# INTEGRATED FISHERIES MANAGEMENT PLAN FOR THE LITTLE COLORADO RIVER WATERSHED

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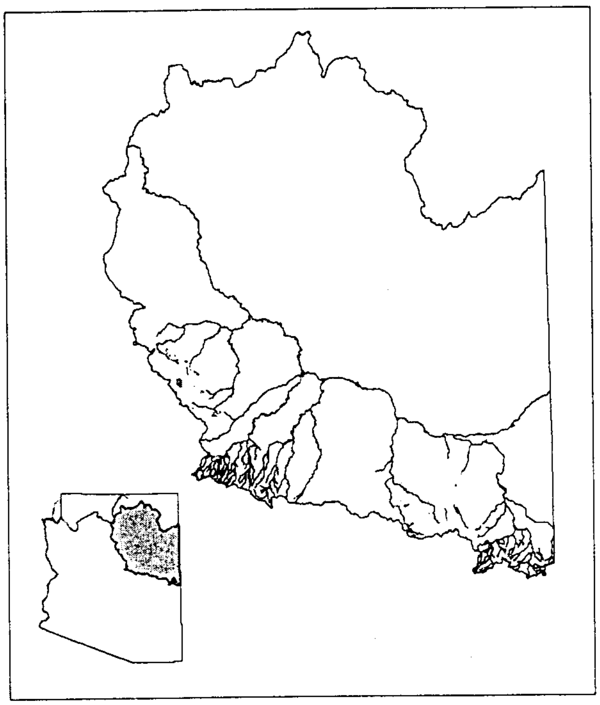

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## FOREWORD

### INTRODUCTION

The Little Colorado River Watershed should provide a place for the conservation of both native fish and sportfish. It should be home to recovered native fishes, and a place where the people of Arizona can find quality sportfishing opportunities. The Arizona Game and Fish Department (AGFD) has not always fully integrated planning and management efforts for sportfish and native fish, and this has sometimes led to undesirable conflicts.

Productive use of Arizona's watersheds dictates that AGFD develops a truly unified approach for fisheries management. We must address the challenges of conservation for all fisheries resources in Arizona and the values they hold for Arizonans. To accomplish this, AGFD is committed to working toward a watershed-based approach to fisheries management. The Little Colorado River watershed was selected as the place to develop these processes because it constitutes an important component of Arizona's fishable waters. Also, many heavily used recreational sportfisheries in the watershed depend upon AGFD's management actions, and the watershed is home to populations of threatened and endangered native fishes. AGFD believes that threatened native fisheries in the watershed are recoverable, while continuing to provide quality recreational fishing opportunities.

Watershed management is an active field. We anticipate the continued formation of watershed councils and associations. These groups are concerned with formulating management goals targeting multiple objectives. The work we present here could frame AGFD's contributions to those councils or associations, whether they are formulating smaller, immediately achievable steps, or larger landscape level prescriptions arrived at in consensus with resource managers and resource beneficiaries. Acceptance that AGFD will have to focus at multiple scales to advance fisheries management is only the beginning of a journey that will not end as long as we manage fisheries resources in the Little Colorado River watershed.

### PROJECT OVERVIEW

In 1995, AGFD fisheries personnel began developing a management approach integrating sportfish and native fish management over a geographically meaningful scale. Both the integration of sportfish and native fish management, and the watershed scale at which management was envisioned, were departures from existing approaches. Ultimately, we developed two approaches with slightly different goals.

The *Integrated Fisheries Management Plan for the Little Colorado River Watershed* (Integrated Plan; Young and others 2001) is the culmination of a collaborative effort by Department staff representing fisheries management interests within Arizona. It was envisioned that the Integrated Plan would be used to create a management plan to provide fisheries personnel with a practical management decision tool. The plan provides site-specific (reach-level) management recommendations needed to meet AGFD's native fish and sportfish mandates. In addition, the recommendations were intended to provide guidance to land management agencies and others operating in areas that correspond to our management reaches.

An alternative conceptual approach was developed to use watershed management tools to work at different scales, so that conflicts between native and non-native fishes could be addressed, as well as habitat restoration and protection. The outcome of this effort was this report, *Fisheries and Watershed Management in Arizona: Looking into the Future* (Watershed Plan; Allison and Kubly 2001). The Watershed Plan assumes AGFD will be cooperating with private landowners and government entities to improve quantity and quality of habitat for fishes. Since AGFD manages non-fish wildlife in the same areas, the plan also addresses other species as management targets.

Both plans were subjected to extensive internal (AGFD personnel) and external (federal agencies, angler organizations, and academia) reviews. Strengths and weaknesses of each approach were then evaluated. It was generally agreed that both approaches offer benefits to fisheries management. AGFD is now considering how to proceed, since the two approaches concentrate on different priorities, work on generally different geographic and temporal scales, and call for different levels of internal expertise and external stakeholder participation. Because the two approaches were developed as part of the same project, this Foreword was written into both documents (Allison and Kubly 2001 and Young and others 2001). It also summarizes the operating parameters of each approach and key issues raised during the review process.

### Operating Parameters

The operating parameters under which the Integrated Plan was developed included:

- The approach will be developed to meet fisheries management needs, not as a framework for ecosystem management, which is a collaborative effort between authorities and stakeholders.
- Project goals will be met by focusing on fisheries management activities within the watershed. The project will not encompass watershed management.
- The plan will focus on management actions within the authority of the Arizona Game and Fish Department, and will exclude private and tribal waters.
- The approach will use existing fisheries data, with additional data incorporated as available.
- Angler needs within the Little Colorado River watershed are currently being met.
- A five-year review and evaluation process will be incorporated into the project.

The operating parameters shared by both approaches were:

- The approach includes mechanisms for balanced management of both sportfish and native fish (conservation/recovery).
- Budget for approach development and implementation is limited.
- Reservoirs are a part of the landscape and often provide important sportfishing opportunities.

## KEY ISSUES IDENTIFIED DURING REVIEW

Several issues and questions were identified during internal and external agency review of both the Integrated and Watershed plans. These review comments were summarized, sorted, and encapsulated into the following key issues:

- Scale. Fisheries and habitat management occur at various spatial and temporal scales. Different scales are appropriate to address scientific, political, and management goals.
- Habitat.
  - Fisheries management includes the restoration and protection of watersheds to increase the quantity and quality of aquatic habitat.
  - Prioritizing habitat restoration areas requires identification of habitat potential.
- Timeline. What are the priorities and possible goals in the short, medium and long-term? What will AGFD actually do in the short, medium, and long-term? The objective is to balance short-term needs and long-term goals.
- Applicability. The process must be applicable to other watersheds.
- Feasibility and potential value. AGFD should provide specifics of anticipated effects on threatened and endangered species, how recovery criteria might be met, and how fishing opportunities would be impacted.
- Partnerships.
  - Due to inclusion of habitat restoration in our process, we will have to build successful partnerships and interactions with entities with other management and regulatory authorities (e.g. local governments, tribes, private landowners, USBR, USFS, USFWS).
  - Recommendations must be usable by partners and outcomes must address needs of stakeholders.
- Data Collection.
  - Available data were collected over an extended time period, using different protocols Standardizing some data collection procedures would result in more comparable data from different projects.
  - AGFD should establish a method for evaluating management effectiveness (including which data to collect).
  - The empirical basis for both approaches requires having all available data at hand, with careful criteria for which data to use and the limitations of these data.
- Is it more appropriate for another agency to take the lead on the watershed management/restoration aspect of the process?
- Any management plan should attempt to address viability of species and include assessment of risk factors. A need to evaluate connectivity of management units was mentioned often in this context.
- Assemblages involving native and non-native fishes (including non-target species).
  - Assemblages, not just single species, have to constitute a significant part of management focus.
  - How should such assemblages be constructed for the best management?
  - Are natives and non-natives always incompatible? At what geographic scale might they be incompatible?
- Selection and validation of framework.
  - Explore and justify approach used.

- ➢ Justify assumptions used when approaching species assemblages. Assumptions include whether poisoning should be used, whether separation of natives and non-natives is necessary, etc. If reintroduction is used as a tool, when and where should it be applied? How will these future actions be decided?
- Any plan should address biological as well as sociopolitical considerations, including the economics of fisheries decisions.

The Integrated Plan (NGTR 146) and the Watershed Plan (NGTR 169) were revised to address some reviewer comments, but most issues summarized here would have to be incorporated in a more overarching modification. Instead, the comments are summarized and compiled in the companion appendix, "Summarized and Excerpted Comments on the Arizona Game and Fish Department Drafts of *Integrated Fisheries Management Plan for the Little Colorado River Watershed* (NGTR 146) and *Fisheries and Watershed Management in Arizona: Looking into the Future* (NGTR 169)." The scope of issues identified highlights the fact that these two documents do not provide a final vision of AGFD's approach to watershed management for fisheries or other resources. That vision is yet to be crafted.

### Where do We Go From Here

Little did we know that the path toward watershed-based fisheries management would present so many possibilities. For instance, the two approaches we developed both use information about fish point locations (samples). However, fish do not remain in 50 m stretches, so one approach extrapolates from these points to describe occupied reaches where local management and day-to-day conflicts between fish species might occur. The other approach extrapolates to delineate watersheds, identifying areas that need to be managed to affect habitat as well.

Both the Integrated and Watershed approaches bring important information and perspective to fisheries management, but neither goes far enough. We have to begin with what we know about the fishes and where they are located, using the available tools to progress toward our objective of ensuring conservation all of the fishes and fisheries values of the Little Colorado River watershed. These two components are steps moving us toward fisheries management at a landscape level with increasingly broader participation of publics with diverse interests. In this section, we propose how AGFD should take the best components of these approaches while also addressing the very valid comments provided by thoughtful reviewers.

These two approaches represent AGFD's larger commitment to watershed-based management. By 2006, such management will be developed for fisheries in at least two watersheds (AGFD 2001). The commitment to watershed management means that if it cannot provide related expertise, AGFD will need to enter into arrangements to bring this expertise to our planning. Sources of external expertise might include other agencies with experience in hydrology as well as larger watershed management groups. Approximately 12 active watershed groups exist in Arizona; one of the largest, most geographically and resource encompassing watershed projects is the Verde Watershed Association. The Verde Valley is a likely watershed for future Department fisheries planning. We see AGFD's likely role in such collaborative groups as providing expertise on native fishes, representing sportfish management interests, and as the source of the largest database with collection information on fishes in the state. Any plans that propose fisheries outcomes, but do not use AGFD's expertise in these areas, would not offer management based on the best available data.

AGFD has strong interest in participating in watershed planning groups to ensure that its interests and those of its customers are well represented. Some aspects of fisheries management can only be provided by AGFD, so its involvement in such planning groups is crucial. Many of AGFD's operations and personnel are dedicated to providing, monitoring, and sometimes taking local management action to benefit native and sport fisheries. However, it has become clear that modern fisheries management focuses on watershed and ecosystem management, requiring considerable quantities of time and other resources, not all of which AGFD can or should provide. This calls for coordination among large groups. Also, fisheries management plans must lay out long- and short-term goals and activities. These plans should build on larger strategies, in cooperation with other parties in the watersheds. One benefit of such planning groups is that from the beginning they can consider acceptable management alternatives, some of which may simultaneously address the needs of AGFD and of other cooperators. For this reason, one of AGFD's roles in watershed associations could be to participate in developing specific alternative management scenarios, and evaluating risk factors and viability benefits to species for each alternative. This is also a foundation of adaptive management.

Regarding its approach to the Little Colorado River watershed, AGFD should move forward toward better partnering with the Little Colorado Multi-Objective-Management group. AGFD's goal could be to identify or develop a working group of interested and expert entities to put fisheries management in a larger and more stable context in the Little Colorado River watershed. Such committees could be targeted for federal funding under the proposed Fishable Waters Act. AGFD might be most interested in participating in a technical committee within the group, and in representing native and sportfishing interests to the larger group. Through participation in such a watershed association, AGFD could identify a more directed set of fisheries objectives for the Little Colorado River. Also, while it has a database of collection information to refer to, this might be the time to improve the quality of the data and of the database. AGFD could develop standard fisheries collection and creel protocols for use in future fisheries management activities; develop standard statewide fisheries database design and maintenance protocols; and locate, assess, geo-reference, and enter statewide fisheries data into the statewide database. To the extent any fisheries management work plan and activity guidance at the local level is called for, over the next three years we will refer to information in the Integrated Plan.

In the Verde River watershed, AGFD is considering focusing on watershed scale multi-objective planning through the infrastructure of the Verde Watershed Association. This could entail development of a Verde River aquatic wildlife technical committee including membership from AGFD, ADEQ, USFS, USFWS, and others. The committee's charges could include identifying and evaluating available frameworks for watershed analysis and planning that address issues already identified in the Little Colorado River watershed. Whether operating within itself or through technical committee, AGFD would need to develop or obtain expertise necessary to guide and facilitate the process of planning and implementing watershed management. To validate and increase the value of its fisheries management, AGFD would need to ensure feedback between management unit specific prescriptions, and prescriptions developed at a landscape scale.

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# CHAPTER 1: FISHERIES MANAGEMENT IN ARIZONA

Kirk L. Young

## INTRODUCTION

The Arizona Game and Fish Department (Department, AGFD), through the Arizona Game and Fish Commission (AGFC), was given responsibility, and authority for management of all wildlife within the state in 1929. Arizona Revised Statute Title 17 codifies this responsibility and defines wildlife as all wild mammals, wild birds and the nests or eggs thereof, reptiles, amphibians, mollusks, crustaceans, and fish, including their eggs or spawn. Guidance for the management of wildlife is provided through a comprehensive planning process and is reflected in AGFD's mission statement and Wildlife 2000 Strategic Plan (AGFD 1995). The mission directs AGFD:

> To conserve, enhance and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.

Wildlife 2000 provides specific guidance for management of native and sportfisheries: "to protect, restore, and maintain nongame and endangered wildlife as part of the natural diversity of Arizona"; and, "to protect, maintain, or enhance the distribution, abundance, availability, and diversity of coldwater and warmwater sportfish and their habitats". More specifically, Wildlife 2000 directs Department personnel to "(d)evelop watershed-based management plans that identify where sportfish and native fish will be managed, and structure management programs to minimize conflict between these two resource groups."

Within the same stream or lake, the various management aspects of AGFD's mission, mandates, and goals are sometimes in conflict. Further complicating the management of sport and native fishes is that management efforts are rarely integrated. Historically, sportfishing activities were conducted with little assessment of costs and benefits, or impacts to other species, while native fish management activities were put forth with little regard to current or future impacts to recreation. Integration was often a forced result of conflict precipitated within AGFD, by the public, or by other agencies.

During early years of fisheries management in Arizona, native fish were largely ignored, and during this era native trout nearly disappeared from the state. Some native fish were looked upon as "trash" fish, and there were successful attempts to eradicate them from certain streams. In more recent times, government agencies and the public have become increasingly sensitive to the plight of native species threatened by extirpation or extinction. Largely due to federal legislation, including the National Environmental Policy Act (NEPA, passed in 1969), the Endangered Species Act (ESA, passed in 1973), and the Clean Water Act, some declining native fishes now are afforded legal protection. Recently, the Department went through a Section 7 consultation with the Fish and Wildlife Service, in compliance with the ESA. This consultation was initiated because of increasing suspicion that predation by stocked sportfish and their progeny is negatively affecting federally listed native fish (Marsh and Brooks 1989; Blinn and Runck 1990, 1993; Blinn and others 1993; Marsh and Douglas 1997).

There are significant challenges facing fisheries management in the next decade. One wildlife management trend which has evolved over the past decade is wildlife management by litigation. Special interest groups are successfully dictating land management actions, and in some cases wildlife management actions, through the judicial system. It is clear that if we do not make decisive, balanced, and meaningful management decisions, other factions will do so on our behalf. Wildlife decisions made through litigation are not likely to result in balanced, measured, or thoughtful furtherance of the AGFD Mission and Strategic Plan direction. Thus, it is in AGFD's best interest to proactively manage native fish and sportfish for the benefit of both.

Other factors are also contributing to the need for a modified approach to fisheries management. Primary among them is the ongoing growth and urbanization of Arizona's human population. One effect of changing demographics is an increasing demand for consumptive uses of limited water resources in an arid land and a burgeoning demand for water-based recreational activities. A second effect is a broadening of public interests from traditional consumptive uses of fish and wildlife to a more eclectic viewpoint that finds increasing importance in maintaining declining indigenous species and their native habitats. These changes affect all aspects of water resources management in Arizona, including the management of native fishes and sportfishes. AGFD must be responsive to the changing needs of Arizona's fish and wildlife resources, and to the public which owns those resources. As responsible stewards of the public trust, we must modify our management to best serve the needs of both present and future generations, while maintaining our commitment to conserve, enhance, and restore the State's diverse wildlife resources.

This report institutes two changes in fisheries management by AGFD. The first change is to integrate the management of native fish and sportfish, rather than treating these two groups of fishes independently. The second change is to plan and conduct fisheries management on a watershed scale. These changes are being instituted for a number of reasons, but primarily because AGFD recognizes that effective management of Arizona's fisheries resources can best be accomplished when they are managed as a single entity.

## Fisheries Management in Arizona

### Sportfish Management

The history of sportfish management by territorial government in Arizona began in 1881 with the formation of the "Arizona Fish Commission", a group of 3 individuals whose job responsibilities paralleled those of early game wardens (Sizer 1980). It was about that same time that the first sanctioned introductions of nonnative fishes began, one of the first being the carp, *Cyprinus carpio* (Rule 1885; Taggart 1885). At that time there were high expectations for carp becoming an important sportfish in the state. This attitude soon changed, however, and by 1905 the laws of the Territory of Arizona considered all fish "except suckers and carp" in their protective provisions. In ensuing years, the list of known introduced species has grown to more than 80 (Table 1·1), a far greater number than the 32 species considered to be Arizona natives. Most of these species were purposeful introductions, placed in Arizona waters in an attempt to increase the diversity of sportfishing experiences.

Table 1·1 Fish species introduced into Arizona by chronological order [a]

| Scientific Name | Common Name | Year First Introduced or Collected | Successful Introduction |
|---|---|---|---|
| *Ictalurus punctatus* | Channel catfish | 1878 | Yes |
| *Cyprinus carpio* | Common carp | 1880 | Yes |
| *Alosa sapidissima* | American shad | 1884 | No |
| *Micropterus salmoides* | Largemouth bass | 1897 | Yes |
| *Ambloplites rupestris* | Rock bass | 1897 | Yes |
| *Oncorhynchus mykiss* | Rainbow trout | 1899 | Yes |
| *Oncorhynchus clarki* | Cutthroat trout | 1899 | Yes |
| *Pomoxus nigromaculatus* | Black crappie | 1903 | Yes |
| *Pomoxis annularis* | White crappie | 1903 | Yes |
| *Salvelinus fontinalis* | Brook trout | 1917 | Yes |
| *Ictiobus niger* | Black buffalo | 1918 | Yes |
| *Ictiobus bubalus* | Smallmouth buffalo | 1918 | Yes |
| *Ictiobus cyprinellus* | Bigmouth buffalo | 1918 | Yes |
| *Perca flavescens* | Yellow perch | 1919 | Yes |
| *Ameiurus natalis* | Yellow bullhead | 1920 | Yes |
| *Ameiurus melas* | Black bullhead | 1920 | Yes |
| *Micropterus dolomieu* | Smallmouth bass | 1921 | Yes |
| *Salmo trutta* | Brown trout | 1924 | Yes |
| *Gambusia affinis* | Mosquitofish | 1926 | Yes |
| *Lepomis cyanellus* | Green sunfish | 1926 | Yes |
| *Morone mississippiensis* | Yellow bass | 1930 | Yes |
| *Notropis stramineus* | Sand shiner | 1938 | No |
| *Fundulus zebrinus* | Plains killifish | 1938 | Yes |
| *Lepomis macrochirus* | Bluegill | 1932 | Yes |
| *Notomegonis crysoleucus* | Golden shiner | 1930s | Yes |
| *Lepomis gulosus* | Warmouth | 1940 | Yes |
| *Micropterus punctulatus* | Spotted bass | 1942 | Yes |
| *Thymallus arcticus* | Arctic grayling | 1943 | Yes |
| *Lepomis microlophus* | Redear sunfish | 1946 | Yes |
| *Pilodictus olivaris* | Flathead catfish | 1940s | Yes |
| *Cottus bairdi* | Mottled sculpin | 1950 | No |

Table 1·1 Continued

| Scientific Name | Common Name | Year First Introduced or Collected | Successful Introduction |
|---|---|---|---|
| *Lepomis gibbosus* | Pumpkinseed | 1950 | No |
| *Pimephales promelas* | Fathead minnow | 1952 | Yes |
| *Morone chrysops* | White bass | 1952 | Yes |
| *Poecilia latipinna* | Sailfin molly | 1952 | Yes |
| *Dorosoma petenense* | Threadfin shad | 1953 | Yes |
| *Stizostedion vitreum* | Walleye | 1957 | Yes |
| *Morone saxatilis* | Striped bass | 1959 | Yes |
| *Ictalurus furcatus* | Blue catfish | 1950s | No |
| *Oncorhynchus nerka* | Kokanee salmon | 1950s | No |
| *Gila atraria* | Utah chub | 1950s | No |
| *Cyprinella lutrensis* | Red shiner | 1950s | Yes |
| *Orechromis mossambica* | Mozambique tilapia | 1960 | Yes |
| *Xiphophorus variatus* | Variable platyfish | 1963 | No |
| *Oreochromis niloticus* | Nile tilapia | 1964 | Unknown |
| *Xiphophorus hilleri* | Green swordtail | <1965 | No |
| *Richardsonia balteatus* | Redside shiner | 1965 | Yes |
| *Esox lucius* | Northern pike | 1965 | Yes |
| *Gillichthys mirablis* | Longjaw mudsucker | 1966 | No |
| *Astyanax mexicanus* | Mexican tetra | 1966 | No |
| *Oncorhynchus kisutch* | Coho salmon | 1967 | No |
| *Acipenser transmontanus* | White sturgeon | 1967 | No |
| *Anisotremus davidsoni* | Sargo | 1967 | No |
| *Bairdiella icistia* | Bairdiella | 1967 | No |
| *Cynoscion xanthulus* | Orangemouth corvina | 1967 | No |
| *Archoplites interruptus* | Sacramento perch | 1968 | No |
| *Tilapia zillii* | Red belly tilapia | 1968 | Yes |
| *Cichlasoma nigrofasciatum* | Convict cichlid | 1969 | No |
| *Cichlasoma meeki* | Firemouth cichlid | 1969 | No |
| *Oncorhynchus aguabonita* | Golden trout | 1971 | No |
| *Anguilla* sp. | Freshwater eel | 1972 | No |
| *Poecilia reticulatus* | Guppy | <1973 | Yes |
| *Poecilia mexicana* | Shortfin molly | <1973 | Yes |
| *Esox masquingongy masquingongy* | Muskellunge | 1973 | No |
| *Oreochromis aureus* | Blue tilapia | 1975 | Yes |
| *Tilapia mariae* | Spotted tilapia | 1970s | Yes |
| *Hypostomus* sp. | Suckermouth catfish | 1986 | No |
| *Parauchenipterus galeatus* | Driftwood catfish | 1989 | No |
| *Ctenopharyngodon idellus* | Grass carp | Unknown | Yes |

Table 1·1 Continued

| Scientific Name | Common Name | Year First Introduced or Collected | Successful Introduction |
|---|---|---|---|
| *Hypophthalmichthys molitrix* | Silver carp | Unknown | Yes |
| *Ameirus nebulosus* | Brown bullhead | Unknown | Unknown |
| *Carassius auratus* | Goldfish | Unknown | Yes |

[a] Sources: Minckley (1973), Courtenay and others 1984, AGFD (1990b), INTERNET: http://nas.er.usgs.gov/bin/nas/fishesstate (5/25/99)

In late July 1944, AGFC instituted the office of Fisheries Biologist, because problems facing the fisheries division were too many to be handled by the Director of Fisheries (AGFD files). Fisheries management specialists were not placed in regional offices until 1973 (Sizer 1980). Although the need for a statewide fisheries management plan was suggested by fisheries biologists in the 1940s (AGFD files), there was no statewide plan or strategy for fisheries management until much later. Sizer (1980) summarized the philosophy of early fisheries management:

> Fifty years ago the fishery management practiced by most game and fish departments was simple. In those days getting the most from the least meant planting plenty of fish to catch. Consequently, nearly all the early efforts of the Commission were aimed in this direction.

Statewide strategies for fisheries management in Arizona were first published in the form of coldwater (Stephenson no date; AGFD 1990a) and warmwater (AGFD 1990b) strategic plans. Both of these plans concentrated on sportfish, most of which were introduced into the state, and did not deal with management of native fish. Stephenson (no date) identified 202 stream segments, excluding the Colorado River, that were individually managed as coldwater fisheries, and referred to them as Stream Management Reaches. Using the same criteria, he identified 158 lakes covering nearly 4000 surface acres. In the first revision of the coldwater sportfisheries strategic plan (AGFD 1990a), the number of stream management reaches was reduced to 159, having a total length of 1470 miles, and the number of lakes was reduced to 64 with approximately 3000 acres. These numbers remained constant in the most recent strategic plan for coldwater sportfishes, which was integrated into the departmental strategic plan (AGFD 1995). A similar approach to identifying individual fisheries has not been taken for warmwater sportfish, rather 12 different types of waterbodies are defined on the basis of habitat type, differences in management goals, and variation in techniques needed for management (AGFD 1990b). None of these plans provided reach specific data-driven management recommendations that incorporated both native fish and sportfish management needs.

The stream reaches and lakes identified in AGFD coldwater strategic plans are managed under one of the following seven broad concepts:

(1) Intensive Use--providing for intensive angling use by stocking catchable (and some fingerling or subcatchable) fish where the demand for harvest cannot be supported by other management techniques, often referred to as "put-and-take" (Noble 1980). These fisheries usually are in areas of

high angler demand, such as near campgrounds, day-use areas, or high use areas other than major metropolitan areas.

(2) Basic Yield--utilizing the natural productivity of waters to grow fish to a harvestable size and provide fisheries of a general nature without special emphasis on any one angling experience and without special regulations. In contrast to intensive use fisheries, the emphasis for stocking is on fingerlings or subcatchables. Both fisheries are characterized by high angler demand and accessibility.

(3) Wildfish--providing an opportunity to catch fish that were both hatched and grown in the wild. These fisheries are all in streams that are typically difficult to access; thus, angler harvest is low.

(4) Blue Ribbon--providing a maximum recreational benefit from a fisheries resource through special regulations and to provide an opportunity for a limited harvest of large fish, which may be either naturally reproduced or stocked. This type of fishery requires special regulations, such as low daily bag limits, size limits, and gear restrictions, that encourage “catch-and-release”.

(5) Featured Species--providing the opportunity to catch species considered to be uncommon or to have unusual qualities. These are species, such as Apache trout, Arctic grayling, brook trout, brown trout, cutthroat trout, or other rare species, or fish with unusual characteristics, e.g. albino rainbow trout.

(6) Urban--providing local angling opportunity for residents of large urban communities. Management often is similar to intensive use, but does not have to be.

(7) Private and Reservation Waters--these are private and reservation waters over which the Department exercises no direct management other than enforcement of applicable state laws and regulations pertaining to stocking permits, prohibited species, and other factors that may negatively affect the state’s natural resources. Anglers licensed by the state can not fish without additional funds or other provisions from private landholders.

The primary management concept addressed in both the coldwater and warmwater sportfish strategic plans is that of supply and demand. Supply is measured as the availability of fish habitat, the availability of fish for catch or harvest, and the availability of variety in angling opportunity. In the case of coldwater fisheries, the latter is held to be a combination of the first two resulting from the type of management. Angler demand is measured as angler days per year, but includes both the actual use of coldwater fisheries and the unmet desires of anglers.

A careful eye will soon discover that many of our so-called lakes in Arizona are really reservoirs whose area and volume are attributable to dams. Dams impounding many of the important fishing reservoirs were constructed with Federal excise taxes on fishing equipment collected under authority of the Federal Aid to Sport Fish Restoration Act (Dingell-Johnson Act) passed by Congress in 1950 and in 1984 by the Wallop-Breaux amendment of that act. Federal Aid funds are also used by the Department to operate the hatcheries that replenish fish to waters depleted by angling pressure or impacts to habitat. Use of Federal funds for sportfish production and sportfish habitat enhancement subjects the Department to compliance with the NEPA and the ESA. Compliance with Section 7 of the Endangered Species Act for AGFD stocking was first evaluated by the Fish and Wildlife Service in a biological opinion rendered in 1995 (U.S. Fish and Wildlife Service 1995).

### NATIVE FISH MANAGEMENT

Native fish management by state government in Arizona lagged behind that of sportfish management by approximately 80 years. AGFD native fish management began in the early 1960s with surveys for Apache trout. Beginning in 1968, surveys and reintroduction attempts were made involving Apache trout, Gila trout, Gila topminnow, and woundfin. In 1974 AGFD hired its first nongame (native) fish biologist. Native fish management was further formalized with the creation of the Nongame and Endangered Wildlife Program in 1983.

Native fish efforts are comprised of inventory, monitoring, management, and research. Inventory of streams is undertaken to delineate distribution of fishes. Despite extensive stream surveys over the last 30 years, inventories have resulted in new fish locations even in heavily surveyed drainages (e.g. Rudd Creek - Little Colorado spinedace, Eagle Creek - loach minnow, and Sonoita Creek - Gila topminnow). Monitoring is conducted to assess the status and trend of populations and habitats. Management involves recovery/conservation planning and implementation of conservation actions such as renovations to remove nonnative species, repatriations, construction of barriers and other measures to protect native fishes and their habitats. Last but not least, research is utilized to support management of native fishes.

Two native fish species Apache trout and roundtail chub, are in the unique position of also being sportfish. Apache trout take is regulated through Section 4 of the ESA and Commission Order. Gila trout may soon be added to the list of native sportfish. Take of all other native fish species is either completely prohibited or unlimited.

## SELECTION OF THE FIRST WATERSHED FOR DEVELOPMENT OF A MANAGEMENT PLAN

The Little Colorado River (LCR) watershed was chosen as the first in which to implement watershed-based fisheries management in Arizona for several reasons: (1) it is one of the most important river basins in the state for recreational sportfishing with approximately 850,000 angler days expended annually for an economic benefit of more than $80 million; (2) it contains 9 native fish species, four of which are federally listed under the Endangered Species Act (Table 1-2); (3) it contains 3 reservoirs that were determined to be potential problem areas for the federally threatened Little Colorado spinedace, due to predation by stocked trout or their progeny, in the recently completed Section 7 consultation (U.S. Fish and Wildlife Service 1995). Thus, the LCR watershed is important for both sportfish recreation and native fish conservation and represented a choice watershed for which integration of management emphasis would provide potentially large benefits to our fisheries constituency.

Table 1-2 List of native and non-native fish species occurring within the LCR watershed

| Scientific Name | Common Name | Standard Abbreviation | Status[a] | | | |
|---|---|---|---|---|---|---|
| | | | S | T | E | W |
| **Native Fish Species** | | | | | | |
| *Catostomus sp.* | Little Colorado sucker | CASP | | | | |
| *Catostomus latipinnis* | flannelmouth sucker | CALA | | | | ✓ |
| *Gila robusta* | roundtail chub | GIRO | ✓ | | | ✓ |
| *Gila cypha* | humpback chub | GICY | | | ✓ | ✓ |
| *Lepidomeda vittata* | Little Colorado spinedace | LEVI | | ✓ | | ✓ |
| *Oncorhynchus apache* | Apache trout | ONAP | ✓ | ✓ | | ✓ |
| *Pantosteus discobolus* | bluehead sucker | PADI | | | | |
| *Rhinichthys osculus* | speckled dace | RHOS | | | | |
| *Xyrauchen texanus*[b] | razorback sucker | XYTE | | | ✓ | ✓ |
| **Non-native Fish Species** | | | | | | |
| *Ameiurus melas* | black bullhead | AMME | ✓ | | | |
| *Ameiurus natalis* | yellow bullhead | AMNA | ✓ | | | |
| *Carassius auratus* | goldfish | CAAU | | | | |
| *Cyprinella lutrensis* | red shiner | CYLU | | | | |
| *Cyprinus carpio* | common carp | CYCA | ✓ | | | |
| *Dorosoma petenense* | threadfin shad | DOPE | | | | |
| *Esox lucius* | northern pike | ESLU | ✓ | | | |
| *Fundulus zebrinus* | plains killifish | FUZE | | | | |
| *Gambusia affinis* | mosquitofish | GAAF | | | | |
| *Ictalurus punctatus* | channel catfish | ICPU | ✓ | | | |
| *Lepomis macrochirus* | bluegill | LEMA | ✓ | | | |
| *Lepomis cyanellus* | green sunfish | LECY | ✓ | | | |
| *Micropterus dolomieu* | smallmouth bass | MIDO | ✓ | | | |
| *Micropterus salmoides* | largemouth bass | MISA | ✓ | | | |
| *Notemigonus crysoleucas* | golden shiner | NOCR | | | | |
| *Oncorhynchus clarki* | cutthroat trout | ONCL | ✓ | | | |
| *Oncorhynchus mykiss* | rainbow trout | ONMY | ✓ | | | |
| *Perca flavescens* | yellow perch | PEFL | ✓ | | | |
| *Pimephales promelas* | fathead minnow | PIPR | | | | |
| *Pomoxis nigromaculatus* | black crappie | PONI | ✓ | | | |
| *Salmo trutta* | brown trout | SATR | ✓ | | | |
| *Salvelinus fontinalis* | brook trout | SAFO | ✓ | | | |
| *Stizostedion vitreum* | walleye | STVI | ✓ | | | |
| *Thymallus arcticus* | arctic grayling | THAR | ✓ | | | |

[a] S=Sportfish, T=Threatened, E=Endangered, W=Wildlife of Special Concern in Arizona (Draft)
[b] Razorback suckers at this location are believed to be flannelmouth sucker hybrids (Dowling and others 1996)

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# CHAPTER 2: THE LITTLE COLORADO RIVER WATERSHED

Kirk L. Young

## GEOGRAPHY AND GEOLOGY

The Little Colorado River (LCR) watershed occupies an elliptical-shaped area of 70160 $km^2$ (27089 $mi^2$) on the Colorado Plateau in northeast Arizona and northwest New Mexico (Fig 2.1). The watershed contains a remarkable variety of landforms indicative of its remarkable geologic history. These landforms include deep canyons eroded into many-colored, horizontally-stratified sedimentary rocks, marine sandstones and mudstones, and the towering San Francisco Peaks and White Mountains, formed by Cenozoic volcanic activity which piled lavas on top of the plateau. Elevation in the watershed varies from 3850 m (12,600 ft) on Mt. Humphreys, highest point in Arizona on the San Francisco Peaks in Arizona, to 830 m (2725 ft) at the mouth of the LCR where it joins the Colorado River in Grand Canyon.

The southern limit of the Colorado Plateau is demarcated by the Mogollon Rim, a precipitous erosional break in the landscape that exposes the layers of marine sedimentary rocks underlying the volcanic mountains. In the central portion of the southern flank of the LCR basin, these marine sedimentary rocks have escaped the volcanic eruptions and lie at the surface. To the north of the volcanic mountains lie the red mesas and buttes of the Moenkopi Formation and the many-colored sandstones and siltstones of the Chinle Formation.

## CLIMATE

Often times temperature, precipitation, and evaporation are treated separately in discussions of climate. In desert regions, it is particularly important to consider these variables together, and especially so when one evaluates their combined effects on the persistence of standing or flowing water.

Elevation affects climate in the LCR watershed more than any other variable. Mean annual precipitation exceeds 75 cm (30 in) in three small areas at the higher elevations, but declines quickly downslope to means of 15 cm (6 in) or less on the Colorado Plateau through which the LCR travels on its way to Grand Canyon. Most precipitation falls in summer, borne by small scale convective storms carrying moisture from the Gulf of Mexico or Gulf of California, or in winter by large-scale cyclonic storms originating in the Pacific Ocean. Winter snows are the main source of sustained runoff in perennial streams giving rise to the LCR.

Mean monthly air temperatures at higher elevations vary from 16°C (60°F) in summer to -4°C (25°F) in winter. Summer temperatures at lower elevations, which average about 32°C (90°F), are considerably higher and differ more from those at high elevations than do winter temperatures (7°C = 45°F).

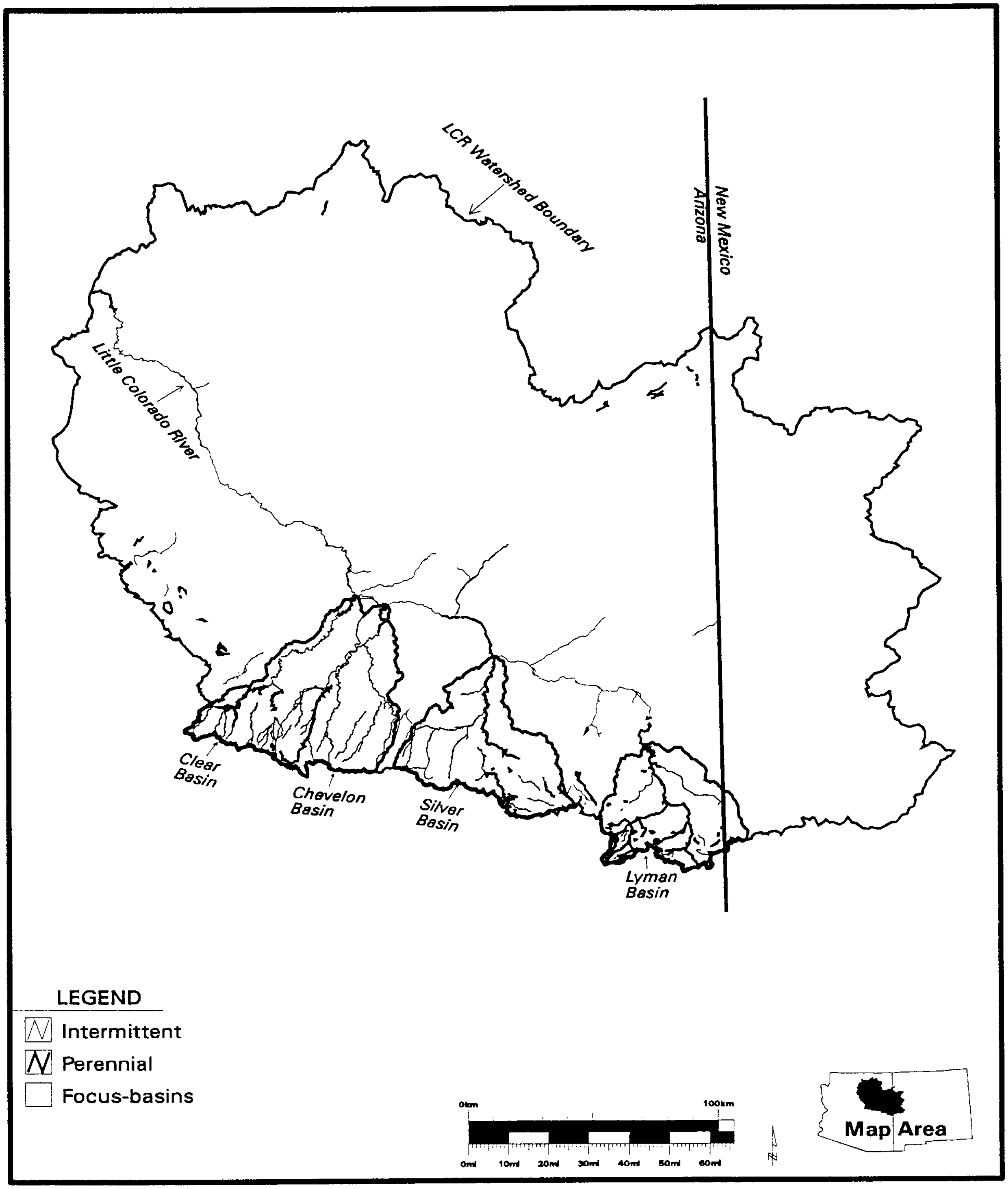


Figure 2·1 Little Colorado River watershed with perennial and intermittent streams and lakes of Arizona.

Equally important to water budgets is the amount of evaporation in the basin. Much of the LCR watershed has annual reservoir evaporation in excess of 127 cm (50 in), and even the higher mountains receiving the largest amounts of precipitation have evaporation of 102 cm (40 in) or greater.

## HYDROLOGY

Four major, north-flowing basins produce most of the streamflow in the LCR. They are the Upper LCR above Woodruff, Silver Creek, Chevelon Creek, and Clear Creek. The major water-bearing tributaries in the eastern part of the LCR watershed arise in the volcanic rocks of the White Mountains. These include Nutrioso Creek, the South, East, and West forks of the LCR, and Silver Creek. To the west where the lava flows cease, two basins--Chevelon Creek and Clear Creek--arise in the marine sedimentary rocks which emerge at the Mogollon Rim.

Estimates of surface water supply and contemporary cultural depletions by the Arizona Department of Water Resources (1989, 1990, 1994) show that approximately 195,224 ac-ft of water is discharged from major water-bearing streams in the Upper LCR wasin to below the confluence of Jacks Canyon and the mainstem (Table 2·1). Cultural depletions of water, including reservoirs, stockponds, irrigation, and interbasin transfers, remove an average of 91,480 ac-ft annually from the discharge. Natural losses add 50,720 ac-ft to that amount. Thus, if cultural depletions were returned to the streams, a theoretical 144,000 ac-ft would pass down the LCR in an average year. ADWR has pointed out, however, that allowing additional water to remain in the streams would promote the growth of additional riparian vegetation, the consumption of which would add to the stream losses.

Table 2·1 Hydrological data for the major water-bearing basins in the Little Colorado River watershed, Arizona-New Mexico

| Basin | Upper LCR [a] | Silver | Puerco | Chevelon | Clear | Jack's | Total |
|---|---|---|---|---|---|---|---|
| Drainage Area ($mi^2$) | 8100 | 924 | 3015 | 800 | 600 | 325 | 13764 |
| Number of Reservoirs | 51 | 33 | 0 | 4 | 4 | 3 | 95 |
| Reservoir Depletion ($ac\text{-}ft \cdot yr^{-1}$) | 6650 | 10160 | 0 | 4780 | 3130 | 3950 | 28670 |
| Number of Stockponds | 2000 | 762 | 205 | 417 | 147 | 192 | 3723 |
| Stockpond Depletion ($ac\text{-}ft \cdot yr^{-1}$) | 5770 | 2460 | 590 | 1690 | 580 | 1280 | 12370 |
| Irrigation (acres) | 14600 | | 0 | 0 | 1010 | 1010 | 16620 |

Table 2·1 Continued

| Basin | Upper LCR [a] | Silver | Puerco | Chevelon | Clear | Jack's | Total |
|---|---|---|---|---|---|---|---|
| Irrigation Diversions (ac-ft) | 18360 | 13770 | 0 | 0 | 6210 | 2890 | 41230 |
| Interbasin Export (ac-ft·yr$^{-1}$) | 0 | 3600 | 0 | 0 | 9600 | 0 | 13200 |
| Total Cultural Depletions (ac-ft·yr$^{-1}$) | 26150 | 30630 | 590 | 6470 | 19520 | 8120 | 91480 |
| Subbasin | Upper LCR [a] | Silver | Puerco | Chevelon | Clear | Jack's | Total |
| Natural Losses (ac-ft·yr$^{-1}$) | 28200 | 4020 | 10900 | 4300 | 3300 | - | 50720 |
| Median Gaged Flow (ac-ft·yr$^{-1}$) | 20460 | 4014 | 46660 | 40680 | 61860 | 21550 | 195224 |
| Estimated Undepleted Flow (ac-ft·yr$^{-1}$) | 46610 | 34644 | 47250 | 35740 | 61810 | 29670 | 255724 |

[a] Portion of basin above confluence with Silver Creek

## LAND OWNERSHIP

Land ownership in that portion of the LCR watershed from which most surface water is generated is divided largely among private landowners (36.2%), the federal government (36.7%), and state government (18.2%). Most of the federal share is managed by the U.S. Forest Service (33.7%), and nearly all state lands are managed by the Arizona State Land Department as state trust lands (18.1%). Arizona Game and Fish Department (Department, AGFD) manages approximately 4450 acres, or 0.12% of the total land base.

## EARLY WRITTEN DESCRIPTIONS OF THE LCR WATERSHED

Today, perennial flow within the banks of the LCR typically disappears below the town of St Johns. The river below this point is mostly wide, sandy, and with the exception of an occasional cottonwood tree, is either dominated by stands of exotic salt cedar, or treeless. On examination of this present day condition, one ponders what this river was like before settlement by Americans of European descent. Did water flow year-around throughout this watershed? What kind of grassland and riparian woodland historically existed here? Written history gives us but a glimpse of what the Little Colorado River watershed was like prior to Anglo settlement; however, this limited historical glimpse tells us that it was remarkably different.

Spanish explorers crossed the LCR in the late 16th century. These early travelers remarked that the river contained many groves of poplars and willows, so many in fact that the explorers Farfan and Quesada named it Rio Alameda (The River of Groves) when they crossed it in 1598 (Colton 1937). The river was also likely referred to as the Rio del Lino (Flax River) in reference to wild flax growing on its banks, and as colorado because of its red-colored, sediment-laden waters by Juan Mateo de Onate in 1604 (Barnes 1960; Bancroft 1962).

Several organized explorations and surveys of this area were undertaken in the mid-1800s. Two surveys offered fairly detailed accounts of land conditions. They were led by Captain L. Sitgreaves in 1851 and Lieutenant E.F. Beale in 1857. Prior to the Sitgreaves expedition, it was thought that the Zuni River might be an avenue to the Gulf of California. Captain Sitgreaves was instructed to determine the course and character of the Colorado River below the Zuni, to its junction with the Gulf of California (Sitgreaves 1854). On September 27, 1851, Sitgreaves reached the LCR and provided the following description of its confluence with the Zuni River, northwest of present day St. Johns:

> At this point the Little Colorado is an insignificant stream, divided into several small channels, flowing through a narrow valley destitute of timber, but covered with a thick growth of rank unnutritious grass.

