INTEGRATION AND EVALUATION OF GLEN CANYON ENVIRONMENTAL STUDIES RESEARCH FINDINGS: THE GRAND CANYON RIVERINE ECOSYSTEM — FUNCTIONS, PROCESSES AND RELATIONSHIPS AMONG BIOTIC AND ABIOTIC DRIVING AND RESPONSE VARIABLES

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FINAL REPORT

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Integration and Evaluation of Glen Canyon Environmental Studies Research Findings: The Grand Canyon Riverine Ecosystem -- Functions, Processes and Relationships Among Biotic and Abiotic Driving and Response Variables

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Integration and Evaluation of Glen Canyon Environmental Studies Research Findings: The Grand Canyon Riverine Ecosystem -- Functions, Processes and Relationships Among Biotic and Abiotic Driving and Response Variables

Abstract

In 1963 Glen Canyon Dam closed and changed the downstream ecosystem for the foreseeable future. In 1980 Lake Powell filled and a second phase of dam management was initiated. When the Bureau of Reclamation proposed upgrading the generators in the dam, concerns were raised about the potential impacts of greater discharges from the dam on the downstream ecosystem. Glen Canyon Environmental Studies (GCES) was initiated in 1982 to address these effects. The first phase of GCES studied the response of individual riverine ecosystem attributes to dam operations. During this period, an uncontrolled flood was released from the dam and GCES conclusions were that floods were detrimental to the downstream ecosystem. The second phase of GCES began in 1989. The research of this phase was initially organized around hypothesis testing and integrated studies. Announcement of the Glen Canyon Dam EIS shortened the study period, reducing potential for fully integrated research.

Experimental test flows were used as part of GCES Phase II research to determine responses of ecosystem components to dam operations. Following these test flows, the dam was operated under Interim Flows (Interim Operating Criteria). These dam discharges were designed to reduce damage by fluctuating releases on the downstream ecosystem. In 1996, the Glen Canyon Dam EIS was completed and the dam was then, and still is, operated under the preferred alterative of modified low fluctuating flows. This alternative also included periodic high releases to build beaches and habitat.

This report is designed to address the many studies under GCES and other documents that report on response of Grand Canyon riverine attributes to dam operations. This report evaluates these documents for their contribution to our understanding of the integration of driving factors and response resources within the canyon. Evaluations and comments on many of the reports include strengths and weaknesses of the research, and its potential applicability toward our understanding of the riverine ecosystem, development of ecosystem models, and development of long-term integrated research and monitoring in the canyon.

Development of a long-term research and monitoring program requires assessment of the many variables that might be measured. The riverine ecosystem is sensitive to perturbation by scientists and thus studies should be limited to a few, well documented, attributes that are indicators of system response. Several methods are suggested to address this need.

Five major riverine ecosystem parameters are evaluated within an integrated framework. These are (1) aquatic food base, (2) fishes (native and non-native), (3) waterbirds, (4) riparian and marsh vegetation, and (5) terrestrial and riparian birds. Several variables that drive these parameters directly and also function as secondary drivers were described, and their roles in influencing responses of the riverine attributes are developed. Most driving variables were discussed for each response parameter. These driving variables included: (1) light, (2) discharge, (3) sediment transport and deposition, (4) geomorphology, (5) aquatic food base (when applicable), and (6) riparian vegetation (when applicable).

Information from the experimental flood in 1996 was evaluated for use in understanding integration among the many riverine attributes, drivers and response variables. The flood experiment used an integrated research approach and produced data showing how changes in one driving variable at a location will alter many interrelated biotic and physical resources.

The report integrates the many response variables and factors that influence their existence in the canyon, and shows, through use of conceptual models, how they are interrelated. For example, discharge drives sediment transport which alters aquatic primary productivity, and forms habitat for aquatic and terrestrial organisms. Discharge also changes fluvial geomorphology which modifies aquatic habitat and food base availability, but terrestrial vegetation tends to stabilize the shoreline, possibly improving habitat for young fish, while producing allochthanous material for the aquatic food base, and habitat for nesting birds. The interrelationships among these many factors shows why it is important to understand the whole system before attempting to manage any single factor.

Integration and Evaluation of Glen Canyon Environmental Studies Research Findings: The Grand Canyon Riverine Ecosystem -- Functions, Processes, and Relationships Among Biotic and Abiotic Driving and Response Variables

Final Report

I. Introduction

A. Background

In 1963 Glen Canyon Dam was closed and the Colorado River below the dam would no longer be "free-flowing". Filling of Lake Powell and operations of the dam for hydropower and water delivery thoroughly controlled discharge (Fig. I-1). Until Lake Powell filled in 1980, input to the lake had little affect on discharge, although other events caused high discharge prior to lake filling. In the early 1980s, a need for information on the effects of operations of Glen Canyon Dam was triggered by concerns that anticipated modifications to generator capacity might increase the impacts of dam operations on the downstream riverine ecosystem. To address these concerns, Glen Canyon Environmental Studies Phase I was established to determine whether perceived ecological changes below Glen Canyon Dam were associated with ongoing dam operations. Studies established by GCES were based on researcher interests in particular riverine resources and were guided by information needs on resource responses to aspects of dam operations, particularly hydrological phenomena (i.e., dam discharges, ramping, etc.) There was little concern then about how changes in one resource might affect others, or how the entire riverine ecosystem complex might be changing over time. Glen Canyon Environmental Studies Phase I, ended in 1986 and produced a series of research reports as well as an "integration" report. The latter reported on response of individual resources as part of the whole system. It also concluded that high, uncontrolled flows as occurred in 1983 were destructive to the whole system and therefore should be avoided. This finding was a result of the wet year of 1983 being followed by additional wet years, especially 1986, which impacted a system that had been scoured and was sediment starved.

Glen Canyon Environmental Studies Phase II was initiated in 1989 following several years of evaluation of the findings of Phase I, some by a National Research Council committee (NRC 1987). Consequently, need for additional research was accepted and new approaches to studying the effects of dam operations were developed. Emphasis was placed on an integrated approach to studying the riverine system to ensure that future management of the canyon's resources would recognize potential synergistic interactions among resources, rather than considering responses of individual resources to changing riverine conditions in a vacuum. Unfortunately, announcement of the Glen Canyon Dam Environmental Impact Study in 1989, and the short time-frame given to the EIS, prevented full development of an integrated study approach to research of the Colorado River below Glen Canyon Dam. Many studies that were part of Phase I ended up being part of Phase II. Several resource agencies sought support for research on resources under their control without considering the necessary quality controls

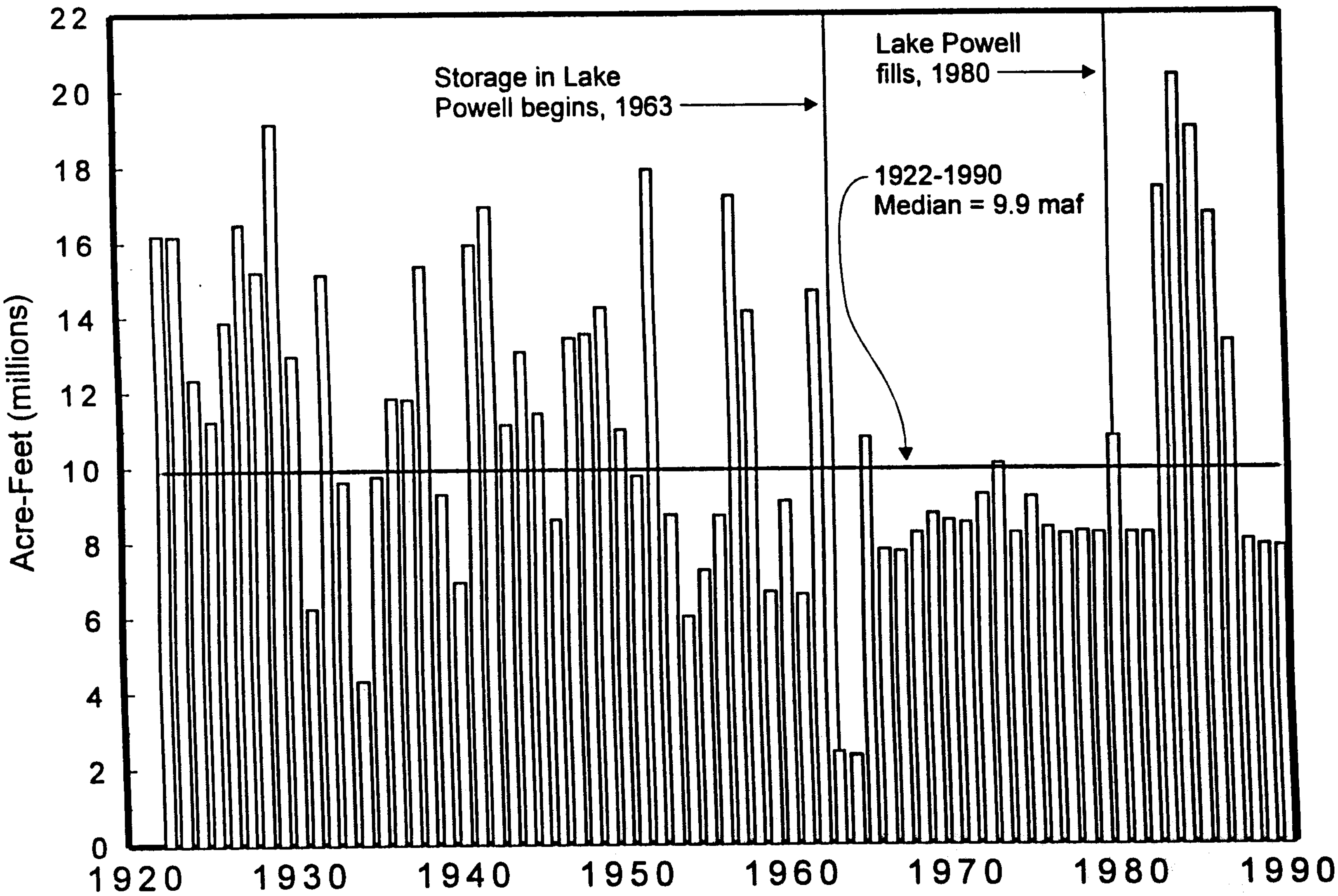


Figure I-1. Annual flows at Lees Ferry from 1922-1990. From the GCDEIS (Reclamation 1995).

needed to develop and carry out credible scientific studies. This deviation from an integrated approach resulted in many studies using different methodologies, often to address response of the same or similar attributes of the canyon to dam operations. Little time was spent on peer reviewing proposals for adequate research design or quality assurance/quality control.

Regardless of the limitations and possible weaknesses of the Glen Canyon Environmental Studies Phase II research, some integration of ideas among scientists occurred and many studies were completed that would help guide an understanding of the effects of dam operations on downstream ecosystem populations and processes. As GCES Phase II closed, several attempts were made to begin to integrate some of the information. In fall 1995 GCES brought together scientists representing both fisheries and sediment oriented disciplines. This meeting resulted in a document that identified many common issues among these disciplines and how information shared between them might be used for management purposes, specifically biological opinion issues. A report from this group was titled, " A Draft Prospectus on Integration of Biological and Physical Data Below Glen Canyon Dam, Arizona: Suggested Approaches for Assessing Biological Opinions". This report is reviewed later.

GCES also funded a "Grand Canyon Data Integration Project" with the objective "to assemble the existing information that pertains to how native fishes and their non-native competitors and predators within the Colorado River ecosystem in Glen and Grand Canyons might respond to a seven-month period of experimental steady dam releases." This report is reviewed later.

Both of the above integration documents were useful tools in evaluation of integration potential of GCES data for this project.

1. Early Phase of Planning Integrated Research.

Planning a research program to understand effects of dam operations had no established model. Dams were constructed on most large western rivers with little regard for the effects of their existence. Concern for how dam operations affected downstream ecosystems was essentially non-existent. Some studies below Glen Canyon Dam showed how changes in river flows and reduction of spring floods and sediment had altered the riparian ecosystem (Turner and Karpiscak 1980, Johnson 1991). Subtle changes resulting from dam operations that often included daily changes in discharge of > 566 cms (> 20,000 cfs), and winter low flows as low as 28 cms (1,000 cfs) were not well understood. Consequently, the scientific group planning the initial research program of GCES selected studies of interest on individual canyon attributes and for which data could be obtained over a short time period.

Many conclusions of the integrated report prepared from GCES I were challenged by the NRC review committee. Scientific integration and evaluation of effects should not have attached values to the conclusions, rather the scientists should have concluded that the combination of floods had made major alterations in the system. Value judgements should have been left to resource managers (e.g., National Park, or AZ Game and Fish), who unfortunately at that time had not fully established long-term resource objectives for resources along the Colorado River.

One important recommendation made by the NRC review committee was that the program should be composed of studies that were integrated and had an ecosystem orientation. The review by the NRC committee attempted to demonstrate in their report how the riverine ecosystem was interrelated (Fig. I-2, from page 31, NRC 1987), and that this approach should be used as a model for future research planning. As the original author of the NRC conceptual model, I have selected to use this model as the guide for integration models used in this report.

Research initiated under GCES, Phase II was considered an extension of that completed in Phase I, except that organization of the research was to be based on integration and hypothesis testing. Since GCES I was heavily influenced by the wet years of 1983 to 1986, an extension of the research program hoped to determine effects of dam operations under more normal, or even dry, low flow years.

In 1989 when the EIS was announced, the time frame for the study was shortened and this greatly impacted the planned integrated research program. Less than two years were available to complete all studies and prepare the EIS. Consequently, in many ways the research program went forward in a fashion similar to GCES I, except that there was still an overriding integration plan that demonstrated the interrelationships among most of the riverine resources (Patten 1991). The need to develop necessary scientific information in a very short period and maintain a semblance of an integrated plan resulted in requests for "experimental flows".

Experimental Test Flows 1990-1991. Dam operations has several components, including discharge rate, fluctuation between low and high daily discharges, and ramping rate, the rate by which dam discharge increased or decreased. Selection of variable levels of each of these three components could produce a wide range in downstream hydrology. If only normal dam operations were studied over the short study period, there was little hope of gaining much information on responses of the many riverine resources, information needed for the EIS. A series of two week long controlled or experimental test flows below the dam were planned to address this issue. This meant that discharge from the dam would follow the same pattern of discharge, daily fluctuations and ramping each day for two weeks, with a low flow before and following to study effects. Experimental flows were approved for a thirteen month period. Use of experimental test flows for studies leading to the EIS, established a precedent for an eventual experimental test flow of greater magnitude following completion of the EIS.

Interim Flows (Interim Operating Criteria). When the experimental test flows ended in fall 1991 Interim Flows were established which had high and low discharges of 566 cms (20,000 cfs) and 142 cms (5,000 cfs) with no more than 142-286 cms (5-8,000 cfs) daily fluctuation, and reduced ramping rates. Scientists emphasized that, although these interim operating criteria would reduce sediment loss from the system, it would tend to store it in channels and eddies and would not maintain elevated sediment deposits. Consequently, with this reduced variability in discharge, they also recommended the need to mimic a flood event to entrain the sediment, build elevated deposits and scour areas that were infilling during low flows. This gave an opportunity for further integrated studies under semi-controlled discharge conditions. Eventually, the selected EIS alternative of Modified Low Fluctuating Flows (MLFF) mimicked Interim Flows. The EIS Record of Decision also included the necessity for periodic high discharges from the dam, some being within power plant capacity, some being much

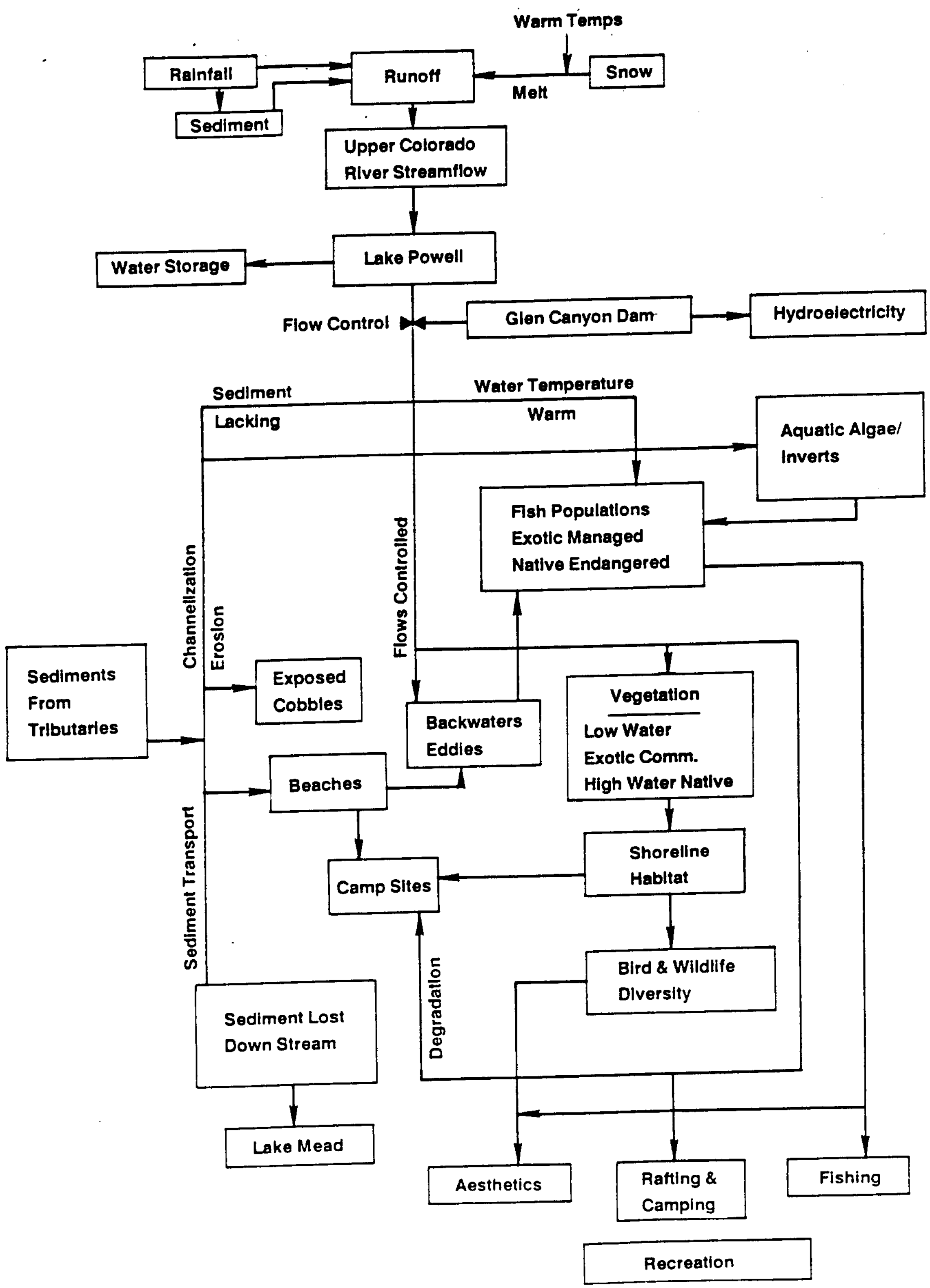


Figure I-2. Conceptual scheme of Glen Canyon ecosystem components and their interactions under present operations of Glen Canyon Dam. (From National Research Council 1987 — Fig. 1.3, page 31).

higher. The former were called "maintenance flows" and the latter were referred to as "beach/habitat-building flows". These high discharges, if used, also offered opportunities for establishing integrated research to demonstrate interrelated responses among canyon attributes.

Flood Experiment. A flood experiment eventually was planned for March/April 1996. The magnitude and duration of the experimental flood had been a contentious point from the early planning. Most scientists thought that the greater the magnitude, the better. Early proposals were as high as 1698 cms (60,000 cfs), with a discharge of over 1415 cms (50,000 cfs) being important for modification of sediment storage, scouring of backwaters and marshes, and possible alteration of debris fans. The greater the magnitude, the greater the total amount of water needed for the experiment. Thus, after various compromises, 1274 cms (45,000 cfs) for one week was agreed on and sufficient water for release during this period was planned into the Annual Operating Plan for the dam.

With an integrated research design in place, the experimental flood occurred from March 22 to April 8, 1996. Teams from several disciplines were placed at study sites within the canyon. Data were collected among disciplines to assure future comparison of results from identically altered conditions. A year after the flood experiment, a symposium was held to review the results and papers prepared within ecosystem sub-units (e.g., sediment, or riparian systems) synthesized the impacts of the controlled, high discharge. Appropriate synthesis papers have been reviewed for this report.

B. Review and Evaluation of Integration Approaches and "Synthesis" Documents

There are many documents that might be useful in developing conceptual ideas about integration among factors and the functioning of the riverine ecosystem with Glen and Grand Canyons. There are also the large number of research reports developed over the past decade or more presenting findings about the response of a particular factor to environmental drivers within the canyon, or a description of the characteristics of some abiotic or biotic component of the riverine system. These individual reports fall under general headings of hydrology, sedimentology, aquatic biology, fisheries biology, riparian vegetation ecology, and riparian faunistic ecology. Each group or heading includes information that is important to understanding how components within other groups might respond to environmental changes or management decisions about resources. A limited number of documents have been briefly reviewed and their contributions toward an understanding of riverine ecosystem integration discussed. These documents, in most cases, are attempts by other authors to show integration or interrelationships among several, if not all, factors. It makes little sense to repeat the process that these authors have gone through, but rather build on their efforts. Some of these documents are more detailed than the output of this report. Their inputs will be used to create a more general integrated model showing responses of most ecosystem components to changes in factors across the whole system.

1. Colorado River Ecology and Dam Management. National Research Council 1991, National Academy Press

This book was an output of a symposium held in Santa Fe, NM and organized by the Glen Canyon Environmental Studies (GCES) review committee of the National Research Council (NRC). This committee had reviewed the first phase of GCES which ended in 1986. GCES Phase I had the misfortune of having high water years during much of the study period and thus concluded that floods were bad. It also was unable to accurately determine the long-term impacts of the Glen Canyon Dam because just as Lake Powell was filled (filling period from 1963 - 1980), high water inputs to the lake required an uncontrolled spill. Thus GCES never was able to evaluate an equilibrium state, if such were to occur.

The NCR committee thought that an overview of conditions of Lake Powell and the Grand Canyon riverine ecosystem following several decades of existence of Glen Canyon Dam would be a suitable contribution to long-term studies and understanding of the Colorado River in Grand Canyon. The symposium was designed to cover each of the primary attributes of the canyon's riverine system and to show how they have changed as a result of the presence of the dam. There was little effort in the planning to show integration among attributes, other than how each related to hydrological controls resulting from dam management scenarios.

The foundation for all papers at the symposium were presentations of laws and policies dealing with dam operations and an explanation of the changes in basic river hydrology. It is the change in hydrological conditions that drives responses of all other attributes, either as the primary driver or as a secondary driver functioning through response of other attributes. These linkages were not clearly presented throughout the symposium, although they were obvious as each response was illuminated.

Changes in sediment transport and river chemistry were described by two speakers. These attributes responded to changes in hydrological changes and thus were secondary drivers, influencing biological attributes of the riverine system. Sediment transport was shown to have been reduced by an order of magnitude, as Lake Powell trapped most of the sediment that normally would have moved through the canyon. Water discharged from Glen Canyon Dam was clear and cold year around, conditions quite different than the pre-dam environment. Below dam hydrology was shown to have wide daily fluctuations as the dam was operated primarily for hydropower production.

Biological responses were presented in an order that has become standard for discussions of the riverine system. First, the aquatic primary producer community which directly responds to changes in river conditions. This was shown to have changed considerably because clear water allows light penetration, and algal productivity in river reaches near the dam was higher than farther downstream where the river picked up sediment. Aquatic invertebrate communities also were altered by new river conditions produced by the dam as well as by introduction of species that would be a food source for the expanding trout fisheries below the dam.

Fish populations were shown to have changed greatly, a consequence of physical changes in the river, for example, lower temperatures, and introduction of exotic, predatory fishes. Few native fish species remained after only two decades of dam operations. Those that did survive appeared to be dependent on tributaries and return current channels in eddy complexes for reproduction or survival of young.

Terrestrial changes along the river were related to vegetation changes. Development of a new high water zone, in the upper stages of power plant capacity, was shown to be dominated by non-native tamarisk. This vegetation had become a whole new habitat for associated animal species, birds, mammals and reptiles. Even the floods of 1983 did not totally remove this new vegetation zone.

A presentation of future research tied to Glen Canyon Environmental Studies Phase II was used to attempt to show the linkages among most of the driving variables and response variables in the riverine system. These linkages were to be used as guides for future research, that is, studies of processes that related changes in one or more factors to responses of riverine attributes of interest to resource managers. A complex flow diagram was presented with several steps between those attributes which are inputs, or which humans manage, and those which are vital resources of interest in the canyon. Because of time limitations, this flow diagram was too complex for overall design of GCES Phase II research. Simpler interactive research was developed, however, each of these simple linkages could, if given time, be fit into the more complex flow model. This one paper in the symposium (Patten 1991) was one of the first efforts at showing how complex the Grand Canyon riverine ecosystem is, and how difficult it would be to study with a goal of producing totally integrated results. It was a good guide to producing this document, but also forewarns one that total integration and synthesis may be an enviable, but unreachable goal.

Concluding Comments and Relation to this Report. This document gives us a broad general background on the changes that have occurred in Glen and Grand Canyons since closure of Glen Canyon Dam. The papers were written, not by researchers so close to the subject that generalization was difficult, but by authors who have worked in the canyon but who also can look at it from a distance and evaluate the importance of time and space in a changing environment. It is a good foundation for developing conceptual integration models and generating trends in changes resulting from altered environmental conditions (stressors).

2. Colorado River through the Grand Canyon. Carothers, S.W. and B. Brown. 1991. University of Arizona Press

This book represents a general integration of much of the information available on the Grand Canyon river corridor at the time of writing (1991). It presents a brief background of the history of the canyon with emphasis on the river corridor, adds ecological components of the canyon, wrapping up the discussion with questions about the future of the canyon and riverine ecosystem based on several options of management. In the concluding chapter the authors present a flow chart (Fig. I-3) of the many factors that come into play in creating the system that now exists. These factors will also play an important part in how the system will respond to future management scenarios. This flow chart is, in many ways, quite similar to the flow chart developed by the National Research Council (1987) and the diagram used in the integration chapter of this report. Carothers and Brown, however, have added more upstream factors as well as those of economics, politics and legal.

Although the authors have limited their discussion of the ecology of the riverine system to the major ecological components, they present a good ecological overview of how the riverine ecosystem has responded to the presence of Glen Canyon Dam. Their discussion starts with the aquatic primary producers and consumers (i.e., invertebrates and vertebrates). They point out the importance of the interrelationships among these aquatic components. They emphasize the changes in the system, for example, loss of native fish species and great increase in non-natives. This follows their general theme of showing how the Grand Canyon riverine system has been altered by the dam and other consequences of management since 1963.

Discussion of the riparian zone is based upon many of the papers written on this subject, but they have added several interesting stories on the interaction of several riparian insects. The story of basic riparian vegetational changes in the New High Water Zone (NHWZ) is well documented, but this book takes these changes to only a few years after the 1983 flood. The authors suggest that an equilibrium was beginning to develop along the shoreline by the late 1970s with the NHWZ being vegetated by tamarisk (*Tamarix ramosissima*) and the "zone of fluctuation" functioning somewhat like the original scour zone. Some evidence suggested that the NHWZ was gradually being invaded by native riparian species and the authors mention that some researchers thought eventually the zone may change to one more dominated by native species. However, the flood of 1983 and high flows in following years appeared to reset the clock. The authors did not have insight into how the system might respond if the daily discharge fluctuations were reduced because the book was published prior to initiation of Interim Flows in 1991. They did suggest that less fluctuation and greater stability to dam discharge might enhance the riverine system.

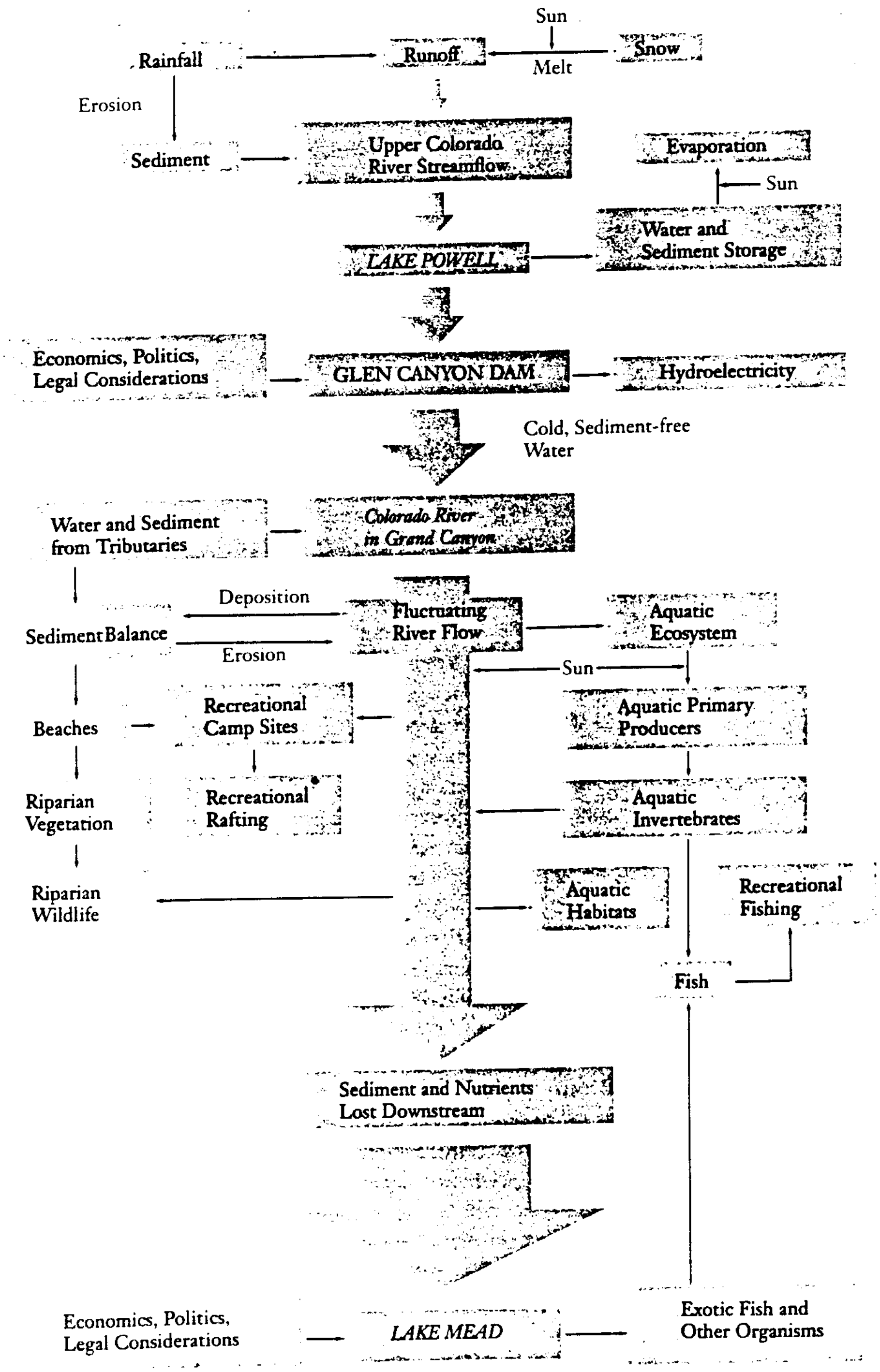


Figure I-3. Simplified flow chart of some of the factors and relationships that influence the Grand Canyon riverine ecosystem above Lake Mead. (From Carothers and Brown 1991 — Fig. 8.1, page 176).

Invertebrate population fluctuations in the riparian system were used to demonstrate some of the interrelationships among human activities (e.g., recreation), floods, and riparian biota. Some species such as harvester ants were shown to have responded to the new beach conditions around the NHWZ. Others insects (e.g., cicadas) were shown to have developed large populations in the newly established tamarisk stands along the river's edge.

Birds are also shown to be opportunistic as they rapidly invaded the NHWZ vegetation. Some species were only known from locations much farther downstream such as the summer tanager and hooded oriole but now are common in the NHWZ. The authors also explain how bird densities in the riparian zone have greatly increased because of the availability of the NHWZ. Although this zone is primarily non-native vegetation (e.g., tamarisk), it has become highly attractive for birds. Only a few bird species were shown to use the woody plants remaining in the OHWZ. Similar responses of vertebrates to the new conditions of the NHWZ are explained in this book. Small rodents apparently increase in population as do several lizard species.

The authors attempt to show the devastating effects of the 1983 floods. They explain how floods of this magnitude (> 2,550 cms, ca. 90,000 cfs) scoured some of the riparian vegetation and thus reduced habitat for birds and other terrestrial vertebrates. Height of bird nests became a critical measure in determining how much a particular species might be impacted. Ultimately, the authors point out, the long-term effect on riparian fauna is closely linked to the ability of riparian vegetation to "recover" from scouring and other damage caused by floods.

Concluding Comment and Relation to this Report. Although the authors point out that some species can recover quickly by in-migrating from the OHWZ, they do not relate the recovery to the initial relatively rapid establishment of these populations as the scour zone from pre-dam days became the NHWZ with abundant vegetation. These cycles of destruction and recovery are the general *modus operandi* of riverine and riparian systems which are disturbance oriented ecosystems. Initiation of "recovery" was 1963 when the dam was closed. Initiation of another recovery cycle was post-1983 flood, while another recovery period, albeit reduced, was initiated with the 1996 controlled flood. These cycles are the foundation on which our understanding of the riverine ecosystem must be based. Response of individual components of the ecosystem to selected perturbation, in this case floods, is one signal. The other and more integrative signal is the response of an individual component to changes in other components as they respond to perturbation.

3. Operation of Glen Canyon Dam, Final Environment Impact Statement. Bureau of Reclamation, 1995.

The Glen Canyon Dam EIS was developed by a group of scientists and resource managers to help explain how the riverine system works downstream from Glen Canyon Dam, and how alterations in operations of the dam might influence this system and its components. It attempts to be integrative, but the approach is more one of showing how individual attributes of the riverine ecosystem might be changed under varying dam discharge scenarios, rather than showing how the whole system will be altered. That does not imply that the reader of this EIS will not come away with a sense of the synergistic relationships among the many driving and response factors. No doubt, it shows that hydrology drives sediment transport which in turn influences stream clarity, beach development, riparian vegetation growth, etc. The EIS is a good document, mostly based on preliminary study results, that guides the reader through an understanding of how a whole system and its parts may be altered, or respond, to changing stressors. Management implications and development of guidelines for adaptive management is a strength of the document.

Concluding Comments and Relation to this Report. The Glen Canyon EIS is lengthy and thus is briefly mentioned here as another foundation document for developing integrative ideas. More extensive integrative ideas, have been developed by some of the other documents cited above. Certainly, the integration workshop held in Flagstaff in fall 1995 generated more ideas for future research and monitoring than the EIS.

4. Prospectus on Integration of Biological and Physical Data Below Glen Canyon Dam, Arizona. Glen Canyon Environmental Studies. 1995.

This is a working document resulting from a meeting a many scientists in Flagstaff August 10-11, 1995. It is an excellent document for guiding research and monitoring agendas in the future. The group broke into several subgroups and developed commentaries on the effects of Glen Canyon Dam around specific Biological Opinion issues. The core topics were (1) physical-habitat relations, (2) trophic dynamics, (3) population ecology of humpback chub, and (4) the role of science in adaptive management. The scientific group addressing these issues included many individuals who had done research in the canyon for many years. They were asked to identify hypotheses and research questions, the data bases which support these, and possible management questions.

The physical-habitat topic gave a foundation for addressing the biological aspects of the integration process, especially as it impacts life history of endangered species. The physical-habitat topic included hydrology, sedimentology and interrelationships with local and regional climate. The role of these in the evolutionary development of native species was discussed and the effects of changes in these factors on long-term survival of native species was used as a basis for commentary on biological processes.

Trophic dynamics issues were used as a foundation for determining possible response issues of endangered aquatic species, such as the humpback chub. Secondary productivity within the aquatic system also was shown to impact those species dependent directly, or secondarily, on invertebrates originating in the river. Humpback chub was used as the primary endangered fish species for postulating hypotheses and management questions.

Conclusions on Applicability to this Report. This document demonstrates many levels of integration among attributes in the Grand Canyon riverine ecosystem. It has developed important questions that should be considered for future research and monitoring. Many points that it has developed, based on input by knowledgeable scientists, are used in this report. Redeveloping the ideas seems inappropriate.

5. Grand Canyon Data Integration Project: Synthesis Report. SWCA Inc. 1997.

GCES also funded a "Grand Canyon Data Integration Project" with the objective "to assemble the existing information that pertains to how native fishes and their non-native competitors and predators within the Colorado River ecosystem in Glen and Grand Canyons might respond to a seven-month period of experimental steady dam releases." This report asked the following questions, most of which are relevant to this integration project:

Do sufficient baseline data exist to evaluate the influence of the steady flow experiment described in the RPA?

Do existing data indicate that the steady flow experiment will likely have an overall positive influence on endangered and other native fishes in Grand Canyon?

Do existing data indicate that a steady flow experiment will not benefit non-native fishes at the expense of endangered and other native fish?

Answers to these questions required an approach at synthesizing information available from GCES studies as well as the open literature. This synthesis resulted in a overview of many of the aquatic ecosystem processes within the canyon and was very useful in fulfilling the objectives of this project. The Grand Canyon Data Integration Project did not evaluate the adequacies of the many studies it cited, or whether data from these studies could realistically be used in an integration approach to understanding the whole riverine system, either from a scientific or management perspective.

The purpose of this document was to compile and review existing, published information to address the potential impacts of steady flows called for by the USFWS Biological Opinion. This information and its synthesis was designed to lead to a workshop that was to address ecological and management implications of steady flows. This document goes well beyond just a cursory review of existing literature of the aquatic ecosystem in the canyon. It documents pre- and post-dam environments in the canyon and how these have altered most components of the river ecosystem. Except for a brief chapter on the aquatic food base, emphasis of this document is on fish species that have or might be expected to be affected by the steady flow.

In addition to background chapters on GCES and the physical environment, as well as one on food base, chapters include (1) state of the Glen/Grand Canyon fishery, (2) life history and ecology of native species (fishes), (3) life history of non-native species (fishes), (4) native/non-native interactions, (5) impact of experimental steady flows, and (6) adaptive management, data gaps and research hypotheses. The chapters on native and non-natives fishes discuss aspects of the life stages of the various species. In this way, this document integrates the physical/ chemical/biological environments controlling fish species and explains how these may be limiting factors. The primary limiting factors for most of the species are (1) water temperature, (2) loss or alteration of habitat, (3) food supply limitation, and (4) diseases.

Water temperature has been shown by many researchers to be an altered factor that tends to remain relatively constant. Stable cool water is quite different than the widely fluctuating temperatures of pre-dam conditions. Habitats for fishes have changed as sediment, a common component of the river, became limited. Sediment loaded waters as well as sediment deposits around channel margins and eddies all changed, creating a habitat with waters of greater clarity and marginal habitats that were perhaps less suitable for native fishes. Clear waters and introduced species also altered the aquatic food base, while enhancing the potential for spread of disease and parasites, especially for non-native species.

The discussion in this document on interactions among native and non-native fish species shows how other areas in the Colorado River basin have seen changes in habitat and fish populations but have not had the level of native species losses as those found in the Grand Canyon area. Factors related to hydrology, sediment transport, fish management all play an important role in this phenomenon.

The chapter on impacts of steady flows attempts to show how fish habitat characteristics might change under this discharge regime. Steady flow will create a set of conditions that may be positive, negative or non-influential for native and non-native fishes. For example, increased ponding, increased water temperatures and increased shoreline and backwater habitat will all be beneficial for native fishes, but they will also be beneficial for non-natives. Few changes caused by steady flows are shown to have differential effects on native vs. non-natives. One condition, an increase in water clarity tends to benefit non-natives over natives.

Concluding Comments and Relation to this Report. This document offers many insights into interaction among environmental factors and fish responses that will be useful for those attempting to design integrated research and monitoring programs on fish populations in the Colorado River. It is a well documented report, sufficiently so that many concepts in it are used in the integration effort of this report. The weakness of the document is that it has not evaluated the strengths of the references used to document its statements. Many of the studies used have some flaws, and yet, their results can be used to explain trends or to develop conceptual tables or flow models.

6. Grand Canyon, A Century of Change. 1997. Robert Webb, University of Arizona Press.

This book is mentioned here because it is useful in demonstrating the temporal nature of changes within Grand Canyon. The book is based on repeat photography about 100 years apart. The author attempts to explain similarities and changes of the repeat photographs. Obviously, a major cause for the changes along the river is the existence of Glen Canyon Dam and it mode of operation. The photos show loss of sediment along the river and invasion of vegetation in the NHWZ, but little change in much of the upland desert. Thus we see stability of the arid ecosystem where there has been little anthropogenic influence, and many changes where management of hydrological and other resources have been great. It is not a book to be used to generate integrative models, but it can be used to support concepts that deal with altered environmental drivers and changing habitat conditions.

C. Objectives of this Study

The objectives of this project may appear to be an attempt to move backwards before going forward with integration and synthesis of GCES data. Some of the integration projects `reviewed above make the assumption that all of the information gained through GCES studies is useful for integration purposes. This may be true if one approaches the information from the perspective of using trends or simple relationships identified in many of the projects. On the other hand, close scrutiny of the research and the reported results may expose weaknesses in methodology or interpretation that reduces the usefulness of the studies for detailed integration and synthesis modeling, but still allows the information to be useful in presenting a general picture of how the many attributes of the riverine ecosystem interact as they respond to changing conditions presented by alteration of dam operations.

Consequently, there is a need to reevaluate many ofthe studies that flowed from GCES I and II in light of how they might be used in the future for both integration and management purposes.

The objectives of this project were:

To assess and evaluate the methodologies utilized in the research and monitoring of the components of the riverine ecosystem in the Grand Canyon as affected by the operation of Glen Canyon Dam. This assessment included the biological and chemical components (and physical where appropriate). This evaluation will be utilized along with other documents to suggest long-term monitoring approaches.

To provide oversight and assistance on the integration of the individual components of the riparian and aquatic studies (and physical when appropriate) completed under the GCES program.

To provide an integrated summary of the ecology (biological and chemical elements, and physical where appropriate) of the Colorado River ecosystem in the Grand Canyon. This document to provide guidance towards the synthesis of the research and monitoring results developed under GCES.

In preparing the final report for this project, specific methodologies have beeb evaluated and recommendations made on their use in long-term monitoring and research. Also, an attempt is made to design a preliminary model of the interrelations among sediment dynamics, riparian dynamics and aquatic biological dynamics. This model should be useful in designing long-term monitoring, as it may help in identification of areas of available knowledge and gaps in knowledge.

II. Use of Integration and Synthesis in Determining Long-term Monitoring Parameters

The Grand Canyon Protection Act of 1992 directed the Secretary of the Interior to establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated "...in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established...". As part of the Glen Canyon EIS, the Bureau of Reclamation and cooperating agencies outlined a plan for developing a long-term monitoring program, based upon Adaptive Management, that would evaluate the effects of Glen Canyon Dam operations, as described in the Record of Decision, on the riverine environment of Grand and Glen Canyons.

Long-term monitoring is used for a variety of purposes including assessing baseline conditions, trends of attributes, implementation of a decision, effectiveness of a decision, project impacts, model efficiency, and compliance to a set of standards. A long-term monitoring program for Grand Canyon should be designed to provide input to an adaptive management program, one which would guide long-term operations of Glen Canyon Dam. Long-term monitoring is repetition of measurements over time to detect change. It should be designed to determine variability of the resources of concern in time and space.

Long-term monitoring within Grand Canyon should recognize the uniqueness of the environment. The environment is both a highly regulated one, but also one that requires respect and as little intrusion of human activity (research and monitoring) as possible. In striking a balance between designing a monitoring program that is highly restrictive and one that measures every riverine attribute at as many places as possible (i.e., highly invasive), it is necessary to scientifically identify those riverine attributes that will give the best evidence of changes, or trends in response to dam management scenarios.

The long-term monitoring program outlined in an appendix of the Glen Canyon Dam EIS presented an extensive list of critical riverine attributes that should be considered for measurement when establishing a monitoring program. It was pointed out at that time, that insufficient data were available to identify a limited list of attributes that could be used to compose a short-list, on which many selected attributes would function as surrogates for others. Table II-1 presents the type of format that was being considered in development of the Glen Canyon Dam long-term monitoring program. This table lists activities or canyon (or dam operations) modifications that would be considered stressors to which monitored attributes would respond. The abridged list of attributes in Table II-1 would be used to measure changes relative to management goals. Each of these would be presented as a single attribute responding to a single stressor (management activity). This approach, unfortunately, will create an extensive list of attributes that should be measured for monitoring, basically the list presented with the GCDEIS. To reduce the number of attributes to monitor using this approach, each attribute is ranked based on how directly it is affected by the management activity (e.g., flood flows), and how sensitive it is to the altered environment.

Scientist may argue the rankings given the attributes in Table II-1. This is not important to this presentation. What is important is that some attributes regularly are ranked with ones or twos while others have low rankings. Those with rankings approaching one should be considered

Table II-1. Sensitivity of Monitoring Parameters to Dam Operation Parameters and River Use Management Activities. 1 = directly affected and highly sensitive; 2 = moderately affected and somewhat sensitive; 3 = indirectly affected and not very sensitive; 4 = largely unaffected

Riverine Ecosystem Parameters	Fluctuations within EIS (ROD)	Floods < 31,000 cfs	Floods > 40,000 cfs	Temperature Control	Fish Management	Recreation Management
Water Quality						
Temp	2 - 3	3	2	1	4	4
pH	2 - 3	3	3	2	4	4
EC	4	4	3	2	4	4
DOC	3 - 4	2 - 3	2 - 3	2	4	3
DO	3	2	1 - 2	1	4	4
Flow						
Peak Flows	1	1	1	3 - 4	4	4
Low Flows	1	3	3	2 - 3	4	4
Stage Changes	1	1	1	3	4	4
Sediment						
Suspended	1 - 2	1	1	4	4	3 - 4
Bedload	2	1	1	4	4	4
Elev. Deposits	1 - 2	1 - 2	1	4	4	3
Channel Characteristics						
X-sections	1 - 2	1	1	4	4	3 - 4
Margin Habitats	1 - 2	1	1	4	4	3 - 4
Eddy Characteristic						
RCC size	1 - 2	2	1	4	4	3 - 4
Reattach.Bar Elevation	1 - 2	2	1	4	4	3 - 4

Riverine Ecosystem Parameters	Fluctuations within EIS (ROD)	Floods < 31,000 cfs	Floods > 40,000 cfs	Temperature Control	Fish Management	Recreation Management
Aquatic Organisms						
Algae	1 - 2	1 - 2	1	1	3	4
Inverts	1 - 2	2	1 - 2	1	2 - 3	4
Native Fishes	2 - 3	2	2	1	2	3
Non-native Fishes	2	2	1	1	1	2 - 4
Riparian						
Veg Canopy %	2 - 3	2 - 3	2	3 - 4	4	2 - 3
Marsh Area	2 - 3	1 - 2	1	3 - 4	4	3 - 4
Plant Species Diversity	2	3	2	3 - 4	4	2 - 3
Birds	2 - 3	3	2	4	4	3
Mammals	2 - 3	3	2	4	4	3
Reptiles	3 - 4	3	2	4	4	3

prime candidates for monitoring. Depending on the driving activity, a long list still might be developed using this procedure. If reducing the impacts of researchers and monitoring scientists is an objective of a long-term monitoring and research program, another method is needed to define the top priority attributes for monitoring. An approach that takes into account linkages among attributes and impacts between factors can be developed based on system integration and synthesis concepts. This approach should reduce this shopping list to a reasonable length, base the selection on knowledge about the system, and reduce the "footprint" of the monitoring program within the canyon.

It is possible to develop an integrated table for narrowing down the list. Most riverine attributes are interrelated to others, so that as one changes so does the other. We know, for example, that if we reduce the amount of sediment deposits (i.e., substrate) available for riparian vegetation expansion, there will be less riparian vegetation which will cause a concomitant reduction in associated birds and other wildlife. These linkages, sometimes many links long, are presentable in a conceptual model. Eventually we will be able to manipulate them within quantitative models. However, until those capabilities are achieved, one integrative approach that recognizes interrelationships among attributes is creation of a matrix with all attributes along both axes (Table II-2). Using a ranking similar to that used in Table I-1, we rank the "strength" of the relationship, that is, how much a change in one will influence the values of the other. Sometime the direction of influence is unidirectional, while in other cases it is bi-directional. For example, in most cases where one of paired attributes is a hydrological parameter, this is a driving variable and the other is a response variable. Peak flows and channel margins are an example of this. These are closely related and receive a one ranking, but obviously if we look at the relationship in the other direction, that is, influence of channel margin habitats on peak flows, there is little that could be called a close or influential driving variable.

Some of the attributes listed in Table II-2 are obvious driving variables that result directly from human activities; these are mostly hydrological. In other cases, the attribute becomes a driving variable if it directly influences another attribute, but it, in turn, may have been closely influenced by another factor. Regardless of the apparent complexity of this table, those attributes that receive many ones and twos are attributes that relate to many processes and thus can be considered integrators within the riverine system. Selection of a few of these, assuming we fully understand their linkages with other factors, is one way to reduce the number of monitoring parameters. Comparison of rankings in Table II-2 with those in Table II-1 will give greater assurance that the correct attributes have been selected. Summation of all rankings for each attribute may also be one way of creating a general, overall ranking for the list. Doing this will tend to emphasize hydrological and aquatic parameters over terrestrial parameters. Thus, it might improve the ranking system to do summations within groups.

The tables presented here are examples. Scientists working with the Grand Canyon Monitoring and Research Center will need to flesh out these tables to assure that all critical attributes are included. For example, these tables do not specifically list endangered species, although some fall under native fishes, and birds. It may be necessary to list specific species; however, other policies (e.g., Endangered Species Act) control the need to monitor listed species and putting them in these tables may cause other attributes to be bypassed.

Table II-2. Sensitivity among monitoring parameters showing strength of interrelationships: 1 = directly related; 2 = moderately related; 3 = indirectly related; 4 = unrelated.

	Water Quality					Flow			Sediment			Channel Charact.		Eddy Charact.		Aquatic Organisms				Riparian			
Riverine Ecosystem Parameters	Temp	pH	EC	DOC	DO	Peak	Low	Stage Chg.	Suspended	Bedload	Elev .Deposits	X-sections	Margin Habitats	RCC Size	Reattach. Bar Elev	Algae	Inverts	Native Fish	Non-Native Fish	Veg Canopy	Marsh Area	Species. Diversity	Birds
<u>Water Quality</u>																							
Temp	1	1	1	1	1	3	3	3	2 - 3	4	4	4	4	1 - 3	4	2	2	1 - 2	1 - 2	3 - 4	4	4	4
pH		1	2 - 3	2	2	3	3	3	3	4	4	4	4	2 - 3	4	1 - 2	2	2	2	4	4	4	4
EC			1	3	3	3	3	3	1 - 2	3 - 4	4	4	4	3	4	1 - 2	1 - 2	1 - 2	1 - 2	3	3 - 4	3	4
DOC				1	2 - 3	2	2 - 3	2 - 3	2	3	4	4	4	3	4	1 - 2	2	2	2	2 - 3	3	4	4
DO					1	1 - 2	2	2 - 3	2	3	4	4	4	2 - 3	4	1 - 2	2	2	2	4	4	4	4
<u>Flow</u>																							
Peak Flows						1	2	1	1	1	1	1	1	1	1	1 - 2	2	2 - 3	1 - 2	2	1	2	3
Low Flows							1	1	1 - 2	1 - 2	1 - 2	1 - 2	2	1	2	1	1 - 2	2	1	1 - 2	1	2	3
Stage Changes								1	1 - 2	1 - 2	1	1	1	1	1 - 2	1	1 - 2	2	1 - 2	3	1	2	3
<u>Sediment</u>																							
Suspended									1	1	1	1	1	1	1	1 - 2	2	1	1 - 2	3	1 - 2	2	4
Bedload										1	2	2	2 - 3	2 - 3	2 - 3	1 - 2	2 - 3	2 - 3	1 - 2	3	3	3	4
Elev. Deposits											1	1	1	2 - 3	1	4	4	4	4	1 - 2	1 - 2	2	3
<u>Channel Characteristics</u>																							
X-sections												1	1	1 - 2	1 - 2	2	2 - 3	2 - 3	2 - 3	2 - 3	1 - 2	3	4
Margin Habitats													1	3 - 4	3 - 4	4	3 - 4	1 - 2	1 - 2	3	2	3	3

Riverine Ecosystem Parameters	Temp	pH	EC	DOC	DO	Peak	Low	Stage	Suspended	Bedload	Elev .Deposits	X-sections	Margin Habitats	Rcc Size	Reattach . Bar Elev	Algae	Inverts	Native Fish	Non-Native Fish	Veg Canopy	Marsh Area	Species Diversity	Birds
Eddy Characteristic																							
RCC size														1	1	2 - 3	2 - 3	1	1	2 - 3	1 - 2	3	4
Reattach.Bar Elev.															1	4	4	4	4	1 - 2	2	2	3
Aquatic Organisms																							
Algae																1	1	1 - 2	1 - 2	4	4	4	4
Inverts																	1	1	1	4	4	4	4
Native Fishes																		1	1	4	4	4	1 - 2
Non-native Fishes																			1	4	4	4	1 - 2
Riparian																							
Veg Canopy %																				1	2 - 3	1 - 2	1
Marsh Area																					1	1 - 2	1
Species Diversity																						1	2
Birds																							1

Conjunctive Monitoring. A monitoring program for Grand and Glen Canyons should be structured around both the interrelationships of the attributes to be monitored and the ability to utilize personnel in such a way as to reduce impacts on the canyon ecosystem. Measurements of interrelated attributes should be taken at the same time and place to assure that interpretation of responses of one attribute can be related to responses of other interactive attributes. Setting up a synoptic study of one attribute from one end of the canyon to the other is only useful if related attributes are being measured at the same time.

