapter C1, Washington, U.S. Government Printing Office, 1970.

Guy, Harold P., Laboratory Theory and Methods for Sediment Analysis, Techniques of Water-Resources Investigations, Chapter C1, Washington, U.S. Government Printing Office, 1969.

Hay, Lauren E., Battaglin, William A., Parker, Randolph S., and Leavesley, George S., "Modeling the Effects of Climate Change on Water Resources in the Gunnison River Basin, Colorado," in Goodchild, *et al*, Environmental Modeling with GIS, New York, Oxford University Press, 1993.

Hemphill, J. E., Toxaphene as a Fish Toxin, Prog. Fish-Culture, 16:41-42.

References and Bibliography

Hoeksema, Robert, Introduction to the Application of Geostatistics and Kriging to Spatial Estimation Problems in Ground Water, Golden, CO, International Ground Water Modeling Center, Colorado School of Mines, 1992.

Johnson, P. W., and Sanderson, R. B., Spring Flow into the Colorado River, Lees Ferry to Lake Mead, Arizona, Report to Arizona State Land Department, U. S. Geological Survey, 1968.

Kaeding, Lynn R., Burdick, Bob D., Schraeder, Patricia A., and McAda, Charles W., Temporal and Spatial Relationships between the Spawning of Humpback Chub and Roundtail Chub in the Upper Colorado River, Transactions of the American Fishery Society, 119:135-144, 1990.

Marley, Robert, and Blandford, Neil, Little Colorado River Phase II Progress Report, Report to The Hopi Tribe, Albuquerque, D. B. Sterphens and Associates, 1995.

Marley, Robert, Little Colorado River Basin Progress Report, Report to The Hopi Tribe, Albuquerque, D. B. Stephens and Associates, 1994.

Marsh, Paul C., Effect of Incubation Temperature on Survival of Embryos of Native Colorado River Fishes, The Southwestern Naturalist, 30(1):129-140, 1985.

Meffe, G. K., Predation and Species Replacement in American Southwest Fishes: a Case Study, Southwestern Naturalist 30(2):173-187.

Miller, R. R., and Hubbs, C. L., The spiny rayed cyprinid fishes (Plagopterini) of the Colorado River system, Miscellaneous Publications of the University of Michigan, Museum Zoology, 115:1-39, 1960.

Miller, R. R., Distribution, variation, and ecology of Lepidomeda vittata, a rare cyprinid fish endemic to eastern Arizona, Copeia 1963:1-5.

Miller, Robert B., Fish Remains from Archaeological Sites in the Lower Colorado River Basin, Arizona, Papers of the Michigan Academy of Science, Arts, and Letters, Vol. XL, 1955.

Miller, Robert R., ICHTHYOLOGY. - *Gila cypha, a remarkable new species of cyprinid fish from the Colorado River in Grand Canyon, Arizona*, in Journal of the Washington Academy of Sciences, Vol. 36, No. 12, December, 1946.

Minckley, C. O., Current Distribution and Status of Lepidomeda vittata (Little Colorado spinedace) in Arizona, Report to Arizona Game and Fish Department, Phoenix, 1984.

Minckley, C. O., Little Colorado River Spinedace, Lepidomeda vittata, Recovery Plan, U. S. Fish and Wildlife Service, Region 2,, Parker Fishery Resource Office, Parker, AZ, 1994.

Minckley, W. L., *Fishes of Arizona*, Sims Publishing, 1973.

References and Bibliography

Minckley W. L., and Carufel, L. H., The Little Colorado River Spinedace, *Lepidomeda vittata*, in Arizona, The Southwestern Naturalist, 12(3):291-302.

Morgan, Ron P., Observations - Dry Bed Sampling Activities, 1993.

National Oceanic and Atmospheric Administration, Climatological Data, Annual Summaries, 1946-1990, Asheville, National Climatic Data Center, 1946 through 1990.

Newcombe, C. P., and MacDonald, D. D., Effects of Suspended Sediments on Aquatic Ecosystems, North American Journal of Fisheries Management, 11:72-82, 1991.

Nisselson, C. L., and Blinn, D. W., Aquatic Habitat Assessment for *Lepidomeda vittata* in East Clear Creek, Arizona, Final Report to Coconino National Forest, Flagstaff, AZ, 1991.

Ord, J. K., and Rees, M., "Spatial processes: Recent developments with applications to Hydrology," in Lloyd, E.H., O'Donnel, T., and Wilkinson, J. C., eds., The Mathematics of Hydrology and Water Resources, London, Academic Press, 1979.

Pickering, R. J., Measurement of "Turbidity" and Related Characteristics of Natural Waters, Washington, U.S. Geological Survey, Open-File Report 76-153, 1976.

Porterfield, George, Computation of Fluvial-Sediment Discharge, Techniques of Water-Resources Investigations of the U.S. Geological Survey, Chapter C3, Washington, U.S. Government Printing Office, 1972.