Sitgreaves descended the Little Colorado in search of the Colorado River and noted stream conditions he encountered. In the vicinity of present-day Woodruff, he commented that the Little Colorado was now flowing between sandy banks fringed with cottonwood trees, and that here it began to look like a river. However, he noted that the river still had little water in its bed. At the confluence with Chevelon Creek (between Joseph City and Winslow), Sitgreaves noted:

> Their confluence produces an intricate labyrinth of sloughs, in which we became involved, and were forced to encamp, not finding an outlet until late in the day.

The next day, Sitgreaves was faced with another aquatic obstacle as he encountered the confluence with Clear Creek, south of present day Winslow:

> Our course was here interrupted by a deep bayou thickly overgrown with rushes, and which, on attempting to turn it, was found to lead to a rocky ravine or canon utterly impassable. We retraced our steps, therefore, and with much difficulty recrossed the river, which, making a bend to the north, winds through a broad plain resembling the bed of a great lagoon from which the water had just subsided, leaving it slimy and intersected with fissures and channels that often impeded our progress.

Upon reaching the Falls of the Little Colorado, Sitgreaves turned west in pursuit of the Colorado River below the "great canyon." He left the Little Colorado River on October 9, after 12 days and 110 miles of travel along its length.

In 1857 Lt. Beale was chosen to lead an expedition to survey a wagon route from Fort Defiance (eastern Arizona) to the Colorado River, near the 35th parallel (Stacey 1929). In September 1857, upon reaching the Little Colorado River near the Rio Puerco confluence, east of present day Holbrook, Lt. Beale described:

> The valley of this river is three miles across, and grass plentiful in the bottoms, as well as on the hills, which are quite low. There is abundance of large cotton-wood trees in the bottom, which resembles very nearly the bottom of the Rio Grande.

Near the confluence with Clear Creek (near Winslow), Beale noted an abundance of wildlife and grass:

> We have seen indications of the greatest abundance of game for the past three days. Elk, antelope, and deer, besides beaver and coyotes in large numbers.
>
> The grass throughout the day has been most abundant, and we have constantly exclaimed, "What a stock country!" I have never seen anything like it; and I predict for this part of New Mexico a larger population, and a more promising one than any she can now boast.

After successfully charting a wagon road to the Colorado River, Lt. Beale, upon his return through the Little Colorado Valley in February of 1858, remarked:

> The more I see of the Little Colorado the better I like it. The stream is of the size of the Gila, but to be likened to that fresh water abomination in nothing else. The soil seems fertile and bears good meadow grass in all parts, while the plains, extending from its banks as far as one can see, are covered with rich grama grass. The growth of timber in the bottom is in places very heavy and almost entirely cottonwood, but on the left bank, a mile or two from the river, cedar is abundant along the whole length of the stream. All who are with me, and who have been raised in the south, declare it to be excellent tobacco and cotton land. I am not sufficiently acquainted with the culture of these products to give an opinion, but for stock of all kinds I should say that a better country is not within the United States.

In 1873, a Mormon expedition was sent to the LCR to establish a settlement. They turned back after encountering intolerable conditions as noted in McClintock (1921): "There was no green grass, and water was infrequent, even along the Little Colorado, it being found necessary to dig wells in the dry channel. Twenty-four miles below Black Falls there was encampment, the road blocked by sand drifts." Based on this one account, it would appear that the dry conditions that exist in the Painted Desert and Moenkopi Wash region of the lower LCR may have been similar historically as well.

## Landscape Changes

Remarkable changes occurred within the LCR watershed between Beale's travel and the turn of the century. Settlement by Americans of European descent in the upper portion of the watershed occurred prior to 1871. By 1871, there was sufficient settlement in the Round Valley area to support a store. The store's owner Henry Springer, gave his name to the town of Springerville (Peterson 1973). In 1872 or 1873, St. Johns was founded and by 1876 portions of Silver Creek were settled by ranchers and farmers. From 1876 through 1890, Mormon settlement increased human habitation of the watershed (Peterson 1973; Tanner and Richards 1977; Abruzzi 1993). Riparian trees must have been more plentiful as a Mormon fort at Sunset (downstream of Winslow) was constructed of cottonwood logs, mainly from drift, and cottonwood logs were sawed for lumber at Obed near St. Joseph (=Joseph City) (McClintock 1921). Settlement of the LCR watershed through the turn of the century significantly altered stream and upland habitats primarily through water development and use, and severe overgrazing (Tellman and others 1997).

### Water Development and Use

Mormon settlers, having found their way to the valley of the LCR, quickly began the task of constructing diversion dams across the river to support their agricultural objectives (Greenwood 1960). In 1876, three dams were constructed at St Joseph, Brigham City (near Winslow), and Sunset. These early dams were constructed of dirt-fill, stabilized by rock, cedar brush and logs (Peterson 1973). The St. Joseph dam measured 12 feet high, 180 feet long and 60 feet deep (Abruzzi 1993). Similar structures were constructed elsewhere in the watershed, and many washed out frequently. The St. Joseph dam was washed out and replaced 11 times from 1876 to 1894 (Tanner and Richards 1977), while a dam constructed in 1878 at Woodruff was washed out and replaced 13 times by 1919 (Peterson 1973).

Today, many water diversion and storage structures exist, testament to the early settler's tenacity coupled with 20th century engineering and financial backing (Table 2·2). The effects of the now abandoned early structures on aquatic species are unknown, but due to their temporal nature, one might presume they had limited impact. However, dam construction and destruction certainly amplified an already extremely dynamic environment, and may have resulted in dewatering of otherwise perennial portions of the lower river during seasonal low flows and drought.

Table 2·2 Reservoirs within the Little Colorado River watershed used for recreation, irrigation and/or water storage

| Reservoir | Date Constructed (Source) |
|---|---|
| Atcheson Reservoir | Unknown |
| Ashurst Lake (natural) | Raised 1954 (ADWR 1994) |
| Bear Canyon Lake | 1964 (AGFD files) |
| Becker Lake | 1880 (AGFD files) |
| Black Canyon Lake | 1963 (AGFD files) |
| Blue Ridge Reservoir | 1962 (AGFD files) |
| Boot Lake | Unknown |
| Bunch Reservoir | 1929 (AGFD files) |
| Carnero Lake | 1878 (ADWR 1994) |

Table 2·2 Continued

| Reservoir | Date Constructed (Source) |
|---|---|
| Chevelon Canyon Lake | 1965 (AGFD files) |
| Chilson Lake | Unknown |
| Cholla Lake | 1961 (ADWR 1994) |
| Clear Creek Reservoir | Unknown |
| Coconino Reservoir | Unknown |
| Colter Reservoir (East Fork Little Colorado) | 1908 (ADWR 1992) |
| Concho Lake | 1880s (McClintock 1921), rebuilt 1930 (AGFD) |
| Cow Lake | Unknown |
| Deep Lake | Unknown |
| Ellis Wiltbank Reservoir | 1913 (AGFD files) |
| Fool Hollow Lake | 1957 (AGFD files) |
| Geneva Reservoir | Unknown |
| Glen Livet Reservoir | Unknown |
| H-V Reservoir | Unknown |
| Harris Lake | Unknown |
| Hay Lake | Unknown |
| Hog Wallow Lake (tributary to South Fork) | 1908 (ADWR 1994) |
| Horse Lake | Unknown |
| Hulsey Lake | Unknown |
| Indian Lake | Unknown |
| Jarvis Lake | Unknown |
| Kinnikinick Lake | 1956 (ADWR 1994) |
| Knoll Lake | 1963 (AGFD files) |
| Lake of the Woods | Unknown |
| Lee Valley Reservoir | 1899, rebuilt 1964 (AGFD files) |
| Little George Reservoir | Unknown |
| Little Mormon Lake | 1950s (ADWR 1994) |
| Little Ortega Lake | Unknown |
| Little Reservoir | Unknown |
| Long Lake (near Show Low) | Modified natural lake (ADWR 1994) |
| Long Lake (upper) | Modified natural lake (ADWR 1994) |
| Long Lake, Lower | Modified natural lake (ADWR 1994) |
| Long Tom Lake | Unknown |
| Love Lake | Unknown |
| Lyman Lake | 1910, washed out in 1915, rebuilt 1920, 1949 (Abruzzi 1993) |
| Lake Mary, Lower | 1904 (ADWR 1994) |
| Lake Mary, Upper | 1941 (ADWR 1994) |
| Lone Pine Reservoir | 1936, condemned in 1989 (ADWR 1994) |

Table 2-2 Continued

| Reservoir | Date Constructed (Source) |
|---|---|
| Marshall Lake | Natural Depression |
| McKay Reservoir | Unknown |
| Mexican Hay Lake | 1908 (ADWR 1994) |
| Mormon Lake | Natural Depression |
| Morton Lake | Unknown |
| Nelson Reservoir | 1891, (Barnes 1960) 1892, rebuilt 1950 (AGFD files) |
| Norton Reservoir | 1916 (ADWR 1994) |
| Nutrioso Reservoir | Unknown |
| Ortega Lake | Unknown |
| Pool Corral Reservoir (tributary to South Fork) | 1908 (ADWR 1994) |
| Potato Lake | Unknown |
| Potato Lake (upper) | Unknown |
| Pratt Lake | Unknown |
| Prime Lake | Unknown |
| Rainbow Lake | Pre-1920s, rebuilt 1963 (AGFD files) |
| Reagan Reservoir | Unknown |
| Red Lake | Unknown |
| Riggs Creek Reservoir | Unknown |
| River Reservoir | Pre-1920, rebuilt 1950 (AGFD files) |
| Rogers Reservoir | Unknown |
| Rudd Reservoir | Unknown |
| Russell Reservoir | Unknown |
| Saint Josephs Reservoir | Unknown |
| Saint Marys Lake | Unknown |
| San Salvador Lake | Unknown |
| Scott Reservoir | 1928, 1945 (ADWR 1994; AGFD files) |
| Soldier Lake | Natural depression, canal built 1800s (ADWR 1994) |
| Soldier Annex Lake | 1935 (ADWR 1994) |
| Sponseller Lake | Unknown |
| Show Low Lake | 1953 (AGFD files) |
| Schoen's Reservoir | 1988, replaced Lone Pine (ADWR 1994) |
| Slade Reservoir | Unknown |
| Sunnyside Reservoir (Fish Creek) | 1912 (ADWR 1994) |
| Tremaine Lake | 1951 (ADWR 1994) |
| Tunnel Reservoir | 1951 (AGFD files) |
| Vail Lake | Unknown |
| Water Canyon Reservoir | Unknown |
| Whipple Lake | Unknown |
| Willow Springs Lake | 1967 (AGFD files) |

Table 2-2 Continued

| Reservoir | Date Constructed (Source) |
|---|---|
| Woodland Reservoir | 1914 (AGFD) |
| Woods Canyon Lake | 1956 (AGFD files) |
| White Mountain Lake<br>(=Daggs Reservoir – Silver Creek) | 1914 (Abruzzi 1993) |
| White Mountain Reservoir (Hall Creek) | 1929 (ADWR 1994) |
| Wiltbank Reservoir (Fish Creek) | 1913 (ADWR 1994) |
| Zion Reservoir (Udall Dam) | 1910 (ADWR 1994) |

### OVERGRAZING

Grazing by cattle and sheep increased commensurate with settlement of the watershed. 1880 census statistics for Apache County (one of the four original counties created by the first legislature of 1864) reflected a human population of 5293, with 5550 cattle including cows, and 30,606 sheep (Bancroft 1962). Census statistics from 1883 showed a human population of 6816, with 43,000 cattle, and 60,000 sheep (Bancroft 1962). Exports from Holbrook and Winslow ranged from 445 tons of cattle and 254 tons of wool in 1885 to 2593 tons cattle and 431 tons of wool in 1889 (Abruzzi 1993).

The single greatest contributor to the influx of cattle and overstocking the range was the creation of the Aztec Land and Cattle Company. In 1884, seeking speculative financial profits and relief from failed and overgrazed Texas rangeland, a group of investors and Texas ranchers formed the Aztec Land and Cattle Company (Kennedy 1968; Abruzzi 1993). The Aztec Land and Cattle Company, known locally as the Hashknife, purchased one million acres of railroad land in the LCR watershed, and soon established approximately 60,000 head of cattle on their lands (Kennedy 1968; Peterson 1973; Abruzzi 1993). The Hashknife range was described by Joseph Pearce as:

> fine rangeland with plenty of water, mountain streams, natural lakes, open springs; much of it was mountainous in forests of pine and cypress and blue spruce and white aspens, while much of it was flat country with tall grasses. (Kennedy 1968)

Hashknife cattle herds grew, in one year their cowboys branded 52,000 calves (Kennedy 1968). Estimates vary, but about 150,000 head of cattle and 120,000 sheep were grazed in the watershed prior to severe drought in the 1890s (Abruzzi 1993; Tellman and others1997). The three year drought resulted in the death of thousands of cattle; fully half the cattle in Apache County died by 1893 (Kennedy 1968; Abruzzi 1993). The extended drought forced the Aztec Land and Cattle Company out of business and, combined with the overstocking of ranges, resulted in widespread grassland deterioration and radically altered range conditions (Colton 1937; Abruzzi 1993).

Kennedy concluded that:

> The Texans fled to Arizona in order to escape the effect of their malpractices. They proceeded to repeat the process in Arizona. Drought and range deterioration followed as a matter of course (Kennedy 1968).

The impact of overgrazing was reflected on by a Mormon settler in the region:

> When we came to Arizona in 1876, the hills and plains were covered with high grass and the country was not cut up with ravines and gullies as it is now. This has been brought about through overstocking the ranges. On the Little Colorado we could cut hay for miles and miles in every direction. The Aztec Cattle Company brought tens of thousands of cattle into the country, claimed every other section, overstocked the range and fed out all the grass. Then the water, not being held back, followed the cattle trails and cut the country up. Later tens of thousands of cattle died because of drought and lack of feed and disease. The river banks were covered with dead carcasses (quoted in McClintock 1921).

Livestock use remained relatively high through 1925. Apache County assessment rolls registered an average of 35,119 head of cattle and 117,762 head of sheep for the years 1916 through 1925, compared to 19,630 cattle and 3882 sheep for the years 1958 through 1967 (Abruzzi 1993).

Through an interview with Mr. William Roden, a sheep rancher in 1884, and an archeological excavation of a house constructed in the 1870s, Colton (1937) documented significant alteration of stream and riparian conditions in the LCR approximately one mile above Grand Falls. In 1935 Colton excavated the partial remains of a house built on the south side of the river below a red sandstone cliff. Frank Hart, for whom Hart Prairie is named, built the house in 1878 or 1879. The river had undermined the east wall and the floor of the house lay 30 inches below the level of the present riverbank. A fairly detailed history of the area was gleaned through an interview with William Roden as recounted by Colton (1937):

> In 1884 Mr. William Roden arrived in the valley with several thousand head of sheep. Frank Hart left the region of Grand Falls and moved up the river with his cattle to the neighborhood of Winslow. When Roden arrived at Grand Falls the flats on either side of the river supported a fine stand of old and young cottonwood trees which produced attractive shady groves, while grama grass covered the surrounding hills. The Frank Hart House then stood over 100 feet from the river, then a narrow stream which flowed the year around. Many beaver lived along its banks feeding on the cottonwood trees. During the 1870s and 1880s thousands of cattle and sheep were placed on the ranges. The ranges carried them easily until a severe drought caused them to eat the grass too closely. At the time of this drought the Navajos moved into the river valley, cutting down the young cottonwoods to feed their starving herds. When the rains came once more in the early nineties, with no grass to hold the water we see the first of those disastrous floods which have followed one another at infrequent intervals over the last forty years. The Navajos called it the "Big Timbers" because it undermined, uprooted, and carried away many of the old cottonwood trees along the river banks and left their whitened trunks to mark the limit, to this day, of the high water forty and fifty years ago.

Colton returned to the Hart house remains in 1937 and in two years the river had cut back 14 feet and only the back wall remained. Colton (1937) surmised:

> We can see the Little Colorado as it was fifty years ago; a narrow, perennial stream lined with cottonwoods and willows. We see it now in a wide, sandy bed, which is dry much of the year. The willows have departed and only a few gnarled cottonwoods remain of the once extensive groves. The surrounding hills that once bore a good stand of grama grass are now covered with a desert pavement of polished pebbles. Navajo sheep see to it that no young trees get a start.

### LITTLE COLORADO RIVER WATERSHED HABITATS TODAY

Land management practices have greatly improved from that which occurred in the late 19th century. Establishment of U.S. Forest lands and subsequent land use reforms have provided protection to mainly headwater portions of the LCR watershed. Principles of these same reforms have also been applied in many cases to private state lands. Improved condition and management of tribal lands continues to be elusive. Reservoirs, Lyman Lake most notable among them, alter stream hydrographs and represent both prominent and permanent fixtures in the watershed. Future water transfers and developments are likely to result from water right settlements within the watershed.

Current conditions in many areas of the LCR watershed remain attributable to historical abuses of the landscape. Today, especially in the lower LCR valley, stream habitats and upland grasslands remain severely impacted. Lower reaches of the LCR, once perennial and characterized by narrow stream banks, are now wide-banked with highly fluctuating intermittent flows. Broad-leaf riparian areas and wetlands have been replaced with salt cedar or are treeless, and adjacent uplands remain highly eroded. Increased urbanization in basin headwaters and proposed water right settlements have increased water demands. Competing with existing and projected human growth, restoration of streams and uplands represent a formidable task. Restoration of the lower LCR valley, if possible, will take decades if not centuries to accomplish.

### LITTLE COLORADO RIVER WATERSHED SPORTFISHERIES

Recollections of anglers who fished for native trout in White Mts. streams and lakes in the late 1800s and early 1900s indicate that this resource was bountiful and easily taken. In the Greer valley "Most of the first tourists came to fish, and what didn't exist at the tip of their pole wasn't very memorable. But the fishing was enough. Golden yellow natives up to eleven inches were everywhere and the limit in the mid-1920s was twenty-five. Fishing season began the first of June and ended in September until the time of World War II" (Applewhite 1979).

Crigler (1993) provides several quotes supporting the contention that native trout were present in high numbers. From the Weekly Miner (1876), "The Colorado Chiquito is 'chock full' of these best of fish, which are to be had for the mere taking" and from The St. Johns Herald (July 1886) "In less than forty minutes we had two frying pans full of magnificent trout on the fire. After dinner he tried his luck for about two hours and returned to camp with thirty-two trout." In July 1896 on the White River beyond Sheep Spring "Fish were so plentiful it didn't mater how you fished. One member of the party was credited with 341 fish one forenoon with other members of the party right close." And "From the diary of Evans Colemen it is recorded that the fishermen who were about ten in number caught 2,445 fish on a six day trip. Two of those days the happy anglers laid off to hunt bear."

By the end of the 1920s unrestricted harvest of native trout in high elevation waters of the White Mountains had depleted many populations. The AGFD response to this depletion was to increase the supply of trout through stocking. The first stocking of non-native trout apparently occurred in 1917, when brook trout (*Salvelinus fontinalis*) were brought from Holbrook to Greer and planted in the upper reaches of the LCR (Miller 1961). This was soon followed by introduction of rainbow trout (*Onychorynchus mykiss*). The first State-operated hatchery dedicated to stocking of trout, on the South Fork of the LCR, was built in 1921 through 1932 and produced rainbows and cutthroat trout (*Salmo clarki*) for distribution to nearly all accessible streams in the White Mountains (Miller 1961). Later there were four rearing ponds added at Government Springs (Applewhite 1979, Sizer 1980). At that time fingerlings were being stocked, as rearing fish to a respectable size had not been perfected.

As time progressed, more hatcheries were built or acquired to supply trout to streams and lakes in the LCR watershed. The Pinetop Hatchery was built in 1931 and the Silver Creek Hatchery was acquired in 1978. For many years, both trout and warmwater fishes were raised in a secured area of Mormon Lake and then released into the lake. Many trout stocked in the LCR watershed were raised outside of the watershed at hatcheries in Payson and Page Springs, Arizona, and in a Fish and Wildlife Service hatchery in New Mexico (Sizer 1980).

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# CHAPTER 3: CELL-BASED FISHERIES HABITAT MODELING

James R. Hatten

## INTRODUCTION

### PURPOSE AND SCOPE

In order to resolve conflicts between native and sportfishes within the LCR watershed, knowledge of their localities and habitat requirements is critical in order to segregate, eradicate, or co-manage them. However, there are thousands of miles of stream channels in the LCR watershed, preventing a complete fisheries inventory at this time. It would therefore be advantageous if the AGFD could model potentially suitable habitats for native and sportfishes with a Geographic Information System (GIS), ideally saving time and money. A GIS is well suited for the examination of spatial data because it is "... an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." (ESRI 1994).

This chapter presents information on native and sportfishes within the LCR watershed, overviews relevant information on basin geomorphology, and provides methods necessary to conduct cell-based modeling of watersheds and fish habitats. Cell-based models efficiently divide the landscape, or any other phenomena, into discrete units called cells, which accurately portray continuous surfaces (ESRI 1992). A GIS was used to create habitat suitability profiles for 6 native and 19 nonnative fishes. The habitat suitability profiles contain the ranges of hydrologic and geomorphic conditions that each fish species was observed in at the 804 sample sites. Potentially suitable habitat is any modeled location that met the criteria found within the habitat suitability profile for each species.

The habitat suitability profiles were used as input criteria to create cell-based, GIS models which depict potentially suitable habitats for four native species: Little Colorado spinedace (*Lepidomeda vittata*), speckled dace (*Rhinichthys osculus*), bluehead sucker (*Pantosteus discobolus*), and Little Colorado sucker (*Catostomus sp*). Habitat suitability models were not created for two other native fishes - Apache trout (*Oncorhynchus apache*) or roundtail chub (*Gila robusta*) - because there were too few sample sites where these rare fishes were observed. Lakes were excluded from the analyses since they are for the most part water impoundments, i.e. man-made features within the study area, while the models pertain only to natural habitats (streams and rivers). There are 19 nonnative fish species that habitat suitability models were not created for, because the focus of this chapter is on habitat suitability of native fishes. However, habitat suitability profiles for every fish species within the study area were produced, and this information can be used in future modeling efforts should it become necessary or useful. The modeling focused on native fishes since they are indigenous to the area, and are threatened by nonnative fishes. Habitat suitability maps are presented which depict potentially suitable habitats for the four target species. Lastly, discussion follows on the pros and cons of cell-based GIS modeling, and appropriate uses and limitations of the habitat suitability models.

## CHAPTER GOALS

The goals of these GIS analyses were twofold: 1) develop cell-based habitat suitability profiles for native and nonnative fishes of the upper LCR watershed; and 2) create cell-based habitat suitability models for a target set of native fishes. Specific objectives in order to accomplish the goals were as follows: 1) create a suite of geomorphic and hydrologic variables for modeling purposes; 2) determine relationships between channel/basin geomorphology (link slope, sample site elevation, Strahler stream order), hydrology (perennial, intermittent, or ephemeral), and native and sportfish distribution patterns; 3) produce habitat suitability models for target fishes of Clear, Chevelon, Silver, and Lyman (upper LCR) basins; and 4) determine the usefulness and limitations of the habitat suitability models for basin-scale fisheries management.

## GEOMORPHOLOGIC OVERVIEW

Geomorphology is the study of the origin of landforms, the processes whereby they are formed, and the materials of which they consist (Dunster 1996). Quantitative geomorphology was pioneered by Robert E. Horton (1932), who broadly classified five factors descriptive of a drainage-basin as related to its hydrology: 1) morphologic, 2) soil, 3) geologic-structural, 4) vegetation, and 5) climatic. Additionally, Horton (1945) was the first to demonstrate that the composition of the stream system of a drainage basin can be expressed quantitatively in terms of stream order, drainage density, bifurcation ratio, and stream-length ratio. Arguably Horton's most important contribution was his development of two stream laws that defined the numbers and lengths of streams of different orders in a drainage basin. The law of stream numbers states that there are fewer streams of higher order than lower order, while the law of stream lengths expresses the average length of stream of a given order in terms of stream order, average length of streams of the $1^{st}$ order, and the stream-length ratio. Put simply, the higher the order of stream, the longer the stream channel. Horton's stream laws are important because they demonstrated that the location, number, and size of streams within a drainage basin are statistically related, because basin hydrology and geomorphology are inextricably related.

Horton's Stream Laws were refined by Strahler (1957), who made an improvement to the methodology for calculating stream order as follows: the smallest fingertip tributaries are designated Order 1. Where two first order channels join, a channel segment of Order 2 is formed; where two of Order 2 join, a segment of Order 3 is formed; and so forth (Figure 3-1). The trunk stream through which all discharge of water and sediment passes is therefore the stream segment of highest order. Strahler emphasized that any usefulness which the stream order system may have depends upon the premise that on average, if a sufficiently large sample is treated, order number is directly proportional to relative watershed dimensions, channel size, and stream discharge at that place in the system. In addition, Strahler determined that order number is dimensionless, therefore, two drainage basins differing greatly in linear scale can be equated or

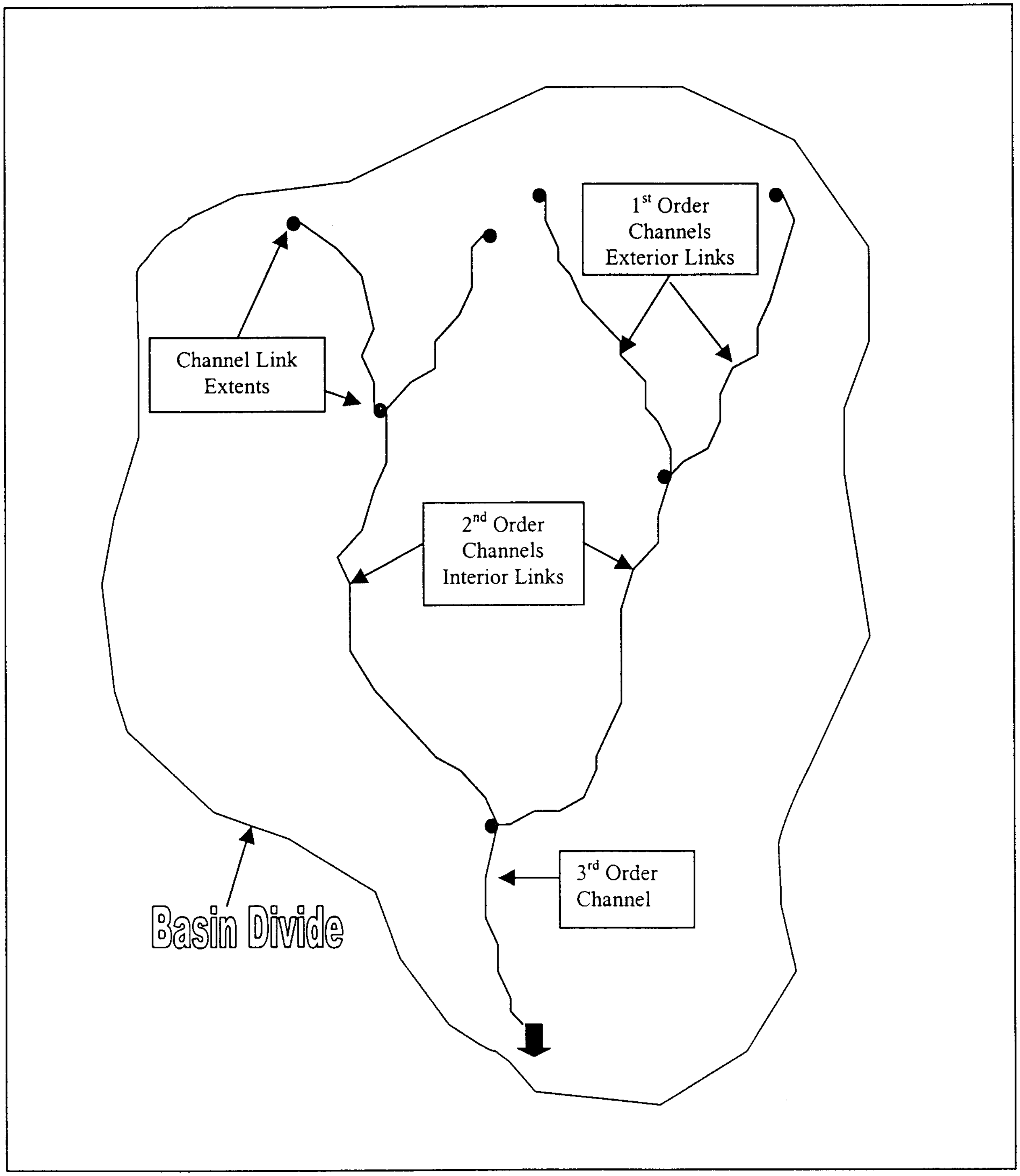


Figure 3-1 A simplified channel network with Strahler orders and channel links delineated.

compared with respect to corresponding points in their geometry through use of order number. Strahler concludes that in order to compare drainage basin areas in a meaningful way, it is necessary to compare basins of the same order of magnitude. Thus, if we measure the areas of drainage basins of the second order, we are measuring corresponding elements of the systems.

Shreve (1966) developed the terms channel link and link magnitude, which are also useful for quantitatively examining channel networks within basins. Channel link refers to a section of channel without intervening forks from either a fork or a source at its upstream end to either a fork or the outlet at its downstream end (see Figure 3-1). Link magnitude is the total number of sources ultimately tributary to a channel. Shreve determined that networks with equal magnitudes have equal numbers of links, forks, sources, Horton streams, and first-order Strahler streams, and are therefore comparable in topological complexity.

It was the pioneering work of Horton, Strahler, Shreve, and others, that built a theoretical foundation that helped enable a newer generation of physical scientists to model channel networks and basin geomorphology with the aid of powerful computers and algorithms. For example, Band (1986) used Digital Elevation Models (a digital lattice of elevation points) to automatically map the stream channel and divide networks of a watershed, partitioning the watershed into a set of fundamental runoff producing subregions, each draining into one stream link. In addition, Jenson and Dominque (1988) demonstrated that computer-generated drainage lines and watershed polygons show close agreement with their manually delineated counterparts, concluding that it is much faster, and costs less, than manual interpretation and digitizing.

The relationship between basin geomorphology and hydrology is complex and largely beyond the scope of this chapter. Furthermore, it is not one of the goals of this chapter to estimate runoff regimes of the focus basins, but a few important points will be discussed. There is considerable evidence that discharge ($Q$) and basin area ($A$) are closely related by a power function (Flint 1974) of the form $Q = aA^x$, where $a$ is a coefficient proportional to the runoff from 1 $mi^2$ (2.6 $km^2$) of basin. Leopold and others (1964) found that for bankfull discharge, $x$ is usually between 0.7 and 0.75. Thus, on average, stream flow increases with basin area. This is important since basin area and stream order are also related (Horton 1945; Strahler 1957).

Lee and Delleur (1976) were able to estimate runoff (cfs) in a basin (recreate or simulate flow regimes) with fair to good results with the following input variables: $B$ (B soil horizon loss); $D$ (a weighting factor = 0.80); $q_0$ (a reference discharge); $C_z$ (channel roughness); and $N$ (a factor used to depict the expansion of the variable source area during a storm) - the value of $N$ equals the sum, over time, of the products of contributing areas and rainfall intensity, which is equal to the total direct runoff volume. All of these variables are also related to many other variables within the basin and there are many equations used to derive their values. Furthermore, Rodriguez-Iturbe and Valdes (1979) found that the structure of the hydrologic response is intimately linked to the geomorphologic parameters of a basin, in addition to a scale variable and a dynamic parameter. Thus, the instantaneous unit hydrograph varies from storm to storm and throughout the same storm as a function of the velocity, which occurs in the different instances of time throughout the basin.

These hydrologic studies (and many others not mentioned) reveal that there is a very complex linkage between basin geomorphology and hydrology. Indeed, it is neither straightforward nor simple, but there are clear indications that basin geomorphology and hydrology are related. Therefore, even though this paper focuses mainly on basin geomorphology, the reader should realize that the physical variables are often correlated with other variables that may be equally important to the biotic integrity of the basin.

DESCRIPTION OF STUDY AREA

The LCR watershed is located within the Colorado Plateau physiographic province, draining 70160 $km^2$ (27089 $mi^2$) of northeastern Arizona and western New Mexico (Figure 3-2). While the LCR watershed is very large, the actual area focused upon for GIS analyses is contained within four tributary basins: Clear Creek, Chevelon Creek, Silver Creek, and Lyman (LCR upstream of Lyman Lake), comprising an area of 8203 $km^2$ (3167 $mi^2$, see Figure 3-2). There were numerous reasons why the GIS analyses were restricted to four focus basins: 1) the LCR Fisheries Management Plan deals only with portions of the LCR watershed, having no jurisdiction on Indian reservations or private lands, 2) most of the perennial waters in the LCR watershed are within the four focus basins (see Figure 3-2), and 3) the majority of fish sample locations are within the four focus basins (Figure 3-3).

Geomorphic descriptive statistics of the focus basins were produced with ARC GRID (see Methods) and are listed in Table 3-1. The focus basins' areas ranged from a high of 2450 $km^2$ (946 $mi^2$, Silver basin) to a low of 1594 $km^2$ (615 $mi^2$, Clear basin), with Lyman (2098 $km^2$ = 810 $mi^2$) and Chevelon (2070 $km^2$ = 799 $mi^2$) basins being of comparable size. It should be noted that Lyman basin is not actually a tributary basin like the other three - rather it is the headwaters of the LCR upstream of Lyman Lake dam. Lyman basin has the highest elevation (3477 m = 11407 ft), while Clear basin has the lowest elevation (1481 m = 4859 ft). When the mean (average) basin elevations were compared, Lyman basin has the highest (2349 m = 7707 ft) and Chevelon the lowest (1980 m = 6496 ft). Basin slopes (degrees) ranged from a high of 57.6 (Clear basin) to a low of 0, with the highest mean slope of 5.9 (Lyman basin), and the lowest mean slope of 3.0 (Silver basin).

Table 3-1 Geomorphic characteristics of the four focus basins

| | Lyman | Silver | Chevelon | Clear |
|---|---|---|---|---|
| Area ($km^2$) | 2089.6 | 2449.7 | 2070.7 | 1593.8 |
| $miles^2$ | 806.9 | 945.9 | 799.5 | 615.4 |
| Mean Elevation (m) | 2349 | 1925 | 1980 | 1988 |
| Minimum Elevation (m) | 1811 | 1584 | 1494 | 1481 |
| Maximum Elevation (m) | 3477 | 2786 | 2410 | 2458 |
| Mean Slope (degrees) | 5.9 | 3 | 4.4 | 5.8 |
| Maximum Slope (degrees) | 50.2 | 45.2 | 54 | 57.6 |
| Minimum Slope (degrees) | 0 | 0 | 0 | 0 |
| [1]Total Channel Length (km) | 4917.4 | 5906.2 | 6204.5 | 5341.3 |
| Channel Density ($km/km^2$) | 2.4 | 2.4 | 3.0 | 3.4 |

[1]Channel lengths determined from cell-based models (DEMs) and don't correspond to stream lengths

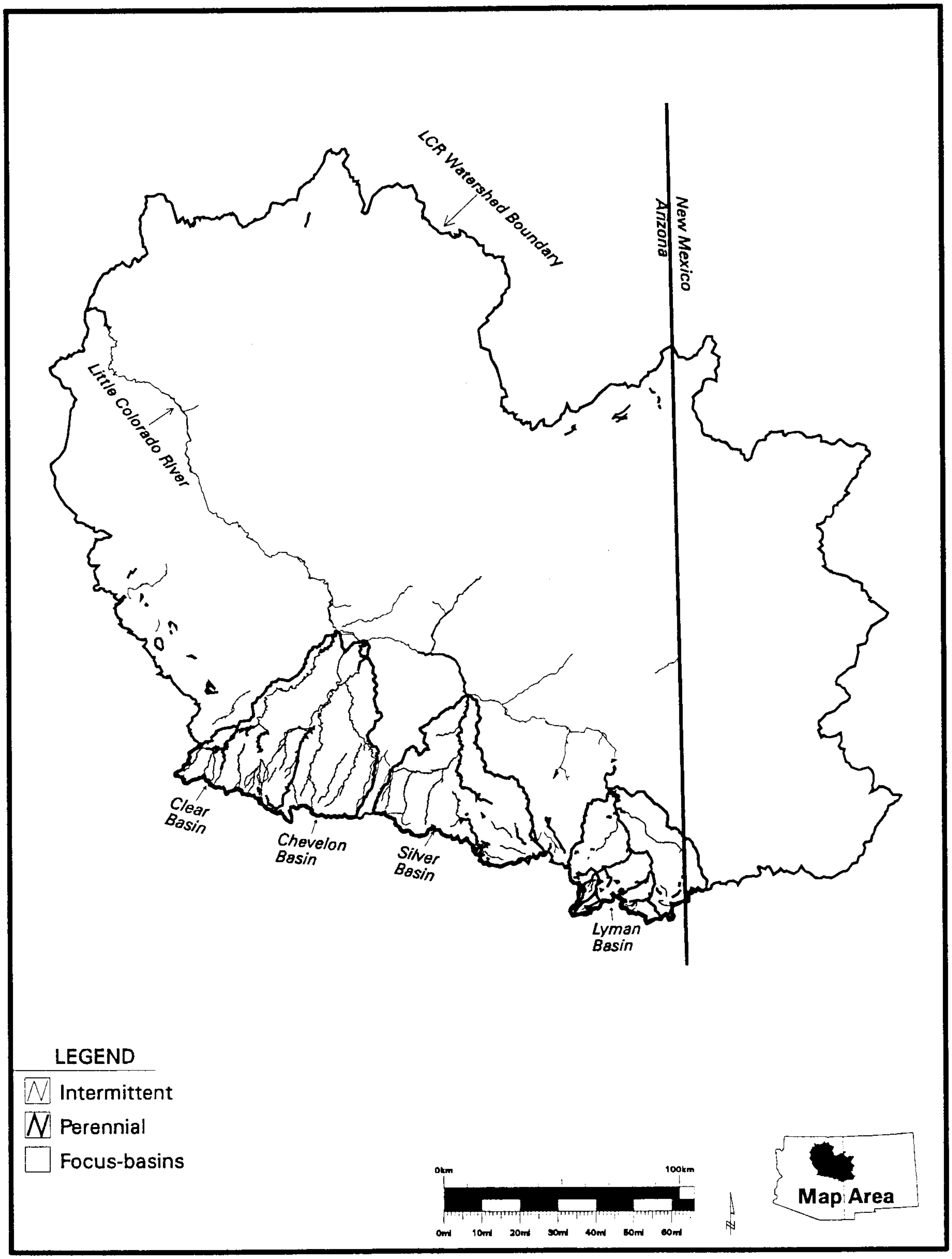


Figure 3-2 Little Colorado River watershed with the 4 focus basins shaded. In addition, perennial and intermittent streams and lakes of Arizona are displayed

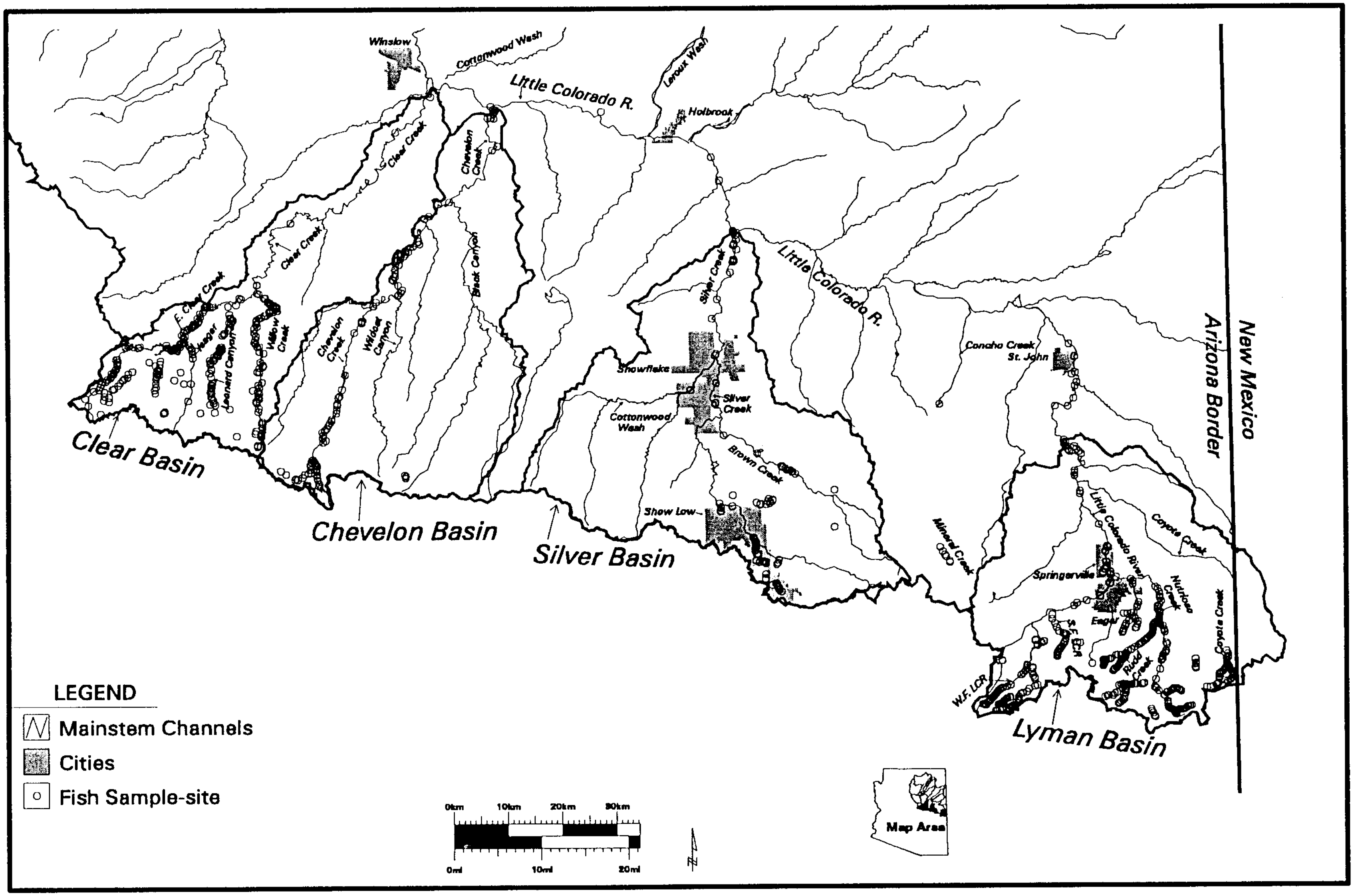


Figure 3·3 Locations of the fish sample sites within the Little Colorado River watershed

All four focus basins are $7^{th}$ order (Strahler 1957), with each basin having relatively comparable lengths of channel for a given order. Concerning channel density (Strahler 1957), which is the length of channel per basin area, Clear basin has the highest density (3.3), closely followed by Chevelon (3.0), then by Silver basin (2.4), and last by Lyman basin (2.3). In general, channel density correlates to surface erosion, thus, Silver and Lyman basins appear more resistant to weathering than Clear and Chevelon basins. The higher stream density within Clear and Chevelon basins is probably due to the greater concentration of sandstone and limestone within their basins, compared with the more resistant basalts of Chevelon and Lyman basins (Arizona State Land Department (ASLD) GIS geology cover). As drainage density increases, the size of individual drainage units, such as the first-order drainage basin, decreases proportionately (Strahler 1957).

Land use, vegetation, and land ownership patterns within the four focus basins were characterized from USGS and ASLD ownership and land use GIS covers. The focus basins' major vegetation class, except Lyman basin, was evergreen forest, followed by mixed rangeland, then by shrub and brush rangeland classes. In contrast, Lyman basin's largest vegetation class was mixed rangeland, followed by the other two classes. However, a portion of Lyman basin is in New Mexico, and was not included in the totals, which may have impacted the evergreen forest class somewhat. Silver basin had the highest percentage of urban/industrial activities (2.93%), followed by Lyman basin (0.66%), then Chevelon basin (0.63%), and last, Clear basin (0.03%). Clear basin appears to be the only completely rural basin, contrasted with Lyman and Chevelon basins, which have a relatively similar urban development pattern. Silver basin is a standout in terms of urban/industrial development patterns, with almost 3 percent of the basin classified as such, and several times higher than the other basins. The principal landowners in the focus basins in order of significance are: 1) the United States Forest Service (USFS); 2) state trust lands; and 3) private. There is a spattering of Bureau of Land Management, AGFD, and Indian reservation lands as well, but they make up less than 10 percent of the total.

## METHODS

### INTRODUCTION

Methods are divided into six sections in order to help the reader understand the techniques employed throughout the chapter: 1) Variable Appraisal and Selection – discusses which variables were chosen for these analyses, and why; 2) Data Formats and Software – a brief background on GIS data-types and software used; 3) Creation of Geomorphic Variables – quantitative information necessary for creating and replicating the cell-based modeling techniques; 4) Preparation of Fish Collections Database – explanation of how the Fish Collections database was edited and prepared for subsequent analyses; 5) Creation of Habitat Suitability Profiles – information on GIS spatial overlay and frequency analyses used to identify suitable geomorphic and hydrologic habitats for fishes; and 6) Cell-based Habitat Suitability

Models – discussion on the mechanics of extracting potentially suitable habitats from grids with information (criteria) from the habitat suitability profiles.

VARIABLE APPRAISAL AND SELECTION

In order to develop a habitat suitability model with a GIS, information on the following parameters was necessary for each target species: 1) locality information, 2) habitat requirements, 3) an appropriate scale for spatial analyses and data interpretation, and 4) habitat variables amenable to GIS modeling.

The AGFD Fish Collections database provided the locations and fish assemblages of the 804 sample sites within the study area. The Fish Collections database is actually a composite of many different studies, with some records over 30 years old. Unfortunately, the Fish Collections database presented difficulties for modeling because collection criteria and methods were never standardized, so there was a lot of variability in the data. Also, many collection records contained empty fields, making them incomparable with other collection records. Another concern for modeling was the fine-scale of the variables used to characterize fish habitats at many sample sites. While fine-scale variables (riffle/pool ratios, stream depth and width, etc) work for some analyses, they were not well suited for the GIS modeling because they were too small, making their detection with remotely sensed imagery, or extraction from DEMs, impossible. High resolution digital imagery (1 m) could be used to identify some stream habitat parameters, but its utility for identifying stream habitats within an automated, computerized modeling environment is questionable. The correct scale at which to model must therefore bridge the gap between fine-scale fish habitat variables and basin-scale variables suitable for GIS modeling. It was the lack of consistency in the fish collection records, and the fine-scale of the habitat data, which prompted the development of a common set of geomorphic and hydrologic variables.