During the research phase of GCES Phase II, most of the studies were related to hydrological events, and few compared changes in multiple factors that may have responded to hydrological changes during the time of study. Planning for research during the 1996 controlled flood tried to correct this single factor approach and research of many attributes that might change during the flood event was designed with teams studying related attribute responses at the same place and time. This was driven by the limited time-frame of the flood event, as well as a limited budget. It should be used, however, as the model for future monitoring efforts, a conjunctive monitoring approach, that will assure correlation of attribute responses and will recognize the interrelationships shown in Table II-2. Conjunctive monitoring will also enhance our understanding of these interrelationships and clarify the rankings given to these relationships on a much more expanded version of Table II-2.

III. Assessment and Evaluation of Glen Canyon Environmental Studies Reports

A. Overview of Strengths and Weaknesses of Methodologies, Research Design, etc. Used in Aquatic and Terrestrial Biological Research Studies.

1. Aquatic Biology

Reports from all research agencies and organizations that were funded to study components of the aquatic biology of Grand Canyon relative to dam operations have been critiqued. Many of the reports required follow-up with principal investigators in order to understand methodologies used or interpretations. In most cases, investigators were cooperative and answers to questions were readily prepared. In some cases, investigators did not respond to several queries and we made our own interpretation of their text.

Some agencies had not completed all of their final reports and answers to our queries about completion dates for the missing reports suggested the reports were delayed for some time. This resulted in incomplete evaluation of the studies from those agencies. Overall, however, sufficient reports were available to evaluate methodologies, data interpretation and usefulness of the data for both detailed and general integration reports.

General observations from evaluation of aquatic studies are presented in this report, while detailed critiques of the strengths and weaknesses of the reports are included in the Appendices.

a. Mechanistic approaches to the Grand Canyon ecosystem.

One component missing from many aquatic biology reports is a clear acknowledgment of the dynamic nature of change in Glen and Grand Canyons. Investigators present data as static description of conditions at particular points in time without addressing mechanisms of change through longer time scales. For example, many studies examined changes in availability of different habitat types by quantifying their relative frequency under different flow regimes. Generally, relative abundance of various habitat types is driven on short time scales (e.g., daily, which is the scale at which most flow changes take place) by the fact that the river occupies varying channel levels as its depth changes. On a longer time scale (seasonal, annual), however, habitat availability changes for particular reaches even at similar discharge levels. Mechanisms for such longer-term changes in habitat availability are rarely proposed. If such mechanisms could be understood, more predictive models of how operations of Glen Canyon Dam affect habitat availability might be devised. It is possible that mechanisms underlying changes in habitat availability (e.g., distribution of sediment, development of riparian vegetation, etc.) are better addressed in studies that focus on riparian and sediment/hydrological aspects of GCES efforts. Given the importance of habitat availability to several of the biological components of Grand Canyon (e.g., native and non-native fishes), this is an important area of overlap between these three categories of GCES projects.

Mechanistic explanations are also rarely proposed for other patterns. For example, USFWS researchers observed catch rates of exotic fishes to increase after summer flooding in the LCR; BIO/WEST found native fishes were caught more readily using nets whereas non-native were captured better using electroshocking; and Otis (1994) and Madduux et al. (1987) observed seasonal shifts in native vs. non-native fish species dominance. An understanding of mechanisms behind such patterns would advance greatly our understanding of the Grand Canyon riverine ecosystem and aid in design of monitoring and management plans. Future research and monitoring should include proposed mechanisms for such patterns, whether derived from experimentation or literature review.

b. Sampling/Data Presentation

Arizona Game and Fish Department performed a study on habitat use by larval fishes in the LCR that raised an interesting, general issue regarding sampling. The investigators evaluated habitat use by sampling intensively from areas where fishes were detected. Fish were detected visually under clear water (low discharge) conditions, and by random dip net sweeps under turbid conditions. Obviously, the clear water was sampled much more intensively than turbid water, as the human eye can detect movement of fishes in clear water over a much broader area than was probably sampled in dip net sweeps under turbid conditions. Bias may also be introduced to such a sampling strategy by fish habitat use under condition of varying turbidity (i.e., fish may preferentially use cover objects in clear water, thus remaining out of sight to an observer). Whether this bias is present in other reports is unclear as not all reports explicitly discuss sampling strategies. This source of bias can be minimized by choosing sampling locations randomly or systematically regardless of visual detection of fish, a strategy used, for example, by USFWS in the LCR.

Another issue about sampling design concerns the various investigator's definition of flow regimes. Flow regimes represent a key component to alternative dam operation strategies, and therefore their definition is central to describing effects of dam operations. Unfortunately, "regime" is a temporal scale-independent term. Many investigators use terms like "fluctuating", "variable", "steady", and "constant" to describe flow conditions as an independent variable in their studies, without clearly defining these terms and occasionally using them inconsistently. This makes it more difficult to directly compare studies performed during different flow regimes. It should also be noted that some studies which examined differential effects of fluctuating versus steady flows (with "steady" defined as unchanging discharge over a period of at least several days) were able to sample only a very limited number of steady flows. Therefore, actual effects of steady flows are not well known. Finally, effects of steady discharge flows will depend upon the actual discharge level (i.e., effects of a steady 142 cms (5,000 cfs) discharge will probably differ from those of a steady 425 cms (15,000 cfs) discharge, with both considered simply as "steady flows"). Future efforts should standardize definitions of "fluctuating' versus "steady" flows, and the effects of each should be defined clearly relative to actual discharges. For example, "fluctuating" flows could be defined as those rising and falling on a daily basis, with "steady" flows as representing discharges that do not change on a daily time scale. A "constant" flow regime could then be defined as a longer period (weeks, months) of either fluctuating or steady flows, and a "variable" flow regime may represent shifts between fluctuating and steady flows on this longer time scale.

Several investigators present results of fish surveys as relative or absolute frequency of occurrence in samples averaged across sampling dates, locations, and/or gear type. Future reports should utilize a standard format for reporting such data. This will aid greatly in compiling synthetic data bases for fish in Glen and Grand Canyons, making it easier to assess long-term effects of Glen Canyon Dam operations. Formats should follow those of BIO/WEST, as they have already developed formalized data bases in dBASE IV format as part of other GCES-sponsored efforts. Future studies should also utilize consistent definitions of sampling transects (in terms of spatial extent and subdivision), identification of substrate types, and level of effort expended while using different sampling gear. Detailed integration between studies is hindered by variation in sampling designs among studies.

A final issue related to data presentation concerns the reporting of catch-per-unit effort (CPUE) data. Some reports define CPUE in terms of catch per unit area, others define it as catch per unit time. One even switches between these two definitions within the same report. These data should be standardized in future studies if long-term comparisons are to be made.

c. Data Analysis

Many investigators utilized appropriate analytical techniques in describing patterns in their data. Specific problems and suggested alternatives are discussed in reviews of project reports (see Appendices). There are some general issues identified from several reports which should be incorporated into future research and monitoring. First, several investigators treated repeated samples from within sampling transects as independent of each other; this is generally not true. By viewing such observations as independent, degrees of freedom in Analysis of Variance and Linear Regression tests are greatly inflated, artificially increasing the power of these tests (i.e., increasing the probability of Type I errors). Conclusions drawn from such analyses are therefore equivocal making integration of studies difficult. This issue can be resolved by averaging across observations within transects and using these means as independent observations, thus using the number of transects as the sample size of a given analysis. Which observations should be averaged depends on the design and goals of any given study, and future sampling designs should be developed around careful consideration of the independence of observations. Persons familiar with experimental design as well as the software to be used in analyses should be consulted prior to implementation of future studies.

Second, several studies reported habitat type-specific capture rates for native and non-native fish species. These capture rate data are then used to describe habitat use patterns for particular species. Such data should be weighted, however, by some index reflecting how easily fish can be sampled in different habitat types. If fish can be detected and/or sampled more easily in riffles or nearshore areas than in areas with complex cover objects, for example, then conclusions regarding habitat use will be biased toward riffles and nearshore areas. This will be true regardless of whether sampling is performed by using passive nets and traps, active electoshocking , or remote telemetry. An index for weighting such capture/detection data might be calculated by sampling a known number of fish in particular habitat types (obtained by exhaustively sampling the area using all available techniques). BIO/WEST presents analyses of sampling gear capture efficiency that could be used in calculating such indices.

A third general concern with data analysis involves description and analysis of habitat categories. Several studies utilized Gorman's "point-pole" technique of classifying and quantifying habitat variables, especially current velocity, substrate and depth. These variables are correlated (e.g., higher velocities occur more frequently with larger substrates), yet subsequent analyses do not take these correlations into account. Also, analysis of such data with regard to differences in availability between reaches or among tributaries varied from study to study, again making integration between studies difficult. Categorical variables based on an underlying continuous gradient (e.g., depth, current velocity) can be analyzed using a ranking test like the Mann-Whitney U-test, whereas categorical variables that are not based on continuous gradients (e.g., cover object classifications) can be analyzed using the Kolmogorov-Smirnov test. Whatever techniques are used, future research should standardize analytical methods to facilitate long-term and broad-scale comparisons.

2. Terrestrial Ecology

a. Riparian Ecosystems Studies

There were a limited number of riparian studies funded by GCES. (See Appendices for critiques and comments).

Two approaches have been taken for riparian ecosystem studies. One approach is historical, using aerial photographs from a series of years to determine changes in riparian cover since dam construction and following the major flooding event of 1983. The other approach is field sampling of established transects related to determination of changes in "polygons" of vegetation types, polygons being mapped on recent aerial photographs.

Historical Approach. Using an historical approach to determine temporal changes of riparian vegetation allows quantification of major changes in cover types that might not be picked up during time-limited "on-ground" studies. To properly evaluate aerial photographs for changes that can be used to suggest responses of riparian vegetation to hydrological events or other disturbance phenomena, as well as time, the photographic series must be properly selected. Preferably, aerial photographs taken every year at the same time of year should be selected. If these are not available, aerials that precede and follow important events (e.g., flood of 1983), and define a regular time period thereafter should be used.

The historical approach for riparian vegetation cover is very useful in that it can be related to changes in sediment deposition patterns occurring throughout the canyon. The sediment integration studies should be describing these changes and related substrate types (e.g., sands, debris fans, etc.).

Historical aerial photogrammetric studies of canyon riparian vegetation used a limited number of photographic years. No photographs were used for conditions prior to dam closure (i.e., pre-1963). Adequate photographs from pre-dam years may not be available or useable for this purpose. Only two years were used between dam closure and the 1983 flood (1965 and 1975). The eight year period between 1975 and 1983 was a period of canyon stabilization and riparian expansion, yet this period was not documented in the historical study. The other three years for which aerials were analyzed, 1984, 1990 and 1992, do not represent any regular pattern or pre- post-event period. 1984 is post-flood, but the years following 1984 were also high water years and riparian responses to these years are lost without using photos from about 1987 or 1988.

The historical approach did suggest that there is a riparian vegetation response to long-term canyon sediment stabilization. Following floods or disturbance events that create sediment deposits, riparian vegetation is slow to establish. Only as the sediment deposit erosion process slows down (i.e., the end of the sediment loss curve), does riparian vegetation appear to increase rapidly in cover. It is integration of the sediment and riparian response curves that may allow development of a model of one portion of riverine/riparian terrestrial dynamics.

Field Studies. Short-term response studies of riparian vegetation to changes created by dam operations have identified factors that caused changes seen in historical photo interpretation. Short-term changes to sediment deposition or erosion can be modeled into longer-term response models being developed for riparian/sediment integration. For example, small fluctuations in dam discharges cause sediment accumulation in riparian marsh areas. This filling phenomenon changes the water-level status of the location from a wet-marsh condition to a damp-soil condition. This change results in invasion of terrestrial riparian species (e.g., tamarisk) which replace the wetland species found in the marsh. Higher discharge events may scour these areas returning the location to marsh or backwater (return channel) conditions. Inundation frequencies thus become an important aspect of future model development. Field studies have also evaluated the response of riparian vegetation to sediment textural types and elevations of sediment deposits. Elevation of riparian vegetation above the water table influences the water uptake ability of riparian plants; this was measured in field studies using plant stem water potential measurements. Field studies used GCES GIS data to develop relationships between riparian vegetation factors and other physical factors. The only relationship developed was that of species diversity and variability in riverine conditions. Many other relationships could be developed with the GIS data, including relationships between individual species (occurrence, cover, or frequency) and riverine attributes such as geomorphology, canyon location, etc. Obviously, any understanding of long-term riparian dynamics must be related to long-term sediment/geomorphological dynamics of the canyon. All of these eventually relate back to hydrological conditions and operations of Glen Canyon Dam.

When the research program of GCES II began to wind down, a monitoring program was put in place. At first it was designed to function as a bridge between the research program and the monitoring program that would be initiated with the final announcement of the Record of Decision tied to the Glen Canyon Dam EIS. The ROD kept being extended and thus a monitoring program was developed tied to Interim Flows, the dam operational regime started in mid-1991. Some of these studies were put together as research projects, to study the effects of Interim Flows, but in reality, they were more monitoring projects.

Decline of the overall stage levels downstream from the dam resulting from Interim Flows caused a reduction in the water table that supported the riparian and marsh communities along the river. Vegetation was used as indicator of drying conditions, especially in the New Dry Zone, the zone exposed below the NHWZ when the river no longer reached power plant capacity flows. This new vegetation zone was available for vegetational encroachment because of less scouring and dry down. Consequently, a zone that had not been closely considered in earlier studies was now of importance. Since these data (1995) are now baseline data for the NDZ, this zone should be studied more closely in the future. It is the zone that will eventually be an indicator of many of the changes caused by dam operations under the ROD.

Methodologies developed for Interim Flow research and monitoring are too time consuming and wrought with potential inaccuracies. Ground measurements are needed occasionally in the riparian zone, but use of aerial photos appears to be the best approach for a non-intrusive, relatively accurate means of measuring change. An expert photo interpreter working with a vegetational ecologist should be able to determine the kinds of changes taking place. This type of monitoring should be done nearly every year, while ground studies (groundtruthing) should be much less often, unless there are extraordinary events (e.g., floods) that would reset conditions.

Most riparian vegetation monitoring programs also looked at endangered and other special species, including invasive, non-native species. These species may change more rapidly than the general vegetation, thus an annual monitoring program should be established in representative sites to monitor progress of these species.

Other Interim Flow studies were being run parallel with those described above. The lower reaches of the canyon were being studied for vegetation, avian and animal responses. Unfortunately, although the studies appeared to be quite integrated, emphasis in the vegetation studies was placed more on vegetation as a habitat, rather than vegetation as a responder to river flows. Vegetation characteristics in these studies are not readily related to those in other reaches of the river. Total vegetation volume (TVV) is a very useful attribute of riparian vegetation, especially when looking at vegetation as avian habitat. It gives a relative cover estimate and is useful for comparison with upstream riparian vegetation from other studies on a relative basis, but not on a direct quantitative basis. In the future, closer coordination is necessary in studies of riparian vegetation as well as other riverine attributes.

In a 1996 draft report, Spence, Kearsley and others demonstrated how coordination is possible. Unfortunately, the vegetation data were limited. Many cross-sections of many riparian areas, especially marshes, from Lees Ferry to Pearce's Ferry, showed changes in elevation, a consequence of sediment erosion/deposition processes. Unfortunately, there did not appear to be any obvious effort to link this study closely to other earlier vegetation studies, but more to beach survey studies. The methodology, however, did follow that used in earlier vegetational sampling in the upper reaches of river. Finalization of this report, not available to this reviewer, might overcome some of the shortages of the report mentioned above.

b. Avian Studies

Many of the avian studies dealt with endangered species such as southern bald eagle and peregrine falcon, but some were directly tied to the riparian corridor. Two groups of birds were studied along the corridor. One was the waterbirds, a group that was essentially non-existent prior to the construction of the dam. The other includes the birds that utilize riparian vegetation and does not include waterbirds.

Most waterbird studies were in the Glen Canyon to Lees Ferry reach. This is a reach with clear water and a large supply of aquatic food. Earlier post-dam surveys described in Stevens et al. (1997) about Grand Canyon waterbirds show that most of the waterbirds were in this reach. This reach is heavily used by short-term recreationists, and the presence of waterbirds is beneficial to the National Recreation Area.

Most waterbird studies were limited to surveying for wintering, transient species. Only two were shown to be regular nesters, mallard and common merganser, and these used areas for nesting not commonly occupied by wintering birds. There is evidence in both the Glen Canyon reach surveys and Steven et al. (1997) that river conditions play an important role in the distribution of the species. The studies in the Glen Canyon reach were more descriptive about locations of the species, emphasizing use of sand and cobble bars, often with pools near by. Obviously, these locations are susceptible to stage changes resulting from fluctuating flows, thus interim flows were shown to be potentially beneficial. Populations of many of the waterbird species surveyed fluctuated from year to year. Exact reasons for these fluctuations are only speculated upon, and little evidence is available to explain what might be fluctuations within a normal range. These studies are good baseline data for long-term studies, but better descriptions of locations and use of resources within the riverine corridor would improve the significance of this research and monitoring to our understanding of the canyon's ecosystem.

Stevens et al. (1997) attempt to account for the differences in abundance of all waterbirds down stream from the dam, as well as, differences in abundance of several guilds of birds (dabblers, waders, shorebirds, etc.). Two factors are shown to play an important role. One is seasonality, with winter being the time of maximum waterbird abundance. The other is distance down stream, a surrogate for the amount of sediment in the river and the river's normalcy. Canyon width was also important with wider reaches of the canyon having more birds, probably a consequence of access to more aquatic and shoreline food.

Stevens et al. (1997) conclude that flow regulations have altered trophic relationships among the many bird species with some guilds having higher ratios with others in relationship to location along the river. This conclusion would be sound if there was evidence that the ratios now calculated have changed as a consequence of how the dam is regulated. Presence of the dam has increased the potential for more waterbirds, while changes in operations may change conditions to favor one guild over another. However, evidence for the "favoritism" of one species over another is not given, and the influence of the downstream changes, changes which are detrimental to waterbird abundance, is overwhelming.

Surveys of non-waterbird birds, that is, riparian bird species was carried out for several years. Survey sites are identified and described, with riparian vegetation sampled at each site. One study was limited to the Glen Canyon reach, attempts to explain differences in presence of some birds post-dam relative to their possible presence pre-dam. Little quantitative evidence is given to support conjecture that the increased shrubby riparian vegetation along the river has enhanced the abundance of bird species. Since pre-dam conditions in what is now the NHWZ were mostly barren, scoured sediments, it is likely that an expanding riparian vegetation community will support more birds. However, it would be nice to have more data on plant communities used by the birds.

Presence of more small birds along the river, especially those using insects emerging from the river, is given as the cause for an increase in peregrine falcons. Falcons are now found nesting in the canyon, whereas, pre-dam this was rare. Again, little quantitative evidence is given to support this hypothesis for falcon increase.

At the other end of the canyon, the Hualapai tribe studied most biological components of the riparian ecosystem. Extensive surveys related bird detections to riparian vegetation volume and structure. These relationships are useful in showing riparian utilization by various bird species, and especially the whole avian community. The weakness of these studies is that the riparian vegetation was sampled with bird habitat as the primary metric rather than vegetational community differences.

From 1993 to 1995 the whole canyon was surveyed for birds in a monitoring program that was to establish a baseline for long-term monitoring. Birds were detected using both walking and floating methods and the methods were compared. This is useful for future selection of accurate, non-intrusive methodologies. The regression between the two methods produced an $r2 = 0.96$. Vegetation was sampled by coarse composition and structure. For some unexplained reason, the sampling method was changed between 1993 and 1994. Plot sizes were changed and the structure of the woody community was redefined. It will be interesting to see how the group works out the differences. The final report of this project was not available at this writing. It should show, hopefully, relationships between bird use and vegetation structure, and bird diet. These data, when available, will increase the potential of linking the avian community to (1) riparian vegetation and the factors that control that, and (2) the aquatic invertebrate populations and those that emerge and use riparian vegetation, and the factors that control the aquatic food base.

From the information available in the many reports on avian communities, it is difficult to develop response models relating changes in riparian vegetation to changes in the avian populations within the canyon. The exception being in the lower canyon.

Surveys of endangered riparian species such as the southwestern willow flycatcher show a close relationship between nesting sites, tamarisk stands and adjacent marshlands. It is this type of relationship that should be developed for other bird species. In the breeding bird survey of the Glen Canyon reach of the Colorado River, researchers recommend that vegetation structure be analyzed prior to creating a flood event; however, the report does not provide a present avian/vegetation-structure relationship that could be used as a model to evaluate future changes in the riparian vegetation along the river.

Perhaps limited funding for avian studies because of emphasis on hydrology/sediment dynamics and "required research" on endangered fish species has created a paucity of avian data. Avian/vegetation relationships for most of the canyon bird species were considered to have been established and reported in the open literature. This also was the basis for limited avian research support. If this is the case, these relationships should be used in interpretation of avian survey data.

c. Wildlife Studies

These studies were very limited but were usually included in riparian surveys (e.g., Hualapai riparian studies). Evaluation of the few studies that surveyed the presence or abundance of riparian animals show that in most cases the number of individuals was too small to attempt any statistical tests of habitat relationships. Also, between years and sampling times, usage of zones within the riparian corridor varied, with the NHWZ being more commonly used one year and the shoreline/transition zone another. There does not appear to be sufficient data in the few studies of terrestrial animals to be able to develop a credible relationship with riparian dynamics for preliminary model building. Perhaps to do this, one should go back to some of the data from GCES I. There were more riparian animal studies undertaken in that phase of GCES than in Phase II. Unfortunately, river conditions were somewhat "abnormal" with high water occurring most of the study period, thus applicability to "normal" conditions, or those of lower flows being recommended for future operations of the dam, is difficult.

B. Corrections and Suggestions for Future Long-term Monitoring and Research.

A review of the studies undertaken in GCES Phase II leads to consideration of how to limit future research and monitoring in the canyon, rather than how to expand it. The research and monitoring programs of GCES Phase I and Phase II were both extremely intrusive on the Glen and Grand Canyon riverine ecosystems. Teams of researchers measured and altered many sediment deposits. Teams trampled plants while measuring vegetation cover and structure, and also associated fauna and flora. Teams netted, shocked and tagged fish to determine their behavioral and spawning patterns. The river was dragged for invertebrates, rafted constantly for sediment measurement, colored for water flow data, and monitored for discharge and sediment transport. Visitors in the canyon were constantly having to "share" space with scientists. It is now time to rethink this process and determine methodologies that (1) will be limited, (2) will measure a few indicators or surrogates for populations and processes, and (3) will find methods which will limit the number of scientists "leaving footprints in the sand."

Development of hydrological models should be in a completion stage. These models, which use data from dam discharges and a limited number of gages along the canyon, should be sufficient to give decision makers and adaptive management teams continuous information on hydrological changes downstream at selected reference points without having to place personnel in those locations. Periodically there should be, however, groundtruthing of the predictions and calculations made by the models.

Sediment transport models and eddy circulation models should also be near completion. Scientists will always "require" one more data point to refine their models. The complexity of the riverine ecosystem within the canyon may require more data points for a sound model than might be needed for a less variable river system. However, there will be opportunities to gather these extra data points and these should be made available during periods of integrated research and monitoring rather than for one particular project.

Do we know enough of about the aquatic ecosystem within the canyon to manage it with less future intrusion? Yes we do. There have been several integrated reports on native fish, some only on the humpback chub. These reports have pulled together research from GCES as well as from the open literature, both peer reviewed and gray. Although there will always be a need for more information to fill in gaps, and opportunities should be made to gain this information, there is little urgency for data which, if absent, will make management of native fish impossible. The same can be said for non-native fish. Perhaps, because these species are totally managed, we know more about them than the natives. The one aspect of fisheries biology that probably needs further study is development of models describing interaction between and among native and non-native fish species, especially under the changing hydrological conditions proposed by several resource management agencies.

Other important components of the aquatic ecosystem are the primary producers (algae) and primary consumers (invertebrates). These form the foundation of the aquatic trophic network. The algae are more productive in clear reaches of the river, supporting a greater number of consumers. Some of these species may be quite sensitive to altered river conditions, not necessarily those already existing under past and present dam operations, but conditions that may be expected under future dam operations. Some of the aquatic food base studies have shown the sensitivity of some of these species to change. These species should be considered as indicators of aquatic ecosystem changes and more thoroughly studied in order to develop response models useful to adaptive management decision makers. Hopefully, one or two species from different trophic levels (i.e., producer and consumer groups) can be identified and used in future monitoring programs. By establishing a representative sampling scheme for detecting changes in these selected species, human impacts can be reduced within the riverine ecosystem.

Riparian vegetation is perhaps one of the slower responding attributes to moderate human-caused hydrological changes within the canyon. Disturbance events such as floods, however, may alter the riparian ecosystem dramatically in a few days or even hours. Under normal dam operations within the limits of the ROD riparian vegetation does not need to be monitored on an annual basis. After a sound set of baseline data is established, ground monitoring of riparian vegetation need be done only every few years (3-5 years). Between ground monitoring efforts, however, regular aerial photographic coverage is needed and photo interpretation should be done on an annual basis. This interpretation should primarily cover changes in vegetational patches (polygons). Emphasis should be placed on vegetation zones nearest the water, with the OHWZ being analyzed with the frequency of the ground studies. Changes in shapes of marsh areas, and ends of RCC which may have marshes should be closely monitored using high resolution aerial photography. This is costly, but it reduces impacts of researchers and probably is less costly than using large teams of vegetation scientists. These data will also be useful in interpreting habitat for avian communities. This assumes that an accurate model of riparian vegetation structure and cover relative to avian utilization has been developed. If this is not the case, development of this model should be a priority in understanding dynamics of the riparian ecosystem.

One aspect of riparian vegetation that may need closer scrutiny than patch dynamics, is the dynamics of listed and non-native invasive species. In the first case, we need to know whether listed species are declining, something that could happen in a few years. In the second case, we need to know how rapidly non-native plants are expanding their range in the canyon. Monitoring selected sites that have been identified from earlier monitoring efforts as representing areas of concern, should be done annually using ground teams.

Avian surveys should continue but on an annual basis in winter and summer. The floating survey method should be used assuming the regression model comparing it with a walking method on the sites is sound. If it is not, then a no-boundary point-circle method should be used. This method, using permanent points, will assure comparison of data obtained in future monitoring efforts. These survey data should be related to vegetation patch dynamics monitored using aerial photography. Hopefully, in time, we will understand the relationships between riparian vegetation and avian communities to model the system and reduce any intrusive methodology. Requirements of the Endangered Species Act should be met through monitoring of listed bird species and their habitats. This is true for all other listed species, for example, the Kanab ambersnail.

One goal of monitoring is to find attributes of the effected ecosystem that can be used as indicators of response of that system to external, and possibly internal, perturbations. Often an indicator is a relatively minor component of the system, but one that is very sensitive to small changes in external driving variables. Components of the avian community often have been used for this, and avian species should be explored as indicators. Small mammals, reptiles or amphibians have also been indicators because they are sensitive to perturbation and must respond quickly to changes in habitat conditions and food availability. These groups have not been closely investigated as indicators, or even as associated species within the riparian ecosystem. Consideration should be given to a thorough study of the potential of using one or more of these groups as indicators of change. This will mean development of a research and monitoring program that may be temporarily invasive.

IV. Evaluation of Possible Approaches to Integration of Data within Individual Riverine Components.

The following comments were developed after reviewing research reports. Some of these ideas were used in Section V, "Integration Summary of Aquatic and Riparian Elements: Responses to a Changing Environment."

A. Aquatic Biology

The role of *Cladophora* and associated diatoms in the Colorado River ecosystem has been studied in several GCES projects. This is especially true in the tailwater upstream of Lees Ferry. A major factor influencing production of *Cladophora* is desiccation under certain flow regimes. Blinn's group at NAU used results of several studies to calculate production rates and how they would be affected by varying flow regimes with respect to stranding and desiccation. These studies did not take into account, however, light saturation of *Cladophora* at varying river levels. Yard's study with GCES suggested that light saturation could occur as deep as 3 meters under the river's surface. This would result in a large amount of *Cladophora* being unable to photosynthesize (i.e., no net-primary production) even while submerged. Thus, Blinn's calculations should be considered as showing the minimum effect that varying flows might have on primary production in this part of the river, and future research should integrate light saturation and *Cladophora* productivity to better assess effects of dam operations.

Another area of integration between biological studies and sediment/hydrology studies involves timing of flow-change events downstream of the dam. Changes in discharge at the dam will affect water levels, current velocities, and sediment loads of particular downstream sites at different times of day. These events could be timed so that conditions conducive to management goals exist at particular sites at appropriate times. For example, high water releases could be timed to reach the mouth of the LCR at mid-day so as to maximize temperature of water subsequently backed up at the mouth of this tributary during that time when Y-O-Y native species are entering the Colorado River. Alternatively, events could be timed such that drifting *Cladophora* and macroinvertebrates reach the mouth of the LCR during nighttime hours when native fish are more active and feeding. Timing these events would require detailed hydrological models (flow models) of current velocity and water temperature coupled with information about how various biotic components respond to conditions imposed by various flow alternatives.

B. Terrestrial Ecosystems

As suggested above in the discussion of evaluation of research projects, aerial interpretation of historical changes in riparian vegetation may be explained with process data presented in the short-term "field studies" based on response of selected riparian species to alternative hydrological scenarios. Short-term changes resulting from interim-flows and the experimental flood, as well as data from earlier test-flows indicate how riparian and marsh ecosystems and their component species both quickly and gradually change as site conditions change. Changes in site conditions relate closely to dam discharge and sediment aggregation/degradation processes. Riparian/marsh vegetation dynamics should be closely linked to physical processes, something that has been done on specific reach or site levels, but needs to be done on a more general conceptual level for the canyon riverine system as a whole. The several reports and open literature papers by Stevens and colleagues are a strong foundation for this conceptual modeling.

V. Integration Summary of Aquatic and Riparian Elements: Responses to a changing environment.

Integration of the complex system that composes the riverine ecosystem of the Colorado River within Glen and Grand Canyons is a daunting task. In the planning process for developing a research program for GCES Phase II in 1989-90, I developed a flow diagram that showed the linkages among many of the factors that either compose the ecosystem or are processes within the ecosystem. The purpose of developing the flow diagram was to justify studying many aspects of the riverine ecosystem that resource managers thought were irrelevant. The diagram, first published in the Sante Fe symposium (Patten 1991, NRC 1991), showed how the canyon and dam attributes that either were managed or were part of natural inputs were linked to the condition of the resources of interest to resource managers. For example, the input attributes included dam operation outputs such as discharge and daily fluctuation, as well as water quality, uses of the canyon (e.g., recreation), and natural phenomenon like local hydrological conditions. Outputs were camping beaches, native and non-native fish populations, birds, riparian vegetation, cultural resources and endangered species. Through a series of process linkages it was possible to explain how changing an input attribute would change the condition of an output attribute or resource.

Unfortunately, although GCES Phase II did address most of the linkages, and in time it should be possible to quantify the steps between inputs and outputs, not all linkages are presently well understood. To better understand the driving variables that control the attributes or resources of interest, a simpler conceptual model is needed. Within this model, sub-models or flow diagrams can be used to explain how particular attributes are controlled by other components of the canyon's riverine ecosystem.

To demonstrate and explain how driving variables function within the canyon, a total conceptual model has been dissected into sub-models that show how several primary drivers influence attributes of interest. Integrating a sub-system is the first step in integrating the whole system.

Because this report deals primarily with biological and chemical aspects of the riverine system, discussions of sediment and hydrology are used as foundations for explaining changes and importance of driving variables. Attributes such as sediment in suspension, moving along the river bed, or building into sand bars will help explain environmental conditions under which biological components and processes must function. Discharge rates and changes will also be shown to be of great influence on the biological system; however, detailed explanations of the relationships between hydrology and sediment transport or deposition are not in the purview of this report.

Another part of the foundation of many studies in the canyon is the use of the geomorphic reaches described by Schmidt and Graf (1990) (Table V-1). These reaches vary in length and width, but they divide the canyon into functional units, useful for explaining environmental variables, changes in driving factors, and resource or attribute responses.

Five attributes are addressed in sub-models as representative of the major resources within the canyon and ones that are of interest to managers. These include (1) aquatic food base, (2) fishes, both native and non-native, (3) riparian and marsh vegetation, (4) waterbird

Table V-1. The geomorphic reaches of Schmidt and Graf (1988) with width and parent material characteristics.

Reach Number	Reach Name	River Miles	Width Character	Major Bedrock Units at River Level
1	Permian Section	0 - 11.3	Wide	Kaibab Limestone Toroweap Formation Coconino Limestone Hermit Shale
2	Supai Gorge	11.3 - 22.6	Narrow	Supai Group
3	Redwall Gorge	22.6 - 35.9	Narrow	Redwall Limestone
4	Lower Marble Canyon	35.9 - 61.5	Wide	Muav Limestone Bright Angel Shale Tapeats Sandstone
5	Furnace Flats	61.5 - 77.4	Wide	Tapeats Sandstone Unkar Group
6	Upper Granite Gorge	77.4 - 117.8	Narrow	Zoroaster Plutonic Complex Trinity Gneiss Elve's Chasm Gneiss Vishnu Schist
7	Aisles	117.8 - 125.5	Narrow	Tapeats Sandstone Vishnu Schist
8	Middle Granite Gorge	125.5 - 139.9	Narrow	Tapeats Sandstone Unkar Group Vishnu Schist
9	Muav Gorge	140.0 - 159.9	Narrow	Muav Limestone
10	Lower Canyon	160.0 - 213.8	Wide	Basalt Muav Limestone Bright Angel Shale
11	Lower Granite Gorge	213.9 - 225	Narrow	Vishnu Schist

From Schmidt and Graf (1990).

populations, and (5) riparian-terrestrial bird populations. Terrestrial wildlife (e.g., mammals and reptiles) are not addressed under the sub-model approach but will be mentioned in approaches to total integration of the system.

The reader should recognize that a discussion of any of the above attributes would produce a very extensive report. The purpose of this report is to demonstrate the usefulness of the information available from GCES and other studies in an integration process for explanation of the condition of each attribute. The many studies used for this report include the detail needed to expand and direct future understanding of these attributes and their driving variables. Also, the many researchers that have produced these studies are better suited to discuss the importance of each aspect of their study and its role in influencing the particular resource, be it biotic or abiotic. My hope is, that in attempting to integrate pieces of the puzzle, I have not totally misinterpreted the results of others' studies, or misused data in the process of creating figures and tables that represent a stage in integration.

A. Aquatic Food Base

The term aquatic food base has become a catch-all term which includes the energy foundation for the larger aquatic animals, primarily fishes. It includes both primary and secondary producers. It is controlled by many external and internal factors and has been found to respond directly to conditions produced by dam operations, conditions that may be constantly changing but also have become more stable (consistent) since the completion of the Glen Canyon Dam EIS. Under pre-dam conditions with the water mostly turbid and temperatures seasonally fluctuating between 0 and 30 C, little autochthonous production took place and aquatic fauna included many invertebrates that required seasonal temperature fluctuations for completion of life cycles. These invertebrates were dependent on allochthonous inputs from tributaries and upstream floods. Today, the river is clearer, primary producers abound in the reaches near the dam and many introduced secondary producers, mostly invertebrates, supply energy to many introduced consumers (primarily fish). Figure V-1 is a conceptual sub-model of the interactive processes that today influence and control the aquatic food base, that is, its quantity and quality (e.g., number and composition of the biological components).

Light. Primary production in the aquatic food chain is the bottom of the aquatic trophic pyramid. Sunlight (i.e., photosynthetically active radiation -- PAR), the energy for primary production, does not fall on the Colorado River all day long at all points because of canyon walls. It often hits the water surface in patches, and in winter when the sun is low the length of time sunlight hits the surface is minimal. The depth light penetrates water is dependent on water quality. Rivers and lakes with large amounts of suspended sediments have very shallow photic zones, the zone where photosynthesis takes place. The shallower the photic zone, the lower the potential primary production.

In a study of potential photosynthesis and primary productivity, Yard et al. (1993) studied the influence of suspended sediment in the Colorado River from below Glen Canyon Dam to Lake Mead. They calculated the amount of attenuation, along with other factors, of sunlight (Par) hitting the water surface. Using two different discharge scenarios (142 and 425 cms) they showed that sediment inputs from several tributaries contributed sufficiently to the suspended sediment to significantly influence vertical attenuation (i.e., the attenuation coefficient) to greatly reduce PAR penetration of the river. There were differences; however, between the low and high discharges. Under low discharge (142 cms), concentration of suspended sediment increased to little over 0.02 g/l between the dam and Lake Mead (Fig. V-2), whereas, the increase in suspended sediment under a discharge regimen of 425 cms was from near zero to over 0.08 g/l (Fig. V-3). Using these data, they were able to show that the vertical light attenuation coefficient rose from about 0.2 to about 0.6 under low discharge, and from 0.2 to 1.2 with high discharge (Fig. V-4). Obviously, the less light penetrating to depth in the river, especially to the river bed substrate where many primary producers are attached, the less primary production.

Blinn et al. (1994) while measuring primary productivity and changes in aquatic organisms resulting from different discharges from the dam also measured light below the surface. In February light measurements (uE/m2/s) at Lees Ferry (RKM = 0) was 1,009, at

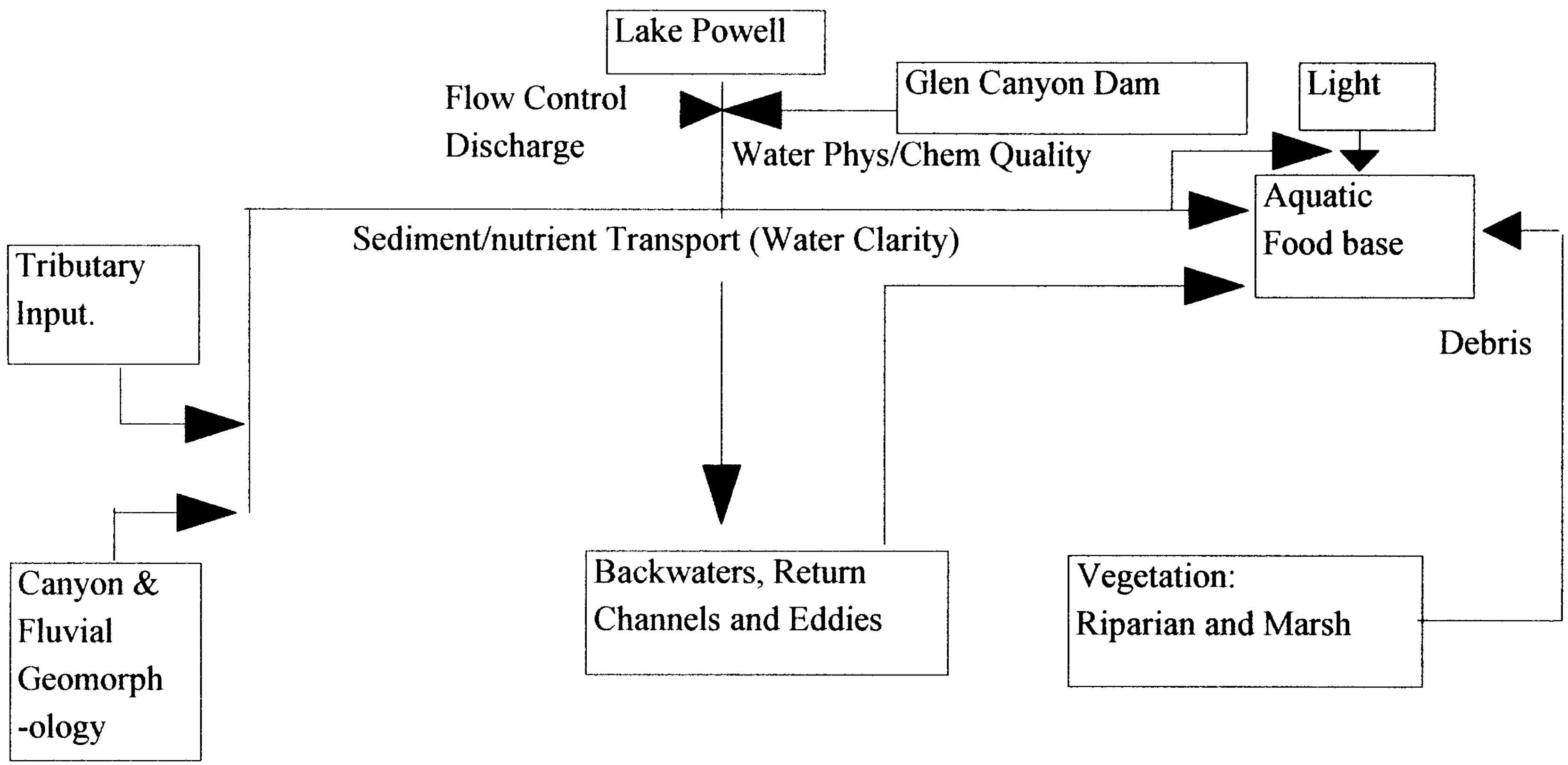


Figure V-1. Conceptual model of primary factors influencing the aquatic food base.

Figure V-2. – Concentration of suspended sediment (g/L) at discharge of 142 m^3/s. The mean concentration value is plotted against distance (km) from Glen Canyon Dam. The standart error in sediment concentration for each site is represented by the error bar. From Yard et al. (1993)

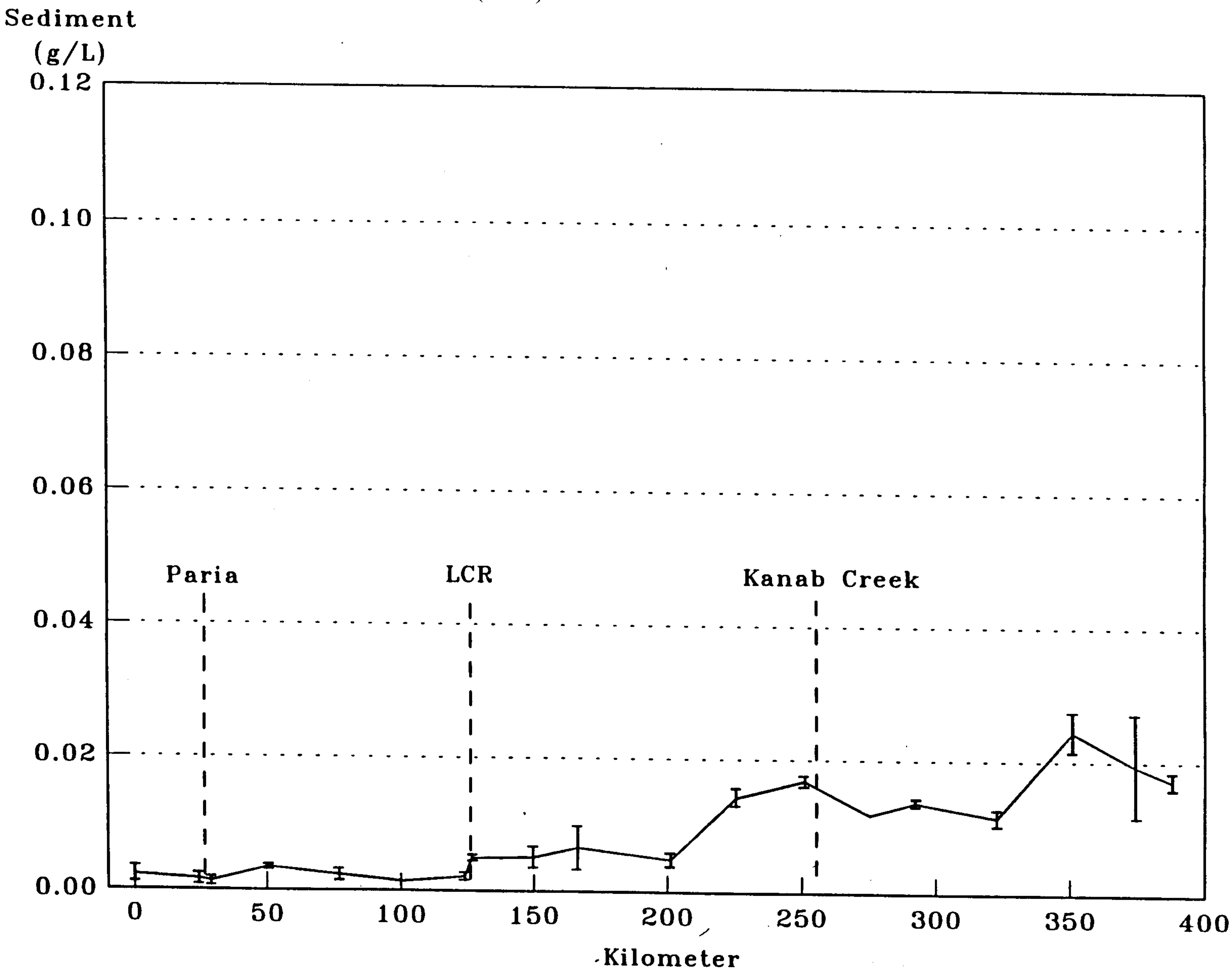


Figure V-3 – Concentration of suspended sediment (g/L) at discharge of 425 m^3/s. The mean concentration value is plotted against distance (km) from Glen Canyon Dam. The standard error in sediment concentration for each site is represented by the error bar. From Yard et al. (1993).

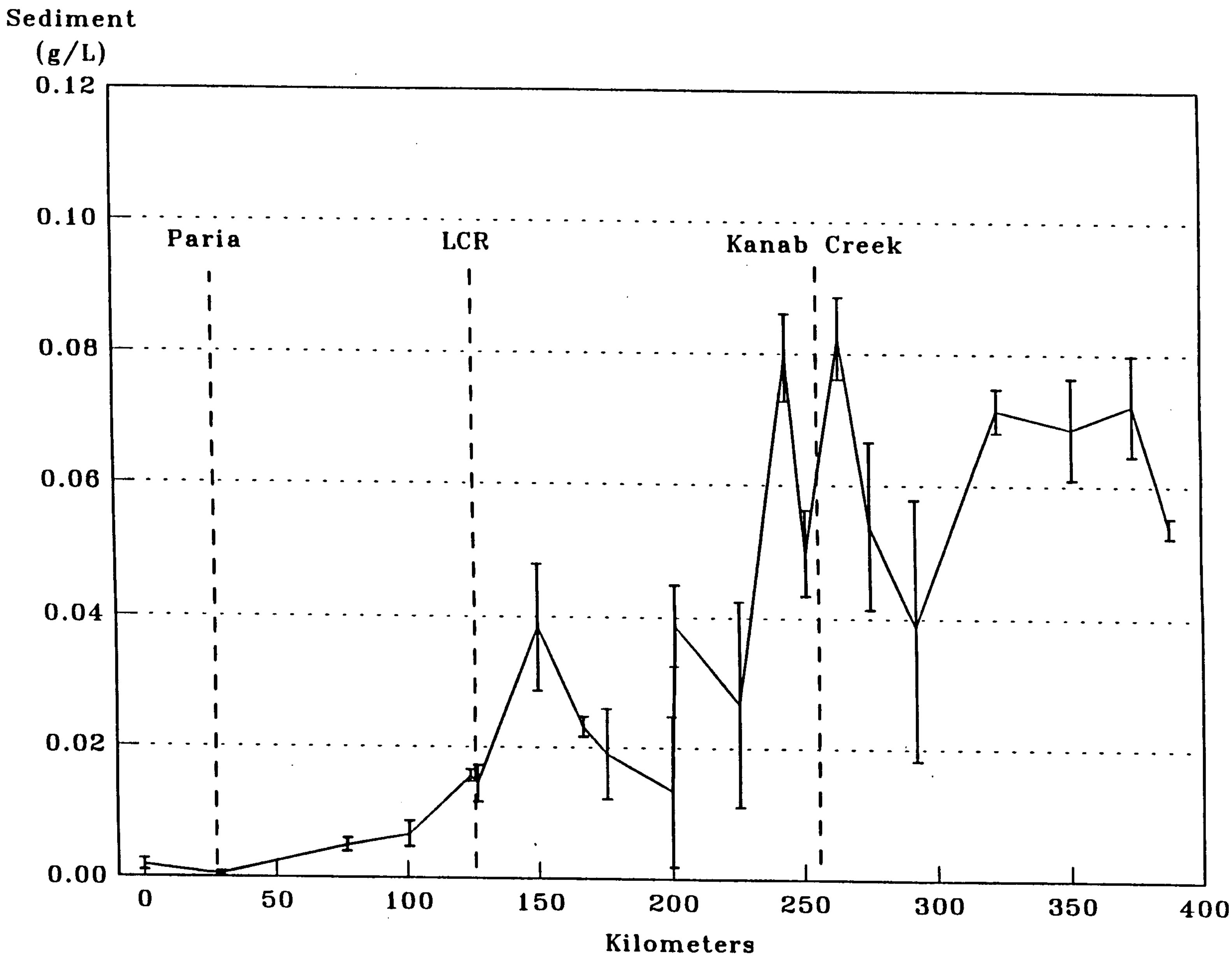
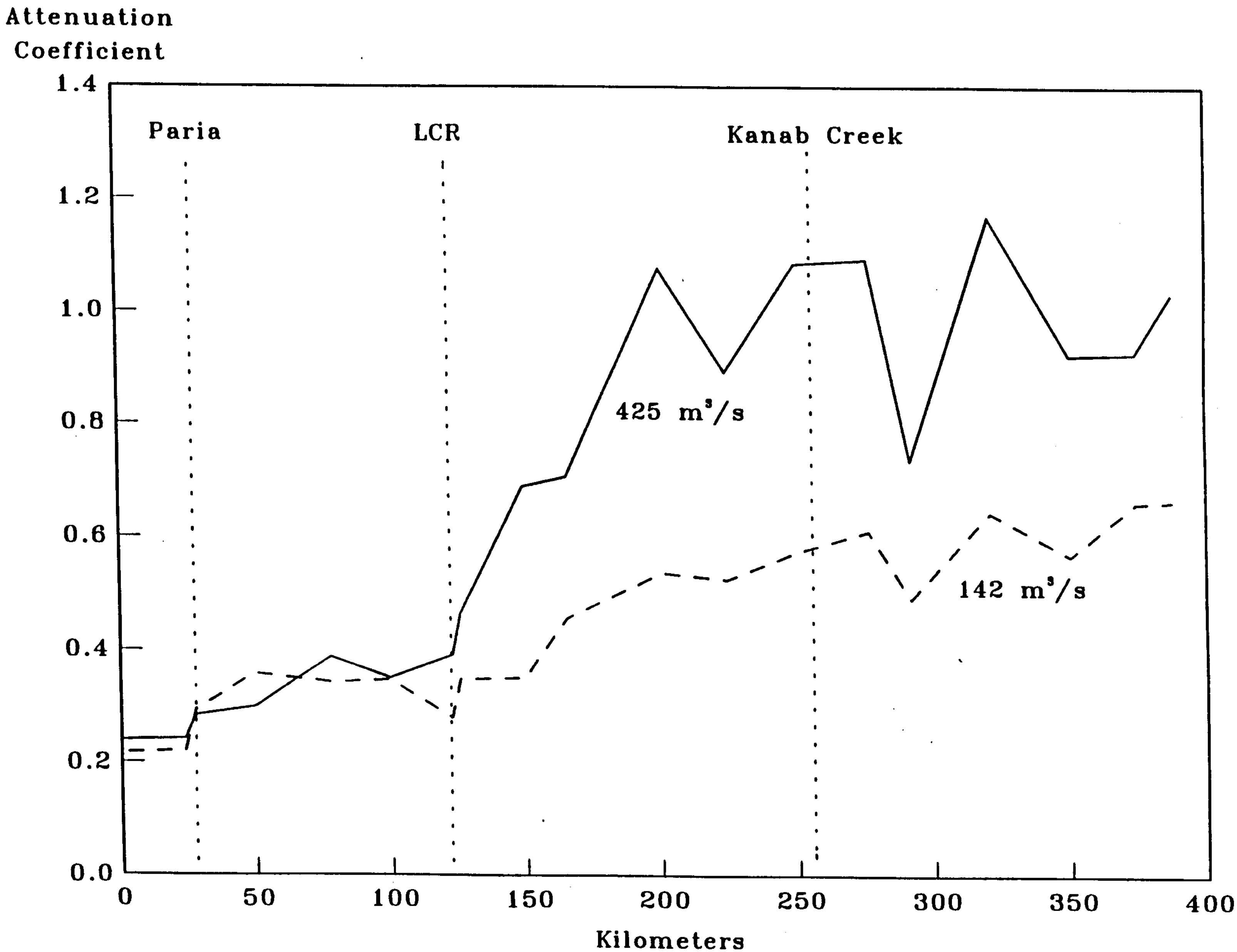


Figure V-4 – Vertical attenuation coefficients, (K_o), for scalar irradiance measured at two steady state discharges of 142 m^3/s and 425 m^3/s on the Colorado River from Glen Canyon Dam (0 km) to Diamond Creek (387 km). From Yard et al. (1993).



Cathedral Wash (RKM = 4.8) 800, and at Gorilla Island (RKM 352) 207. In June respective light measurements were 2,303, 1,927, and 2,576. The rise at the end was apparently due to clear water following a dry spring and early summer. These data support findings of Yard et al. (1993).

Light is an obvious driving variable for primary production and amount of aquatic food for higher trophic levels. To exemplify this, biomass measurements of a major primary producer, *Cladophora glomerata*, are shown in Figure V-5. These measurement were taken at stations down stream from Glen Canyon Dam and show that near the dam and above the Paria River tributary input, primary production is high. Below this it falls off considerably.

Light does not function independently of other driving variables. Both discharge and sediment load influence light penetration and thus primary production. Suspended sediment directly influences light penetration, while discharge rates influence the capacity of the river to carry sediment and erode sediment from river banks and the river bed. Several sediment rating curves have been established for gages on the Colorado River and this information can be used for predicting light attenuation potentials.