Renne, J. N., and Minckley, W. L., Native Fishes of Arid Lands: a Dwindling Resource of the Desert Southwest, U. S. Department of Agriculture National Forest Service, General Technical Report RM-206, 1991.

Reynolds, S. E. State Engineer, Climatological Summary of New Mexico, Precipitation, 1849-1954, Technical Report Number 6, Santa Fe, State of New Mexico, 1956.

Reynolds, S. E. State Engineer, Climatological Summary of New Mexico, Temperature, 1850-1954, Frost, 1850-1954, Evaporation, 1912-1954, Technical Report Number 5, Santa Fe, State of New Mexico, 1956.

Reynolds, S. E. State Engineer, New Mexico Streamflow and Reservoir Content, 1888-1954, Technical Report Number 7, Santa Fe, State of New Mexico, 1956.

Rhodes, Hannah R., and Myers, Donald E., "GRASS Used in the Geostatistical Analysis of Lakewater Data from the Eastern Lake Survey, Phase I," in Goodchild, M. F., et al, eds, Environmental Modeling With GIS, New York, Oxford University Press, 1993.

Sellars, William D., Hill, Richard H., and Sanderson-Rae, Margaret, Arizona Climate - One Hundred Years, 1885-1985, Tucson, University of Arizona Press, 1985.

References and Bibliography

Sellars, William D., and Hill, Richard H., Arizona Climate 1931-72, Tucson, University of Arizona Press, 1974.

Sublette, J. E., Hatch, M. D., and Sublette, M., The Fishes of New Mexico, Albuquerque, University of New Mexico Press, 1990.

Suckling, P. W., A Climate Departure Index for the Study of Climatic Variability, Physical Geography, 8:179-188, 1984.

Trewartha, Glenn T., An Introduction to Climate, New York, McGraw-Hill Book Company, 1968.

U. S. Department of Agriculture, Soil Conservation Service, Little Colorado River Basin, Arizona-New Mexico, Summary Report and Four (4) Appendices, 1981.

U. S. Department of Agriculture, Weather Bureau, Climatic Data from The Establishment of Stations to 1930, inclusive, Section 25 - Northern Arizona, Washington, U. S. Government Printing Office, n.d.

U. S. Department of Commerce, Weather Bureau, Climatic Summary of the United States-Supplement for 1931 through 1952, Arizona, Climatography of the United States No. 11-2, Washington, U. S. Government Printing Office, n.d.

U. S. Department of Commerce, Weather Bureau, Decentennial Census of United States Climate - Climatic Summary of the United States-Supplement for 1951 through 1960, Arizona, Climatography of the United States No. 86-2, Washington, U. S. Government Printing Office, n.d.

U. S. Fish and Wildlife, Endangered and threatened wildlife and plants; proposal to determine *Lepidomeda vittata* (Little Colorado Spinedace) to be a threatened species with critical habitat, Federal Register 59(99):21095-21101, 1985.

U. S. Fish and Wildlife, Endangered and threatened wildlife and plants; notice of finding on 6 petitions, Federal Register 51(136):282583-28585.

U. S. Fish and Wildlife, Endangered and thresatened wildlife and plants; findings on certain petitions, Federal Register 48(115):27273-27274.

U. S. Fish and Wildlife, Review of vertebrate wildlife for listing as endangered or threatened species, 1982.

U. S. Geological Survey, Water Resources Data for Arizona and New Mexico, to 1993, WATSTORE and QW Databases, Reston, through 1993.

References and Bibliography

Valdez, R. A., and Nilson, B. C., Radiotelemetry as a Means of Assessing Movement and Habitat of Humpback Chub, Transactions of the Bonneville Chapter of the American Fisheries Society, Salt Lake City, University of Utah, 1982.

Valdez, Richard A., and Clemmer, Glenn H., Life History and Prospects for Recovery of the Humpback and Bonytail Chub, in Miller, Tyes, and Carlson, eds., Fishes of the Upper Colorado River System: Present and Future, 1982.

Ward, Timothy, Personal communication with Ron Morgan and Robert Marley, 1993.

Wegner, David L., Memorandum to Vernon Masayesva, Chairman, Hopi Tribe, December 29, 1992.

Wheeler, G. M., Report on the United States geographical surveys west of the One Hundredth Meridian, Geographical Reports, Vol. I, Washington, 1889.

Wickham, Matthew, The Geochemistry of Surface Water and Groundwater Interactions for Selected Black Mesa Drainages, Little Colorado River Basin, Arizona, Tucson, The University of Arizona, Masters Thesis, 1992.

Yard, Michael D., Personal communication regarding humpback chub, 1994.

Yard, Michael D., Haden, George A., and Vernieu, William S., Photosynthetically Available Radiation (PAR) in the Colorado River: Glen and Grand Canyon, Flagstaff, Glen Canyon Environmental Studies, Draft Report, 1993.