Geomorphic variables offer an alternative to using stream habitat variables for fisheries habitat suitability modeling (Platts 1979; Lanka and others 1987; Kruse and others 1997. For instance, instead of determining whether a fish is in a micro or macro stream habitat (plunge-pool, cascade, glide, etc.), the focus shifts to geomorphic variables like stream order and channel link slope. Geomorphic variables offer several distinct advantages over stream habitat variables in a GIS analysis: 1) they can be created (extracted) quickly and cheaply from Digital Elevation Models (DEMs) available from the USGS; 2) geomorphic variables such as Strahler stream order (Strahler 1957), elevation, channel link slope (Shreve 1966), basin relief, topographic surfaces (slope and aspect), and hydrologic divides can be extracted quickly and accurately with a GIS (Douglas 1986; Jenson and Dominque 1988; Tarboton and others 1991); and 3) DEM data are georeferenced, making them ideal for GIS overlay operations that can code large data sets with their appropriate geomorphic values, quickly and efficiently.

The utility of geomorphic variables has been demonstrated in fisheries analyses. For instance, Platts (1979) found Strahler stream order effective in estimating approximate stream size (width and depth), channel substrate, channel gradient and elevation, and low-flow water volume. Platts also found fish abundance and assemblages changed in relation to stream order in a predictable fashion, and concluded that stream order was an effective variable for better understanding fisheries and land management issues. Furthermore, Lanka and others (1987) found numerous significant univariate correlations between geomorphic variables, stream-habitat variables, and trout standing stock in both high-elevation forest and low-elevation rangeland streams. In particular, when multiple-regression equations were developed for predicting trout standing stock, the models were dominated by geomorphic variables that predicted as accurately as the stream habitat variables. Lanka and others (1987) concluded that stream habitat is a function of geologic processes within a drainage basin, thereby making geomorphic variables a good predictor of trout standing stock. More recently, Kruse and others (1997) found geomorphic variables (channel slope, elevation, stream size, and upstream barriers) were all important predictors of the presence or absence of Yellowstone cutthroat trout, and logistic models using geomorphic variables were highly effective at predicting trout presence or absence.

In addition to basin geomorphic variables, the seasonal and spatial presence of water plays an important role in fish presence and distribution. Indeed, Platts (1979) found that most 1$^{st}$ and 2$^{nd}$ order channels had no fish in them because they were ephemeral (flow infrequently), or too small. Within the White Mountains of Arizona, Clarkson and Wilson (1995) found that stream discharge, pool width, and mean water depth, were significant contributors to explaining trout biomass. Throughout Arizona, it is not uncommon for stream channels to be ephemeral or intermittent (seasonally flow). Therefore, a variable that accounts for hydrologic conditions (presence or absence of water) is desirable for fisheries analyses and the development of fish habitat suitability models.

Four hydrology covers (GIS layers) were used in the development of the habitat suitability profiles: 1) the Arizona Land Resource Information System (ALRIS) Hydro cover, which contains most blue-lines (streams) found on 7.5 minute USGS topographic map, meeting strict guidelines of the Environmental Protection Agency; 2) the AGFD perennial stream cover, which was created as part of a statewide perennial riparian study (Valencia and others 1993); 3) the AGFD intermittent stream cover, which was created as part of a statewide intermittent riparian study (Wahl and others 1997); and 4) the AGFD stream-type cover, which was created for this project by appending the perennial and intermittent stream covers together, then appending a modeled ephemeral channel network to it. The resultant stream-type cover contained all three stream types (perennial, intermittent, and ephemeral). The four hydrology covers were used for different purposes, and at different stages in the analyses, to create the most accurate habitat suitability models possible.

### Data Formats and Software Used in Analyses

Within a GIS data are represented as either vector or raster, depending on the source data and the compilation methods. Raster data are evenly spaced cells, while vector data are points, lines, or polygons. Each data type has advantages depending on the goals of the project. The advantages of the raster format are efficient processing, large quantities of available data (satellite imagery, DEMs, scanned aerial photography), and different feature types can be organized on the same layer within ARC GRID (Chou 1997). In contrast, the advantages of vector feature types are higher spatial accuracy because the data are not partitioned into cells. However, for spatial analyses, cell-based processing is much more efficient (ESRI 1992; Chou 1997)

In order to extract and create the geomorphic variables necessary for the spatial overlays and analyses, Environmental Systems Research Institute (ESRI) GIS software (ARC/INFO, ARC GRID, and ArcView's Spatial Analyst) was used for various portions of this project. Of these, GRID, which is an ARC/INFO module, was used for all DEM manipulations, data extractions, and cell-based (raster) modeling. GRID is ideal for working with DEMs because it is specialized for cell-based modeling applications. The cell-based environment greatly improves processing speed, allows large sets of information to be processed efficiently and quickly, and accurately portrays continuous surfaces such as DEMs. Vector covers were converted into grids, and analyses were conducted within the cell-based modeling environment. The concepts and data models behind cell-based modeling are beyond the scope of this paper, but should the reader be interested, a good reference book is: Cell-based Modeling with GRID (ESRI 1992). At a minimum, readers should be aware that in a grid, geographic units are regularly spaced cells, and the location of each unit is referenced by row and column positions.

### Creation of Geomorphic Variables

The LCR watershed within Arizona encompasses 620 USGS 7.5 minute quadrangles, and for each quadrangle there is a DEM which corresponds exactly with its boundaries. The 7.5 minute DEMs are available from the USGS in either 30-m (98 ft) and/or 10 m (33-ft) resolutions. In addition, each DEM has online metadata that states its vertical accuracy, which is very important for understanding the accuracy of any extracted data. The four focus basins encompass 88 DEMs, which were obtained from the Arizona State Lands Department (ASLD), or USGS. If a DEM had more than one resolution available, then the highest resolution was selected.

In order to create the geomorphic variables (Strahler stream order, elevation, and link slope) for the four focus basins, 88 DEMs were mosaiced together with GRID's MOSAIC function. All sinks in the DEMs (accidental depressions in the DEM; Jenson and Dominque 1988) were located and filled with a suite of GRID functions designed for that purpose. The vast majority of sinks within a DEM are errors in the data since holes in the landscape are considered rare (Tarboton and others 1991). Unfortunately, this method also fills real depressions in the landscape, like sinkholes or closed basins, and results in error. Therefore, the results were carefully reviewed to see if any sinks or closed basins were filled in.

Once the sinks were located and filled, channel networks were extracted with GRID's TEMPSTREAMNET function, with the flow accumulation threshold set at 100. The flow accumulation threshold specifies how much drainage area is required before a first-order channel is extracted (ESRI 1992), and should correspond closely to the blue lines on USGS topographic maps (Tarboton and others 1991). A flow accumulation threshold of 100, which equals 9 ha (22 acres), was selected after overlaying the extracted network on the ALRIS Hydro cover, satellite imagery, and the 804 sample sites, to determine the best correspondence. A Strahler stream-order grid was then created from the channel network grid with the GRID STRAHLER function (Figure 3-4).

The last geomorphic variable created was channel link slope, which was extracted and calculated with a series of GRID operations, using both Local and Zonal functions (ESRI 1992; Chou 1997). Channel link slopes were created in a three step process: 1) identify all channel links, 2) extract the high and low elevation points along the link, and 3) divide the length of the link (number of cells × 30 m) by the elevation difference (high – low elevation). Channel link slopes overestimate the true channel slope somewhat, because cells do not represent channel meanders precisely. However, the slope calculations were done the same way every time, so the output products (channel link slopes) were consistent and repeatable.

In addition to the DEM data, two AGFD stream covers (perennial and intermittent) were converted to grids with the ARC LINEGRID command, after merging the two hydrology covers together with the ARC APPEND command. In order to produce an ephemeral channel network, several steps were executed: 1) all channels were extracted from the mosaiced DEM, 2) the perennial and intermittent portions of the channel network were masked by overlaying the perennial and intermittent covers, 3) all remaining channels (those not masked) were extracted from the DEM and coded as ephemeral, and 4) the perennial, intermittent and ephemeral covers were then merged, then converted to a grid. This method assumed that all channels not contained on the AGFD perennial and intermittent stream covers were ephemeral. The newly created hydrology cover, which was named the AGFD stream-type cover, contained an attribute (stream type) that denoted whether a stream was perennial, intermittent, or ephemeral.

PREPARATION AND CODING OF THE FISH COLLECTIONS DATABASE

All covers were clipped (cut) with the LCR watershed boundary to reduce file size, restrict the analyses to the LCR watershed, and to make plotting and data interpretation easier. In order to view and analyze the data, the geographic coordinates associated with each record in the Fish Collections database (latitude and longitude derived from USGS maps) were converted to a Universal Transverse Mercator (UTM) projection (NAD 27, Zone 12). The collection records were then converted to an ARC/INFO point cover with ARC GENERATE. Next, a unique sample site ID was assigned to each set of records that had the same UTM coordinates, which aggregated the 27,949 records into 804 unique sample sites, with each site having one or more associated records (see Figure 3-3). The sample site length varied throughout the focus basins because sample length was never standardized. The median site length was 50 m (164 ft), with a SD of 144.5 m (474 ft). There were multiple records associated with each sample site (a one to many relate) because: 1) there were oftentimes multiple efforts to catch fish within a reach, but those efforts were assigned to the same sample site, and 2) some sample sites were sampled on

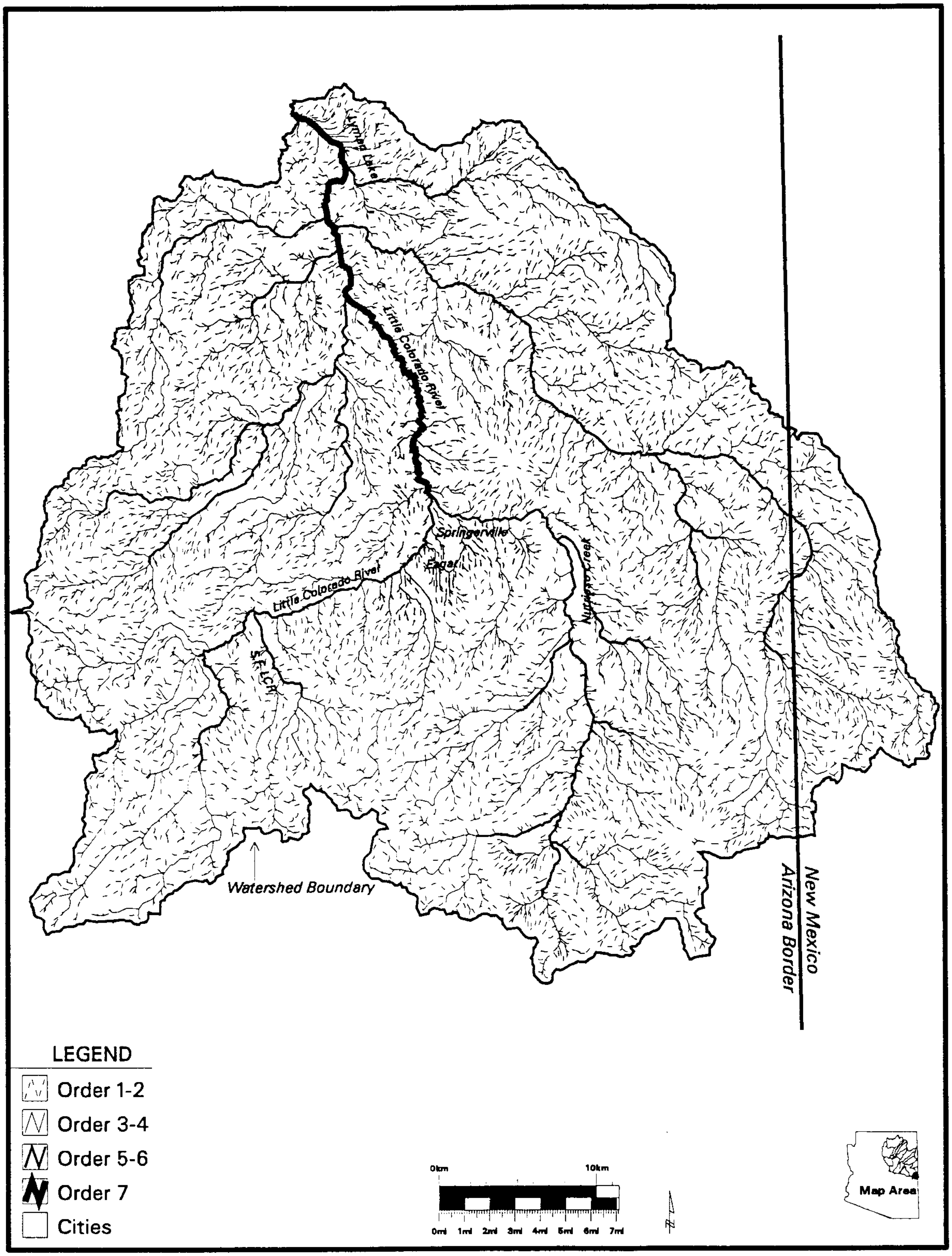


Figure 3-4 Strahler stream order network within Lyman basin

more than one occasion. Aggregating records by sample site location made the site the smallest unit in all subsequent analyses, with each location (easting, northing) representing the downstream end of the site. Sample site aggregation collapsed the temporal and spatial axis of the data and evenly weighted fish presence, regardless of the number of species occurrences through time.

A GIS overlay was used to code the 804 sample sites with their respective focus basin (Clear, Chevelon, Silver, and Lyman basins). Spatial errors in sample site locations were examined by overlaying the sites (points) on the ALRIS Hydro cover, then identifying points that were more than 100 m (328 ft) from the channel. Any sample site locations that were farther than 100 m (328 ft) from the channel were identified, and new locations that fell within the 100-m buffer were assigned to them. An unknown amount of spatial error is inevitable for the sample sites because of the following reasons: 1) the sample site locations were taken off of 7.5 minute topographic maps, which have spatial error associated with them, 2) additional spatial error incurred while locating sample sites on the map (i.e. the user probably could not identify exactly where he was), and 3) the ALRIS Hydro cover has spatial error which incurred during the digitizing process. It was difficult to calculate the amount of spatial error resulting from these methods because most sample site locations were not obtained with a Global Positioning System (GPS) receiver, and there are no permanent field markers for most sample sites. Spatial error of up to 100 m (328 ft) was assumed for many sample site locations, but this was just an educated guess - each sample site may have more or less spatial error.

In order to overlay and code the sample sites with their respective geomorphic and hydrologic values, the geomorphic and hydrologic grids were first converted into vector covers with the GRIDPOLY function for elevation, and the GRID STREAMNET function for the stream order and link slope grids. In order to reduce the size and processing time required to perform the overlay analyses, GRID's SETMASK command was used to mask all areas other than the sample sites. In order to correctly code sample sites that did not directly overlay the modeled channel network (there could be 100 m spatial error), ArcView's Spatial Analyst's PROXIMITY function was used to create a polygon cover out of the stream covers, with each polygon coded with the nearest stream order, or link slope value. Thus, sample sites with spatial error were still assigned a value of the nearest channel. The accuracy of this method involved GIS overlay operations, then examining maps generated with ARC/PLOT. Any sample sites that had obvious attribute errors were identified and corrected within ARC/EDIT.

### CREATION OF HABITAT SUITABILITY PROFILES

Once the sample sites had been assigned an elevation, link slope, hydrologic value, or stream order, then summary information was generated with ARC's FREQUENCY command. The attributed data were then transferred from a UNIX workstation to an NT workstation, imported into EXCEL and SPSS, and examined. Two of the four physical variables were continuous (elevation and link slope), and for purposes of producing frequencies or observing patterns in the data, they were aggregated (partitioned) into discrete classes. Channel link slope data were partitioned into 12 classes by rounding to the nearest half number. Elevation data were partitioned into 14 classes in 152.4 m (500 feet) intervals - class 1 started at 1371.6 m (4500 feet), and class 14 started at 3352.8 m (11000 feet). The other two variables were left alone since their data types were already interval (stream order and stream type).

Relative frequencies of target species within each variable class (i.e. stream order 1, 2, or 3) were identified by standardizing the data by sample site frequency. Data standardization clearly revealed patterns in the collection data by showing the percentage of sites within each variable class that contained a target species (i.e. 20 percent of 3$^{rd}$ order sample sites observed Little Colorado spinedace). Data standardization was necessary since some classes were sampled much heavier than other classes. However, data standardization did not account for the unequal lengths of the sample sites, or the nonrandom sampling distribution. The standardized data were then portrayed in a series of relative frequency histograms (Ott 1993) for each species and variable class, thus allowing the reader to clearly see the relationships among basin/channel geomorphology, hydrology, and fish species distributions.

### CELL-BASED HABITAT SUITABILITY MODELS

The range of geomorphic and hydrologic conditions that each species was observed in was examined both within and between basins. However, some of the analyses, and all of the habitat suitability modeling, focused upon the whole study area, i.e. aggregating the focus basins' data into one set. Fish collection data were aggregated for modeling because there were very large holes in the data due to uneven sampling (see Figure 3-3). For example, areas that lacked samples were the lower half of Clear Creek, lower order channels of Chevelon and Silver basins, and intermittent channels of Lyman basin. However, when the focus basins were combined, then the holes in the data were not as pronounced. Thus, data aggregation was considered beneficial to model development, although there are tradeoffs in aggregating (lumping) or splitting data. The most obvious drawback to data aggregation is the creation of habitat suitability models that are too general, since the distribution of native fishes might be due to biologic versus physical conditions. However, given the clumped and nonrandom distribution of the sample sites, lumping the data provided the best database to model with since it provided sample sites within each geomorphic and hydrologic class.

Once the range of hydrologic and geomorphic conditions was determined for each fish species (a habitat suitability profile), GIS was used to extract all suitable grid cells using Boolean logic and conditional statements. For example, if a target species was observed within a specific range of physical conditions (i.e. 4$^{th}$ – 7$^{th}$ order channels, 2000 – 3000 m elevation, stream type = 1, and link slope < 2 percent), then a query of the four grids (one grid for each variable) extracted all suitable cells. The resulting output grid was a single layer that showed all locations within the focus basins where suitable habitat might occur, based upon where the species has been observed. Since the output grids were not derived from a statistical model, no probability is associated with their cells. The output grids were then compared with the fish collection museum records in order to determine if the target species had been observed in other geomorphic or hydrologic classes. If so, then the model would be expanded to incorporate the historic data as well. The output grids were used to produce habitat suitability maps that depict all potentially suitable habitats for each target species.

## RESULTS

### HABITAT AVAILABILITY VERSUS SAMPLE SITE FREQUENCY

Figures 3·5·a-d show the percentage of sample sites (total = 804) found within each variable class, plotted against the total habitat available for that class. Concerning stream order (Figure 3·5·a), the lower order channels (1 – 3) comprised the majority of channel lengths, but they were proportionately under-sampled, while the less common 4$^{th}$ – 7$^{th}$ order channels were proportionately over-sampled. In relation to channel link slope (Figure 3·5·b), slope classes 0, and 3 – 8, were proportionately over-sampled, while slope classes 1 – 2 were proportionately under-sampled. In contrast, slope classes greater than 8 were very rare, but had some sampling in them. Regarding stream type (Figure 3·5·c), perennial streams accounted for 2.7 percent of all channel lengths, intermittent accounted for 4.4 percent, and ephemeral accounted for 92.9 percent. However, the distribution of sample sites by stream type was very different, with 51.4 percent of sample sites located on perennial streams, 24.8 percent on intermittent streams, and the remainder ephemeral (23.8 percent). Thus, the percentage of sample sites located on perennial and intermittent channels was disproportionately large compared with the actual amount available, while ephemeral channels were proportionately under-sampled. Concerning elevation (Figure 3·5·d), class 5 was proportionately sampled, while elevation classes 2 – 4 were proportionately under-sampled, and elevation classes 1 and 6 – 13 were proportionately over-sampled.

### PHYSICAL CHARACTERISTICS AND DISTRIBUTION PATTERNS OF THE SAMPLE SITES

Figures 3·5·a-d depict the percentage of sample sites found within each variable class. The sample sites were distributed very differently among the four focus basins - Lyman basin had 367 sample sites, followed by Clear basin (274), Chevelon basin (93), and Silver basin (70). The inequitable sampling regime became more apparent after comparing the total amount (length) of channels available within each Strahler stream order, which was similar among the focus basins (Figure 3·6). The pronounced clumping observed in the sample sites (see Figure 3·3) is attributable to numerous factors: 1) combining fisheries data from different projects into a single Fish Collections database, 2) non-standardized sampling protocols, 3) a non-random approach to sampling, and 4) a focus on either water permanency or a target species.

The mean stream order sampled was 4.5, with a low of 1 and a high of 7. Thus, the full range of stream orders was sampled, although not equally within or between basins (Figure 3·7·a). Both Clear and Lyman basins had 1$^{st}$ – 7$^{th}$ order streams sampled, while Chevelon and Silver basins had only 4$^{th}$ through 7$^{th}$ order sampled. Since the amount of stream channel within each of the seven Strahler-orders is relatively similar within the focus basins, it can be safely concluded that

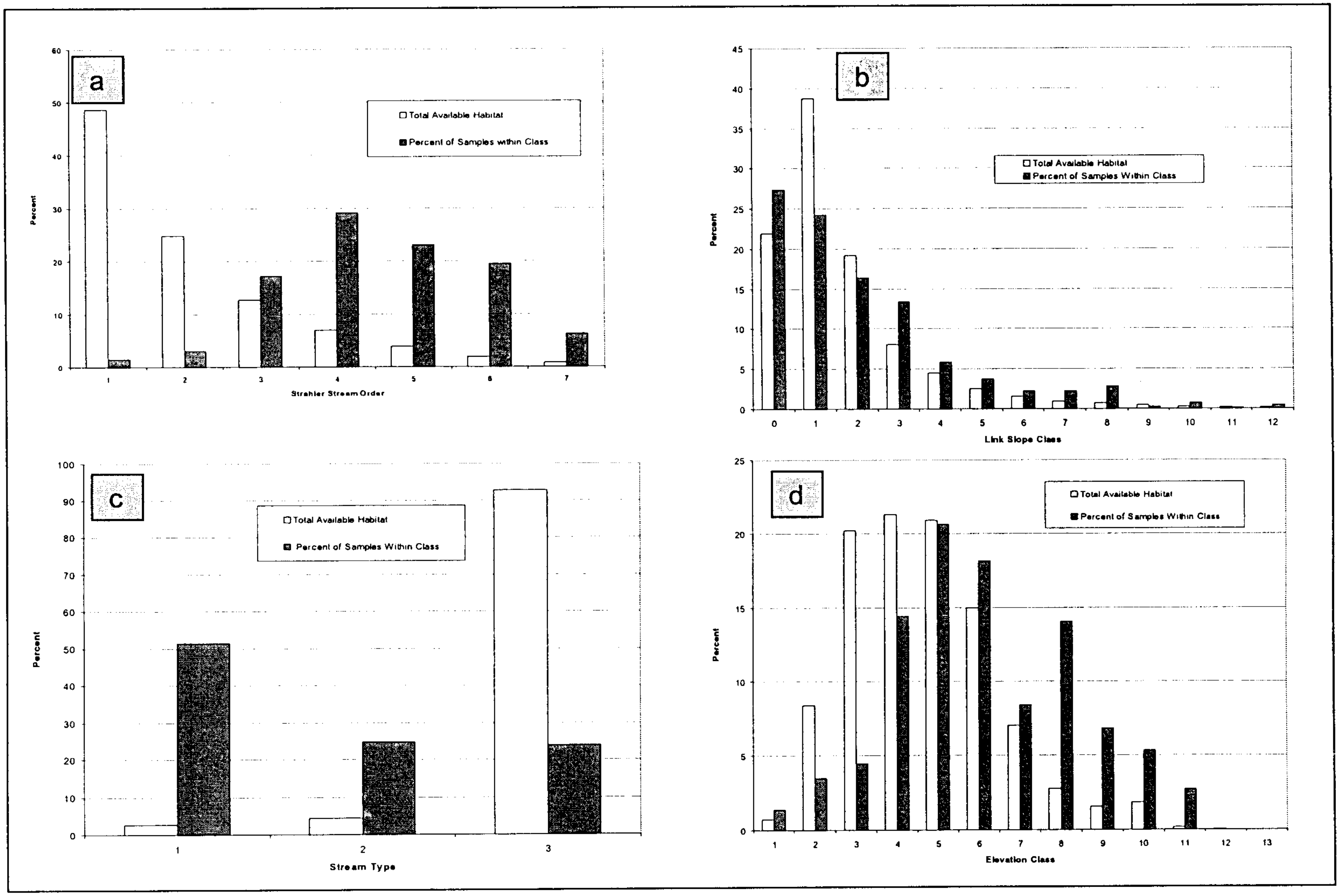


Figure 3-5 Percentage of sample sites within each variable class versus total available habitat for the class

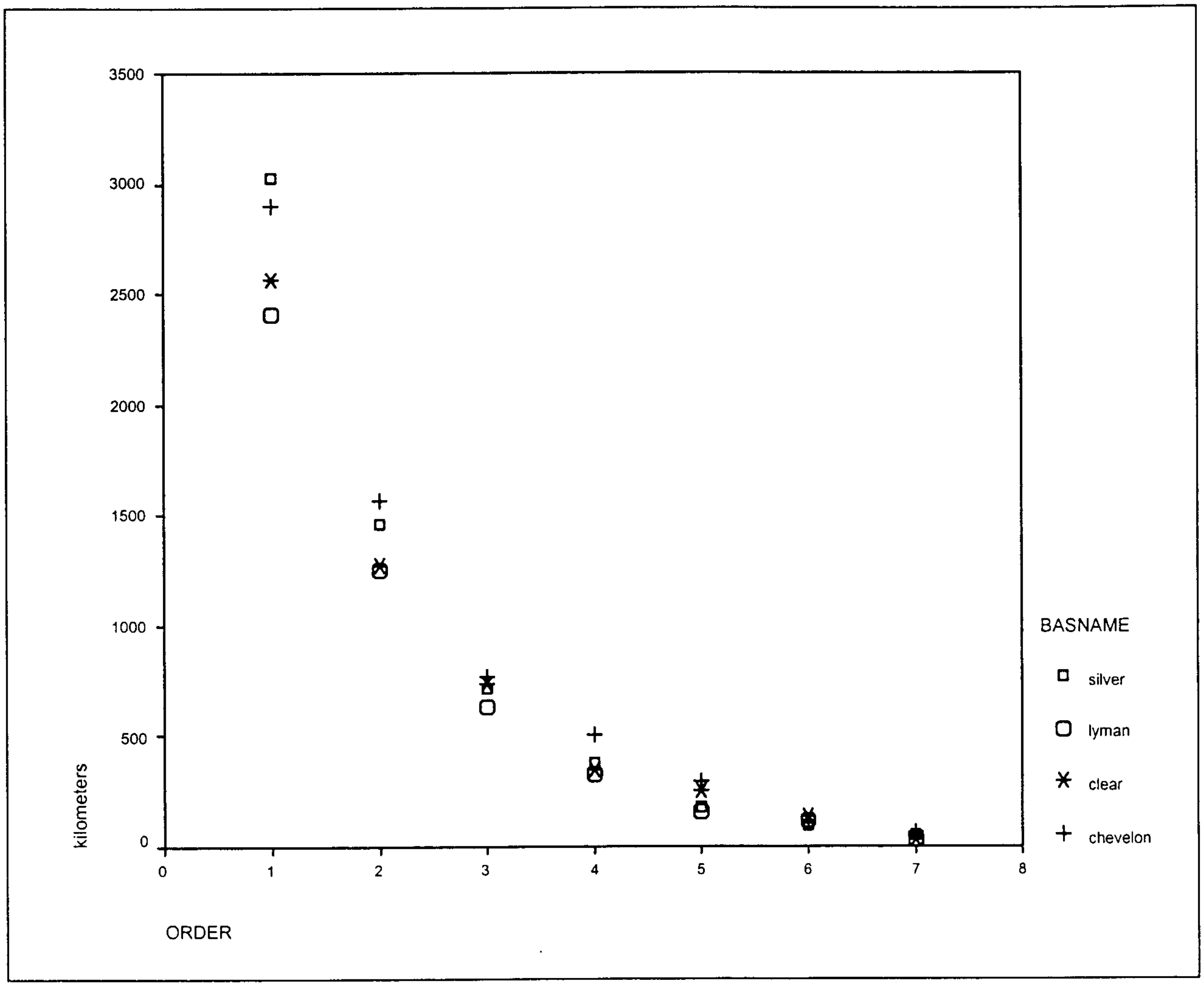


Figure 3·6 Inter-basin comparison of channel lengths by Strahler stream order within the focus basins

Chevelon and Silver basins have been proportionately under-sampled. The tendency of fisheries personnel to sample higher-order channels might be attributable to the increased likelihood that water will occur there.

The most commonly sampled link slope classes were 0 – 4, with a mean of 2, a high of 12, and a low of 0. Once again, Lyman basin had the greatest range (0 – 12) in link slopes sampled (Figure 3·7·b), while Silver basin had the smallest (0 – 3). In contrast, Chevelon and Clear basins had a similar range of slope classes sampled (classes 0 – 8 and 0 – 7, respectively). The distribution of sample sites by stream type is shown in Figure 3·7·c. While each focus basin had stream types 1-3 sampled, the perennial stream reaches had twice as many sample sites as the intermittent or ephemeral reaches (Figure 3·5·c).

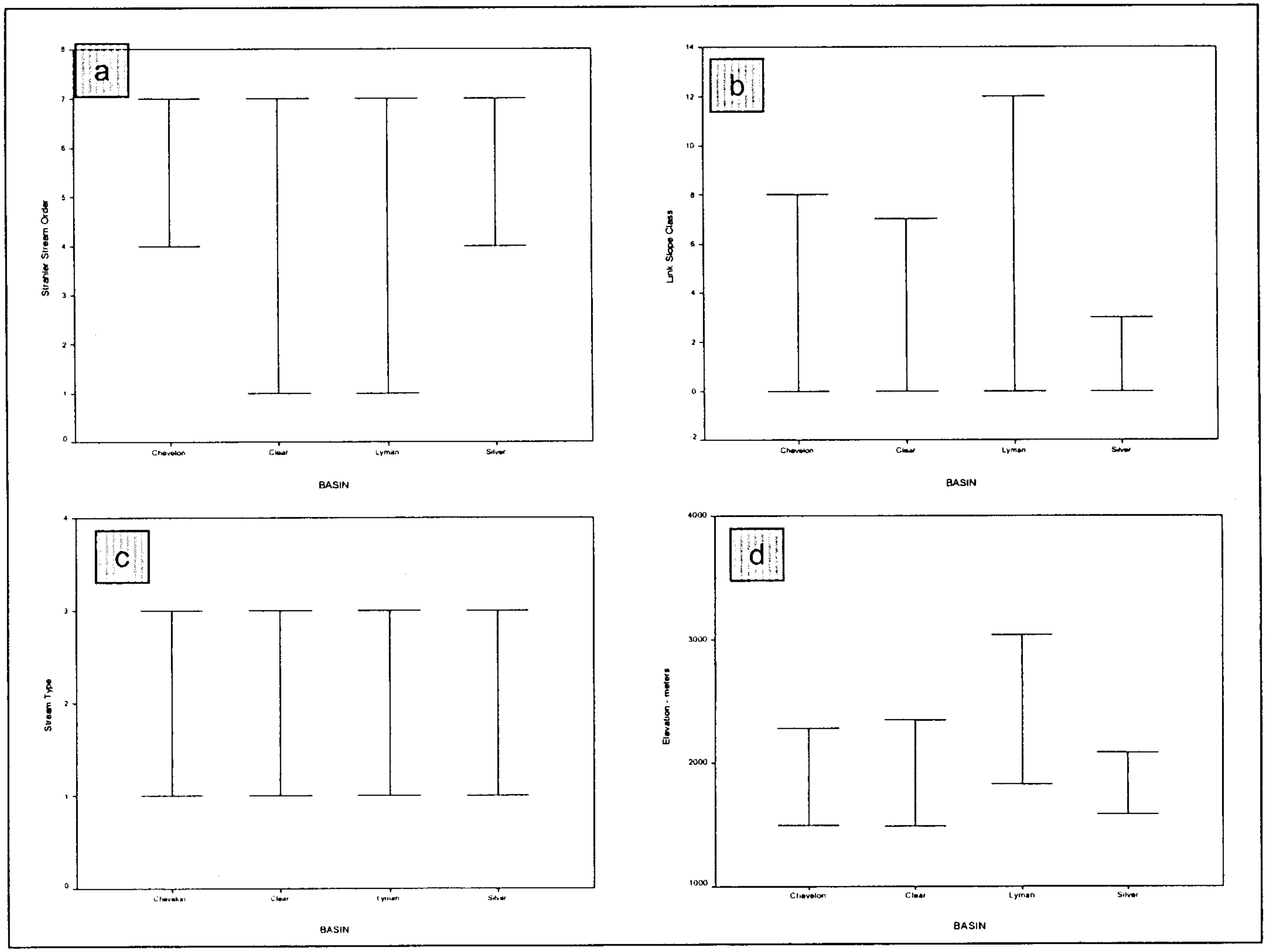


Figure 3-7 Inter-basin comparison of sample site distributions for each variable class

The mean elevation of the sample sites was 2223 m (7292 feet), ranging from a low of 1486 m (4874 feet) to a high of 3036 m (9961 feet). Figure 3·7·d shows that the range of elevations sampled was very different among the focus basins, with Lyman basin having the greatest range of sample sites and Silver basin the least. The higher elevation sampling conducted within Lyman basin is related to the fact that the mean elevation of the basin is substantially higher than the other three basins (see Table 3·1). In addition, many higher elevation perennial streams are located on the flanks of Mount Baldy, which provided sampling opportunities that did not exist in the other basins. Furthermore, Chevelon and Clear Creek basins have stream outlets that are lower in elevation than Silver or Lyman basins, which explains why they were sampled at lower elevations.

### Correlation Analysis: Sample Site Physical Characteristics

The results of a Spearman's correlation analysis among the four physical variables at the 804 sample sites are listed in Table 3·2. The correlation analysis revealed that larger stream orders correlated with a decrease in elevation and channel link slope, and an increase in water permanence, which makes good intuitive sense and is well substantiated in the literature. It is important to note that the correlation coefficients were not the result of a random sample – instead they represent conditions found at the 804 sample locations. Also, the P values need to be viewed with caution since the spatial autocorrelation between the variables were not accounted

Table 3·2 Results of a Spearman's correlation analysis for the geomorphic and hydrologic variables at the 804 sample sites ($p < 0.01$)

| | Elevation Cat | Elevation | Link Slope | Order | Stream Type |
|---|---|---|---|---|---|
| Elevation Cat | 1 | 0.989 | 0.666 | -0.731 | 0.139 |
| Elevation | 0.989 | 1 | 0.672 | -0.736 | 0.147 |
| Link slope | 0.666 | 0.672 | 1 | -0.580 | 0.204 |
| Order | -0.731 | -0.736 | -0.580 | 1 | -0.482 |
| Stream Type | 0.139 | 0.147 | 0.204 | -0.482 | 1 |

for, which can lead to faulty significance levels (Clifford et al. 1989). Unfortunately, correcting for spatial autocorrelation among the sample sites was not straightforward since the sample sites were confined to linear channel networks; thus Euclidean distance between sites was not appropriate. Linear networks require special methods in order to calculate spatial autocorrelation (nearest-neighbor-on-a-line), which requires that the distance between each neighboring point be calculated. However, this method was not possible due to the fact that the point locations were overlaid on the channel network, but were not actually a part of the network. Thus, calculating the distance between neighbors must be done manually, which was a daunting task considering the sample size. The end result was that spatial autocorrelation among the sample sites was not accounted for, thus the P values remain suspect. However, the shear size of the sample ($n = 804$), and the high significance levels ($P < 0.01$), provide some measure of confidence in the P values, since larger sample sizes result in a more robust statistic.

### LITTLE COLORADO SUCKER HABITAT SUITABILITY PROFILE

Little Colorado sucker (CASP) was observed at 90 sample sites, within all four focus basins, between 1494 and 2287 m (4902 ft and 7503 ft), in all three stream-types, in 3rd – 7th order channels, and link slope classes less than 5 (Table 3-3, Figure 3-8). Little Colorado sucker was most commonly observed in Chevelon basin (21.5% of sample sites), equally common in Clear and Silver basins (15.7%), and least commonly observed in Lyman basin (4.3% of sample sites). An examination of the museum records did not extend the geomorphic and hydrologic range of CASP.

Table 3-3 Geomorphic and hydrologic range that each native and nonnative species was observed in (habitat suitability profiles) and the number of observations throughout the focus basins

| Species Native | Elevation Range (m) | Elevation Range (ft) | Stream Type Range | Stream Order Range | Link Slope Range % | Occurrence |
|---|---|---|---|---|---|---|
| CASP | 1494 - 2287 | 4900 - 7501 | 1 - 3 | 3 - 7 | 0 - 4 | 90 |
| GIRO | 1704 - 1878 | 5589 - 6159 | 1 - 2 | 5 - 6 | 0 | 8 |
| LEVI | 1493 - 2338 | 4897 - 7669 | 1 - 3 | 3 - 7 | 0 - 3 | 85 |
| ONAP | 2418 - 2933 | 7931 - 9620 | 2 - 3 | 1 - 4 | 1 - 12 | 26 |
| PADI | 1494 - 2890 | 4900 - 9479 | 1 - 3 | 3 - 7 | 0 - 5 | 184 |
| RHOS | 1493 - 2890 | 4897 - 9479 | 1 - 3 | 2 - 7 | 0 - 6 | 330 |
| Species Nonnative | | | | | | |
| AMME | 1495 - 2047 | 4904 - 6714 | 1 - 2 | 5 - 7 | 0 - 2 | 5 |
| AMNA | 1494 - 1677 | 4900 - 5501 | 1 | 7 | 0 - 2 | 11 |
| AMRU | 1486 | 4874 | 1 | 7 | 0 | 1 |
| CAAU | 1592 | 5222 | 1 | 7 | 2 | 1 |
| CYCA | 1486 - 1854 | 4874 - 6081 | 1 | 7 | 0 - 2 | 20 |
| CYLU | 1493 - 1949 | 4897 - 6393 | 1 3 | 5 - 7 | 0 - 1 | 12 |
| FUZE | 1493 - 2109 | 4897 - 6917 | 1 3 | 6 - 7 | 0 - 1 | 5 |
| GAAF | 1857 - 1865 | 6091 - 6117 | 1 | 6 | 0 - 2 | 10 |
| ICPU | 1494 - 2109 | 4900 - 6917 | 1 | 5 - 7 | 0 - 2 | 8 |
| LECY | 1486 - 2244 | 4874 - 7360 | 1 - 3 | 5 - 7 | 0 - 3 | 48 |
| LEMA | 1664 - 2049 | 5458 - 6721 | 1 | 5 - 7 | 0 - 1 | 4 |
| MISA | 1486 - 2049 | 4874 - 6721 | 1 | 5 - 7 | 0 - 1 | 5 |
| NOCR | 1494 - 1967 | 4900 - 6452 | 1 - 2 | 6 - 7 | 0 2 | 14 |
| ONCL | 2243 - 2244 | 7357 - 7360 | 1 | 6 | 0 | 3 |
| ONMY | 1658 - 2811 | 5438 - 9220 | 1 - 3 | 1 - 6 | 0 - 8 11 | 217 |
| PIPR | 1493 - 2837 | 4897 - 9305 | 1 - 3 | 3 - 7 | 0 - 3 5 | 180 |
| SAFO | 2006 - 2981 | 6580 - 9778 | 1 - 3 | 1 - 6 | 0 - 10 | 69 |
| SATR | 1859 - 2885 | 6098 - 9463 | 1 - 3 | 3 - 7 | 0 - 7 9 | 111 |
| STVI | 1987 | 6517 | 1 | 6 | 3 | 1 |

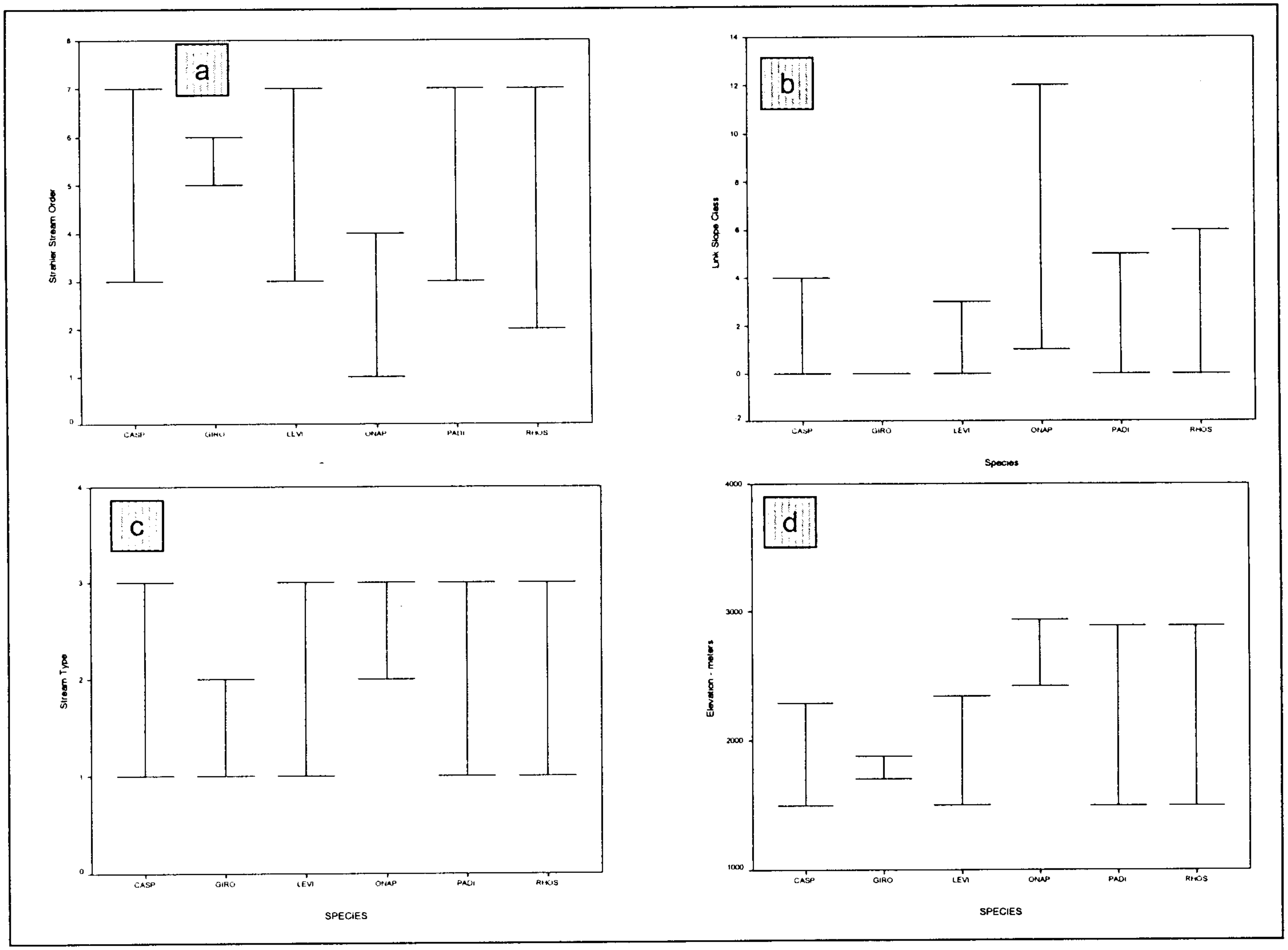


Figure 3·8 Distribution of native fishes for each variable class (all basins combined)

An inter-basin comparison found differences in the geomorphic and hydrologic ranges occupied by CASP (Table 3-4). Little Colorado sucker was only observed in 7th order channels of Silver basin, compared with 5th – 7th orders in Chevelon and Lyman basins, and 3rd – 7th orders in Clear basin. There were also pronounced differences in the range of link slope classes in which CASP was observed; for instance, CASP was only observed in slope classes less than 2 in Silver basin, compared with 0 – 4 in Lyman basin, and 0 - 3 in Chevelon and Clear basins. Regarding stream type, CASP was observed only in perennial waters of Lyman and Silver basins, compared with perennial and intermittent waters of Chevelon basin, and all three classes for Clear basin (see Table 3-4). Concerning elevation, CASP was found in a wide range of conditions, but was conspicuously absent above 1697 m (5568 ft) in Silver basin.