Discharge. River discharge or flow rate not only relates directly to amount of sediment in suspension, as explained above, it also influences productivity of the aquatic food base in other ways. If the river is maintained at high discharge, the river stage will remain high and there will be more wetted surface for attachment of primary producers (periphyton) and other benthic components of the aquatic food base. As the river drops, more shoreline and primary and secondary producer substrate is exposed for desiccation. If the river stage stays lower, then these exposed areas will no longer be productive. However, if the river rises only after a short period, many of the producers may survive. We thus see the effects of fluctuating flows.

The length and timing of the fluctuation has been shown to be critical to survivorship of primary producers. Twelve hours of exposure at night hardly affects the primary producer, in this case the algae *Cladophora*, while 12 hours in daylight has a significant effect (Fig. V-6). Longer periods of exposure will desiccate greater amounts of algae. As more sediment enters the river flow, algae must grow closer to the surface to be photosynthetically active. Not only do they become more susceptible to desiccation, but a greater percentage of the primary producer community is at risk because it occurs in the photic zone which is shallow downstream.

Sediment in Transport. Increasing discharge and associated velocities cause a geometric increase in the amount of sediment carried in suspension. The availability of sediment to go into suspension is a combination of sediment stored in the channel, in deposits on the channel margins and within eddy complexes, and inputs from tributaries. These latter inputs are the sediment supply for the other storage deposits. Consequently, sediment in suspension increases stairstep-like downstream from the dam. Little sediment is available between the dam and the Paria River. It increases at that point and then again at the LCR. By the time the river enters Lake Mead it may be carrying a great deal of sediment, but still much less than under pre-dam conditions. This stair-step arrangement of sediment in suspension is shown above to influence availability of PAR, primary productivity and productivity associated aquatic fauna and flora.

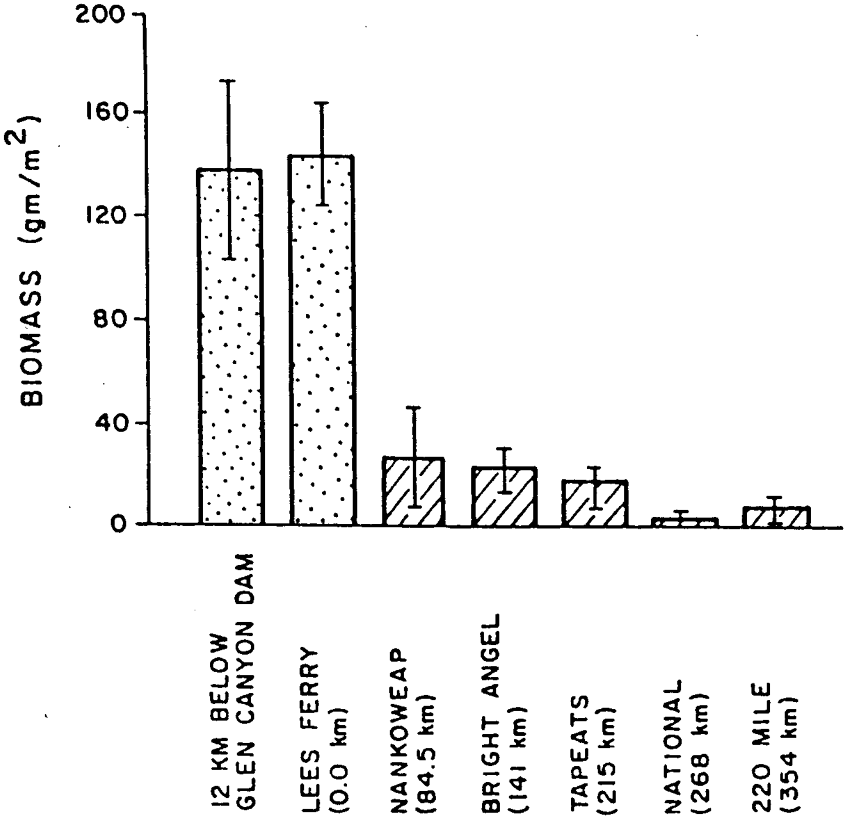


Figure V-5. Biomass of *Cladophora glomerata* at selected sites in the Colorado River through Glen and Grand Canyons, Arizona, during July 1985 (n = at least 15 samples). Bars with diagonal hatch lines represent sites with Secchi disc readings <2.0 m; vertical bar lines represent ±SE.

From Usher and Blinn (1990).

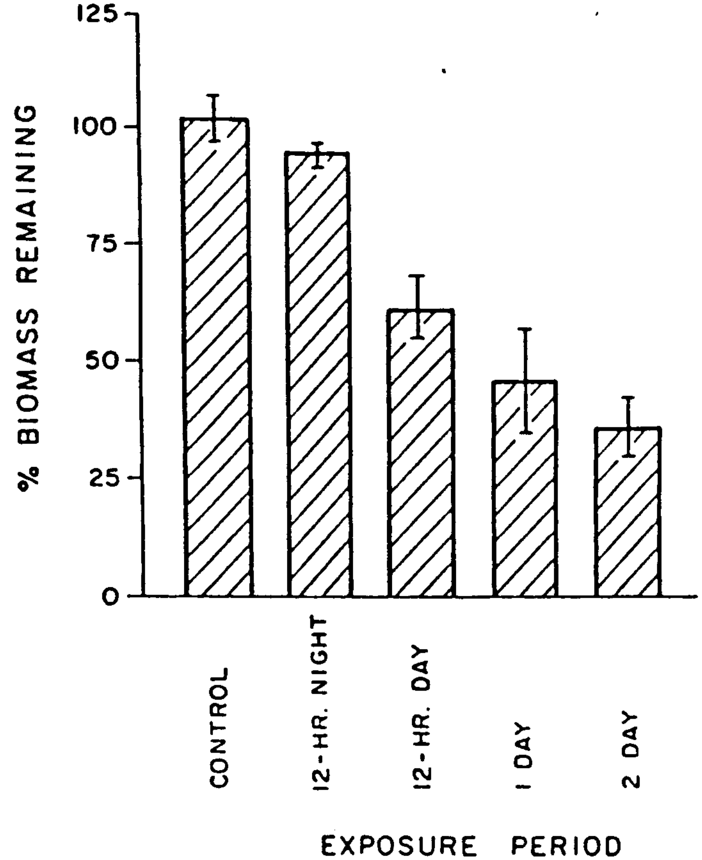


Figure V-6. Percent mean biomass of *Cladophora glomerata* remaining after various one-time exposure periods (n = 9). Vertical bar lines represent ±SE.

Geomorphology. Canyon geomorphology which includes canyon width and fluvial conditions also comes into play in productivity of the aquatic food base. In areas where the canyon is wider, the shorelines tend to have shallow slopes. These conditions present a potential for more substrate in shallow waters for primary and secondary producers. However, more surface area is exposed on shallow slopes during fluctuations in river level than on steep sloped river margins. This then becomes a trade-off between having greater amounts of substrate available for productivity, especially when the river has little or no daily fluctuation, and exposing greater amounts of primary producer to desiccation.

Fluvial geomorphology also influences primary production in the Colorado River. In the upper reaches which tend to be scoured of sediment, cobble bars were the primary substrate for the primary producer *Cladophora*. Downstream Blinn et al. (1994) found more primary producers in riffles than in pools. They suggested that pools collect more fine particles (sands etc.) that do not make good substrate for algae, while ripples tend to have more bare rocks, good substrate. Another reason may be that pools are deeper, with substrates often below the photic zone, especially down stream where there is more sediment in suspension. Pools below major tributaries tend to have greater amounts of sand, at least for periods following input events from the tributary. Graf et al. (1995) have shown that following a sediment input event from the Paria River, cross-sections across the channel below the confluence of the Paria and Colorado River build a deposit of sand. This deposit then gradually declines in volume over time but is recharged following another event. They also showed that below the Little Colorado River (LCR) confluence with the Colorado River, cross-sections near the confluence were first "filled", but that over time the deposition peak moved downstream (Fig. V-7). These changes in bedload and sand deposits, many in pools, creates an unstable condition for establishment of primary producers in the aquatic system.

Backwaters or return current channels (RCC) in eddy circulation areas are also geomorphically oriented areas that influence the aquatic food base. These areas often have warmer temperature, sometimes higher nutrients, and are shallower and more "stable" than the open channel. These conditions may enhance primary productivity and development of secondary producers. They are commonly used by young fishes, a location with potentially a better environment and more food.

Water Quality: The water quality in the Colorado River is a product of ecological processes taking place in Lake Powell, tributary inputs, and biogeochemical processes within the river. Water passing through the generator penstocks is taken from the hypolimnion layer in the forebay behind the dam. Several phenomena influence the quality of this water, one being the internal seche within the lake which causes the quality of water to change slightly over time. Other factors that control the limnetic processes in the lake also play a role. These have been studied, but are not discussed in this document. Also, the planktonic community found in the river below the dam has it origins in the forebay of the lake.

From the dam to Lake Mead, water quality in the river varies and might be expected to be a significant driving variable. However, the water moves through the canyon and keeps the variation small and within tolerance limits of most aquatic organisms that presently exist. This does not imply that these conditions were appropriate for the organisms that existed pre-dam.

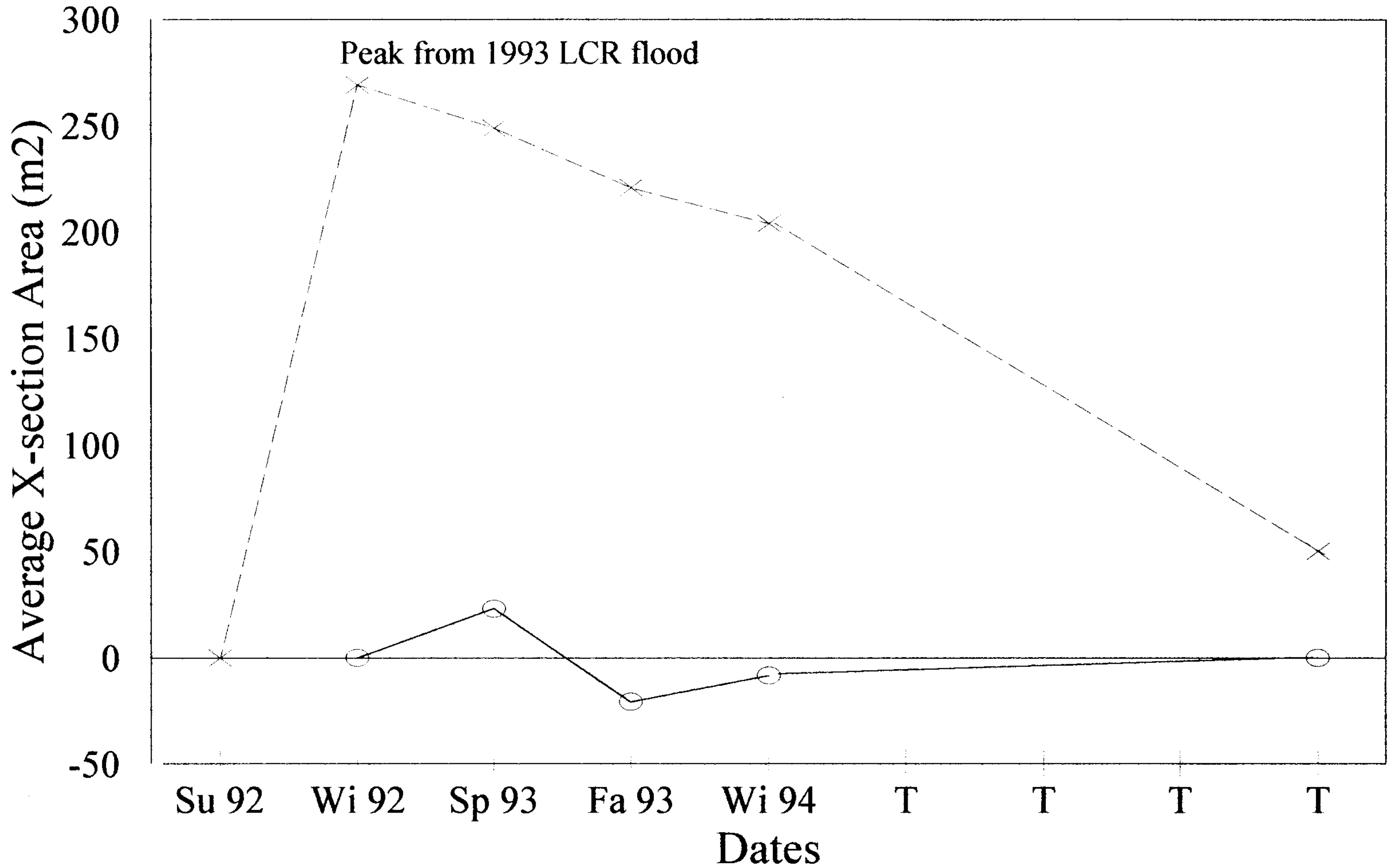


Figure V-7. Accumulated change in bathymetric cross-section area over time. X (dashed line) is cross-sections just below LCR and O (solid line) is cross-sections farther downstream. T is projected future time with cross-sections approaching equilibrium. Data modified from Graf et al. (1995).

Data from both Arizona Game and Fish (Maddux et al. 1987) and Blinn et al. (1993) show relatively similar results. Temperature (C) ranges 10-12 (AGF) and 7-17 (Blinn), DO (mg/L) ranges 9-11 (AGF) and 7-12 (Blinn), pH ranges 8+/- (AGF) and 7-8+/- (Blinn), and conductivity (uS/cm) ranges 710-750 (AGF) and 840 to 1100 (Blinn). It is unlikely that within these ranges the present biotic community is placed at risk. With Interim Flows, temperatures downstream have warmed slightly (> 18 C). This shift has reduced DO slightly, nearly eliminated *Gammarus*, but also increased overall productivity of the benthic community.

Terrestrial Vegetation: Riparian vegetation and associated fauna (especially invertebrates) are potential sources of allochthonous organic matter debris and energy to the aquatic ecosystem. Small discharge fluctuations may scour and transport some riparian vegetation into the river, but the overall influence is probably small. During flood events, however, water scours through standing and down vegetation removing litter and transporting it downstream. This litter often collects in eddies and is gradually ground up and becomes available to aquatic invertebrates as an energy source. Insects in the shoreline vegetational community and on other shoreline substrates also fall into the stream becoming food for fishes.

Energy Flow. Primary production is the biological energy foundation for the whole aquatic ecosystem. As mentioned above, the amount of energy fixed by primary producers is a function of the amount of sunlight penetrating the water. Using numbers from Blinn et al. (1994) and other sources, I have estimated the energy flow through the lower levels of the aquatic ecosystem (Table V-2). Energy conversion is very low from light to primary producers but improves between primary and secondary producers. Attached algae are not as readily used by secondary producers as epiphytic diatoms. Tests run by Blinn et al. (1994) showed that *Gammarus* preferentially selected living on *Cladophora* with epiphytic diatoms than without. Table V-2 also shows the difference in estimated energy flow at a location with clear water (Lees Ferry) and a location just downstream, Cathedral Wash, that is influenced by sediment inputs from the Paria. Light energy available at Cathedral Wash was about 80% of that at Lees Ferry, whereas primary productivity was about 25%. The amount of energy in *Gammarus* developed in the two locations apparently would support about 113 kg of trout per year at the clear-water location and 37 kg at the Cathedral Wash location. To support this demonstration of the influence of sediment on primary productivity, data from Blinn et al. (1994) showed that there was a decrease of only 15% in productivity at Cathedral Wash compared to Lees Ferry. A greater decrease was expected but the year was dry and there was little sediment input from the Paria River.

Biotic Changes. The biological composition of the aquatic food base can be used as an indicator of the environmental changes that occur downstream from Glen Canyon Dam to Diamond Creek or Lake Mead. In the clearer water reaches of the canyon, that is, near or above the Paria confluence, *Cladophora glomerata* was the most common filamentous algae. However, farther down stream, *Oscillatoria* spp. became more dominant as *Cladophora* almost dropped out. However, *Cladophora* remained an important part of the organic drift downstream. The Glen Canyon reach, between Glen Canyon Dam and Lees Ferry, produces > 50% of the aquatic

Table V-2. Estimates of energy flow (kj/ha/yr) within the aquatic ecosystem from light input through secondary production in the upper reach of the Colorado River in Grand Canyon. Parenthetical numbers are percent of higher trophic (energy) level. (Energy conversion between some levels is too small to indicate). Percentage conversion for Gammarus is based on epiphyte harvesting. Certain assumptions were used: average 10 hours of sunlight input per day over the year, light input averaged for the year was 60%of solar constant at Lees Ferry and 50% at RMK 3-5, and no substrate exposed. Primary and secondary production data are modified from Blinn et al. 1994. Primary production is from *Cladophora glomerata* and *Oscillatoria* spp. and epiphytic diatoms. Secondary production total includes the sum of *Gammarus lacustris* and Chironomid larvae production.

	Sunlight	Primary Production		Secondary Production		
Location	Light Energy	*Cladophora glomerata* and *Oscillatoria* spp.	Epiphytes (e.g.,diatoms)	*Gammarus lacustris*	Chironomid Larvae	Secondary Production Total
Lees Ferry RKM 0	106.7×10^9	232.4×10^6 (0.002)	3.1×10^6	1.47×10^6 (47.4)	4.9×10^5	1.96×10^6 (0.008)
Cathedral Wash area RKM 3-5	88.9×10^9	88.3×10^6 (0.001)	9.3×10^5	4.45×10^5 (47.8)	1.49×10^5	5.94×10^5 (0.007)

food base but comprises < 5% of the river between the dam and Lake Mead. Periphyton sampled by AGF (1993) showed greater standing crop of periphyton nearer the dam (RKM -22.8 and -22.5 (RM -13.5 and -14)) than RKM -6.5 (RM -4) above Lees Ferry.

Gammarus lacustris, an introduced aquatic invertebrate, is a major food source for trout and other fishes. Its preferred substrate is *Cladophora*. This relationship is strong from the dam to Lees Ferry and weak from Lees Ferry to Diamond Creek (Shannon et al. 1994 and 1996). AGF (1993) data show that *Gammarus* had higher densities nearer to Lees Ferry than locations near the dam. The different measurements used by AGF and Shannon et al. make data comparison difficult. There was no affinity between *Gammarus* and *Oscillatoria* in tests on substrate preference for *Gammarus*. The conclusion is that the epiphytic diatom community on *Cladophora* is the reason for the preference. If *Cladophora* declines, then *Gammarus* is expected to decline in its contribution to the aquatic food base, except perhaps in the drift.

The epiphytic diatom community that adheres to *Cladophora* and other substrates in the river is an important food source for higher trophic levels. The changing river also changes this community. *Achnanthes affinis* and *Diatoma vulgare* are the most common diatoms in the Lees Ferry reach 22% and 32% respectively in a study by Hardwick et al. (1992) (Fig. V-8). *A. affinis* declines in dominance downstream, while *D. vulgare* remains essentially unchanged. The four species that composed 79% of the community at Lees Ferry only composes 33% of it at RM 220 (RKM 360) and this is mostly *D. vulgare*.

Communities of other organisms show a variable change in composition downstream. Using representative groups of invertebrates to demonstrate this (Figs. V-9 and V-10), it is impossible to generalize about locations of invertebrate concentrations, either by river kilometer or by year. Riffle data shown in Figures V-9 and V-10 tell quite a different story between years, the exception being that *Gammarus* tends to occur more in the upper reaches of the canyon where temperatures remain cool and extensive stands of *Cladophora* are available. Miscellaneous macroinvertebrates were more common at mid-reaches in 1995 and upper reaches in 1996. Similar results were shown in Shannon et al. (1996) for pools. Some generalizations can be made. Macroinvertebrates tend to decline downstream, chironomids tend to be found in pools in upper reaches but mostly in riffles in lower reaches. Oligochaeta remain variable in pools and riffles throughout the canyon. Detritus is commonly found in both pools and riffles although it was highly variable.

Drift. Drift becomes an important source of food within the downstream aquatic ecosystem. Epiphytic diatoms appear to be the food of choice for invertebrates in the Lees Ferry reach and anywhere where *Cladophora* maintains a high contribution to periphyton. As transported sediment increases and photosynthetic potential decreases, the river becomes heterotrophic and organic drift, which includes particles of algae with epiphytic diatoms attached, free diatoms, and invertebrates and detritus, becomes the primary energy source for other invertebrates and fishes. The amount of drift has been shown to be closely related to the river discharge. Increasing discharge dislodges algae and other organic particles and sends them downstream. Large detritus is more readily pulverized during high discharge, adding it to the energy source available to lower trophic levels in the aquatic system. From LCR downstream, energy in the organic components of drift is probably the primary, if not sole source, of energy

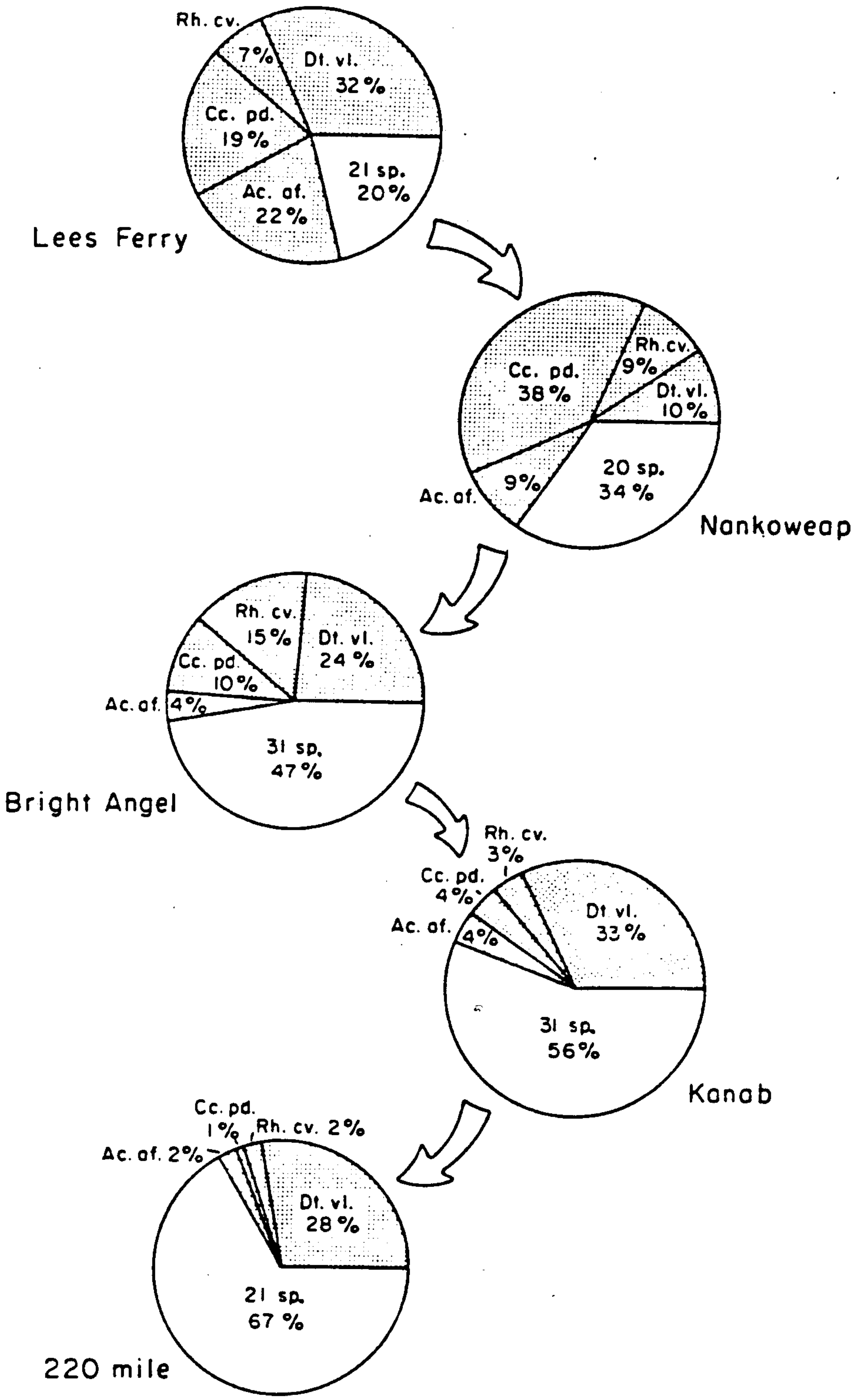
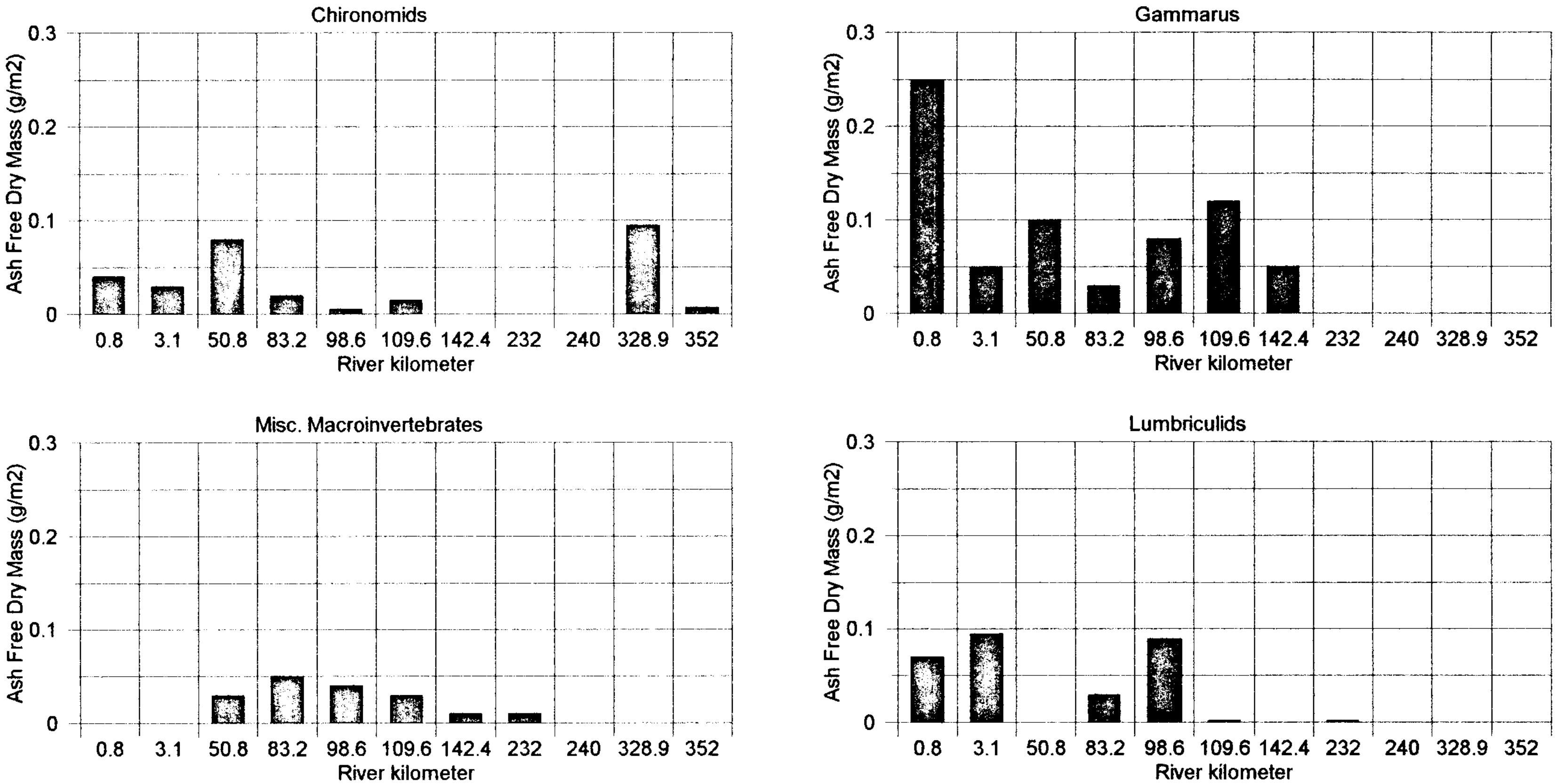


Figure V-8. -Relative frequency of the four co-dominant diatom epiphytes on *Cladophora glomerata* at Lees Ferry with distance downstream in the Colorado River through Glen and Grand Canyons. The number of remaining species and their relative contribution is listed for each site. Ac. af. = *Achnanthes affinis,* Co. pd. = *Cocconeis pediculus,* Dt. vl. = *Diatoma vulgare,* Rh. cv. = *Rhoicosphenia curvata.* From Hardwick et al. (1992).



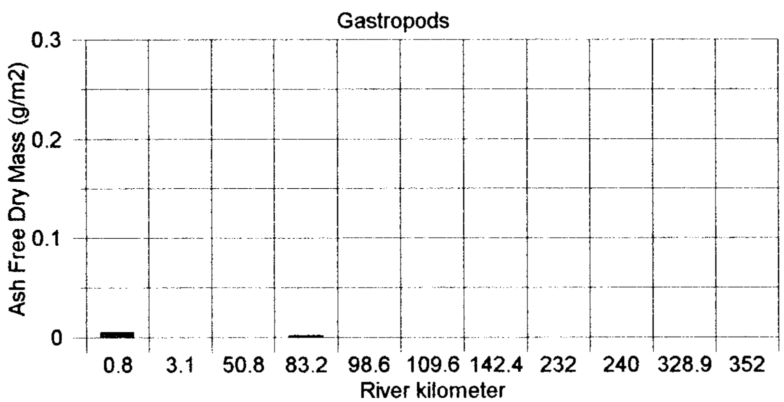
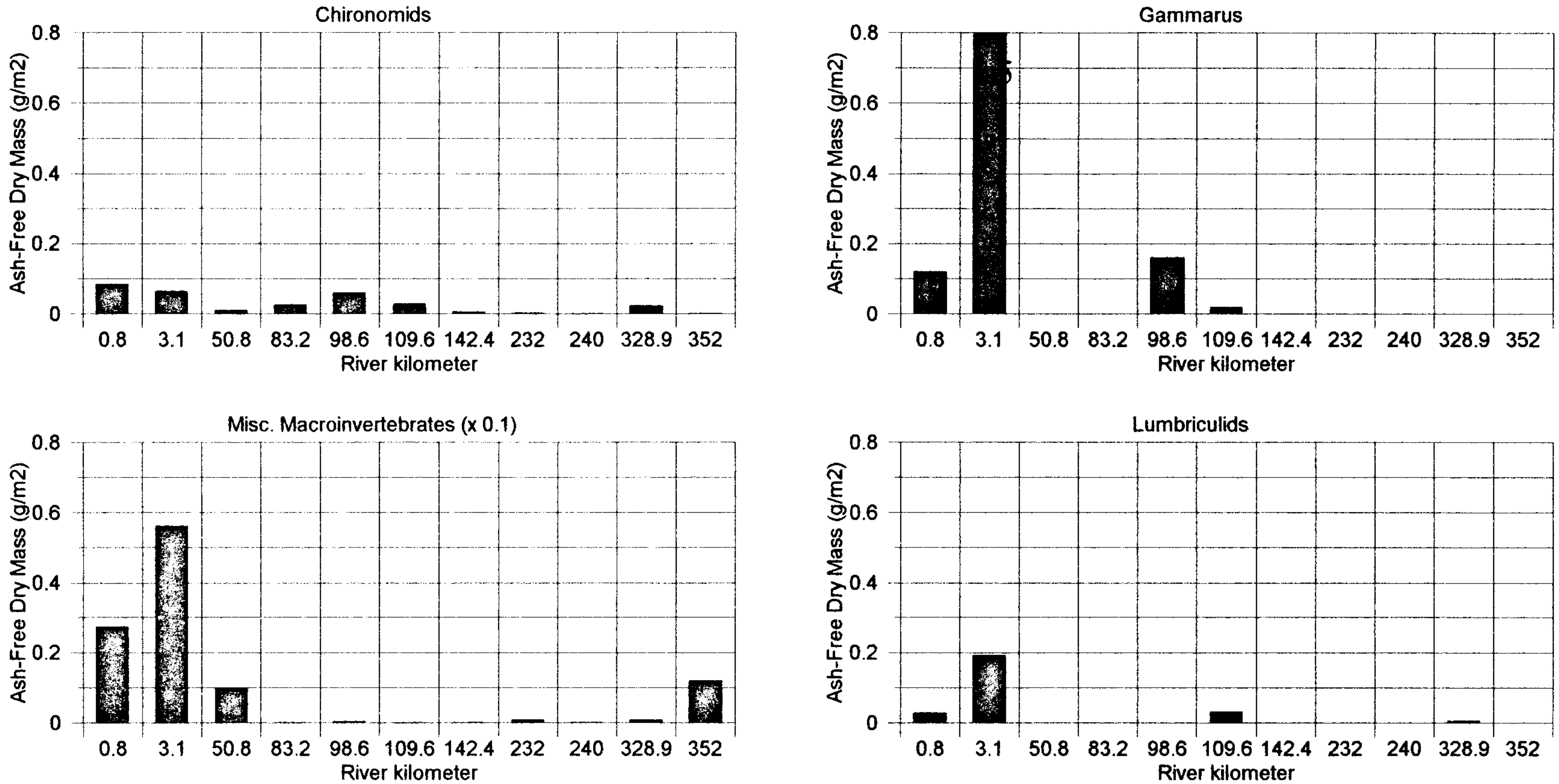


Figure V-9. Average ash-free dry mass for several invertebrate groups collected in March 1995 from riffles in the Colorado River from Lees Ferry (RKM 0) to RKM 352. Data from Shannon et al 1996.



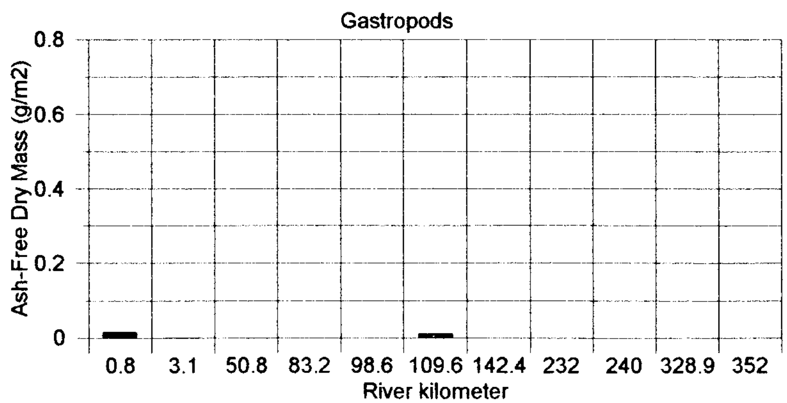


Figure V-10. Average ash-free dry mass for several invertebrate groups collected in March 1996 from riffles in the Colorado River from Lees Ferry (RKM 0) to RKM 352. Data from Shannon et al. 1996.

within the aquatic system.

Summary. The aquatic food base, like most attributes in the Grand Canyon riverine ecosystem, is a product of many controlling factors. Some of these factors are directly influenced by humans, for example, discharge from the dam, while others are totally external (e.g., sunlight). The interactions among these factors produces a constantly changing ecosystem, one to which the biotic components of the system must adapt. The system also has gradients from the dam to Lake Mead, and from shallow depths to deep depths. The river does not function as most rivers do, following the river continuum concept, in that the major primary producer reaches of the river are the "upper" end. These are the reaches with clear water and high solar energy inputs. Comparing the river to "normal" rivers is inappropriate. The dam is placed in the middle of the river, thus the "upper" end is not really the start of the river which under natural conditions would be more heterotrophic. It is a highly managed system, controlled by many external human factors and inputs. Thus the aquatic food base, the foundation for all aquatic life within the river, is also not "natural" and is the product of resource managers requirements for water, power, recreation and trout fisheries.

B. Fishes (Native and Non-native)

The fish community in Glen and Grand Canyon has changed drastically as a result of the presence of Glen Canyon Dam and through other activities of humans attempting to improve sport fisheries in the area or through accidental introduction of non-native species. Several early records indicate the presence of eight native species in two families, Cyprinidae (chubs and minnows) and Catostomidae (suckers), in the late 1800s (Miller 1959). In recent post-dam collections only two of the Cyprinidae remain (humpback chub and speckled dace), and the three Catostomidae remain (razorback sucker, bluehead sucker, and flannelmouth sucker). All of these species no longer use the whole mainstem of the Colorado River as habitat. Some use tributaries (e.g., chub in the LCR for spawning), while bluehead and flannelmouth are still ubiquitous within the canyon. Additions to the canyon fish community are nine non-native fishes. These include rainbow, cutthroat, brown, and brook trout (rainbow and brown being most common), common carp, striped bass, fathead minnow, channel catfish, and plains killfish.

This mixture of native and non-native fishes is not evenly distributed throughout the canyon reaches. In all reaches non-native comprise the higher percentage of the community, in some reaches ten to fifty times the native population (Table V-3). The use of tributaries by native fishes as refugia from the changed canyon river environment definitely influences these relationships, but the overall changes that have occurred within the riverine ecosystem also have played an important role in supporting and/or enhancing populations of non-native species.

Two documents have been prepared recently that thoroughly cover the response of native and non-native fishes to the conditions now present in the canyon (1) "Grand Canyon Data Integration Project" prepared by SWCA (1997), and (2) "Life History and Ecology of the Humpback Chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona" prepared by R. Valdez and R. Ryel of Biowest (1995). Discussions in these documents on river and terrestrial conditions that influence fish life-cycles should be referred to when determining potential long-term research and monitoring programs of fisheries in the canyon. I have used these documents to assist in this very brief write-up and refer the reader to them for more detailed information. Additionally, most discussion of response of native fishes will be based on information about humpback chub because this is the most studied species of the natives and has been used throughout GCES as the "fish species of concern" relative to studies on endangered fish species.

There are many environmental variables that influence the fish populations in the canyon. These factors often interact and form a suitable or unsuitable environment for some life-stage of a particular fish species. A conceptual sub-model (Fig. V-11) shows the interactions among these factors and their relationships to the native and non-native fishes. In the model native and non-natives are grouped because the environments created by human and natural controls of canyon and riverine attributes is available to all species, or is avoided by many species.

Discharge. Discharge in the Colorado River below Glen Canyon Dam to Lake Mead is a function of volume of water released from Glen Canyon Dam in response to power and water demands. Because dam operations respond to hydropower needs, discharge may fluctuate daily; however, needs of several downstream ecosystem components, such as fishes, have changed the

Table V-3. Relative distribution of native and non-native fish species in the Colorado River by reach during 1984-1986

Reach	RM	RK	Native percent	Non-Native percent
10	-15.5 to 0	-25 to 0	17	83
20	0 to 62	0 to 99.8	8	92
30	62 to 88	99.8 to 141.6	8	92
40	88 to 166	141.6 to 267	2	98
50	166 to 225	267 to 410.3	19	81

From Valdez and Ryel (1995).

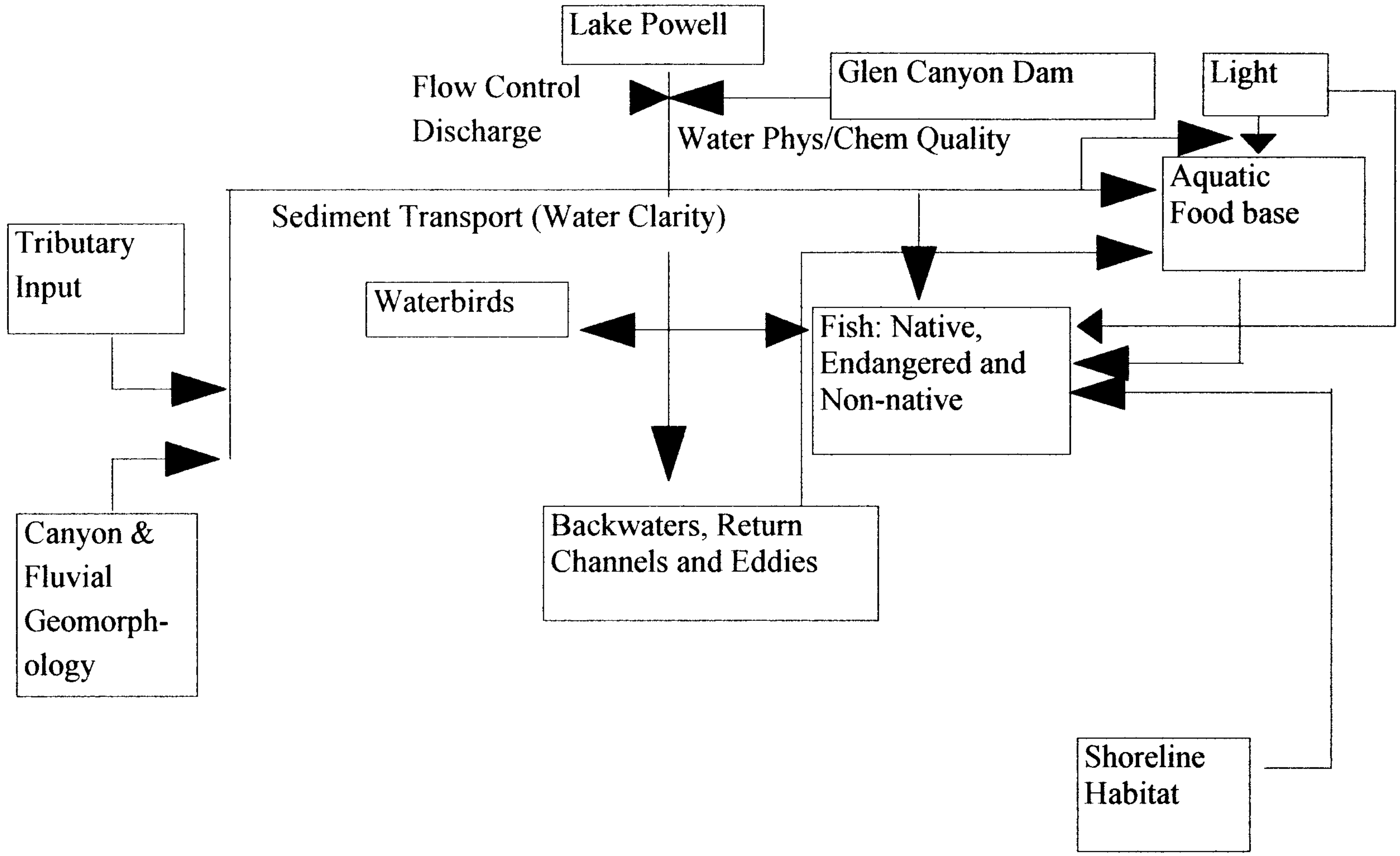


Figure V-11. Conceptual model of primary factors influencing native and non-native fish growth, reproduction and distribution.

patterns and amounts of the discharge. Consequently, at present under the Glen Canyon Dam EIS-ROD modified low fluctuating flow (MLFF) and future low steady flows dictated by a Biological Opinion agreement between Bureau of Reclamation and USFWS, river flow will be more benign than prior to Interim Flows (essentially the same as MLFF). All of these dam discharges are small compared to spring floods of 1.380 cms (60,000 cfs) to over 3,396 cms (120,000 cfs) that occurred regularly prior to the dam, and large compared to frequent very low < 28 cms (< 1,000 cfs) winter flows. Discharge in the canyon is the sum of dam discharge and tributary inputs, both playing an important part in the amounts of materials (sediment and debris) carried by the river.

River discharge (i.e., volume per time) is directly related to velocity of the river and cross-sectional area. Velocity determines how much sediment the river puts into suspension and transports. For any location one normally develops a sediment transport/discharge rating curve, but the amounts of sediment still are closely related to velocity. Thus turbidity of the river is a direct function of discharge and is discussed below (see Sediment Transport). River discharge or velocity also influences the amount of food materials put into drift, that is, the abrasive action of high discharge will break loose periphyton and associated epiphytic diatoms and invertebrates and in upper reaches and transport them downstream.

Ability of fish to swim or maintain energy conserving activity in the river is directly related to velocity. Fish distribution is related to habitats suitable for energy conservation and habitats where food is available. Different life stages of a fish species may require different habitats. Young of the year (Y-O-Y) cannot withstand high velocities, but as the fish matures it can use locations with increasing river velocity. This does not mean that it will stay in a high velocity location, but rather, that it tolerates these areas, may use them for feeding, and will not be readily transported downstream. Local velocities within the river vary among several geomorphic or substrate locations, causing fish to be selective in using different shoreline conditions (see Geomorphology below). Fish sampling data show distribution of life-stages relative to hydraulic units (Valdez and Ryel 1995). Eddies were most commonly used (88%) by adult humpback chub, especially areas with low velocity vortices (< 0.3 m/s). Subadults had no affinity for eddies. Runs were used intermediately, while only 4% of collections were in RCCs. Very low numbers were in riffles and pools.

A discharge characteristic that is directly related to dam operations and is not commonly found in unregulated rivers is daily fluctuations in discharge. During "normal operations" of the dam, prior to Interim Flows, the daily fluctuation was as great as 566 cms (20,000 cfs), but with Interim Flows and MLFF daily fluctuations are no greater than 142 to 226 cms (5,000 to 8,000 cfs). The upramping process rapidly increased the velocity of the river which in turn suspended much of the sediment that had settled when the fluctuating cycle was at low discharge. Thus a fluctuating flow, especially one with great daily fluctuations, carried more sediment, was more turbid with less visibility, than a steady flow, except of course, if the steady flow was a "flood" flow with very high discharge.

Fluctuating flows create temporary pooling at tributary mouths, potentially can cause stranding of fishes (especially salmonids), and limit spawning of salmonids in the mainstem through exposure and desiccation of redds. For example, temporary pools at the LCR mouth often were occupied by Y-O-Y humpback chub which were swept into the mainstem as the discharge and associated river stage dropped. Steadier flows reduced this potential. Fluctuating flows also rapidly change conditions along the shoreline requiring fish that have selected an appropriate habitat relative to substrate and velocity to move, putting them at risk from predation or being carried downstream if young.

Discharge directly influences the aquatic food base (see Aquatic Food Base section). High discharge and widely fluctuating discharge both tend to increase drift; although comparisons of steady flows with Interim Flows (low fluctuations) showed steady flow creating more drift. Some of these steady flows had relatively high discharge. Fluctuating flows, if lows were during the night, had less desiccating effect on benthic flora and fauna, then low steady flows which exposed shoreline during the day.

Steady flows tend to create warmer water conditions in the mainstem, and especially in backwaters (RCC) and along the shoreline (Hoffnagle 1996). Valdez and Ryel (1995) indicated increases of 1 C at RKM 56 (RM 35), and a 4 C difference between mainstem and shoreline waters near Diamond Creek. Both warmed areas may be occupied by juvenile native fishes. Warmer temperatures reduce the amount of energy needed for swimming. Increased productivity in the aquatic food base may also be a consequence of warmed river water, or warmed areas along the shoreline.

Sediment in Transport. The pre-dam Colorado River carried ten times more sediment past the Grand Canyon gage than the post-dam river (Andrews 1991). Except for drought cycles and periods with limited precipitation events on the watershed, the Colorado River was very turbid and thus visibility within the river was very low. High turbidity reduces primary productivity and has a great effect on the aquatic food base on which the present complement of fishes depend. Obviously, native fishes using the river under pre-dam conditions found sufficient food within the river (e.g., benthic invertebrates, drift, inputs from tributaries, etc.) to survive and maintain a viable population. Natives now may have a greater food potential because of the high level of productivity of the food base in the Glen Canyon reach and the concomitant resulting organic drift, but the clarity of river water has required natives, exemplified by humpback chub, to modify their feeding pattern. In a turbid river, humpback chub could feed at any level with little concern for predators using sight-feeding. Clear water puts the chub at high risk, thus they tend to feed near the surface at night, utilizing food sources at depth during the day. In eddies humpback chub were in water < 2 m at night and 2-5 m in day (Valdez and Ryel 1995). Juvenile fishes using backwaters also are at risk from predation because of the clarity of these slow moving water habitats. Other species such as the flannelmouth sucker are bottom feeders and not as impacted by reduced sediment in suspension and increased visibility.

Sediment in transport may gradually fill in RCC or backwaters reducing this type of habitat. High discharges scour these areas and re-create more available RCCs, but these apparently will be short-lived if MLFF is to be the normal discharge from the dam into the future. Periodic controlled high discharges (floods) from the dam may be required to maintain these habitats.

Water Quality. The two primary water quality characteristics that influence fishes in the canyon appear to be amount of suspended sediment and water temperature. Both of these are directly related to discharge and have been discussed above. Water temperature changes since dam closure have been as dramatic as the decrease in amount sediment in transport, changing from a range of 0 - 26 C pre-dam to 7 - 13 C post-dam (Fig. V-12), . Temperature change has been implicated as perhaps the primary reason for change in composition of fishes in the river, extirpation of native fishes, and enhancement of habitat for non-native fishes (Minckley 1991). There is no way, unfortunately, to predict what the fish community would be in the canyon had only temperature and sediment changed and no non-native fish introduced. Adults of most native fishes can withstand post-dam colder waters, but some still are found in areas where the river or its tributaries are warmer. Common humpback chub locations are near LCR mouth and near warm spring inflows. Some of the suckers primarily utilize tributaries.

Temperatures for spawning play a more important role in recruitment and survival of a species. Humpback chub spawn in waters 16 - 22 C and almost exclusively use the LCR for spawning. Flannelmouth suckers spawn in waters 17 - 23 C and use tributaries (e.g., Kanab, Shinumo Ck, and Paria). Bluehead suckers spawn in waters 17 -23 C and use swift rocky substrates in tributaries, while razorback suckers spawn in lentic waters of 10 - 20 C.

Geomorphology. Several of the discussions above indicate use by humpback chub and other native fishes of various fluvial geomorphic or hydraulic settings. Eddies are most used by adult chubs, for example, and near shoreline habitat is preferred by fish seeking zones with low velocities. Different shoreline types have different river velocity ranges (Fig. V-13). Talus shorelines create very low velocities while cobble bars create high velocities. Expectedly, young fish will select areas with low velocities based on their swimming abilities. Most cobble bar shorelines have velocities above those useable by young humpback chub, while other types are more suitable. Interestingly, there is a reverse side to this story. The amount of habitat available on a cobble bar tends to remain unchanged as discharge drops, while a talus shoreline may lose most of its suitable habitat (Converse 1996). Thus, under fluctuating flows, cobble bar shorelines may be preferable to talus, because as habitat is lost along the talus shoreline young fish are forced to enter the main flow which may have higher velocities.

Location of fish populations is not random nor evenly distributed. They tend to select canyon reaches that offer particular characteristics. For example, adult humpback chub were found often in reaches which had many large, closely spaced recirculating eddies and expansion zones, often wide geomorphic reaches. Reaches that precluded these conditions usually had few chubs. Within these reaches adult chubs were often associated with debris fans that created the eddy complex.

Aquatic Food Base. Many of the native fishes are general feeders, while some, especially the suckers, utilize food attached to or near the bottom of the channel. Trout, especially those in the Glen Canyon reach, utilize diatoms and invertebrates attached to *Cladophora* as well as other drifting organic material. Utilization of the aquatic food base by humpback chub has been well studied. Juveniles use benthic insect larvae and organic debris. Invertebrates make up the major portion of the adult diet including 14 aquatic taxonomic groups and 9 terrestrial groups found in gut samples. This compares to 16 aquatic and 14 terrestrial groups found in drift samples (Fig. V-14). Although *Cladophora* makes up a large part of the

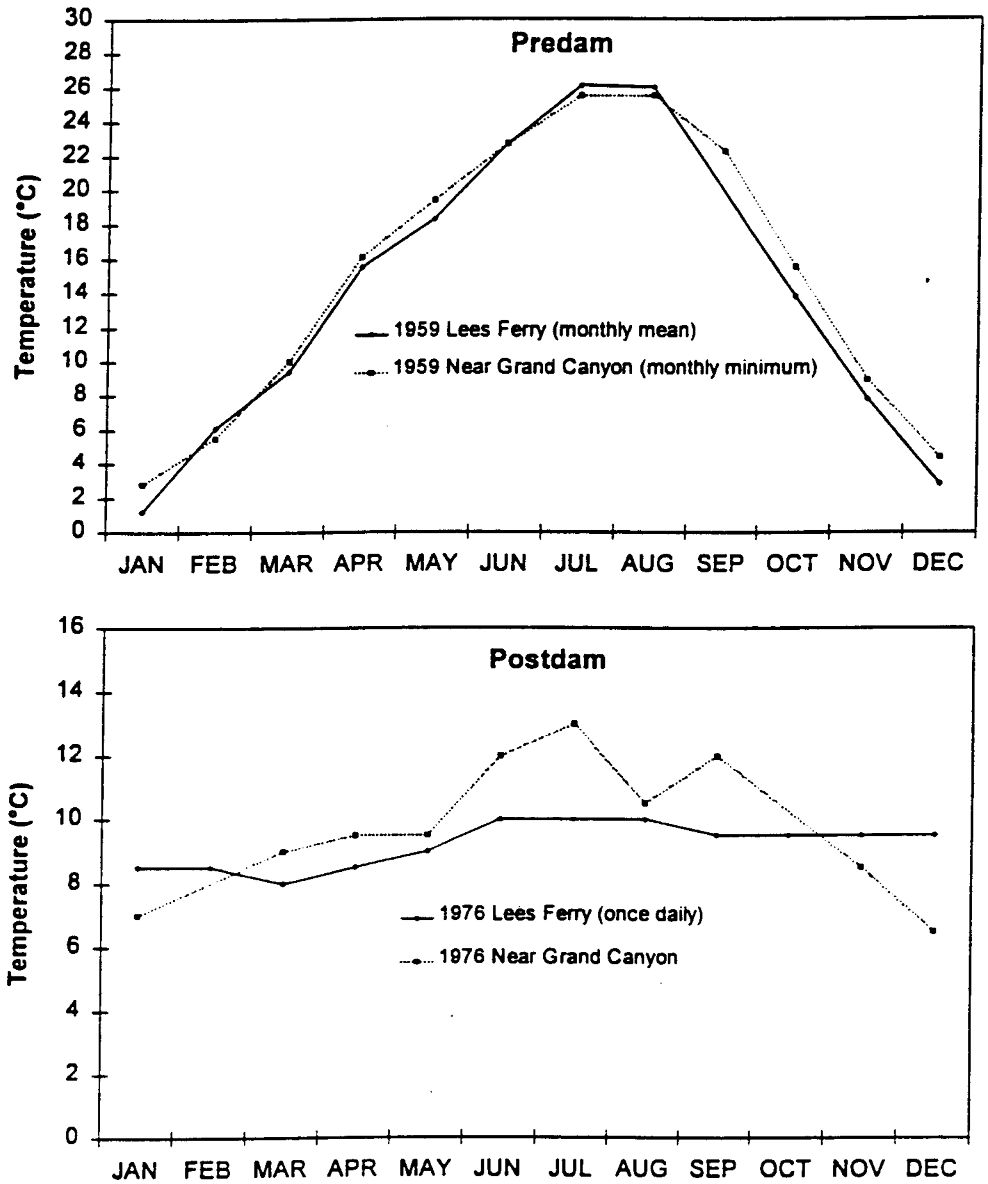


Figure V-12. Predam and postdam annual temperature trends at Lees Ferry and Near Grand Canyon (Phantom Ranch). (From Valdez and Ryel 1995).