Table 3-4 Range of geomorphic and hydrologic conditions that each target species was observed in, by basin

| basin Name | Species | Stream-type | Strahler order | Link-slope | Elevation Range | N |
|---|---|---|---|---|---|---|
| Chevelon | CASP | 1 - 2 | 5 - 7 | 0 - 3 | 1494 - 2056 | 20 |
| | GIRO | 1 - 2 | 5 - 6 | 0 | 1704 - 1878 | 7 |
| | LEVI | 1, 3 | 7 | 0 - 1 | 1493 - 1530 | 5 |
| | PADI | 1 - 2 | 5 - 7 | 0 - 1 | 1494 - 1878 | 6 |
| | RHOS | 1 - 3 | 4 - 7 | 0 - 3 | 1493 - 2257 | 34 |
| | SATR | 1,3 | 4 - 5 | 0 - 4 | 1878 - 2281 | 26 |
| Clear | CASP | 1 - 3 | 3 - 7 | 0 - 3 | 1527 - 2199 | 43 |
| | GIRO | 2 | 6 | 0 | 1751 | 1 |
| | LEVI | 1 - 3 | 3 - 6 | 0 - 3 | 1990 - 2207 | 19 |
| | PADI | 1 - 3 | 3 - 6 | 0 - 3, 5 | 1826 - 2199 | 91 |
| | RHOS | 1 - 3 | 2 - 6 | 0 - 5 | 1751 - 2242 | 186 |
| | SATR | 1 - 2 | 4 - 6 | 0 - 2 | 1859 - 2170 | 18 |
| Lyman | CASP | 1 | 5 - 7 | 0 - 2, 4 | 1829 - 2287 | 16 |
| | LEVI | 1 | 5 - 7 | 0 - 2 | 1832 - 2338 | 52 |
| | ONAP | 2 - 3 | 1, 3 - 4 | 1 - 12 | 2418 - 2933 | 26 |
| | PADI | 1 | 3 - 7 | 0 - 4 | 1829 - 2890 | 77 |
| | RHOS | 1 | 3 - 7 | 0 - 6 | 1829 - 2890 | 97 |
| | SATR | 1 | 3 - 7 | 0 - 9 | 2039 - 2885 | 62 |
| Silver | CASP | 1 | 7 | 0 - 1 | 1585 - 1697 | 11 |
| | LEVI | 1 | 7 | 0 - 1 | 1589 - 1603 | 9 |
| | PADI | 1, 3 | 5 - 7 | 0 - 3 | 1592 - 1871 | 10 |
| | RHOS | 1, 3 | 4 - 6 | 0 - 1, 3 | 1859 - 2071 | 13 |
| | SATR | 1 | 5 - 6 | 0 - 3 | 1975 - 2049 | 5 |

Figures 3-9-a-d show the standardized (relative) occurrence of CASP for each variable class. An exponential relationship between CASP occurrence and stream order became evident (Figure

3·9·a). There were no sightings of CASP in 1st – 2nd order channels, less than 10 percent occurrence in 3rd – 5th order channels, increasing to 18.5 percent in 6th order channels, and 58 percent in 7th order channels. In relation to channel link slope, an inverse exponential relationship between CASP occurrence and channel slope became apparent (Figure 3·9·b). For instance, 24 percent of sample sites with a link slope class of zero observed CASP, decreasing to 11.3 percent for a slope class of 1, and 2 percent occurrence in slope class 4. The lack of CASP observations above slope class 4 might represent a gradient threshold for this species, or an extirpation zone. Concerning stream type (Figure 3·9·c), 13.3 percent of perennial sample sites observed CASP, 14.6 percent of intermittent sample sites observed CASP, while only 3.1 percent of ephemeral sample sites observed CASP. It is interesting to note that more CASP were observed in intermittent-coded sample sites than perennial. In relation to elevation (Figure 3·9·d), CASP occurrence was inversely related to the elevation classes; 54.5 percent of sample sites observed CASP in elevation class 1 (1371 m - 1524 m, 4498 ft - 5000ft), then a steady decrease in CASP occurrence, with only 1.5 percent occurrence in class 7 (2286 m - 2438 m, 7500 ft - 7999 ft).

### LITTLE COLORADO SPINEDACE HABITAT SUITABILITY PROFILE

Little Colorado spinedace (LEVI) was observed at 85 sample sites, within all four focus basins, between 1493 and 2338 m (4898 - 7671 ft) elevation, within all three stream types, in stream orders 3 – 7, and link slope classes less than 4 (see Table 3·3). Little Colorado spinedace was most commonly observed in Lyman and Silver basins (14.2 and 12.9% of sample sites, respectively), and less commonly in Clear and Chevelon basins (6.9 and 5.4%, respectively). An examination of the museum records did not extend the geomorphic and hydrologic range of LEVI.

An inter-basin comparison found large differences in the ranges of stream order, elevation, and stream types occupied by LEVI (see Table 3·4). For instance, within Chevelon and Silver basins, LEVI was only observed in 7th order channels, and only at five and nine sample sites, respectively. Clear basin had the largest range of observations by stream order, with LEVI found in 3rd – 6th order channels. Within Chevelon, Lyman, and Silver basins, LEVI was predominantly found in perennial waters, but found mainly in intermittent waters within Clear basin. Once again, this discrepancy may be real, but might be related to an inaccurate GIS stream-type cover (i.e. there may be perennial or interrupted-perennial waters that were classified as intermittent). The very small range in elevation that LEVI was observed within Chevelon and Silver basins is probably due to their limited distribution within these basins; indeed, it is possible that LEVI is close to extirpation within these basins, but more investigation needs to be conducted. Regarding elevation, the lack of LEVI observations above 2338 m (7671 ft) might represent a temperature threshold for this species, or a zone of extirpation.

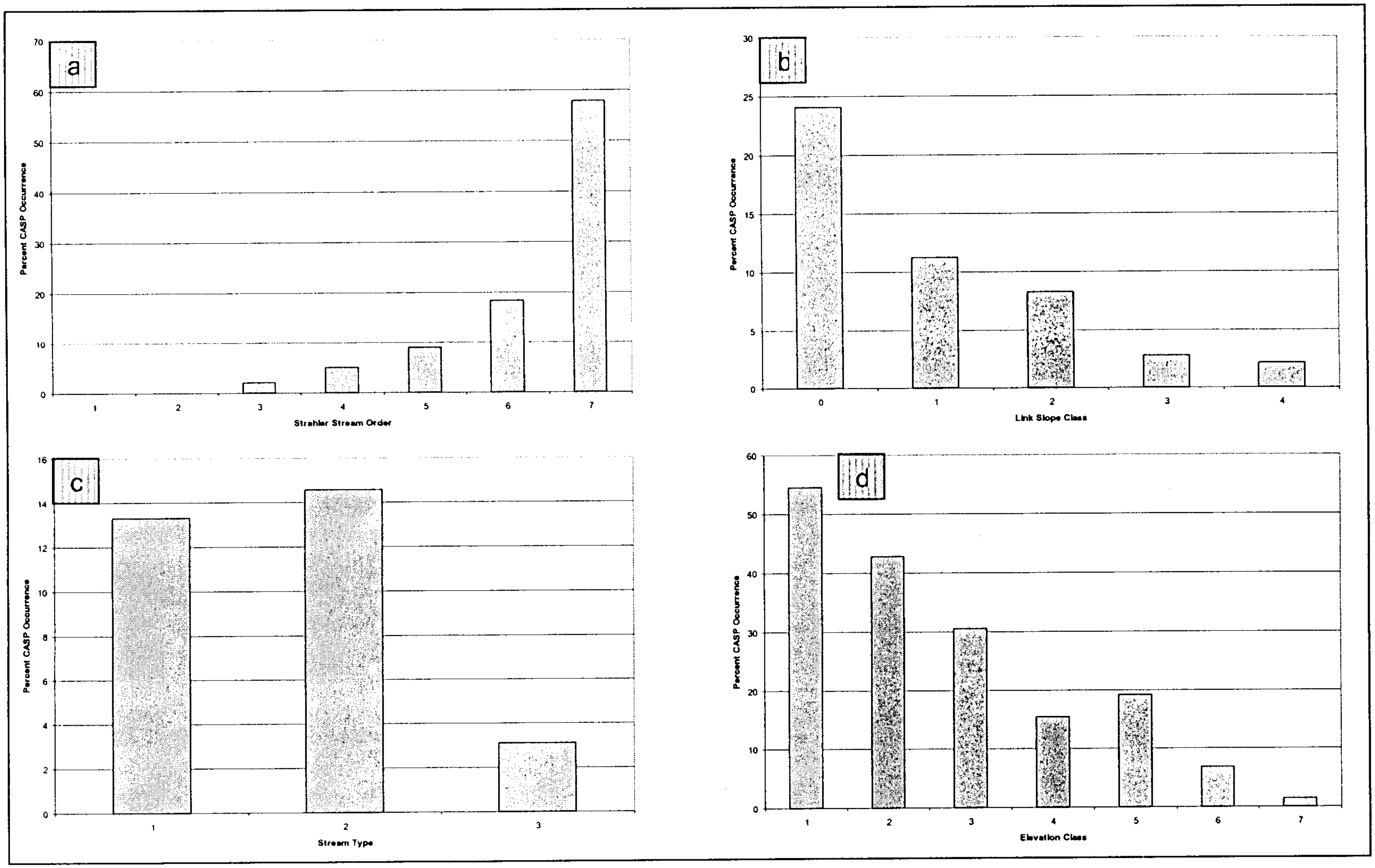


Figure 3-9 Relative occurrence of CASP for each variable class; data standardized by sample site frequency

Figures 3·10·a-d show the standardized (relative) occurrence of LEVI for each variable class. There was a clear exponential relationship between LEVI occurrence and stream order (Figure 3·10·a). In fact, LEVI's relative occurrence pattern was very similar to CASP, with no observations in $1^{st}$ – $2^{nd}$ order channels, then exponentially increasing in the $3^{rd}$ – $7^{th}$ order channels. In $3^{rd}$ order channels LEVI was only observed in 1.4 percent of the sample sites, increasing steadily to 42 percent occurrence in $7^{th}$ order channels. Concerning channel link slope (Figure 3·10·b), LEVI showed an inverse relationship, where 18.2 percent of sample sites observed LEVI in slope class 0, then decreasing steadily to 1.8 percent occurrence in slope class 3. The lack of observations of LEVI above slope class 3 might represent a channel gradient threshold, or a zone of extirpation.

In regards to hydrology (Figure 3·10·c), there was an inverse relationship with rate of LEVI occurrence; LEVI was observed at 16 percent of the perennial sample sites, 8 percent at intermittent sample sites, and 1.6 percent occurrence at ephemeral sample sites. Regarding elevation, the only clear pattern that emerged was that LEVI was most commonly observed in elevation classes 1 – 2 (1372 m - 1676 m, 4501 ft - 5499 ft), then a decline (although not steady) down to elevation class 7 (2286 m – 2438 m, 7500 ft - 7999 ft), with none observed above class 7. There were two interesting patterns worth noting. First, the almost complete lack of observations in elevation classes 3 – 4 (1676 m - 1981 m, 5499 ft - 6499 ft), and no observations above class 7. While there was no explanation for the scarcity of LEVI sightings in elevation classes 3 – 4, class 7 might represent a temperature threshold for LEVI, or a zone of extirpation. While elevation classes 3 and 4 were proportionately under-sampled (Figure 3·5·d), this did not explain the scarcity of LEVI in those classes.

### Bluehead Sucker Habitat Suitability Profile

Bluehead sucker (PADI) was observed at 184 sample sites, within all four focus basins, between 1494 and 2890 m (4902 and 9482 ft) elevation, within all three stream types, stream orders 3 - 7, and link slope classes less than 6 (see Table 3·3). Bluehead sucker was most commonly observed in Clear and Lyman basins (33.2 and 21.0% of sample sites, respectively), and least common in Chevelon (6.4%) and Silver basins (14.3%). An examination of the museum records did not extend the geomorphic and hydrologic range of PADI.

An inter-basin comparison found large differences in the ranges of stream order, elevation, and stream types occupied by PADI (see Table 3·4). In some respects, PADI was found at sample sites with similar physical characteristics as LEVI and CASP were found, except PADI was also found at higher elevations and slightly steeper channels. For the most part, PADI was only observed in perennial waters within Chevelon, Lyman, and Silver basins, but found often in intermittent and ephemeral-coded channels within Clear basin. This pattern suggested that either the Clear basin stream type cover has errors, or native fishes are more adept at exploiting a wider range of hydrologic conditions within Clear basin.

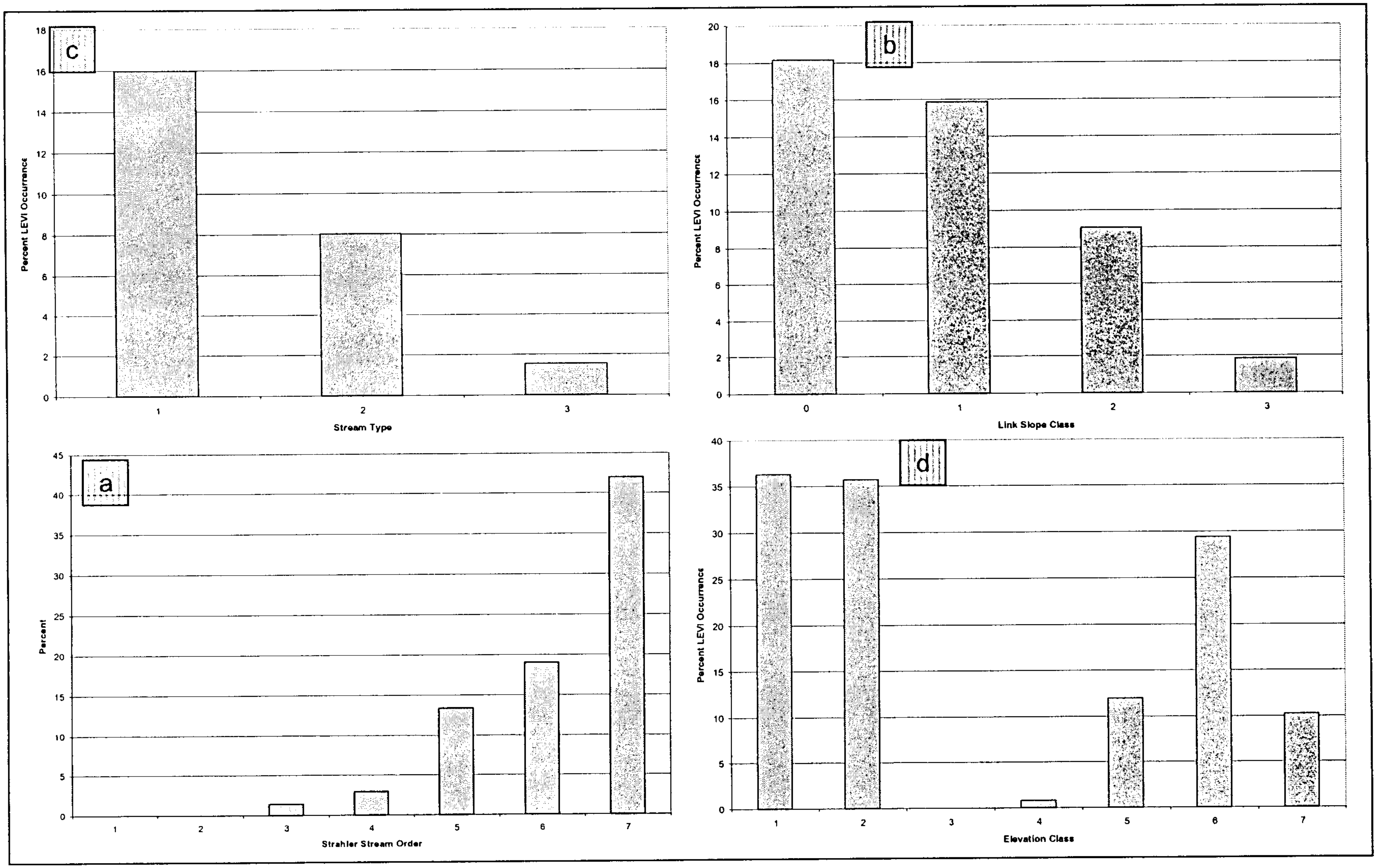


Figure 3·10 Relative occurrence of LEVI for each variable class; data standardized by sample site frequency

Figures 3·11·a-d show the standardized occurrence of PADI for each variable class. Bluehead sucker occurrence increased as stream order increased (Figure 3·11·a), but unlike LEVI and CASP, this relationship was not exponential or predictable. Bluehead suckers were not observed in $1^{st}$ – $2^{nd}$ order channels, and less than 15 percent of the $3^{rd}$ - $4^{th}$ order sample sites observed PADI. In contrast, PADI was observed in over 30 percent of $5^{th}$ – $7^{th}$ order channels. In relation to channel link slope (Figure 3·11·b), PADI occurrence was generally inverse to link slope, except for slope class 1, which had a higher occurrence rate than slope class 0. Sample sites within slope classes 3 - 5 observed PADI less than 11 percent of the time, while sample sites with slope classes less than 3 had between a 19.7 to 42 percent occurrence.

In relation to stream type (Figure 3·11·c), PADI occurrence declined as water permanence declined, with 32.5 percent of perennial sample sites observing PADI, 18.6 percent of intermittent sample sites, and only 6.8 percent of ephemeral sample sites. Regarding elevation (Figure 3·11·d), PADI had a strong showing in elevation classes 1 – 10 (1372 m - 2896 m, 4501 ft - 9501 ft), except for a lack of observations in classes 8 – 9 (2438 m - 2743 m, 7999 ft - 2743 ft). The lack of PADI observations in classes 8 – 9 was not explained by sample site distribution since there was a disproportionately high sample rate within those classes (Figure 3·5·d).

### SPECKLED DACE HABITAT SUITABILITY PROFILE

Speckled dace (RHOS) was observed at 330 sample sites and within all four focus basins, making RHOS the most widely distributed and common native fish within the study area (see Table 3·4). Speckled dace was found between 1493 m and 2890 m (4898 ft and 9482 ft) elevation, within all three stream types, stream orders 2 – 7, and link slope classes 0 – 6 (see Table 3·3). The only other native fish found to inhabit $2^{nd}$ order channels, or greater than 5.5 percent link slope, was Apache trout. Speckled dace was most commonly observed in Clear basin (67.9% of sample sites), less common in Chevelon basin (36.6%), and least commonly observed in Silver and Lyman basins (18.6 and 26.4%). An examination of the museum records did not extend the geomorphic and hydrologic ranges of RHOS.

An inter-basin comparison found differences in the geomorphic and hydrologic ranges of RHOS (see Table 3·4). For instance, RHOS was observed in channel orders 2 - 6 in Clear basin, orders 3 - 7 in Lyman basin, and above $3^{rd}$ order in Silver and Chevelon basins. Some of the discrepancies were easily explained, like the lack of sample sites below $4^{th}$ order in Chevelon and Silver basins (Figure 3·7·a) explained lack of RHOS occurrence in those orders. Concerning elevation, RHOS occupied a large range of elevations, although not equally between basins. Regarding channel link slope, RHOS was found in a range of slope classes similar to CASP, LEVI, and PADI, except for a slightly higher upper end (Figure 3·8).

Figures 3·12·a-d show the standardized relationships between RHOS occurrence and the four variable classes. There was a clear pattern of increasing RHOS occurrence as stream order increased (Figure 3·12·a), but unlike the other native species, RHOS appeared to diminish

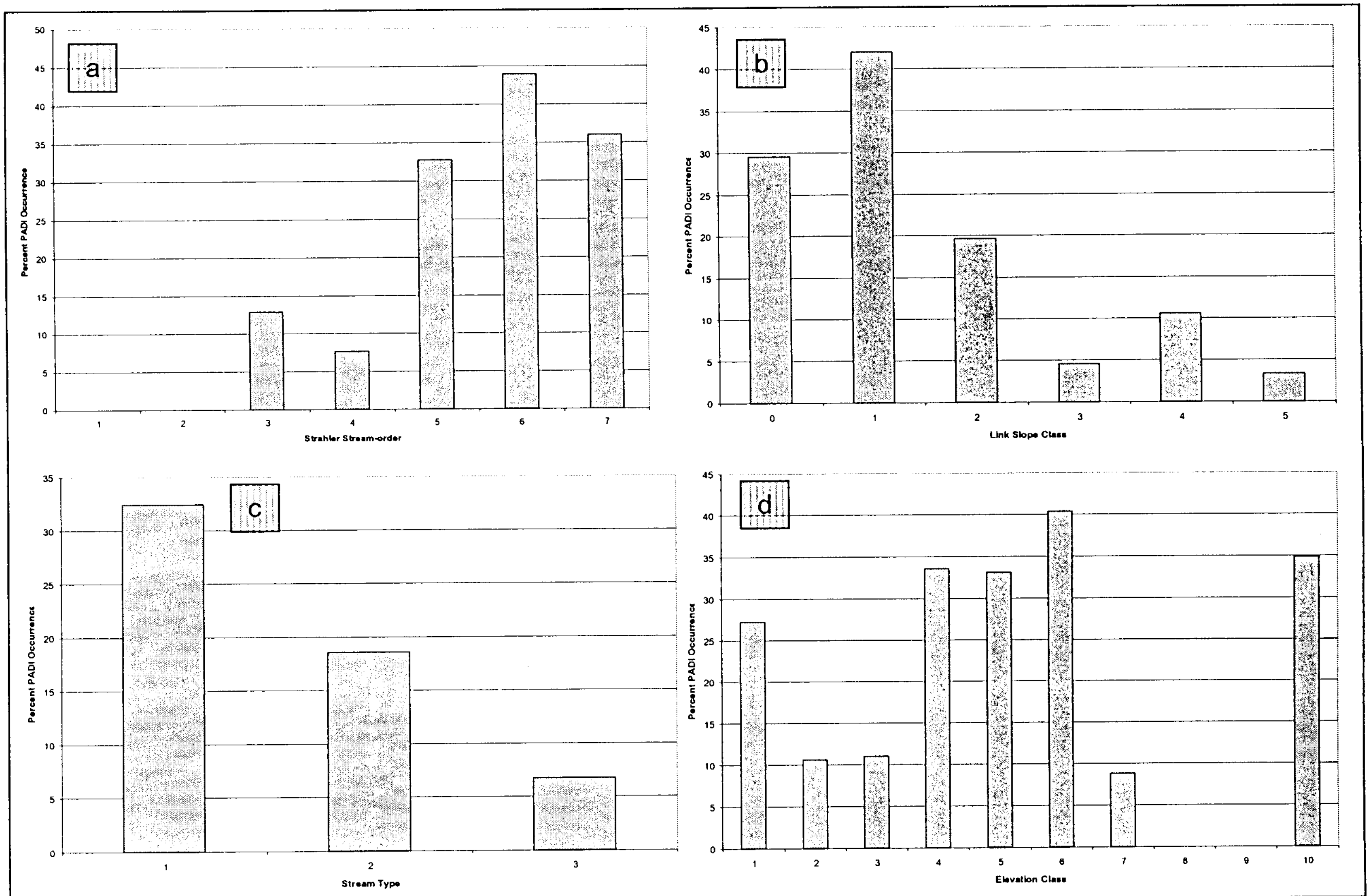


Figure 3-11 Relative occurrence of PADI for each variable class; data standardized by sample site frequency

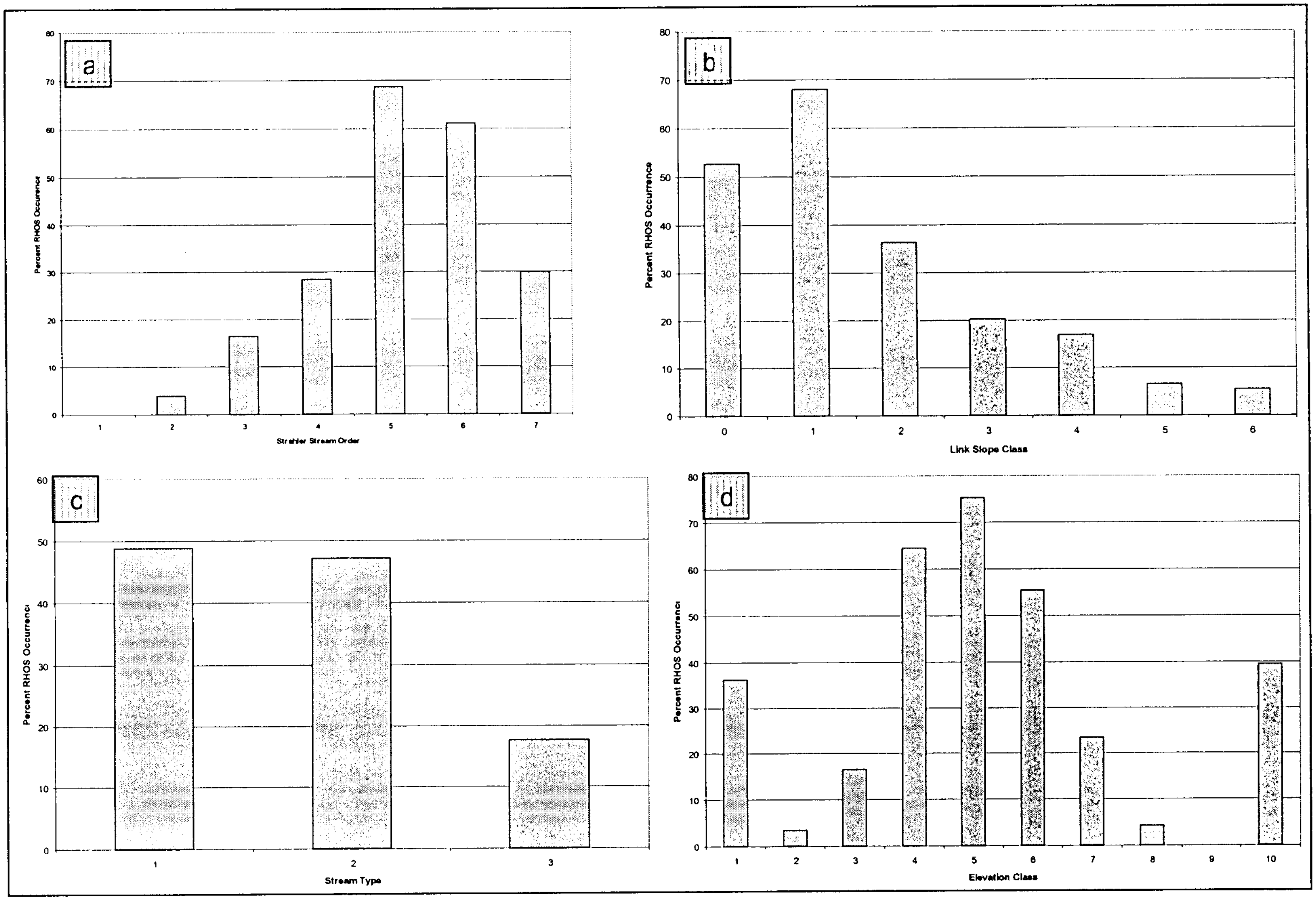


Figure 3-12 Relative occurrence of RHOS for each variable class; data standardized by sample site frequency

steadily in frequency after stream order 5. Speckled dace was observed in 2nd – 7th order channels, with only a 4 percent rate of occurrence in 2nd order sample sites, increasing steadily to 68.8 percent occurrence in 5th order sample sites, then decreasing to 30 percent occurrence in 7th order sample sites. The bell-shaped occurrence rate for RHOS might represent a preference for the middle-order channels, but testing of this hypothesis is required.

Concerning channel link slope (Figure 3·12·b), RHOS occurrence showed an inverse relationship with channel slope, with the exception of slope class one, which had greater RHOS occurrence than slope class 0. Speckled dace occurred between 52.7 and 68.2% of the time in slope classes 0 and 1, respectively, then trailed off steadily to only 5.6% occurrence in slope class 6. Regarding stream type (Figure 3·12·c), RHOS had an equally strong showing in intermittent versus perennial waters (47.2% and 48.9%, respectively), and a 17.7% rate of occurrence in ephemeral waters. The relatively high rate of RHOS occurrence in ephemeral waters was twice as high as the other natives, which suggested an increased tolerance to ephemeral waters. Concerning elevation (Figure 3·12·d), RHOS had an inconsistent but strong showing for elevation classes 1 – 10 (1372 m - 2896 m, 4501 ft - 9501 ft), with the exception of class 9 (2591 m - 2743 m, 8501 ft - 8999 ft), where they were absent. There was an increased likelihood of observing RHOS in the middle elevation classes, with a 75.3 percent rate of observation in elevation class 5 (1981 m - 2134 m, 6499 ft - 7001 ft), compared with a 36.4 and 39.5 percent rate of occurrence in elevation classes 1 and 10.

### Roundtail Chub Habitat Suitability Profile

Roundtail chub (GIRO) was observed in only two of the four focus basins, at eight sample sites. Seven of the sample sites where GIRO was observed are in Chevelon basin, and one is in Clear basin. Roundtail chub was observed between 1704 m (5590 ft) and 1878 m (6161 ft), in perennial and intermittent waters, in 5th – 6th order channels, and in link slope class zero (see Table 3·3). An examination of the museum records did not extend the range in which GIRO was observed. The very narrow range in physical conditions and locations that GIRO was observed emphasized how rare it is, appearing perilously close to extirpation in the four focus basins. Also, the lack of GIRO in lower-order channels suggested that either it has been extirpated from those sites, or it has a preference for larger channels. The small number of sample sites where GIRO was observed made the development of a habitat suitability model inappropriate.

### Apache Trout Habitat Suitability Profile

Apache trout (ONAP) was observed at 26 sample sites, but only within Lyman basin (see Table 3·4), making ONAP the only native fish species confined to a single focus basin. Apache trout was found between 2418 – 2933 m (7933 - 9623 ft) elevation, in intermittent and ephemeral channels, in stream orders 1 – 4, and link slope classes 1 – 12 (see Table 3·3). Apache trout was the only native species found in 1st order channels, above 6 percent link slope, or above 2,896 m (9501 ft) elevation. An examination of the museum records did not extend the range in which

ONAP was observed. The small number of sample sites where ONAP was observed made the development of a habitat suitability model inappropriate.

### Native Fish Community Habitat Suitability Profile

There was considerable overlap among the geomorphic ranges that the native fishes were observed in (see Table 3·3; see Figure 3·8). Little Colorado sucker, LEVI, PADI, and RHOS, were all observed in 3rd – 7th order channels, between 1,494 m – 2,287 m (4900 - 7501 feet), in all three stream types, link slope classes 0 – 3, and in all four focus basins. Roundtail chub and ONAP were so limited in distribution that it was difficult to include them in the analysis. It is noteworthy, however, that GIRO was only observed within the geomorphic envelope of the before mentioned group.

### Habitat Suitability Models

Using the information from Table 3·3, ARC GRID extracted all potentially suitable habitats (cells) for CASP (Figure 3·14), LEVI (Figure 3·15), PADI (Figure 3·16), and RHOS (Figure 3·17), within the focus basins. In general, CASP and LEVI habitat suitability models looked very similar, with the exception of more potentially suitable habitat for LEVI in higher elevations. In comparison, the higher elevations where PADI was observed resulted in a large increase in potentially suitable habitat within Lyman basin. Lastly, RHOS, which was found in the widest range of geomorphic conditions, has the greatest amount of potentially suitable habitats within the focus basins. Figure 3·18 shows all potentially suitable habitats for a native fish community assemblage composed of LEVI, PADI, RHOS, and CASP; the upper elevation zone of potentially unsuitable habitat at the 2,287 m contour (7,501 feet) showed clearly in Lyman basin.

## Discussion

### Interpretation and Utility of Models

The habitat suitability models are essentially geographic envelopes that encompass all areas having similar geomorphic and hydrologic conditions as the sample sites that contained target species. However, the habitat suitability models do not discriminate among the ranges of geomorphic and hydrologic conditions within the envelope. For instance, the standardized data presented in Figures 3·9 - 3·12 show clear patterns among variable classes and species relative occurrence, but the models do not reflect this. Therefore, another descriptor for the habitat suitability models is unweighted models, since they show all areas of potentially suitable habitat, but don't show the most likely areas of occurrence within the envelope. Weighted models were not developed since the models have no statistical basis and the weights could be misinterpreted. However, the relative frequency histograms can be used to interpret the models and identify the most likely areas of occurrence for each target species.

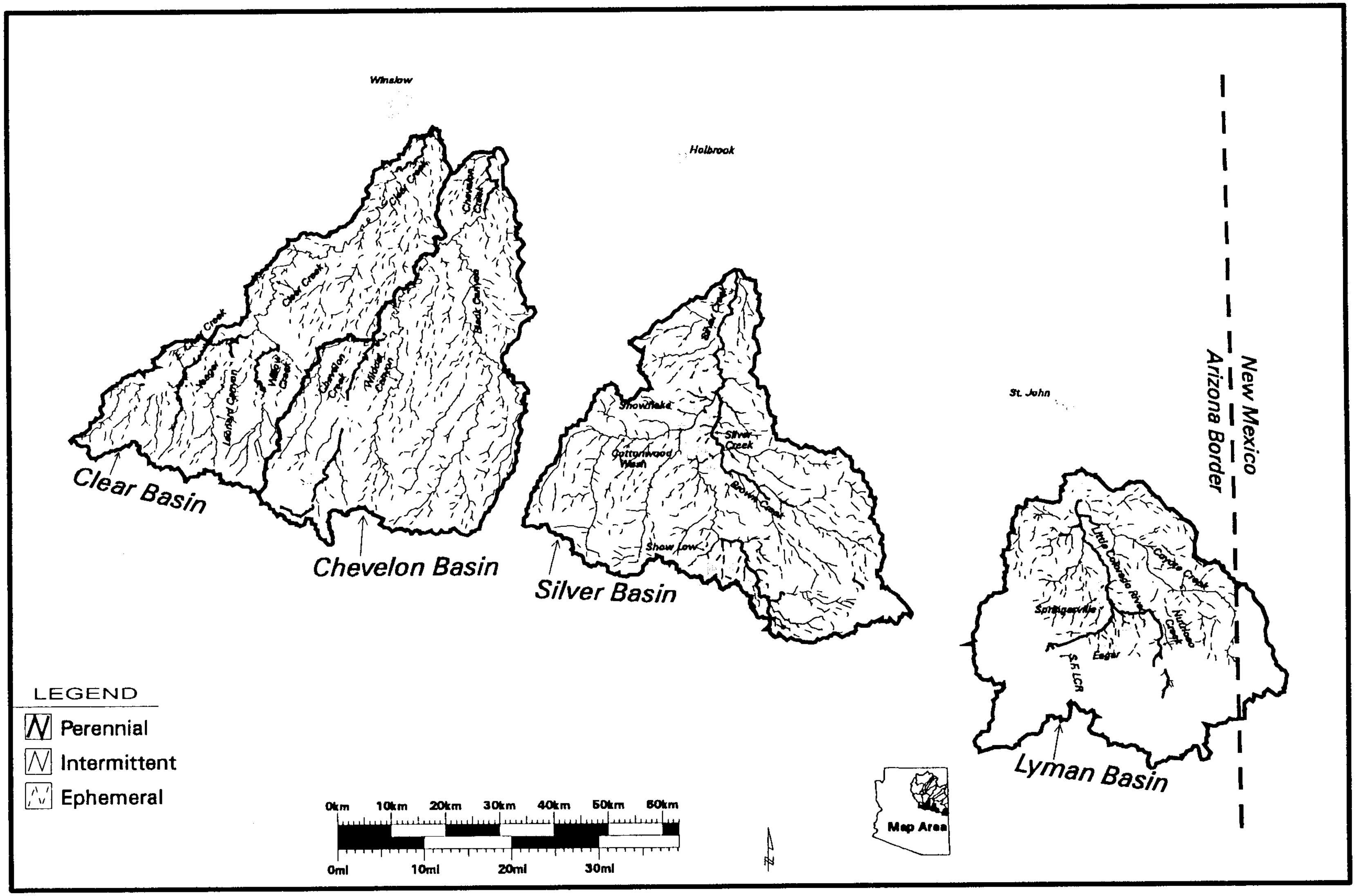


Figure 3·13 Potentially suitable habitats for Little Colorado sucker within the focus basins; habitats partitioned by stream type

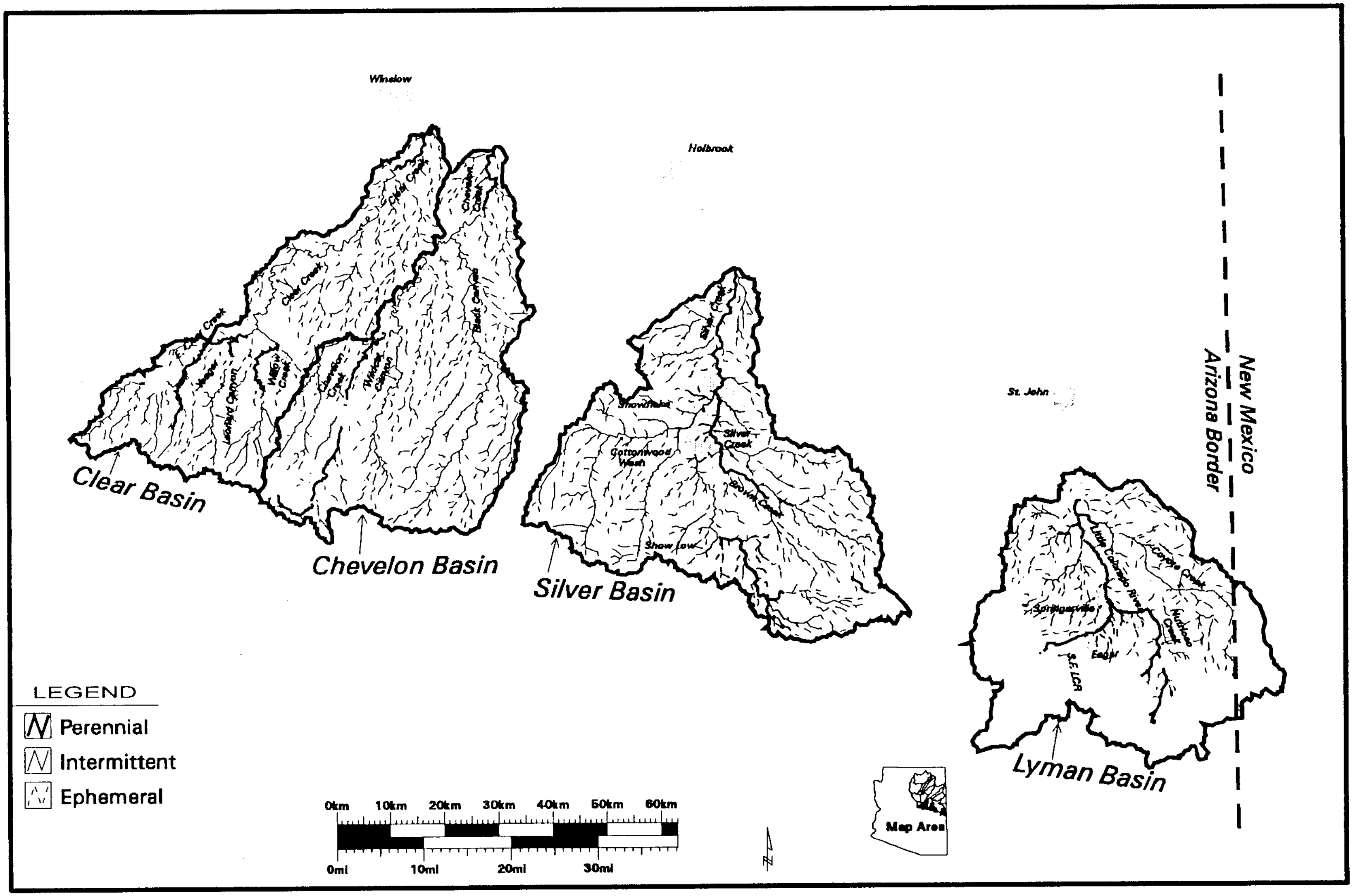


Figure 3·14 Potentially suitable habitats for Little Colorado spinedace within the focus basins; habitats partitioned by stream type

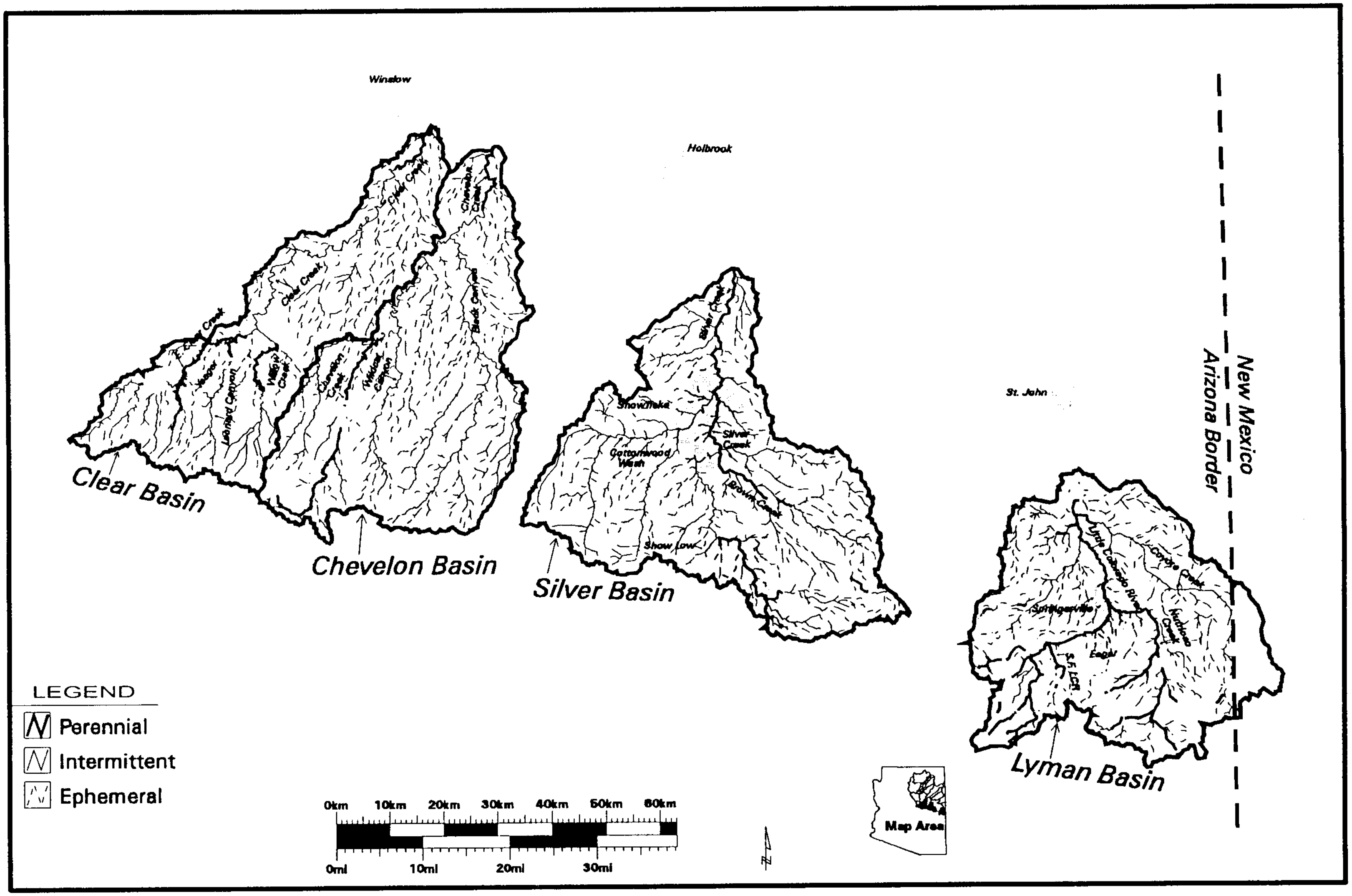


Figure 3-15 Potentially suitable habitats for bluehead sucker within the focus basins; habitats partitioned by stream type

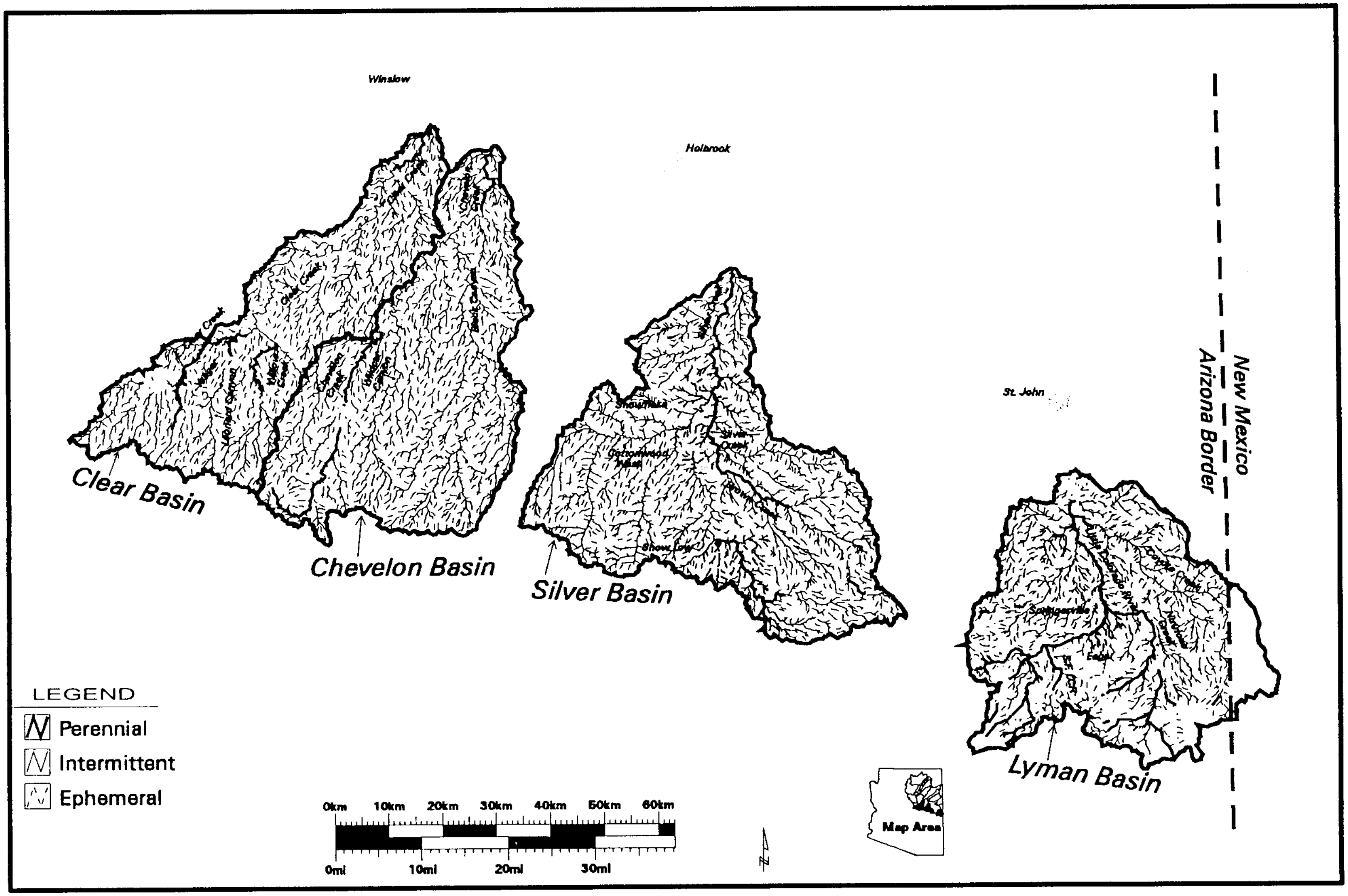


Figure 3-16 Potentially suitable habitats for speckled dace within the focus basins; habitats partitioned by stream type

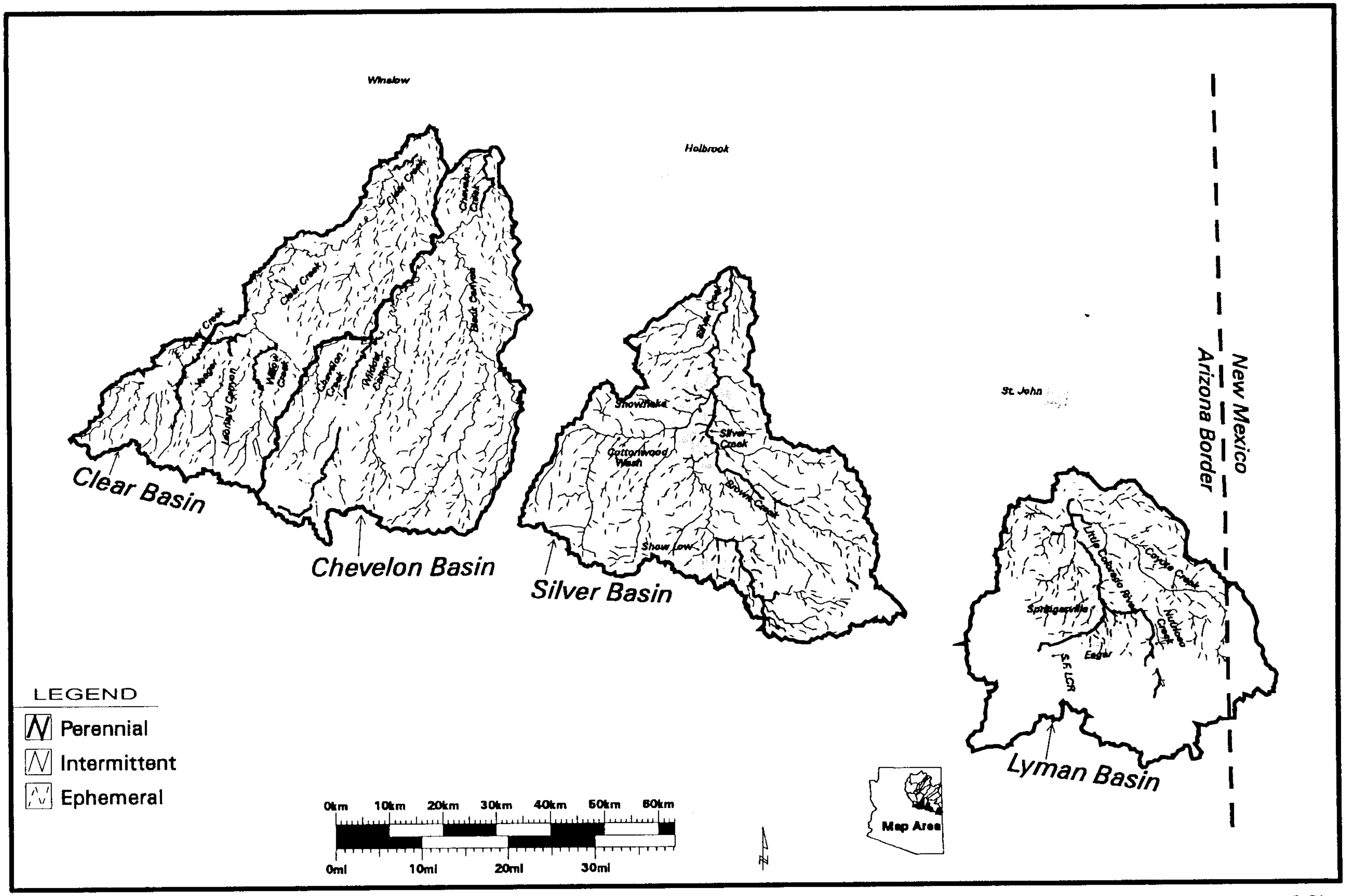


Figure 3-17 Potentially suitable habitats for a native fish community assemblage (CASP, LEVI, PADI, RHOS)

The habitat suitability models are reflective of the geomorphic and hydrologic conditions that each target species was observed in, and each of the four physical variables influenced the range of potentially suitable habitats. For instance, Strahler stream order affects the total length of channel extracted, since channel length decreases exponentially with increasing order (Figure 3·6). Thus, it is not surprising that RHOS has the greatest range of potentially suitable habitats (Figure 3·17), since it was observed in the widest range of channel orders and slopes (see Table 3·3). In contrast, CASP (Figure 3·14) has the smallest range of potentially suitable habitats, since it was found in the lowest channel slope and elevation classes.

The habitat suitability models have immediate utility for conflict resolution between native and sportfishes within the LCR watershed, defining the geographic boundaries where potentially suitable habitats exist for target species. For instance, CASP and LEVI showed a clear elevation boundary (Figure 3·8·d) above which they were not observed (2287 m and 2338 m, 7503 ft and 7671 ft, respectively). In addition, once sample-effort was controlled (standardized), patterns emerged in the data that suggested geomorphic preferences, or residual populations of native fishes (i.e. CASP/LEVI occurrences were exponentially related to stream order and inversely to channel link slope). The geographic envelopes that the habitat suitability models display are potentially suitable areas for: 1) channel restoration or enhancement; 2) native fish repatriation areas, and 3) native fish management zones.

Another benefit of the habitat suitability models is the hypotheses they help generate concerning the distribution patterns of native and nonnative fishes. For instance, there are large portions of the focus basins that are devoid of native fishes, but the models predict are potentially suitable habitats. A good example is the absence of spinedace above 1593 m (5226 ft) in Silver basin (see Table 3·4); there is a long stretch of perennial habitat along Silver Creek that the model predicts is suitable - perhaps if sample effort were increased, LEVI would be detected. Another hypothesis is that land use activities within Silver basin have impacted the LEVI population, leading to scarcity or extirpation. There are dozens of hypotheses the models help generate, one only has to look at the maps and figures presented in this paper to begin the process of discovery.

### Limitations of Native Fish Habitat Suitability Models

There are limitations and weaknesses associated with the habitat suitability models and caution needs to be employed in their uses. For instance, the stream type cover used in model development appears useful in the sense that there were obvious patterns among the three stream type classes and the target species' occurrence rates (see Figures 3·9·c – 3·12·c). However, in areas of Clear and Chevelon basins, fisheries personnel have identified interrupted-perennial reaches that are currently coded as ephemeral or intermittent. For clarification, the AGFD perennial and intermittent stream coverages were developed for riparian vegetation inventories, and the main criteria were seasonal. There was a minimum stream length criterion of 0.8 km (0.5 mi.) required before a perennial or intermittent stream segment was mapped (Valencia and others 1993), therefore, the spatial resolution of these covers is 0.8 km. While a minimum mapping unit of 0.8 km might be sufficient for riparian vegetation inventories, it appears somewhat limited for fisheries inventories. As more field inventories are performed in the study area, more interrupted-perennial stream reaches are being discovered and reclassified. This has important implications for management, and model development, since the permanent pools act as fish refugia during summer lowflow periods, areas that the fish can migrate from when higher flows return.

The lack of an interrupted-perennial class, and low spatial resolution, helped explain why some of the ephemeral-coded sample sites (which was the default stream type) had such good sightings of fish, since there may actually have been permanent pools in the vicinity. It is equally likely that many of the perennial-coded reaches were spatially discontinuous, with intermittent and ephemeral reaches interspersed. Until a better GIS hydrology coverage is developed, the current one should be used with caution.

Another weakness of the habitat suitability models was the DEM data obtained from the USGS. Not all DEMs had the same vertical accuracy standards or cell resolutions, which caused errors when extracting channel networks or calculating channel link slopes. Indeed, some DEMs had vertical errors of 3 m (10 ft), while others had only 1 m (3 ft) error. Vertical errors undoubtedly resulted in errors in channel link slope, channel extraction, sink filling and removal, etc. Fortunately, the quality of DEMs is rapidly increasing as the USGS completes an overhaul of its spatial data, which should result in decreased vertical error and increased cell resolution.

Another problem with the habitat suitability models is the fact that the 804 sample sites used for model development were not randomly selected, and are clumped or sparse throughout the focus basins (see Figure 3-3). Deficiencies in the sampling design unquestionably impacted the habitat suitability models in undesirable and unpredictable ways; therefore, the habitat suitability models should be viewed as potentially suitable habitat versus suitable habitat. A good example of the inequitable sampling regime is the lack of sample sites in $1^{st}$ – $3^{rd}$ order channels in Silver and Chevelon basins. It is possible that if some of the lower order channels had been sampled, then the current habitat suitability profiles and models for the target species would be different. Indeed, the under-representation of some habitat types necessitates that the current geographic boundaries of the models be viewed as minimum extents, which could expand if representative sampling occurred in each basin.

One last issue to consider - the models were built with information derived from the current distribution of native fishes. However, the distribution of native fishes have been impacted by the following: 1) nonnative fishes, 2) land use activities, 3) groundwater withdrawal, diversion, and impoundment, 4) unwise logging and grazing activities, and 5) chemical renovations. All of those activities unquestionably impacted the native fishes, resulting in extirpation or scarcity. Thus, the habitat suitability models present potentially suitable habitats derived from an impacted landscape, resulting in conservative models. This has serious consequences for fisheries managers, because areas outside of the modeled boundaries might also be suitable. Conversely, there are areas within the suitable habitat envelopes are likely to be unsuitable, especially considering the fact that the spatial resolution of the hydrology cover was 0.8 km (0.5 mi). This undoubtedly resulted in an overstatement of the potentially suitable habitats within the envelopes. Having stated the model limitations, perhaps the best description of the models is that they are liberal internally, but conservative externally.

### VARIABLE CHARACTERIZATION AND ACCURACY ASSESSMENT

In order to characterize the variability in the four physical variables (link slope, elevation, stream type, and stream order), additional work in the field is required. Of paramount importance is whether the GIS modeling produces consistent and reliable models, and what the range of natural variability is within each variable class. For example, what is the variance in the channel widths associated with each stream order, how much spatial error is associated with the stream type coverage (i.e. are perennial reaches continuous or interrupted), how much slope variation exists within a channel slope class, and how accurate are the channel networks extracted from the DEMs. A full assessment of the variables is lacking, but preliminary work is encouraging. For instance, only a small range of overlap exists (20 – 50 m, 66 - 164 ft, on average) between the channel network extracted from the DEMs, and the statewide ASLD Hydro cover. Furthermore, there is close agreement between the modeled basin divides and the hydrologic divides obtained from the ASLD hydrologic unit divide (HUC) coverage (< 3.0% difference in area). For clarification, a certain amount of spatial offset is inevitable between modeled and digitized products, since both methods produce spatial error unique to the source data and techniques employed. Higher resolution DEMs (10 m, 33 ft) will produce the least error, but they are only available for a small portion of the state.

The habitat suitability models need accuracy assessments conducted to determine the following: 1) agreement between potentially suitable habitats displayed on the maps and ground-truth data (channel slope, stream type, elevation, channel order), and 2) agreement between habitat suitability models and target fish presence for areas not previously sampled. Each one of these accuracy assessments has a unique set of challenges and problems associated with its implementation and interpretation. There are actually three types of accuracy that need to be determined in an accuracy assessment (Story and Congalton 1986): 1) overall accuracy, 2) producer's accuracy, and 3) user's accuracy. Overall accuracy represents the accuracy of the overall product (the map), but it does not indicate how the accuracy is distributed across the individual classes (for example, perennial, intermittent, or ephemeral). In contrast, producer's accuracy examines errors of omission, i.e., something is on the ground that is not on the map. Lastly, user's accuracy examines errors of commission, i.e., something is on the map but is not on the ground.

Conducting an accuracy assessment of the biological aspects of the habitat suitability models is not straightforward, since native fish distributions and abundance have been impacted by detrimental land use and management activities. For instance, stream renovation (poisoning of fishes) was fairly common in some areas, resulting in extirpation of native fishes from numerous stream reaches. Presence of nonnative fishes, along with water-intensive land use activities, also lead to extirpation or scarcity of native fishes. Therefore, if a native fish is not observed in a location that is predicted suitable (error of commission), the habitat may still indeed be suitable.

Ideally, each one of the three types of accuracy/error should be quantified, so the models and maps have an accuracy assessment associated with them.

Another consideration is the additive effects of spatial error that results when analyzing two or more data layers together (Walsh and others 1987). The effects of combining multiple grids for data extraction purposes may contribute more error than if a single layer was used for model creation. However, the grid environment is the best possible since the cells of all grids extracted from a master DEM are georeferenced. Ultimately, the amount of spatial error introduced by cell-based modeling will have to be assessed at different scales in order to determine if they are acceptable or not. Spatial errors of 50 m (164 ft) might be inconsequential at a basin-scale, but might be grounds for concern at the reach-scale. Unfortunately, accuracy assessments of the habitat suitability models will take a small study and probably most of a field season in order to produce. As of yet the money and time have not been allocated for determining the accuracy of the GIS products, so model accuracies will remain unknown until this is done. Therefore, cautious use of the models is suggested, especially since the individual and combined error components have not been assessed.

In spite of the unquantified error associated with the cell-based models, their usefulness for fisheries managers and scientists is still considerable. The strong patterns in the standardized data provide insight into the biology of the native fishes. One of the most notable examples is the exponential relationship between LEVI occurrence and channel order (see Figure 3·10·a). An exponential relationship is rarely accidental in nature, and will likely to hold up under increased scrutiny. Until a more involved study is conducted, it is prudent to suspect that these are indeed important habitats for LEVI, as well as the other native fishes.

### Other Potential Variables

The habitat suitability models are derived from four physical variables, but could probably be improved with the inclusion of biotic and land use variables. The Normalized Difference Vegetation Index (NDVI), which is correlated with density and biomass of vegetation (Jensen 1983), is a candidate variable since streamside riparian vegetation (density and width) correlated with trout biomass in the study area (Clarkson and Wilson 1995). In addition, land use variables such as the percentage of basin covered with roads, the amount of logging or grazing activities, or the amount of agriculture within a basin, might also prove useful in helping to explain the presence or absence of native fishes. There are undoubtedly many other biotic and land use variables that could prove useful for fisheries modeling, and the physical variables should only be considered as the first layers of information.

### Benefits of GIS Modeling for basin-scale Fisheries Management

A large benefit of GIS is the ability to graphically display spatial information once it has been georeferenced. An examination of the sample sites within the LCR watershed (see Figure 3·3) immediately showed their clumped and non-random distribution within and between basins. This information can be used to modify current and future sampling protocols and improve data collection. Color coding a target species and plotting it on a map can also bring out important spatial patterns that were not apparent before. Information about species assemblages can also be obtained by looking at associations of fishes over space and time.

Another advantage of GIS for fisheries management applications is the cell-based modeling environment, which created a suite of variables useful for spatial analyses. The geomorphic variables proved useful in understanding basin-scale relationships among fishes and their habitats. In addition, the ability to query multiple grids with map algebra and Boolean logic, extracting cells that meet defined criteria, is very difficult with non-digital (analog) products (maps, sketches, etc.). Lastly, automated GIS routines make it possible to quickly extract basin divides, stream networks, stream order, channel link slopes, and elevation, then code large data-sets with their appropriate attributes. All of these factors make the use of GIS increasingly beneficial to fisheries managers.

Perhaps the most promising aspect of cell-based modeling is the ability to partition a watershed into logical sub-units with a suite of biotic and abiotic variables. The patterns in the standardized data (see Figures 3·9 – 3·12) suggests that the physical variables are important to native fishes, and could prove useful in a stratified-random sampling regime. Stratifying a basin by stream order will help insure that different order channels are not under-sampled, or missed completely, as was the case in Silver and Chevelon basins. In addition, the cell-based modeling environment is ideal for extracting tributary basins of a selected order, which would provide a good starting point for partitioning a watershed into smaller management units.

## Conclusions

- A Geographic Information System proved invaluable as an analytical tool for developing information to be used for fisheries management, watershed analysis, and management decisions.

- The distribution of sample sites throughout the four focus basins was clumped and non-random (see Figure 3·3). Within Silver and Chevelon basins, only 4$^{th}$ – 7$^{th}$ order channels were sampled (see Figure 3·7·a), while Lyman and Clear basins had 1$^{st}$ – 7$^{th}$ orders sampled. Lower elevation channels were proportionately under-sampled (see Figure 3·5·d), while the upper elevation channels were proportionately over-sampled. In contrast, the different channel slope classes appeared to be proportionately sampled (see Figure 3·5·b). Regarding hydrology, the perennial and intermittent channels were proportionately over-sampled (see Figure 3·5·c), while the ephemeral channels were proportionately under-sampled.

- Cell-based modeling proved useful for developing a suite of geomorphic and hydrologic variables (stream order, link slope, elevation, stream type).

- The stream type cover has spatial and seasonal inaccuracies, but still revealed important patterns in the data. The stream type cover will undoubtedly be used in numerous other studies, but before this happens, it should be refined and improved, making it more useful for analysis and management decisions.

- All three geomorphic variables helped distinguish patterns in the distribution of native and sportfishes at the 804 sample sites (see Figures 3·9 – 3·12). There was an exponential relationship between LEVI/CASP occurrence and channel order (see Figure 3·9·a and 3·10·a). Fifty-eight percent of the 7th order sample sites observed CASP, compared to 42 percent occurrence for LEVI. There was an inverse relationship between link slope and all target native species (see Figures 3·9·b – 3·12·b). Little Colorado spinedace, CASP, and PADI occurred in 3rd – 7th order channels, while RHOS occurred in 2nd – 7th order channels. Only salmonids (SAFO, ONMY, and ONAP) occurred in the 1st order channels, or above 6 percent link slope.

- There were differences in the geomorphic and hydrologic ranges that the target fishes were observed in for each focus basin (see Table 3·4). Some of these inter-basin differences can be explained by sample site locations (Chevelon and Silver basins), while others cannot. For instance, LEVI was observed only in 5th - 7th order channels of Lyman basin, compared with 3rd – 7th order channels of Clear basin. Additional research is needed to identify whether these inter-basin differences are attributable to biotic and/or abiotic factors.

- The overlap in the target fishes' geomorphic and hydrologic ranges suggests that CASP, LEVI, RHOS, and PADI are a native community assemblage; GIRO and ONAP may also belong to this native community assemblage, but scarce data made it difficult to ascertain.

- LEVI and CASP had an upper elevation range (2338 m and 2287 m, 7671 ft and 7503 ft, respectively), which might represent temperature intolerance, or a zone of extirpation resulting from biotic and/or abiotic factors.

- The four physical variables appear useful for a stratified-random approach to sampling, which could result in statistically valid models.

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# CHAPTER 4: HABITAT ANALYSIS FOR FISH IN LITTLE COLORADO RIVER WATERSHED

Linda J. Allison

## INTRODUCTION

### USE OF EMPIRICAL INFORMATION IN A WATERSHED APPROACH TO FISHERIES MANAGEMENT

Goals of the watershed management approach for fisheries developed in this volume include cultivation of a pro-active stance toward native fish management to improve status of native fish populations, promotion of delisting of currently listed species, and avoiding the need for future federal listings. Unlike sportfish management, native fish management resorts to stocking populations only as a last resort. For this reason, management for native fish is directed toward populations that are self-sustaining over the long-term. Pro-active management for native fish requires identifying 1) the number of subpopulations that would best assure stability of the overall metapopulation, 2) regions where these subpopulations would be expected to persist and thrive, 3) appropriate type of local habitat, and 4) compatible species assemblages. Thus, a watershed management plan is designed to meet criteria to address needs of many species, of important associations, and of the habitats in which these species and associations occur.

The first requirement is usually addressed using comprehensive population viability analysis, which is not the subject of this chapter. The second question requires knowledge about habitat preference, with habitat described by large-area variables such as elevation range, stream order, and so on. See Chapter 3 for development of non-probabilistic models for these variables in this watershed. The third issue addresses the type of local habitat used, say within a particular stream segment. For the fourth question, there are some studies addressing specific pairwise interactions (Blinn and others 1993; Robinson and others 1998), but no extensive literature exists and there is certainly no analysis of how often antagonists are living very close to one another in the Little Colorado River (LCR) watershed.

The last three issues could be addressed with habitat selection experiments, behavioral experiments involving other species, and observational work describing 1) where each species occurs, 2) what other fish occur with them and how they interact, and 3) what habitat features describe these areas. We would prefer information from sites the fish prefer, which may differ from habitats they currently use because habitats are degraded, are no longer available, or are present but occupied by a non-native species with which the focal species cannot co-occur.

Some non-native fish species are self-reproducing. Unlike AGFD management priorities for native fishes, AGFD does not have a general interest in enhancing populations of non-native, non-sportfish, and there is no requirement for all non-native sportfisheries be self-sustaining. However, an evaluation of the habitat use and patterns of co-occurrence of self-reproducing non-native fishes with other species would be meaningful when considering how to develop management for all fishes in a watershed.

Here, I use existing observational data on occurrence of fish species in part of the Little Colorado River watershed to describe biotic and abiotic features associated with the current distributions of native or non-native, self-reproducing species. These data may serve as a rough description of current suitable habitat for each species; however, there are limitations to observational data when we would like to know the causes of this distribution. For instance, even if abiotic conditions at a particular site are otherwise suitable, the species may be absent due to presence of a predator or competitor with which it is incompatible. Using observational data alone, we will not know which abiotic and biotic factors caused the present distribution and will be unable to predict whether future occurrence patterns for a given species will be affected by supplementation or removal of other species, or by enhancing habitat in particular areas. This chapter will also address the fact that these data were collected for use in other projects and only a handful have been analyzed to describe habitat use by particular species.

### An Empirical Base Built on Data from Traditional Fisheries Projects

Since 1986, the Nongame Branch Native Fish Program has collected all data in one relational database, currently called the Fish Collection Database. Because all encountered fish are recorded, the database also has records on non-native fish. Data were collected under various projects, and some have been published (Silvey and Thompson 1978; Novy and Lopez 1989, 1990a, 1990b, Denova and Abarca 1992; Dorum and Young 1995; Davidson and Ward 1997a, 1997b). Currently, regional fish specialists at AGFD collect data under projects targeting both sport and nongame species. Data from regional fish specialists are entered in the database as time and funding allow. There has not been a concerted effort to maintain a set of reports and protocols for all data.

The Fish Collection Database contains the most extensive collection of fish records from the Little Colorado watershed; however, it does not cover all Arizona Game and Fish Department (Department, AGFD) studies in the watershed, nor is the entire area represented. Data that may be housed in AGFD Research Branch would provide more coverage of the area otherwise represented by the current database. It is also likely that inclusion of data from studies at Northern Arizona University and Arizona State University would provide greater spatial and temporal coverage of the area. The Fish Collection Database mostly contains data from four subbasins of the Little Colorado River: Clear, Chevelon, Silver, and Nutrioso (the Upper Little Colorado River; ULCR); however, sampling in Clear and Nutrioso basins generated the most samples and covered the largest proportion of each basin (see Figure 3-3). For the analysis presented here, I used data from the ULCR, for which data were available to me at the earliest date. Samples were collected from headwaters as high as 3037 m (9964 ft) down to Lyman Lake at 1829 m (6000 ft).

Some differences exist in sample methods and site selection even between studies considered under the same project heading. In 1992, working on Little Colorado spinedace, Denova and Abarca (1992) chose sample sites by 1) documenting all streams with historical records of Little Colorado spinedace, 2) over-flying the area to document standing water on federally held lands, 3) walking through every continuous area of standing water so-documented. Also working on Little Colorado spinedace, Dorum and others (1996) do not specify how sites were chosen, nor how they initially broke groups into "permanent" and "random" sites. The goal of the second study was to visit every "permanent" site every year, while Denova and Abarca (1992) sought only to visit every standing-water area at least once during the 2-year study. The two studies also differed in that failure to collect the target species resulted in increased efforts at that site for Dorum and others (1996).

The report that follows will illustrate one way to approach habitat use analyses with this sort of data set. Naturally, the analysis also provides some information on habitat use by the most common lotic fish in the area covered. Beyond simple analysis of the data, the report will describe how the results can be interpreted, given the lack of common sampling design among projects and the observational nature of the data.

## METHODS

### GENERAL PATTERNS OF DATA COLLECTION

The available database consists of species records of visits for particular sites. On some of these visits, habitat data were recorded. Therefore, we can look at instantaneous associations between focal fish species and other species or habitat characteristics. Some important caveats have to be emphasized about how data were collected. Records from the ULCR span a time period of 1976 through 1998. Of the 436 site visits recorded, 11 occurred in the 1970s and 32 in the 1980s; all others occurred in the 1990s. The data do not, therefore, describe current habitat use, nor was sampling adequate to investigate temporal variability. Regarding spatial distribution, although sampled sites were chosen before arrival at sites (often spaced systematically), streams and stream reaches were not chosen at random, since sampling was done in the context of a specific protocol with a specific goal. In fact, none of these studies used protocols calling for random or stratified sampling. One consequence of this is that an analysis showing an association between a particular species and a particular habitat type may be an artifact of heavier sampling in that habitat. Furthermore, some regions and reaches have been more heavily sampled than others, which presents two problems: 1) An analysis using these areas is not similar to one using a random sample of sites, so the analysis may not be applicable to the larger area. 2) Samples taken from the same area or contiguous reaches may not be independent.

While the above considerations lead us to be cautious in interpretation of this analysis, in this report the primary goal is to demonstrate an approach to analysis for use in watershed management. Part of this product is a consideration of how to select appropriate variables and records for analysis.

In the original studies, especially those describing habitat condition, the reports ultimately commented on the overall habitat condition of the stream or reach, averaged over all sample sites. These averages were often compared (not statistically) to earlier studies using the same sample sites. It is fine to use the averaged information as a descriptor, and lack of independence between sites does not affect this. I found no comments addressing why particular species might be *absent* from a particular stream, and no attempts to generalize results for particular streams or reaches to the larger basin. Consequently, lack of a random sampling scheme and or representativeness of these samples did not affect earlier studies, except that the scope of the data limited the scope of the analyses and conclusions.

### CHOOSING AND MODIFYING VARIABLES FROM THE DATABASE FOR ANALYSIS

Most fields in the original database were not deemed useful for this type of management-applicable analysis (sex of fish, tag colors for recaptured fish, non-UTM location information, etc), or because the format was not amenable to use (no standardized entry categories). Some species were identified by more than one code in the original database, so these codes were synonymized before analysis. Other modifications to species codes are indicated in Table 4·1. Also, although many records reported the number of fish caught, I converted this information into a field on whether the species was present at a site, without regard for the actual number caught. This step made it easier to compare data from different habitat conditions and studies, because it is less difficult to detect a species than to enumerate it. Note that juveniles and adults were analyzed as one group.

Some variables were generated externally and appended to the database. The first few of these variables (stream order, elevation, and link slope) were generated by James Hatten using digital elevation models (see Chapter 3). A fourth variable, water permanence, was created from existing hydrology covers as described in Chapter 3.

For purposes of this analysis, I used all records from all studies to identify locations where each species had been found. This is only a problem if detection ability was different between studies. Further, when using habitat measurements, it is usual to keep records from separate studies in separate analyses, perhaps combining results in a meta-analysis. However, no field or set of fields in the database can be used to associate each record with a specific study or published report, so I decided to keep habitat data from all studies together for the preliminary examination of variables. Once I chose the set of variables to be analyzed, I considered methods to minimize bias from individual studies. For instance, I could decide to use one set of studies that used the same protocol (General Aquatic Wildlife System - GAWS - USFS 1990). These studies can be identified as a group using two database fields in combination, so that if appropriate, only records from these studies could be used for some analyses. Some critical sifting of the records and variables was undertaken. For instance, although both GAWS and Native Fish survey protocols evaluate the three most common substrates in a habitat, the two types of surveys use the designation "gravel" to indicate two different size categories (Table 4·2). I only used samples taken under the GAWS protocol to analyze the association between species presence and substrate type.

Table 4·1 Species codes that were modified before analysis and may occur in the database but not in the work plan. Comments paraphrased from D. Dorum (pers. comm.)

| Species code | Comments | Action taken |
|---|---|---|
| CAPA | Unknown sucker | Deleted |
| CAPL | Rio Grande sucker. Possibly a misidentified bluehead sucker | Deleted |
| CALA | Flannelmouth sucker. Reclassified based on assumption there are none above Grand Falls | Recoded to CASP |
| CASP | Believed to be PADI at this elevation. Some sites were revisited to confirm species identity | Recoded to PADI, at sampleids LUC001, LUC002, LUC003, ROI001, ROI002 |
| DACE | May be speckled dace or Little Colorado spinedace | Deleted |
| LEVI? | | Deleted |
| NOXX | Unidentified shiner | Deleted |
| PACL | Desert sucker. Assumed to be PADI in this region. | Recoded to PADI |
| PADI | Believed to be CASP at some sites. Some sites were revisited to confirm species identity | Recoded to CASP at sampleid RJD001 |
| PAXX | There is only one species of *Pantosteus* in the area of analysis | Changed to PADI, deleted at one site |
| UNSU | Unknown sucker | Deleted |
| TROUT | | Deleted |
| ???? | | Deleted |

From the above discussion, it should be clear that the sample size and even the data set will have to differ depending on the variable analyzed. Although 691 visits were made to lotic and lentic sites, only 339 different lotic sites and 29 lentic sites were visited. (Some were visited multiple times). Considering only lotic sites, the GAWS protocol was used on 436 visits to 320 different sites.

Table 4·2 Discrepancies in substrate class definition

| Classification | Nongame size range (mm) | GAWS size range (mm) |
|---|---|---|
| Boulder | >256 | >305 |
| Rubble | - | 76 - 305 |
| Cobble | 64 - 256 | - |
| Pebble | 32 - 64 | - |
| Gravel | 2 - 32 | 3.2 - 76 |
| Sand | 0.0625 - 2 | - |
| Sand and Silt | - | < 3.2 |
| Silt | < 0.0625 | - |

At this stage, variables that might have been used for habitat use analysis were classified as 1) likely to be as comparable between protocols as within protocols, 2) suitable for analysis on a limited set of samples collected under a given protocol, 3) replicating information available from other variables, 4) too rarely represented by important categories to be analyzed (for instance, gear type is rarely anything but electroshocker), or 5) too rarely collected to be analyzed. Table 4·3 lists available habitat variables and provides reasoning for any variables dropped from analysis.

Table 4·3 Variables available for analysis, reason for not analyzing or data set used if analyzed

| Variable | Reason not analyzed | Data set used if analyzed[a] |
|---|---|---|
| Crayfish | Only 8 entries with any data | - |
| Gear type | Few non-electroshocker entries | - |
| Grazing | Too few entries with low or no grazing | - |
| Average site width | Highly correlated with stream width, which was analyzed | - |
| Water temperature | Some entries apparently Fahrenheit | - |
| Conductivity | Only 31 non-missing entries | - |
| Discharge | Only 14 non-missing entries | - |
| dO2 | Only 56 non-missing entries | - |
| Effort length | Most samples standard 50 m length | - |
| Effort width | Stream width analyzed instead | - |
| Habitat length | Most samples 50 m length, crossing habitats | - |
| Stream width | - | All sampling protocols |
| Link slope | - | DEM-generated variable (Chapter 3) |
| Percent aquatic vegetation | Only 52 samples with non-missing values | - |
| Percent riparian vegetation | Only 50 samples with non-missing values | - |
| Stream order | - | DEM-generated variable (Chapter 3) |
| Water permanence | Highly correlated with stream order; few observatiosn in non-perennial waters | Generated as described in Chapter 3 |
| Elevation | - | DEM-generated variable, (Chapter 3) |
| Habitat type and percentage | - | All sampling protocols |
| Substrate type and percentage | Protocols differ in classification schemes | GAWS only |

[a]GAWS surveys are identified by site numbers with F1 through F10. Survey project may have been listed as "Research," "Region I survey," or "GAWS." The lowest GAWS survey was taken at 2193m

The final set of habitat use variables analyzed (indicated in the last column of Table 4-3) was stream order, elevation, water permanence, stream width, percentage of habitat types within a site, percentage of substrate types within a site, and link slope. Note that, despite concerns about using data from studies collected using different protocols, only two such variables from the database (stream width and type) were used in the final analyses. For illustrative purposes, I analyzed these variables, realizing that the quality of these analyses can not be evaluated.

### Choosing Species for Analysis

Just before construction of reservoirs in this basin no large lentic water bodies were present. With the exception of Little Colorado sucker, native fish are still in a higher proportion of lotic than lentic systems (Table 4.4).

Table 4.4 Occurrence of each species in the 339 lotic and 29 lentic habitats in the ULCR.

| Species | Common name | Sites present: Lakes/Reservoirs | | Sites present: Streams/Rivers | |
|---|---|---|---|---|---|
| | | Count | % | Count | % |
| NATIVE SPECIES | | | | | |
| CASP | Little Colorado sucker | 15 | 51.7 | 16 | 4.7 |
| LEVI | Little Colorado spinedace | 0 | 0.0 | 52 | 15.3 |
| ONAP | Apache trout | 4 | 13.8 | 26 | 7.7 |
| PADI | Bluehead sucker | 4 | 13.8 | 77 | 22.7 |
| RHOS | Speckled dace | 0 | 0.0 | 97 | 28.6 |
| NON-NATIVES MANAGED AS DESIREABLE SPORTFISH IN ULCR | | | | | |
| ICPU | Channel catfish | 8 | 27.6 | 1 | 0.3 |
| LEMA | Bluegill | 2 | 6.9 | 0 | 0.0 |
| MISA | Largemouth bass | 6 | 20.7 | 0 | 0.0 |
| ONCL | Cutthroat trout | 3 | 10.3 | 3 | 0.9 |
| ONMY | Rainbow trout | 19 | 65.5 | 85 | 25.1 |
| SAFO | Brook trout | 8 | 27.6 | 55 | 16.2 |
| SATR | Brown trout | 11 | 37.9 | 61 | 18.0 |
| STVI | Walleye | 6 | 20.7 | 0 | 0.0 |
| THAR | Arctic grayling | 2 | 6.9 | 0 | 0.0 |
| NON-NATIVES NOT MANAGED AS DESIREABLE FISH IN THE ULCR | | | | | |
| CYCA | Common carp | 9 | 31.0 | 2 | 0.6 |
| ESLU | Northern pike | 2 | 6.9 | 0 | 0.0 |
| FUZE | Plains killifish | 0 | 0.0 | 1 | 0.3 |
| LECY | Green sunfish | 9 | 31.0 | 7 | 2.1 |
| NOCR | Golden shiner | 2 | 6.9 | 0 | 0.0 |
| PEFL | Yellow perch | 1 | 3.4 | 0 | 0.0 |
| PIPR | Fathead minnow | 5 | 17.2 | 46 | 13.6 |
| PONI | Black crappie | 5 | 17.2 | 0 | 0.0 |

Only 29 lentic sites were visited, compared to 339 lotic ones, although the size of these sampled units is not really comparable. In addition, for statistical analyses, there should be several observations in order to describe habitat use and associations a given species. Only species found often in rivers and streams were considered for the analysis (Table 4.4). All native fish in the drainage met this criterion (Little Colorado sucker, Little Colorado spinedace, Apache trout, bluehead sucker, and speckled dace), as did some non-native fish (rainbow trout, fathead minnow, brook trout, and brown trout). Non-native fish are often stocked; nevertheless, analyses of habitat use and species co-occurrence patterns were completed for all of the above fish. For non-native fish and for Apache trout (which are largely reintroduced), patterns may reflect habitat conditions where humans put these fish rather where they would sort themselves out without human intervention

## ANALYSES

### Habitat use

Chapter 3 describes "envelopes" of large geographic areas currently used by each species. In this analysis, I ask whether we can refine these envelopes in any way, and demonstrate how sample data should be analyzed for this purpose. For instance, within the elevation range occupied by a given species: Can we say in which elevations more fish have been found? Do fish use particular stream orders? Has a species been found associated with a particular substrate, in a particular habitat (pool, riffle, run), or in a particular temperature range?

At each site, records indicate whether a fish was there. The variables used to describe presence may be "continuous" (elevation, stream width) or "categorical" (stream order). The analysis used to relate presence/absence data to continuous and categorical variables is a logistic regression (Hosmer and Lemeshow 1989). Logistic analysis makes no assumptions about the distribution of the population data, so no tests for normality of equality of variances were performed. One output of logistic regression is an estimate of the "odds" of finding the fish under particular circumstances. Odds, here, means the ratio of the probability a species is present to the probability the species is absent. For a continuous variable, the odds ratio tells us the increased likelihood of finding the fish given one unit change in the continuous variable; therefore, choice of units is important. We do not want to know the increased odds of finding a fish if we move one meter up in elevation. Therefore, the range for each continuous variable was examined to help determine how to build measurement units.

Table 4·5 indicates that consistent units of 200 m (656 ft) may be too large, creating too few classes for some species, and units of 150 m (492 ft) somewhat better. Smaller elevation units were not considered, because this would lead to more elevation classes than can be meaningfully analyzed by the number of samples available. I therefore designated elevation units of 150 m, starting at 1800 m (5906 ft). The column on the far right of Table 4·5 indicates how many elevation classes a fish crosses. To make analyses comparable, I used elevation limits described by these classes for all subsequent analyses. For instance, although Little Colorado sucker has been found between 1829 m (6000 ft) and 2287 m (7503 ft), the classes it was found in describe a range from 1800 m to 2400 m (7874 ft). This is the range of samples I considered when analyzing the relationship between species presence and elevation, and also between species presence and substrate type or habitat. I considered treating stream order as a continuous variable. This would be valuable if the logit increased linearly with stream order. However, fish are often absent at higher and lower stream orders, but common in mid-ranges, so the relationship with stream order is not linear. Instead, the relationship between this variable and fish presence was most accurately described by leaving stream order as a categorical variable.

Table 4·5 Defining the elevation envelope and categories for logistic analyses

| Species | Number of samples | Elevation limits (meters)[a] | Classes in 200 m increments from 1800 m | Classes in 150 m increments from 1800 m | Analyzed elevation (meters) |
|---|---|---|---|---|---|
| CASP | 16 | 1829-2289[b] | 3 | 4 | 1800-2399 |
| LEVI | 52 | 1832-2338 | 3 | 4 | 1800-2399 |
| ONAP | 26 | 2418-2933 | 3 | 4 | 2400-2999 |
| ONMY | 85 | 2088-2811 | 5 | 7 | 1950-2849 |
| PADI | 78 | 1829-2890 | 6 | 8 | 1800-2999 |
| PIPR | 46 | 1829-2837** | 6 | 7 | 1800-2849 |
| RHOS | 97 | 1829-2890 | 6 | 8 | 1800-2999 |
| SAFO | 55 | 2141-2971 | 5 | 6 | 2100-2999 |
| SATR | 61 | 2039-2885 | 5 | 7 | 1950-2999 |

[a]Five lowest samples taken at about 1850 m, then none until 2000 m
[b]No PIPR between 2284 and 2827 m. Three observations recorded over 2827 m

Analyses were used to identify variables of interest for further exploration. I was interested in highlighting all variables of potential interest, not in eliminating variables from future consideration on the basis of this problematic data set. For my purposes, univariate analyses are suitable, although multivariate analyses would allow consideration of relationships between independent variables. In order to evaluate sets of variables simultaneously, we can only analyze records with data for all variables of interest. Few records included all variables. Although there may be many records with information on either of two habitat variables, this is not indicative of the number of records with information for both variables, for instance. This problem is exacerbated by the fact that some levels of a categorical variable were often represented by few samples, so when the category is considered on the basis of a further variable, some combinations of interest might have no information at all. For these reasons, univariate analyses were done, with no attempt to describe the relative contribution of each variable to describing the presence of each species; however, it is important to remember that there may be strong correlations between the independent variables. These associations were explored using only records collected under the GAWS protocol, for which all variables analyzed were present. Because the data sets were fairly unbalanced and because the goal is to identify potential variables of interest, not to develop predictive models, goodness-of-fit tests were not pursued. However, information derived from confidence intervals is used to discuss whether the effect estimates are stable

Associations between habitat and geomorphic variables
Because not all samples contain measurements for all variables of interest, I used univariate analyses to maximize the number of samples contributing to each analysis. Because only one variable is considered at a time, it is not possible to evaluate relative and overlapping correlations between habitat variables and particular species; however, we do expect correlations to exist. One premise of watershed analysis is that geomorphology and upstream processes shape habitat in downstream areas (see Chapter 3 and references therein). Therefore, we expect strong associations between geomorphic variables (because geomorphology might change consistently as we move downstream), between geormorphic variables and habitat features (because habitat features are largely generated by upstream geormorphology), and between habitat features (because all are a product of upstream geomorphology). I used Spearman's rho to examine associations between independent variables in the analysis.

Associations between fish species
Sampling was not conducted at random; each survey was directed at gathering a particular set of information. This means that the samples were also not independent of one another because habitat of particular species usually was targeted. To test for associations between pairs of species, I used randomization (Manly 1997) to test whether the number of co-occurrences was significantly lower or higher than predicted if the focal species had independent of any of the other species. Specifically, I ran a simulation by randomly shuffling the occurrence records of the species of interest among the 439 existing samples. The number of co-occurrences of the species with each of the other species is then recorded and the process is repeated 1000 times. This distribution of 1000 random co-occurrences is used as the likely distribution if two species occur independently. I report on how unusual the observed frequency of co-occurrences is, if the species are actually occurring independently. This analysis asks whether specific fish pairs occur at random in the basin.

A second analysis was conducted to address whether, within the elevation envelope of a particular species, its co-occurrence with other species was random. For this analysis, the number of sampling occasions depends on the elevation envelope of the species.

General approach to multiple comparisons using similar or identical data sets
Some of the variables analyzed use the same data sets as others, but most habitat variables were analyzed using data sets filtered only for that analysis. If it were desirable to correct for multiple comparisons, it is not clear how this would be done for partially overlapping data sets. Furthermore, the purpose of this analysis is to describe patterns that warrant further attention. I am more concerned with identifying potentially important variables than with incorrectly identifying a variable as interesting. Since I was more interested in type II errors than in type I errors, and because I will not use this data set to draw conclusions about variables analyzed, no corrections were made for multiple comparisons.

As noted, corrections could not have been made where data sets for tests of different habitat variables overlapped only partially, but when testing for associations between species, as many as 72 comparisons were made using the same data set. I note this here for the interested reader.

## RESULTS

### ASSOCIATIONS BETWEEN HABITAT VARIABLES

All considered geomorphic variables were significantly associated, although some of the associations are not strong (Table 4·6·a). Stream order had a strong negative association with elevation, which is not surprising, because higher order streams develop as channels join with other channels downstream. As elevation drops (and stream orders are higher), slopes decrease significantly and there is significantly more perennial water. Note that all samples from fifth- through seventh-order stream segments are in habitat classified as perennial, whereas samples collected in first- through fourth-order stream segments may occur in intermittent or ephemeral waters (Table 4·7).

Table 4·6 Spearman's rho for significant associations between geomorphic and habitat variables. Data are from samples collected using the GAWS protocol

Table 4·6·a Associations between analyzed geomorphic variables (n=320). Only associations significant at the alpha=0.05 level are reported

| | Elevation | Stream order | Link slope | Water permanence |
|---|---|---|---|---|
| Elevation | | -0.724 | 0.441 | -0.158 |
| Stream order | | | -0.488 | 0.488 |
| Link slope | | | | -0.306 |

Table 4·6·b Association between geomorphic variables and habitat variables. For substrate or habitat analysis, samples were scored by proportion of area covered by each category. Only associations significant at the alpha=0.05 level are reported

| Habitat variable | Habitat category | N | Elevation | Stream Order | Link slope | Water permanence |
|---|---|---|---|---|---|---|
| Substrate | Boulder | 295 | | 0.168 | 0.320 | 0.116 |
| | Gravel | 297 | 0.442 | -0.310 | | |
| | Rubble | 297 | | | 0.395 | |
| | Sand and silt | 297 | -0.306 | 0.127 | -0.448 | |
| Stream width | Stream width | 318 | 0.217 | 0.129 | | 0.468 |
| Habitat | Pool | 74 | -0.449 | 0.532 | | |
| | Riffle | 74 | 0.354 | -0.501 | | |
| | Run | 74 | | | | 0.353 |

Table 4·6·c Associations between analyzed habitat variables. For substrate or habitat analysis, samples were scored by proportion of area covered by each category. Spearman's rho (upper number) and sample size (lower number) are reported only for associations significant at the alpha=0.05 level

| | Substrate | | | | Stream width | Habitat | | |
|---|---|---|---|---|---|---|---|---|
| Habitat | Boulder | Gravel | Rubble | Sand and silt | | Pool | Riffle | Run |
| Boulder | | -0.133<br>295 | 0.459<br>295 | -0.513<br>295 | 0.293<br>295 | 0.369<br>74 | -0.281<br>74 | - |
| Gravel | | | -0.133<br>297 | -0.345<br>297 | - | -0.499<br>74 | 0.508<br>74 | - |
| Rubble | | | | -0.688<br>297 | 0.177<br>297 | - | - | - |
| Sand and silt | | | | | -0.294<br>297 | 0.327<br>74 | -0.368<br>74 | - |
| Stream width | | | | | | - | - | - |
| Pool | | | | | | | -0.783<br>74 | - |
| Riffle | | | | | | | | -0.386<br>74 |

Table 4·7 Classification of the 339 lotic sites in the Upper Little Colorado River basin by stream order and water permanence

| Stream order | Permanent | Intermittent | Ephemeral | Total |
|---|---|---|---|---|
| 1 | 0 | 8 | 1 | 9 |
| 2 | 3 | 6 | 3 | 12 |
| 3 | 30 | 1 | 48 | 79 |
| 4 | 82 | 17 | 43 | 142 |
| 5 | 44 | | | 44 |
| 6 | 42 | | | 42 |
| 7 | 11 | | | 11 |
| Total | 212 | 32 | 95 | 339 |

Associations between geomorphic variables and habitat features were generally weaker than between geomorphic variables (Table 4·6·b), and Spearman's rho for these associations was never much higher than 0.50. Elevation and stream order, which are strongly and negatively associated, therefore showed opposite associations with the same habitat feature. For instance, as elevation increases (and stream order decreases), the amount of gravel substrate increases and of sand or silt substrate decreases. The amount of area covered by pools decreases while that of riffles increases. Some weaker associations involving elevation and stream order did not show opposite trends; stream width increases weakly as both elevation and stream order increase. Increasing slope is associated with more boulders and rubble and less sand or silt; no other habitat variables were associated with link slope. Both stream width and area covered by runs increased in areas with more permanent water. Water permanence did not show anything but weak associations with any other habitat feature.