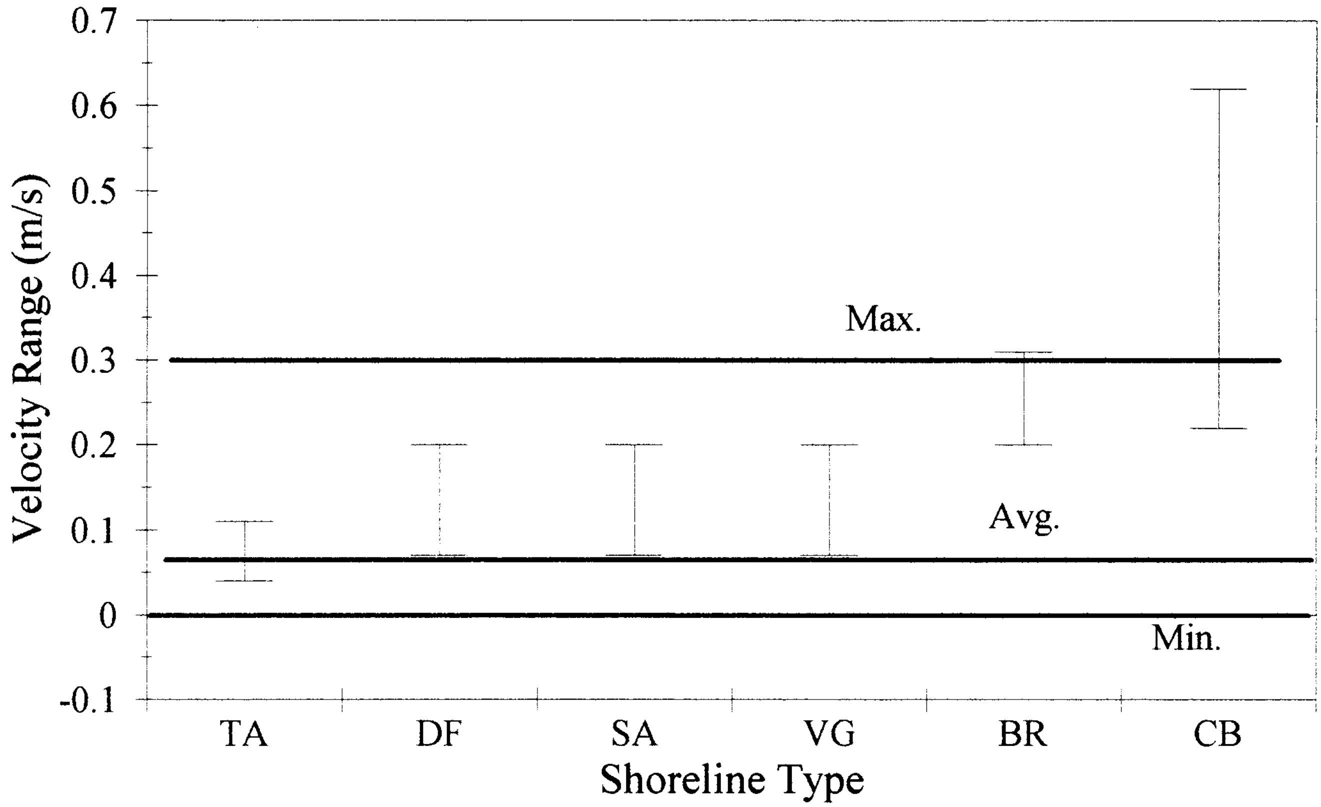
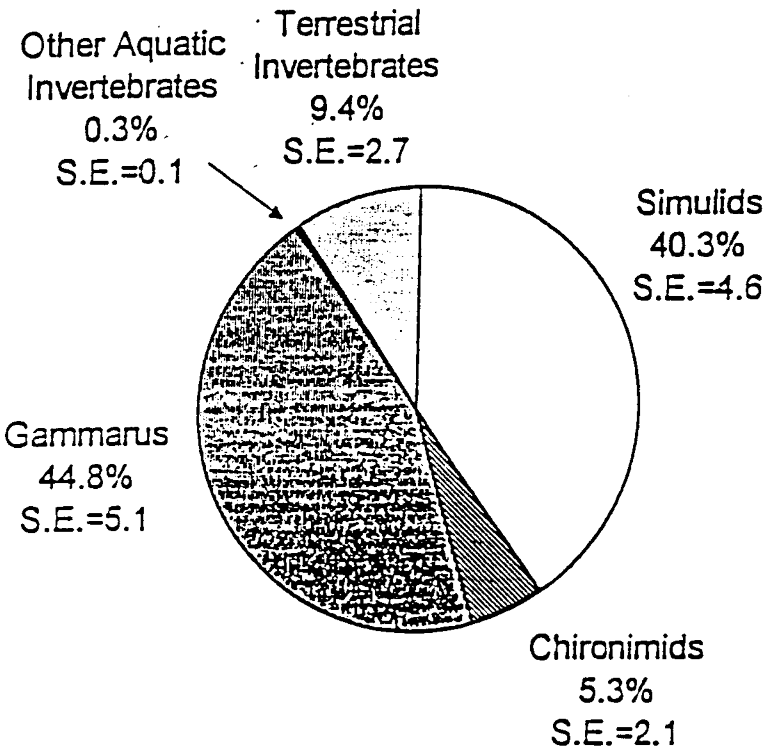


Figure V-13. Differences in velocity ranges among shoreline types with comparison of maximum, average and minimum flow velocities selected by Y-O-Y humpback chub. TA (talus), DF (debris fan), SA (sandbar), VG (vegetation), BR (bedrock), CB (cobble bar). Data from Valdez and Ryel (1995) and Converse (1996).



Middle Granite Gorge Aggregation

N=24

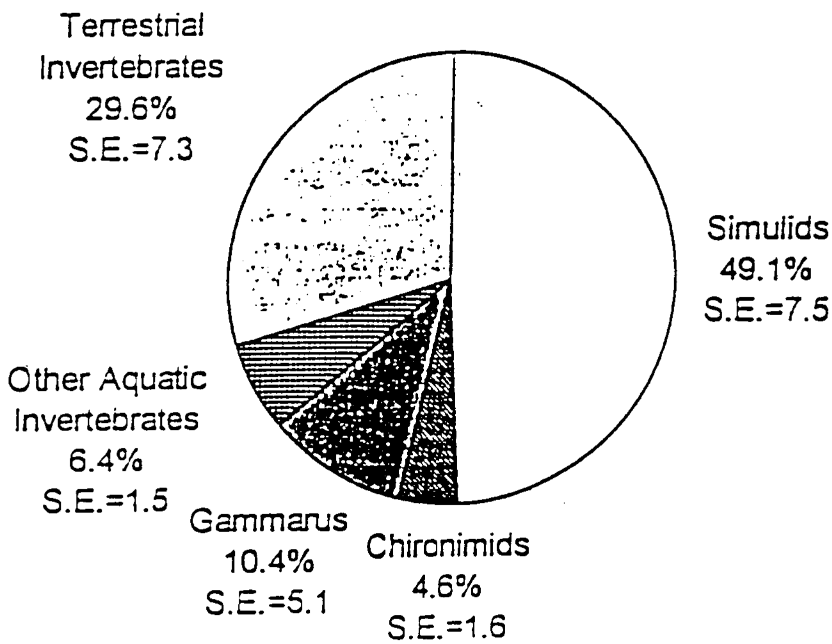


Figure V-14. Volumetric composition of invertebrates found in stomach contents of humpback chub from the Little Colorado River aggregation and the Middle Granite Gorge aggregation during 1992-93. (From Valdez and Ryel 1995).

drift available for native fish, it has been found to be much lower in gut samples (ca. 23%), and some studies show it much lower yet. In humpback chub simulids were most common (ca. 78%), chironomids next (ca. 58%) and *Gammarus* third (ca. 51%) (Valdez and Ryel 1995). Seeds and terrestrial allochthonous plant material made up a small portion of the food base as did other small fishes. This, along with habitat shading along the banks by tamarisk, demonstrates the importance of the NHWZ vegetation as a potential input to the food base for aquatic organisms.

There is little evidence to suggest that the aquatic food base available to native and non-native fishes is a limiting factor in their population numbers and survival. It was suggested that the research flows in 1990-91 caused desiccation of *Cladophora* in the Glen Canyon reach and thus major losses in the food base for trout in that area. However, there was little evidence to support this conclusion, other than circumstantial evidence that the population continued a downward change in body weights, a phenomenon that was ongoing prior to research flows.

Competition and Predation Among and Within Fish Community. Existence of many non-native fishes creates the potential for competition for food and space between native and non-native fishes. There is little evidence that space or food is limiting for either group. What may be occurring is predation by some non-native fishes on young of native fish species. Channel catfish have been found with young humpback chub in their guts. Striped bass is piscivorus and is found as far upstream from Lake Mead as Havasu Creek or perhaps farther. Some of the salmonids also utilize larval and juvenile fish as food. The potential is great for predation of natives by non-natives to be a major factor in controlling the composition of the fish community in the canyon. Out of 37 native southwestern fish species, only four are know piscivores, while 26 out of 57 introduced fishes are piscivorus. Conditions presently existing in the Colorado River in Grand Canyon do not favor native fishes. They no longer can readily spawn in the mainstem and, except for a few species, their populations tend to be clustered. Non-native fishes can take advantage of the new conditions. Temperatures favor spawning of salmonids, and clustering of prey fish improves predation.

Summary. The fish community in the Grand Canyon no longer is dominated by native fishes. Temperature and sediment changes resulting from waters discharged from Glen Canyon Dam have created relatively inhospitable conditions for native fishes and acceptable if not favorable conditions for non-natives. Native fishes must be selective in habitats chosen for feeding, spawning and existing, and many of these habitats no longer exist or change by the hour or day. They are dependent on the aquatic food base which is highly influenced by controlled conditions from the dam. The NHWZ vegetation may have replaced high turbidity in some cases as a "shade" source, and it contributes to the food base. Because the canyon has a wide variety of geomorphic habitats, both terrestrially and along the shoreline, native and non-native fishes can not utilize the full reach of the canyon for habitat. For some species, the only means of survival is use of tributaries, not only for spawning but for existence.

C. Waterbirds

Waterbirds, which for this discussion include water fowl and piscivorus birds such as eagles, were considered rare in the pre-dam period. Stevens et al. (1997) cite several references where people observed waterfowl along the river, but none of them reported a constant presence of birds at any time of year. It is obvious from recent observations that waterfowl and even opportunistic eagles feeding on spawning trout have greatly increased since construction of Glen Canyon Dam. The shoreline environment has changed, discharge is different and availability of non-native fish, especially trout, has greatly increased. Thus, factors that interact to produce appropriate conditions for increases in waterbirds are primary a product of conditions created by existence of the dam and its particular form of operation. Figure V-15 represents a conceptual sub-model of the interrelationships among these factors.

Seasonality. Very few species of waterbird observed in the canyon breed or nest there. Most species use the canyon as a place to occupy during winter season and then move on to their nesting grounds. Mallards and common mergansers were two species that used the canyon to raise young. Both Stevens et al. 1997 who have surveyed the canyon for waterbirds from 1972 to 1996, and Grahame and Pinnock (1994) who monitored the Glen Canyon reach (the first 25 km below the dam) note that total waterbird counts are highest in winter and lowest in summer. Stevens et al. (1997) also note that separate guilds of birds seasonally use the canyon differently. Divers and dabblers follow the general pattern of high in winter and low in summer. Waders tend to be low only in June, while shorebirds are lowest in November and December. Raptors were lowest in summer and November. These patterns probably relate to availability of food. For example, eagles use spawning trout at Nankoweap Creek around February. Of all of the variables accounting for differences in waterbird occurrence, seasonality was found to have the highest correlation through use of canonical ordination and relating environmental variables to axis values.

Discharge. Although seasonality is found to be the variable with the highest correlation with occurrence of waterbirds, discharge is a driving variable that probably would be highest if pre-dam and post-dam conditions were compared. Pre-dam discharge ranged from very high spring flows to low winter flows. They were sufficiently high to carry large amounts sediment and did not allow development of protective vegetative cover along the shoreline. Consequently, as mentioned above, few waterbirds were observed in the canyon. It is likely that should the dam be removed or operated to fully mimic natural flows, the waterbird population would greatly decrease.

Today, discharge still plays an important role in controlling the distribution of waterbirds along the Colorado River. High discharges resulting from wet years and high inflows to Lake Powell result in greater amounts of sediment in transport. It will also cause more scouring of shorelines and wet-marsh vegetation, habitats used by waterbirds. High daily fluctuations also influence shoreline habitat and usually suspend more sediment than near-steady flows. Higher discharges create pools at tributary mouths allowing trout to move up tributaries for spawning. Nankoweap Creek is the prime example of this phenomenon. Spawning trout thus were available

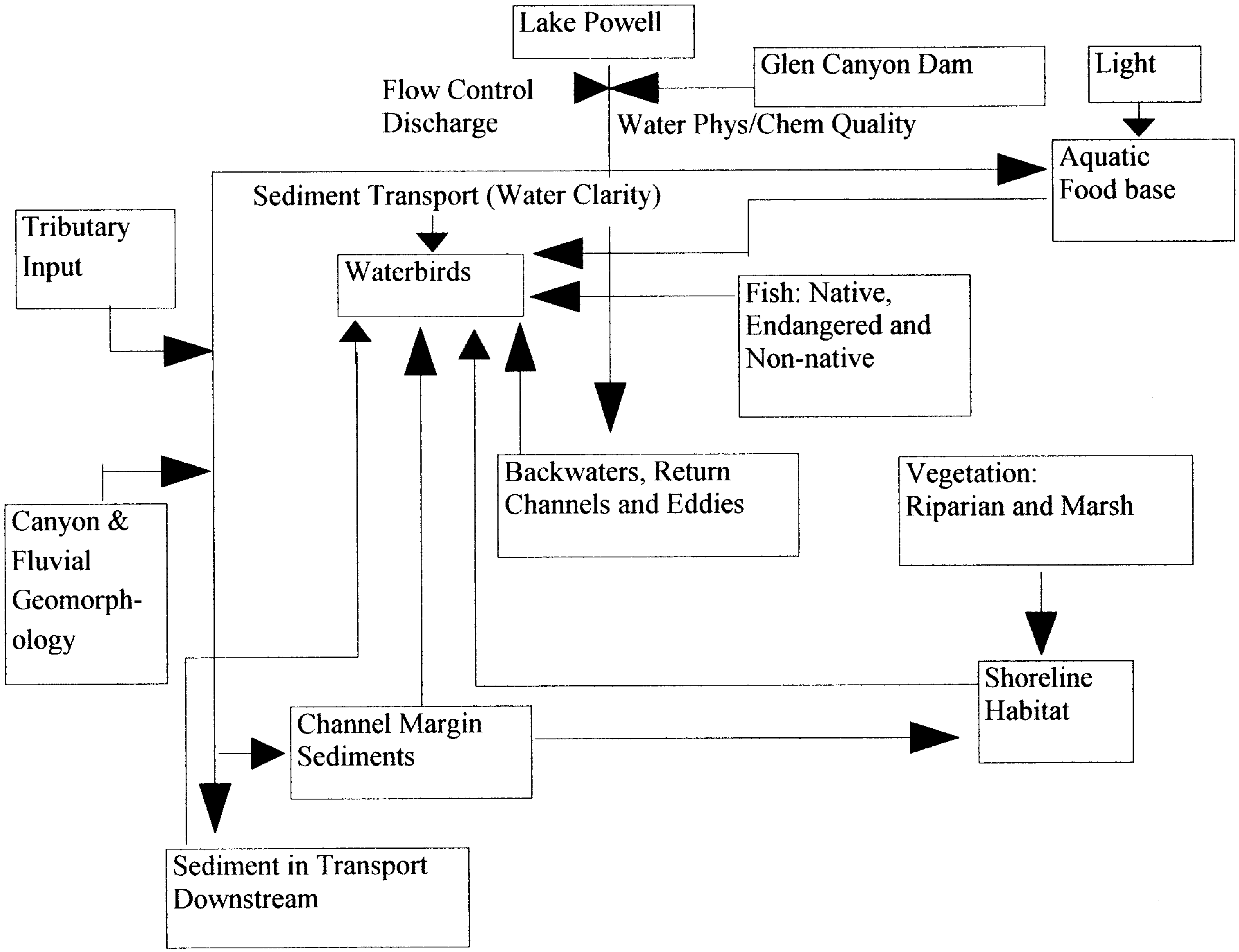


Figure V-15. Conceptual model of factors influencing waterbird distribution.

for opportunistic feeders such as wintering bald eagles. Interim Flows were found to improve the waterbird populations in the Glen Canyon reach. Grahame and Pinnock (1994). They suggested that the increase in water fowl in this area may be a result of stabilization of reed and cattail marshes because of less daily fluctuation under interim flows.

Sediment Transport. Sediment transport appears to be highly correlated with occurrence of waterbirds. The amount of sediment is directly a product of discharge, sediment rating curves having been established for most of the stream gages in the canyon. It is also a product of length of flow of a river starting with clear water. Clear water is high energy water and it picks up sediment until it reaches a "saturation" point. This assumes sediment is available in the river channel or along the shore. Figure V-7 presented under the Aquatic Food Base section shows how sediment in the river channel gradually moves down stream, to be replaced by sediment input events from tributaries. This is one of the primary roles of tributaries in the functioning of the aquatic ecosystem in the canyon. Tributaries are also refugia for aquatic organisms such as native fishes (discussed in fishes section).

In analysis of their waterbird data, Stevens et al. (1997) divided the river into three segments based on clarity of the water (i.e., sediment in suspension). The upper segment from the dam to Lees Ferry was the clear water segment, from Lees Ferry to the LCR was the variable turbid segment, and below the LCR was the usually turbid segment. This ranking recognizes two aspects of sediment transport. First the river gradually picks up sediment as it moves downstream, and second, the major tributaries greatly influence the amount of sediment in the river. Figure V-16 shows Secchi disk depth reading for each of the 12 reaches recognized by Stevens et al. This geomorphic reach division is a modification of that of Schmidt and Graf (1990). The upper reach was divided above and below the confluence of the Paria River at Lees Ferry. This was done to account for sediment inputs from the Paria in the water clarity ranking.

Distance downstream is a surrogate for sediment in transport. Distance downstream was highly positively correlated with waterbird occurrence. Figure xx shows the results of waterbird surveys and demonstrates the close affinity between distance downstream, Secchi disk depth readings and bird numbers with total numbers decreasing downstream. Total AARE (birds/km of river/hour of observation) dropped from nearly 10,000 to less than 100 from reach one to reach two. Again, guilds did not exactly follow this pattern. Divers and dabblers tended to follow the pattern and decreased dramatically. Of the two, dabblers were common in the upper reaches. Waders decreased downstream and then increased again in reaches 8-10. Shorebirds dropped out at the farthest reaches.

Sediment in the river decreases visibility and reduces primary productivity (see Aquatic Food Base section). Diving birds, waders and dabblers all depend on sight to find food in the river. Thus their decrease down river is an obvious correlative with inability to spot food. It is difficult to explain why some guilds increased down river without knowing the exact specifics of discharge, sediment transport and other conditions during the survey.

Geomorphology. Geomorphic conditions of the shoreline habitat apparently play a role in distribution of waterbirds, both seasonal and breeding. The primary locations for sighting waterfowl in the Glen Canyon reach were sites with large sand and cobble bars usually with a

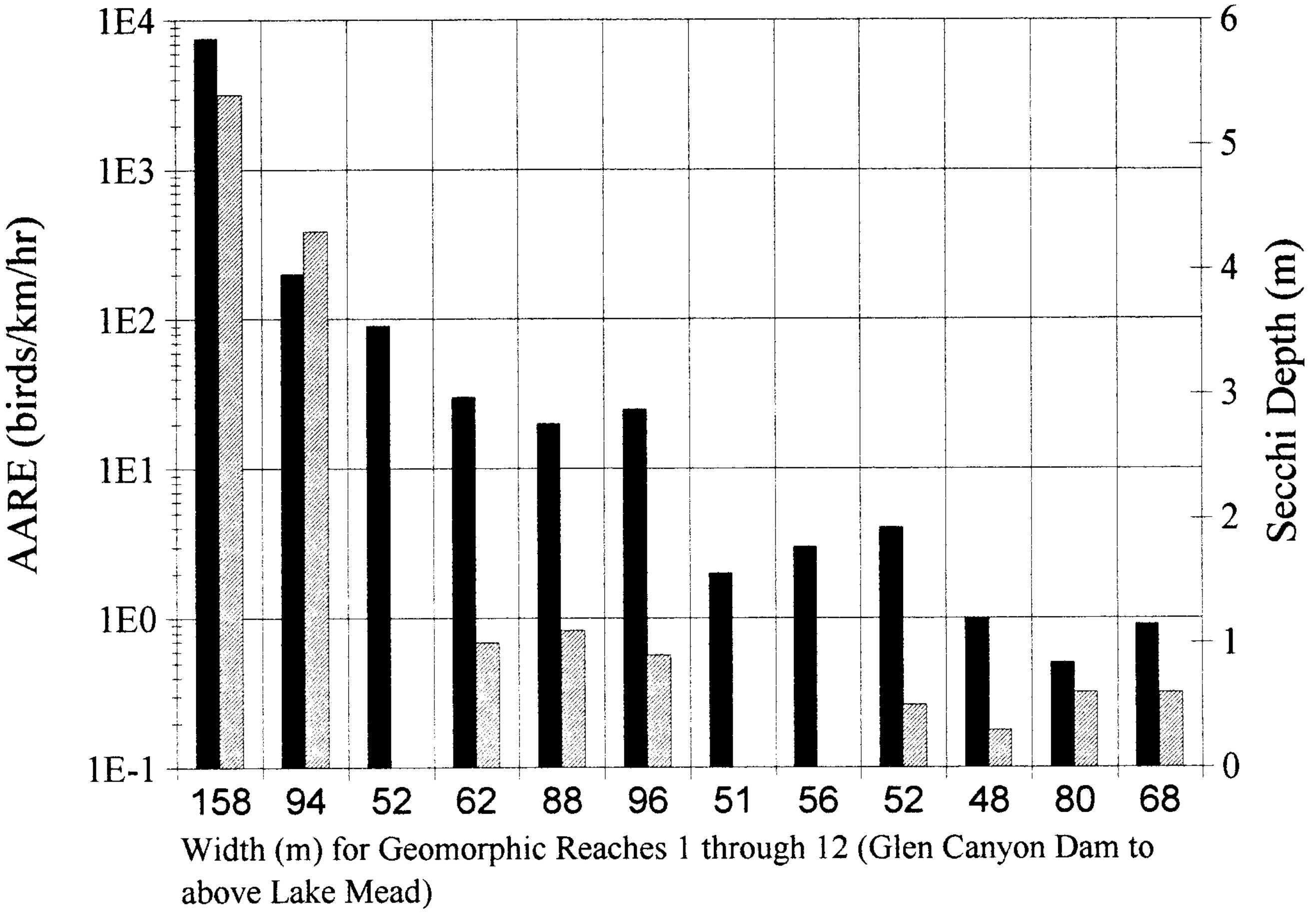


Figure V-16. Factors influencing abundance of waterbirds (data adapted from Stevens et al. 1997), black bar is AARE.

pool or wet-marsh (slough) nearby (Grahame and Pinnock 1994). Exposed sand and cobble bars, especially the cobbles, are signs of armoring of beaches, a consequence of scour by high discharges with sediment-free water. Apparently these are favorable sites for gathering of water fowl. Nesting of waterfowl, mallard and merganser, in this reach were generally in the straight stretches of river away from the sand/cobble bars which tend to be on river curves. Stevens et al. (1997) noted mallard nests in most large eddy systems in the clear water and variable turbid river segments. Grahame and Pinnock did not mention use of large eddy systems, perhaps because not many exist in the upper reach.

Reach-width was also found by Stevens et al. (1997) to have a weak correlation with distribution of waterbirds. Narrow reaches tended to have fewer birds (Figure V-16). Comparison can only be made within reaches with similar sediment in the river, because this factor overrides reach-width if one compares narrow reaches in clear water segments with wide reaches in turbid water segments. Wide reaches usually have greater sediment depositions and large eddies. They also tend to have more riparian and marsh vegetation. Narrow reaches often have little sediment stored because the steep canyon walls do not offer appropriate conditions for creating reduced velocity discharge which deposits sediment. Wide reaches may have more gradual slopes which enhances potential for waders, dabblers and shorebirds to take advantage of food within shallow water.

Aquatic Food Base. The aquatic food base changes downstream from one dominated by periphyton algae to one that is mostly drift except in ripples. The Aquatic Food Base section explains these differences. The availability of food in the river, and the ability to see and eat it, is a critical factor in success of use of any particular reach along the river by waterbirds. Thus the clear water segment of the river with high primary productivity and easily available aquatic food is the main location of waterbirds. Their numbers decrease downstream with apparent loss in availability of food.

Riparian and Marsh Vegetation. Vegetation growing along the shoreline produces habitat that may be used by waterbirds. Overhanging vegetation creates a shady cool environment while wetland thickets along stream's edge may be used for cover. Wet-marshes in return current channels (RCC) may also be used as nesting areas for mallards, and vegetative cover for other birds. The more integrated the riparian and marsh vegetation is with the open river and eddy bays, the greater the potential use by waterbirds. Shorebirds also may use shoreline vegetation as a food source.

Summary. Waterbird distribution in Glen and Grand Canyons functions similarly to distribution of the aquatic food base. Except for seasonality which is a primary driving factor (e.g., more birds in winter), downstream distances play a critical role in abundance of waterbirds. Downstream distances are a surrogate for clarity of water, a primary driving factor controlling amounts of periphyton and primary productivity in the aquatic food base. Visibility in the water and accessability of food determine how many, and what guild of waterbirds may occur at any one location along the river.

D. Riparian and Marsh Vegetation

Before Glen Canyon Dam was constructed (1963), little riparian vegetation grew on the margins of the Colorado River. A riparian vegetation zone did exist, but it occurred at a river stage equivalent to moderate spring high flows (2520-2800 cms; ca. 90-100,000 cfs) (see top diagram in Figure V-17). This zone is now called the Old High Water Zone and includes several semi-riparian species that are relatively drought tolerant (e.g., Acacia, mesquite, hackberry). Effects of the dam on downstream riparian vegetation has been well documented (Turner and Karpiscak, 1980 Johnson 1991). Changes that took place in the riparian zone that was exposed to invasion by "new" riparian species is one that not only relates to changes in discharge patterns in the river, but also the occurrence and availability of propagules of non-native riparian species.

Following closure of the dam, river margins and sediment deposits in the 708 to 2547 cms (25,000 to 90,000 cfs) stage zone were exposed. The lower portion of this zone, called the New High Water Zone (NHWZ), was readily invaded by non-native tamarisk, nearly creating a mono-specific tamarisk community. Between this zone and the river there was a scour zone that was influenced by the daily stage fluctuations of the river responding to hydropower discharges from Glen Canyon Dam. This scour zone seldom supported vegetation, and when it did, it was usually annual plants, or short-lived plants that could withstand occasional inundation and scouring (see middle diagram in Figure V-17).

In 1991 Glen Canyon Dam was operated under an Interim Flow scenario. Dam discharges under these flows could not exceed 566 cms (20, 000 cfs) and daily fluctuations were limited to 140 or 226 cms (5,000 or 8,000 cfs) depending on the water month (i.e., total volume of water released). Consequently, the zone between the NHWZ and the new high river stage level was exposed to possible invasion by riparian plants. This zone had little scour and yet was wetted at its base by upper limits of dam discharge. This zone is now called the New Dry Zone (NDZ) (see lower diagram in Figure V-17). Consequently, the riparian vegetation "equilibrium" that had been established during normal operations pre-Interim Flows was now upset and a new set of responses occurred.

In addition to changes in the riparian vegetation community along the Colorado River, another vegetation type flourished following closure of the dam. Marsh vegetation, usually plants that require relatively stable wet conditions, appeared in locations that maintained the semblance of wetness, that is, the surface was periodically inundated and the soils stayed wet. Maintenance of wet soils during periods when the river stage dropped required moisture holding soils, that is, fine soils. Many locations that fit these requirements of wetness and fine soils were found at or near the heads of return current channels (RCC) in eddy complexes.

Consequently, as a result of dam and river management, three riparian vegetation zones and a marsh vegetation type developed following dam closure and modification of flows to meet various legal and policy decisions. These vegetation communities continue to respond to many of the same driving factors that control other attributes in the riverine ecosystem within the canyon (see conceptual sub-model, Figure V-18). How the vegetation has and may respond will dictate the future form of the riparian zone and it influence on other canyon attributes.

Discharge. Response of riparian vegetation to changes in discharge patterns from

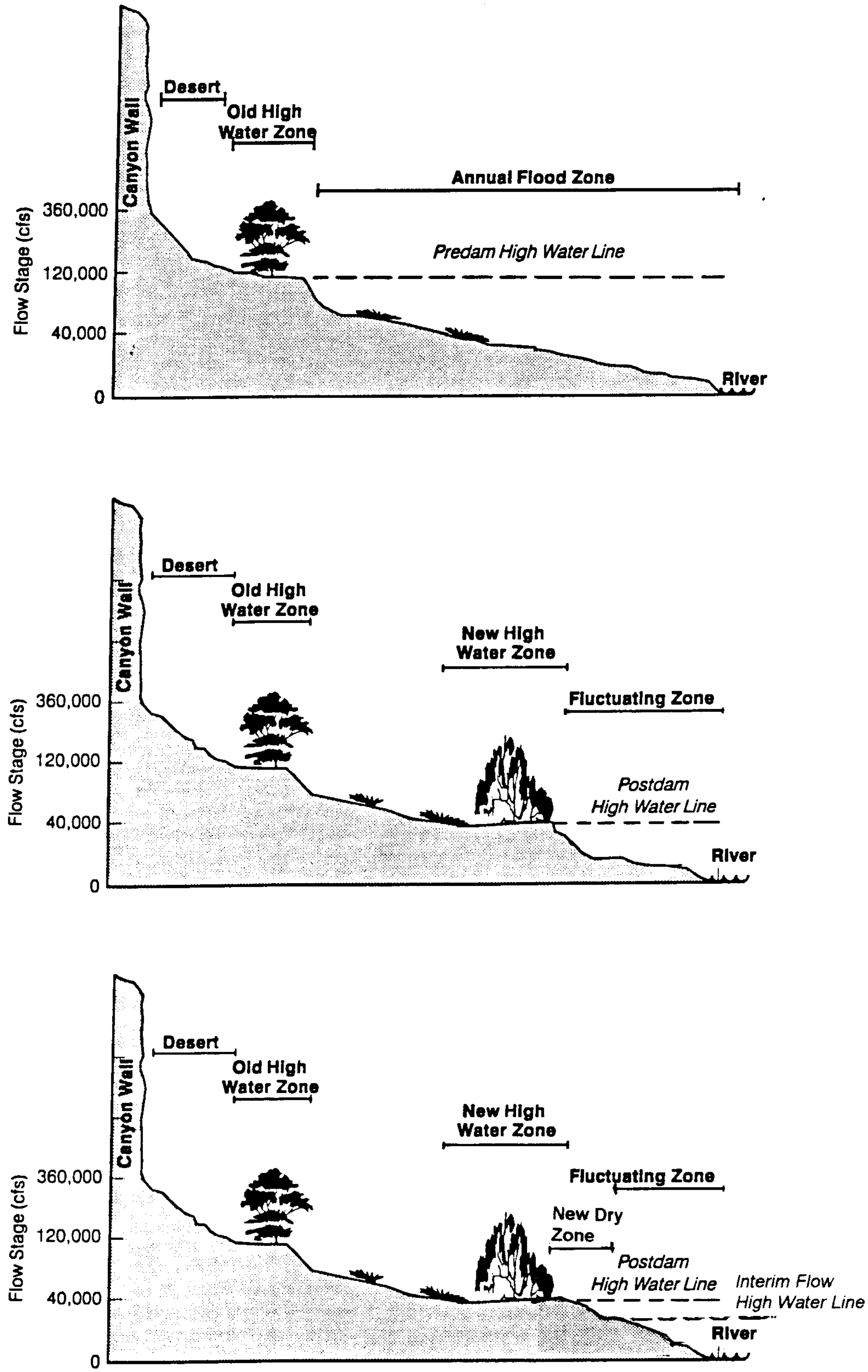
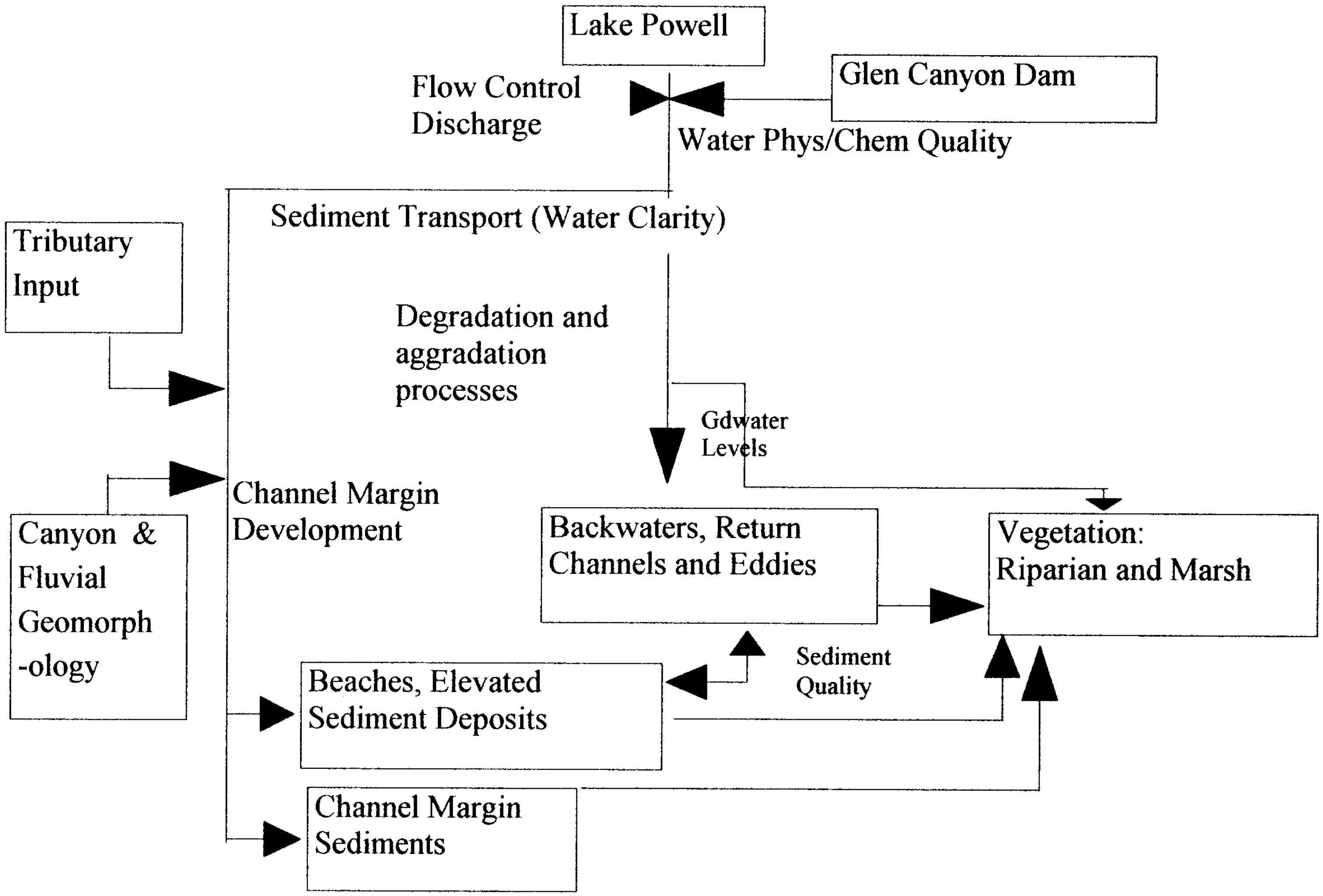


Figure V-17. Grand Canyon riparian zone, predam (before 1963) *top*, post dam and pre-Interim Flows (1963-1991) *middle*, and post-Interim Flows (after 1991) *bottom*. (Top two figures from Glen Canyon Dam EIS.)



FigureV-18. Conceptual model of primary factors influencing riparian and marsh vegetaton distribution.

unregulated to regulated resulting from closure of Glen Canyon are explained above. Now that the canyon riverine ecosystem is functioning under a regulated flow scenario, the question is how will the riparian and marsh vegetation respond to present and future changes in discharge patterns. The shift from normal dam operations (i.e., hydropower demands and discharges as high as 849 cms (30, 000 cfs)) to an operational scheme that limits peak flows and daily fluctuations (i.e., Interim Flows and now MLFF operations) can be viewed as an experiment in determining riparian vegetational response to a highly regulated discharge. The role of river discharge is not only how much water and how high the river stage, but also the quantity and quality of sediment the river scours, moves and deposits.

Following initiation of Interim Flows (1991), several studies were designed to determine how much the lower stages produced by the limit on high discharge rates may alter riparian vegetation that had become established in the canyon. As pointed out above, a New Dry Zone (NDZ) was available for invasion by riparian plants, but this also meant potentially limiting water available to higher zones, especially the NHWZ (the OHWZ was left "high and dry" after dam closure). Using photogrammetric comparisons between 1991 and 1994 Stevens and Ayers (1995) were able to show that some vegetation zones changed considerably following initiation of Interim Flows (Fig. V-19). Vegetation in the NDZ increased immensely. In some cases it went from little or no vegetative cover to relatively dense cover. The channel margin and bar platforms shown in Figure V-19 represent vegetation within the NHWZ. In cover, this vegetation showed little change, increasing at some locations and decreasing at others. The other vegetation type that showed some major changes was that in the return current channels (RCC), mostly marsh vegetation. If the declining stage associated with Interim Flows tended to dry out the marsh location in the RCC, then vegetation cover declined. If more RCC surface was made available for marsh invasion, vegetation cover increased.

Kearsley and Ayers (1996) sampled many riparian vegetation communities along the Colorado River to determine impacts of Interim Flows. They used changes in plant species composition (i.e., shifts from mesic to more drought tolerant species) to determine response of a plant community. Their data support the photo interpretations of Stevens and Ayers (1995). They found that riparian and marsh areas responded more to drying resulting from a dropping river stage than did the NDZ and beach habitat. Dropping stage lowers groundwater levels in adjacent sediments, reducing water uptake by those species with limited root systems. Dates compared in this study were after initiation of Interim Flows and the NDZ was established. The new river stage could maintain plants that invaded the NDZ, but it created drought conditions for plants at higher elevations, unless as explained for beach habitat, the plants were initially drought tolerant or were phreatophytes with long root systems, able to reach water at some distance.

Marsh vegetation gradually changed as Interim Flows continued. In a comparison of the number and cover of marsh vegetation by reach, Stevens and Ayers (1995) showed that from 1993, two years after initiation of Interim Flows, to 1995 the greatest increase in marsh patches was in narrow reaches of the canyon (Fig. V-20). The area of marshes increased in a similar pattern (Fig. V-21).

Combining data from several sources, it is possible to speculate on the response of the different riparian vegetation zones to present or future patterns in river discharge (Table V-4). If low steady flows are used for an extended period of time, several of the riparian zones may dry

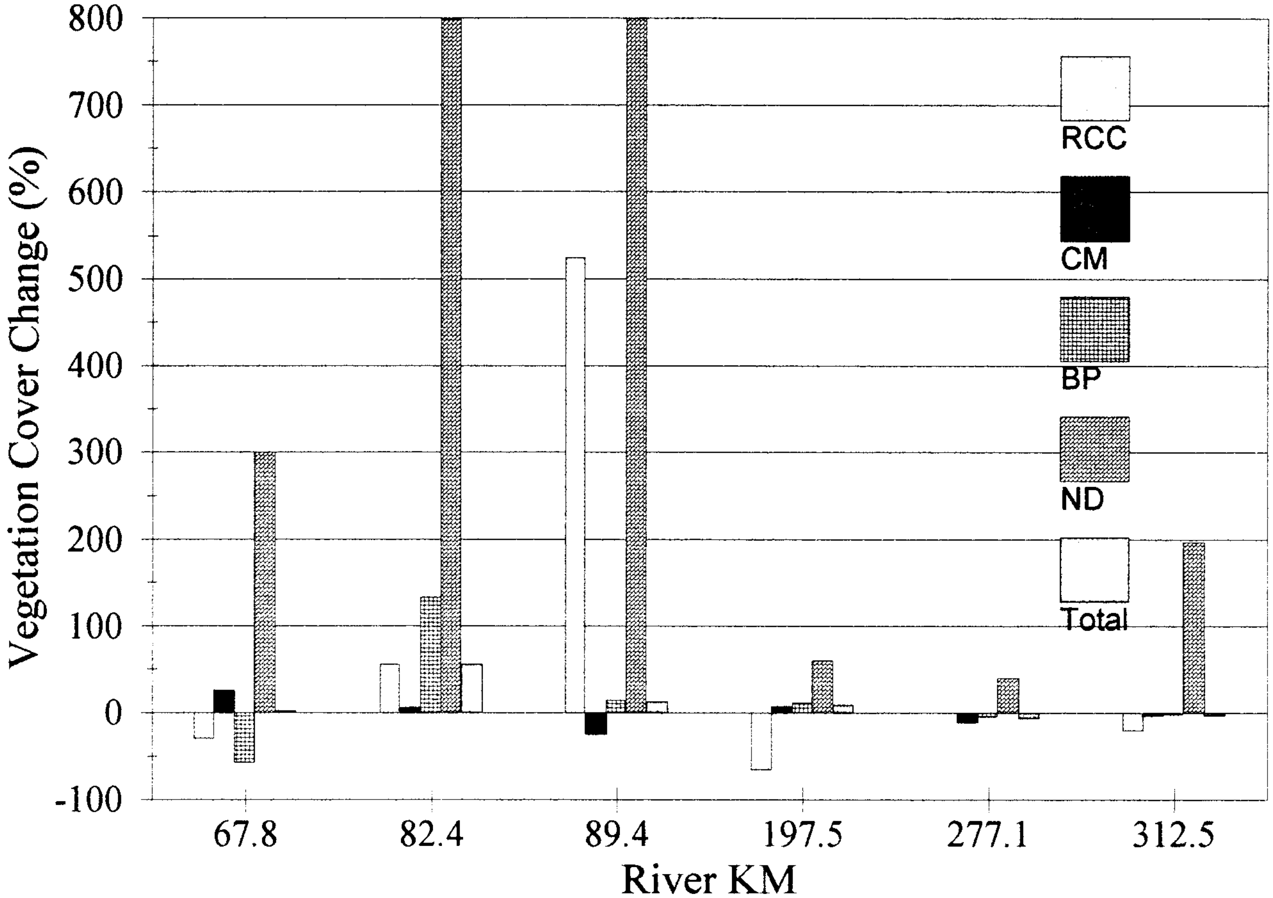


Figure V-19. Vegetation cover change (%) resulting from Interim Flows (1991-1994) at six river locations based on photo interpretation. RCC (return current channel, CM (channel margin), BP (bar platform), ND (new dry zone). All locations except 197.5 are in wide reaches. (Data from Stevens and Ayers 1995.)

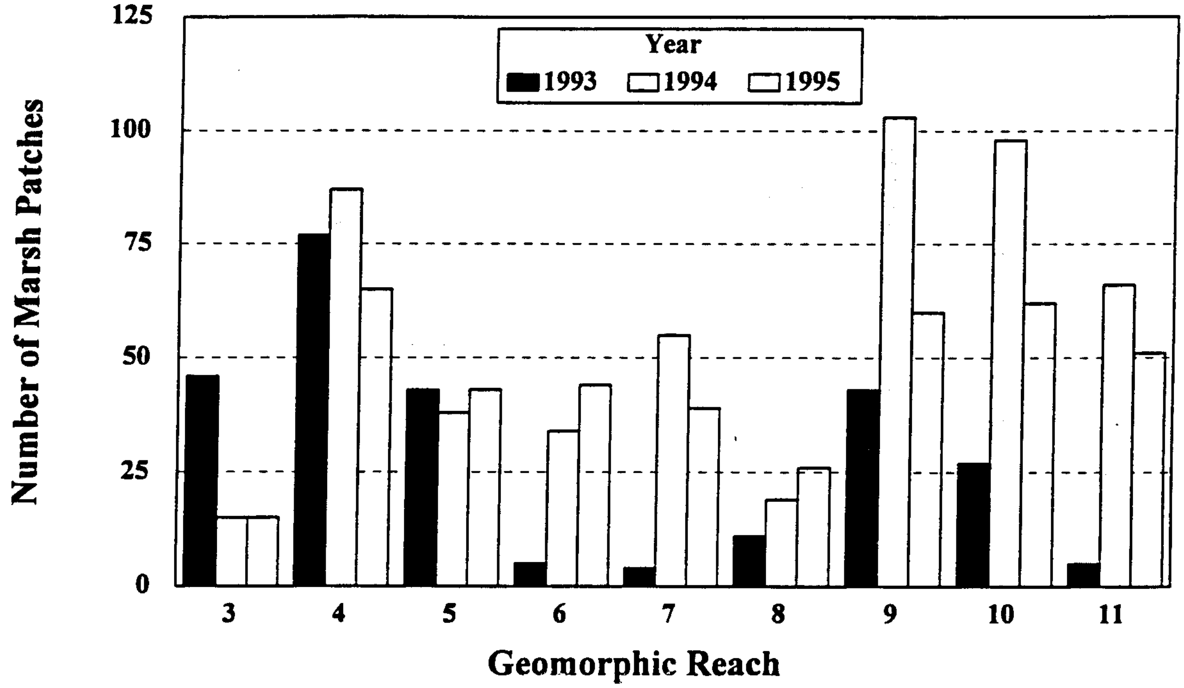


Figure V-20. Changes in the number of marsh patches in the geomorphic reaches of Schmidt and Graf (1990) between 1993 and 1995. (From Stevens and Ayers 1995).

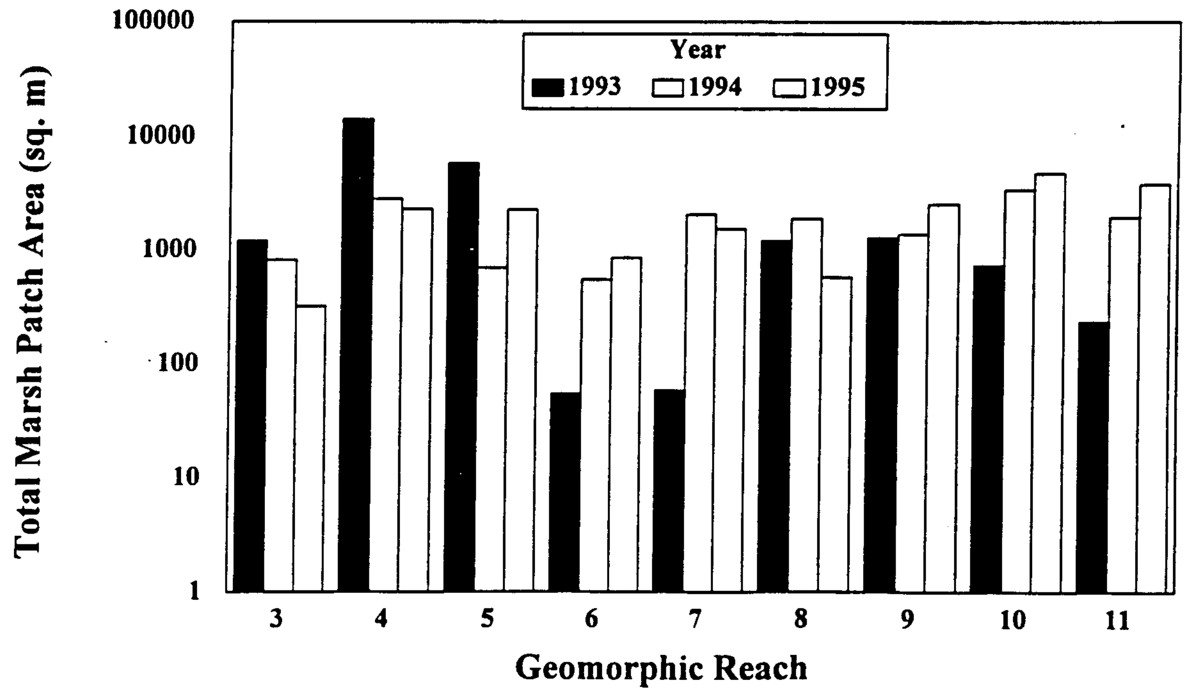


Figure V-21. Changes in the total area of patches of marsh vegetation in each of the geomorphic reaches of Schmidt and Graf (1990) between 1993 and 1995. (From Stevens and Ayers 1995).

and a plant species composition shift may occur from mesic to xeric species. If for some reason the dam is operated in the previous "normal operations", many of the new riparian vegetation communities, especially the NDZ, will be scoured. Other potential, but improbable operational scenarios are presented in Table V-4 with the predicted responses of the several riparian zones.

Sediment Transport and Deposition. Sediment deposits are the foundation of the riparian vegetation communities along the Colorado River. Vegetation must establish on sediment (i.e., soils of one texture or another) that can hold sufficient moisture and supply adequate nutrients for establishment and maintenance of each stage in the life-cycle of a riparian species. Because the riverine ecosystem is dynamic and, as all riparian ecosystems, is a disturbance system, sediment deposits also are dynamic. Some deposits have been shown to change by the hour, especially those in eddy complexes where changes in river discharge and stage have a rapid influence (Cluer and Dexter 1994). Some marginal deposits may also respond in this fashion. Because of their ephemeral nature, these deposits are not suited for supporting riparian vegetation.

Longer-term changes in river discharge play an important role in amounts of sediment transport and deposition. Floods carry large amounts of sediment and form deposits in separation and reattachment bars associated with eddies and at appropriate locations along the river margin. Under pre-dam conditions when high spring floods occurred on a regular basis, sediment deposits were constantly being eroded and put into suspension only to be redeposited as the flood receded. These deposits and their locations were so dynamic that few if any plants could establish and survive on them.

Regulated discharge from the dam now is sediment free and tends to pick up sediment from eddies, bars and margins downstream. Consequently, sediment deposits gradually are reduced in size and volume and eventually approach a stable equilibrium (Fig. V-22). When a flood occurs and sediment is available in the channel to go into suspension, sediment deposits are reformed, often at levels above the high water discharge of managed dam operations. The cycle then continues and the new deposits are gradually undercut by steady or fluctuating flows and their size decreases and they become more stable, that is, less change in surface area and volume.

These changes in elevated, stored sediment in bars, beaches and channel margins appear to have played a role in long-term changes in riparian vegetation distribution and presence. Waring (1996) studied an aerial photo-series of three reaches within the canyon to determine changes in riparian vegetation cover in the NHWZ and OHWZ. From the earliest of the photos just after dam closure (1965) to the most recent (1993) there was a relatively large increase in riparian cover for two of the three reaches. An interesting interpretation of the results of the study is based on results of the intermediate photos and extrapolation of data for the pre-1983 flood conditions. From 1965 to pre-1983 riparian vegetation cover increased, apparently slowly to begin with and then more rapidly (Fig. V-23). A similar pattern of increase occurred after the 1983-86 high water years. As expected, the 1983 flood greatly reduced the riparian cover. A comparison of Figures V-22 and V-23 (vegetation change with sediment change) shows that as sediment deposits become more "stable" riparian vegetation cover increased. After depositional processes occurring during a large flood event end, erosional processes prevail and the "new"

Table V-4. Response of riparian vegetation zones to different river discharge patterns.

Zones (Veg. Types)	Discharge Patterns [cms (cfs)] < 283 (< 10,000)	142-566 (5,000-20,000)	< 142-850 (<5,000-30,000)	>850-1133 (>30-40,000) No regulation	Periodic Flooding
Marsh RCC/Inundation bar	Existing marshes become more xeric, some fill in, may be insufficient flux to create or maintain	Fill in and gradual drying, little opportunity for rejuvenation	Creates marsh communities, with occasional scour and maintenance	Occasional marsh may exist, regular high flows will keep reopening RCC	Scour as well as deposition of marsh areas, may maintain RCC for marsh development
New Dry Zone 566-793 cms stage Channel or eddy margin	Vegetation loss in upper elevations with survival, but shrinkage, of drought plants tolerant	Created by this discharge regime, gradual shift to more xeric species	Scoured sufficiently to have limited vegetation - primarily herbs (annuals ?)	Will not create or sustain vegetation in this zone	Limited scouring, but wetting of this zone - may help maintain non-xerophytes
Riparian Strip 793-1133 cms stage Channel margin	Dry down and loss of community - Tamarisk may survive because of drought tolerance	Some evidenceof recruitment of cottonwood - maintained by this regime	Created by this discharge regime but dominated by non-native woody species	Eventual scour of this zone	Limited scouring but maintenance of riparian species — may enhance native recruitment if timed correctly
Beach 708-1133 cms stage Separation/ reattachment bars	Dry, xeric vegetation if any	Dry, xeric vegetation on higher elevations and limited riparian on lower	Riparian encroachment and maintenance on mid to low elevations	Scouring and maintenance of open sand beaches	Limited scour, but may help maintain invasive riparian species
Debris Flows 990-1416 cms stage	Dry, little chance for mesic vegetation	Dry, little chance for mesic vegetation	Limited moisture available — may maintain some mesic vegetation	Periodically wetted and may support some riparian vegetation	Periodically wetted only if floods mimic natural floods in discharge
Old High Water Zone > 1416 cms stage	Long-term demise of riparian (mesic) vegetation in this zone	Little opportunity to wet extended root zone — eventual demise	Survival, with some mortality, of woody species but essentially no recruitment	The riparian zone of pre-dam — maintained by this discharge regime	Large floods may maintain riparian species in this zone — gradual demise more likely

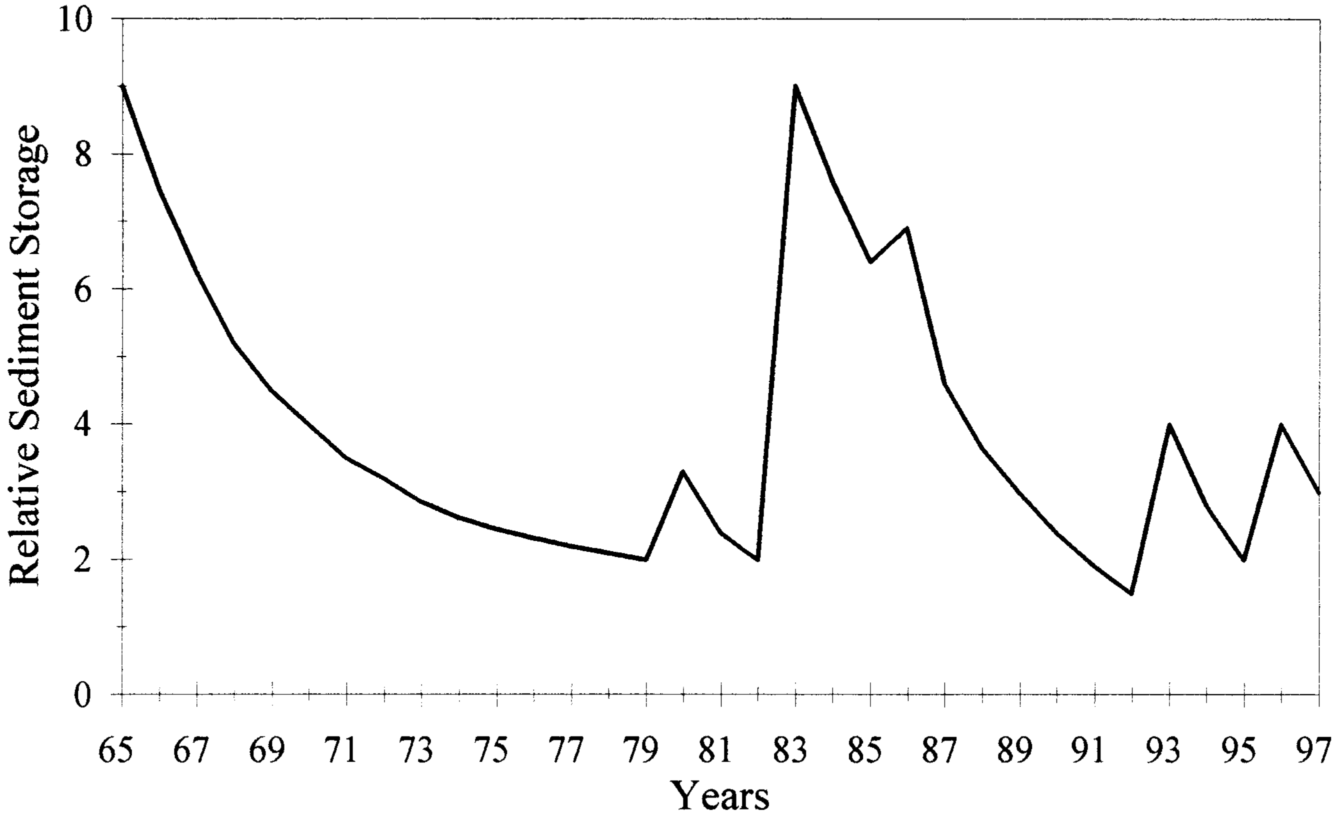


Figure V-22. Relative changes in elevated sediment storage at typical sand bar complex that supports riparian vegetation. Increases are result of variable high discharge events.

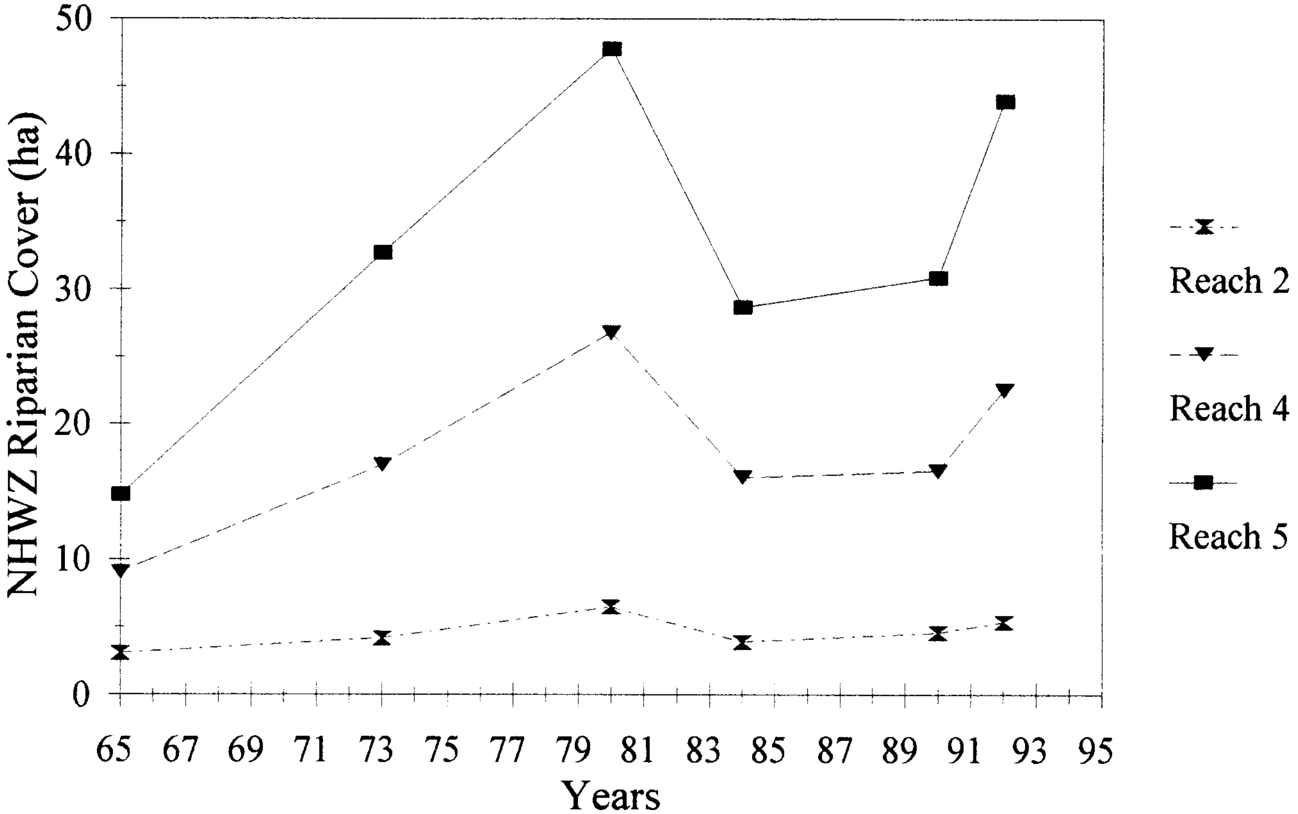


Figure V-23. Estimates of riparian vegetation cover in the New High Water Zone for three reaches. Based on data from Waring (1996), except for 1980 data which were estimated from losses due to 1983 flood.

deposits decrease, rapidly at first and then more slowly. This stabilization of the sediment enhances potential for invasion and reestablishment of the NHWZ riparian vegetation.

The OHWZ riparian vegetation is not greatly influenced by the type of flood event that can be produced by Glen Canyon Dam. Riparian vegetation cover in the OHWZ essentially was unchanged during the period from dam closure through the 1983 flood (Fig. V-24). A decline in 1990 and increase in 1992 may be a result of a multi-year drought period in the late 1980s which may have affect the large amount of tamarisk that had invaded the OHWZ as well as the NHWZ. The contribution of tamarisk to the OHWZ is more than expect if one compares Figures V-24 and V-25 (OHWZ w/ and wo/ tamarisk).

Marsh vegetation follows a similar historical pattern as NHWZ (Fig. V-26). Marsh area within the canyon greatly increased as sediment deposits tended reach an equilibrium with the dam operational discharges and many RCCs were developed and occupied by hydric plant species. The 1983 flood greatly altered RCCs at many eddy complexes within the canyon because, for one reason, the flood stage was sufficiently high to overtop debris fans that were the geomorphic cause of the downstream eddy. It then took several years, during which there was a smaller high discharge event (1986), for marsh habitat conditions to reoccur and marsh vegetation reestablish.

Sediment has many textures from fine clays to coarse boulders. Substrate for riparian vegetation tends to be in the clay-loam to sand textural range. Very coarse sand does not hold much water and is not high in nutrients. Sand, which may include some finer particles, may have sufficient moisture holding capacity and nutrients to support a wide variety of plants species. On the other hand, higher levels of nutrients and ready water availability may enhance growth and maintenance of species that function in a dominant role. A study by Stevens and Ayers (1994) of the importance of texture in supporting various riparian species showed that coarse textured soils tended to support a greater richness of species, while finer soils enhanced seedling development of tamarisk and density of sapling and mature phreatophytes in the canyon riparian communities (Fig. V-27). These findings do not mean that fine soils are required for establishment of phreatophytic plants in the riparian zone, but rather, fine soils enhance their establishment and growth.

Geomorphology. Canyon and fluvial geomorphology play an important role in presence and expansion of riparian and marsh vegetation communities in the canyon. Existence of reattachment and separation bars on which riparian vegetation grows depends on presence of eddy currents, a consequence of debris fans and rapids in most reaches of the canyon. Width of reaches within the canyon influence the amount of alluvium and sediment deposits on which riparian vegetation develops. Wide reaches tend to have greater cover of riparian vegetation. The greatest extent of riparian vegetation is in the reach which includes the upper end of Lake Mead. Here the deltaic sediments support extensive stands of willow and other riparian species, excellent habitat for birds and other wildlife.

Other Factors. Distribution of riparian vegetation not only is dependent on abiotic factors such as discharge and sediment, but also on other abiotic and biotic factors which determine dissemination rates and distances of riparian species. Propagules of many riparian

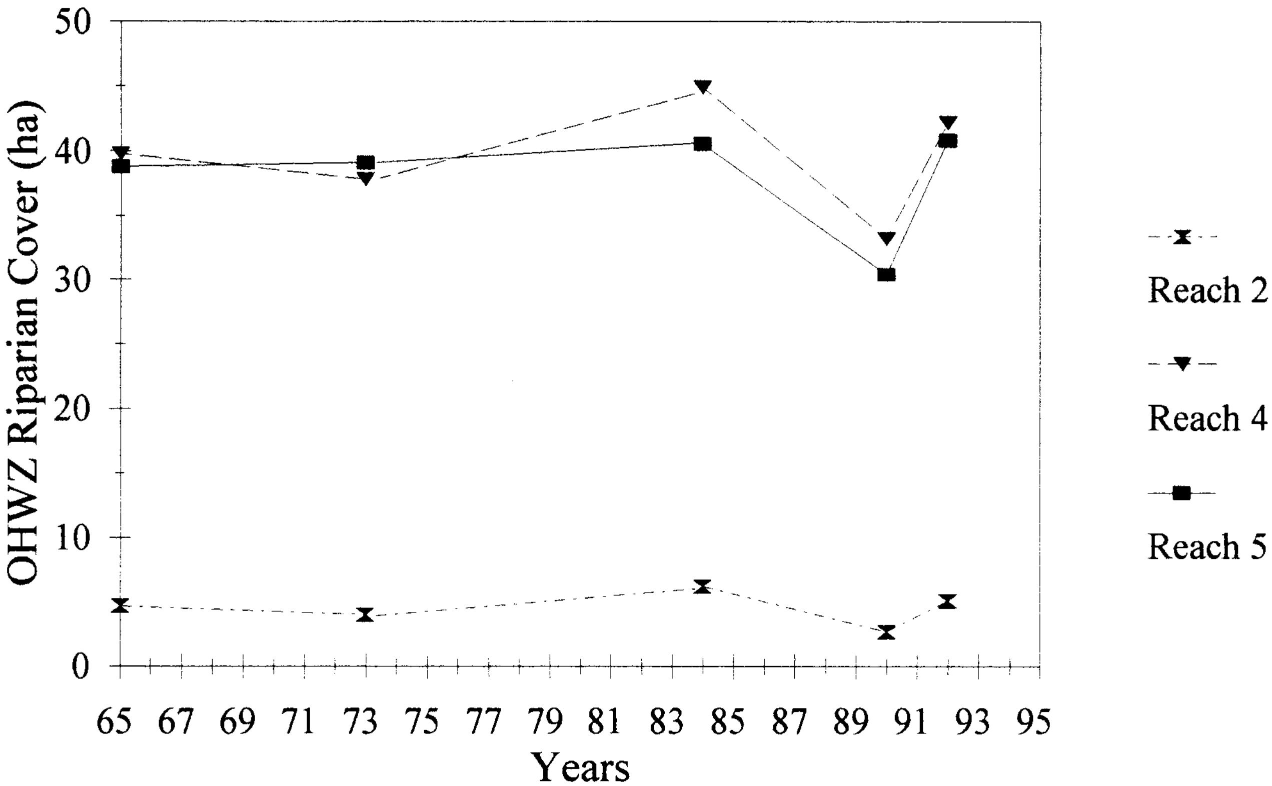


Figure V-24. Estimates of riparian vegetation cover including tamarisk in the Old High Water Zone for three reaches. Based on data from Waring (1996). 1980 data were not estimated because little change was expected at this stage.

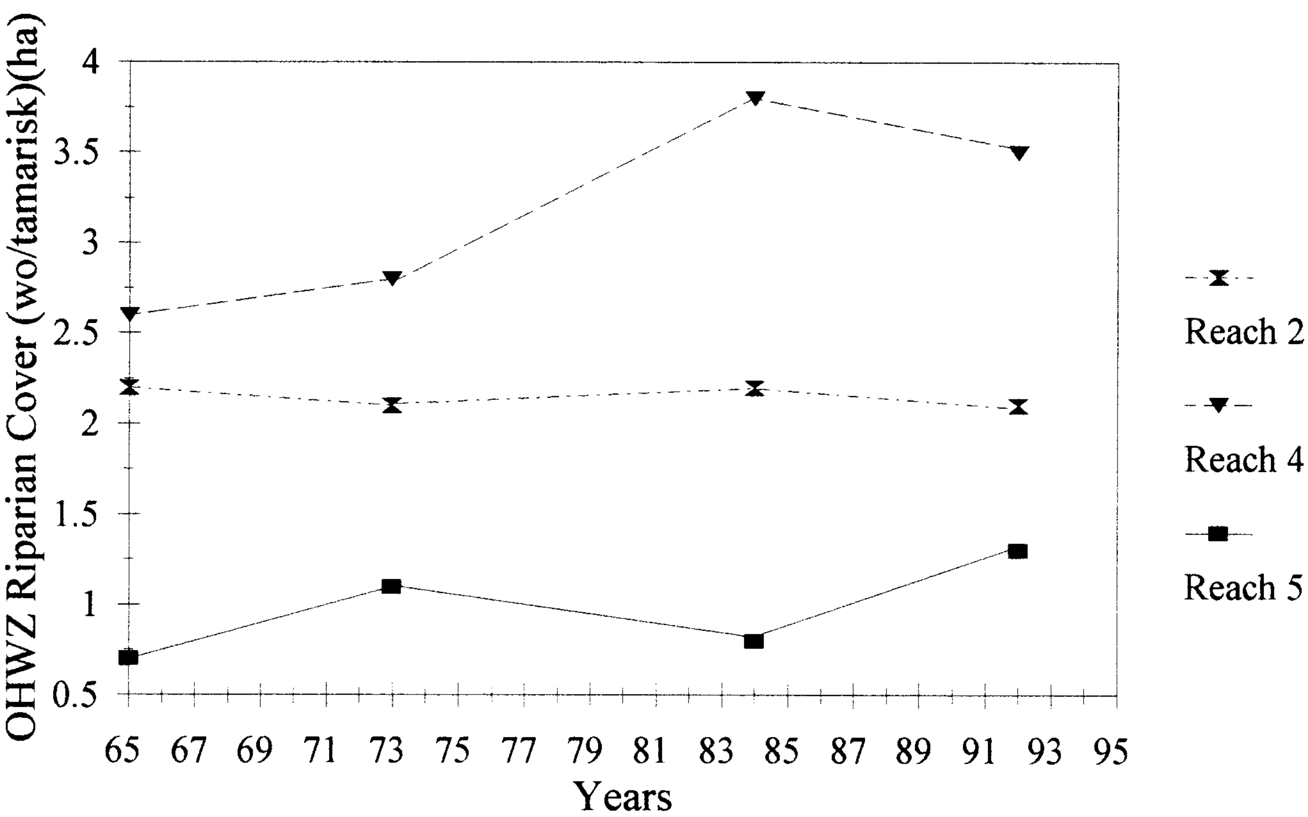


Figure V-25. Estimates of riparian vegetation without tamarisk in the Old High Water Zone for three reaches. Based on data from Waring (1996).

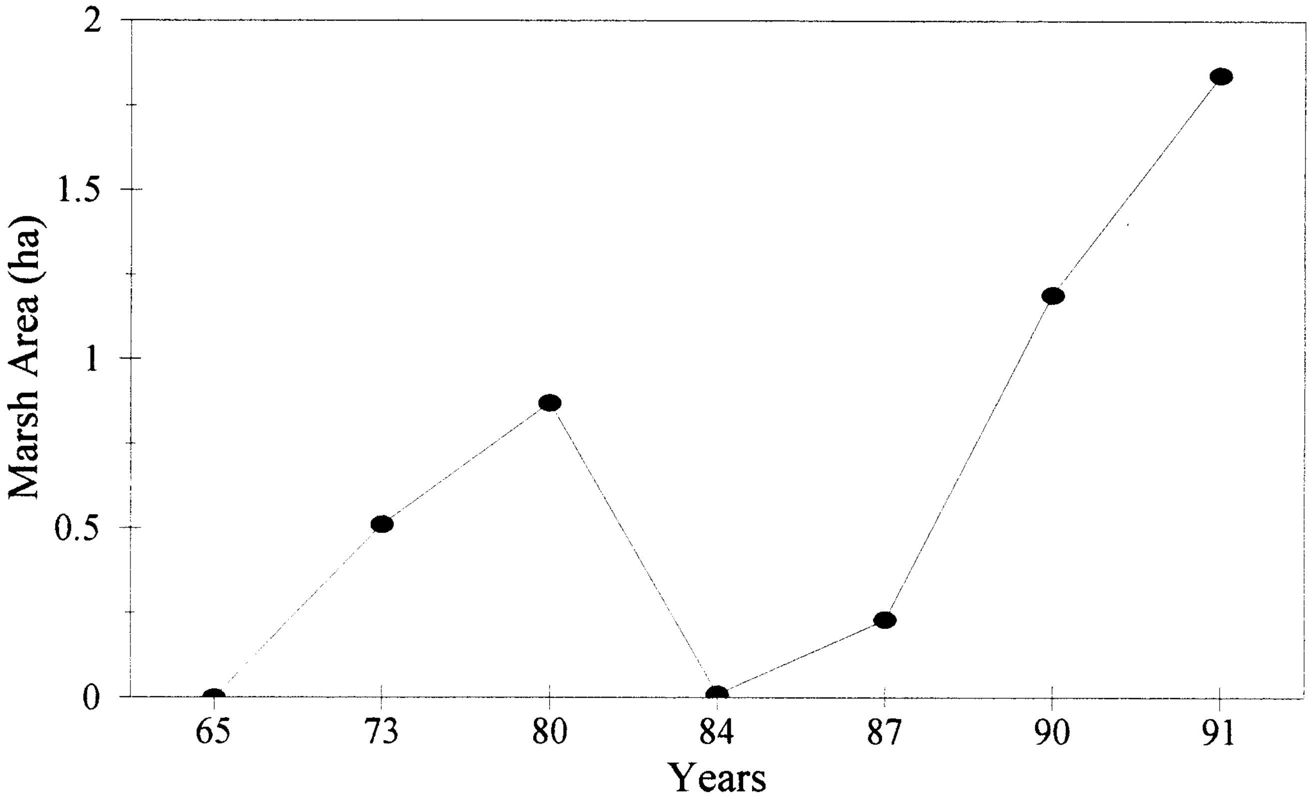
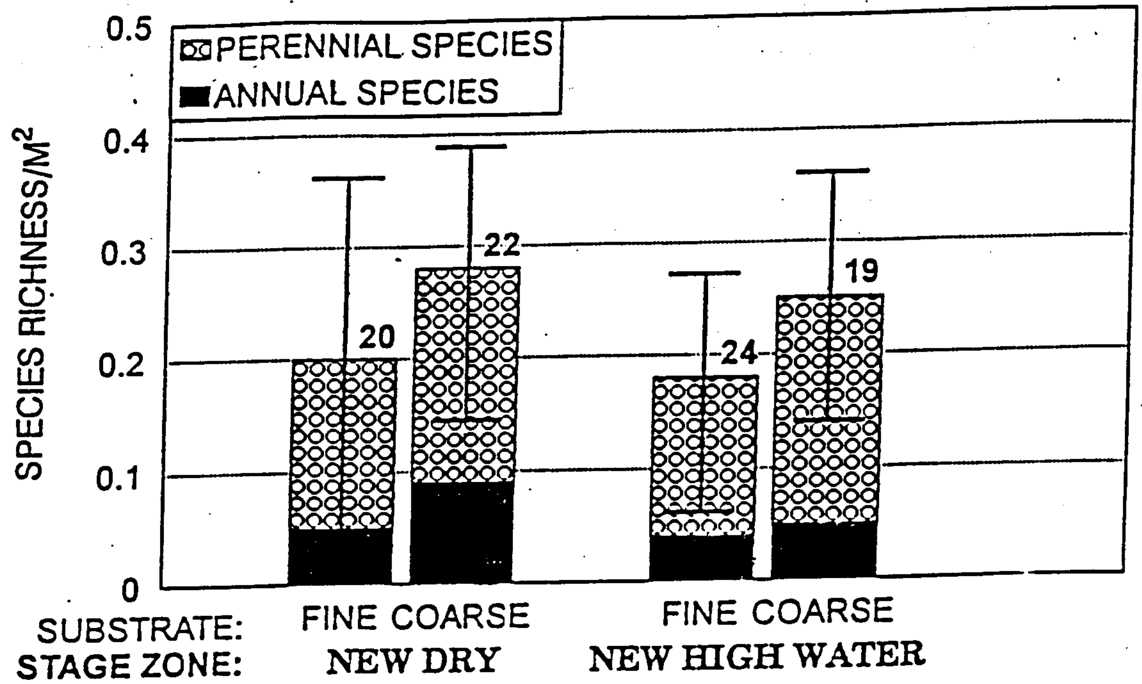


Figure V-26. Estimate of total marsh area (ha) from estimates made at seven marsh locations between RKM 69 and RKM 312. (Data from Stevens et al. 1995).



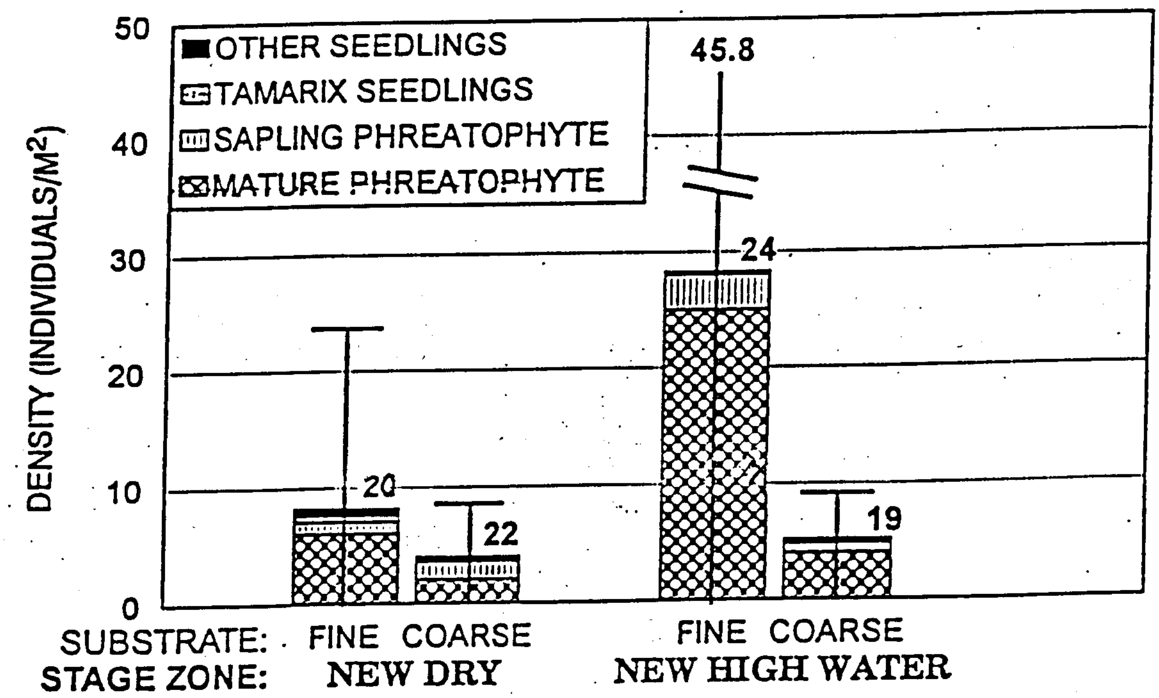


Figure V-27. (Upper Graph): Mean perennial and annual riparian plant species richness/m^2 on "new dry" versus "new high water" zone plots in fine versus coarse substrata along the Colorado River in Grand Canyon, Arizona in 1993. Number of plots sampled and 1 sd are provided.

(Lower Graph): Mean perennial seedling, sapling and mature plant stem densities, and *Tamarix ramosissima* seedling densities/m^2 on "new dry" versus "new high water" zone plots in fine versus coarse substrata along the Colorado River in 1993. Number of plots sampled and 1 sd are provided. (From Stevens and Ayers 1995).

species are dispersed by wind and water. Some are borne by birds and animals. As long as there is a seed source, potential for establishment of riparian species is great, assuming the site conditions are suitable.

Summary. Riparian and marsh vegetation in Glen and Grand Canyons has changed greatly since closure of Glen Canyon Dam. The existence and operation of the dam has altered hydrological and fluvial geomorphological conditions of the downstream riverine ecosystem. The interaction among these two factors and the availability of windblown or water borne propagules of riparian species has allowed rapid invasion of new riparian habitat exposed by decreased spring flows and regulated discharge from the dam. Over time, if these external drivers become less variable, changes in the riparian community should be reduced. However, it is likely that through natural processes and dam operational management schemes, hydrological disturbances will always be a part of the canyon environment. Subsequently, cycles of riparian and marsh vegetation development and loss will continue, causing constant changes in those canyon attributes that depend on riparian and marsh habitat for survival.

E. Riparian and Other Terrestrial Birds

Most of the avian community connected to the riverine ecosystem, aside from waterbirds, is associated with riparian and marsh vegetation communities that line the river. With construction of Glen Canyon Dam riparian vegetation along the river greatly changed (see Riparian and Marsh Vegetation section). Factors that influence presence and abundance of the terrestrial avian community are often directly related to operations of the dam, or attributes that have been altered directly by dam operations. Often it is impossible to separate driving and response factors as these two paired, functioning synergistically, may become a driving factor for another canyon attribute such as terrestrial birds or aquatic food base. Figure V-28 shows a conceptual sub-model of the primary driving variables that influence presence and abundance of the non-waterbird, terrestrial avian community in the canyon. The avifauna in the canyon is quite rich. Avifaunal surveys in the Glen Canyon reach resulted in detection of 36 bird species (Grahame and Pinnock 1994), while another survey from Glen Canyon Dam to Pearce Ferry in Lake Mead detected 72 species of which 13 abundant species were breeding avifauna (Petterson and Spence 1997). Within the terrestrial bird community there are species that are now listed as threatened or endangered. The primary species of concern within the canyon is the southwestern willow flycatcher. This species is dependent on riparian vegetation and appears to be "hanging on" within the canyon. Its requirements will be discussed separately.

Discharge. The primary role of river discharge in distribution or presence of terrestrial birds is its role in shaping the riparian vegetational community and aquatic food base. Changes in discharge since dam construction, as discussed above in the Riparian and Marsh Vegetation section, have influenced the development of a new riparian zone (NHWZ) closer to the active river channel. More recently, with discharge from the dam dictated by Interim Flows and the ROD-MLFF guidelines from the Glen Canyon Dam EIS, another riparian zone, the New Dry Zone, has developed at the lower margins of the NHWZ. Different levels of discharge also have been found to enhance or reduce the vigor and cover of marsh and riparian vegetation.

Discharge is shown above (Aquatic Food Base section) to influence development of aquatic organisms. This influence is through sediment transport and river clarity, and stage fluctuations and shoreline exposure and wetting. Many of the insects used by terrestrial birds have their origins as larvae in the aquatic ecosystem.

Sediment Transport. In a fashion similar to discharge, and directly related to discharge rates, sediment transport influences both riparian and marsh vegetation, and the aquatic food base. The amount of sediment in transport increases downstream as more sediment enters the mainstream from tributaries and the river picks up sediment from the channel bed and margins. Sediment in transport is the source of new substrate and nutrients for riparian vegetation. It also alters the cover of marsh vegetation through deposition in RCC areas with marshes.

Increasing sediment reduces productivity of the aquatic food base, with much of the energy rich organic material found in drift. Over 90% of primary production in the river is in the clear-water Glen Canyon reach. Macroinvertebrates and insect larval stages are found in various amounts downstream where sediment levels tend to increase (see Aquatic Food Base section).

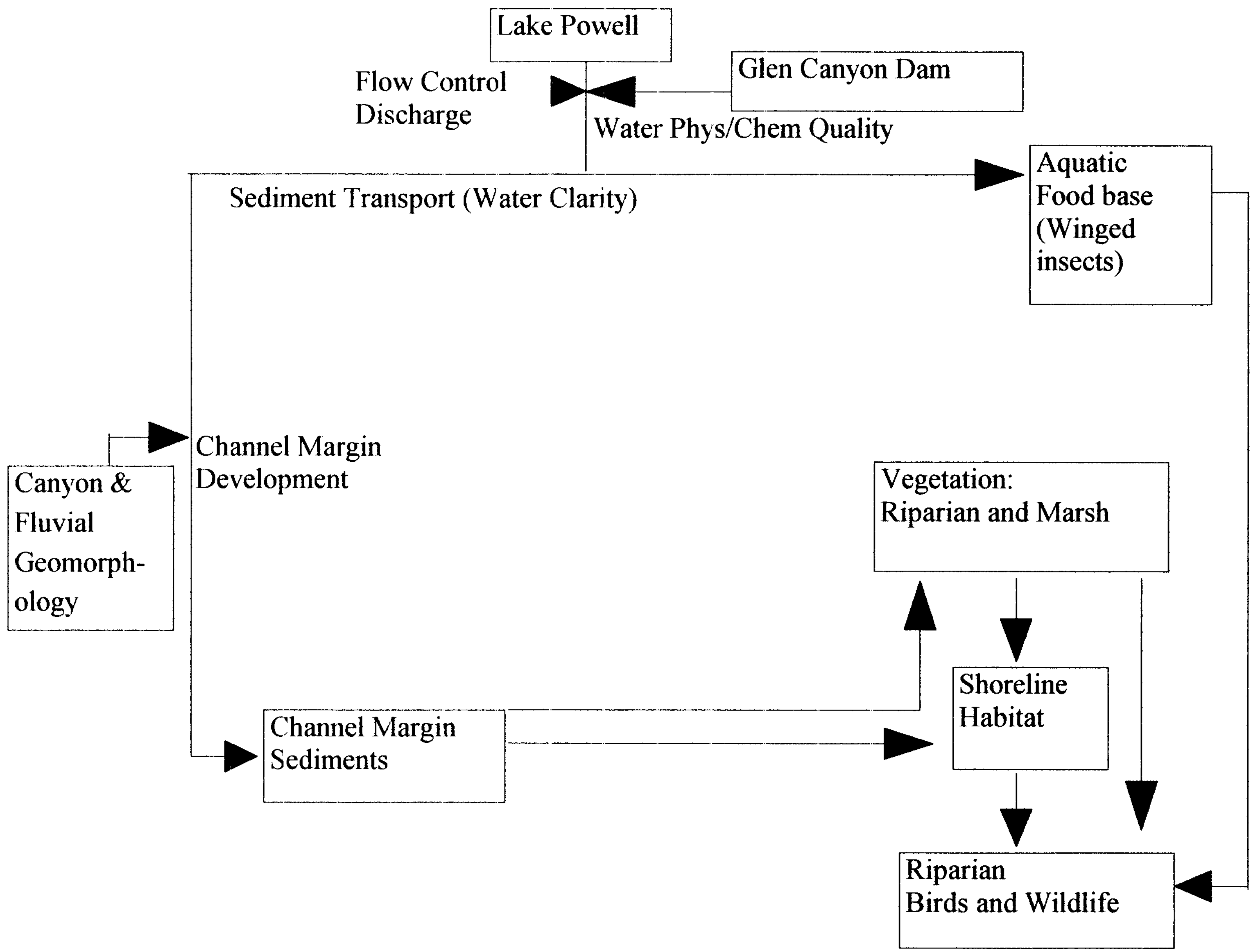


Figure V-28. Conceptual model of primary factors influencing non-waterbird avian distribution.

Geomorphology. Canyon geomorphology directly controls the locations of large stands of riparian vegetation and marsh areas. Wide reaches tend to have more shoreline in the zone wetted by the river (NHWZ and NDZ) within normal discharge fluctuation. These areas thus support greater amounts of riparian vegetation. Location of debris fans and other canyon geomorphological features often control the location of eddy complexes. Return current channels (RCC), exposed following high discharge, are often sites of marsh vegetation. Other geomorphic features in the canyon may also influence riparian vegetation avian habitat. For example, straight reaches often have extensive marginal vegetation. Canyon cliffs also offer habitat to several cliff dwelling terrestrial birds such as the canyon wren and predatory birds such as the peregrine falcon.

Aquatic Food Base. The aquatic ecosystem is a source of food for terrestrial avifauna. There are many terrestrial invertebrates that have an aquatic larval stage. Adults of these taxa emerge from the river, often in extensive hatches, and may utilize riparian vegetation as locations for drying and for food (e.g., sucking or boring insects). Above the river and in the foliage they become a major food resource for the avian community. Several insect taxa have only aquatic larval stages while other have both aquatic and terrestrial larval stages. For example, these assemblages may include for aquatic only: Ephemeroptera, Odonata, and Tricoptera; and for terrestrial and aquatic: Neuroptera and Diptera. The importance of the aquatic food base in distribution and abundance of terrestrial avifauna is directly related to ability of the various taxa of invertebrates to utilize the river for reproduction. Conditions that may limit success in reproduction are explained in the Aquatic Food Base section above.

Riparian and Marsh Vegetation. Most detections of terrestrial, non-waterbird species during avifaunal surveys in the canyon were associated with riparian or marsh vegetation. This vegetation zone is quite diverse, a consequence of river management through dam operations. A New High Water Zone (NHWZ) established following closure of the dam (Turner and Karpisack 19xx, Johnson 1991). The Old High Water Zone remaining is declining in vigor, and recently with Interim Flows and MLFF flows a New Dry Zone has developed. Development of these zones are extensively discussed in the Riparian and Marsh Vegetation section.

Most of the avifaunal surveys only briefly describe the vegetation within which detections are made. Association of bird species with particular riparian plant species is not well documented in GCES monitoring surveys, but can be found in other publications (see Bureau of Reclamation EIS 1995). The Glen Canyon Dam EIS presented a figure showing the potential utilization of riparian zones by different bird species (Fig. V-29). Also, in their report on riparian resource surveys in the lower reaches of the canyon the Hualapai Tribe (SWCA 1995) showed the use of riparian plant species for nesting by several bird species (Table V-5). These reports show the importance of different riparian zones as habitat for species within the avian community.

Not only can the riparian vegetation community along the Colorado River in Grand Canyon be separated into several zones based on influence of discharge scenarios, each with its on species assemblage, but characteristics of the vegetational community within each zone vary from point to point along the river. In order to relate riparian vegetation to avian use, several

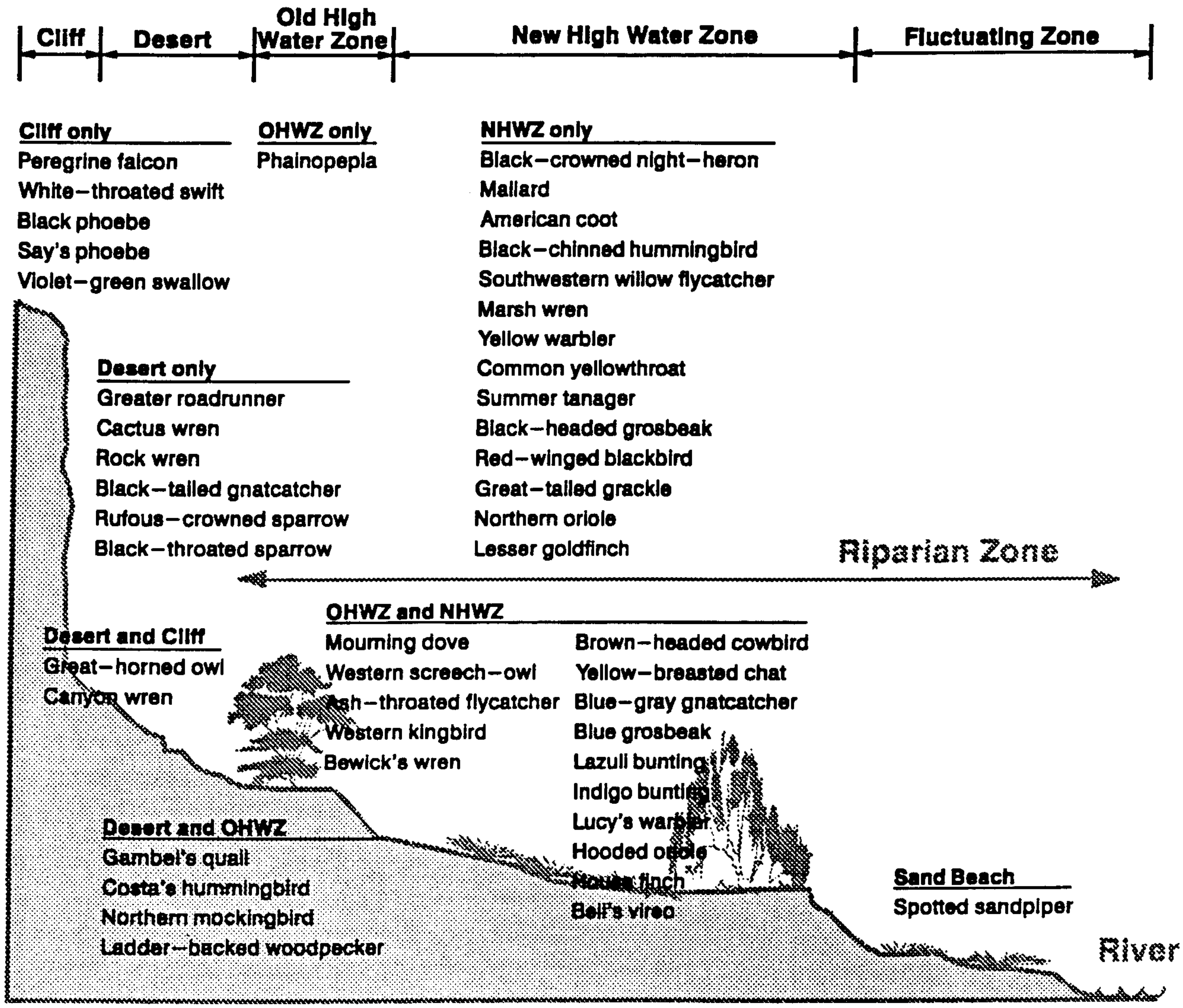


Figure V-29. The importance of riparian vegetation as wildlife habitat is exemplified by nesting birds. The majority of birds nesting along the river corridor nest in riparian vegetation. (From Bureau of Reclamation — GCDEIS, 1995).

Table V-5. Nest substrate plants used by birds nesting in riparian vegetation as compared to next substrate availability as a percentage of total vegetation volume (TVV) and live TVV along the Colorado River from National Canyon to Tincanebits Canyon (rkm 268-427), April to June 1993-1994. A dash indicates no nests were found. TVV values were weighted mean values for each nest substrate plant species (mean value at all sites combined weighted by the size of each site). (From SWCA 1995).

Nest Substrate Plants	Number of nests by bird species[1]										Total Nests	% of Total Nests	% TVV	% of Live TVV
	BH	BW	BG	P	BV	LW	YW	CY	YC	SS				
Tamarisk	3	1	5	-	18	7	-	2	10	5	51	65.4	67.8	67.0
Cattail	-	-	-	-	-	-	-	5	-	1	6	7.7	4.0	2.9
Honey mesquite	-	-	-	1	4	-	-	-	-	-	5	6.4	2.6	2.8
Baccharis sp.	1	-	-	-	2	-	-	-	2	-	5	6.4	9.2	8.7
Catclaw acacia	-	-	4	-	-	-	-	-	-	-	4	5.1	0.8	0.7
Goodding's willow	-	-	-	-	1	-	2	-	-	-	3	3.8	3.1	3.6
Arrowweed	-	-	-	-	1	-	-	-	-	-	1	1.3	3.1	3.1
Coyote willow	-	-	-	-	-	-	-	1	-	-	1	1.3	4.1	4.7
Hackberry	-	-	-	-	1	-	-	-	-	-	1	1.3	0.9	1.0
Long-leaf brickellbush	1	-	-	-	-	-	-	-	-	-	1	1.3	0.1	0.1
Total nests	5	1	9	1	27	7	2	8	12	6	78	100.0	95.7	94.6

[1] Bird species codes as follows: BH = Black-chinned Hummingbird, BW = Bewick's Wren, BG = Blue-gray Gnatcatcher, P = Phainopepla, BV = Bell's Vireo, LW = Lucy's Warbler, YW = Yellow Warbler, CY = Common Yellowthroat, YC = Yellow-breasted Chat, and SS = Song Sparrow.

vegetational parameters should be measured. The 1995 riparian resource report from Hualapai Tribe (SWCA 1995) used several of these parameters in attempting to relate total avian community use with riparian vegetation. Two figures were developed using data from the report. Figures V-30 shows the relationship between Maximum Detection of Nesting Birds and Total Vegetation Volume (TVV), and Figure V-31 shows the relationship between Bird Density and Vegetation Layer Index. TVV and Vegetation Layer Index are closely related and either generally can be used to describe vegetation structure. It is description of vegetation structure that permits evaluation of usage of riparian vegetation by birds. Most vegetation sampling produces cover and density data and this is useful for evaluating bird usage, but structure is more useful. It is possible to estimate cover from the TVV data, but it is only an estimate. TVV values approaching 2 may be interpreted to be around an aerial cover value of 75%, while TVV values near 0.5 are somewhat similar to cover values < 25%. These are very rough estimates but they may be useful in applying cover data from riparian vegetation monitoring to TVV and bird usage estimates using a regression model. Better yet, riparian monitoring, or measurements of riparian vegetation during avian surveys, should all measure TVV.

Utilization of riparian vegetation at other locations from Glen Canyon Dam to the upper reaches of the lower Colorado River sampling area, is still in data analysis. Some sites are described as tamarisk thickets, or tamarisk with sandbar willow, but this is not very useful to attempts at closely relating the avian community and riparian community.

Southwestern Willow Flycatcher. The southwestern willow flycatcher (SWWFC) has recently been listed as endangered by the USFWS. There is little evidence that it was a common bird in the canyon prior to dam construction. It probably utilized riparian areas in tributaries, but since the riparian zone near the river was scoured regularly by high spring flows, and the vegetation in the OHWZ does not include normal SWWFC habitat, the likelihood of it being present in any number, if at all, is small. Recent annual surveys for SWWFC have shown that its population seems to fluctuate from year to year, both nesting and non-nesting birds (Sogge et al. 1993, 1994 and 1995). Its habitat appears to be predominantly tamarisk, but at most locations there usually is some nearby presence of willow, either *Salix exigua* (sandbar willow) or *S. gooddingii* (Goodding willow) and marshy areas. Habitat patch size for SWWFC ranges between 0.4 - 0.6 ha. Nesting patches are about 0.3 ha and breeding territory is about 0.2 ha. There certainly are sufficient patches of this size with appropriate vegetation if the potential for the population is too increase. Nesting, when observed, is usually in a tall tamarisk patch. Since this is the most common large woody plant along the river, this is not unexpected if its presence is going to continue. Nesting height in large tamarisk in the NHWZ is usually over 3.5 m (BR 1996). Thus it is seldom at risk from inundation by *high discharge*. On the other hand, high discharges carry large amounts of *sediment* which may alter conditions in adjacent marshes which appear to play an important role as an insect forage area and SWWFC survival.

Probably more important than availability of appropriate habitat for SWWFC survival is the presence of the brown-headed cowbird. This species parasitizes the SWWFC nest and greatly reduces the reproductive potential of the SWWFC. Nesting pairs of SWWFC may attempt to breed several times in a year following nest parasitism by cowbirds, but often the same results of egg loss occur.

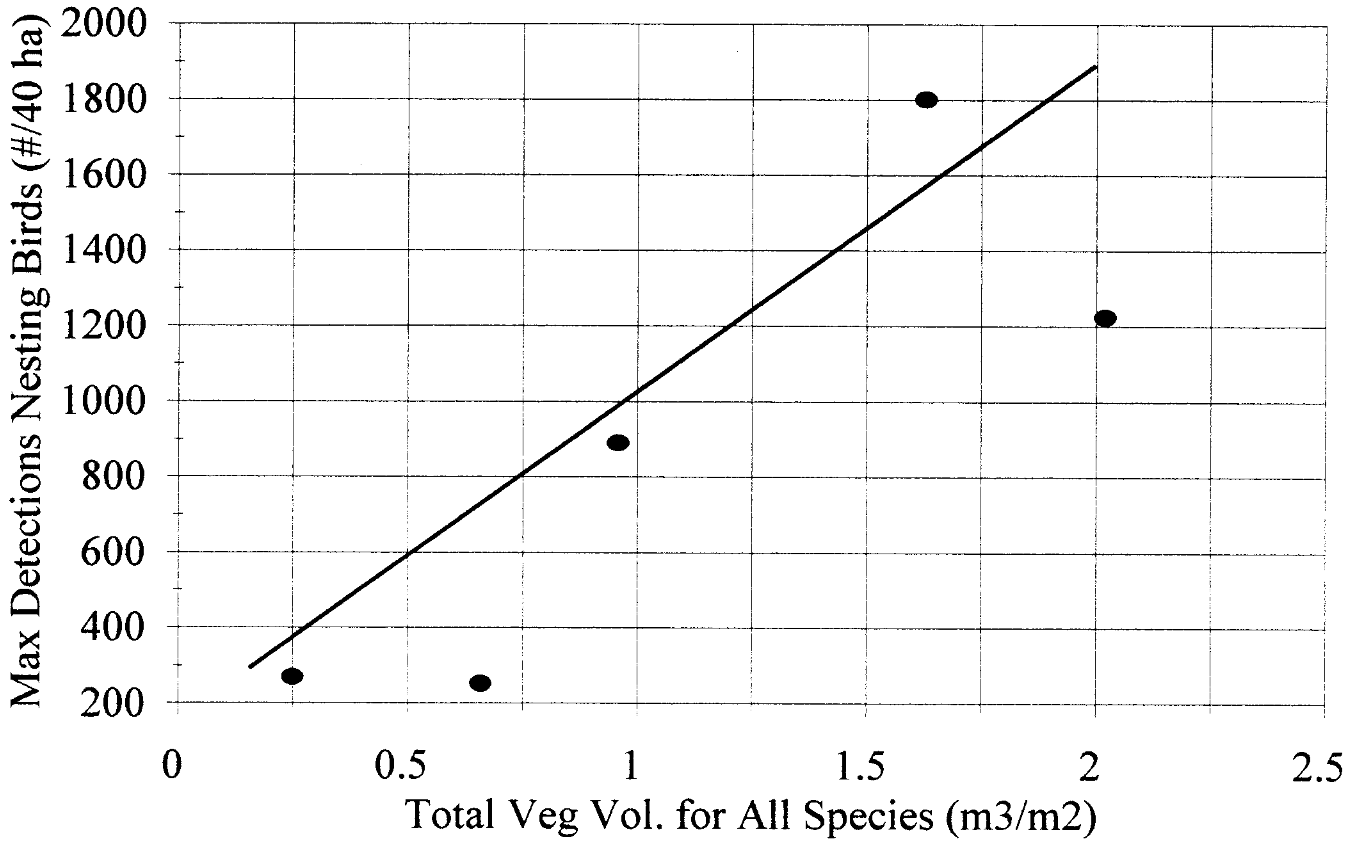


Figure V-30. Relationship between bird detections and vegetation volume of riparian vegetation along the lower Colorado River between RKM 268 and 398, $r2 = .714$, $p < .10$.

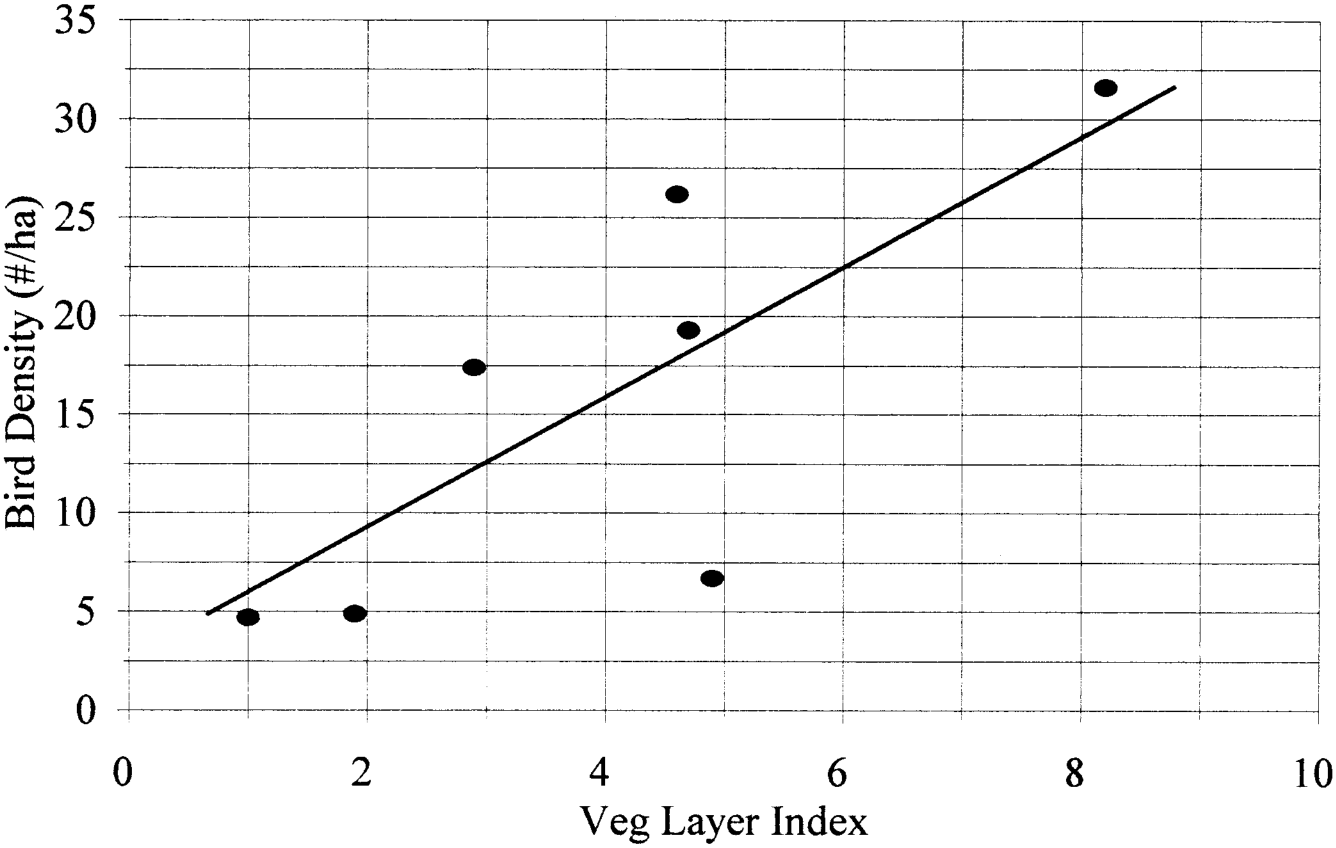


Figure V-31. Relationship between bird densities and riparian vegetation layer index along the lower Colorado River. $r2 = .622$, $p < .05$.

VI. Grand Canyon Beach-Habitat Building Flood
Review of Selected Synthesis Papers

In April 1997 the Grand Canyon Monitoring and Research Center held a symposium reviewing the findings of the March/April 1996 Experimental Beach/Habitat Building Flood. Several synthesis papers were written following this symposium. These were to illustrate the findings within selected areas of resources within the canyon. Three of these papers are directly pertinent to this report. The others, especially sediment and hydrology are important, but should be reviewed by experts more conversant with the topic.