Significant associations between habitat features varied from weak to moderately strong (Table 4·6·c). Not surprisingly, all four substrates were associated with one another; only boulders and rubble were positively associated. Similarly, habitat variable associations were negative between riffles and both pools and runs. Pools were negatively associated with gravel, and positively associated with boulders and sand or silt. Riffles had exactly the opposite associations; the more area covered by riffle, the fewer boulders and the less sand or silt, and the more gravel. Stream width had a weak negative association with presence of sand or silt. It had a positive association with presence of boulders and rubble.

### Associations Between Particular Species and Habitat Features

Minimum and maximum elevations for each species are given in Table 4·5. This table also reports the number of samples available within the apparent range of occurrence of each species. Associations with habitat features are not analyzed separately for different age classes, although it would not be surprising if juveniles and adults of the same species use different habitat. Summary of results is given in Table 4·8. Because univariate analyses were used, no statements can be made about the relative strength of associations between a fish species and sets of habitat variables. When interpreting analysis of the association between a species and any habitat feature, we must always keep in mind the many statistically significant, moderately strong associations between geomorphic and habitat variables.

Table 4·8 Logistic regression for predicting presence of each species within its observed elevation range. Odds ratios give rate at which species presence increases as the variable increases one unit (continuous variables) or compared to average (stream order) or ephemeral (water permanence). Odds ratios less than one indicate decreased likelihood of fish presence. Confidence intervals not containing "1" indicate odds ratio is statistically significant. Stream widths were log transformed. In the ULCR basin, 339 samples were available to evaluate elevation, stream order, link slope, and water permanence, 320 to evaluate substrate, and 436 to evaluate habitat type and width.

Table 4·8·a CASP (Little Colorado sucker)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 92 | 16 | 0.10 | [0.031, 0.309] |
| Stream order | 4th<br>5th<br>6th<br>7th | 8<br>31<br>42<br>11 | 0<br>1<br>5<br>10 | Stream order *was significantly predictive* overall, although paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| Water permanence | Perennial<br>Intermittent<br>Ephemeral | 91<br>0<br>1 | 16<br>0<br>0 | Concentration of presences in one category led to significant effects of water permanence but also to models for which odds ratios were unstable | |
| Link slope | 1 degree | 92 | 16 | 0.74 | [0.427, 1.286] |
| Stream width | Each unit 1.7X wider than previous one | 74 | 8 | 8.76 | [2.138, 35.893] |
| Substrate type | Quintiles of area with:<br>Boulder<br>Rubble<br>Gravel<br>Sand/silt | 54 | 1 | Too little information to build a model | |
| Habitat type | Quintiles of area with:<br>Riffle<br>Pool<br>Run | 79 | 24 | 1.10<br>0.84<br>1.07 | [0.696, 1.727]<br>[0.502, 0.953]<br>[1.049, 1.994] |

Table 4·8·b LEVI (Little Colorado spinedace)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 92 | 52 | 0.80 | [0.474, 1.342] |
| Stream order | 4th | 8 | 0 | Stream order *was not significant* overall, and paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| | 5th | 31 | 16 | | |
| | 6th | 42 | 29 | | |
| | 7th | 11 | 7 | | |
| Water permanence | Perennial | 91 | 52 | Concentration of presences in one category led to significant effects of water permanence but also to models for which odds ratios were unstable | |
| | Intermittent | 0 | 0 | | |
| | Ephemeral | 1 | 0 | | |
| Link slope | 1 degree | 92 | 52 | 0.37 | [0.226, 0.619] |
| Stream width | Each unit 1.7X wider than previous one | 74 | 47 | 1.60 | [1.105, 2.306] |
| Substrate type | Quintiles of area with: | 54 | 29 | | |
| | Boulder | | | 0.73 | [0.061, 8.759] |
| | Rubble | | | 3.54 | [0.485, 25.782] |
| | Gravel | | | 1.67 | [0.619, 4.485] |
| | Sand/silt | | | 1.90 | [0.779, 4.638] |
| Habitat type | Quintiles of area with: | 79 | 52 | | |
| | Riffle | | | 0.51 | [0.314, 0.830] |
| | Pool | | | 1.03 | [0.761, 1.406] |
| | Run | | | 0.97 | [0.711, 1.314] |

Table 4·8·c ONAP (Apache trout)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 245 | 26 | 0.54 | [0.330, 0.900] |
| Stream order | 1st<br>2nd<br>3rd<br>4th<br>5th | 9<br>10<br>79<br>134<br>13 | 1<br>0<br>12<br>13<br>0 | Stream order *was not significant* overall, and paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| Water permanence | Perennial<br>Intermittent<br>Ephemeral | 120<br>32<br>93 | 0<br>1<br>25 | Concentration of presences in one category led to significant effects of water permanence but also to models for which odds ratios were unstable | |
| Link slope | 1 degree | 245 | 26 | 0.98 | [0.828, 1.156] |
| Stream width | Each unit 1.7X wider than previous one | 246 | 30 | 0.42 | [0.278, 0.620] |
| Substrate type | Quintiles of area with:<br>Boulder<br>Rubble<br>Gravel<br>Sand/silt | 240 | 29 | 0.33<br>0.60<br>0.70<br>1.21 | [0.075, 1.411]<br>[0.290, 1.236]<br>[0.346, 1.422]<br>[0.675, 2.153] |
| Habitat type | Quintiles of area with:<br>Riffle<br>Pool<br>Run | 74 | 22 | 3.53<br>6.14<br>0.16 | [0.777, 16.023]<br>[1.274, 29.563]<br>[0.034, 0.785] |

Table 4·8·d ONMY (Rainbow trout)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 293 | 85 | 1.01 | [0.815, 1.247] |
| Stream order | 1st | 1 | 0 | Stream order *was significantly predictive* overall, although paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| | 2nd | 1 | 0 | | |
| | 3rd | 64 | 8 | | |
| | 4th | 135 | 52 | | |
| | 5th | 44 | 21 | | |
| | 6th | 42 | 3 | | |
| | 7th | 6 | 1 | | |
| Water permanence | Perennial | 182 | 65 | 2.89 | [1.538, 5.424] |
| | Intermittent | 18 | 5 | 2.00 | [0.621, 6.443] |
| | Ephemeral | 93 | 15 | -- | -- |
| Link slope | 1 degree | 293 | 85 | 1.19 | [1.080, 1.309] |
| Stream width | Each unit 1.7X wider than previous one | 285 | 76 | 1.44 | [1.180, 1.752] |
| Substrate type | Quintiles of area with: | 260 | 73 | | |
| | Boulder | | | 0.85 | [0.446, 1.637] |
| | Rubble | | | 0.61 | [0.354, 1.044] |
| | Gravel | | | 1.08 | [0.680, 1.715] |
| | Sand/silt | | | 0.36 | [0.215, 1.715] |
| Habitat type | Quintiles of area with: | 136 | 33 | | |
| | Riffle | | | 1.41 | [1.019, 1.960] |
| | Pool | | | 1.17 | [0.852, 1.617] |
| | Run | | | 0.85 | [0.618, 1.174] |

Table 4-8-e PADI (Bluehead Sucker)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 337 | 78 | 0.39 | [0.303, 0.501] |
| Stream order | 1st | 9 | 0 | Stream order *was significantly predictive* overall, although paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| | 2nd | 10 | 0 | | |
| | 3rd | 79 | 9 | | |
| | 4th | 142 | 6 | | |
| | 5th | 44 | 15 | | |
| | 6th | 42 | 37 | | |
| | 7th | 11 | 11 | | |
| Water permanence | Perennial | 211 | 78 | Concentration of presences in one category led to significant effects of water permanence but also to models for which odds ratios were unstable | |
| | Intermittent | 32 | 0 | | |
| | Ephemeral | 94 | 0 | | |
| Link slope | 1 degree | 337 | 78 | 0.24 | [0.170, 0.337] |
| Stream width | Each unit 1.7X wider than previous one | 320 | 62 | 1.59 | [1.287, 1.959] |
| Substrate type | Quintiles of area with: | 294 | 44 | | |
| | Boulder | | | 1.31 | [0.453, 3.765] |
| | Rubble | | | 1.34 | [0.727, 2.473] |
| | Gravel | | | 1.42 | [0.855, 2.372] |
| | Sand/silt | | | 2.43 | [1.558, 3.782] |
| Habitat type | Quintiles of area with: | 153 | 65 | | |
| | Riffle | | | 0.31 | [0.209, 0.457] |
| | Pool | | | 0.68 | [0.510, 0.910] |
| | Run | | | 1.47 | [1.091, 1.960] |

Table 4·8·f PIPR (Fathead minnow)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 298 | 46 | 0.15 | [0.092, 0.254] |
| Stream order | $1^{st}$ | 1 | 0 | Stream order *was significantly predictive* overall, although paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| | $2^{nd}$ | 1 | 0 | | |
| | $3^{rd}$ | 64 | 1 | | |
| | $4^{th}$ | 135 | 2 | | |
| | $5^{th}$ | 44 | 1 | | |
| | $6^{th}$ | 42 | 31 | | |
| | $7^{th}$ | 11 | 11 | | |
| Water permanence | Perennial | 187 | 46 | Concentration of presences in one category led to significant effects of water permanence but also to models for which odds ratios were unstable | |
| | Intermittent | 18 | 0 | | |
| | Ephemeral | 93 | 0 | | |
| Link slope | 1 degree | 298 | 46 | 0.18 | [0.104, 0.254] |
| Stream width | Each unit 1.7X wider than previous one | 286 | 35 | 2.05 | [1.546, 2.718] |
| Substrate type | Quintiles of area with: | 260 | 18 | | |
| | Boulder | | | 0.00 | [0.000, huge] |
| | Rubble | | | 1.87 | [0.712, 4.889] |
| | Gravel | | | 1.63 | [0.855, 3.097] |
| | Sand/silt | | | 3.14 | [1.702, 5.806] |
| Habitat type | Quintiles of area with: | 141 | 46 | | |
| | Riffle | | | 0.34 | [0.230, 0.507] |
| | Pool | | | 0.64 | [0.486, 0.839] |
| | Run | | | 1.57 | [1.192, 2.058] |

Table 4·8·g RHOS (Speckled dace)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 337 | 97 | 0.39 | [0.305, 0.494] |
| Stream order | 1st | 9 | 0 | Stream order *was significantly predictive* overall, although paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| | 2nd | 10 | 0 | | |
| | 3rd | 79 | 10 | | |
| | 4th | 142 | 14 | | |
| | 5th | 44 | 24 | | |
| | 6th | 42 | 39 | | |
| | 7th | 11 | 10 | | |
| Water permanence | Perennial | 211 | 97 | Concentration of presences in one category led to significant effects of water permanence but also to models for which odds ratios were unstable. | |
| | Intermittent | 32 | 0 | | |
| | Ephemeral | 94 | 0 | | |
| Link slope | 1 degree | 337 | 97 | 0.36 | [0.285, 0.463] |
| Stream width | Each unit 1.7X wider than previous one | 320 | 79 | 1.44 | [1.188, 1.739] |
| Substrate type | Quintiles of area with: | 294 | 61 | | |
| | Boulder | | | 1.57 | [0.714, 3.464] |
| | Rubble | | | 1.23 | [0.708, 2.120] |
| | Gravel | | | 1.45 | [0.904, 2.316] |
| | Sand/silt | | | 2.28 | [1.512, 3.444] |
| Habitat type | Quintiles of area with: | 153 | 72 | | |
| | Riffle | | | 0.38 | [0.273, 0.538] |
| | Pool | | | 0.74 | [0.559, 0.973] |
| | Run | | | 1.36 | [1.028, 1.789] |

Table 4·8·h SAFO (Brook trout)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 327 | 55 | 2.19 | [1.716, 2.801] |
| Stream order | 1st | 9 | 4 | Stream order *was not significant* overall, and paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| | 2nd | 10 | 3 | | |
| | 3rd | 79 | 15 | | |
| | 4th | 142 | 25 | | |
| | 5th | 44 | 1 | | |
| | 6th | 42 | 7 | | |
| | 7th | 1 | 0 | | |
| Water permanence | Perennial | 201 | 48 | 29.17 | [3.960, 214.867] |
| | Intermittent | 32 | 6 | 21.46 | [2.472, 186.261] |
| | Ephemeral | 94 | 1 | -- | -- |
| Link slope | 1 degree | 327 | 55 | 1.02 | [0.912, 1.137] |
| Stream width | Each unit 1.7X wider than previous one | 312 | 41 | 1.60 | [1.241, 2.055] |
| Substrate type | Quintiles of area with: | 294 | 40 | | |
| | Boulder | | | 0.35 | [0.134, 0.926] |
| | Rubble | | | 0.77 | [0.450, 1.308] |
| | Gravel | | | 0.41 | [0.219, 0.760] |
| | Sand/silt | | | 0.46 | [0.273, 0.783] |
| Habitat type | Quintiles of area with: | 135 | 13 | | |
| | Riffle | | | 1.06 | [0.678, 1.672] |
| | Pool | | | 1.08 | [0.690, 1.695] |
| | Run | | | 0.92 | [0.590, 1.450] |

Table 4-8-i SATR (Brown trout)

| Variable | Categories or units | Samples in elevation range with data for this variable | Samples with fish present | Odds ratio for each unit | 95% Confidence interval for odds ratio |
|---|---|---|---|---|---|
| Elevation | 150 m | 332 | 62 | 1.17 | [0.965, 1.407] |
| Stream order | 1st | 9 | 0 | Stream order *was significantly predictive* overall, although paucity of samples or recorded presence in some categories led to unstable odds ratio estimates | |
| | 2nd | 10 | 0 | | |
| | 3rd | 79 | 2 | | |
| | 4th | 142 | 39 | | |
| | 5th | 44 | 10 | | |
| | 6th | 42 | 7 | | |
| | 7th | 6 | 4 | | |
| Water permanence | Perennial | 91 | 16 | Concentration of presences in one category led to significant effects of water permanence but also to models for which odds ratios were unstable | |
| | Intermittent | 0 | 0 | | |
| | Ephemeral | 1 | 0 | | |
| Link slope | 1 degree | 332 | 62 | 0.90 | [0.804, 1.015] |
| Stream width | Each unit 1.7X wider than previous one | 319 | 55 | 2.39 | [1.832, 3.121] |
| Substrate type | Quintiles of area with: | 294 | 50 | | |
| | Boulder | | | 1.27 | [0.633, 2.533] |
| | Rubble | | | 0.78 | [0.460, 1.330] |
| | Gravel | | | 0.46 | [0.263, 0.817] |
| | Sand/silt | | | 0.20 | [0.098, 0.424] |
| Habitat type | Quintiles of area with: | 148 | 28 | | |
| | Riffle | | | 1.18 | [0.856, 1.624] |
| | Pool | | | 1.14 | [0.824, 1.564] |
| | Run | | | 0.88 | [0.640, 1.214] |

<u>Elevation</u>

Within its elevation envelope, brook trout increased with increasing elevation; Little Colorado sucker, bluehead sucker, fathead minnow, and speckled dace decreased in frequency within their elevation envelopes as elevation increased.

Stream order

Odds ratios reported in the table compare prevalence of the fish in a given order to its prevalence overall. A ratio less than one indicates occurrences at frequencies less than average for the drainage overall. Of the stream orders present in the analyzed elevation range for each species, Little Colorado sucker, bluehead sucker, fathead minnow, and speckled dace increased as stream order increased. Brook trout increased as order decreased, and rainbow trout and brown trout were more likely to be found in some stream orders than in others, but there was no association between increasing stream order and fish presence.

Water permanence

All samples from fifth through seventh-order stream segments are in habitat classified as perennial, whereas samples collected in first- through fourth-order stream segments may occur in intermittent or ephemeral waters (Table 4·7). Only Apache trout, rainbow trout, and brook trout occurred in samples from intermittent or ephemeral class reaches.

Link slope

Rainbow trout increased as slope increased, while Little Colorado spinedace, bluehead sucker, fathead minnow, and speckled dace increased as slope decreased.

Stream width

All species showed detectable trends in occurrence as stream width changed. Wider habitats were associated with increasing occurrence of Little Colorado sucker, Little Colorado spinedace, rainbow trout, bluehead sucker, fathead minnow, speckled dace, brook trout, and brown trout. Apache trout was more likely to be found as stream width decreased.

Substrate

I first examined sample frequencies and found that fewer than 10 samples had any observations from sites with bedrock, organic material, logs, or tree roots. These substrates were dropped from analysis. Brook trout, brown trout, bluehead sucker, fathead minnow, and speckled dace had detectable associations with substrate type. Brook trout was negatively associated with boulders, gravel, and sand or silt substrates (See Table 4·2 for definition of GAWS survey categories). Brown trout was negatively associated with gravel and sand or silt. Bluehead sucker, fathead minnow, and speckled dace were positively associated with sand or silt.

Habitat

Only fifteen samples had any component described as a "glide," so this information was combined with that for "runs" for analysis. Little Colorado sucker, bluehead sucker, fathead minnow, and speckled dace were negatively associated with pools and positively associated with runs; the latter three were also negatively associated with riffles. Little Colorado spinedace was negatively associated with riffles; rainbow trout was positively associated with riffles. Apache trout was positively associated with pools and negatively associated with runs. Brown and brook trout showed no significant habitat associations.

ASSOCIATIONS BETWEEN FISH SPECIES

The hypothesis that negative associations between fish species drive local extirpation of native fish leads to the prediction that negative interactions will be reflected in negative associations in co-occurrence. Another possibility is that negative interactions do not cause local extirpation but nonetheless have negative impacts on native fish. In this case, the impacted species may be present (so no negative association is detected), but will occure in smaller numbers when it exists with impacting species. It should also be remembered that samples generally cover 50m stream segments, so positive associations may not mean the species co-occure locally. Results of tests for association are given in Table 4-9.

Note that all basin-wide associations with Apache trout are negative. In the ULCR, Apache trout was stocked into areas that were first poisoned to remove other fish. Also, fish barriers usually separate Apache trout stocking locations from downstream fish. The apparent positive association between Apache trout and Little Colorado sucker or Little Colorado spinedace detected within the elevation envelopes of these species is an artifact of the fact that the elevation envelope of Apache trout has no overlap at all with the envelopes of these two species; therefore, the randomization process could not result in more than zero co-occurrences. The basin-wide negative association between Apache trout and Little Colorado sucker or Little Colorado spinedace can be explained entirely by lack of overlap in elevation range. The negative associations between Apache trout and all other species, with which elevation ranges overlap, are best explained by the stocking practice described above, although speckled dace were removed before at least one stream poisoning and were returned when Apache trout were reintroduced (Novy and Dreyer 1995).

All other negative associations significant at the 0.05 level occur between rainbow trout and other species. Rainbow trout are not negatively associated with brook trout and brown trout. Associations between rainbow trout and most other species are consistent between the basin level and within species' elevation envelopes. That is, the negative association between rainbow trout and bluehead sucker at the whole-basin level is not an artifact of living at disjunct elevations. Exceptions are Little Colorado sucker and Little Colorado spinedace, which have a significant negative association at the basin level, but within their envelopes of occurrence, they are less negatively associated with rainbow trout.

Other associations between Little Colorado sucker or Little Colorado spinedace and other species appear somewhat negative at the whole basin level, but neutral within their elevation envelopes. This apparent change in the nature of the association is related to the relatively restricted elevation ranges of Little Colorado sucker and Little Colorado spinedace. These results leave open speculation as to whether Little Colorado sucker and Little Colorado spinedace currently occupy elevation ranges restricted since introduction of non-natives, with which they are incompatible. If so, current habitat use may reflect avoidance of negative interactions with other species more than it reflects habitat preference. For instance, Davidson and Ward (1997a), citing Minckley and Carufel (1967), say that Little Colorado spinedace "may be trout-like in behavior and habitat requirements," and justify use of GAWS indices to discuss habitat quality for Little Colorado spinedace. If it is true that Little Colorado spinedace and trout general have similar habitat preferences, why did the current analysis show negative associations? The answer to these questions cannot be addressed by this analysis.

Just as occurrence of negative association may not demonstrate antagonistic interaction, positive association may not demonstrate positive interactions, only similar habitat use. Because they share the same narrow elevation envelope, Little Colorado sucker and Little Colorado spinedace are positively associated basin-wide, but are not associated within that elevation envelope. However, both species are positively associated with bluehead sucker, fathead minnow, and speckled dace within the basin and within their narrow elevation range. Note that we expect negative interactions between fathead minnows and larvae of suckers of the genus *Catostomus* (Dunsmoor 1993). In addition, Little Colorado sucker and brown trout show strong overlap basin-wide and within each species' elevation band, while Little Colorado spinedace shows a strong overlap with brook trout within the range of elevations where it occurs.

Table 4·9 P-values for tests of association between pairs of species. P-values in each row represent the proportion of bootstrapped samples for which the observed co-occurrence was surpassed. Note that a very high p-value might indicate a significant negative association between two species; very low p-values might indicate positive association. See text for discussion of special circumstances surrounding ONAP localities

Table 4·9·a Co-occurrence with other species at all sites in the basin. This table should be roughly symmetric

| Species | CASP | LEVI | ONAP | ONMY | PADI | PIPR | RHOS | SAFO | SATR |
|---|---|---|---|---|---|---|---|---|---|
| CASP | - | 0.000 | 0.916 | 0.972 | 0.000 | 0.000 | 0.000 | 0.939 | 0.044 |
| LEVI | 0.000 | - | 0.998 | 0.994 | 0.000 | 0.000 | 0.000 | 0.846 | 0.941 |
| ONAP | 0.929 | 0.999 | - | 0.999 | 0.999 | 0.999 | 0.999 | 0.964 | 0.998 |
| ONMY | 0.979 | 0.997 | 0.998 | - | 0.999 | 0.999 | 0.999 | 0.277 | 0.093 |
| PADI | 0.000 | 0.000 | 0.999 | 0.999 | - | 0.000 | 0.000 | 0.389 | 0.415 |
| PIPR | 0.000 | 0.000 | 0.998 | 0.999 | 0.000 | - | 0.000 | 0.571 | 0.637 |
| RHOS | 0.000 | 0.000 | 0.999 | 0.999 | 0.000 | 0.000 | - | 0.656 | 0.457 |
| SAFO | 0.943 | 0.862 | 0.963 | 0.273 | 0.397 | 0.573 | 0.649 | - | 0.008 |
| SATR | 0.039 | 0.943 | 0.993 | 0.088 | 0.429 | 0.626 | 0.475 | 0.011 | - |

Table 4·9·b Cooccurrence at sample sites within the elevation range of the focal species (identified in rows). This table will not necessarily be symmetric

| Species | CASP | LEVI | ONAP | ONMY | PADI | PIPR | RHOS | SAFO | SATR |
|---|---|---|---|---|---|---|---|---|---|
| CASP | - | 0.108 | 0.000 | 0.878 | 0.009 | 0.000 | 0.000 | 0.734 | 0.001 |
| LEVI | 0.129 | - | 0.000 | 0.926 | 0.000 | 0.002 | 0.000 | 0.018 | 0.541 |
| ONAP | 0.000 | 0.000 | - | 0.998 | 0.887 | 0.278 | 0.955 | 0.991 | 0.998 |
| ONMY | 0.964 | 0.999 | 0.999 | - | 0.999 | 0.999 | 0.999 | 0.001 | 0.095 |
| PADI | 0.000 | 0.000 | 0.999 | 0.999 | - | 0.000 | 0.000 | 0.437 | 0.408 |
| PIPR | 0.000 | 0.000 | 0.998 | 0.999 | 0.000 | - | 0.000 | 0.023 | 0.641 |
| RHOS | 0.000 | 0.000 | 0.999 | 0.999 | 0.000 | 0.000 | - | 0.667 | 0.486 |
| SAFO | 0.450 | 0.652 | 0.970 | 0.360 | 0.186 | 0.197 | 0.436 | - | 0.003 |
| SATR | 0.011 | 0.942 | 0.996 | 0.104 | 0.392 | 0.546 | 0.460 | 0.006 | - |

## Conclusions and Recommendations

### Do we Know which Factors Contribute to Native Fish Distributions?

The data used here provide information from fish locations that were non-randomly chosen with respect to geomorphic features. Furthermore, several samples were taken from the same spatial unit, for instance the same segment of stream. These samples are obviously not independent of one another. For this reason, statistical analysis of the samples in-hand can only be used to make inferences about the rest of the basin if: 1) spatial units that were sampled are representative of those that were not sampled, and 2) related samples (from the same spatial units) do not bias the analysis toward those units most heavily sampled. Both of these are major assumptions and will have to be considered carefully when evaluating the analysis. Also, for purposes of analysis, I had to assume that if a fish was present at a sampled site, it was also detected.

Are sampled stream reaches representative of those in the rest of the basin?

Stream orders and elevation categories were not sampled in proportion to their prevalence (Chapter 3). This means that results of this analysis cannot be easily applied to unsampled areas. Also, some unsampled segments of fifth through seventh order streams do not hold permanent or even interrupted water (D. Dorum, pers. comm.). If this pattern holds up, and unsampled segments are not viable fish habitat, we come to the disturbing conclusion that much more of the fifth through seventh order streams in the area might be suitable for fish management if they held water. This implies that strong management emphasis for the watershed should be directed at recovering flow patterns in these areas.

How might samples from the same geomorphic units bias the analysis?
All other habitat variables being similar, samples taken close together are expected to be more similar than samples taken far apart. This means that if a fish is detected at one site, it is likely to be detected at nearby sites. If a fish is absent at one site, it is likely to be absent at nearby sites. Some protocols used to collect data analyzed here specifically call for sampling of a series of neighboring sites, one after the other. This would affect the analysis by making some associations with other species or with particular habitats seem quite strong although the actual associations in the basin overall are weaker.

Interpreting absence
In this analysis, I assumed that during a given collection, biologists could determine whether a species was present or absent. However, while we can state confidently that if a fish was caught, it was present, failure to detect a fish does *not* mean it was absent. Whether the records can also be used to evaluate absence depends on how complete the surveys were. For instance, of the 552 visits to stream habitats in the ULCR, 41 covered at least 200 m (656 ft) of channel length. Another measure of our confidence might be the use of depletion sweeps. Three-pass depletion sampling was done at 182 sites that were 50 m (164 ft) long. Each approach relies on a different means of sampling thoroughly, and it is beyond the scope of the data set to compare the two. Considering only the three-pass depletion samples, Table 4·10 reports how often species that were detected at these sites were first detected on the first, second, or third pass. Little Colorado sucker was only detected one time during three-pass depletion sampling, so no evaluation is possible. Ninety-five percent confidence intervals are reported for likelihood of detecting on the first pass, and those for Little Colorado spinedace, bluehead sucker, and brook trout have detection rates that are statistically lower than 100%. There is no particular reason to use 95% confidence intervals, and if we are conservative and consider 90% confidence intervals, we would conclude that fathead minnow and speckled dace detection is also compromised if one-pass sampling is used. Because different protocols were used to collect data for this data set, it is not clear how sampling effectiveness has affected this analysis. Sampling effectiveness does not affect how data are analyzed; however, it affects how we interpret the analysis. We cannot exclude the possibility that each species uses habitats beyond the range of elevation, stream order, etc. where it has been seen. It is also possible that some species are more common than reported in harder-to-sample habitats such as deep pools.

Number of samples available for analysis of different habitat variables
Table 4·8 indicates the number of samples collected with information on the variable of interest, taken in the elevation range of the species. The number of samples available for analysis varies considerably according to the variable of interest, which means there were less powerful analyses for some variables than for others. Some variables were constrained not only in number but also in location. GAWS surveys in the ULCR basin do not go below 2177 m (7142 ft). This leaves out over 300 m (984 ft) from the elevation range of Little Colorado sucker, Little Colorado spinedace, bluehead sucker, fathead minnow, and speckled dace, and represents the majority of the observed elevation range of Little Colorado sucker and Little Colorado spinedace. The elevation restriction

of GAWS surveys is also smaller than the observed elevation range of rainbow trout, brook trout, and brown trout in this basin.

Table 4·10 At sites where a species was eventually caught, likelihood of capture on first, second, third depletion pass. Only sites used for three-pass depletion were considered

| | | Pass in which species first occurred | | | | |
|---|---|---|---|---|---|---|
| Species | Samples in which caught | 1st | 2nd | 3rd | Probability caught on first pass | 95% Confidence interval |
| CASP | 1 | 1 | | | | |
| LEVI | 34 | 29 | 4 | 1 | 0.85 | [0.734, 0.972] |
| ONAP | 17 | 16 | 1 | | 0.94 | [0.829, 1.053] |
| ONMY | 69 | 67 | 1 | 1 | 0.97 | [0.931, 1.011] |
| PADI | 53 | 44 | 8 | 1 | 0.83 | [0.729, 0.931] |
| PIPR | 29 | 23 | 6 | | 0.79 | [0.646, 0.941] |
| RHOS | 67 | 59 | 6 | 2 | 0.88 | [0.803, 0.958] |
| SAFO | 37 | 29 | 7 | 1 | 0.78 | [0.651, 0.916] |
| SATR | 45 | 43 | 2 | | 0.96 | [0.895, 1.016] |

## Questions we Would Like to Answer but Cannot

### Species associations

Table 4·5 indicates which species pairs occurred together more or less often than expected by random chance. What do these patterns mean? Negative associations may mean that the species have negative interactions, or they may indicate that the species use very different habitat. It may be that a different set of sample sites would not have shown any pattern. Observational data, such as was used here, can be used to identify patterns, but it is not possible to use these data to decide which of the above interpretations is correct.

### Habitat use

As with species associations, we cannot unequivocally interpret associations between species and habitat variables. In addition, the ability to test for associations was much lower for some variables than for others. Table 4·8 indicates the number of samples in the chosen elevation range with information for each variable, and numbers differ greatly among variables.

### Modifying Sampling Protocols to Collect Data Appropriate to this Type of Analysis

Table 4·8 reports that for the data set used, fish presence in a sample could often be predicted based on elevation or stream order. However, the table also shows that some elevations or stream orders were poorly sampled, so data for analysis were very unbalanced. Ideally, the same number of samples would be collected from each stratum of interest (elevation or stream order, for example), regardless of how many linear miles of that stratum exist in the drainage. Within each stratum, samples should also be carefully collected to represent a range of stream widths, substrates, and types. Examination of the Fish Collection Database indicates these other variables may be very informative as well. Above all, samples should be collected using random site selection within strata. Reliance on a single protocol developed to evaluate suitability of habitat for trout (GAWS) will interfere with developing more appropriate sampling procedures, and will affect interpretation.

### How these Data Could be Applied in a Watershed Management Plan

The data used for this analysis were originally collected for other purposes. Reports written using these data have concentrated on describing the condition of the stream, and for stating whether a particular species was present at a given site. The data are therefore easiest to apply at the local scale, and are used this way in the Integrated Fisheries Management Plan proposed in Chapter 5. However, the current condition of fisheries is not only a function of interspecific interactions, but also of available habitat. Habitat, described for instance by width or depth of a water channel, is clearly a function of processes at different scales. Many of these processes originate outside the water channel, which also takes them outside the realm of traditional fisheries surveys and monitoring. The analyses presented here could help bridge the type of information we might get from watershed analysis and the information we generate as wildlife biologists.

The approach used here to describe habitat and species assemblage where each species was found has rarely been done before at AGFD (but see Robinson and others 1998). This approach should be carried to a more realistic level by trying to describe habitat use of all stages of the life cycle for species of interest. In other words, habitat for a particular species is not one thing; a range of habitats may be useable by the species, with some habitats being more effective, while others are of most importance for one part of the life cycle. It is critical to describe the types, quantities, and distribution of habitat types needed to complete the life cycle of a given fish species.

The analyses presented here hint at descriptions of habitat use by species in a subbasin of the Little Colorado River. To make habitat use descriptions useful for management it would also be necessary to assess the current and potential availability of these habitats in the river basin. Instead, fish monitoring projects usually include habitat measurements made at a very local scale, but it is not clear how to link these descriptions to processes that generate such habitats. For instance, before offering management suggestions, reports on pool-to-riffle ratios in specific streams would do well to evaluate upstream processes that might explain adverse changes. Linking local habitat to processes that modify it would require descriptive and dynamic watershed analysis, which has not traditionally been part of fish monitoring projects. Following such a watershed analysis, native fish experts could consider the current extent and location of suitable habitat constellations, and could advise management on amount and connectivity of habitat necessary to attain conservation and management goals.

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# CHAPTER 5: DEVELOPMENT OF AN INTEGRATED FISHERIES MANAGEMENT PLAN FOR THE LITTLE COLORADO RIVER WATERSHED

David B. Dorum and E. Patricia Lopez

## INTRODUCTION

This project was undertaken in order to develop an approach to integrate the management of fish resources on the scale of a watershed. This differs from current practices of managing fish at population or species levels. Although this plan does not address watershed management per se, we intend to make the databases and other resources we have assembled available to entities undertaking wider watershed management planing. We hope that in this way, this work will lend itself to the addition of management prescriptions aimed at other taxa, and would constitute the fisheries portion of a broader reaching watershed management plan.

The project has three goals: 1) To reduce current and future potential conflicts between native fish management and non-native sportfish management; 2) To provide an integrated management strategy whereby all fish management activities within the watershed work toward meeting long-term fisheries goals for the watershed; 3) To cultivate a pro-active stance toward native fish, thus improving the status of native fish within the watershed, promoting delisting of currently listed species, and preventing the need for future federal listing.

These goals translate into the need to have a variety of fish species within the watershed. These fish can broadly be categorized into game species (sportfish) and native fish species. With two exceptions (roundtail chub and Apache trout), sportfish in Arizona are non-native. Because these groups of fish generally have different biological requirements and are managed for different purposes and by different means, it makes sense that they be examined using different criteria, and where necessary, managed in geographically discrete areas.

Fish management actions are implemented to achieve management goals for target species. The specific type of management action is further delineated by, among other things, habitat type, land ownership and the physico-chemical properties of the waters being managed. Given this and the logistical limits inherent to management programs, a body of water with a homogeneous set of the above-mentioned factors constitutes a logical geographic unit on which to apply a set of management actions. Following this reasoning, we decided the approach to take for this plan is to divide waters within the watershed into sub-basins, and then further divide them into individual units of management. Using a specific set of criteria, we determine the highest and best use for each unit, that is, whether the unit would help meet native fish conservation and recovery goals, or whether it is better suited to serve the needs of the angling public. For each unit, we list desired fish species and management actions designed to bring about or maintain the desired fish species assemblage.

Preceding chapters have presented the history and background of the project as it relates to fisheries management, a description of the physical geography of the Little Colorado River (LCR) watershed, analyses of existing fisheries data and their applications, and a discussion on the use of GIS and creation of habitat suitability models.

This chapter will focus on the methods used to arrive at both a process and a plan. The process is one that we hope to apply to other watersheds, with only minor modifications as necessary to accommodate the unique circumstances within any given watershed, while the plan itself is specific to the LCR watershed and consists of detailed descriptions of physical, biological, and social characteristics, along with specific management prescriptions for all known waters that could conceivably constitute fish habitat. Additionally, this chapter contains the results of a brief analysis and summary of the management unit summaries.

## METHODS

Except where noted, the Core Management Planning Group (CMPG) carried out the actions and decisions made in formulating this plan. The CMPG is comprised of six Department professionals: the Regional Fisheries Program Managers within whose region the watershed lies, (in this case Jim Novy in Region I, based out of Pinetop and Scott Reger in Region II, based out of Flagstaff), the Fish Management Program Supervisor (Bill Silvey, now retired), the Nongame Native Fish Program Manager (Kirk Young, now the Fish Management Program Supervisor), the Watershed Fisheries Management Project Coordinator (David Dorum), and the Nongame Senior GIS Analyst (Jim Hatten). In addition, we sought input and feedback from other agency and academic professionals at several stages in the plan's development.

The process we developed and followed to achieve the goals of the plan is mapped in Figure 5·1 a-d. The process incorporates the following components, which were carried out by different groups of individuals, either simultaneously or sequentially:

1. Gathering and georeferencing of fisheries data from the LCR watershed
2. Determination of angler and native fish needs in the LCR watershed
3. Watershed analysis and development of habitat suitability models
4. Management unit delineation
5. Determination of management emphasis and initial management recommendations
6. Intra and inter-unit conflict resolution
7. Evaluation, internal and external review, and implementation

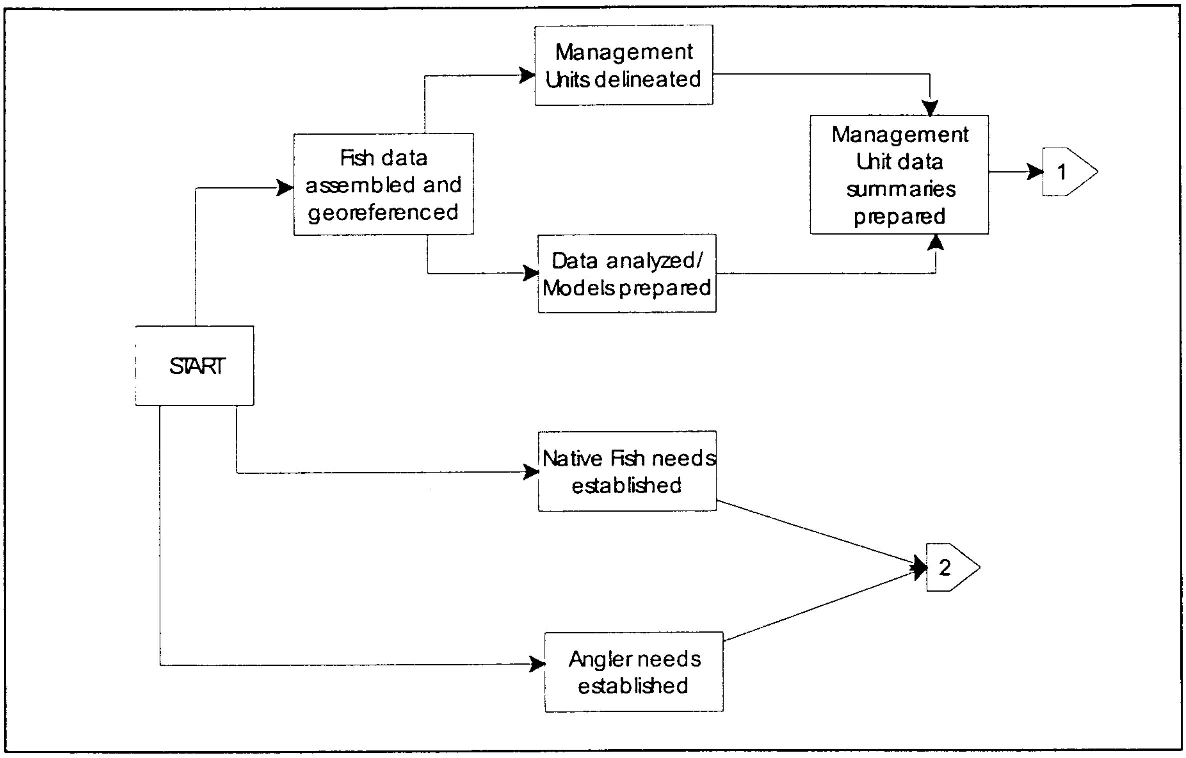



Figure 5·1·a Process map: data assembly and analysis

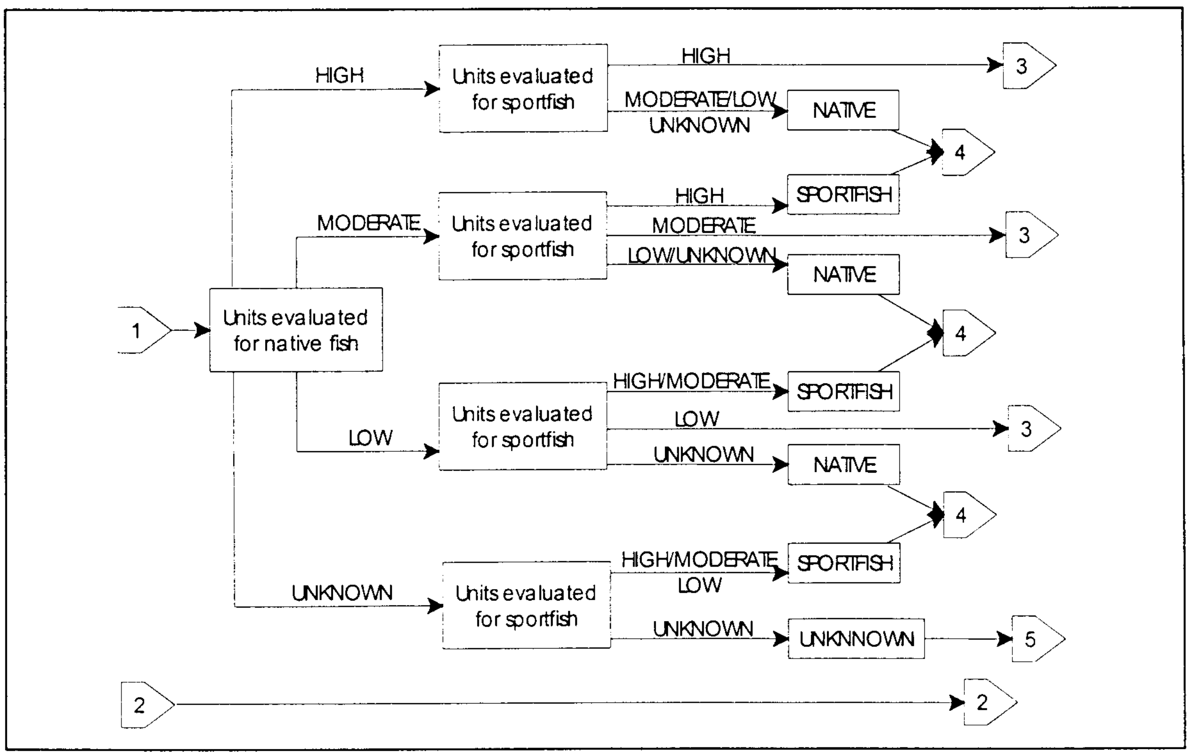



Figure 5·1·b Process map: management unit evaluation

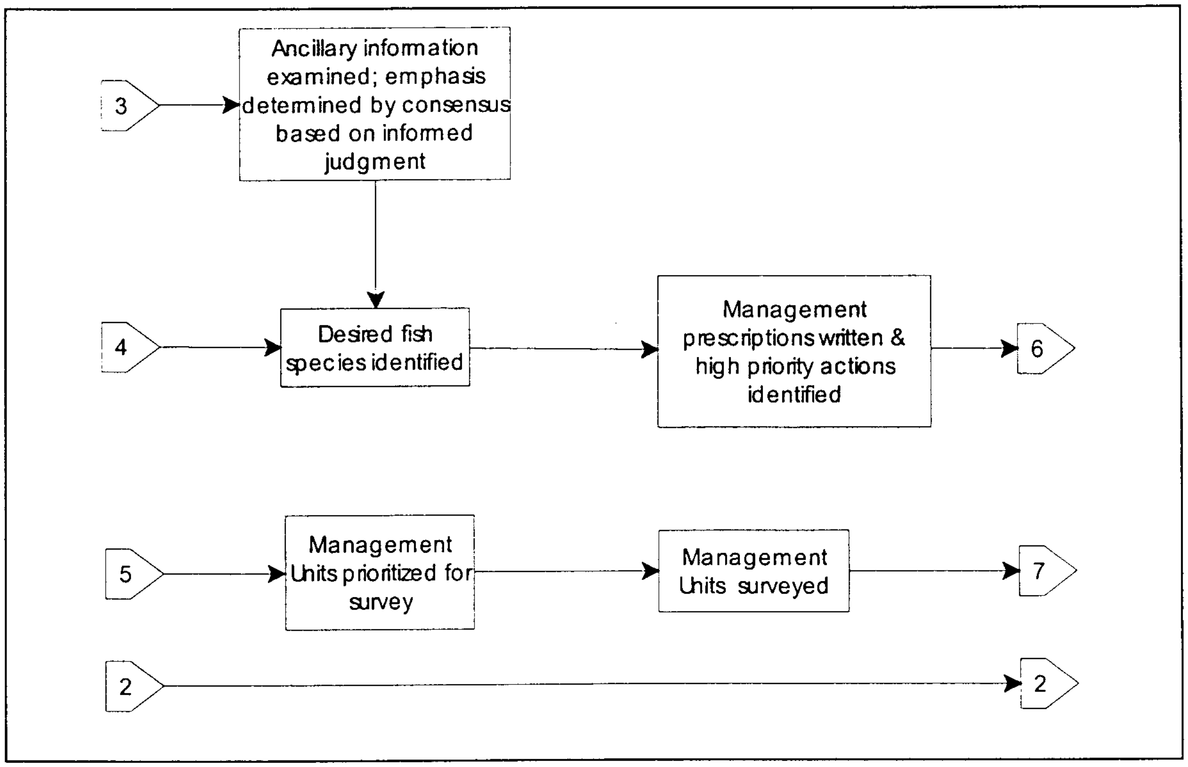



Figure 5-1-c Process map: management prescriptions

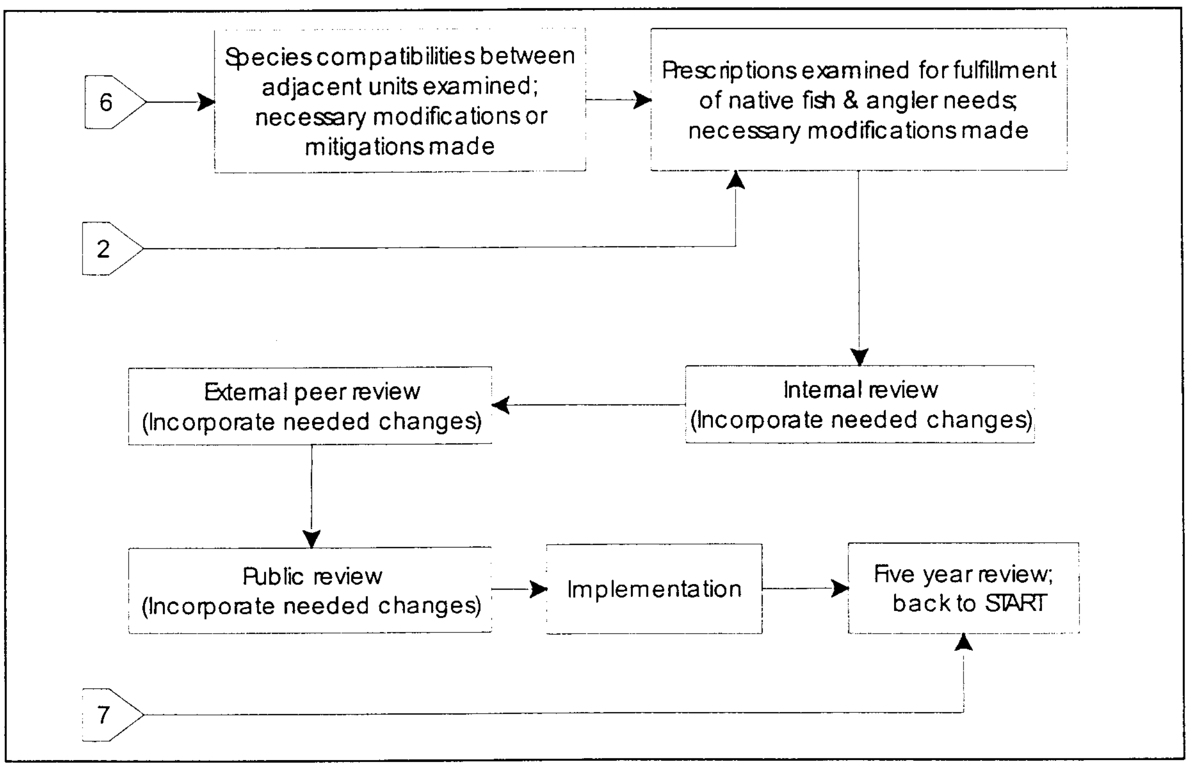



Figure 5-1-d Process map: review and implementation

### GATHERING AND GEOREFERENCING OF FISHERIES DATA FROM THE LCR WATERSHED

Project personnel (David Dorum and Pat Lopez) compiled fish occurrence data from existing databases both within and outside the Department. General fish survey information from AGFD Regional surveys, Research Branch surveys, selected surveys done by the US Forest Service, the Bureau of Land Management, and The Nature Conservancy was georeferenced and incorporated into the Native Fish Database, which was subsequently renamed the FISH COLLECTION database. Museum fish collection records from the University of Michigan Museum of Zoology, the Museum of Southwestern Biology, the National Museum of Natural History, the Museum of Northern Arizona, Arizona State University Fish Collection, and the University of Arizona Fish Collection were georeferenced and compiled into a computerized MUSEUM database.