The Beach/Habitat Building Flood was designed to create a high discharge condition that no longer is part of normal operations of Glen Canyon Dam. Several hypotheses appropriate to this report were to be tested. (1) The flood would elevate sediment and recreate "beaches" above normal discharge levels of dam operations. (2) The flood would scour backwaters and improve RCC habitat for native fishes, but may also reduce marsh vegetation in these locations. (3) The flood would scour some of the NHWZ vegetation. (4) The flood would alter geomorphic conditions and riparian vegetation without greatly modifying the fish community or endangered species such as the SWWFC or Kanab ambersnail.

The flood created sufficient discharge and high stage to entrain much sediment and scour a great deal of organic material from the shoreline vegetational communities. On the other hand, the magnitude of the flood was smaller than most pre-dam spring flows and only half the discharge reached during the 1983 uncontrolled release from the dam. The experiment did allow scientists to closely study responses of many canyon attributes and add another data point to improve the sediment transport and other models. Questions asked after doing the flood experiment were, did we learn anything and were the hypotheses validated? Brief commentaries on the synthesis papers written following the anniversary symposium help answer these questions.

Aquatic Food Base Response to the 1996 Test Flood Below Glen Canyon Dam, Colorado River, Arizona.

Shannon, J.P., D.W. Blinn, T. McKinney, P.L. Benenati, K.P. Wilson, and C. O'Brien. 1997.

Scour, Drift and OM Transport. The flood scoured and entrained both benthic primary and secondary producers. The majority of scour and occurrence of organic drift was in the first 48 hours following shortly after arrival of the initial wave. Organic drift shifted from pre-flood dominance by autochthonous organic matter to during-flood allochthonous matter. The flood stage was sufficiently high to scour litter and other material from the shoreline marsh and riparian zones. During the early stages of the flood, this flotsam included large pieces of woody plants from within the riparian zone. This material soon was entrained within eddy recirculation zones but over time eventually moved downstream and either was pulverized or floated into Lake Mead.

The early period of the rising flood hydrograph put much sediment and detritus into suspension resulting in a significant decrease in light intensity in the water. As the peak flow continued, light intensities increased as the water cleared. This was true both near the dam and over a 100 km downstream. Apparently the high discharge scoured most available sediment and debris in the first few days of the flood and thereafter, became sediment starved. The improvement in light intensity within the river appeared to be influential in rapid recovery of the benthic community following the flood.

Pools and Riffles. The flood influenced benthic species in pools differently depending on substrate response. Response of sediment clast composition to the flood was site specific. At Lees Ferry sand increased while gravels and silt decreased; and Nankoweap and Tanner remained 100 % sand. A loss of silt/clay in pools generally means a loss in macroinvertebrate biomass.

Riffles were more susceptible to change from the flood than pools. Post-flood biomass was greater than pre-flood for *Cladophora glomerata*; miscellaneous algae, bryophytes and macrophytes; chironomids, *Gammarus lacustris*, tubificids and gastropods; but lower for lumbriculids.

Summary. Overall, however, *Cladophora* did not change significantly at Lees Ferry or near the LCR but did elsewhere. Chironomids changed little, but *Gammarus* showed a steady increase after the flood. Macro-algae and macrophytes were greatly reduced following the flood. The introduced species *Chara contraria* was greatly reduced, especially in the tailwater area where it was well established.

Although a great deal of benthos and other material was put into drift with arrival of the hydrostatic wave, occurrence of high flows and clear water following the flood experiment may have enhanced recovery of the aquatic food base system. The occasional flood event does not appear to significantly set back the food base for any length of time. There is little in these results, however, to suggest altered methodologies of dam management in order to enhance the food base.

Effects of an Experimental Flood on Fishes of the Colorado River in Grand Canyon

Valdez, R.A., T.L. Hoffnagle, W.C. Leibfried, C.C. McIvor, T. McKinney and R.S. Rogers. 1997.

Native Fishes. The flood apparently had little effect on native fishes in the canyon. Discharge and sediment transport conditions developed during the flood were no different than occasional pre-dam conditions developed during spring runoff. The native fishes are adapted to high discharge and turbid waters.

Survey of native young and adult fishes pre and post the flood event showed little difference in abundance and location. Apparently native fishes were capable of finding refugia to withstand the high discharge, a response they have used over millennia. Humpback chub movement after the flood was no different than pre-flood. Spawning of native fish species occurred as normal with flannelmouth suckers spawning in the Paria River and humpback chub spawning in the LCR. Perhaps a beneficial consequence of the flood event was that the aquatic food base became more diverse downstream and thus the diet of native fishes was more diverse after the flood.

Non-native Fishes. Effects of the flood on non-native fishes were short-term. Some of the young of non-natives were moved downstream. For example, the percentage of young trout in the tailwater-reach declined in surveys immediately following the flood, but their numbers increased downstream. Non-native species, flathead minnow and plains killfish, moved to shoreline and backwaters during the flood. Their numbers decreased near the LCR but increased downstream near Lava Falls, another indication that non-native fishes do not tolerate high discharges as well as native fishes. Densities of non-native fishes recovered within 5 to 8 months after the flood experiment. Most likely the reinvasion of the mainstem was from tributaries and reproduction in backwaters.

The magnitude of the flood discharge was insufficient to alter population dynamics between native and non-native fishes. Non-natives were present in the canyon prior to dam construction but their density and richness have greatly increased since. To reduce native/non-native competition through use of dam operations it is likely that much higher discharges for longer periods will have to become part of long-term dam management. This should be accompanied by an assured source of sediment. Both are unlikely as the dam cannot reach pre-dam high flood magnitudes, dam management will wish to preserve water for hydropower and water delivery, and sediment augmentation is questionable.

Backwaters. Studies of aerial photos following the flood indicate that eight new backwaters were created; however, field surveys do not substantiate this claim. Field surveys occurred following some post-flood high flows which may have altered reattachment bars and filled or modified the "new" backwaters. What is obvious from this experiment and studies during GCES is that backwaters tend to be relatively ephemeral. They can form under particular discharge patterns, a result of scouring and eddy circulation processes, but as discharge patterns change and availability of sediment in transport increases or decreases, the backwaters may be left dry, inundated or filled in. Interim Flows tended to cause fill-in of backwaters and RCC because the daily fluctuations were reduced from normal operations, backwaters were at the upper level of fluctuation and thus susceptible to sediment deposition, and potential for scouring of backwaters was minimal. Utilization of backwaters by native and non-native fishes thus becomes opportunistic.

Planned Flooding and Riparian Trade-Offs: The 1996 Colorado River Planned Flood.
Stevens, L.E., T.J. Ayers, J.B. Bennett, K. Christiansen, M.J. Kearsley, V.J. Meretsky, A.M. Phillips, R.A. Parnell, J. Spence, M.K. Sogge, A.E. Springer and D.L. Wegner.

This paper discusses possible trade-offs among several canyon attributes in consideration of creating managed floods. Most of the trade-offs related to either conditions that have developed post-dam or populations of species, now considered endangered, that survived pre-dam conditions or may not have had a significant density in the canyon pre-dam. One premise of the paper appears to be that post-dam conditions are more acceptable than pre-dam conditions and we should be concerned if we are altering post-dam conditions.

Marshes. Well established marshes in RCC were not greatly affected by the flood. Even velocities of 0.9 m/s did not appear to scour fine soils from the RCC. These marshes were not part of the pre-dam riverine ecosystem but post-dam they have become an important habitat for biodiversity within the canyon. Their ability to withstand a small flood event is significant in that they will continue to offer ecosystem services to many other organisms in the canyon.

Channel margin marshes did not fair as well as RCC marshes. They were either buried or scoured by the flood. One potential benefit of burial is that decomposing buried vegetation may increase groundwater nutrient levels, thus enhancing growth of riparian vegetation. There is some consideration that coarse sediment deposits that support riparian vegetation may have insufficient nutrients compared to finer deposits. Although finer deposits do carry more nutrients, there is little evidence to support a premise that riparian species require fine soils for recruitment and maintenance. However, fine soils with higher nutrient levels will increase the potential for success of these species.

Riparian Vegetation. Sand bar and channel margin riparian vegetation within the flood discharge stage were impacted by sediment deposition. Herbaceous vegetation was buried under 1-2 m of sediment in some locations. Here again, decaying herbaceous vegetation may add nutrients to groundwater. Woody perennials that were buried by sediment rapidly recovered by sprouting up through the deposits. Seed sources on the ground were either buried or washed downstream.

The experimental flood apparently was not high enough to have a significant impact on the riparian zone (NHWZ). Although herbaceous vegetation was buried, it is likely that this component of the riparian vegetational community will quickly recover. Along other rivers that have little or no regulation, the near-shore vegetation often is buried by small and large floods, but quickly recovers (Stromberg et al. 1991, 1997). Recovery is a process of vegetative encroachment through the new sediment layer by rhizomatous plants or invasion by seeds.

The OHWZ riparian vegetation was not affected by the flood. Flood stage at 1,275 cms is well below the OHWZ vegetation which occurs above the 2,800 cms stage. Earlier studies following other floods have also showed little response of vegetation in the OHWZ to these events.

Endangered Species. Concern over impacts on several endangered species required study of their responses to the flood. Kanab ambersnail was closely studied. Prior to the flood, many individuals were moved above the flood stage into territory occupied by other individuals, a procedure normally opposed by the USFWS in managing endangered species. Many of these were lost to predation by small mammals. Those that remained below flood stage were probably lost and become part of drift and the downstream food base.

Sites of the southwestern willow flycatcher were also closely watched during the flood experiment. Their nests were well above flood stage and most of associated marsh areas were only slightly impacted. Northern leopard frog in the Glen Canyon reach was underground during the flood and thus not impacted.

Avifauna. There is little evidence that either water fowl or other birds that use the riparian zone or other parts of the canyon were affected by the flood. The flood was of short duration and most of these species could move out of harm's way.

VII. System Integration

In an attempt to bring together the many factors that influence the riverine ecosystem, show their importance to the attributes of interest to resource managers, as well as their interrelationships, all of the conceptual sub-models have been combined into on overall conceptual model (Fig. VII-1). In order to create a semblance of understanding, this diagram is missing a few features found in the sub-models. On the other hand, it is possible to use a diagram of this type to explain the interactive changes taking place among variables as selected driving factors are altered. These will be taken in the order they were used in discussions of each resource attribute above, but for purposes of simple example, one can pick any point within the diagram and work backwards along arrows or forwards. Taking beaches and elevated sediment deposits, it is possible to see that these are formed or influenced directly by sediment in transport which is driven by discharge. They are also a product of the dynamics of eddy currents which is also a product of discharge rates. They, in turn, are a sediment source for the eddy, an edge for backwaters (RCC) which are "habitat" for young fishes, waterbirds, other creatures that depend on that type of shoreline habitat, and marsh vegetation. Consequently, changes in attributes and processes along these pathways (arrows) may change other components, the amount of change dependent on the "strength" of the arrow.

Discharge. Of all variables considered in this document, discharge of water from the dam with its various parameters is the only driving variable that has no response function. The factors that control discharge are outside the ecological realm of the riverine ecosystem along the mainstem Colorado River within the canyon. Characteristics of discharge that are of concern as drivers of other variables include highs and lows, fluctuation ranges, and rates of up-ramping and down-ramping. During normal dam operations prior to research and Interim Flows, highs were close to 849 cms (ca. 30,000 cfs) and lows near 28 cms (1,000 cfs). Daily fluctuations were as great as 566 cms (20,000 cfs), and ramping rates often were as great as 113-226 cms/hr (4-8,000 cfs/hr). Interim Flows and Modified Low Fluctuating Flows (MLFF) greatly reduced high flows to 556-708 cms (20-25,000 cfs), daily fluctuations to 142-226 cms (5-8,000 cfs), and ramping rates to 113 cms/hr (4,000 cfs/hr) up, and 42 cms/hr (1,500 cfs/hr) down.

Although MLFF has greatly reduced the impacts of a highly fluctuating river, we have learned a great deal about how the system responds to changes in discharge over the years of GCES. If discharge is altered, the following responses are directly altered: (1) amount of debris and other materials, including organisms, dislodged and/or transported on and below the surface, (2) amount of sediment in suspension, (3) amount of sediment moved along the channel bed, (4) amount of sediment eroded and deposited along channel margins and in eddy complexes, and (5) amount of shoreline that is wetted or exposed. Each of these response variables becomes important as a driving variable for other components of the riverine system.

Changes in the capacity of the river to dislodge and/or transport debris and other materials directly influences the availability of autochthonous and allochthonous materials downstream from the upper reaches of the canyon which supports primary productivity. These materials are the energy source for the downstream system. Low steady flows may not transport much material, while high discharges may dislodge and transport a large amount of material.

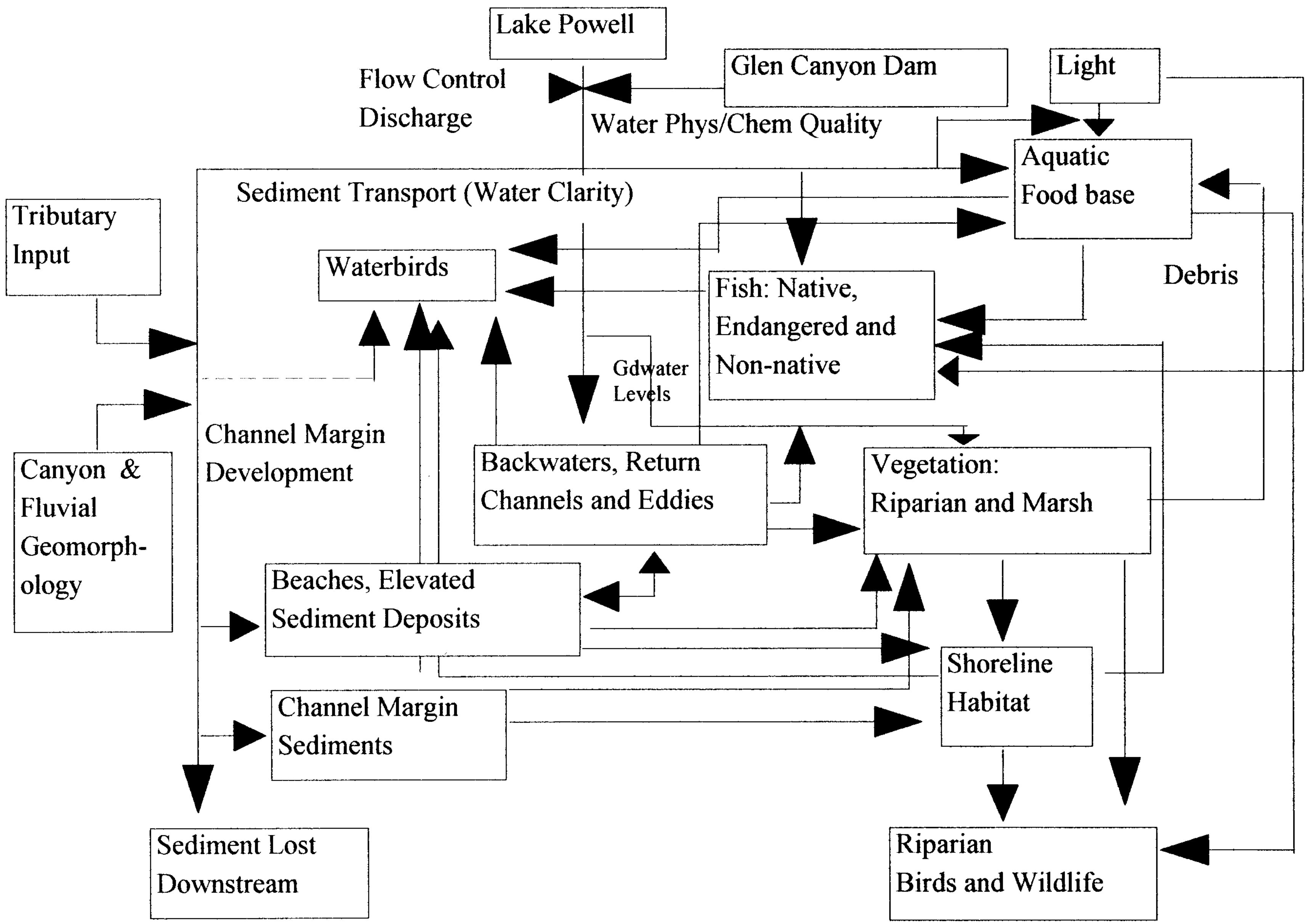


Figure VII-1. Conceptual model of interrelationships among abiotic and biotic components of the Grand Canyon riverine ecosystem

Discharges with large fluctuations also dislodge many primary producers in the Glen Canyon reach, and remove occasional invertebrates and debris from shorelines.

Capacity to carry sediment in suspension is geometrically related to increasing discharge. This is also true with the amount of sediment that is moved along the channel bed. As river velocity increases more and more sand particles are moved. Smaller particles, that is, finer sand, silt and clay is put in suspension by lower velocities. Continued sediment transport with little inputs from tributaries will gradually deplete the system while deposits in Lake Mead continue to grow. Sand in suspension in a high velocity river causes scouring and abrasion, a phenomenon that not only affects geomorphological attributes but biological, often removing riparian vegetation. As the amount of sand in suspension increases, the amount that is picked up by the sediment rich river decreases. At this point, when velocity begins to decrease, sediment falls out and is deposited.

The process of erosion and deposition of sediment is one of the most important functions of discharge as a driving variable. Pre-dam conditions had sufficient inputs of sediment that, when sediment was eroded during floods, sediment in suspension readily replaced it when the flood subsided. Under post-dam conditions sediment is constantly being removed from the system unless some event in the watershed of a tributary brings new supplies of sediment. Consequently, all components of the riverine ecosystem that are dependent on existence of sediment deposits are affected. These deposits are platforms for riparian vegetation and associated fauna, and recreational camping. Deposition may form platforms for vegetation but it also buries vegetation, many marsh areas at the heads of RCCs being inundated and then buried under sediment during high discharge events. The sand bars and return channels formed in eddy recirculation zones also form habitat for many organisms. The RCCs may be used by young native fishes and, as they fill in, become locations for development of marshes. The bars form shoreline habitat which above water is used by shorebirds and below water is habitat for fishes.

Fluctuating discharge constantly inundates and exposes portions of the shoreline and marginal sediment deposits. Inundation may drown some habitats and the species they support, for example marshes, while exposure may cause desiccation of habitat. Primary producers in the upper reaches, mainly the algae *Cladophora*, have been shown to be very susceptible to extended periods of exposure. Rapid changes in river stage resulting from fluctuating flows cause elevated hydraulic heads in sediment deposits which tend to cause surface erosion as the water seeps out. These rapid changes also increase potential for calving of above-water sediment deposits causing sediment to move from an elevated location available for terrestrial organism use to storage within the channel or eddy recirculation zone.

Sediment in Transport or Storage. Although sediment in transport is a response variable to river discharge, it is also a very important driving variable for many other canyon attributes. It influences many components of the aquatic and semi-aquatic riverine ecosystem. As pointed out above, sediment in transport is deposited as the velocity of the river decreases. This can occur when discharge from the dam decreases, or in locations where the energy of the river is dissipated, such as RCC. Both of these occurrences cause sediment deposition, one forming bars (separation and reattachment) and the other reducing low elevation zones such as at the heads of RCC where small bodies of open water may be used by young fishes because the water warms, and marsh vegetation may develop on the wetted, but not permanently inundated substrate. Sediment deposited in these areas may be finer than that carried by the higher velocity mainstem. Fine sediments often are higher in nutrients than coarse sediments and thus these RCC or backwater zones may be enriched. Nutrient enrichment enhances ecesis (i.e., recruitment and successful establishment) of marsh and riparian vegetation.

Sediment in suspension in the mainstem influences every trophic level of the aquatic ecosystem. Water turbidity reduces transparency and depth of penetration of PAR (photosynthetic active radiation), thus controlling the amount of primary production. Only in the Glen Canyon reach from the dam to Lees Ferry, is the water transparent most of the time. Here, primary production is at its peak. Once tributaries input sediment as from the Paria River, transparency of the river decreases reducing primary productivity. Prior to dam construction the fish community in the Colorado River included eight native species. Most of these fishes were adapted to turbid water and fed freely near the surface during daytime. With advent of clearer water under post-dam conditions, these fishes now avoid surface waters during the day, only feeding near the surface at night. Water clarity also makes these native fishes more susceptible to predation by non-natives which visually seek prey. This is especially true for young fish in clear backwaters and channel margins where river velocity is low and sediment in transit is reduced.

Availability of primary producers and associated epiphytes and water clarity also drive the presence and abundance of waterbirds. Many waterbird species dive, wade or dabble for food. Ability to find sufficient food for maintenance of the many waterbird species that winter in the canyon is dependent on the aquatic food base being available near shore and visible. Consequently, reach width and distance downstream from the dam are important variables in determining distribution of waterbirds. Wider reaches tend to have shorelines more conducive to wading and dabbling birds, while the distance downstream is a direct correlate for sediment in suspension and water clarity.

Sediment in storage in the channel also influences several trophic levels. Sand tends to accumulate in pools above rapids and near eddies. Sand substrate is not conducive for attachment of periphyton such as *Cladophora*, thus these areas are low in primary productivity. Sand substrate also is unstable and thus is not readily used by benthic invertebrates which prefer hard substrates for attachment. Sand moving along the channel bed prevents development of redds by native and non-native fishes. Most fishes prefer very coarse sand or small pebbles for forming redds.

Aquatic Biological System. The aquatic food base, a response variable to river conditions including discharge, sediment in storage, substrate and water chemistry, is in turn a driving variable for higher aquatic trophic levels, primarily fishes. The status and condition of the fish community, a response variable to availability of aquatic food, is also a driving variable for piscivorus organisms. These include predatory fishes and birds (e.g., bald eagle). There is little evidence that the aquatic food base is limiting to the fish community. However the quality of the food base changes from the dam to Lake Mead. In the upper end it is highly productive, while in the lower end it is composed mostly of drift, allochthanous materials and a limited number of benthic invertebrates. These downstream changes are driven by water quality, both sediment in suspension and temperature.

In most cases, the fish community composes the upper trophic levels in the aquatic system. Only when predation from eagles, for example, takes spawning fish is there a higher trophic level. Trout lost by standing also are consumed by scavengers. Both of these examples of consumption by a higher trophic organism occur because of fluctuations in river discharge. During discharge peaks, water pooled near the Nankoweap Creek inflow allowed spawning trout to move upstream. These fish were preyed upon by wintering bald eagles. Trout were also stranded in drying pools in the Glen Canyon reach during downramping periods of fluctuating flows.

Terrestrial Biological System. Development of riparian vegetation is a response variable to many of the riverine conditions created by dam operations. Pre-dam river flows were forceful enough to prevent establishment of a riparian community on the banks of the river exposed during baseflows. Post-dam conditions have enhanced recruitment conditions for riparian vegetation along the channel margins (NHWZ), but because the dam was constructed after many non-native, riparian plant species had been introduced into the Southwest, the riparian community is dominated by non-native woody species, primarily tamarisk. The stability of this community to high flows was shown in 1983 when nearly 60% of it survived flows as high as 2,632 cms (93,000 cfs) and in 1996 when most of it survived an experimental flood of 1,274 cms (45,000 cfs). Conversely, these high discharges carrying much sediment tended to greatly reduce marsh communities, another form of riparian vegetation, either through scouring or burial. Recent Interim Flows and MLFF have dropped the river stage and the groundwater level supporting riparian communities. Consequently, a new zone (New Dry Zone) has been exposed and available for encroachment of riparian vegetation, while the NHWZ vegetation has been stressed and mesic species have declined in abundance.

Riparian and marsh communities may be response attributes to many of the riverine conditions, but their existence, structure, and vegetative status function as a driving variable for many other terrestrial organisms. Avian populations along the river are closely dependent on the availability of riparian vegetation. Some species still utilize vegetation in the OHWZ, but many are now found in NHWZ trees. The endangered southwestern willow flycatcher is dependent in the riparian zone and utilizes tamarisk trees for nesting. These trees are usually located near some willows and marsh areas. Small mammals and reptiles also depend on the NHWZ riparian community as habitat.

Individuals within the terrestrial vertebrate community (e.g., birds, mammals, lizards, etc.) are prey for top carnivores. Some birds which have taken advantage of increased invertebrate food sources above the river and in riparian vegetation are food for predatory birds such as the peregrine falcon. Small mammals and reptiles may be food sources for larger mammals such as coyotes.

Conclusion. The riverine ecosystem includes many interactive components. Some of these solely function as driving variables, while others function both as driving and response variables (Table VII-1). Abiotic factors such as discharge, sediment in transport and geomorphology strongly influence the response of the biological communities within the canyon.

The level of synergism among the abiotic factors determines the significance of their influence on biotic factors. High discharge and narrow reaches are not suitable habitat conditions for most organisms. Moderate discharge, little fluctuation and wide reaches create habitats conducive to both aquatic and terrestrial organisms. The riverine ecosystem within the canyon is complex and no two places have the same set of conditions. Therefore, there is a need to better understand how the many factors interact, and how with a change in one factor, some or all of the others will respond. This report has attempted to illuminate some of the interrelationships among components which should guide future research and monitoring efforts, assuring they are designed in an integrated fashion.

Table VII-1. Interaction between and among driving and response variables downstream of Glen Canyon Dam. X to XXX is low to high interaction or interdependence. ? is a questionable association. AFB is aquatic food base, PP is primary productivity, SP is secondary productivity.

Response Variables	Driving Variables: Light PAR	Canyon Geomorph-ology	Discharge	Sediment Transport	Sediment Deposits	AFB Prim. Prod.	AFB 2ndary Prod.	Fish	Waterbirds	Riparian Veg.	Marsh Veg.	Birds	Mammals and Reptiles
Light		X		XXX									
Canyon Geomorph-ology			X	XX	X								
Discharge		XX											
Sediment Transport		XX	XXX		XX								
Sediment Deposit		XXX	XXX	XXX						X	X		
AFB-PP	XXX	X	XX	XX	X			X	XX				
AFB-SP	X	X	XX	XX	X	XXX		XX	XX	X			
Fish	X	XXX	XXX	XXX	XX	XXX	XXX				?		
Waterbirds		XX	XX	XX	X	XX	XXX	XX		X	XX		
Riparian Veg.	XXX	XXX	X	X	XXX						?	?	
Marsh Veg.	XXX	XXX	XX	X	XXX					X		?	
Birds						X	XX	XX		XXX	XX	X	?
Mammals and Reptiles							?		?	XX	X	X	

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Appendix

List of Reports and Articles Reviewed

Terrestrial Reports (Avian and Riparian)

TER 0100	Winter Bald Eagle monitoring: Winter Bald Eagles in Grand Canyon 1993-1994. (Sogge and Tibbits)
TER ????	Influence of fluctuating flows from Glen Canyon Dam and effects of human disturbance on wintering Bald Eagles along the Colorado River in Grand Canyon, AZ (Brown and Stevens).
TER 0101	Evaluation of the current and historical riparian vegetation trends in Grand Canyon using multitermporal remote sensing analyses... (Waring)
TER 0102	Effects of interim flows from Glen Canyon Dam on riparian vegetation (Stevens and Ayers)
TER 0104	Status of Southwestern Willow Flycatcher along the Colorado River between Glen Canyon Dam and Lake Mead. 1993, 1995. (Sogge et al.)
TER 0105	Grand Canyon avian community monitoring, 1993-94. (Sogge et al.)
TER 0106	Breeding and wintering waterfowl on the Colorado River from Glen Canyon Dam to Lees Ferry. (Graham and Pinnock).
TER 0106	1994 Breeding Bird Survey along the Colorado River from Glen Canyon Dam to Lees Ferry 1994 and 1995 reports. (Graham and Pinnock)
TER 0106?	Avian community monitoring in the Grand Canyon (Petterson and Spence) 1997
Article	Dam and geomorphological influences on Colorado River waterbird distribution, Grand Canyon, AZ. (Stevens et al.)
TER 0164	Bridging the Gap: Transition monitoring of riparian vegetation from Glen Canyon Dam to Pearce Ferry. (Spence, Kearsley et al.)
TER 0600	Monitoring and evaluating the impacts of Glen Canyon Dam Interim Flows on riparian communities in Lower Grand Canyon. (Hualapai Tribe)
TER 0600	Status of riparian resources in Lower Grand Canyon, FY 1995 (Hualapai Tribe)

Aquatic Reports (by contractor)

BIOWEST	
AQU 0600	Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Ck. to Lake Mead (project taken over by SWCA) ---- also Hualapai aquatic resources study (Leibfried for SWCA)
AQU 0701	Life history and ecology of the endangered humpback chub (Valdez)
AQU 0701	A geomorphic assessment of subadult humpback chub habitat in the Colorado River in the Grand Canyon (thesis draft)

Glen Canyon Environmental Studies

AQU 0900	Photosynthetically available radiation in the Colorado River (Yard)

University of Arizona Master's Theses

AQU 0433	An evaluation of habitat conditions.... below Atomizer Falls LCR (Mattes)
AQU 0434	Distribution, abundance and composition of fishes in Bright Angel and Kanab creeks.... (Otis)
AQU 0435	Spawning, movement and population structure of flannelmouth sucker in Paria River (Weiss)
AQU 0429	Distribution and abundance of fishes in Shinumo Ck in the Grand Canyon (Allan)

Arizona State University

AQU 0400	Ecology and conservation biology of humpback chub in the LCR (Douglas/Marsh)

US Fish and Wildlife Service

AQU 0200	Habitat use by humpback chub in the LCR and other tributaries (Gorman)

National Park Service/NAU

AGU 0100	Aquatic food base studies (Blinn, Stevens and Shannon)
PB88-183454	Cladophora glomerata and its diatom epiphytes in the Col. River : distribution and desiccation tolerance (Usher , Blinn et al)
WAQ 0100	Influence of geochemical processes on nutrient spiraling within recirculation zones ... (Parnell et al)

Arizona Game and Fish Dept.

AQU 0300	Effects of Glen Canyon dam operations on Gammarus lucustris in the Glen Canyon dam tail water (Ayers and mcKinney)
AQU 0302	Effects of nighttime atmospheric exposure on proximate composition of periphyton (Ayers and McKinney)
AQU 0307	Spatio-temporal distribution, habitat use and larval drift of native fishes in the LCR (Robinson et al)
AQU 0313	Limnology and the distribution of native fishes in the LCR (Robinson et al)
AQU 0314	Temperature tolerance of humpback chub and Colorado squawfish.... (Lupher and Clarkson) dft report
AQU 0317	Glen Canyon dam and the Colorado River: responses of the aquatic biota to dam operations. (Morgensen et al) interpt
AQU 0322	Concentration and transport of particulate organic matter below Glen Canyon dam (Angradi and Kubly) in J. AZ/NV Acd Sci.
AQU 0333	Effects of atmospheric exposure on chlorophyll a, biomass and productivity of te epilithon of tailwater river. (Angradi and Kubly) in Reg Rivers and Research
AQU 0335	Changes in temperature of backwaters during fluctuating vs short term steady flows... (Hoffnagle) ppdrft

AQU 0336	Distribution and prevalence of the Asian fish tapeworm... (Brouder and Hoffnagle)
WAQ 0300	Effect of different flow regimes on periphyton standing crop and organic matter and nutrient loading rates...... (Ayers and McKnney)
WAQ 0303	Water chemistry and zooplankton in the Lake Powell forebay... (Ayers and McKinney) drftfnl
PB88-183439	Changes in water quality parameters and fish usage of backwaters during fluctuating vs short term steady flows.... (Hoffnagle)
PB88-183462	Effects of varied flow regimes on aquatic resources of Glen and Grand Canyons (Maddux, Kubly et al)

Terrestrial Reports
Comments by Duncan Patten

Winter Bald Eagle Monitoring: Winter Bald Eagles in Grand Canyon 1993-1994.
TER 0100. (Coop. 8029-8-0002). M.K. Sogge and T.J. Tibbitts 1994.

This project continues the bald eagle surveys taken in earlier years using helicopter, ground surveys in the canyon around Nankoweap Creek and surveys from Nankoweap Overlook.

Authors attempted to correlate trout and eagle use at Nankoweap with dam discharge. No correlation was found, but using a days delay of flow in 1994 they were able to show an inverse correlation between trout in Nankoweap and discharge. It appeared that there were more trout when mainstem flows decreased.

Eagle foraging success was higher in Nankoweap than in the nearby river, which supports earlier findings. In 1993/94 a pair of eagles defended an area at Nankoweap and may have caused reduction in foraging in that area by other eagles.

This report also evaluated monitoring strategies for eagles. Attempts at regular surveys from Nankoweap Overlook were stymied by bad weather conditions and that location was not considered a place for consistent data. Their recommendation was to cancel river trips and surveys at Nankoweap Creek, do not do the overlook surveys, but continue to do helicopter surveys because these give a better estimate of the total eagle population through the Park and do not emphasize the opportunistic foraging of eagles at Nankoweap.

Influence of Fluctuating Flows from Glen Canyon Dam and Effects of Human Disturbance on Wintering Bald Eagles Along the Colorado River in Grand Canyon, Arizona.
B.T. Brown and L.E. Stevens. 1991.

This report includes data from eagle surveys in 1990 and 1991. The Grand Canyon is considered an eagle stop over in the winter, and the eagles function as opportunistic forages. One location that has a high number of eagles, and yet a small percentage of those found, is the Nankoweap Creek confluence with the Colorado. Numbers here are high in February.

The report discusses flow dependent spatial foraging patterns at or near Nankoweap Creek.

It was discovered that as flows increase, foraging attempts of eagles at Nankoweap also increase by 50 - 100%, while foraging attempts along the river and at pools decrease. Their data for 1991 support the latter statement while data from 1990 are ambiguous. It appears from the data that the foraging along the river declines rapidly after the discharge reaches over 25,000 cfs.

Most foraging (99%) by eagles is for rainbow trout.

This report addresses monitoring approaches to bald eagles. Correlations were made between counts from the river at Nankoweap and from Nankoweap overlook. The recommend monitoring from the rim (overlook) in February and March.

Later studies on eagles does not support this recommendation.

Current and Historical Riparian Vegetation Trends in Grand Canyon, using multitemporal remote sensing analysis of GIS site. Final Report.

TER 0101. G.L. Waring. 1996. Coop. Agreement CA 8000-8-0002

The report uses aerial photographs from 1965, 1973, 1984, 1990 and 1992 of the GCES GIS reaches 2, 4, and 5 in Grand Canyon to determine changes in riparian vegetation cover in the New High Water zone (NHW) and along the active channel margins. The assumption for selection of the photo years was to represent approximate pre-dam conditions (1965), early vegetation cover following normal operations and pre-1980s floods conditions (1973), post-1980s floods conditions (1984), pre-interim flow conditions (1990) and post one year of interim flows (1992).

Selection of photo years may have been dictated by availability of photos, but they do not fairly represent the conditions they are intended to represent. For example, 1965 is two years after the dam was closed and a coffer dam was used during construction. 1973 is ten years prior to the large 1983 floods and thus cannot be considered legitimate conditions immediately pre-flood. The 1990 photos are just prior to the research flows which altered riparian conditions prior to the initiation of interim flows, and 1992 is only one year of interim flows and may not fully present the consequences of interim flows. In addition to selection of years, the photo dates (i.e., months) are highly variable, including months of May, June and October. The use of the particular aerial photos allows comparisons among the dates selected, but they do not allow a fair comparison of changes in riparian vegetation in response to particular dam operations or discharges and thus the information may be difficult to use in attempts to model integration of riparian vegetation changes relative to dam operations for future management purposes.

The author makes some assumptions in interpretation of the information from the aerial photographs which may not necessarily be valid. For example, the 1984 photo (post-1983 flood conditions) was considered a good context or baseline for evaluating interim flow or future dam operations. Also, that apparent vegetation stability or increase in cover is considered to support the goal of interim flows, that is, "minimizing resource losses" along the riverine system.

Adjustment of 1990 vegetation cover to make 1990 data more compatable to other years probably is a logical process, but it could be challenged because the low levels of cover compared to other years is assumed to be mapping differences by individuals rather than actual differences. A regression equation was used to "correct" the data, not a correlation coefficient as stated. Multiple stepwise regression analyses allows one to determine cause of variability of data, while correlations, which were not done, show relationships, but no cause and effect.

In the results, the author's interpretation of differences between pre-dam 1965 and 1992 riparian vegetation cover implies a continued increase in cover over this period. In reality, the "clock was reset" in 1983/84 and no legitimate comparisons can be made between 1965 and 1992, other than they are different points in time. Comparison of 1973 and 1984 also cannot be interpreted as changes due to the 1983 flood. This would assume that there was no change between 1973 and 1982 (the year just prior to the flood) which probably is not the case.

In Table 3, data are presented for sides of the river. Would it not have been better to compare riparian vegetation cover relative to various sediment deposit types, for example, those being identified by Schmidt.

For future modeling purposes it might be possible to use the data from these photos in two series, if 1982 information were available. The 1984-1990-1992 series shows an "exponential" increase in riparian vegetation with a peak in 1992. This could be interpreted as a slow recovery following the 1983 flood with a gradual increase in the rate of riparian vegetation establishment. If one could establish a 1965-1973-1982 series, might not we see a gradual development of riparian vegetation following the closure of the dam with establishment "exponentially" increasing through 1982 prior to the 1983 flood. If this were the case, 1982 cover may be as great if not greater than 1992.

Assuming a riparian vegetation recovery (or development) curve shows slow early recovery with more rapid later recovery following a disturbance such as a flood, one might compare this curve with a sediment deposition curve. The sediment deposition curve shows rapid degradation following a depositional disturbance such as a flood, with degradation and "stability or equilibrium" of sediment deposits being achieved in time (e.g., ca. ten years). These similarities in response to disturbance may be appropriate for consideration in development of future integration models of the two phenomena.

It is curious in reviewing the data from this report that the 1965 photos do not show any NHW zone riparian vegetation below the LCR. Is this still the effect of LCR flooding while the upper reaches are beginning to show the intrusion of riparian vegetation in a dam controlled NWH zone? It is also of importance to future dam operation management decisions that the 1984 photos show a "rejuvenated" OHW zone riparian zone following the 1983 floods of approximately 92,000 cfs. This argues for regular floods to maintain this zone or, at least, the lower portions of this zone.

The information from this study can be closely related to on-the-ground research information from studies during the research flows and during interim flows. Response of riparian vegetation during research flows based on long-term, permanent quadrat data support the findings of this study when 1990 and 1992 photos are compared.

The effects of interim flows from Glen Canyon Dam on riparian vegetation along the Colorado River in Grand Canyon National Park.

TER 0102. L.E. Stevens and T.J. Ayers. Coop. Agreement CA 8021-8-0002.

This report has several chapters, each dealing with a separate wetland component of the canyon riverine system. This is a comprehensive report and should, in general, be used as a guide for future studies of marsh and other riparian communities along the Colorado River.

Chapter on "effects on fluvial marshes" uses some methodologies cited only in a published paper, while others are explained here. Unfortunately for anyone reading this report, the methods are thus not fully clear, but since they have had peer review they are acceptable to the scientific community.

The use of inundation frequency will be useful in future integration models, to sort out the responses of the various riparian communities to dam discharges and their associated downstream stages.

The use of geomorphic information is important, and the series of profiles for the marshes should allow generalization toward future models. The shapes of sand bars is also apparently important to colonization by marsh species. The differences in profiles of marshes above and below the LCR are not as obvious as the discussion seems to point out. The authors suggest that the 1993 LCR flood caused some major differences above and below the LCR. Scouring below the LCR reduced the marsh cover as shown in some figures, but this is not obvious in others. The authors do not give evidence of a significant difference among marshes in different canyon or geomorphic settings.

Throughout this chapter and the chapter on Salix water relations, *Salix exigua* is considered as a marsh plant, albeit one that colonizes when the marsh area is no longer regularly inundated. *S. exigua* is also used as an indicator of water stress (see following discussion) in marshes. It is questionable whether *S. exigua* can truly be considered a "marsh plant", but rather an early riparian colonizer. It may be a useful species, however, in developing woody plant response models to various levels of inundation and river stages.

Chapter on "xylem water potential of *Salix exigua*" uses the willow species as an indicator of moisture stress. As a early colonizer of sand bars, which often have wide moisture gradient over time and space, *S. exigua* may be appropriate as an indicator of locations of greater moisture availability, but not necessarily a "moisture stress indicator". In order to determine daily xylem potential fluctuations, the authors measured water potential at pre-dawn and midday. Predawn has generally be recognized to be dawn +/- 2 hours or less, not from midnight. Hydration of the plant tissue continues until shortly after sunrise, thus a midnight reading is too early for full rehydration. Midday is generally recognized to be 1400 hrs +/- 1 hr, not 1100 to 1630 hr. With these wide ranges in xylem potential readings, the data from this study can only be used as trends and general indicators, not specific responses to external conditions.

Analysis of stem growth uses dependent or related variables as independent variables in the regression equation, for example, stem growth is related to stem length, an indicator of prior conditions for that stem. Thus stem length is not independent of stem growth, especially when calculating growth as a percentage of total stem length.

Salix exigua establishes over a wide range of conditions. The marsh and lower edge of the sand bar are only two of these conditions. They tend to be on one end of the moisture gradient. Was it possible to sample willow on the very dry end of the moisture gradient where willow still exists? This type of information would have put the xylem water potential data in a broader perspective. Regardless, this information on water potential demonstrates at least one of the processes that controls the distribution of riparian, and perhaps marsh, species along the riverine corridor in Grand Canyon.

The chapter on "effects of interim flows on non-marsh species" uses long-term quadrats, available for future data collection. The importance of this study is identification of a "new dry" zone that has developed because of the controlled lower stages resulting from interim flows. Thus the NHW zone can be divided into a zone that is periodically wet, and has marsh species and other species requiring regular inundation (this the authors have divided in geomorphic types), and the new dry zone which is commonly above any discharge.

Significant changes in vegetation composition occurred between 1992 and 1993 as explained by changes in eigenvalues from DCA for the various axes. Axis 1 apparently is a moisture gradient axis, thus if the eigenvalue is reduced between 1992 and 1993, this means that the variation in the data is less explained by that axis. It does not necessarily mean that dryness has become the explanatory factor in place of a moisture gradient. But there is no doubt that, based on species composition, that the number of drought tolerant species increases between 1992 and 1993.

The increased occurrence of *Populus fremontii* in the lower riparian zone, especially in the narrow canyon may be a result of less beaver activity in that zone, but it also may indicate that conditions established in the 1990s may be more conducive to their recruitment.

Chapter V on application of GCES GIS analysis to riparian plant diversity shows how the GCES GIS capability can be used to help analyze variability in riverine data. In this case, the GIS capability was used to test hypotheses on species diversity, which it did quite well. However, there were many other "tests" that could have been accomplished with the same GIS capability. These included the relationships between species and riverine attributes such as geomorphology and other factors that are in the GIS data base. If the full GIS data base is available during the integration period of this study, requests may be made for various tests of relationships, both paired and multiple approaches. These tests may be compared to multiple regression models and other models being developed by GCES and integration project scientists.

Status of Southwestern Willow Flycatcher Along the Colorado River between Glen Canyon Dam and Lake Mead: Summary 1993.

TER 0104. M.K. Sogge et al. 1993.

This is a report on sightings of Southwestern Willow Flycatchers (SWWFC) along the river based on an series of extensive survey trips. This report attempts to describe the locations where SWWFC were detected and also discusses SWWFC biology, Brown-headed Cowbird predation and management recommendations for SWWFC sites.

The descriptions of vegetation at the sighting locations is very qualitative. There should have been better quantitative sampling and the data should have been tied to riparian vegetation sampling. The locations are described below in order to give a sense of the vegetational relationships of the birds.

RM -9	A small wetland areas w/cattails, dense tamarisk in wet areas, tall Salix gooddingii (SAGO) behind marsh. (patch size 1.0 ha)
RM -8.8L	Tamarisk patch w/seepwillow (Baccharis) along the river. (patch size 1.2 ha).
RM 46.5 R	Saddle Canyon area. Dense tall tamarisk w/ scattered short willows and a wetland strip along the river. (patch size 0.8 ha).
RM 50.5	Dense tall tamarisk bordered by sandy bay with some willows throughout the border of sandbar, horsetails common. (patch size 0.5 ha)
RM 71 L	Cardenas Marsh. Dense tall tamarisk patch bordered by willow, seepwillow and small marshy area. Tall SAGO nearby. (patch size 0.9 ha)
RM 260 L	Quartermaster Canyon. Dense patch of tall SAGO and tamarisk. Large cattail marsh behind riparian strip. (patch size 0.7 ha)
RM 276.7 R	Dense tall willow (Salix exigua and S. gooddingii), flooded at base by lake. 6-8 m of tree exposed above water line.

There are three common descriptors for most of the sites. Tamarisk stands, tall willow nearby, and marsh or wetland vegetation (e.g., cattail) nearby.

Management recommendations for the nest or detection sites is to close them and reduce recreational use.

Because there is some overlap between this study and the riparian resource study of the Hualapai downstream, it would have been helpful to show the connections.

Status of Southwestern Willow Flycatcher along the Colorado River in Gand Canyon National Park — 1995.

TER 0104. M.K. Sogge et al. 1995

This is a continuation of the Southwestern Willow Flycatcher study. In this case surveys were made of historically known sites of SWWFC but these were limited to RM 46 to RM 71 (Cardenas Marsh). In this reach, 3 territorial non-breeding males were detected and one breeding pair.

Males wer at RM 50.5 L, 51.4 L and 65.3 L. The pair was at RM 50.5 L.

Brown-headed Cowbirds were at all locations and were noted to have parasitized a nest.

The breeding pair were at a habitat with large patch of dense tall tamarisk adjacent to small backwater area and a sandbar. Nest was in a tall tamarisk.

Authors noted that detections of SWWFC are generally in areas dominated by tall tamarisk and willows in the NHWZ. They did not use the semi-arid species in the OHWZ (e.g., Acacia, and mesquite).

NHWZ vegetation sizes at SWWFC sites were about 0.4 to 0.6 ha. nesting patches were 0.3.

They noted that interim flows could not inundate nests because they were above 3.5 m in the trees.

Their management recommendations were the same. Closure of the nest sites and perhaps other locations where SWWFC is found.

Grand Canyon Avian Community Monitoring 1993-1994 Annual Progress Report.
TER 0105 M.K. Sogge et al.

This is a progress report on general avian monitoring in the canyon from RM 0 to RM 226 (Lees Ferry to Diamond Creek).

56 patches of riparian vegetation were sampled. Patches ranged in size from 0.01 ha to > 2 ha, with most < 0.2 ha.

Birds were detected using both walking and floating surveys. These methods were checked against each other. Regression between the two was r2 = 0.96. Some species were undercounted by float by method while others were slightly over counted.

Birds were also mist netted at 5 impact study sites. These were used for determining use and movement at the sites and to get stomach contents for diet analyses.

Vegetation was sampled by stratifying coarse vegetation composition and structure. Strata were named after the dominant species and physiographic location (e.g., debris fan) was noted. Data were collected in randomly located quadrats.

In 1993 quadrats were 2x10 m, while in 1994 they were 2x2 m. In 1993, the vegetation was stratified into four layers >3m, 2-2 m, 1-2m, and herb/shrubs, while in 1994 the strata were >2m trees, and <2m shrubs.

There is no indication of how they were going to compromise the difference in vegetation sampling between years, nor how this vegetation sampling of riparian community was to be compared to that done under the riparian vegetation project. Obviously these were not organized.

At the end of this report year data were still being pulled together, so the usefulness of this report is very limited. Even stomach content data were limited to stating that 226 birds had been lavaged. These data are to be used to determine both dietary requirements but also what plant community was used for foraging.

The final report is expected to answer all of these questions and hopefully relate detection and foraging to particular riparian plant communities. It would be useful if these data were compared with data from the Hualapai riparian studies where there was a slight overlap.

Breeding and Wintering Waterfowl on the Colorado River from Glen Canyon Dam to Lees Ferry.

TER 0106. J.D. Grahame and C.A. Pinnock 1994.

This project had several objectives of which most were addressed in this report. They included addressing species composition, identification of species breeding and those wintering, affinity of species to particular shoreline habitats, periods influx and efflux, and effects of dam operations.

For this project, the river was divided into 16 one mile reaches. Within these reaches, the most commonly used were, by declining order, River miles 0 to -0.9 (Lees Ferry), -15 to -15.9 (just below dam), -12 to -12.9 (a large sand and cobble bar with a large pool behind it), -12 (bars and backwaters), -9 to -9.9 (sand and cobbles, a slow flowing reach — Duck Island), -6 to -6.9 (Hidden Slough), and -3 to -3.9 (rear water hole near sand and cobble bar).

From this list it is apparent that the waterfowl like some quiet water but near sand and cobble bars. Is this because in this reach the erosion and armoring of the shores has produced extensive cobble bars and thus this is what the water fowl use.

Breeding species, Mallards and Common Merganser tend to nest in areas along straight stretches and not near where most wintering birds are located.

More abundant water fowl have shown the greatest increases (i.e., Mallard, Goldeneye, Lesser Scaup, and Gadwell.

Interim flows appear to be improving population levels of most species. This is probably a result of less disturbance of shorelines by fluctuating flows.

One objective that is not addressed is the effects of dam operations, and one that is only casually addressed is the habitat of the species. One needs to pull the sand and cobble bar data from the text where there are no concluding comments.

This report presents much data to address the objectives, but essentially now analysis of the data. The information is useful only as trend baseline data.

1994 Breeding Bird Survey Along the Colorado River from Glen Canyon Dam to Lees Ferry.

Breeding Birds Along the Colorado River through Glen Canyon - The 1995 Report.
TER 0106 J.D. Graham and C.A. Pinnock

These two reports are combined because one is an annual report (1993 and 1994), while the other (1995) is a final report for the same project.

The 1994 report reports 26 bird species detected in the monitoring effort. The report gives list and trends of the species over time. It used a Wilcoxian test to compare 1993 data with 1994 data. This test shows that for combined species (all birds detected) there were no significant differences between 1993 and 1994. More birds were detected in 1994 if the tests were limited to the upper end of the study reach (i.e., sites 1-7 out of 21). Some species were shown to have more detections in 1994 while others were higher in 1993. This report does not answer the question about what vegetation types the birds are found in, both high detection sites and locations of individual species.

The 1994 report if obviously a progress report, but it does little to give guidance for understanding ecosystem relationships of the bird species.

The 1995 report has more extensive reporting but it still does not clarify the vegetational associations of the bird species. It makes a recommendation at the end of the report, that if the spike flow is done, vegetation structure of the 21 sample sites should be made prior to the test.

This report summarizes the bird counts not only for 1995, but also 1993-94 and using other data, it presents detections for the many species from 1992-95.

Each species is described about its occurrence in along the river with comments about the presence of the species pre and post-dam. For example, mallards and common mergansers were not detected prior to the dam, and their presence is considered a consequence of flows from the dam.

There is conjecture, but no data, about the effects of interim flows. Because these flows are considered to have enhanced development of marsh and riparian shrubby habitats, they are considered to also have enhanced habitat for many riparian species. They also point out that some species have adapted well to the increased habitats in the NHWZ, but little quantitative evidence is given to support this statement.

This report also indicates that Peregrine eyries have shown up after the dam and a few other species have shown up along the Glen Canyon portion of the river post-dam.

It is suspected that the Peregrines are now finding more prey as the avian population that is dependent on aquatic insects increases, and other species are finding an expanded riparian habitat, regardless whether it is native or non-native plant species.

1996 Avian Community Monitoring in the Grand Canyon
J. Petterson and J.. Spence 1997.

Note: only even pages available for review.

This monitoring program included avian surveys in 1996 from Glen Canyon Dam to Pearce Ferry in Lake Mead. GCNRA survey trips were May and July, while GCNP trips were April, May and June.

21 points were established in 10 patches of suitable vegetation in GCNRA reach, and 98 permanent points were established downstream. There is no mention whether these points or locations are the same as surveyed in prior years.

Two methods of censusing were used: total count walking surveys and fixed radius point-counts. Walk through (unbounded) and unbounded point-counts detected more species than 50 m radius point-counts. Some species were likely to be detected in either method (e.g., Lucy's warbler) while other species were more commonly found with one or the other method.

This report goes on to compare methodology. But it seems that from comparisons of unbounded vs bounded census techniques, an unbounded technique would gather more complete data. Longer count periods also produced more birds detected. A set amount of time should be established for future monitoring efforts and that time strictly adhered to or else data will never be comparable.

This report recommends that in order to link bird census data with operations of the dam, there needs to be good habitat data which means looking at changes in OHWZ and NHWZ relative to bird census sites. Some data have been collected, according to earlier monitoring reports (e.g., Sogge et al. 1995), but no one seems ready or able to analyze these vegetation data and relate them to bird numbers, and importantly to riparian vegetation data collected elsewhere in the canyon. Until that is done, attempts at integration between avian and vegetation communities will be non-existent. The only exception being attempts at relating the two in the lower canyon by the Hualapai Tribe.

Dam and Geomorphological Influences on Colorado River Waterbird Distribution, Grand Canyon, Arizona

Stevens, L.E., K.A. Buck, B.T. Brown, and N.C. Kline. 1997. Regulated Rivers: Research and Management 13: 151-169.

This paper attempts to pull much of the past survey information together with canyon attributes to explain the distribution of waterbirds in Grand and Glen Canyons. It is comprehensive and thoroughly covers present and historical information on waterbirds in the canyon.

The approach was to divide the canyon first in three segments based on clarity of water: clear water (CW), variable turbid (VT), and usually turbid (UT). This is basically Glen Canyon Dam to Paria, Paria to LCR and below the LCR. The canyon was also divided into the 13 Schmidt and Graf geomorphological reaches which describe width and narrowness of the canyon. Putting this together with nearly 14 years of surveys in all seasons, ti was possible to describe causes for water bird distribution and presence.

In general, waterbirds decrease down stream, with the highest presence in reach 1 the clear water reach. Dabblers follow this general pattern as do waders, although these increase again in reaches 8-10. Shorebirds drop out in reaches 12 and 13.