Other databases accessed include the Fisheries Branch STOCKING database, the HERITAGE DATA MANAGEMENT SYSTEM (HDMS) database, the newly created Region I CREEL database, the Fisheries Branch RUN WILD database, and the State Lands Department GIS database. CREEL, STOCKING, HDMS and State Lands databases are all georeferenced.

### DETERMINATION OF NATIVE FISH AND ANGLER NEEDS IN THE LCR WATERSHED

In order to fulfill the objectives set forth in this plan, it was imperative to determine the minimum number of populations required for each native fish species to maintain that species in the watershed. Because information crucial to making such determinations (habitat use for instance) is incomplete or missing for a number of native fish species, it was necessary to gather a group of experienced native fish biologists from other agencies and academia to help determine native fish needs. The main objective of the group was to determine the desired locations and numbers of populations for each species of native fish in the LCR watershed. Desired locations were identified to basin level (e.g. one population of spinedace in the Silver Creek basin).

This step was carried out concurrently with, and independent of, the development of habitat suitability models and the delineation of management units.

An analogous analysis of the needs and desires of anglers is necessary to balance the interests of this plan. These desires may include, for example, opportunities to fish for a specific species or size class of fish, fishing at a special location, or fishing from boats. Of course public desires must be compatible with the watershed's capacity to effect them in order to be considered. At the time of writing, however, we did not have the detailed information needed to make such determinations. Fisheries Branch personnel are currently developing a method of obtaining this information. In the meantime, Department Fisheries personnel affirm that angler needs within the LCR are currently being met or exceeded.

### DEVELOPMENT OF HABITAT SUITABILITY MODELS

The objectives of this section were to provide information on geomorphology, native and sportfishes habitat preferences within the LCR watershed, and to develop habitat suitability models for four native fish (LC spinedace, speckled dace, bluehead sucker, and LC sucker). A full discussion of this topic is found in chapter 3. In this chapter, we use the habitat suitability models as a multi-purpose tool for such tasks as prioritizing areas for survey for which we have no fish survey data, and to help justify the repatriation of species into areas where we suspect they might have been historically but for which there are no collection records.

### Management Unit Delineation

We define "management unit" as any stream or length thereof, or any other body of water (such as lakes, reservoirs, stock tanks, or ponds). The language of this definition is intended to be all encompassing so that all possible fish habitats are considered. As such, "management unit" includes only aquatic habitats. More precisely, streams or portions of streams are designated a management unit if they meet one of the following conditions:

1. The channel is documented as being perennial (generally included in the AGFD Perennial Coverage), and therefore is believed to hold potential for fisheries management
2. Although not included in the AGFD Perennial Coverage, there is reason to believe that all or a portion of the channel may be perennial (based on fisheries survey data, knowledge of CMPG members, personal communication with people familiar with the channel in question, USGS 7.5' Topographic map blue lines indicating potentially perennial channels, and/or proximity and topographic similarity to known perennial channels).

Determining the physical boundaries of these management units is the first step in formulating the actual plan. We delineate management units in order to provide fisheries managers and land management agency personnel with the relevant, site specific management actions needed for the effective, on the ground management of a desired fish species assemblage.

Delineation began by breaking the LCR watershed streams into basins following USGS hydrologic unit boundaries. Within each basin, we then delineated specific management units based on one or more of the criteria listed below:

- Areas of change in fish species occurrence
- Areas of significant change in maximum and/or minimum water temperature or other water quality parameters
- Areas of significant change in habitat condition (quality)
- Areas of change in habitat type (lake vs. stream, perennial vs. ephemeral or intermittent)
- Areas of significant change in flow regime (natural vs. modified hydrograph), water rights, or water use
- Areas of significant geomorphologic change (stream elevation, gradient, substrate, etc.)
- Areas of change in stream order
- Locations of current or potential future barriers/hindrances to upstream and/or downstream fish movement
- Areas delineated in species recovery plans or other wildlife/habitat management plans

- Current or known future land ownership boundaries
- Land use boundaries
- Areas of uncertain status, where more in-depth data analysis/collection is needed

New GIS layers and associated databases were created for both lentic management units and lotic management units (LAKE and STREAM).

DETERMINATION OF MANAGEMENT EMPHASIS AND MANAGEMENT RECOMMENDATIONS

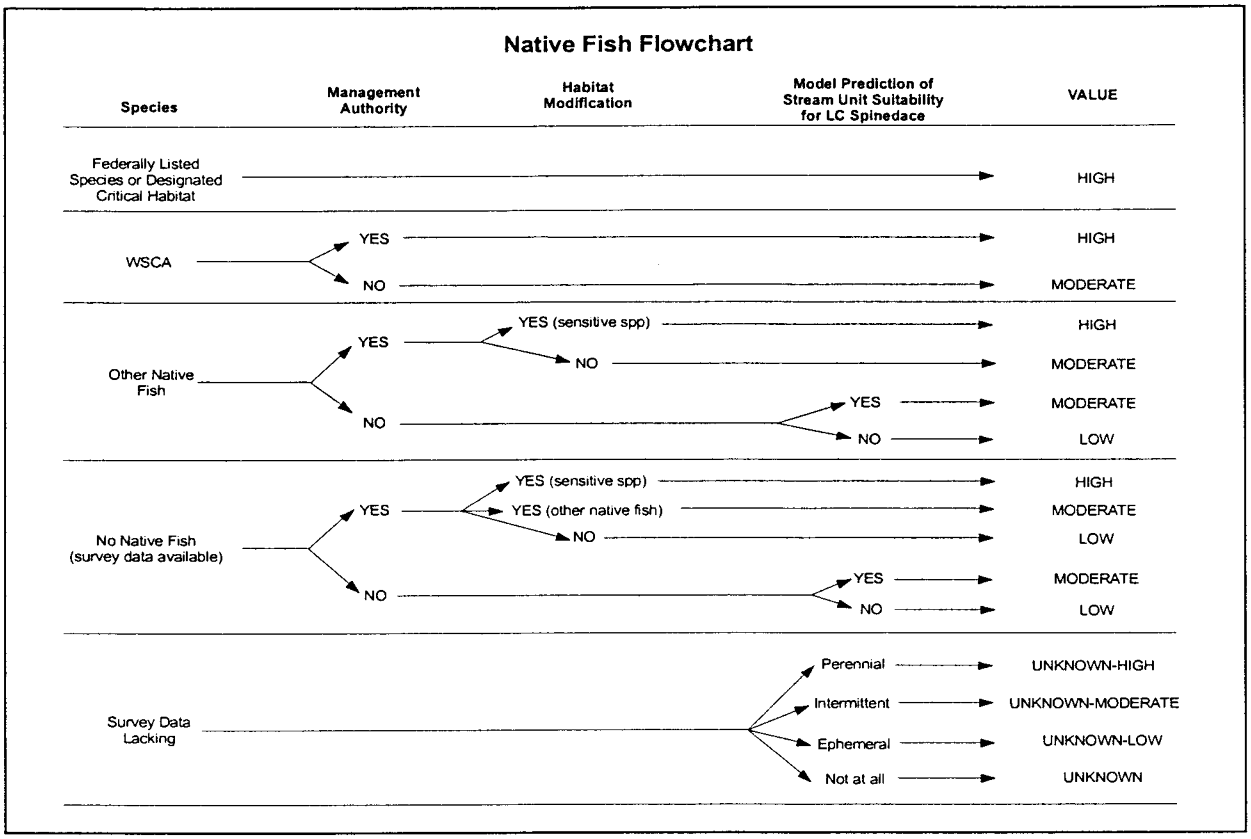
For each management unit, project personnel prepared data summaries containing the following information, if available: physical parameters (UTMs, elevation, flow type, etc.), vehicular access, fish species occurrence, the occurrence of non-fish sensitive species (listed in HDMS), critical habitat designations, land ownership, stocking information, special angling regulations, and any other pertinent information such as notes about past chemical renovations or die-offs.

With summarized information in hand, we evaluate each unit's relative value for native fish conservation using the Native Fish Flowchart (Figure 5·2·a); we then evaluate the unit's relative value for sportfish opportunities using the Sportfish Flowchart (Figure 5·2·b). Flowcharts were developed by two groups of fisheries personnel from various branches of the Department. Participants discussed, then agreed upon what gives value or importance to a particular body of water from the standpoint of either native fish management or sportfish management.

Criteria used to evaluate a unit's relative value for native fish are: the presence of native fish species and their listing status; the Department's ability to manage wildlife in the management unit (tied to land ownership); the potential for renovating a unit, if necessary, for translocation of sensitive fish; and, in the absence of native fish or fish occurrence data, whether the management unit in question is within potentially suitable habitat for LC spinedace (the only federally listed species for which a habitat suitability model was created). Habitat suitability models are based on four variables (flow type, stream order, link-slope, and elevation). Criteria are all examined sequentially, and not all need contribute to the value of a management unit.

Possible outcomes of the flowchart are HIGH, MODERATE, LOW and UNKNOWN (usually due to lack of data). We underscore that the values thus arrived at are management values, that is, both biological and non-biological criteria are used to arrive at the values (Figure 5·2·a Native fish flowchart definitions).

Criteria used to evaluate a unit's relative value as a sportfishery are: access; the type of fishery (either self-sustained or not, or a special fishery concept not dependent upon the other criteria to be of high value); relative angler use for the given type of fishery; and the potential for increasing angler use at the site by reasonably feasible means. Possible outcomes for the sportfish flowchart are HIGH, MODERATE, LOW and UNKNOWN. Again, these values represent the unit's relative value from a management perspective.




## Figure 5·2·a Management unit evaluation flowchart for native fish

Native fish flowchart definitions

1. Species
   - Federally listed species or designated critical habitat: the management unit lies within or partially within critical habitat, or listed fish occur. In the LCR drainage, listed species are humpback chub, Little Colorado spinedace, razorback sucker, and Apache trout
   - WSCA: surveys indicate the presence of fish species listed in Wildlife of Special Concern in Arizona (draft). In the LCR drainage, the only WSCA species is roundtail chub
   - Other native fish: non-federally listed and non-WSCA species occur within the management unit
   - No native fish: repeated surveys in a given management unit have not revealed the presence of any native fish
   - Survey data lacking: the management unit has never been surveyed for fish or fish surveys are more than 10 years old

2. Management authority
   - Yes: the management unit is predominantly federally owned land, AGFD owned land, or privately owned land (including tribal and local government properties and State Trust Land) where there is a history of commitment to conservation or a M.O.U.
   - No: the management unit is predominantly privately owned land, tribal land, and State Trust Land

3. Habitat modification
   - Yes: the management unit is suitable for translocation of sensitive native fish, or could be made to be with effective habitat modification or renovation. The action must be within the technical, financial, and jurisdictional ability of the Department to effect, either independently or with the cooperation of other government and/or private entities. Effective is defined as likely to maintain the desired result for the foreseeable future, with little or no maintenance
   - No: the habitat in the management unit is unsuitable and cannot be effectively modified as defined above

4. Model prediction of stream unit suitability
   - Yes: geomorphic suitability models predict the presence of LC spinedace within a management unit based on four variables: elevation, water type, stream order and link slope. Only the stream type is shown in the flowchart, and it must be perennial
   - No: the geomorphic suitability model indicates the area is not perennial

Where survey data is lacking, geomorphic suitability models are used to prioritize the management unit for future surveys. The area falls within a geomorphic suitability envelope for LC spinedace, which incorporates elevation, stream order, link slope, and stream type. Priorities are determined by stream type, with perennial waters being most urgently in need of survey.

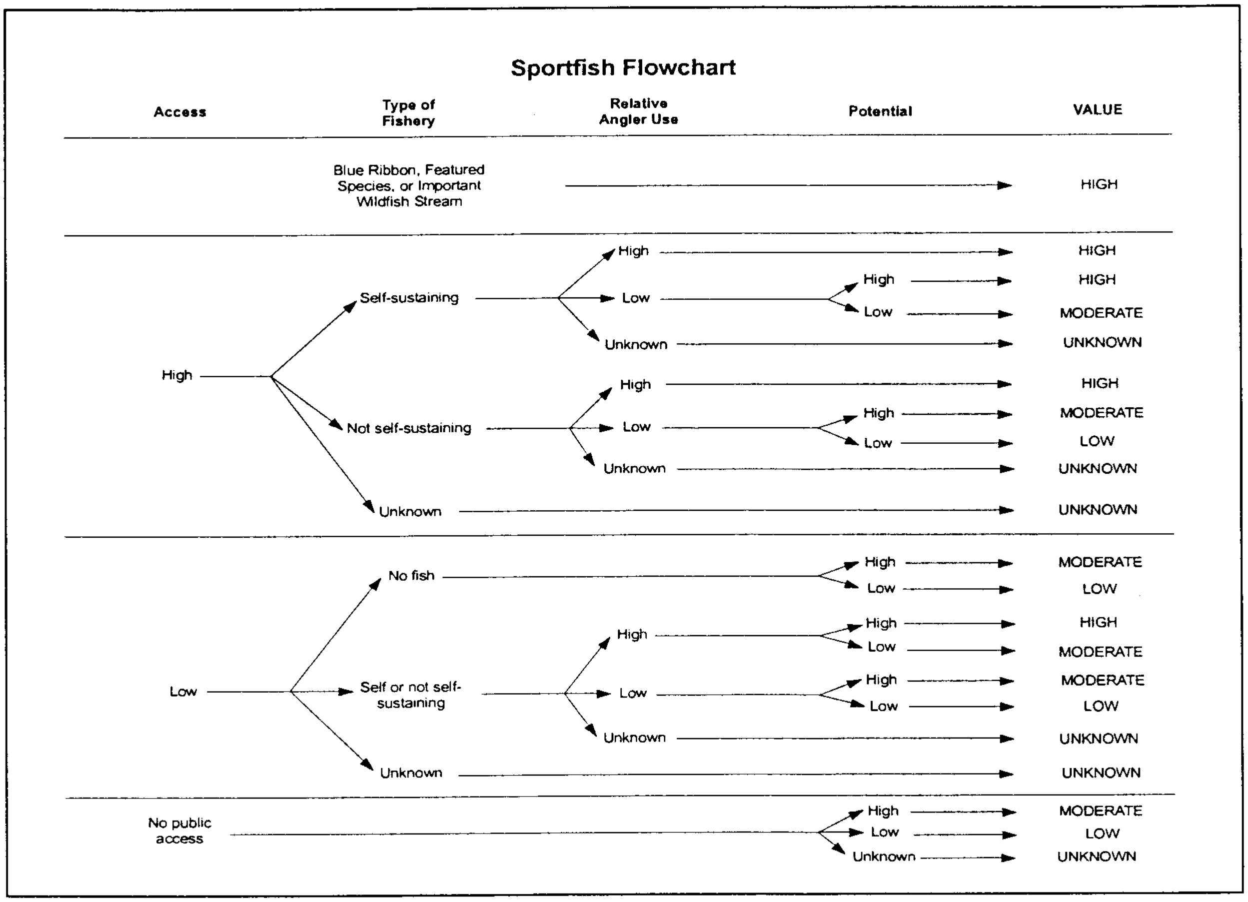



Figure 5-2-b Management unit evaluation flowchart for sportfish

Sportfish flowchart definitions

If closed to fishing, a management unit is not evaluated for sportfish

1. Access
   - High: accessible to the public by two-wheel drive vehicle or motorized boat
   - Low: accessible to the public by four-wheel drive/off-road vehicle, by non-motorized boat, or by foot, or access is limited by special permits
   - No public access: private landowner restricts access, or the area is not accessible by foot or boat

2. Type of fishery
   For the purposes of this evaluation, only the self-sustaining presence of desired sportfish are considered
   - Self-sustaining: the persistence of the fish is not dependent on stocking, either in the unit or near it
   - Not self-sustaining: the persistence of fish is dependent on stocking, either directly in the unit, or at a point nearby from which the fish can easily migrate

3. Relative angler use
   - High or Low with respect to the type of fishery in the unit. Potential sources of information for determining relative angler use are : AGFD creel surveys, surveys of regional fisheries personnel and wildlife managers, National/State Parks surveys
   - Unknown: no information is available

4. Potential
   High or Low as determined by the likelihood of significant increase in angler use by improving access, changing the type of fishery, or through education/management modification. Improvements must be within the technical, financial, and jurisdictional ability of the Department to effectuate, either independently, or with the cooperation of other government and/or private entities.

Once we evaluated a unit for both its native and sportfish value, we compared the relative values to each other; the higher of the two determined the management unit's ultimate management emphasis. For example, if a unit rated MODERATE for native fish and LOW for sportfish, that unit was assigned a native fish management emphasis. We then identified the desirable fish species composition for the unit. Often, this list is comprised of all native fish or all sportfish, but can contain both, and does not exclude any fish already present in the unit, except where specified. The desired native fish species were determined by evaluating current and historic fish collection records and the habitat suitability models.

When values were the same for both native and sportfish (i.e. MODERATE/MODERATE), we further examined the unit in the context of contiguous units and other ancillary data; we then selected an appropriate management emphasis by consensus and based on an informed judgment.

At the time of evaluation and emphasis designation, and in consultation with the regional fisheries program manager concerned, we made management recommendations for each unit, and added these, along with emphasis and desired species, to the unit summary sheets. At monthly meetings, CMPG members were provided the opportunity to review decisions and recommendations for each unit and to make changes as needed.

Management units which received an UNKNOWN value form both the native fish flowchart and the sportfish flowchart did not receive an emphasis nor a listing of desired species, since insufficient data was available to us. These units did, however, receive management recommendations, which consisted of the recommendation that the unit be surveyed, and whether the survey was deemed a priority or not (generally based on the habitat suitability model for LC spinedace). Following survey results, these units will be reevaluated.

Privately owned lakes and ponds were not evaluated in this plan. We included them for informational purposes only. We also did not evaluate a stream reach being used as part of a hatchery because it already has a special and important purpose as a fish production facility.

All of the descriptive information from unit summaries as well as desired species and management emphasis was entered into the georeferenced STREAM and LAKE databases. Separate databases were created for the easy handling of both notes and management recommendations.

### Intra and Inter-unit Conflict Resolution For Desired Fish Species

In order to reduce current and future potential conflicts between native fish management and non-native sportfish management, we must recognizing that management units are interconnected and do not function independently of one another. It is therefore important to look at the possible effect of management recommendations of one unit upon adjacent units. More specifically, it is important to examine the relationships between the different desired fish species. The following is a description of the methods developed by the CMPG for identifying and addressing potential inter-species conflicts.

At some level, all fish species occurring together interact. These relationships are frequently adversarial in nature, and are manifested by competition, hybridization, or direct predation. Since our objective at this stage, however, is to examine the interactions of the desired fish species in one management unit with those in adjacent units, we selected only those species pairs that, if managed for together or in adjacent waters, might jeopardize our management goals by pitting them against one another. For instance, any non-native predatory fish managed for in the presence of a listed or WSCA native fish species is cause for concern.

While we recognize the deleterious effect of non-native, non-sportfish species, such as carp and small baitfishes such as golden shiner or fathead minnows, nowhere in the LCR watershed do we include these species among those that are desirable, and therefore we do not consider them for antagonistic pairing. These species are addressed on a case by case basis within the management unit recommendations.

Because we emphasized managing for native fish assemblages within management units, we did not feel that it was necessary to examine the interaction between non-native piscivorous species and the non-listed native fish. Instead, we relied on the presence of sensitive fish species and the subsequent conservation and recovery efforts afforded them to provide adequate safeguards for these species. Nor were we concerned with possible antagonistic pairs of non-native sportfish.

Of the desired non-native piscivorous species that occur in the LCR watershed, many are strictly lake or larger river fishes, and only occasionally find themselves, usually after a flood event, in streams where they remain only temporarily and thus have minimal impact on any native fish fauna present (J. Novy, pers. comm.). We have eliminated such species from consideration: bluegill, northern pike, largemouth bass, yellow perch, and black crappie. In addition, we discounted those non-native piscivorous fish that we did not include as a desired species: black and yellow bullheads, and green sunfish. Again, these species are dealt with on a case by case basis within the management unit recommendations.

We also excluded from consideration those native fish (flannelmouth sucker, humpback chub, and razorback sucker) that, within the LCR watershed, occur only within the downstream most management unit (LCR001; Little Colorado River, Colorado River to Navajo Indian Reservation Boundary), since there are no adjacent management units for which we have a desired fish species assemblage, and the desired species assemblage for the unit itself consists solely of native fish. The nearest management unit (LCR003; Little Colorado River, Navajo Indian Reservation Boundary near Winslow to Woodruff Dam on Silver Creek) is separated from LCR001 by over 151 miles (243 km) of intermittent stream channel.

All of the above considerations yielded the following pairs of species that may present a conflict if they are managed for together or in close proximity:

Apache trout - Roundtail chub
Apache trout - LC spinedace
Apache trout - Channel catfish
Apache trout - Walleye
Apache trout - Smallmouth bass
Apache trout - Rainbow trout
Apache trout - Brown trout
Apache trout - Brook trout
Roundtail chub - LC spinedace
Roundtail chub - Channel catfish
Roundtail chub - Brook trout
Roundtail chub - Rainbow trout
Roundtail chub - Smallmouth bass
Roundtail chub - Walleye
Roundtail chub - Brown trout
LC spinedace - Brook trout
LC spinedace - Channel catfish
LC spinedace - Walleye
LC spinedace - Smallmouth bass
LC spinedace - Rainbow trout
LC spinedace - Brown trout

We listed all management units that contain the above species pairs as desired species and our Senior GIS Specialist wrote a program that sought these same pairs in adjacent units. We examined the outputs in conjunction with management recommendations for their respective units. In some cases, we modified management unit boundaries, management recommendations, and/or the desired species assemblage. In the species compatibility section, we list mitigating factors, or explanations for the situation and why it cannot be changed.

EVALUATION, INTERNAL AND EXTERNAL REVIEW, AND IMPLEMENTATION

In the course of the development of the Integrated Fisheries Management Plan, extensive reviews were repeatedly conducted, both internally (Department personnel) and externally (federal agencies, academia, interested public) at various stages of the plans completion.

An evaluation of how well the plan has met the stated goals for this project can only come after the plan has been implemented, and results from the various management actions have been assessed. If implemented, we are envisioning a five year review period for the plan, at which time the CMPG will be expected to go through the entire process again, and make changes to the process and the plan as necessary. A critique of the process will also be undertaken prior to any integrated fisheries management planing in subsequent watersheds.

## RESULTS

### NATIVE FISH NEEDS

This section is composed of two separate results. The first, in regular type, are the actual recommendations made by a group of native fish experts for each species of native fish in the LCR above Grand Falls[a]. The second, in Italics, is a statement of how the final management plan addresses those recommendations. These statements may be cross-reference with management recommendations for specific units found in Appendix A. Also, for a graphic display of the current situation and what is planned for native fish, please see maps showing current and desired locations in Appendix B)

Little Colorado Spinedace

Manage this species in accordance with the 1997 Recovery Plan, which calls for the maintenance of the existing known populations at the following locations:

- East Clear Creek drainage, above Blue Ridge Reservoir
  *Addressed by desired species and management recommendations for CLE007: East Clear Creek, Blue Ridge Reservoir to Potato Lake*
- East Clear Creek drainage, below Blue Ridge Reservoir
  *Addressed by desired species and management recommendations for LEO001: Leonard Canyon, East Clear Creek to Knoll Lake*
- Chevelon Creek, near the LCR confluence
  *Addressed by desired species and management recommendations for CHE001: Chevelon Canyon, Little Colorado River to Horse Canyon*
- Portions of Nutrioso and Rudd Creeks
  *Addressed by our desired species and management recommendations for NUT002: Nutrioso Creek, Forest Boundary to Nelson Reservoir; NUT004: Nutrioso Creek, Nelson Reservoir to Hulsey Creek; and RUD001: Rudd Creek, Nutrioso Creek to McKay Reservoir Diversion*
- Silver Creek, downstream of Canoncito gauging station
  *Addressed by desired species and management recommendations for SIL001: Silver Creek, Woodruff Dam to Southern Canyon Boundary*
- Upper Little Colorado River from Zion Reservoir upstream
  *Addressed by desired species and management recommendations for LCR006: Zion Reservoir to Lyman Lake; LCR008: Lyman Lake to Nutrioso Creek; and LCR009: Nutrioso Creek to 261 Road Crossing*

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[a] Native Fish Expert Group Meeting participants (November 17, 1998): Rob Clarkson, U.S. Bureau of Reclamation; Stewart Jacks, U.S. Fish and Wildlife Service; Dennis Kubly, Arizona Game and Fish Department; Paul Marsh, Arizona State University; Chuck Minckley, U.S. Fish and Wildlife Service; Terry Meyers, Apache-Sitgreaves National Forest; Scott Reger, Arizona Game and Fish Department; John Rinne, Rocky Mountain Experimental Stattion, USFS; Tony Robinson, Arizona Game and Fish Department; Roger Sorenen, Arizona Game and Fish Department; Kirk Young, Arizona Game and Fish Departmrent

In addition, the Recovery Plan calls for the establishment of refugia populations for each of the drainages where current populations exist:

- East Clear Creek above Blue Ridge Reservoir: Potato Lake is identified as a possible refugium site in the Recovery Plan
  *Addressed by desired species and management recommendations for POT002: Potato Lake; and HOU002: Houston Draw, Forest Road 95 to Headwaters*
- East Clear Creek below Blue Ridge Reservoir: no specific site is mentioned in the Recovery Plan but Hart Canyon, a tributary of Willow Creek has been suggested. A portion of Hart Canyon runs through Arizona Game & Fish Department property (Vincent Ranch)
  *Addressed by desired species and management recommendations for BUC001: Buck Springs Canyon, Leonard Canyon to Upper Buck Springs; and HAT001: Hart Canyon, Willow Creek to Headwaters (specifically the Vincent Ranch Pond)*
- Chevelon Creek near the LCR confluence: the Recovery Plan calls for refugia at both upper and lower Chevelon. No specific sites are identified in the Recovery Plan but Chevelon Canyon Wildlife Area, located just upstream of the LCR confluence and owned by Arizona Game & Fish Department has been suggested for lower Chevelon Creek. No sites have been identified formally or informally for upper Chevelon drainage
  *Lower Chevelon is addressed by desired species and management recommendations for CCW001: Chevelon Creek Wildlife Area. We are also suggesting Mineral Creek as a refugium for LEVI from Chevelon Creek, though Mineral Creek is not in the Chevelon drainage. Also, we are recommending looking for additional refugia sites within a number of tributaries to upper Chevelon Canyon. There is currently only one population of LEVI in the Chevelon drainage, consequently all refugia for this drainage will be replicates of this single population*
- Nutrioso and Rudd Creeks: no specific refugia localities have been identified for this population either in the Recovery Plan or informally
  *Addressed by management recommendations for SIP001: Sipe White Mountain Wildlife Area Ponds*
- Silver Creek: the Recovery Plan calls for the establishment of a refugium at the State owned Silver Creek Hatchery
  *Addressed by proposed refugia sites at the Silver Creek and Pinetop (Billy Creek) Hatcheries*
- Additional refugia sites identified in the Recovery Plan include the Little Colorado River at Wenima Wildlife Area (Arizona Game & Fish Department property), the Pinetop State Hatchery, and the Flagstaff Arboretum
  *The plan does not consider Wenima Wildlife Area ponds because they are flooded by the LCR during high flows*

The Recovery Plan calls for additional repatriation sites. Those proposed thus far in the LCR management plan include portions of Show Low, Walnut, and Billy Creeks.
*The plan recommends evaluating the following sites for LEVI repatriation: SHO004: Show Low Creek, Fool Hollow Lake to Show Low Lake; SHO006: Show Low Creek, Show Low Lake to Billy/Porter Creek Confluence; WAL003: Walnut Creek, Rainbow Lake to Woodland Reservoir; and BIL002: Billy Creek, AGFD Hatchery Boundary to Pinetop Spring.*

Note: As envisioned by the CMPG, the utilization of ponds as refugia sites is an interim step toward LC spinedace recovery. It is our hope that as repatriations occur throughout the watershed and are found to be successful, the necessity for pond refugia will unlimitedly become unnecessary.

Speckled dace
Manage for no net loss of any populations. Repatriate in those drainages of the upper LCR where we suspect they were poisoned from. This species should be managed as part of an assemblage that includes bluehead suckers and LC suckers, at the appropriate elevational range for all three species. Speckled dace should not be repatriated (at least initially) into management units that are serving as LC spinedace refugia sites.
*The plan is consistent with the above recommendations*

Bluehead suckers
Manage for no net loss of any populations. Repatriate in those drainages of the upper LCR where we suspect they were poisoned from. This species should be managed as part of an assemblage that includes speckled dace and LC suckers where elevational range is appropriate for all three species
*The plan is consistent with the above recommendations*

LC suckers
Manage for no net loss of any populations. Repatriate in those drainages of the upper LCR where we suspect they were poisoned from. This species should be managed as part of an assemblage which includes bluehead suckers and speckled dace where elevational range is correct
*The plan is consistent with the above recommendations*

Roundtail chub
Maintain and enhance the two existing populations (Clear Creek and Chevelon Canyon)
*Clear Creek covered by desired species for CLE003: Clear Creek, Clear Creek Reservoir to Forest Boundary; Chevelon Canyon is covered by desired fish species for CHE002 and CHE003: Chevelon Canyon, Horse Canyon to Chevelon Canyon Dam*

Repatriate so that ultimately there are two populations in each of the following four sub-basins:

- The upper LCR
  *Covered by recommendations for LCR006: Little Colorado River, Zion Reservoir to Lyman Lake and LCR008 and LCR009: Little Colorado River, Lyman Lake to 261 Road Crossing*
- Silver Creek
  *Covered by recommendations for SIL002: Southern Canyon Boundary North of Snowflake to White Mountain Lake, and SIL005: Bourdon Ranch Road to Silver Creek Hatchery No Fishing Boundary*
- Chevelon Creek
  *Covered by recommendations for CHE001, CHE002, and CHE003: Little Colorado River to Chevelon Canyon Dam, and CHE005: Chevelon Canyon Lake to Woods Canyon*
- East Clear Creek
  *Units CLE003 and CLE004: Clear Creek Reservoir to Leonard Canyon are adjacent, and probably cannot be considered as two populations. In addition, we are recommending the evaluation of LEO001: Leonard Canyon, East Clear Creek to Knoll Lake for GIRO translocation. This would likely occur following LC spinedace delisting*

Roundtail chub used for captive propagation and repatriation must come from within the LCR watershed.

Zuni bluehead sucker
Surveys are needed to determine if this species has been extirpated from Arizona before any specific species recommendations can be made
*The plan recommends surveys of the Zuni River, especially near the New Mexico border*

Apache trout
Management of this species is to be driven by the Implementation Plan for Apache Trout Recovery (Apache Trout Recovery Team, in prep.). The Implementation Plan calls for headwater streams of the LCR with appropriate conditions and within their former range to be repatriated with Apache trout.
*The plan is consistent with the above recommendations*

### SPECIES COMPATIBILITY ISSUES

Results of a database search for potentially incompatible species within units are in Table 5-1. For each management unit affected, the table lists the unit code, followed by the potentially incompatible species pair(s), followed by a number corresponding to a mitigating factor or explanation for placing these species together. These explanations are listed at the end of this section.

Table 5·1 Results of a database search for potentially incompatible species within management units

| Unit number | Potentially antagonistic species pairs | Explanation or mitigating factor number |
|---|---|---|
| BEC001 | ONMY × ONAP | 7 |
| CHE001 | GIRO × LEVI | 8 |
| CHE002 | GIRO × LEVI | 8 |
| CHE003 | GIRO × LEVI | 8 |
| CHE005 | GIRO × ONMY; GIRO × SATR | 2 |
| CLE004 | GIRO × LEVI | 8 |
| EFL001 | ONAP × SATR | 9 |
| LCR006 | GIRO × LEVI | 8 |
| LCR008 | LEVI × GIRO | 8 |
| LCR009 | LEVI × GIRO | 8 |
| LCR013 | ONAP × ONMY; ONAP × SATR | 9 |
| MIN001 | LEVI × ONAP | 11 |
| SFL001 | ONAP × SATR | 9 |
| SHO004 | GIRO × LEVI | 8 |
| SHO006 | GIRO × LEVI | 8 |
| SIL002 | GIRO × LEVI | 8 |
| SIL005 | GIRO × LEVI | 8 |
| WFL001 | ONAP × ONMY; ONAP × SAFO; ONAP × SATR | 9 |

Results of a database search for potentially incompatible species between units are twofold: first, we list potentially antagonistic species pairs and the number of locations (adjacent units) in which they were found; Table 5·2, with specific locations and explanation or mitigating factor code number, follows.

ONAP × GIRO = 2
ONAP × LEVI = 5
ONAP × ICPU = 0
ONAP × MIDO = 0
ONAP × STVI = 0
ONAP × ONMY = 3
ONAP × SATR = 4

ONAP × SAFO = 2
GIRO × LEVI = 11
GIRO × ICPU = 5
GIRO × MIDO = 0
GIRO × STVI = 4
GIRO × ONMY = 8
GIRO × SATR = 3

GIRO × SAFO = 0
LEVI × ICPU = 8
LEVI × MIDO = 0
LEVI × STVI = 4
LEVI × ONMY = 19
LEVI × SATR = 2
LEVI × SAFO = 0

Table 5-2 Unit pairs that have potentially antagonistic species pairs as desired fish species. Upstream water is listed first; E/M stands for explanation or mitigating factor number. The upstream unit and species are listed first

| Unit pairs | Unit names | Species pairs | E/M |
|---|---|---|---|
| NUT001/LCR008 | Nutrioso Cr., lower/LCR, below Nutrioso | LEVI × GIRO | 8 |
| NUT003/NUT002 | Nelson Res./Nutrioso Cr. | ONMY × LEVI | 1,3,4 |
| RUD002/RUD001 | Upper Rudd Cr./lower Rudd Cr. | ONAP × LEVI | 2 |
| NUT004/NUT003 | Nutrioso Cr./Nelson Res. | LEVI × ONMY | 1,2,3 |
| COL001/NUT004 | Lower Colter Cr./Nutrioso Cr. | ONAP × LEVI | 2 |
| NUT005/NUT004 | Upper Nutrioso Cr./Nutrioso Cr. | ONAP × LEVI | 2 |
| BEC001/LCR008 | Becker Lake/LCR below Nutrioso Cr. | ONAP × GIRO, ONAP × LEVI, ONMY × GIRO, ONMY × LEVI | 2,5,6,7 |
| NUT001/LCR009 | Lower Nutrioso Cr./LCR above Nutrioso Cr. | LEVI × GIRO | 8 |
| SFL001/LCR010 | South Fork LCR/LCR to FS bdy. | ONAP × ONMY, ONAP × SATR | 5 |
| LCR009/BEC001 | LCR above Nutrioso Cr./Becker Lake | GIRO × ONAP, GIRO × ONMY, LEVI × ONAP, LEVI × ONMY | 5,7 |
| LCR009/LCR008 | LCR above Nutrioso/LCR below Nutrioso | GIRO × LEVI (Recip) | 8 |
| LCR010/LCR009 | LCR to Fs bdy,/LCR above Nutrioso | ONMY × GIRO, ONMY × LEVI, SATR × GIRO, SATR × LEVI | 14 |
| WFL001/EFL001[b] | West Fork LCR/East Fork LCR | ONMY × ONAP, SAFO × ONAP, SATR × ONAP | 5 |
| LEE001/WFL001[c] | Lee Valley Lake/West Fork LCR | ONAP × ONMY, ONAP × SAFO, ONAP × SATR | 5 |
| EFL002/EFL001 | Upper East Fork LCR/Lower East Fork | ONAP × SATR | 5 |
| LCR007/LCR006 | Lyman Lake/LCR below Lyman | ICPU × GIRO, STVI × GIRO, ICPU × LEVI, STVI × LEVI | 12 |
| LCR008/LCR007 | LCR above Lyman/ Lyman Lake | GIRO × ICPU, GIRO × STVI, LEVI × ICPU, LEVI × STVI | 2 |
| SIL002/SIL001 | Silver Cr. below White Mtn. Lake/Lower Silver Cr. | GIRO × LEVI | 8 |
| COT001/SIL002 | Cottonwood Wash/Silver Cr. below White Mtn. Lake | LEVI × GIRO | 8 |
| SHO004/SHO003 | Middle Show Low Cr./Fool Hollow Lake | GIRO × ICPU, LEVI × ICPU, GIRO × ONMY, LEVI × ONMY, GIRO × STVI, LEVI × STVI | 13 |
| SHO006/SHO005 | Upper Show Low Cr./Show Low Lake | GIRO × ICPU, LEVI × ICPU, GIRO × ONMY, LEVI × ONMY, GIRO × STVI, LEVI × STVI | 13 |
| BIL001/SHO006 | Upper Show Low Cr./Lower Billy Cr. | LEVI × ONMY | 13 |
| POR001/SHO006 | Upper Show Low Cr./Lower Porter Cr. | LEVI × GIRO, LEVI × ONMY | 13 |
| POR002/POR001 | Scott Res./Lower Porter Cr. | ICPU × LEVI, ONMY × LEVI | 13 |

[b] East and West Fork of the LCR meet to form the mainstem LCR; they are adjacent but one does not flow into the other

[c] Lee Valley lake is located on the East Fork LCR drainage but the dam and spillway flow into the West Fork LCR

Table 5·2 Continued

| Unit pairs | Unit names | Species pairs | E/M |
|---|---|---|---|
| WAL003/WAL002 | Walnut Cr. below Woodland/Rainbow Lake | LEVI × ICPU, LEVI × ONMY | 13 |
| WAL004/WAL003 | Woodland Lake/Walnut Cr. | ICPU × LEVI, ONMY × LEVI | 13 |
| CHE001/LCR003 | Lower Chevelon/LCR below Silver Cr. | GIRO × LEVI | 8 |
| CHE002/CHE001 | Chevelon below FS/Lower Chevelon | GIRO × LEVI (Recip) | 8 |
| CHE003/CHE002 | Chevelon above FS/Chevelon below FS | GIRO × LEVI (Recip) | 8 |
| CHE004/CHE003 | Chevelon Canyon Lake/Chevelon Cr. | ONMY × GIRO, SATR × GIRO, ONMY × LEVI, SATR × LEVI | 2 |
| CHE005/CHE004 | Upper Chevelon Canyon/Chevelon Canyon Lake | GIRO × ONMY, GIRO × SATR | 10 |
| CLE003/CLE002 | Clear Creek below FS/Clear Creek Res. | GIRO × ICPU, GIRO × ONMY | 12 |
| WLL001/CLE004 | Willow Creek/Clear Cr. above FS | LEVI × GIRO | 8 |
| LEO002/LEO001 | Knoll Lake/Lower Leonard | ONMY × LEVI | 1,3 |
| LEO001/CLE004 | Lower Leonard Canyon/Clear Cr. above FS | LEVI × GIRO | 8 |
| CLE006/CLE005 | Blue Ridge Reservoir/Lower East Clear Creek | ONMY × LEVI | 1,3 |
| CLE007/CLE006 | Upper East Clear Creek/Blue Ridge Reservoir | ONMY × LEVI | 1,3 |
| HOU001/CLE006 | Lower Houston Draw/Blue Ridge Res. | LEVI × ONMY | 5 |
| GSC001/CLE006 | General Springs Can./Blue Ridge Res. | LEVI × ONMY | 12 |

Explanations and/or Mitigating Factors

1. Stocking regime minimizes downstream and/or upstream movement of stocked fish (no spring stocking prior to cessation of dam overflow or after Labor Day)
2. Survey history shows no/low occurrence of desired sportfish species, indicating that minimal movement from adjacent units, and/or unsuitable habitat and/or water quality conditions limiting persistence of desired sportfish entering the unit
3. Special regulations implemented to reduce trout numbers
4. Active removal of trout following summer spill-over is in the management recommendations
5. Current or proposed barrier will prevent natural upstream movement of fish
6. Water removed for irrigation passes through a screen to prevent fish movement
7. Apache trout in Becker Lake are a sportfish enhancement population; not a recovery population

8. Roundtail chub and LC spinedace historically occupied the same systems, and probably occurred together; therefore, we contend that there is no incompatibility at the population level. Also, the Native Fish Expert Group has expressed the need to re-establish communities of native fish rather than focusing on a single species

9. Stocked Apache trout and non-native trout will co-exist in this unit until it is renovated and barriers are erected to provide for exclusive Apache trout sportfishing and restoration

10. Non-native trout and roundtail chub co-occurred in upper Chevelon Creek before the renovation of 1965; non-native trout presently occur in small numbers and are not actively stocked; roundtail chub are managed as part of a sportfish assemblage

11. Interactions between LC spinedace and Apache trout probably occurred historically at the lower elevation of Apache trout range; Apache trout in this system occur in small numbers, and do not occupy the lower portion of the unit

12. There is not enough information at this time to know whether the fish assemblage in one unit is present in units above or below it in sufficient numbers to be a problem

13. We suspect the reason LC spinedace and other native fish are not currently present is due to past chemical renovations. The Show Low Creek system provides an opportunity to repatriate native fish species in the presence of non-natives, the presence of which we have little control over

14. We cannot control the presence of non-native sportfish in LCR010 because it flows through private lands and landowners stock fish. Similarly, we do not affect the presence of LC spinedace in the unit downstream of it because most of it flows through private land

## MANAGEMENT UNIT SUMMARIES AND PRESCRIPTIONS

The principal product of the project is a collection of fisheries information and accompanying management recommendations on the Little Colorado River and its tributaries. Summary information, desired fish species, and management recommendations are listed for each management unit in Appendix A (98 lake units and 154 stream units). Additionally, each management unit can be located on the reference maps in Appendix B. Individual decisions made while applying native and sportfish flowcharts to arrive at a particular management emphasis are listed for each management unit in Appendix C.

Most of the information in unit summaries is of a descriptive nature. The last three items listed (management emphasis, desired fish species assemblage, and observations and recommendations), on the other hand, are the result of analysis and evaluation. Management emphasis is a broad categorization referring to the overall best use of a particular management unit. When it happens to be sportfish, we specify, if appropriate, the particular sportfish management concept under which the unit is to be managed. The management emphasis is not exclusionary, however. There can be sportfish in a unit with a native fish emphasis (both Apache trout and roundtail chub, for instance, are classified as sportfish), and as such, the designation is of less significance than the list of desired fish species or the individual management recommendations.

Lakes

Ninety-eight lake units were delineated. Normal surface acres ranged from less than one to 1400. Figure 5·3 displays percentages of units with each of the management emphases, including those units for which we do not have enough information to make an evaluation (UNKNOWN). Excluded from the figure are the emphases of "N/A" and "NONE". When a body of water is entirely on private land, we do not evaluate it with flowcharts, and the emphasis given is therefore "N/A". Some of these waters are used as private fee-for-fishing lakes while the primary use of others is unknown. Lakes and ponds given the emphasis of "NONE" are those first selected for analysis based on historical stockings or water holding capacity, but that upon closer evaluation, were found not to be of any immediate value for fish (other than, in some cases, their ability to increase downstream water flow).

Figure 5·4 is similar to figure 5·3, but the percent given is of the number of surface acres in each management emphasis category. It is less than comprehensive because we are lacking surface acre information for several lakes and ponds.