Total AARE (an adjusted measurement for survey period, that is, number of birds per km of river per hour of survey time) dropped from slightly less than 10,000 to over 100 from reach 1 to reach 2, the point below which the Paria River inputs sediment.

The paper mentions mallard nests in every large eddy on CW and VT segments. Grahame and Pinnock in their surveys of waterbirds in the Glen Canyon reach noted that mallard nests were in the straight stretches of river, while other wintering waterbirds were on the sand and cobble bar areas. This may be conflicting information, although most sand and cobble bars are probably on river bends (e.g., point bars).

The data show dabblers decreased rapidly downstream as did divers, but the ratio shifted with dabblers more common on upper reaches.

The authors indicate that flow regulation has "altered" the trophic structure of these bird guilds. There is little evidence for this statement because the authors also indicate that historically there were few waterbirds on the river under pre-dam conditions, and essentially not quantitative data. It would be better to say that flow regulations have "created" this arrangement in the trophic structure among the various bird guilds.

Seasons were also shown to be important. Many more waterbirds were found during the winter compared to summer.

Also, width of the canyon played a small role in distribution of birds. For example, there were more dabblers in winter in the wider reaches of the VT and UT segments, but this did not occur in summer.

Canonical ordination of waterbird numbers and environmental relationships show that Axis 1 was positively correlated with seasonality (greater presence in winter), and distance downstream (declining presence downstream), and negatively with reach width.

Axis 2 was positively correlated with reach width (the primary geomorphic feature) (more birds in wider reaches).

Seasonality is considered the primary influence over guild distribution. This is one reason why other survey efforts have concentrated on winter.

The authors point out that the results of their study support the "serial discontinuity concept" presented by Ward and Stanford (1983), which states that a river "recovers" from flow regulation over distance relative to river size and tributary size and inputs. Thus the Colorado River before it enters Lake Mead is nearly back to "normal" and there are few waterbirds present, a condition similar to pre-dam conditions.

Bridging the Gap: Transition Monitoring of Riparian Vegetation from Glen Canyon Dam to Pearce Ferry. TER 0164. Draft Final Report. Spence, Kearsley, et al. 1996.

This study used the methodology of Kearsley and Ayers. A random plot selection within vegetational polygons. If there is a question about this method it is that selection of points varied by polygon size and that the method is time consuming but workable.

The vegetation mapping to determine polygons was based on a 1995 set of aerial photographs. Species cover in the random plots was estimated five times to get an average and improve accuracy.

This type of sampling (monitoring) should not be done more often than about 5 years apart, except after some major disturbance event (e.g., a controlled high flood event). It is time consuming and unlikely will add much to the information base of the riparian zone if done more often.

If there is a major concern over encroachment of non-native riparian species in this zone, then a regular sub-monitoring program should be established to address this concern. Selected sites where non-native have established, and where there is some evidence of early ecesis, should be monitored on an annual basis.

This report also addressed changes in marsh vegetation and micro-topography. Marshes were originally measured twice a year, a frequency that appears too often.

Data presented in this draft report included many x-sections of marshes with changes in topography. Many marshes were shown to have increased in elevation between 1995 and 96 by about 0.2 m. A few did not change while one showed a 0.2 m decrease in elevation. Increases in elevation were related to proximity to the mouth of the RCC, the nearest receiving most deposition, while the marshes close to the head of the RCC had little deposition.

This is tied to the beach (sandbar) survey which showed that areas at, and upstream of, the eddy separation point received larger amounts of sediment. Those below were scoured.

As a draft final report, this report lacked much data analysis and this was to be done before the final was prepared. Regardless, this report demonstrates the relative stability of riparian vegetation in the NHWZ, while showing that marshes associated with RCC are much more dynamic over a short period when the river was not going through any major disturbance event, and fluctuations was limited.

Monitoring and Evaluating the Impacts of Glen Canyon Dam Interim Flows on Riparian Communities in Lower Grand Canyon. TER 0600 Final Report. Hualapai Tribe.

This report attempts to create a comprehensive monitoring program in the Lower Grand Canyon. It includes vegetation, birds, mammals and reptile monitoring data and some attempts at interrelating these data.

Vegetation monitoring data do not show any change in time during the interim flows. The authors suspect that there were changes but they blame the lack of statistical changes on the fact the plots were lumped and annual plants were eliminated in the analyses. If they have raw data available, they should have gone back and re-analyzed the data with various approaches to separation of plots. It is likely, however, that they would still find little change in vegetation over the relatively brief period of interim flows.

Vegetation data appeared to be designed to create relationships with bird and other faunistic data. This is useful, but it may also be one cause for weakness in showing possible vegetational changes. Unfortunately, when reviewing the vegetation data to develop relationships between birds and vegetation several discrepancies appeared. Vegetation at the avian monitoring sites differs between tables and figures. For example, Figure 7 shows Goodding willow at sties 5, 6, 7, and 8, while Table 3 shows Goodding willow only at site 8. Presence of certain riparian species is important in interpreting the use of the riparian areas by birds in general as well as particular species. In Table 6 (page 179-I) Goodding willow was shown to be used by Bell's Vireo and Yellow Breasted Chat. This was the only riparian plant species used by the Chat. Thus accuracy in describing sites is imperative. Just one more reason for consideration of re-analysis of vegetation data as the group continues monitoring in the future.

Their data support their conclusions that vegetation and associated bird populations were stable between 1992 and 1994 between Diamond Creek and Separation Canyon. This is a reach of the Colorado River where the river begins to function more like an unregulated river than the upper reaches nearer Glen Canyon Dam. They also show that changing lake levels in Lake Mead have caused extensive erosion and change in the shoreline riparian community below Separation Canyon. This is more a consequence of management of Lake Mead and Hoover Dam rather than interim flows. It would be expected that any type of discharge from Glen Canyon Dam would have little effect on Lake Mead shoreline vegetation, assuming operations at Hoover Dam was coordinated with inflows to Lake Mead and small or large discharges from Glen Canyon Dam would not create lake elevation decreases or increases at Lake Mead.

The mammal and reptile studies in this report are purely baseline. The mammalian trapping numbers were too small to allow any type of statistical analysis. They showed a slightly higher population in the transition zone, but the significance, if any, was not determined. The reptile data showed slightly higher populations in the riparian zone.

The data in this report are useful for determining trends in riparian community changes, but the significance of any change during interim flows is lost because of limited data, or inappropriate lumping of data.

Status of Riparian Resources in Lower Grand Canyon, FY 1995. TER 0600. Draft Final Report. Hualapai Tribe.

This is an extension of the studies done under interim flows (1992-1994). There were efforts in this report to develop statistical tests around the findings.

Avian studies. Eight sites were selected for avian population counts. The absolute count method was used. Extensive tables are presented showing the count and density of bird species at each site. These data were also grouped to show differences in the avian communities. Nest searches were also part of this study, giving some indication of reproductive success of the avian species.

Vegetation studies included GIS mapping of each site and a random line-intercept method of vegetational data collection. This is quite different from some of the vegetational sampling methods used in the upper Grand Canyon riparian vegetation studies, but it allows a quick method for describing the vegetation and is probably adequate for a status report, especially if the primary interest is avian communities, which seems to be the case. Vegetation data included vegetation volume and layer indices which are useful for comparison with bird densities and distribution.

Although this report "begs" for more analyses among riparian parameters especially using vegetation as the driving variable. It has, however, made a good initial cut at statistically showing relationships between site conditions and plant and animal populations. Because vegetation volume index and vegetation layer index are highly correlated ($r = .98$), it is possible to plot response curves for bird densities with just the vegetation layer index. This relationship has a an $r2 = .546$.

Mammalian data were also statistically analyzed in this report, compared to the interim flow report which had little analyses. Differences in mammalian distribution among riparian, transition zone and upland, although apparent, were not statistically significant.

Aquatic Reports

Comments by Paul Brunkow, Arizona State University

Life History and Ecology of the Endangered Humpback Chub.

Valdez, R.A., et al. BIO/WEST final report:. Contract #O-CS-40-09110. AQU0701

Review is focused on chapters 5 - 9 of the final report, as these are chapters that summarize the majority of data actually collected by B/W. Each chapter separate chapter is reviewed as if they were separate manuscripts. A review of the synthetic chapter 10 will follow.

CHAPTER 5: Distribution and Abundance

This chapter benefits from its inclusion of pre-dam information on fish distribution and abundance in the Colorado River. Historical species accounts and timing of introduction of non-native fish to the river system appear to be well referenced, as does the description of species occurrences after Glen Canyon dam was completed. The authors do not make any attempt to directly compare their results with these accounts, which would not be feasible given differences in sampling techniques, seasonal timing, and motivation of these older studies.

Catch per unit effort data are correctly identified by the authors as being difficult to deal with statistically. B/W calculated both arithmetic and geometric mean catch/effort statistics so as to make their data comparable with those of other researchers, and they used geometric means for temporal and spatial comparisons within their own datasets.

The authors provide a very complete synopsis of their collection data for the time of this study, even including capture of single individuals of various species. Data tables presented here, however, generally collapse spatial and/or temporal information in ways that limit the usefulness of the tables. Table 5-4, for example, shows capture data for age classes of several different fish species across all regions within each year, and Table 5-5 shows the same data across all years for each region. Therefore, determining annual or seasonal changes in spatial overlap of native and non-native fish will require inspection of raw data (either directly from B/W or from Appendices). Such a comparison would indicate, for instance, if species co-occurrence changed between research and interim flows.

Effectiveness of different fish capturing/trapping techniques and equipment are highlighted in this chapter. It is noted on p. 5-16 that in one sampling analysis native fish were captured most frequently with nets at a variety of tributary inflows, whereas non-natives dominated electrofishing catches at the same locations. The authors suggest that this was due to "inherent gear selectivity for species and habitat" without any further discussion. It seems that more explanation for this difference is warranted, especially in light of any long-term sampling plans.

The authors describe nine mainstem aggregations of humpback chub, giving their locations in Table 5-11 and Fig. 5-9. These aggregations were defined as distinct groups of fish "with no significant exchange of individuals with other aggregations". The aggregations accounted for 94% of all mainstem humpback chub captures by B/W. Identification of these groups should play a part in future management plans; however, the stability of these aggregations should be monitored carefully in the future.

Rainbow trout are presumed to be limited to areas upstream of the LCR confluence due to increases in turbidity at this point. However, there does not appear to be a systematic effort in this report to determine importance of temperature changes in the mainstem to this distributional pattern. Raw capture data for trout and humpback chub, either from B/W or from appendices, could be used to determine which variable (turbidity or temperature) explains more variation in distribution of these species. Management plans designed to control one or the other of these variables may have weaker or stronger effects on non-native species, depending upon this relationship.

CHAPTER 6: Demographics

In using length-weight regression data to calculate condition indices, one must assume that fish used in original regressions represent somehow the "average" condition for that species. The authors say that constants used in their calculations of condition indices for humpback chub came from a pool of 550 fish handled during 1900-91 (p. 6-2), but they do not indicate where these fish were captured or what time of year they were captured. Note that in Table 6-1, condition indices are then calculated for 1693 fish captured from 1990-93, but Fig. 6-4 contains length-weight data for 4632 fish; it is unclear how the 1693 fish were selected from the pool of 4632 fish.

It is encouraging that mean condition values in Table 6-1 approach 1.0 within each year, because this implies that the 550 fish used in original regressions were representative of the 1693 fish used in this analysis.

The authors imply on p. 6-20 that condition indices (Kn's) of rainbow trout are lower than expected and more variable (this is also stated in the conclusion to Chapter 9). However inspection of Tables 6-1 and 6-3 and Figures 6-5 and 6-8C leads to different conclusions. Mean Kn within each year is slightly higher for trout than for chub, and variability of these means within each year (measured as standard error) is very similar for trout and chub. Also, variability among individuals within each month ("Standard Error" column in the tables) tends to be lower for trout than for chub. Thus, trout do not appear to have lower and more variable Kn as suggested in this report (this issue will come up again when the authors discuss the possibility of competition between trout and chub in Chapter 9).

An interesting connection might be made between Kn data presented here with resource distribution data presented by Blinn et al. (AQU0100).

Transition checks in scale growth rings were used to estimate time of transition of fish from LCR to the mainstem. The authors make the assumption that all young fish found in the mainstem at the LCR confluence were hatched in the LCR. It should be noted, however, that any fish successfully hatching in the mainstem (which would probably only occur in warm springs or other tributary inflows) and then moving to the LCR confluence will also show a transition check in growth rings.

On p. 6-15, it is claimed that Kn of fish caught below LCR confluence did not differ significantly from that of fish caught above confluence, but the P-value reported is 0.003 (which is significant).

It is claimed on p. 6-23 that, because back-calculated minimum size at transition from the LCR to the mainstem was 52 mm, there must be little or no survival of fish that attempted the transition smaller than that size. This conclusion is weakened by the fact that we do not know how many fish < 52 mm actually attempted the transition; if fish this small do not attempt the transition to begin with, then we cannot attribute their absence in the mainstem to mortality (given that little or no reproduction is occurring in the mainstem).

Fig. 6-11 is also used by the authors as evidence for lack of long-term survival of fish that make the transition at < 52mm. This would be more convincing if Fig 6-11B was almost an exact duplicate of 6-11A, except for 6-11B being truncated relative to 6-11A on the left side of the histogram. Instead, 6-11B appears to be an almost exact copy of A moved up the "Total Length" axis by about 15 mm. This suggests systematic errors in back-calculated lengths-at-transition may better explain discrepancies between these two figures. A closer examination of the monthly size-frequency histograms of chub captured at the confluence mentioned at the bottom of p 6-10 would help resolve this issue. Unfortunately, these figures were apparently left out of our copy of Appendix F; I was unable to obtain copies of these figures from either BIO/WEST or the GCES office in Flagstaff.

Another point related to this issue: Fig. 6-17 and p. 6-38 suggest that brown trout (a potentially major predator on chub according to the authors) do not eat chub < ~ 80 mm SL, so if mortality plays a role in limiting density of chub < 52mm in the LCR mainstem aggregation, it is probably not due to predation. Unfortunately, no information is given about the presence of small chub in stomachs of predators. It may be that small chub simply are digested too quickly for identification from stomach contents (if truly present, they may have been classified as "unidentified material").

Asian tapeworms are reported as the only internal parasite observed in chub from stomach flushes. B/W did not set out to thoroughly examine the incidence of parasites in these fish (p.6-9); however, they probably underestimate occurrence of tapeworms in fish if the stomach flushing technique was not able to dislodge all tapeworms from a fish.

CHAPTER 7 Habitat

The authors point out a correlation between density of chub downstream of Lava Canyon (RM 65.4) and density of eddy complexes (P. 7-13). This correlation certainly exists, but there are still almost 200,000 m^2 of eddies below Lava Canyon. The fact that eddy density is only halved while chub density is almost zero suggests that something other than eddy density is probably limiting chub density in this part of the river.

Cumulative numbers of adult chub captured by river mile do not match when comparing Fig 7-6 with Fig 7-8. Fig 7-6 suggests they captured about 4000 fish by RM 75, but Fig 7-8 shows only ~875.

Minor note: p. 7-16, 7-17: Figs. 7-9D and 7-10B are supposed to be exactly the same piece of Colorado River, yet they appear to be quite different pictures. It may be that Fig 7-9 shows bathymetric (geologic relief?) maps which are independent of flow volume, whereas Fig. 7-10 shows velocity isopleths at a specific flow volume.

On p. 7-23, the authors suggest that subadult chub prefer vegetated habitats because of the higher geometric mean CPE shown for that habitat type (Fig. 7-15). There should be included here, however, a discussion of the ease with which these fish can be captured in the different habitats.

CHAPTER 8: Movement

It is pointed out on p. 8-9 that fish from LCR aggregation showed higher net displacements than fish from the MGG aggregation, and that this difference might be due to the larger size of the reach occupied by the LCR aggregation. Individuals in the MGG aggregation used a higher proportion of their subreach (13%) than did individuals in the LCR aggregation (8%).

Figs. 8-9 and 8-12 show movement patterns of individual fish into and out of the LCR. For these to be considered spawning movements, however, these movements should occur within one season and be tied to approximate spawning dates. Figure captions indicate that these are data collected over the entire sampling period. I was unable to obtain actual capture/ recapture dates for these data.

I was also unable to determine how BIO/WEST defined "moving into the LCR" or "captured in the LCR" operationally for field personnel.

On p. 8-16 and in Fig. 8-18, the authors describe and test for differences in seasonal net-displacement patterns of radio-tagged fish. The caption indicates that these are data for the entire sampling period; however, it seems that variability as indicated by the error bars should be comprised of only within-season, within-single year capture data. For example, a fish captured in Spring 1991 and then not re-captured until Spring 1992 should not be included in these data.

The authors conclude on p. 8-17 that turbid conditions resulted in more near-surface activity of chub. They do not assess, however, possible effects of turbidity on radio-telemetry.

In the section on effects of flow, ramping rate, and magnitude of flow change (p. 8-21), it is pointed out that mean ramping rates and mean magnitudes of daily flow change were both higher during research flows than during interim flows. However, it's also clear that variability in these two variables was also much higher during research flows. That is, day-to-day variation in ramping rate and daily flow change was higher during November 1990 - July 1991 (this is also indicated in Chapter 3).

On p. 8-25 (and on p.9-17), the authors refer to adult chub as having high condition factors (Kn) throughout the study. However, the mean value of Kn for adult chub throughout the study is about 1.0, meaning that fish display the expected condition value at all sizes. It is unclear if the authors' conclusion that fish have high condition factors is made relative to other populations or perhaps other species.

CHAPTER 9: Food Habits

Fig. 9-4 displays the effect of season on diet of chub, including fish from both the LCR and MGG aggregations. It may be more informative to re-do this analysis as the effect of season on diet within region, given that diets in each region are quite different (Fig. 9.3).

Fig. 9-2 shows how drift nets were set in the river to collect drifting macroinvertebrates and algae. It is not clear if the surface nets actually sampled the surface film of the water where terrestrial invertebrates might be entrained. Also, the authors stress the importance of recirculating eddies as places where adult chub can feed on entrained food items while hovering in the water. However, apparently no drift samples were taken in re-circulating eddies where the fish actually feed. In the absence of this information, we must assume that availability in the river was the same as availability in these eddies.

The authors suggest that rainbow trout represent potential competitors of chub because of similarity in diet between these species. Again, they make reference to trout having lower and more variable condition indices during the study as evidence that chub may be more efficient at foraging. As mentioned above, however, trout Kn's were actually higher than those for chub and even less variable. Another way to assess competition between chub and trout would be to correlate Kn for each species through time. A negative correlation would support a competition hypothesis (but inspection of Figs. 6-5 and 6-8C suggests that no such correlation exists).

CHAPTER 10: Integration and Recommendations

As this is a synthetic chapter for the final report, many of the comments I would make have already been made in reference to the appropriate chapter.

The authors suggest that LCR presented a better habitat for growth for subadult chub, but that the mainstem was better for adults (p.10-11). Information from ASU and/or USFWS on Kn of adult fish in the LCR may help to confirm this. Also, having individual lengths and weight at re-capture for fish used in Fig. 8-12 (p.8-13) might help to determine if Kn of adult fish declined upon entering the LCR.

On p. 10-16, the authors use electrofishing catch rates to estimate survival of subadults in the mainstem. They estimate a survival rate of 0.097 to one year of age, and then assume a 3-year survival rate of 0.001; I assume they arrived at this 3-year value by cubing the 1-year rate (about 0.1). It seems, however, that survival rate after one year probably greatly increases, as it does from 6-months to one year (p. 10-16). Therefore, the authors may be underestimating the number of surviving subadults after three years, which would affect their estimate of successful adult replacement rate made on p. 10-17.

After suggesting that subadult survival does not appear sufficient for adult replacement, the authors point out that adult densities were "relatively stable" (p. 10-17) during their study. They indicate that this must be due to adult recruitment from another source, such as the LCR. This will be an important point of integration between this study and those of ASU and USFWS. If the LCR is an adult source to the mainstem LCR aggregation, then it must be determined if LCR chub density is stable. It appears that all chub in the mainstem LCR aggregation and in the LCR itself should be considered as a single population, and that "population stability" should be assessed at that level.

The authors describe life-history attributes of Asian tapeworms on p. 10-27, and they mention that this parasite could become more common if mainstem temperature were maintained at > 20° C and appropriate cyclopoid copepods (as intermediate hosts) were present. It seems like someone should know if those copepods are present in the mainstem and their distribution.

A geomorphic assessment of subadult humpback chub habitat in the Colorado River through Grand Canyon.

Converse, Y.K. 1996. (AQU0701- thesisdraft: this was apparently sub-contracted out to Utah State University as a Master's thesis by BIO/WEST - see first sentence of Methods on p. 16).

p. 4: Note the conclusion here that humpback chub in Grand Canyon occur in two aggregates: one resident to mainchannel Colorado River, and one resident to the LCR. This is the first time I remember seeing an author separate the chub that occur in/near the LCR into two separate aggregates.

p. 20: Here the author assumes that "shoreline structure most strongly influenced channel hydraulic conditions within 2.5 m of the shoreline" without providing much of a justification for this assumption. Also, it is unclear as to how she defined "depth" for different shoreline types in her analyses.

p. 21: Note that fish density sampling unit is unit time^{-1} and not unit area^{-1}. It is not clear in this report if assuming a one-to-one time-to-area fish sampling ratio (i.e., converting catch per unit time to fish density) is valid when sampling effort varied across habitat types as in this study.

p. 28: The conclusion that subadult chub disperse and then use specific shoreline types seems too strong here. Clearly, from Table 7 (p. 31) chub use area with higher amounts of cover, but the results shown in Figure 5 (p. 32) and the significant interaction between reach and shoreline type in Table 8 (p. 31) suggest that chub will occur within most shoreline types as long as there is sufficient cover. Note that the author's definition of "cover" (p. 20) seems very inclusive and general; there doesn't appear to be any treatment of different types of cover (e.g., rock, roots, etc.).

p. 33: Note the author's definition of "habitat quality" as frequency of cover (percent occurrence of cover). Other aspects of "habitat quality" as commonly used in aquatic ecological studies (e.g., suspended sediment concentration, density of food resources) are ignored in this definition.

p. 39: The author's suggestion that preference for cover reflects predator avoidance seems unlikely given the scale at which "cover" was defined here (very broad, presumably encompassing centimeters to meters) compared to the scale at which predation on smaller fish could occur.

Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Creek to Lake Mead.

Valdez, R.A. Contract # 1-FC-40-10930. There are two reports under this title, called "Phase I" (AQU0600-ph1fnl) and "Phase II" (AQU0600-ph2rpt). Several concerns I had in the Phase II report were also noticed in the Phase I report; thus, only the Phase I report is summarized here.

Note that the project was taken over by SWCA, Inc.; their report is reviewed below.

Overall, both reports are based on the same techniques and analyses that are utilized in BIO/WEST's final report on the life history and ecology of humpback chub. BIO/WEST has not yet responded to my request for clarification on that report, and thus I will not address specific methodologies and/or analyses that raised concerns in the present report. When B/W addresses issues that I raised in their report on humpback chub, I will submit a revised summary of all three of these final reports.

Note that these reports summarize data collected during 11 trips from June 1992 to January 1995; data from the first seven trips are summarize in the Phase I report, and the remainder are summarized in Phase II.

Ph I, p. 22: Note an interesting disparity here between this report and others. In tributaries in this study (Spencer Creek), concentration of dissolved oxygen varied inversely with temperature (expected as cold water can hold more oxygen). This implies that oxygen levels were highest during nighttime and early morning hours. In several other studies (e.g., Hoffnagle (AGFD) WAQ0303, and Robinson et al. (AGFD) AQU0313), oxygen levels varied positively with temperature; that is, warmer water during the daytime had more oxygen. This was probably due to increased rates of photosynthesis when the tributary (LCR) was exposed to sunlight. The disparity suggests that primary productivity may be lower in Spencer Creek, but such measurements were not made during this study (p. 50). I will contact the authors to determine if data on *Cladophora* densities exist.

Ph I, p. 36: Figure 7B is not very useful as a description of seasonal changes in fish composition for RM 226 - 280 considering that there is a major shift in fish species composition below Bridge Canyon (RM 235).

Ph I, p. 46: The authors raise here an interesting point about the influence of Glen Canyon Dam operations on the Colorado River through lower reaches of Grand Canyon. They argue that fish species composition, macroinvertebrate density, water quality, and beach/sediment stability probably depend more upon fluctuations in the level of, and recreational use of, Lake Mead rather than operations of Glen Canyon Dam. The influence of Lake Mead, with respect to both water level fluctuations as well as non-native fish dynamics, seems to be limited to the area below Bridge Canyon (Rm 235) according to this report. This suggests that perhaps monitoring of effects of Glen Canyon Dam could be limited to the area between the dam and Bridge Canyon.

Hualapai aquatic resources study: Transition monitoring of Glen Canyon Dam interim operations on aquatic resources between National Canyon and Pearce Ferry.

Leibfried, W. C. 1996. AQU0600-drftfnlrpt.

Apparently, SWCA Inc. took over this part of the project from BioWest and completed another series of surveys during 1995. They used sampling techniques similar to those used by BIO/WEST, but they only sampled during spring, summer, and fall periods. Note that this study examined resources between National Canyon and Pearce Ferry, which represents 66 more river miles than studies performed by BIO/WEST.

p. 11: A slight difference in macroinvertebrate sampling is noted here. This study only sampled drifting macroinvertebrates at the surface, citing Valdez and Hugentobler 1993 as demonstrating there to be no significant difference in drifting macroinvertebrate densities between surface and sub-surface flow. However, prior work performed by BIO/WEST in this region of Grand Canyon noted substantial differences between surface and sub-surface flow (e.g., Valdez 1995, AQU0600-ph2rpt, p. 25).

p. 16 ff.: Analysis of invertebrate assemblage is much more detailed in this study than in BIO/WEST's report in terms of taxonomic diversity; however, only relative abundances are given. Statistical tests are applied to volume estimates, but these estimates are not reported by taxon, as in BIO/West's report. Therefore, absolute densities of invertebrates cannot be determined from this study, except for one sampling period (Table A-1, p. 55).

p. 23: The author cites statistical tests showing drifting invertebrate densities to be higher during steady flows in 1995 than during fluctuating flows at an equivalent period of time during 1994. Clearly, abundances of invertebrate taxa shown in Table A-1 (p. 55) are higher in September 1995, but this could be due to year-to-year differences in invertebrate productivity rather than due to effects of flow regime. It is interesting to note that BIO/WEST found *lower* invertebrate densities during what they defined as "steady flows" in their study (AQU0600-ph2rpt, p. 25). The author of the present study also alludes to this on p. 48.

p. 29: Here the author suggests that because YOY flannelmouth suckers were found below Diamond Creek, this indicates that successful spawning took place below Diamond Creek. It seems just as likely, however, that these YOY were displaced from spawning areas above Diamond Creek and displaced downstream later.

p. 47: Note the shift in fish species composition below Bridge Canyon Rapids, similar to that observed by BIO/WEST. This offers further support to viewing Bridge Canyon Rapids as a logical end-point for long-term monitoring efforts within Grand Canyon, at least until management/native re-stocking efforts in Lake Mead become more active.

p. 48: Mean length of flannelmouth suckers captured during this study was 334 mm TL. The author argues that, based on age/size calculations by Carothers and Minckley in 1981, these fish were likely 4 -5 years old. The suggestion is then made that this result implies that flannelmouth successfully spawned during the experimental flow operation criterion under which Glen Canyon Dam was operating. This conclusion is only true if such operations of the dam (and subsequent effects on conditions within the river) did not alter the relationship between age and growth in this fish. Given the sensitivity of fish growth to various abiotic conditions, it seems that this possibility should be studied in more depth prior to such conclusion being made.

Photosynthetically available radiation (PAR) in the Colorado River: Glen and Grand Canyon. Yard, M. D., G. A. Haden, and W. S. Vernieu. 1993. AQU0900-drft.

p. 15: Here the authors document a linear relationship between sediment concentration and light attenuation; note, however, that no comparison with non-linear models was performed to see if a non-linear model accounted for more variation in the data. The authors also point out on the following page that this study involved only a very narrow range of sediment concentrations, and that this relationship may be non-linear at higher sediment concentrations.

p. 16: The correlation between light attenuation and distance downstream from Glen Canyon Dam noted here probably occurs because of a correlation between sediment concentration and distance as seen in figures 3 and 4. Since the authors already demonstrate a correlation between sediment concentration and light attenuation (see above), the correlation between attenuation and distance is not surprising.

p. 16: The authors present evidence that water originating from Glen Canyon Dam was very "optically stable" during this study; note, however, that this study only covered a two month period of time in one year.

p. 19: To analyze the relationship between sediment load, light attenuation, and distance downstream from Glen Canyon Dam, the authors examined the effects of sediment carrying capacity, hydraulic conditions, and channel width using multiple stepwise regression. Only channel width was significantly related to light attenuation, and only at high discharge (425 m^3/s). It would be informative here to quantify variability in channel width at low and high discharges; the relationship between light attenuation and channel width may have only been observed at high discharge because it is only during high discharge that enough variability in channel width exists for a statistical relationship to be detected. This would also imply that variability in light attenuation of the river is more variable during higher discharges. Channel width variability under differing discharge regimes may be available in other, non-biological GCES studies.

p. 20 and others: The authors frequently cite the use of ANOVA in their analyses, when they apparently mean linear regression (which is the more appropriate analysis).

pp. 25 and 26, Figures 9 and 10: The authors assumed a light intensity of 920 μE to be the intensity at which photoinhibition occurred in *Cladophora*. Note in these figures that the saturation depth (depth where light intensity was measured as 920 μE) was about 3 m below the surface at low flow and 2 - 3 m below the surface at high flow. The phenomenon of production by *Cladophora* being limited by photoinhibition was not taken into account in other studies examining the effects of flow regime on production of lower trophic levels. For example, Blinn et al. (AQU0100) examined the effects of flow regime on *Cladophora* production from the point of view of stranding and desiccation of *Cladophora*. They measured area of *Cladophora* sites exposed (i.e., above river surface) under low flow conditions to calculate how much negative impact on primary production low flow conditions would have. According to the present study, a significant fraction of *Cladophora* biomass that was still inundated under low flow conditions may not have been photosynthesizing; this implies that production calculations of Blinn et al. may have greatly overestimated actual production values.

p. 27: The authors cite the importance of *Cladophora* to the Grand Canyon ecosystem. It is unclear, however, how important *Cladophora* itself is to the Grand Canyon ecosystem, since *Oscillatoria* becomes the primary producer downstream of the Paria River confluence (see Blinn et al., AQU0100). This study did not analyze light attenuation with respect to the requirements of *Oscillatoria* (e.g., saturation point, compensation point), so it is unclear how patterns of light attenuation might affect production by *Oscillatoria*. These authors themselves suggest the importance of this on p. 34.

U.A. Master's Theses (part of contract # 1- AA- 40 - 10480).
General notes for all four theses:

- In general, each study quantified habitat quality variables (depth, velocity, and substrate type) by dividing these variables into categories and then quantifying occurrence of category type. Two-sample Kolmogorov-Smirnov tests were then used to assess whether habitat availability differed between study sites, or if habitat use by fish differed from patterns of habitat availability by comparing cumulative relative distributions of each habitat category. This procedure is valid; however, any information on correlation between habitat variables (e.g., correlation between velocity and substrate type) is lost in this approach. Therefore, authors might conclude that fish selected lower velocity microhabitats as well as microhabitats of a particular substrate type. Fish may, however, be selecting only the velocity category and not responding to substrate type per se. I will attempt to contact the authors to get raw data on habitat quality variables to determine if habitat types are correlated in these systems.
- A general theme uniting these four reports is the possible effects of Glen Canyon Dam itself on native fishes of the Colorado River. A suggestion that is frequently offered is to compare Grand Canyon populations with those from the Upper Basin Colorado River, suggesting that these Upper Basin areas are "more pristine" (Otis, p. 133). It is important to distinguish between, and consider both, the physical effects of the dam itself and the biotic influence of introduced species when comparing Grand Canyon with Upper Basin areas.

An evaluation of habitat conditions and species composition above, in, and below the Atomizer Falls complex of the Little Colorado River.

Mattes, W.P. (AQU0433)

- p. 19: Transects were established every 20 m throughout the lower 21 km of the LCR. I have thus modified Table 1 on p. 16 to indicate the number of transects per sampling area based on my understanding of the author's sampling design; these range from 1 - 45 transects per area. I assume that the number of points sampled along each transect was determined by stream width.

Follow-up e-mail correspondence on 12/11/96: Mattes indicated that actual sampling efforts were quite variable with respect to number of points sampled on which dates. This accounts for highly variable degrees of freedom presented in several of the analyses discussed below.

- p. 17: I will try to contact the author to determine why only certain areas were sampled for particular variables. Also note that far fewer of these areas were actually evaluated on any given sampling trip (e.g., see Tables 4, 19, 20, 21).
- p. 20: The author's distinction between macro- and micro-habitat measurements seems largely arbitrary. The "macrohabitat" measurements were taken every meter across transects, which is the same scale at which habitat data were obtained, for example, to define the "microhabitat" of an area seined.
- p. 27: Note that CPUE in this study has units of time^{-1} instead of area^{-1} as in other studies.
- p. 30 (Table 5): A consequence of the point from p. 19 above. The degrees of freedom in this ANOVA table do not match at all with what I would have expected given the number of

transects supposedly sampled in each area. I will contact the author to find out which data points were actually used in this analysis.

Also note that some of the variables analyzed in the table (e.g., pH, conductivity, alkalinity) will be correlated, leading to bias in stated effects of area. Not all variables reported in this table were analyzed on all dates (I will try to determine why); also note that month is not included as an independent variable in this table and thus effects of month cannot be evaluated.

- p. 33 (Table 9): Another consequence of p. 19: this table only reports one or two observations from areas that had up to 45 transects according to author's description of his sampling design.

- p. 43 (Table 16A): Same problem as noted immediately above. I will try to resolve this issue.

- p. 48: Author uses modal velocity to describe "average" velocity conditions in different areas at different sampling times. The mode would not be as good a descriptor as mean with some estimate of variance, as fish may be responding quite strongly to variability in water currents in an area as well as average velocity.

- p. 67: Here the author talks about physiological limitations to fish distribution upstream of the Atomizer Falls complex. This information should be coupled with the AGF study that more explicitly tested the physiological tolerances of fish in different regions of the LCR (Robinson et al. 1995, AQU0313).

Distribution, abundance, and composition of fishes in Bright Angel and Kanab Creeks, Grand Canyon National Park, Arizona.

Otis, E.O. AQU0434

- p. 38: Standard density estimates are calculated for each species/size class by multiplying density estimates from riffles and pools by the relative frequencies of these two habitats in Bright Angel Creek. The author uses mean relative frequencies of 0.76 and 0.24 for each of these habitats; however, he could have used the actual relative frequency of each habitat in each reach for more accurate estimates. This modification would probably not affect overall density estimates (see below).

- p. 39: Here the author proposes using density estimates obtained from the top 2 seine hauls in each reach (those two seine hauls that yielded the greatest quantities of fish) as a standard density estimate, and he evaluates the validity of this procedure by comparing $SDE_{top\,2}$ to the standard density estimates obtained from the program CAPTURE (for bluehead sucker and speckled dace). He assumes that estimates provided by CAPTURE represent "true" densities. It seems, however, that data going into the CAPTURE estimates will be biased by "inefficient" seine hauls, or at best be representative of only the top two or three seine hauls anyway. Thus, both CAPTURE estimates and $SDE_{top\,2}$ may fail to represent "true" fish density, even though both are highly correlated (see p. 42).

- p. 43, p. 34, and p. 87: There are caveats given throughout this report about differences in sampling effort between Bright Angel and Kanab creeks. Apparently, Kanab Creek provided a physical layout that was just simply much more difficult to sample than Bright Angel. For example, on this page, the author indicates that only pool sites were sampled within Kanab Creek, whereas both pools and riffles were sampled on Bright Angel Creek. I will attempt to determine why these differences existed.

- p. 88: Note the following tradeoffs in sampling effort pointed out by the author: effective sampling on Bright Angel vs. inefficient sampling on Kanab, and samples taken throughout the year on Kanab vs. temporally restricted sampling on Bright Angel.

- p. 90: Note the rapid shift in dominance from rainbow to brown trout. From 1979 to 1988, rainbow trout relative abundance declined from 97% to 76.5%; however, rainbow abundance declined from 76.5% to maximally 19.4% from 1988 to 1992.

- p. 101: The author references an AGF study by Maddux et al. (1987) as showing a seasonal shift in dominance of native vs. non-native fish in tributaries. No mechanism for this shift is given here; I will also review Maddux et al. (which is a GCES Phase I report) to see if such mechanisms are proposed there. Note that the author did not observe such shifts in this study.

- p. 130: Author references other studies discussing small size of fish inhabiting small streams and tributaries relative to fish living in large, riverine systems. Note that this pattern was also observed in Nathan Allan's thesis for rainbow trout and bluehead suckers (AQU0429).

- p. 133: Without developing some kind of predictive relationship between body size and fecundity and/or size at maturity, it seems premature to suggest that variation in these parameters among populations of bluehead suckers represents some kind of population-level divergence in life-history strategies. All such differences may be tied to differences in body size, which itself may be more or less environmentally controlled (a likely null hypothesis alluded to later in the paragraph).

Follow-up e-mail correspondence on 11/18/96: The author did confirm that the biggest reason for sampling differences between Kanab and Bright Angel creeks was the physical layout of each stream as limiting certain sampling techniques. He does feel confident that areas that were sampled in Kanab Creek were sampled efficiently and that his data will lend themselves to future monitoring efforts on this tributary.

The author also pointed to restrictive NPS policies with regard to scheduling sampling trips and the duration of these trips. This apparently greatly limited his ability to sample regularly and/or sample each tributary thoroughly on any given trip.

Spawning, movement and population structure of flannelmouth sucker in the Paria River.
Weiss, S.J. AQU0435

- p. 12: Here the author compares dietary studies of flannelmouth from the Upper Basin with those from Grand Canyon. It may be possible to extend this discussion as a comparison of pre- versus post-dam diets of flannelmouth (and other native species) in Grand Canyon. Especially noteworthy is the inclusion of *Gammarus* and chironomids in the diet of Grand Canyon fish. Note also on p. 13 the allusion to the Paria River as being similar to the pre-dam Colorado; no information or citations are offered to support the validity of this comparison.

- p. 20: Two spawning locations were marked for more detailed study at RK 2.8 and 6.0. It is unclear if these were the only two major spawning sites, or if these were chosen randomly out of a larger collection of spawning sites. The implication from p. 44 and 46 is that these were sites where the author happened to come across spawning fish.

- p. 34: The author discusses measuring re-captured, PIT-tagged fish in an effort to determine average growth rates during this study. Several fish were originally measured in error, as shown by the high number of negative growth values shown in Table 11 on p. 68. Weiss says he retained these negative values in growth estimates in growth regressions, and concludes on p. 65 that no measurable growth was detected during this study. An alternative approach would be to convert all negative estimates to zeroes (i.e., no growth occurring during that period of time) and re-calculate the regressions. However, inspection of Table 11 reveals that many of the negative growth errors are of the same magnitude as estimates of positive growth; thus, no useable growth estimates could be derived from these data.

- p. 52: Author points out that condition factors for flannelmouth observed during the study were highest from March 27 - April 1, implying that this must be the spawning season. However, these highest values (1.03 - 1.05) do not seem to be very much higher than the lowest values observed from April 8 - 10 for males (0.94) and May 30 - June 3 for females (0.95). Behavioral evidence may be better evidence of spawning than condition indices in this study.

- p. 68 (Table 11) and p. 71 (Figure 22): Note that graphical representation of data presented in Table 11 (this author's recapture data) is not shown, and raw data for Figure 22 (taken from other contractors) are not provided.

- p. 74: Suggestion from author's caveats about patterns in Table 12 (p. 75) is that there were no significant differences in available habitat distributions versus habitat used by fish during this study.

- p. 99: Author reviews other studies showing that sub-adult flannelmouth have not been captured between Glen Canyon Dam and the Paria River since 1984. Note, however, that BIO/WEST did catch many young-of-year and juvenile flannelmouth in areas of the Colorado River below RM 56 (Kwagunt Rapids).

- p. 103: Here the author offers an explanation for why young flannelmouth tend to be restricted to lower reaches of the Colorado while adults tend to be concentrated between Glen Canyon Dam and the Paria. This explanation (echoed by other AGF researchers) suggests the Paria as a spawning ground, with young fish dispersing downstream to grow, then returning to the Paria area as adults. It is not clear how these juvenile fish are able to survive brown trout predation described by BIO/WEST as being severe.

- p. 104: Conclusions are made here about patterns of spawning flannelmouth movements. The author concludes that, because seven fish tagged in the Paria during this study were recaptured in the LCR soon after spawning, these fish must have migrated from the LCR for the purpose of spawning. Also, he concludes that 15 fish originally tagged in downstream locations and subsequently captured in the Paria during the spawning season must have migrated there to spawn. These conclusions seem unwarranted based on these observations. It is possible that these fish simply moved to the Paria area and took up residence there. Evidence against this possibility would be found in capture records from further downstream *after* spawning.

- p. 105: The author suggests that high productivity in the Colorado around the Paria River may be inducing residency in large flannelmouth. This high productivity is a dam artifact; what did the flannelmouth do before the dam? Where were they concentrated?

Follow-up e-mail correspondence on 11/14/96: The author indicated that several aggregations of fish were observed in the Paria during his sampling efforts, but that neither time nor equipment availability permitted extensive sampling and/or monitoring of these aggregations. Thus, sites at RK 6.0 and 2.8 were the only sites where spawning behavior was observed, protocols established, and necessary equipment was available for fish capture and habitat measurement. Another aggregation was observed at RK 4.85, but actual spawning was not observed. The author is confident that the largest congregations of spawning fish were studied in the lower part of the river.

Distribution and abundance of fishes in Shinumo Creek in the Grand Canyon

Allan, N.L. (AQU0429)

- p. 23 and following: Author details extent of sampling efforts on Shinumo Creek from 1992 to 1993. He points out that no transects were measured in October 1993, transects were only measured from the confluence up to 6.8 km from the confluence in January and March 1993, and transects were only measured from the confluence up to 4 km and then 6 - 6.8 km in June 1993. Implication from following text is that stream conditions were "inappropriate" during these periods for any other sampling.

- p. 31: Results of analyses of habitat variables compared between sampling trips. 6 of the 14 significant differences invoked by the author are not significant differences when tests are controlled for multiple comparisons with the sequential Bonferroni correction. With these corrections applied to Table 6 on p. 34, there do not appear to be significant seasonal changes in depth or velocities in this study; however, substrate types did appear to be quite variable even after these corrections are applied. Clearly, there are still some patterns observed with respect to depth and velocity changes, but they are not statistically significant. This is pointed out again on page 49.

- p. 50: The author discusses changes in relative abundance of three fish species; he points out (and it should be emphasized) that these changes are probably more due to differences in sampling technique than to seasonal differences. The changes described here, for instance, do not match seasonal patterns described by Maddux et al. 1987 in an AGF report cited by another of these Master's theses.

- p. 51: The author explains absence of native fish from January and March samples by suggesting that they seek cover under substrates in cold water. I assume that this cover in Shinumo Creek was provided by dense in-stream root structures, which appear to be unique to Shinumo Creek when compared with other tributaries (e.g., Paria, Kanab, Bright Angel).

- p. 56: Reference to Baltz and Moyle 1984 seems appropriate as they found vertical segregation between a sucker and rainbow trout across as shallow a range as 0 - 25 cm (water depth was 50 cm and less in the present study). Baltz and Moyle also studied fish that were in general larger than those in this study.

- p. 57: The author suggests that predation by introduced fish may lead to extirpation of native fish; this may be especially true for introduced trout. Various studies have found that rainbow trout have very few fish remains in stomach contents; however, it is pointed out that larval fish may digest quickly and that predation pressure on larval native fishes may be underestimated by studying stomach contents. This possibility should be raised with brown and rainbow trout diet studies by BIO/WEST.

A brief analysis: the author shows trout size-frequency distributions on p. 48. Several trout are > 200mm TL. Using BIO/WEST's brown trout length - mouth diameter model on p. 6-39 of their final report (and assuming a similar allometric relationship between length and mouth diameter in rainbow trout), rainbow trout this size could consume fish with a body depth of 20 mm or less. Certainly, young stages of native fish as well as more fully grown speckled dace would fall into this size range and be susceptible to trout predation.

- p. 58: Fish in Shinumo Creek, regardless of species, appear to be smaller (with respect to TL), than when found in other areas of the Colorado River. The author suggests that this may reduce competition and predation, allowing the coexistence of three species in Shinumo Creek above the waterfall near the confluence with the Colorado. It is certainly possible that small trout may not be as efficient piscivores as their larger conspecifics, but it is not clear why smaller size *per se* would reduce competition in Shinumo Creek. Evaluating this possibility requires more detailed examination of food availability and size-specific food use for each species.

- p. 59: Here the author begins a long discussion concerning why bluehead suckers might be smaller in the upper reaches of Shinumo Creek than near the confluence. Three possibilities include truncated age distribution (shorter life spans), genetic differences, and reduced individual growth due to lower food resources. The first two possibilities cannot be addressed at this stage (unless museum collections yield bluehead suckers from Shinumo Creek for aging). I will try to determine if other researchers (e.g., Dean Blinn's group) have evaluated invertebrate and/or algal densities in Shinumo Creek. These possibilities are raised again on page 65.

FOLLOW UP: Phone conversation with Allan on 11/13/96

- He suggested that the main reasons for sporadic sampling efforts described above were related to time limitations, especially with respect to coordinating work schedules with raft trips that delivered him to, and picked him up from, Shinumo Creek.
- Root structure complexity in Shinumo Creek probably was higher than in Kanab Creek, but not some of the other tributaries; thus, it probably does not explain well why he was unable to capture native fish in winter sampling efforts. He really was not able to offer any other kind of explanation for this. He does not believe that fish leave the stream in winter, because the high barrier near the confluence would prevent any re-invasion the following spring.
- Allan mentioned that he has a draft version of a report describing his efforts on Havasu Creek, which were the primary focus of his thesis program and that were cut-off due to possible conflicts with the Havasupai Tribe. He said that he will send me a copy of this draft report after improving it slightly and contacting Gene Maughan at UA.

Allan also informed me that Ted Otis and Gene Maughan authored a report on Tapeats and Deer Creeks that was submitted to either the GCES office in Flagstaff or the Fish and Wildlife office in Pinetop.

Ecology and conservation biology of humpback chub (*Gila cypha*) in the Little Colorado River.

Douglas, M.E., and P.C. Marsh. 1996. #1-FC-40-10490 AQU0400

This project report is broken into four sections, and each will be reviewed here separately.

Section 1: Population estimates/population movements of *Gila cypha*, an endangered fish in the Grand Canyon region of Arizona. (Published: Copeia 1996(1):15 - 28). Comments organized by page number of the Copeia reprint.

p. 20: Here the authors points to increases in population estimates in Jan./Feb. of 1992 at the confluence as evidence of staging prior to an upstream spawning migration (supported by other authors, such as BIO/WEST). However, estimates do not "peak in early March and then gradually decrease through June" (see Fig. 3B). There is another sharp peak in density estimates in May that then drops off suddenly.

p. 23: Note the difference in approaches to estimating population densities by these authors versus, for example, BIO/WEST. Here estimates are made by month, which allows the more reliable use of population estimates based on the assumption of closure. BIO/WEST analyzed their data over the course of several years, leading to a much higher risk of violating the assumption of closure.

It should be noted, however, that BIO/WEST also included population estimates of humpback chub based on open population models in their final report (AQU0701-fnl, p. 6-26). These estimates matched fairly well with estimates provided by closed population model estimates, suggesting that either a) both types of models are poor predictors of population dynamics for this species, or b) this species' population dynamics behaved as if populations were closed even over long time periods.

p. 25: The authors suggest that changes in the thermal regime of the mainstem have led to a shift in the life history of humpback chub, some of which may be old enough to have experienced all of the changes brought about by the dam since its closure. Thus these fish have "developed" (as opposed to "evolved") a strategy that includes migrating into, and maintaining residency in, the LCR. It is suggested that conditions in the LCR more closely match pre-dam conditions in the mainstem than those currently present in the mainstem. While this is certainly likely, a more explicit comparison of pre-dam Colorado River and current LCR conditions should be offered relative to long-term conservation plans for humpback chub.

A related point is offered on this page relative to the importance of the LCR to current populations of humpback chub. The authors suggest that the LCR is important to conservation of chub because of their possible alteration of life history to include the LCR as a breeding site. It is clear, however, that the LCR is important to conservation of the chub regardless of whether or not patterns observed today represent a life-history shift or a simple selection in favor of individuals which historically used the LCR for breeding.

Section 2: Endangered humpback chub, *Gila cypha*, as prey of introduced fishes in the Little Colorado River, Arizona, with notes on fish stocking in the Grand Canyon region.

p. 37: The authors conclude that there are no published reports of humpback chub as prey of several of the introduced species in the LCR. It should be pointed out that BIO/WEST confirmed humpback chub in stomach contents of brown trout, and that they received numerous reports of humpback chub as prey of rainbow trout from other Grand Canyon investigators (AQU0701-fnl, Chapter 6).

General notes added after conversations with the authors 12/12/96: The size of smallest prey item that could be identified as humpback chub in the stomach contents of another fish was approximately 25 - 30 mm, at which size the pharyngeal arches were ossified. Representation of prey items in stomach contents of predaceous fish in this study was by percent frequency of occurrence as opposed to percentage mass or volume.

Section 3: Population densities of *Catostomus latipinnis* (the flannelmouth sucker) and *Catostomus* (*Pantosteus*) *discobolus* (the bluehead mountain sucker) in the Grand Canyon region of Arizona: life histories of migratory vs. non-migratory species.

p. 63: Here the authors point out that efforts to gain baseline data on fish species not currently threatened or endangered should be given high priority before these fish also decline in abundance. It seems that this is a general issue that has not been addressed very explicitly in GCES.

p. 67: Note that open population model estimates are used here because of the longer time span of this study, and because estimates were generated for the entire LCR instead of separate reaches as was done for humpback chub.

Section 4: Survivability of an endangered species (*Gila cypha*) in the Grand Canyon region of Arizona: results of a five-year mark/recapture study.

p. 107: Note that open population model estimates are used here in contrast to models used in Section 1. This was done because of the long time span of this study and the fact that closure could not be demonstrated over the course of this study.

p. 110-111: The conclusion that "1994 was clearly a problematic year for *G. cypha*" is made here, and various hypotheses are offered to account for this, including predation and increased interactions with non-native species. It is important to note that the authors also point out that increased water clarity or altered water chemistry (due to a large flood) may have altered fish behavior in a way that affected the probability of capture. The implication here is that fish populations did not actually decline, but that fish became harder to sample.

The authors argue that predation is not a likely cause for the decline because all size classes of chub show equivalent declines. However, inspection of Fig 4-5 (p. 132) and Table 4-5 (p. 125) clearly show that the very largest fish did enjoy much higher levels of survivorship than the other size classes in 1994.

Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River.

Gorman, O.T. (AQU0200-anlrpt93 and fnlprov).

Note that both the 1993 annual report and the final report will be reviewed here; many of the analyses are distributed through both reports.

AQU0200-anlrpt93

p. 5: A general note about this and the final report concerns one of the major stated goals of this study. There is a stated desire to use the LCR as a model system for establishing a second spawning population of humpback chub in Grand Canyon. The author's argument is that the more closely another tributary matches the LCR in terms of overall availability of habitat, the more suitable that tributary will be for establishing such a population. This seems like a valid goal, except that it could be refined to say that the more closely habitat availability in a given tributary matches habitats *that are actually used by humpback chub* in the LCR, then the more likely that tributary could be used successfully by a second population. This issue will come up again later in this review.

p. 6: The observation that catch of exotic fishes increases following summer flooding seems to be an important aspect to the biology of this system, but no potential mechanism that might explain why this happens is given.

p. 7: Here the author points out that they observed some adult humpback chub to regurgitate YOY chub while being handled, and then claims that they "have no doubt that one of the major food items of adult humpback chub...was YOY chub." However, at least according to the data presented here, only five YOY chub were obtained in this fashion, meaning that no more than 5 adults out of all the adults they handled during 1993 (208 according to Table 5) regurgitated YOY chub. Thus, it seems premature to conclude that YOY are an important diet component of adults based on these data.

The consumption of YOY by adults should be quantified; a strong year-class limitation such as this undoubtedly affects future management decisions and strategies. It should be noted that BIO/WEST did not find any fish remains in gut contents of 158 adult humpback chub sampled for dietary analyses during their study (AQU0701-fnl, p. 9-4). It may be possible that regurgitated fish in the present study were captured by adults while enclosed in close proximity with YOY in nets.

AQU0200 - fnlprov

p. 5 and general: Hypotheses are presented here that guided the "analysis and interpretation of...study objectives in the LCR." It is important to note, however, that statistical analyses were not applied to the datasets presented in this report; thus, the hypotheses stated remain untested per se. Justification for this is given on p. 15, where the author points out that many of the datasets are non-normally distributed and consist of categorical data. Thus, parametric tests based on measures of central tendency (t-tests, ANOVA, etc.) are difficult to apply or inappropriate.

However, data presented in the frequency histograms, even though non-normally distributed, are still amenable to various non-parametric tests, such as rank tests and goodness-of-fit tests. And even though some of the variables are reported in a categorical fashion, the categories are established along a continuous gradient (e.g., substrate particle size, current velocity). Note also that they summarized some of the histogram data using Principal Components Analysis; however, no statistical tests were applied to the resultant PCA scores. Below, I will present some preliminary analyses of data presented in frequency histograms with reference to some of the conclusions offered by the author.

Note also a shift in emphasis away from a hypothesis-testing role of this study (one of the original guiding frameworks for GCES Phase II) to one of information-gathering as indicated on p. 29 under "Management Recommendations."

Analyses of selected data sets in this report

Primary variables analyzed by the authors were depth, current speed, substrate type, and presence of various cover features. Depth, current speed, and substrate were assigned to categories that reflected underlying continuous gradients. Therefore, these data can be analyzed using the Mann-Whitney U-test (MWU), a non-parametric test based on ranking of the observations. "Cover" (CVR) and "Corrected Cover" (CCV) are truly categorical variables (i.e., they do not reflect directly an underlying continuous gradient). Therefore, these data are best analyzed with the Kolmogorov-Smirnov test (KS), a non-parametric goodness-of-fit test that determines how well two distributions match each other.

Utilizing these tests, conclusions concerning habitat use on page 3 of Appendix 4 (p. IV-3) can be more quantitatively addressed. For example, speckled dace do use significantly shallower water both during the day and at night (MWU: $P < 0.001$, and $P < 0.001$, respectively). However, use of substrates (day: MWU $P > 0.08$; night: MWU $P > 0.05$), cover features (day: KS $P > 0.1$; night: KS $P > 0.08$), and corrected cover features (day: KS $P > 0.05$; night KS $P > 0.29$) did not differ between speckled dace and humpback chub in a statistically significant fashion.

Conclusions regarding diel patterns of habitat use by humpback chub are also not supported by analysis of data presented. Depth of water used did not differ significantly between day and night sampling periods in June 1992 (MWU $P > 0.24$). Use of cover features (KS $P > 0.70$) and corrected cover features (KS $P > 0.10$) also did not differ significantly between day and night. Humpback chub also did not differ significantly in use of substrate categories (MWU $P > 0.1$) or current speeds (MWU $P > 0.28$) between day and night periods. Some of the conclusions drawn by visual inspection of graphs are clearly biased by the presence of a very few points at the extremes. For example, the conclusion that humpback chub use deeper water during the day seems to be driven by the presence of a few more observations above the 140-150 cm categories shown in Figure 3 of Appendix 4 (DPH2 on p. IV-12) relative to the same depth category for DPH2 on p. IV-13. However, only 176 humpback chub were handled during June 1992 (p. IV-5); thus, this difference only represents something on the order of 5 additional fish caught in deeper water during daytime sampling periods.

The same analytical procedures can be applied to comparisons of other tributaries with the LCR in terms of habitat availability. For example, I have compared depth, substrate, and current speed distributions between Havasu Creek (p. VIII-18) to those in LCR for June 1992 (p. IV-8). Distribution of depths differed significantly between 6/92 LCR and 1993 Havasu (MWU $P < 0.04$), but not between 6/92 LCR and 1994 Havasu data (MWU $P > 0.10$). Neither 1993 or 1994 Havasu data on current speed distributions differed from the LCR (MWU $P > 0.8$ and MWU $P > 0.10$, respectively). Substrate distributions differed significantly when comparing 6/92 LCR data to both 1993 Havasu (MWU $P < 0.05$) and 1994 Havasu (MWU $P < 0.04$) data. Thus, Havasu is comparable to the LCR with respect to certain variables during certain years.

Diel catch rate data presented in Table 2 of Appendix V (p. V-8) can be subjected to a single degree-of-freedom, goodness-of-fit (Chi-squared) test. Using this analysis, YOY humpback chub were significantly more active during the day, whereas adult humpback chub were significantly more active during night sampling periods, as suggested by the author. Both YOY and adult speckled dace were significantly more active during daytime sampling periods, as were YOY bluehead sucker. No other significant differences in diel activity levels are detected on this table.

The authors also made use of principal components analysis (PCA) in their descriptions of habitat use by humpback chub and other species. Note that no statistical tests were applied to the resulting PCA scores. Inspection of the resulting plots (e.g., p. V-73) does show changes in patterns of habitat use as suggested by the authors. However, some of the differences observed graphically may be due to radically different sample sizes used in constructing the figures. A change in shape of a PCA plot may occur simply due to sampling a greater number of points and sampling more of the available habitat.

Another multivariate analytical procedure used by the authors was discriminant function analysis (DFA). This technique was used to identify differences among tributaries with respect to habitat variables (see Appendix VII, p. 4 ff.). Note that variability (standard deviation) in measurements of particular variables were used in addition to mean values in the calculation of discriminant functions (Table VII-1, p. VII-5). These means and standard deviations were calculated across habitat transects. The justification given for doing this is that data sets based on original habitat sampling points were too large. This is one of the first times that I remember seeing an author consider explicitly the level of variability in certain variables, yet there is no discussion of how inclusion of this kind of variable might change interpretation of habitat use patterns. That is, variability in depth or substrate size themselves may be of importance to a fish, in addition to mean depth or substrate size along a particular transect.

As discussed in other project reviews, there has been no attempt to describe correlations between independent variables in this study. It may be useful, especially when evaluating other tributaries in Grand Canyon, to have a better understanding of the habitat variables most strongly related to growth and reproductive success of humpback chub.

The author points out that sub-adults and adults seem to select deeper water when it is available in the LCR (e.g., DPH histograms p. VIII-18). However, it is clear that a large fraction of adults and sub-adults still use shallower water (i.e., < 160 cm) even when deeper water is available. This study also found that adults did not appear to change their habitat use patterns during spawning (p. VI-2). Thus, even though habitat distribution differs in some respects between Havasu Creek and the LCR, Havasu Creek does provide habitats which adults and sub-adults actually use in the LCR. Havasu Creek may be even more appropriate as a site for the establishment of a second breeding population of humpback chub than suggested by a simple comparison of relative availability of particular habitat types.

A final consideration, however, when comparing habitat quality between the LCR and other tributaries is spatial scale. The LCR is the largest tributary in Grand Canyon. Thus, even habitats that are present at relatively low frequency within the LCR offer relatively large physical spaces to fish (e.g., on an areal basis). Any given habitat (e.g., substrate type or water depth) may be present in a tributary at the same relative frequency as in the LCR, but because other tributaries will be smaller, they will present less absolute areal representation of this habitat to fish. Also, a desirable habitat type may be present in one tributary at a lower frequency relative to another and still be present at a higher absolute areal representation if the former tributary is larger. Thus, when making comparisons between tributaries, absolute size should be considered explicitly.

<u>Other Comments</u>

General: The author discusses on p. 9 of Volume I the Master's theses performed by U. of Arizona students under sub-contract to USFWS. Those data, however, are not presented in this report, nor are the results of those studies compared with data in the present study. The author explains that methodology used in the Master's studies were incompatible with such comparisons. With respect to fish distribution data, that is probably accurate. The Master's projects utilized active sampling techniques, including seining, snorkeling, and electrofishing, whereas the present study used passive, net-oriented sampling techniques.

However, with respect to habitat availability (re: determining an appropriate location for a second spawning population of humpback chub), the data sets are probably comparable. The Master's projects utilize the same "point-pole" techniques used by Gorman and others to determine distribution of depth, current, and substrate. Determination of category boundaries for these variables were identical between all studies. The major difference between the Master's projects and the present study is that the present study used a very regular, triple-transect sampling scheme (Figure 4, Volume I) whereas the Master's projects utilized single transects spaced every 20 - 200 m. However, relative representation of each habitat type can still be calculated from all data sets and thus compared among tributaries.

The author also suggests that habitat availability studies have not been carried out on the mainstem Colorado River. However, BIO/WEST did sample habitat availability, as did Yvette Converse, who performed her study as part of a Master's thesis at Utah State University under sub-contract to BIO/WEST. Sampling of habitat was done on a much finer scale in the present study as compared to the studies by BIO/WEST. BIO/WEST assigned shoreline types into rather coarse categories such as sand, vegetation, talus, etc. However, they also measured depth and substrate on a finer scale, using categories similar to those assigned by USFWS. Thus, some comparison could be made between USFWS and BIO/WEST habitat use and availability data sets.

Future research on habitat availability and use in the mainstem Colorado should try as much as is feasible to replicate the sampling regime used by USFWS. An advantage to this approach would be that researchers could then determine habitats that are actually avoided by humpback chub and other species. Habitat data from the LCR suggests that humpback chub utilize almost all habitat types available to them (e.g., all depths, currents, and substrate categories) in this tributary. I would expect that the mainstem Colorado would present a much wider range of habitat types, some of which may not be utilized by fish. Thus, it could be determined the habitat types that these fish actively avoid, which may be useful in determining location(s) of future breeding aggregations.

p. VIII-4: Here the author reports observation of many dead, dying or diseased fish in Kanab Creek, attributing this to potentially limiting abiotic conditions present in that tributary (low oxygen, high temperatures). The U. of Arizona Master's thesis by Otis (AQU0434) also reports dead fish in Kanab Creek. However, Otis found such fish across a wide range of abiotic conditions, and suggested that the primary cause of death was *Lernaea* infection.

NPS/NAU report (Aquatic foodbase studies) AQU0100
Contract #9-AA-40-07920 NPS Cooperative Agreement #CA-8009-8-0002
Blinn, Stevens, and Shannon

Revised 4 March 1997 - revisions based on new version of final report sent by Joe Shannon from NAU directly (i.e., did not come through GCES office). This report is dated 1 December 1994. Page numbers below (unless otherwise noted) refer to original report (AQU0100-fnl) sent from the GCES office. Comments addressing some of the concerns below based on information in the December 1994 report are preceded by bold-faced indicators.

This report is divided into 7 chapters; the bulk of research is reported in chapters 3 - 5, and this review will focus on those chapters. Additional information will be added to this review as I integrate data from other studies and after contacting the authors about certain issues raised in this review. I don't have very many comments on this report; overall, the research was performed well and most analyses appear appropriate. Therefore, I will not divide my comments by chapter. Instead, I will just refer to page numbers in the document.

p. 52: The authors identify a relationship between Cladophora biomass and water temperature and Secchi depth, and another relationship between Oscillatoria biomass and Secchi depth. These stepwise regressions are significant, but the very low R^2 values suggest that these relationship are weak at best (especially given the high number of degrees of freedom).

p. 54-55: Here the authors describe effects of substrate type on biomass of various biotic components, pointing out that riffle/cobble (>3.0 cm diameter) and silt were the "most productive" substrates (i.e., contained the highest biomass of macroinvertebrates, etc.). This is evidenced by a MANOVA test, which incorporates the responses of all biotic components simultaneously.

Distribution of substrata (especially silt) is one of the most important effects that Glen Canyon Dam has had on the Colorado River, and these distributions play a large part in dam management decisions.

Revision Authors did not analyze taxon responses to specific substrates. However, they do show more detail of macroinvertebrate responses in a MANOVA table on page 15 of the December 1994 report. Distribution of algae and macroinvertebrates was significantly affected by "habitat" (pool vs. riffle vs. tributary) and "reach width" (wide vs. narrow). Notably, *Cladophora*, chironomids, gastropods, lumbriculids, and tubificids were significantly affected by these variables. Elsewhere in these reports, it is suggested that attached filter-feeders (e.g., simuliids) will prefer gravel or cobble surfaces, whereas chironomids and oligochaetes will prefer silty substrates. The author's variable "habitat" is probably correlated with substrate predominance (e.g., pools will have finer substrates, riffles will have gravel and/or cobbles, etc.). This is probably also true of their "Reach width" variable (narrow reaches will tend to have bare boulders or bedrock and wide reaches will have finer substrates). Because of these correlations, I would expect that many of these affects on standing stock of macroinvertebrates are driven by changes in substrate types.

Also, turnover rates of these different substrate types may have strong effects on macroinvertebrate/algal standing crop and/or productivity. Integration of substrate turnover data (from Jack Schmidt, USU?) with data from this study and AGF's "Lower Trophic Level" studies would be especially useful.

Finally, the authors have not assessed biotic "productivity" *per se* in this study; standing biomass is their typical response variable. I will inquire as to whether productivity estimates were made and if we could include those data in a final integration/synthesis.

Revision The authors present a detailed analysis of secondary productivity of *Gammarus* in the December 1994 report. Because *Gammarus* could be easily divided into size classes, the authors used the size-frequency approach to quantify production of this amphipod.

However, chironomids were not divided into size classes or cohorts; all were dried and weighed together in each sample. Thus, the authors were able to calculate mean standing biomass of chironomids across all sampling dates. They then cited another study (Berg and Hellenthal 1991) as calculating an average productivity-to-mean biomass (P/B) ratio for north temperate chironomids as 9.5. Using this value along with their estimate of mean biomass, the authors estimate chironomid productivity as ~ 17 - 18 kg dry mass ha^{-1} yr^{-1} for Lee's Ferry. This is somewhat unsatisfactory. In essence, the authors used another study's productivity measure to estimate productivity at Lee's Ferry. Berg and Hellenthal used only a small portion of a third order stream in Illinois (Juday Creek) in their study. The use of their P/B ratio here is only valid if turnover and predation rates on chironomids were comparable between Lee's Ferry and Juday Creek.

p. 57: A downstream shift in importance from diatoms to bacteria in the diets of macroinvertebrates is described here. I agree that overall role of bacteria in downstream food webs is an interesting issue; however, from a management perspective, the rapid decline in macroinvertebrate densities downstream argues against focusing much effort on studying bacteria. Bacteria do not appear to be compensating for downstream loss of diatoms. It would be interesting to determine if bacterial density actually increases downstream.

p. 63 & 74: It is unclear how recovery of biotic elements was actually measured (esp. Cladophora). It may have been measured as change in biomass of elements already on the rocks when they were re-submerged, or it may have been measured as recovery of the spaces actually cleared as part of the experiment.

p. 64-65: Here the authors present results of Experiments I and II. They describe effects by comparing biomass on treatment rocks at the beginning and then at the end of the experiment, comparisons which reveal significant reductions in some biotic elements. They then compare biomass on initial and final "control" rocks, pointing out that there is no significant change. This works, but the appropriate comparisons should be between treatment rocks and control rocks at the beginning (when there should be no difference) and then treatment rocks and control rocks at the end. This provides a more direct control for time effects during the experiments.

p. 74: MANOVA revealed no significant effect of treatment on drifting rates of various biotic elements in Experiment V. However, the authors claim increases in drift of Cladophora and Gammarus after day and night exposures using "descriptive" statistics in isolation. Examining the means and standard errors, though, it seems as if these differences are slight at best.

p. 74 & 81: In this text, the authors develop a model to predict standing crop of three, major food base taxa (epiphytic diatoms, chironomid larvae, and Gammarus) at several different flow regimes. They conclude that highest potential amount of "ecosystem energy" will be available at high water flows, because the greatest area of river channel will then be inundated. However, ecosystem energy should be expressed in terms of productivity and not standing crop. It is essential to know levels of macroinvertebrate productivity at these different flow levels if we are to estimate how much energy per unit time will be available to higher trophic levels (e.g., fish).

p. 86: The authors conclude here that "ecological potential of this fluvial ecosystem" is driven by the quantity and rate of benthic production. However, studies by BIO/WEST on the feeding habits of humpback chub indicated that allochthonous import of terrestrial insects became increasingly more important downstream. Figures in this report suggest that standing crop of algae, chironomids, and Gammarus decline sharply below 70 - 80 km from Lee's Ferry (equivalent to RM 42 - 48). This suggests "ecological potential" of this system is driven by in situ benthic production between Lee's Ferry and the area surrounding President Harding Rapids. Below that point, higher trophic levels (fish) will depend increasingly on drift from this productive area and terrestrial invertebrate input.

p. 87: Under "Monitoring Recommendations" #3, the authors point out that recolonization of macroinvertebrates and algae varies by taxon and season and that algae generally recolonize more slowly. It seems that more detailed discussion of mechanisms of re-colonization is warranted.

General note: It seems that discussion regarding benthic production in this system (esp. between the dam and President Harding Rapids), and the importance of that production to the remaining river system, would benefit with comparisons to pre-dam conditions. What was benthic production like in this region before the dam?

A related idea is the fact that the Glen Canyon Dam - Lee's Ferry region is effectively now the headwaters of the Colorado River through Grand Canyon with respect to stability of benthic production and its provision to downstream reaches.

p. 92: Increased drift should not be listed as both a positive and a negative consequence of fluctuating flows. Drift out of the Lee's Ferry region of course reduces benthic production available to higher trophic levels; but drift out of this region also supplements terrestrial inputs for downstream reaches. Since fluctuating-flows experiments were not performed downstream of Lee's Ferry, we do not know the affect of fluctuating flows *per se* on downstream food supplies.

Revision p 60 of December 1994 report: The authors report that suspended sediments did not affect rate of primary production (measured as rate of photosynthesis) in February 1994, but sediments did affect primary production in August 1994. They do not propose a reason for this difference, but it does seem that, given the lower algal biomass present in winter, algal producers may be light-saturated, even under conditions of high sediment load.

Revision p. 50 of December 1994 report: Here the authors suggest that Page, Arizona may be a source of excess nutrients, metals, and pathogens, especially under conditions of high storm run-off. This possibility should be investigated further.

Cladophora glomerata **and its diatom epiphytes in the Colorado River through Glen and Grand Canyons: distribution and desiccation tolerance.**

Usher, H.D., D. W. Blinn, G. G. Hardwick, and W. C. Liebfried. 1987. National Technical Information Service #PB88-183454 (Contract #6400042).

This is another GCES Phase I study performed by Northern Arizona University in conjunction with Arizona Game and Fish Department.

This study was performed over the same time frame as other GCES Phase I studies; however, these authors were able to simulate effects of fluctuating flows on desiccation tolerance in *Cladophora* through the use of laboratory experiments. Therefore, they were able to gain some useful information despite high, steady releases from Glen Canyon Dam.

p. 4 and ff.: A large portion of this report is literature summary focusing on the ecology of *Cladophora*. I did not review this part of the report.

p. 32: Three depths were chosen for sampling: 1 foot, 1 - 4 feet, and > four feet. How much more than four feet in depth the authors sampled is not clear, nor is it clear how much deeper than four feet in depth *Cladophora* may occur. Note that these variables are also not clearly defined in the GCES Phase II study by NAU personnel (Blinn et al.). Therefore, it is not clear in this report how much of the representative habitat of *Cladophora* was sampled during this study.

p. 33: Here the authors point out that diatom densities were evaluated relative to area of substrate (cobble), not relative to area or volume of *Cladophora*. Since *Cladophora* was the only substrate inspected for occurrence and densities of diatoms, any changes in density of *Cladophora* (on an areal basis) will necessarily result in like changes in diatom densities. Therefore, we cannot evaluate effects of depth or distance downstream on diatom density as they occur on *Cladophora*, which is the response of interest. To strengthen the concern of the authors on this page, the failure to measure diatom density relative to *Cladophora* area or volume is definitely a "source of bias in the interpretation of the results."

p. 33 and 34: The desiccation tolerance experiments were performed in the laboratory at NAU, which required collecting *Cladophora*-covered cobbles and returning them to the lab. Note that Ayers and McKinney in a GCES Phase II AGFD report (AQU0302) found that simply removing rocks from the river channel resulted in a significant change in nutrient quality of *Cladophora*. This initial shock to the algae may have biased some of the results of the present study. In the GCES Phase II study from NAU (AQU0100) this is partially resolved in that those desiccation experiments were performed right at the river's edge.

A related point: Desiccation due to river level decline probably represents a very different physical disturbance regime to the algae than simply removing cobbles from water (whether in the lab or in buckets near the river's edge). As river levels drop, algae that will eventually be exposed are subject to the wave action of the river's surface for a relatively long period of time. Thus, it seems as if the desiccation paradigm that has been used by NAU and AGFD researchers may actually underestimate the severity of the actual desiccation event to algae.

p. 35: The authors stated that they attempted to remove silt from Cladophora samples prior to evaluating organic carbon content. Here in the results they describe a pattern of decreasing organic carbon content with distance downstream from the dam in the shallowest sampling sites. There is a possibility that silt loads increased downstream (as shown by Yard - AQU0900), and that the higher levels of silt were more difficult to remove from the downstream samples.

p. 35 and ff.: Results are presented as a series of one-way ANOVAs to show effects of time, depth, and season. These tests should have been performed as fully-crossed ANOVAs so that interactions between variables could be more carefully examined.

p. 37: In their desiccation experiments, the authors observed that *Cladophora* on control cobbles (those that remained in artificial streams in the lab) showed measurable growth ranging from 15-36%. This is apparently despite the rather severe loss of nutrients after removing cobbles from the river channel observed by Ayers and McKinney (AQU0302).

p. 38: Conclusions regarding the effects of repeated exposures on *Cladophora* apparently rest heavily on whether or not bleached filaments are viable, which was not addressed in this study.

Influence of geochemical processes on nutrient spiraling within the recirculation zones of the Colorado River in the Grand Canyon.

Parnell, R. A., J. B. Bennett, A. Springer, and B. Petroutson. 1995. WAQ0100 - fnl

p. 12: A couple of different techniques were used to measure dissolved oxygen; an oxygen probes was used until it broke, and then a "modified Winkler titration" method was used. The authors claim they compared these techniques using several samples to insure that they were compatible, but they provide no evidence that they were indeed compatible. This issue also arises with regard to carbon analyses on p. 14, where alkalinity was originally measured using pH titrations, and then later estimated using a carbon analyzer. Again, no information is provided on the consistency of these different techniques.

p. 18 and ff.: Note that no statistical tests were performed to more rigorously analyze the data presented. Trends are discussed throughout the Results section; however, the reader has no information on whether patterns discussed represent statistically significant results.

p. 18: Here the authors point out that levels of orthophosphate measured in this study differ substantially in magnitude and pattern of distribution from those reported in Maddux et al. 1988; GCES Phase I Arizona Game and Fish Department study). It should be noted, however, that these latter authors discuss a methodological difference between their study and others examining phosphorus levels that limits comparison across studies. In the end, the authors of the present study offer no explanations as to why these differences might have been observed.

p. 18 and ff.: The authors present a very brief discussion of nutrient concentration patterns downstream from Glen Canyon Dam, but they then present results concerning effects of beach geochemistry on oxygen and nutrient concentrations one site at a time. Therefore, no general downstream patterns (or lack thereof) are quantified or discussed. Since only four sites were used, it would have been difficult to detect significant beach effects even if data had been analyzed appropriately.

p. 31: The authors offer the conclusion that fluctuating flows may accelerate the export of nitrogen and increase the storage capacity of return current channel sediments for phosphorus without indicating the potential importance of these effects.

Effects of Glen Canyon Dam operations on *Gammarus lacustris* in the Glen Canyon Dam tail water.

Ayers, A.D., and T. McKinney. AQU0300-drfnrpt.

p. 3: It is unclear here how many transects were sampled at each site. It seems that sampling locations along a transect will not be independent of each other; thus, the number of independent observations at each site will be determined by the number of transects at each site. This problem is carried through to the ANOVA tables beginning on page 36. It is unclear on these tables why the error degrees-of-freedom change with various tests. This is actually a problem that has been noted in other AGFD reports.

p. 4: The authors do not explain in their methods how instantaneous death rates were actually measured. It seems likely that they compared densities of size classes between two sampling dates; the difference was then death rate. A negative death rate would then be interpreted as net growth in population density. If that is the case, it is then not clear how death rate (i.e., actual mortality) was distinguished from recruitment to another developmental stage.

General note: The very significant three-way interaction terms in analyses for *Gammarus* density seen in Tables 5 - 9 (pp. 36 - 38) make it very difficult to ascribe changes in density to any particular main effects. There seems to be so much variability between sites and sampling times that predicting *Gammarus* density would be very problematic. However, resolution of questions concerning degree-of-freedom in these tests may alter the patterns of these interpretations.

Effects of nighttime atmospheric exposure on proximate composition of periphyton.
Ayers, A. D. and T. McKinney. 1996. AQU0302

General note: This study examined effects of nighttime exposure on nutrient quality of periphyton. No daytime exposure studies were performed. Also, this study did not take into account any photoinhibitory effects; that is, this study did not account for nutrient changes that may occur when *Cladophora* is exposed to high levels of solar radiation but still submerged. As such, results of this study should be viewed as representing the minimum effect of dam operations on periphyton nutrient quality.

p. 2.5.2: Here the authors state that they removed cobbles from immediately below the 5000 cfs flow level; since this is the minimum flow level allowed from Glen Canyon Dam, this means that they used cobble colonized by periphyton that was never exposed to the atmosphere. It is conceivable that there exist some strains of *Cladophora* and associated epiphytic diatoms that are more resistant to effects of atmospheric exposure and that may be selectively favored at higher flow elevations.

p. 2.5.7, fig 2.5.1: The authors conclude that there were significant effects of time after removal from the river (not after application of the treatment) on all three nutrient components. From the figure, this appears to be only true for lipids, which the authors explain as loss of epiphytic diatoms when the cobbles were removed from the river. Protein and carbohydrate, however, do not seem to show any real trend. Perhaps another set of control cobbles, these being cobbles that remained in place in the river, should have been used.

Spatio-temporal distribution, habitat use, and larval drift of native fishes in the Little Colorado River, Grand Canyon, Arizona.

Robinson, A.T., R.W. Clarkson, and R.E. Forrest. 1995. AQU0307

General note: This study examines habitat use and distribution of larval native fishes on very fine spatial scales compared to several other studies. In particular, the authors divide three variables into fine divisions: current velocity (1 cm/s increments), water depth (10 cm increments), and distance from shore (10 cm increments). Sampling was performed, however using dip nets (under high discharge conditions), the size of which is unspecified in the manuscript. It is possible, however, that dip nets sampled many of these habitat-type divisions simultaneously.

p. 5 - 6: Note that the authors only evaluated habitat overlap among native fish species. "Unused" habitat was only that habitat used by larval fish other than native species; it was not habitat that was not used by any fish species. Thus, they evaluated whether or not certain species used habitat in ways different from other fish species, and they did not assess qualities of habitats where fish were not found.

p. 5: Note that habitat use during base flow conditions was evaluated at sites where larval fishes were observed (presumably through the clear water). Under turbid conditions, habitat use was measured only when presence of fish was indicated by their presence in random dip net sweeps. Thus, the authors did not sample habitats randomly under base flow conditions, and probably sampled habitats much more intensively under these conditions. This may not affect their interpretation of the data since they are only comparing habitat variables among those sites where native fishes were found, but this difference in sampling strategy should be noted.

p. 6: The authors claim that none of the independent variables included in their analyses were correlated with $r \geq 0.5$. Considering these variables included depth, current velocity, distance from shore, and substrate, this result does not seem likely.

p. 13 and Fig. 31: This figure suggests that larval fishes uniformly avoided "turbidity" as a cover (feature class #6 in Table #1) under high discharge conditions. This doesn't seem possible unless areas of the river very close to the shoreline are relatively clear under high discharge. Also, it is not clear in the manuscript how they evaluated proportion of the available habitat that was turbid versus that which was not turbid (required for calculation of Jacobs' D).

p. 61, Fig. 17 and following: These figures are confusing. If the vertical axes show proportion of habitat points sampled which contained the specific species/larval stage of fish at each value along the horizontal axes, why is it that total numbers of habitat points (H) are not the same in each chart? Also, it seems that the number of fish (F) in each chart should be at least the magnitude of H, if not considerably higher. If vertical axes show proportions of total number of fish (F) found in each habitat type along the horizontal axis, then the bars in most charts do not seem reflective of F's seen in the figure.

Limnology and the distributions of native fishes in the Little Colorado River, Grand Canyon, Arizona.

Robinson, A.T., D.M. Kubly, and R.W. Clarkson. AQU0313

General note: According to original contract sheet from the GCES office, this project AQU0313 was supposed to include other tributaries as well.

p. 5: Note that the relocation experiment was only performed in June. The lack of error bars in Figure 2, which summarizes abiotic conditions by river kilometer, means that we cannot assess whether there were any differences in patterns of these variables in different seasons.

p. 4: Note that periphyton and benthic invertebrates were only sampled in June and August.

p. 10: The authors conclude that, because invertebrate densities are generally higher in upper reaches of the LCR, food limitation must not be operating to limit the presence of fish other than dace in these reaches. There may potentially be a cause-and-effect problem with this interpretation, though. Perhaps there are more invertebrates in the upper reaches because there are fewer fishes. This possibility should be addressed prior to formulating management plans based on invertebrate productivity of the upper reaches.

Temperature tolerance of humpback chub (*Gila cypha*) and Colorado squawfish (*Ptychocheilus lucius*), with a description of culture methods for humpback chub.
Lupher, M.L. and R.W. Clarkson. (AQU0314-drftrpt).

This study examined the effects of temperature and post-hatching age on cold-tolerance and growth in humpback chub and squawfish in laboratory experiments. Cold-tolerance was evaluated as immediate behavioral response to being moved from 20° C water to 10°C water. These results are only presented as observations made during the experiments; no statistical analyses were applied to these data. It does appear that there are significant effects of age on cold-tolerance; that is, larger (older) fish appear to tolerate cold shock better than younger fish. There is no discussion of the level of variability among fish of the same age in this report.

Response of fish to varying temperatures in terms of growth is measured as change in mass and length as a function of original mass and length (thus, effects of original mass and length are removed). Again, no statistical tests are applied, and it is unclear as to which sample size was used by the authors in their discussion. Note that while there were multiple fish within aquaria maintained at each temperature, there were only two or three aquaria for each treatment. These data could have been more profitably analyzed as a two-way ANOVA with initial age and development temperature as separate factors. Again, however, it does appear that culture temperature does have a significant effect on weight and length gain, in that fish grown at warmer temperatures grow faster than those reared at lower temperatures.

TROUT STUDIES

Glen Canyon Dam and the Colorado River: Responses of the Aquatic Biota to dam operations.

Morgensen, S.A., *in* Angradi, T.R., R.W. Clarkson, D.A. Kingsolving, D.M. Kubly, and S.A. Morgensen. AQU0317-intrpt.

The majority of AGFD trout studies have apparently not been received by either GCES or the Center for Environmental Studies at ASU. The following review focuses on a chapter in the above titled report. I will include reviews of other trout studies as they become available from AGFD.

p. 73: Note calculation of mean substrate particle diameters; apparently, particle size class which contained up to 16% of mass of substrate samples and particle size class which contained up to 84% of mass of substrate samples were used in the calculation of geometric mean substrate size. The author does not indicate how much variability might have existed around the 16% and 84% cut-off points in terms of particle size classes. It is possible that in one sample, for example, size class x contained up to 14% of the sample mass with inclusion of size class x + 1 containing up to 20% of sample mass, whereas in another sample size class x contains 14% of sample mass with inclusion of size class x + 1 containing up to 16% of sample mass. While "mean" particle size in each sample is quite different, their calculation will result in the same estimate. An assumption is obviously being made that such errors are randomly distributed across all samples; this calculational procedure, however, results a large amount of error in particle size estimates. An alternative approach would be to calculate densities of particles within each size class, then calculate a weighted average particle size using masses of all particle size classes in the sample.

p. 73: The author states that a subsample of redds from -4.0 mile bar were plotted to calculate percentage of redds present at different river elevations. By only using data from this bar, any information concerning interactions between substrate particle size distribution and redd location is lost. Note that substrate particles size distributions differed between bars (Figure 3.1, p. 77).

p. 75: Here the author describes techniques used in classifying habitat use by trout. While I assume that they used the "point-pole" methods of classifying substrate types as is described in many other GCES reports, no detail on classification is given. It is also apparent from the discussion here that more detailed data were collected from "wadeable" locations; despite the use of a boat in deeper water, it appears that less detailed information was collected from these locations. This results in a bias of trout habitat use data toward shallower water and lower river elevations.

p. 75: Providing data on mean substrate particle sizes within bars and across all bars is not very informative given the variation within and between bars with respect to particle size distributions.

p. 76: Table 3.2 - The general shift in size distribution from larger to smaller particle sizes from upstream to downstream transects within bars seems clear. However, note that 7 - 19 transects were taken per bar, thus each column in this table represents differential sampling effort among bars. Note also the lack of variability estimates around mean values given in the table.

p.76: The author states that gravel samples were collected in June and July 1991 after "high flows had partially redistributed sediments." Clearly an assumption is being made here that these high flows redistributed sediments of all size classes in a similar fashion such that the distribution of sediment sizes on bars did not change.

p. 76 and 79: Active redds were not sampled for substrate particle size distributions in this study. The conclusion offered on p. 79 is that active redds would contain less fine sediments than other non-spawning substrate samples; this is presumably based upon results in other published studies. Given the status of trout in the Glen Canyon dam tailwater, it seems that many such samples could have been taken without harming trout populations; thus arriving at an independent assessment of redd locality selection by trout in the tailwater.

p. 87: No support for the conclusion regarding seasonal differences in mortality due to stranding is given (only one observation during the November to February time period is given specifically in Table 3.7). It is also not possible to assess time-to-kill data on a seasonal basis from the data given in Table 3.7. The data do not "suggest" that time from pool isolation to mortality ranged from 4 to 64 hours; this is clearly shown in Table 3.7. What is suggested is that time to mortality is highly variable and may be very site-specific.

p. 89: Here the author describes habitat use as a percentage of time spent in different habitat types. However, there is no discussion of how these percentages were calculated. If these represent encounter data (i.e., percentage of observations in which fish were detected within particular habitat types) rather than per-unit-effort data, then these data may be biased by habitat-specific encounter probabilities. For example, if radio-tagged trout are easier to detect in runs, then they will be encountered more frequently in runs, regardless of how frequently they actually make use of that habitat type.

p. 91: Substrate use data are summarized here without reference to any possible correlations between substrate type and habitat type (e.g., whether or not sand is a predominant substrate type in eddies, etc.).

p. 93: Here the author concludes that effects of fluctuating flows within Glen Canyon on trout spawning behavior are unknown. This may be treated in subsequent reports, but it is important to note that examining these effects is explicitly part of contract #9-FC-40-07940.

Concentration and transport of particulate organic matter below Glen Canyon Dam on the Colorado River, Arizona.

Angradi, T.R. and D. M. Kubly. AQU0332 pp (Journal of The Arizona-Nevada Academy of Science 28: 12-22 (1994).

Page numbers refer to manuscript page numbers.

General note: The research presented in this paper spans GCES research flows at Glen Canyon Dam as well as interim flows that began in August 1991, which represent very different flow regimes. No mention of this is made in the paper.

- p. 13: Note that only 3 out of 15 sampling dates were during constant flows; comparisons between fluctuating and constant flow conditions should thus be interpreted carefully.

- p. 15: A weak relationship between flow and CPOM concentration is suggested by Figure 4. The authors suggest that hysteresis (differing relationships between discharge and flow altering seston concentration in similar flows at different times of day) may be contributing to the scattering of points around the line. Inspection of other data in the paper, however, suggests that flows at 1600 hours were similar to flows at 2200 h, and Figure 3 suggests that seston concentrations were also similar at these points in time. Thus, hysteresis probably is not having a very strong effect in Figure 4.

Also, it seems as if ascending versus descending flows could have been included for each data point in Figure 4 as categorical covariates to remove any such effects.

- p. 14: In analyzing the effect of flow on seston concentration, the authors used time of day as a surrogate estimate of flow rate. Actual flow rate could have been used as a covariate with time of day to gain perhaps an even more accurate analysis of these effects. Also, all mass (mg AFDM l^{-1}) data should have been log-transformed prior to analyses.

- p. 19: Sample sizes given for regressions of seston concentration on distance from the dam suggest that the authors took multiple samples from each sample site on each date, and then entered these as independent values. Such observations would not be independent of one another and should not be treated statistically as independent points.

Effects of atmospheric exposure on chlorophyll *a*, biomass and productivity of the epilithon of a tailwater river.

Angradi, T.R. and D.M. Kubly. AQU0333 - pp (Regulated Rivers and Research 8: 345-358, 1993).

Page numbers refer to published manuscript page numbers.

- p. 346: The authors focus on effects of daytime exposures of *Cladophora* to sunlight, citing Usher and Blinn 1990 (and Blinn et al. 1992 in other parts of the paper) as finding night-time exposures to result in relatively low loss of *Cladophora* biomass. However, it should be noted that Blinn et al. did find almost a 25% biomass decrease in *Cladophora* exposed during night-time conditions. Thus, the scenario proposed by these authors on p. 355 that *Cladophora* "thrives" even when exposed to night-time exposure should be modified.

- p. 349: Statistical analyses: Most of these experiments should have been analyzed using repeated-measures ANOVA because the same experimental units were sampled over several time points. Also, ANCOVA could be used to analyze these data; this would still allow examination of the effects of re-inundation time (their primary independent variable of interest), while testing simultaneously for treatment effects during the re-inundation period after effects of re-inundation time had been accounted for. For example, in Figure 3, the control units suffered an unexplained loss of biomass at the beginning of the study (authors suggest this was due to disturbance induced by repositioning the boxes) but they recovered much more quickly than the experimental units. This suggests that not only does exposed *Cladophora* suffer a biomass loss, but also exposed *Cladophora* cannot recover from such biomass loss as rapidly as unexposed *Cladophora*.

Also, their data are expressed as percentages of original chlorophyll and biomass remaining; these percentages are then log_{10}-transformed. Percentages should be angularly transformed.

- p. 351: There are indications in the authors' sluiceway experiment that recolonization by algae other than *Cladophora* can occur after exposure. The authors claim that *Ulothrix* (alga that recolonized tiles rapidly in the sluiceway) is relatively rare in the river itself; however, studies such as these that follow only chlorophyll *a* density as a response variable should distinguish which algae contribute to these estimates.

- p. 353: No clear indication is given as to whether or not exposed filaments of *Cladophora* might eventually recover and begin to grow again or if new accrual of chlorophyll *a* is solely due to re-colonizing algae. On page 354, the authors equate destruction of chlorophyll with loss of filaments, yet they emphasize that even "severely damaged" filaments can remain attached after re-inundation. They conclude that productive capacity of the epilithon is largely destroyed after eight hours of exposure.

- p. 353: Re: model of lost Gross Primary Production (GPP) in Figure 8. Surface in (a) was generated by using regressions involving log_{10}-transformed percentages, which may or may not greatly alter the surface from what it would be if angularly-transformed percentages had been used. Also, GPP lost shown in (b) should be expressed as percentage of GPP lost, since (a) tells us that GPP will increase with chl *a* density.

Changes in temperature of backwaters during fluctuating vs. short-term steady flows in the Colorado River, Grand Canyon.

Hoffnagle, T. L. 1996. AQU0335-ppdrft

p. 4: Changes in release patterns from fluctuating to steady flows are here discussed as both positive and negative to native fishes; in the end, they should not be considered as both. Historically, backwaters must have formed during floods and then remained undisturbed for long periods of time (i.e., historically, the Colorado must have operated more similarly to "steady" release conditions observed today). Increases in temperature and invertebrate production must have been quite high under these conditions (according to results of the present study), and yet presumably larval native fishes flourished under these conditions. The present study was very short-term, only performed at one time of year; therefore, results of this study with regard to long-term larval native fish performance cannot be assessed.

p. 7: Results of the study are summarized in detail for each backwater examined (n = 4). This prohibits discussion about changes in temperature and other conditions being possibly correlated with other biotic and abiotic variables specific to backwaters (e.g., depth, vegetation cover, substrate, etc.). The backwaters used were of only two types (i.e., two with standing vegetation and two without), and they were located within 8 kilometers of each other near the LCR. Thus, general conclusions about the effects of flow regime on conditions of backwaters are limited.

General note: This study compared backwater conditions under a fluctuating flow regime and only one steady flow level (8200 cfs). Results obtained in these backwaters, and general effects of flow regime on backwater conditions, are probably sensitive to the flow level studied under steady flows. Perhaps a greater number of favorable backwaters would be maintained at different steady flow levels.

p. 9: The authors point out that during fluctuating flows, flow peaks reached the LCR early in the day. Their study sites were therefore subject to steady or decreasing flows during the remainder of the day when insolation and ambient temperatures were highest. This highlights a general aspect to management of dam operations that has not been well addressed in these reports; namely, timing of events at the dam will affect timing of those effects at various sites downstream with regard to any interactions between those events and time-of-day.

p. 16: Here the authors suggest that use of backwaters by larval fishes under steady flows probably will not increase until food availability in backwaters increases due to increased temperature. However, use of the backwaters can only change in larval fish have access to backwaters after they have been isolated during steady flows. If the return channel of a given backwater is too shallow, then any larval fish not already in the backwater will not be able to enter the backwater. This possibility for any given backwater is obviously sensitive to the discharge selected for a steady flow regime.

Distribution and prevalence of the Asian fish tapeworm, *Bothriocephalus acheilognathi*, in the Colorado River and tributaries, Grand Canyon, Arizona.

Brouder, M.J., and T.L. Hoffnagle. (AQU0336)

- p. 5: It is not clear how far sampling efforts extended into tributaries.

- p. 5: Note in the first sentence of Methods that fish were collected as part of another diet study, and that the focus here was on small (< 150 mm) fish.

- p. 8: Here there is a discussion about the possibility of *B. acheilognathi* becoming established in Kanab Creek based on capture of an infected speckled dace in this tributary. An important consideration not outlined here is whether or not appropriate copepod species are present in Kanab Creek in sufficient numbers to facilitate an invasion of tapeworm in this tributary.

Effect of different flow regimes on periphyton standing crop and organic matter and nutrient loading rates for the Glen Canyon Dam tailwater to Lee's Ferry.
Ayers, A.D. and T. McKinney. 1995. WAQ0300 - drftfnl

- p. 2: The authors explicitly point out that this study focused on those ecosystem elements that represent direct provisioning of food to those fish species for which AGFD is responsible for managing.

- p. 4: A suggestion is made that patterns of algal growth and colonization since 1992 indicate a conversion from heterotrophy to autotrophy in the Glen Canyon reach related to dam operations. I assume the authors attribute this to long-term (1 year +) effects of the shift to interim operations (which began August 1, 1991), although this is not very clear in the report.

- p. 5: Note the changes in techniques for collecting CPOM, especially the later inclusion of techniques to collect the 750 - 1000 μm size range. These changes probably did not affect their overall description of CPOM dynamics, since this intermediate size range represented a very small fraction of total seston.

- p. 5: Note the authors used optical density of samples at various wavelengths to measure chl *a* concentration, whereas most other authors have used fluorescence. Equivalence between these techniques should be provided.

- p. 9, and Figs. 2.2.1., 2.2.2: There seems to be some disparity between patterns of FPOM biomass and FPOM chl *a* concentration in this study. This may be due to periods of time when FPOM may not have been comprised of photosynthetically active phytoplankton.

- p. 9: The authors point out a correlation between magnitude of variability in CPOM and variance in river stage in Figs. 2.2.3 and 2.2.5. Variability in river stage was also positively correlated with CPOM biomass; therefore, C.V. of CPOM biomass should be compared to variance in river stage in order to strengthen any inference based on this correlation.

- p. 17 - 18, Tables 2.2.9 - 2.2.14: Note that so many of the interaction terms in the authors' analyses of periphyton biomass are significant that they are not in a position to be able to assess any independent effects of month, river mile, or river elevation. This complexity is also reflected in the discussion. They conclude that interim flows have favorably affected the periphyton community (last sentence, p. 29) by noting that the effect of river elevation decreases between 1993 and 1994 datasets (e.g., compare effect of elevation in Tables 2.2.9 and 2.2.11 with that in Table 2.2.13). This conclusion is not warranted by simple inspection of the ANOVA tables; the tables only indicate that differences between elevations have decreased. Inspection of Figure 2.2.10 indicates that one effect of interim flows may be that periphyton biomass at the 8000 cfs level now more closely tracks that at the 5000 cfs level (supporting the ANOVA tables above). However, notice on the same figure that periphyton biomass at the 5000 cfs level (permanently inundated) reached its lowest levels seen in the prior three years. Thus, the periphyton community as a whole may or may not be favorably impacted by interim flows.

- p. 28: Here the authors discuss possible problems associated with interpreting periphyton density data collected using the cobble-collection technique that they used. This issue raised a general question that was not addressed in this report: were the cobbles randomly selected at each sampling site? If only cobbles that had periphyton growing on them were used, this would greatly overestimate the overall density of periphyton at any given site. Such sampling strategies should be made more explicit in future reports.

- p. 28: *Chara* appeared in this study to be less affected by fluctuating flows than *Cladophora*. While biomass of *Chara* was generally lower at the higher river elevation, chl *a* and phaeophytin concentrations were usually comparable. This difference in response between *Chara* and *Cladophora* should be emphasized in future research.

- p. 40, Table 2.2.17: Comparing the error degrees of freedom here to that of Table 2.2.13 suggests that fewer data points were used in the analysis of chl *a* concentration than were used in biomass analyses.

Water chemistry and zooplankton in the Lake Powell forebay and the Glen Canyon Dam tailwater.

Ayers, A.D., and T. McKinney. March 1995. WAQ0301 - drftfnl
Revised: 12 May 1997, based on WAQ0301-fnl. Bold-faced page numbers refer to pages in the final draft.

p. 2.1.7: In their cover letter, the authors state that one of the main revisions of this report was the inclusion of statistical analyses. On this page, they report zooplankton densities by depth over day and night samples from July 1990 collections. Data for each taxon are analyzed using separate Kruskal-Wallis tests; the non-parametric test was used as they could not normalize these data. However, densities of all these taxa are undoubtedly inter-correlated, and therefore these data should have been analyzed using some kind of multivariate procedure. It is also unclear if these analyses were done correctly based on inspection of Tables 2.1.3 - 2.1.8. Using the Kruskal-Wallis test with each day/depth sample as separate categories prevents comparing day and night density differences, and the lack of post-hoc multiple comparisons prevents identification of more specific patterns within the dataset.

p. 2.1.9: Here the authors compare zooplankton densities by date between Glen Canyon Dam draft tubes and Lee's Ferry. These comparisons are performed using Chi-squared analysis with each date as a separate category and numbers of each taxon observed in the draft tubes as an expected count. This is a completely inappropriate use of Chi-squared. Many of their "expected" counts are zero (0), which is not permissible in Chi-squared analyses ("observed - expected squared divided by expected" is undefined when "expected" = 0; it is not equal to 0). Using a goodness-of-fit test like Chi-squared also prevents comparison of overall mean densities. Some kind of repeated-measures ANOVA should have been applied to these data, except that replicate samples were not taken at each location.

p. 6-7: Comparison of zooplankton densities and composition between the draft tubes and Lee's Ferry collections from Oct. 1989 to Dec. 1991 showed that they were very similar in these two regions. However, mean densities appeared to be lower at Lee's Ferry than in the draft tubes in samples taken from June 1993 to January 1995.

p. 22: The conclusion offered here about seasonal warming of Lake Powell being more dependent on spring runoff than on summer ambient air temperatures should be expanded. As noted by the authors, this may have important impacts on the development of a multi-level intake structure.

p. 23: The authors' conclusion that rotifer densities remained relatively low may be influenced by the fact that they sampled zooplankton with 80μm nets, which may not capture rotifers effectively. A brief comparison of samples collected with nets of smaller mesh may have allowed these investigators to determine how well they estimated rotifer densities in this study.

p. 2.1.30 and ff: The authors point out in their cover letter that one revision to this final report was the addition of more general zooplankton ecological information. However, this is manifest here as simply a review of zooplankton literature with little or no relevance to the Lake Powell/Glen Canyon system.

p. 23: Their data indicate possible tailwater reproduction by copepods - this possibility should be expanded because of the importance of copepods to dynamics of Asian tapeworm (*Bothriocephalus*).

p. 24: The authors point out that cladocerans may have been destroyed during their sampling efforts with a diaphragm pump; they contrast their results with studies that found higher cladoceran densities in the lake. They incorrectly conclude that any bias introduced by their sampling procedure must have been slight by pointing out that their samples contained 1 - 62% cladocerans. To really evaluate this, they should compare their estimates with those from net samples. In the end, cladoceran densities may not have much of an impact on the Glen Canyon ecosystem (re: if most primary production is due to *Cladophora*, which cannot be eaten by cladocerans); thus, effects of the dam on cladocerans probably shouldn't be a focus of future studies.

p. 2.1.40: In discussing the downstream losses of zooplankton below the tailwater, the authors have focused on the potentially filtering activity of filamentous algae without considering the importance of fish predation.

Changes in water quality parameters and fish usage of backwaters during fluctuating vs. short-term steady flows in the Colorado River, Grand Canyon.
Hoffnagle, T.L. WAQ0303

p. 1: Note the very limited temporal aspect to this study: only 25 - 31 May 1994. Note also that throughout this study, "steady" flows represented relatively low discharge (233 cms).

p. 3: Important methodological note: only temperature was measured in several backwaters, and temperature, pH, conductance, and oxygen were all measured in only one backwater.

p. 11: Indication here that oxygen dynamics in these backwaters are driven more by photosynthesis than temperature changes during the day. This conclusion was also suggested for the LCR by Robinson, Kubly, and Clarkson in the report above (AQU0313).

p. 12: Here the author proposes that conductivity in backwaters is driven more by exchange of water through sandbar and across the mouth than exchange of water between the backwater and the bank.

Effects of varied flow regimes on aquatic resources of Glen and Grand Canyons.

Maddux, H.R., D. M. Kubly, J. C. deVos, W. R. Persons, R. Staedicke, and R. L. Wright. 1987. #PB88-183439

This is a GCES Phase I report; the final draft was published both by Arizona Game and Fish as well as National Technical Information Service. CES at ASU possesses a copy of both; this report does not have a number assigned to it as in other GCES Phase II reports.

General note: The purpose of this study was to examine responses of a wide range of aquatic resources to varied flow regimes in Glen and Grand Canyons. By varied flow regimes, the authors meant to study both steady flows as well as fluctuating flows. However, BOR required that water be released from Glen Canyon dam at a high steady rate during most of this study; any fluctuating flows that were allowed by BOR only occurred during autumn and winter seasons. Therefore, the stated goal of this project could not be achieved. This is pointed out by the authors at several points in this report. The entire report is therefore nothing more than a description of the state of various response variables measured during the study. This may have represented new information at the time; however, the authors cite several other studies within this report, suggesting that many of the data summarized had already been collected by other investigators.

In almost all instances of data presentation throughout this study, statistical tests are not applied. Thus, the reader is left with subjective descriptions of trends with no confidence that variability in the data sets can be reliably explained by seasonal and/or flow regime differences.

p. 29: The usefulness of these data beyond simple description is further limited by the practice of the authors to summarize data across all sampling points during the study. For example, Table 3.4 shows descriptive statistics for various water quality measures, based on data collected over the entire study period. Thus, no seasonal or flow regime effects can be discerned.

p. 53 and ff: In their chapter summarizing fish species distributions, the authors present data in such a way as to show percentage of a given species caught within a study using a particular technique, instead of showing percentage of catch within that reach comprised of that species. Therefore, one cannot determine composition of fish communities in the different reaches.

p. 59 and others: The authors routinely switch units reported with catch per unit effort (CPUE). In some cases, CPUE is expressed as #fish/unit time, in other cases it is reported as #fish/unit area. Without clear discussion in the Methods section of how time might relate to area in terms of sampling efforts (e.g., how long to sample a particular area with a particular piece of sampling equipment), it is difficult to compare estimates of fish density in different reaches and in different habitat types.

p. 98 and ff: In the chapter on habitat utilization, no statistical analyses were applied to data presented, so conclusions regarding observed trends are tenuous at best.

p. 116 and 117: Again, the authors switch in their use of units for CPUE between per unit time and per unit area.

p. 117: The authors justify lack of statistical analyses here in terms of the pattern of responses in the data set; non-parametric tests would likely have solved these problems.

p. 136: No information on how larvae and fry were collected is provided; this makes it difficult to compare these data to those from other studies or to other efforts of this study.

p. 165: Locations of sampling points along the river channel for zooplankton are not provided.

p. 165: Note the difference in analysis of larval versus adult food use patterns. Prey items from larval stomachs were counted and then diet composition was expressed in numerical percentages, whereas adult food items were expressed as percent volume for each prey type. This makes it difficult to describe changes in food usage throughout ontogeny of these fish.

p. 183: Here the authors present some rather striking patterns in year-class strengths of rainbow trout in different study reaches. However, they do not provide any suggested explanations for these patterns. Such suggestions would help to focus future research efforts.

p. 198: Another consequence of BOR-dictated release patterns is highlighted here. The authors wanted to study effects o low flows on stranding and redd-dewatering. However, the low flow in October 1984 allowed by BOR of which the authors took advantage (5000 cfs) was too low to allow them to sample much of the river channel. Thus, stranding and dewatering information is only provided for a low number of sites in the tailwater area.

p. 202: The authors concluded here that fluctuating flows could affect native and sport fishes based on their observations made during a three-day, low flow period. However, while flow was low (5000 cfs), it was not fluctuating; therefore, this conclusion is not strongly supported by their data.

p. 208: Note that in the spillway experiment examining the effects of fluctuating flows on rainbow trout embryo and alevin survival, sediment-free water was used. In the mainchannel, fluctuating, sediment-laden water may have very different effects.

p. 231: The authors' analysis of effects of flow on rainbow trout catch rates in the Lee's Ferry fishery are confounded with seasonal differences in trout behavior (e.g., spawning); thus, no conclusion can be supported here.

Zooplankton of the Colorado River: Glen Canyon Dam to Diamond Creek.

Haury, L. R. 1986. GCES Phase I, National Technical Information Service #PB88-183462.

This is another GCES Phase I study; the contract was with Scripps Institute of Oceanography, in conjunction with Arizona Game and Fish Department.

General: As with the AGFD Phase I study, this study took place during a period of high, steady releases from Glen Canyon Dam, as operated by Bureau of Reclamation. Therefore, the author was unable to study the effects of fluctuating flows on the ecology of zooplankton in the Colorado River, despite this being an objective of the original project. The author also points out many times in the report that sampling was sporadic and sometimes spatially limited, which greatly limits the usefulness of this data set as a baseline for future research.

p. 4: Sampling dates and extent of the river sampled are presented here in Table 1. Note that while six trips were made to the river, on only four of those trips were more than a few miles of river channel sampled. Also, on only three of those four trips were samples collected anywhere near Diamond Creek (RM 225); the fourth trip apparently terminated at RM 132.

p. 5: The author states here that, because of multiple sampling methods, restricted number of sampling sites and times, and "inherent high variability of planktonic systems," no statistical analyses of data presented are undertaken. This obviously limits the extent to which trends can be interpreted in this study.

p. 8: Here the author points out that no downstream trend in abundance or taxonomic representation occurred over the 240 miles of the river, which is in contrast to other studies that show replacement of species based on morphological characteristics and swimming ability. However, no possible explanations are offered for this rather striking finding. The author does point out that overall "condition" of zooplankton decreased downstream, but "condition" is not very well defined or quantified in this report.