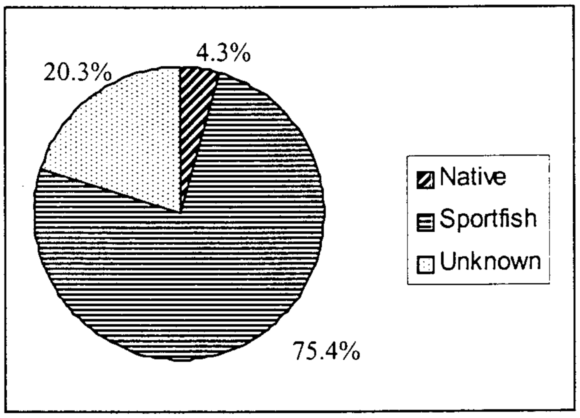


Figure 5·3 Percent of lake units with management emphases of Native, sportfish, or Unknown

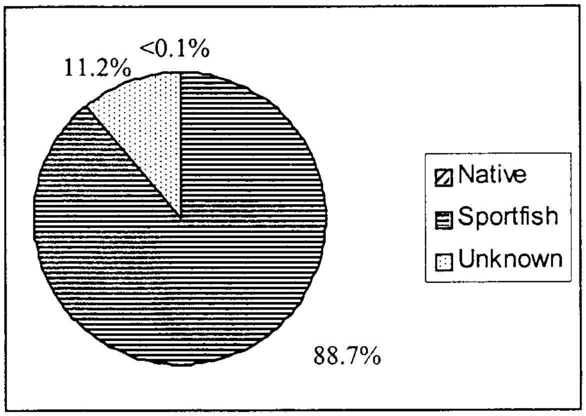


Figure 5·4 Percent of lake surface acres with emphases of Native, sportfish, or Unknown. Surface acres dedicated to native fish are so few (5 total, 0.07%) that they do not even show up in the piechart.

In summary, the two figures demonstrate that 52 lake units representing 6432 surface acres are dedicated to sportfish management, three lake units representing 5 surface acres are dedicated to native fish management, and 14 lake units, representing 813 surface acres, are unknown.

Streams

One hundred fifty-four stream units were delineated. We examined and included into unit summaries, a total of 1534.8 miles (2468.2 km) of stream. Unit lengths ranged from 0.1 mile (0.2 km) to 75.2 miles (121.0 km), with an average unit length of 9.9 miles (16.0 km). A stretch of stream 0.8 mi. (1.3 km) long, used as a fish rearing facility, received no management emphasis and so is excluded from further analyses.

Figure 5·5 shows a total of 822.5 mi. (1323.4 km, or 53.6 %) of the streams analyzed have an unknown management emphasis, meaning we do not have enough information to determine the value of these streams for fish management. The same figure shows 644.3 mi. (1036.7 km, or 42.0 %) of the streams analyzed have a native fish emphasis, while 67.2 mi. (108.1 km, or 4.4 %) of the streams analyzed have a sportfish emphasis.

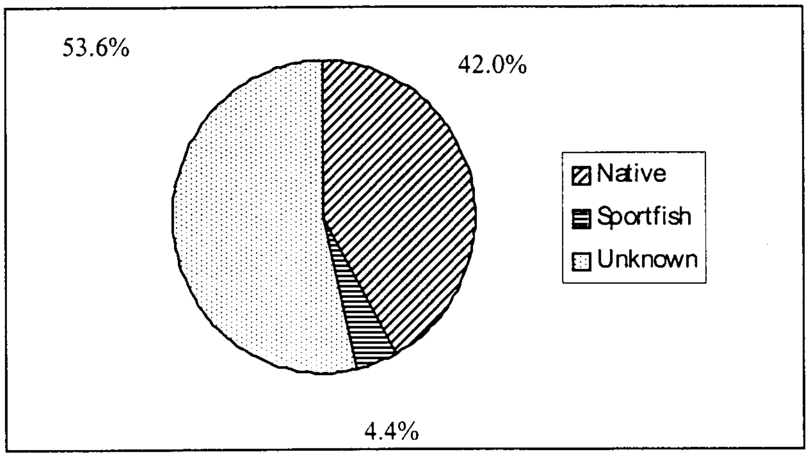


Figure 5·5 Percent of stream miles with emphases of Native, sportfish, or Unknown

Figure 5·6 illustrates, however, that a proportion (26.9 mi. = 43.3 km) of designated native fish streams are in fact Apache trout streams open to angling.

We must point out that though it appears a disproportionate length of streams is devoted to native fish conservation, the majority (362.5 mi. = 583.3 km, or 73.1 %) of the stream lengths with a native fish emphasis are identified as being interrupted perennial. This means that an unknown but likely smaller portion of that 362.5 miles of stream is habitable fish stream. Figure 5·7 illustrates that of the streams identified as perennial, 133.3 mi. (214.5 km, or 58.6 %) have a native, non-Apache trout emphasis, while 94.1 mi. (151.4 km, or 41.4 %) are either sportfish emphasis or Apache trout streams open to angling. Absent from this comparison are 125.9 mi. (202.6 km) of stream with a native fish emphasis but for which it is not known whether the waters are interrupted perennial or perennial.

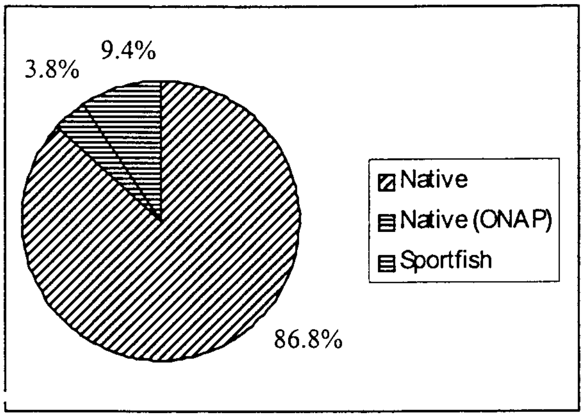


Figure 5·6 Percent of stream miles with emphases of Native (86.8%), sportfish (9.4%), or Native and designated as Apache trout streams open to angling (ONAP, 3.8%)

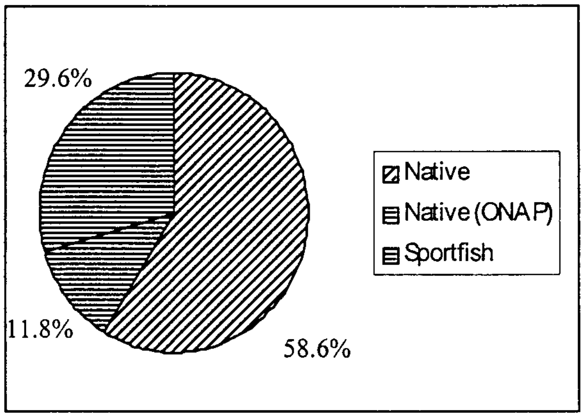


Figure 5·7 Percent of known perennial waters with emphases of Native (58.6%), sportfish (29.6%) or Native but designated as Apache trout streams open to angling (ONAP, 11.8%)

For quick reference by the angler, fishery manager, or the interested reader, we have summarized and condensed management unit summaries into tables 5·3 and 5·4. Table 5·3 summarizes all lake units alphabetically by name. It also lists, for each unit, average surface area, management emphasis, fish species detected or stocked within the last 10 years, desired sportfish concept, and desired fish species, with those species which have not been detected or stocked within the past ten years in bold. Table 5·4 summarizes stream units, also alphabetically by name. Included is the unit length, management emphasis (and concept, if the management emphasis is sportfish), all fish species detected or stocked within the last 10 years, and desired fish species, with those species which have not been detected or stocked within the past ten years in bold. For species name abbreviations please see table 1·2.

Table 5·3 Lake Management Unit Results

| Lake or Pond Name | Unit ID Code | Avg. Area Acres (HA) | Emphasis | All Fish Species Detected or Stocked Within Last 10 Years[d] | Desired Concept | Desired Fish Species |
|---|---|---|---|---|---|---|
| Als Lake | ALS001 | - | None | Unknown | None | None |
| Ashurst Lake | ASH001 | 161 (65.1) | Sportfish | ESLU, ONMY, ONCL | Intensive Use | ONMY |
| Bear Canyon Lake | BER002 | 60 (24.3) | Sportfish | ONCL, ONMY, SAFO, THAR | Intensive Use | ONMY, THAR |
| Becker Lake | BEC001 | 85 (34.4) | Sportfish | CASP, ONMY, ONAP, PIPR, SATR | Blue Ribbon, Intensive Use | CASP, ONAP, ONMY |
| Bill's Lake[e] | BLL001 | 5 (2.0) | N/A | Unknown | N/A | N/A |
| Black Canyon Lake | WFB002 | 78 (31.6) | Sportfish | PADI, ONMY, SAFO, SATR | Basic Yield/ Intensive Use | ONMY, PADI |
| Blue Ridge Res. | CLE006 | 70 (28.3) | Sportfish | CASP, RHOS, CYLU, LECY, NOCR, ONCL, ONMY, PIPR, SATR | Intensive Use | CASP, ONMY |
| Boot Lake | BOO001 | 30 (12.1) | None | Unknown | None | None |
| Bunch Reservoir | BUN001 | 20 (8.1) | Sportfish | ONMY, SATR | Basic Yield/ Intensive Use | ONMY |
| Camillo Tank | CAM001 | 8 (3.2) | None | Unknown | None | None |
| Carnero Lake | CAR002 | 65 (26.3) | Sportfish | Unknown | Blue Ribbon | ONMY |
| Chevelon Canyon Lake | CHE004 | 200 (80.9) | Sportfish | CAPA, CASP, LECY, ONMY, SATR | Blue Ribbon | CASP, ONMY, SATR |
| Chevelon Canyon Willidfe Area Ponds | CCW001 | 10 (4.0)<br>50 (20.2)<br>60 (24.3) | Native | None | - | **LEVI** |
| Chilson Tank | CHI001 | 3 (1.2) | Sportfish | Unknown | Warmwater | LEMA, MISA |
| Cholla Lake | CHO001 | 360 (145.7) | Sportfish | ICPU, LECY, LEMA | Warmwater | ICPU, LEMA, MISA |
| Clear Creek Res. | CLE002 | 45 (18.2) | Sportfish | CASP, CYCA, ICPU, LEMA, ONMY | Intensive Use/ Warmwater | CASP, ICPU, LEMA, **MISA**, ONMY |
| Coconino Res. | COC001 | 5 (2.02) | Sportfish | ESLU, ONCL, ONMY, SATR | Intensive Use | ONMY |

[d] Unless we believe the lake has dried or killed after the last observation
[e] Private Lake; not managed by AGFD

Table 5·3 Continued

| Lake or Pond Name | Unit ID Code | Avg. Area Acres (HA) | Emphasis | All Fish Species Detected or Stocked Within Last 10 Years[d] | Desired Concept | Desired Fish Species |
|---|---|---|---|---|---|---|
| Concho Lake | CON002 | 60 (24.3) | Sportfish | ICPU, LECY, MISA, ONCL, ONMY, SAFO | Basic Yield | ONMY |
| Cow Lake | COW001 | 6 (2.4) | None | Unknown | None | None |
| Daves Tank | DAT001 | 1 (0.4) | Unknown | Unknown | Unknown | Unknown |
| Deep Lake | DEP001 | 6 (2.4) | None | Unknown | None | None |
| Ducksnest Lake | DUC001 | - | None | Unknown | None | None |
| Edler Lake | EDL001 | - | N/A | Unknown | N/A | N/A |
| Ellis Wiltbank Res. | EWR001 | 26 (10.5) | Unknown | Unknown | Unknown | Unknown |
| Flagstaff Arboretum Pond[e] | FAP001 | 0.35 (0.14) | N/A | LEVI | - | N/A |
| Fool Hollow Lake | SHO003 | 149 (60.3) | Sportfish | AMME, CYCA, ICPU, LEMA, MIDO, MISA, NOCR, ONMY, PONI, SATR, STVI | Intensive Use/ Warmwater | ICPU, LEMA, MISA, ONMY, PONI, STVI |
| Geneva Reservoir | FIS002 | 57 (23.1) | None | None | None | None |
| Harris Lake[e] | HAR001 | 15 (6.1) | N/A | None | N/A | N/A |
| Hay Lake | HAY001 | 37 (15.0) | None | None | None | None |
| Hog Wallow & Pool Corral Lakes | SFL002 | 80 (32.4) & 72 (29.1) | None | None | None | None |
| Horse Lake | HOS001 | 8 (3.2) | None | Unknown | None | None |
| Hulsey Lake | HUL002 | 3 (1.2) | Sportfish | ONMY, SATR | Intensive Use | ONMY |
| H-V Reservoir[e] | H-V001 | 33 (13.4) | N/A | Unknown | N/A | N/A |
| Indian Lake | IND001 | - | None | Unknown | None | None |
| Jarvis Lake[e] | JAR001 | 6 (2.4) | N/A | Unknown | N/A | N/A |
| Kinnikinick Lake | KIL001 | 126 (51.0) | Sportfish | ICPU, ONMY, SATR | Intensive Use/ Warmwater | ICPU, ONMY, SATR |
| Knoll Lake | LEO002 | 55 (22.3) | Sportfish | SATR, RHOS | Intensive Use | ONMY |
| Lake of the Woods[e] | WAL001 | - | N/A | Unknown | N/A | N/A |

Table 5·3 Continued

| Lake or Pond Name | Unit ID Code | Avg. Area Acres (HA) | Emphasis | All Fish Species Detected or Stocked Within Last 10 Years[d] | Desired Concept | Desired Fish Species |
|---|---|---|---|---|---|---|
| Lee Valley Res. | LEE001 | 35 (14.2) | Sportfish | ONAP, PADI, PIPR, SAFO, THAR | Featured Species | PADI, ONAP, THAR |
| Little Mormon Lake | LML001 | 70 (28.3) | Sportfish | ICPU | Warmwater | ICPU, **LEMA** |
| Little Ortega Lake | LOR001 | 225 (91.1) | Sportfish | None | Warmwater | **ICPU, LEMA, MISA** |
| Little Reservoir[e] | LIT001 | 65 (26.3) | N/A | Unknown | N/A | N/A |
| Long Lake, Upper | LGL001 | 25 (10.1) | None | Unknown | None | None |
| Long Lake (Silver Creek) | LON001 | 200 (80.9) | Sportfish | ICPU, MISA, ONMY, CYCA | Basic Yield | ONMY |
| Long Lake, Lower | LOL001 | 268 (108.4) | Sportfish | CYCA, ESLU, ICPU, ONMY, STVI | Intensive Use/ Warmwater | ICPU, ONMY, STVI |
| Long Tom Lake | LOG002 | 3 (1.2) | Sportfish | ONMY, SATR | Basic Yield | ONMY |
| Love Lake[e] | LOV001 | 20 (8.1) | N/A | Unknown | N/A | N/A |
| Lower Lake Mary | WLT002 | 500 (202.3) | Sportfish | CYLU, ESLU, LECY, LEMA, LEMI, MISA, ONMY, PEFL, PONI, SATR, STVI | Warmwater/ Intensive Use | ESLU, LEMA, MISA, ONMY |
| Lyman Lake | LCR007 | 1400 (566.6) | Sportfish | CASP, CYCA, ESLU, ICPU, LEMA, MISA, ONMY, PONI, STVI | Warmwater | ICPU, LEMA, MISA, PONI, STVI, CASP |
| Marshall Lake | MAR001 | 35 (14.2) | Sportfish | ONMY | Basic Yield/ Featured species | ONMY, **SAFO**, **THAR** |
| Mexican Hay Lake | MEX001 | 100 (40.5) | Sportfish | None | Basic Yield | **ONMY** |
| Mormon Lake | MOM001 | 600 (242.8) | Sportfish | Unknown | Warmwater | LEMA, MISA, PEFL |
| Mormon Lake Lodge Tank | MLT001 | - | Sportfish | ONMY | Intensive Use | ONMY |
| Morton Lake | MOR001 | 10 (4.0) | Sportfish | Unknown | Intensive Use | ONMY, SATR |
| Mud Lake | MUD001 | - | Sportfish | ICPU, SATR | Warmwater | ICPU |
| Ned Lake | NED001 | 10 (4.0) | Unknown | Unknown | Unknown | Unknown |
| Nelson Reservoir | NUT003 | 60 (24.3) | Sportfish | CYCA, LECY, MISA, ONCL, ONMY, PADI, PONI, SAFO, SATR | Intensive Use | ONMY, PADI |

Table 5·3 Continued

| Lake or Pond Name | UNIT ID CODE | AVG. AREA ACRES (HA) | Emphasis | All Fish Species Detected or Stocked Within Last 10 Years[d] | Desired Concept | Desired Fish Species |
|---|---|---|---|---|---|---|
| Norton Reservoir | NOR001 | 56 (22.7) | None | None | None | None |
| Nutrioso Reservoir[e] | AUG002 | 31 (12.5) | N/A | Unknown | N/A | N/A |
| Pete's Retreat Pond[e] | PET001 | - | N/A | Unknown | N/A | N/A |
| Pine Lake[e] | WAL006 | 54 (21.8) | N/A | Unknown | N/A | N/A |
| Pine Tank | PIT001 | - | Unknown | Unknown | Unknown | Unknown |
| Pintail Lake | PIN001 | - | Unknown | Unknown | Unknown | Unknown |
| Potato Lake | POT002 | 5 (2.0) | Native | PIPR | - | **LEVI** |
| Potato Lake (Upper) | PTT001 | 15 (6.1) | None | None | None | None |
| Poverty Spring Tank | POV001 | - | N/A | None[f] | N/A | None |
| Powerline Tank | POW001 | - | Sportfish | LEMA | Warmwater | LEMA |
| Pratt Lake | PRA001 | 5 (2.0) | Sportfish | SATR | Basic Yield | **ONMY**, SATR |
| Prime Lake | PRI001 | - | None | Unknown | None | None |
| Rainbow Lake | WAL002 | 80 (32.4) | Sportfish | ICPU, LECY, MISA, ONMY, SAFO, SATR | Intensive Use/ Basic Yield/ Warmwater | ICPU, **LEMA**, MISA, ONMY |
| Reagan Reservoir | REA001 | 50 (20.2) | Unknown | Unknown | Unknown | Unknown |
| Redhead Lake | RED001 | - | Unknown | Unknown | Unknown | Unknown |
| Red Lake | REL001 | - | Unknown | Unknown | Unknown | Unknown |
| River Reservoir | LCR012 | 50 (20.2) | Sportfish | CAPA, ONMY, SAFO, SATR | Intensive Use | CAPA, ONMY |
| Rogers Marsh | COL003 | 10 (4.0) | Unknown | Unknown | Unknown | Unknown |
| Rogers Reservoir | COL002 | 10 (4.0) | None | Unknown | None | None |
| Schoen's Lake | SHO001 | - | Sportfish | Unknown | Warmwater | ICPU, LEMA, MISA, STVI |
| Scott Reservoir | POR002 | 80 (32.4) | Sportfish | AMME, ICPU, LECY, LEMA, MISA, ONMY, SATR | Intensive Use/ Basic Yield/ Warmwater | ICPU, LEMA, MISA, ONMY |

[f] Green sunfish found in this metal cattle drinker in 1994 were all removed

Table 5·3 Continued

| Lake or Pond Name | Unit ID Code | Avg. Area Acres (HA) | Emphasis | All Fish Species Detected or Stocked Within Last 10 Years[d] | Desired Concept | Desired Fish Species |
|---|---|---|---|---|---|---|
| Show Low Lake | SHO005 | 100 (40.5) | Sportfish | AMME, CYCA, ICPU, LEMA, MISA, NOCR, ONMY, SATR, STVI | Intensive Use/ Basic Yield/ Warmwater | ICPU, MISA, ONMY, STVI |
| Sin Agua Tank | SIN001 | - | Sportfish | LEMA | Warmwater | LEMA |
| Snake Tank #2 | SNA001 | 5 (2.0) | Sportfish | MISA | Warmwater | **LEMA**, MISA |
| Soldier Annex Lake | SOL001 | 90 (36.4) | Sportfish | ESLU, ICPU, STVI | Warmwater | ICPU |
| Soldier Lake | SOL002 | 30 (12.1) | Sportfish | ICPU, LECY, LEMA, LEMI, MISA, ONMY, SATR, STVI | Warmwater | ICPU, LEMA, MISA |
| Sponseller Lake | SPO001 | 34 (13.8) | Sportfish | None | Basic Yield | **ONMY** |
| Sipe WMWA Tanks | SIP001 | - | Native | Unknown | - | None |
| Telephone Lake | TEL001 | 12 (4.9) | Unknown | Unknown | Unknown | Unknown |
| The Cienega | CIE001 | - | Unknown | Unknown | Unknown | Unknown |
| Tremaine Lake[e] | TRE001 | 500 (202.3) | N/A | Unknown | N/A | N/A |
| Tunnel Reservoir | TUN001 | 15 (6.1) | Sportfish | ONMY, SATR | Intensive Use | ONMY |
| Upper Lake Mary | WLT003 | 450 (182.1) | Sportfish | ESLU, ICPU, LEMA, ONMY, PEFL, PONI, STVI | Warmwater | ESLU, ICPU, LEMA, **MOMI**, PEFL, PONI, STVI |
| Vail Lake | VAI001 | - | None | Unknown | None | None |
| Water Canyon Reservoirs | WAC002 | - | Unknown | Unknown | Unknown | Unknown |
| Whipple Lake | WHI001 | 50 (20.2) | Sportfish | CYCA, ICPU, MISA, ONMY | Basic Yield | ONMY |
| White Mountain Lake[e] | SIL003 | 80 (32.4) | N/A | Unknown | N/A | N/A |
| White Mountain Res. | HAL002 | 20 (8.1) | Sportfish | ONMY | Basic Yield | ONMY |
| Willow Springs Lake | WIL002 | 158 (63.9) | Sportfish | MISA, ONMY, SAFO, SATR | Intensive Use | ONMY |
| Woodland Lake | WAL004 | 10 (4.0) | Sportfish | ICPU, LECY, LEMA, MISA, ONMY, SATR | Intensive Use/ Basic Yield/ Warmwater | ICPU, LEMA, MISA, ONMY |
| Woods Canyon Lake | WOO002 | 52 (21.0) | Sportfish | NOCR, ONCL, ONMY, SAFO, SATR | Intensive Use | ONMY |

Table 5·3 Continued

| Lake or Pond Name | UNIT ID CODE | AVG. AREA ACRES (HA) | Emphasis | All Fish Species Detected or Stocked Within Last 10 Years[d] | Desired Concept | Desired Fish Species |
|---|---|---|---|---|---|---|
| Zion Reservoir | LCR005 | 640 (259.0) | None | Unknown | None | None |

Table 5·4 Stream Management Unit Results

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Adair Spring and Tributary | ADA001 | 0 (0) | Unknown | Unknown | Unknown |
| Alder Creek | ALD001 | 18.4 (29.6) | Unknown | Unknown | Unknown |
| Auger Creek | AUG001 | 6.0 (9.7) | Native | None | **RHOS** |
| Barbershop Canyon | BAR001 | 14.0 (22.5) | Native | CASP, ONMY, PADI, PIPR, RHOS, SAFO, SATR | CASP, **LEVI**, PADI, RHOS |
| Bear Canyon (Below Bear Canyon Lake) | BER001 | 4.2 (6.8) | Native | CASP, ONCL, ONMY, PADI, RHOS, SAFO, THAR | CASP, PADI, RHOS |
| Bear Canyon (above Blue Ridge Res.) | BRC001 | 13.4 (21.5) | Native | CASP, ONMY, PADI, PIPR, RHOS | CASP, **LEVI**, PADI, RHOS |
| Beaver Canyon | BEA001 | 6.0 (9.6) | Unknown | Unknown | Unknown |
| Benny Creek | BEN001 | 9.2 (14.8) | Unknown | Unknown | Unknown |
| Big Springs | BIG001 | 0.2 (0.3) | Native | RHOS | **CASP**, **LEVI**, **PADI**, RHOS |
| Billy Creek (lower) | BIL001 | 5.9 (9.5) | Native | LECY, NOCR, PIPR | **CASP, LEVI, PADI, RHOS** |
| Billy Creek (upper) | BIL002 | 0.4 (0.7) | Native | SAFO | **LEVI** |
| Black Canyon (lower) | BLA001 | 27.5 (44.3) | Unknown | Unknown | Unknown |
| Black Canyon (upper) | BLA002 | 28.1 (45.2) | Unknown | Unknown | Unknown |
| Brown Creek (lower) | BRO001 | 15.8 (25.5) | Native | LECY, PADI, PIPR, RHOS | LEVI, PADI, RHOS |
| Brown Creek (upper) | BRO002 | 3.0 (4.9) | Unknown | Unknown | Unknown |
| Buck Springs Canyon | BUC001 | 6.5 (10.4) | Native | None | **LEVI** |

Table 5·4 Continued

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Butler Canyon | BUT001 | 2.0 (3.3) | Unknown | Unknown | Unknown |
| Cabin Draw | CAB001 | 4.2 (6.8) | Unknown | Unknown | Unknown |
| Canyon Diablo (lower) | DIA001 | 49.0 (78.8) | Unknown | Unknown | Unknown |
| Canyon Diablo (upper) | DIA002 | 10.6 (17.0) | Unknown | Unknown | Unknown |
| Carnero Creek (lower) | CAR001 | 19.5 (31.4) | Unknown | Unknown | Unknown |
| Carnero Creek (upper) | CAR003 | 0.9 (1.4) | Unknown | Unknown | Unknown |
| Chavez Draw | CHA001 | 5.5 (8.9) | Unknown | Unknown | Unknown |
| Chevelon Canyon (lower) | CHE001 | 11.0 (17.7) | Native | AMME, AMNA, CASP, CYCA, CYLU, FUZE, ICPU, LECY, LEVI, NOCR, PADI, PIPR, RHOS | CASP, **GIRO**, LEVI, PADI, RHOS |
| Chevelon Canyon (mid-below ASNF) | CHE002 | 38.4 (61.8) | Native | AMME, CASP, GIRO, ONMY, NOCR, PADI, PIPR, RHOS | CASP, GIRO, **LEVI**, PADI, RHOS |
| Chevelon Canyon (mid-above ASNF) | CHE003 | 18.9 (30.4) | Native | CASP, CYLU, GIRO, ONMY, PADI, PIPR, RHOS, SATR | CASP, GIRO, **LEVI**, PADI, RHOS |
| Chevelon Canyon (upper) | CHE005 | 12.2 (19.7) | Sportfish (Wildfish) | CASP, CYLU, ONMY, RHOS, SATR | CASP, **GIRO**, ONMY, **PADI** RHOS, SATR |
| Cienega Draw (Clear Creek) | CIN001 | 1.1 (1.8) | Unknown | Unknown | Unknown |
| Cienega Draw (upper LCR) | CIE002 | 11.2 (18.0) | Unknown | Unknown | Unknown |
| Circle Bar Draw | CIR001 | 9.1 (14.7) | Unknown | Unknown | Unknown |
| Clear Creek (lower) | CLE001 | 1.6 (2.6) | Unknown | Unknown | Unknown |
| Clear Creek (mid-below ASNF/CNF) | CLE003 | 43.1 (69.3) | Native | CASP, GIRO, LECY, NOCR, ONMY, PIPR, RHOS | CASP, GIRO, RHOS |
| Clear Creek (mid-above ASNF/CNF) | CLE004 | 20.9 (33.7) | Native | CASP, NOCR, ONMY, PADI, PIPR, RHOS, SATR | CASP, **GIRO, LEVI**, PADI, RHOS |
| Colter Creek | COL001 | 12.3 (19.8) | Native | ONMY, RHOS | **ONAP, PADI**, RHOS |
| Concho Creek (lower) | CON001 | 13.1 (21.1) | UNKNOWN | Unknown | Unknown |

Table 5·4 Continued (streams)

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Concho Creek (upper) | CON003 | 0.2 (0.3) | Unknown | Unknown | Unknown |
| Coon Canyon | COO001 | 2.5 (4.0) | Unknown | Unknown | Unknown |
| Cottonwood Wash | COT001 | 9.4 (15.1) | Native | LECY, PIPR | **LEVI** |
| Coyote Creek (lower) | COY001 | 28.6 (46.0) | Unknown | Unknown | Unknown |
| Coyote Creek (middle) | COY002 | 5.3 (8.5) | Unknown | Unknown | Unknown |
| Coyote Creek (upper) | COY003 | 10.4 (16.7) | Native | ONAP | ONAP |
| Crackerbox Canyon | CRA001 | 4.0 (6.5) | Unknown | Unknown | Unknown |
| Dane Canyon | DAN001 | 9.0 (14.5) | Native | ONMY, RHOS | RHOS |
| Davis Creek | DAV001 | 10.2 (16.4) | Native | None | Unknown |
| Deer Lake Canyon | DEE001 | 3.7 (6.0) | Unknown | Unknown | Unknown |
| Dick Hart Draw | DIC001 | 3.7 (5.9) | Unknown | Unknown | Unknown |
| East Clear Creek (lower) | CLE005 | 19.3 (31.1) | Native | CASP, CYLU, NOCR, ONMY, PADI, RHOS, SAFO, SATR | CASP, **LEVI**, PADI, RHOS |
| East Clear Creek (upper) | CLE007 | 14.1 (22.7) | Native | CASP, LEVI, ONMY, PADI, PIPR, RHOS | CASP, LEVI, PADI, RHOS |
| East Fork LCR (lower) | EFL001 | 12.7 (20.7) | Sportfish (Wildfish) | ONMY, PADI, PIPR, RHOS, SATR | **ONAP**, PADI, RHOS, SATR |
| East Fork LCR (upper) | EFL002 | 6.0 (9.7) | Native | PADI, PIPR, RHOS, SAFO, SATR | **ONAP**, PADI, RHOS |
| East Fork Woods Canyon | EFW001 | 2.9 (4.7) | Unknown | Unknown | Unknown |
| East Miller Canyon | EMC001 | 4.3 (6.9) | Unknown | Unknown | Unknown |
| Fish Creek | FIS001 | 8.9 (14.3) | Unknown | Unknown | Unknown |
| Fred Haught Canyon | FRE001 | 2.7 (4.3) | Unknown | Unknown | Unknown |
| General Springs Canyon | GSC001 | 8.0 (12.9) | Native | RHOS | **LEVI**, RHOS |
| Gentry Canyon (Chevelon Canyon) | GEN001 | 0.6 (1.0) | Unknown | Unknown | Unknown |

Table 5-4 Continued

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Gentry Canyon (Clear Creek) | GET001 | 7.2 (11.6) | Unknown | Unknown | Unknown |
| Grama Draw | GRD001 | 7.0 (11.3) | Unknown | Unknown | Unknown |
| Grapevine Canyon | GRA001 | 4.3 (6.9) | Unknown | Unknown | Unknown |
| Grapevine Canyon (Canyon Diablo) | GRP001 | 14.7 (23.6) | Unknown | Unknown | Unknown |
| Hall Creek (lower) | HAL001 | 6.0 (9.7) | Unknown | Unknown | Unknown |
| Hall Creek (upper) | HAL003 | 4.0 (6.4) | Unknown | Unknown | Unknown |
| Hart Canyon | HAT001 | 6.9 (11.1) | Native | Unknown | LEVI |
| Hobson Canyon | HOB001 | 2.7 (4.3) | Unknown | Unknown | Unknown |
| Horse Trap Canyon | HOR001 | 5.0 (8.1) | Unknown | Unknown | Unknown |
| Houston Draw (lower) | HOU001 | 2.4 (3.8) | Native | ONMY | **LEVI** |
| Houston Draw (upper) | HOU002 | 3.7 (5.9) | Native | ONMY | **LEVI** |
| Hulsey Creek | HUL001 | 5.1 (8.2) | Unknown | Unknown | Unknown |
| Jacks Canyon (lower) | JAC001 | 38.3 (61.7) | Unknown | Unknown | Unknown |
| Jacks Canyon (upper) | JAC002 | 28.7 (46.2) | Unknown | Unknown | Unknown |
| Joe Baca Draw | JOE001 | 3.3 (5.3) | Unknown | Unknown | Unknown |
| Jumping Springs Canyon | JUM001 | 1.9 (3.1) | Unknown | Unknown | Unknown |
| Kehl Canyon | KEH001 | 4.0 (6.4) | Native | ONMY | **CASP, LEVI, PADI** |
| Kinnikinick Canyon | KIN001 | 4.4 (7.1) | Unknown | Unknown | Unknown |
| Lake Hole to McKay Spring | HOL001 | 5.5 (8.8) | Unknown | Unknown | Unknown |
| Lang Creek | LAN001 | 3.3 (5.3) | Unknown | Unknown | Unknown |
| Lee Valley Creek | LEE002 | 1.6 (2.5) | Native | ONAP, SAFO | ONAP, **PADI** |
| Leonard Canyon | LEO001 | 23.2 (37.4) | Native | CASP, LEVI, ONMY, PADI, PIPR, RHOS | CASP, LEVI, PADI, RHOS |

Table 5·4 Continued

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Lily Creek | LIL001 | 3.2 (5.1) | Unknown | Unknown | Unknown |
| Limestone Canyon | LIM001 | 3.7 (6.0) | Unknown | Unknown | Unknown |
| Little Colorado River (Confluence with Colorado River) | LCR001 | 2.4 (3.9) | Native | CALA, CYCA, FUZE, GICY, ICPU, MOSA, ONMY, PADI, PIPR, RHOS, SATR, XYTE, XYTE × CALA | CALA, GICY, PADI, RHOS |
| Little Colorado River (Navajo Res. to Silver Creek) | LCR003 | 75.2 (121.0) | Native | AMNA,CAAU, CASP, CYCA, CYLU, ICPU, LECY, PADI, PIPR | CASP, **LEVI**, PADI |
| Little Colorado River (Silver Creek to Zion Reservoir) | LCR004 | 54.2 (87.3) | Unknown | CASP, CYCA, PIPR | Unknown[9] |
| Little Colorado River (Zion Reservoir to Lyman Lake) | LCR006 | 30.9 (49.7) | Native | CASP, CYCA, FUZE, LECY, LEVI, PADI, PIPR, RHOS | CASP, **GIRO**, LEVI, PADI, RHOS |
| Little Colorado River (below Nutrioso Creek) | LCR008 | 18.4 (29.6) | Native | CASP, CYCA, LECY, LEVI, PADI, ONMY, PIPR, RHOS, SATR | CASP, **GIRO**, LEVI, PADI, RHOS |
| Little Colorado River (Nutrioso Cr. to FS 261 Crossing) | LCR009 | 5.9 (9.5) | Native | CASP, FUZE, ICPU, LECY, LEVI, PADI, PIPR, RHOS, SAFO, SATR | CASP, **GIRO**, LEVI, PADI, RHOS |
| Little Colorado River (FS 261 Crossing to ASNF) | LCR010 | 6.4 (10.3) | Sportfish (Wildfish) | CASP, PADI, RHOS, SATR | CASP, ONMY, PADI, RHOS, SATR |
| Little Colorado River (ASNF to River Reservoir) | LCR011 | 4.7 (7.6) | Sportfish (Wildfish) | ONMY, PADI, RHOS, SATR | PADI, RHOS, ONMY, SATR |
| Little Colorado River (upper) | LCR013 | 2.1 (3.4) | Sportfish (Intensive Use) | ONMY, SATR | **ONAP**, ONMY, **PADI**, **RHOS**, SATR |
| Little Springs Canyon | LSC001 | 12.3 (19.8) | Unknown | Unknown | Unknown |
| Lockwood Draw | LOC001 | 0.9 (1.5) | Unknown | Unknown | Unknown |
| Long Draw | LNG001 | 0.6 (1.0) | Unknown | Unknown | Unknown |
| Long Tom Canyon | LOG001 | 7.1 (11.4) | Unknown | Unknown | Unknown |
| Maverick Canyon | MAV001 | 1.6 (2.6) | Unknown | Unknown | Unknown |

[g] CASP were collected from the 656 ft (200 m) sampled, but it is unknown if this is representative of the 43 mi (69 km) long unit

Table 5·4 Continued

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Merritt Draw | MER001 | 3.9 (6.3) | Unknown | Unknown | Unknown |
| Middle Leonard Canyon | MLC001 | 4.0 (6.4) | Unknown | Unknown | Unknown |
| Milk Creek | MIL001 | 4.8 (7.7) | Native | None | **RHOS** |
| Miller Canyon | MLL001 | 12.9 (20.7) | Native | CASP, ONMY, PADI, RHOS | CASP, **LEVI**, PADI, RHOS |
| Mineral Creek | MIN001 | 5.8 (9.3) | Native | ONAP | **LEVI**, ONAP |
| Mineral Ditch Complex | MIN002 | 9.9 (15.9) | Unknown | Unknown | Unknown |
| Moonshine Draw | MOO001 | 0.8 (1.3) | Unknown | Unknown | Unknown |
| Nutrioso Creek (lower) | NUT001 | 7.3 (11.8) | Native | PADI, PIPR, RHOS | **LEVI**, PADI, RHOS |
| Nutrioso Creek (mid-below Nelson Res.) | NUT002 | 5.7 (9.2) | Native | LECY, LEVI, ONCL, ONMY, PADI, PIPR, RHOS, SAFO, SATR | LEVI, PADI, RHOS |
| Nutrioso Creek (mid-above Nelson Res.) | NUT004 | 9.7 (15.6) | Native | LEVI, ONMY, PADI, PIPR, RHOS, SAFO | LEVI, PADI, RHOS |
| Nutrioso Creek (upper) | NUT005 | 8.7 (14.0) | Native | ONMY, RHOS, SAFO | **ONAP**, RHOS |
| Oso Draw | OSO001 | 13.0 (21.0) | Unknown | Unknown | Unknown |
| Paddy Creek | PDD001 | 5.0 (8.1) | Native | ONMY, RHOS | **ONAP**, RHOS |
| Padre Canyon | PAD001 | 19.0 (30.6) | Unknown | Unknown | Unknown |
| Palomino Canyon | PAL001 | 5.2 (8.4) | Unknown | Unknown | Unknown |
| Pius Farm Draw | PIU001 | 6.9 (11.2) | Unknown | Unknown | Unknown |
| Porter Creek (lower) | POR001 | 1.4 (2.3) | Native | LECY, MISA, ONMY, PIPR | **CASP, LEVI, PADI, RHOS** |
| Porter Creek (upper) | POR003 | 1.2 (2.0) | Unknown | Unknown | Unknown |
| Potato Lake Draw | POT001 | 2.3 (3.7) | Native | PIPR | **LEVI** |
| Pratt Lake Tributary | PRA002 | 1.1 (1.8) | Unknown | Unknown | Unknown |
| Quaking Aspen Canyon | QUA001 | 2.9 (4.7) | Unknown | Unknown | Unknown |
| Rio de Flag | RIO001 | 5.0 (8.1) | Unknown | Unknown | Unknown |

Table 5·4 Continued

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Rosey Creek | ROS001 | 3.0 (4.9) | Unknown | Unknown | Unknown |
| Rudd Creek (lower) | RUD001 | 4.6 (7.4) | Native | LEVI, ONMY, PADI, PIPR, RHOS, SAFO | LEVI, PADI, RHOS |
| Rudd Creek (upper) | RUD002 | 9.1 (14.7) | Native | ONMY, SAFO | **ONAP, PADI, RHOS** |
| Show Low Creek (lower) | SHO002 | 15.0 (24.1) | Unknown | Unknown | Unknown |
| Show Low Creek (middle) | SHO004 | 7.7 (12.4) | Sportfish (None) | LECY, ONMY, SATR, STVI | **CASP, GIRO, LEVI**, ONMY, **PADI, RHOS** |
| Show Low Creek (upper) | SHO006 | 2.4 (3.8) | Sportfish (None) | LECY, MISA, ONMY, PIPR, SATR | **CASP, GIRO, LEVI**, ONMY **PADI, RHOS** |
| Silver Creek (lower) | SIL001 | 19.4 (31.2) | Native | AMNA, CASP, CAAU, CYCA, LECY, LEMA, LEVI, PADI , PIPR | CASP, LEVI, PADI, |
| Silver Creek (mid-below White Mountain Lake) | SIL002 | 18.6 (29.9) | Native | CYCA, LECY, NOCR, PIPR | **CASP, GIRO, LEVI, PADI, RHOS** |
| Silver Creek (mid-above White Mountain Lake) | SIL004 | 3.0 (4.9) | Unknown | Unknown | Unknown |
| Silver Creek (upper-below Hatchery) | SIL005 | 1.4 (2.3) | Sportfish (Intensive Use/ Featured Species) | GAAF, LECY, NOCR, ONMY, PADI, PIPR, RHOS | **CASP, GIRO, LEVI, ONAP**, PADI, RHOS |
| Silver Creek (upper-Hatchery) | SIL006 | 0.8 (1.3) | N/A | GAAF, LECY, NOCR, ONAP, ONMY, PADI, PIPR, RHOS | N/A |
| Slim Jim Canyon | SLI001 | 4.2 (6.7) | Unknown | Unknown | Unknown |
| South Fork Little Colorado River | SFL001 | 8.5 (13.7) | Sportfish (Wildfish) | CASP, ONMY, RHOS, SATR | CASP, **ONAP**, RHOS |
| Thompson Creek | THO001 | 3.2 (5.2) | Native | LECY, PIPR | **CASP, PADI, RHOS** |
| Turkey Creek | TUR001 | 7.3 (11.8) | Unknown | Unknown | Unknown |
| Unnamed Spring to Schuster Spring | SCH001 | 1.1 (1.7) | Unknown | Unknown | Unknown |
| Unnamed Tank to Fran Day Spring | HLS001 | 3.6 (5.8) | Unknown | Unknown | Unknown |

Table 5·4 Continued

| STREAM NAME | UNIT ID CODE | Unit Length mi (km) | EMPHASIS (SPORTFISH CONCEPT) | All Fish Species Detected or Stocked Within Last 10 Years | Desired Fish Species |
|---|---|---|---|---|---|
| Unnamed Tributary to Knoll Lake | LEO003 | 1.9 (3.1) | Unknown | Unknown | Unknown |
| Vigil Run | VIG001 | 3.0 (4.9) | Unknown | Unknown | Unknown |
| Walnut Creek (below Woodland Reservoir) | WAL003 | 2.4 (3.9) | Native | ONMY, RHOS | **CASP, LEVI, PADI**, RHOS |
| Walnut Creek (above Woodland Reservoir) | WAL005 | 1.5 (2.4) | Unknown | Unknown | Unknown |
| Walnut Creek (Flagstaff) | WLT001 | 15.7 (25.2) | Unknown | Unknown | Unknown |
| Water Canyon | WAC001 | 13.3 (21.4) | Unknown | Unknown | Unknown |
| Watts Creek | WAT001 | 4.9 (7.9) | Unknown | Unknown | Unknown |
| Weimer Canyon | WEI001 | 3.7 (5.9) | Unknown | Unknown | Unknown |
| West Chevelon Canyon | WCC001 | 30.6 (49.2) | Unknown | Unknown | Unknown |
| West Fork Little Colorado River | WFL001 | 9.1 (14.7) | Sportfish (Intensive Use/ Wildfish) | ONMY, SAFO, SATR | **ONAP**, ONMY, SAFO, SATR |
| West Fork Black Canyon | WFB001 | 4.7 (7.6) | Unknown | Unknown | Unknown |
| West Leonard Canyon | WLC001 | 8.3 (13.3) | Native | LEVI, RHOS | LEVI, RHOS |
| Wildcat Canyon | WLD001 | 33.4 (53.8) | Unknown | Unknown | Unknown |
| Wilkins Canyon | WLK001 | 14.0 (22.6) | Unknown | Unknown | Unknown |
| Willow Creek | WLL001 | 31.4 (50.5) | Native | CASP, PADI, PIPR, RHOS, SAFO | CASP, **LEVI**, PADI, RHOS |
| Willow Springs Canyon | WIL001 | 3.4 (5.5) | Native | RHOS, SAFO, SATR | **CASP, PADI**, RHOS |
| Woods Canyon | WOO001 | 5.8 (9.4) | Native | ONMY, PIPR, RHOS, SAFO, SATR | **CASP, PADI**, RHOS |
| Woods Creek | WOD001 | 1.5 (2.4) | Unknown | Unknown | Unknown |
| Yeager Canyon | YEA001 | 13.6 (21.9) | Native | ONMY | **CASP, LEVI, PADI** |
| Youngs Canyon | YOU001 | 0.1 (0.2) | Unknown | Unknown | Unknown |
| Zuni River | ZUN001 | 63.4 (102.1) | Unknown | Unknown | Unknown |

## GEOREFERENCED DATABASES AND GIS COVERS

In order to facilitate the summarization of data for numerous discreet geographic areas delineated by the management units, it was necessary to georeference (provide geographic coordinates for) existing databases (Fish Collection and Stocking databases) and create new georeferenced databases (Museum, Creel, Management Actions, And Notes databases) when none had previously existed. Georeferencing made it possible for the databases to be imported into ArcView, a GIS software package, which then allowed us to quickly and accurately group and summarize data by Management Unit as the units were delineated and re-delineated as circumstances required.

Along with the Management Unit printouts (Appendix A), the databases will be directly available to fisheries managers, providing them with the latest data available and the ability to manipulate the data as their needs dictate. The Stream and Lake Management Unit GIS covers and Management Actions Database, in particular, will allow managers to quickly sort through the numerous management units and associated management actions to greatly aid in prioritizing and planing work activities, and facilitating the completion of recovery actions.

### Fish Collection Database (formally the Native Fish Database)

This existing database was augmented with AGFD Region I and II, Research Branch, and Forest Service fisheries survey data. All survey locations were georeferenced as part of this project when sufficiently detailed site location information was available.

The database provides fish species occurrence, general habitat, survey methodology, and location information.

### Stocking Database

This existing database was georeferenced as part of this project.

The database provides dates and general locations of spotfish stocking activities, providing numbers and average sizes of stocked fish by species.

### Museum Database

This database was created for this project from fish collection records provided by the University of Michigan Museum of Zoology, the Museum of Southwestern Biology, the National Museum of Natural History, the Museum of Northern Arizona, Arizona Sate University Fish Collection, and the University of Arizona Fish Collection. All records were georeferenced when sufficiently detailed site location information was provided.

The database provides fish species occurrence information by species and collection date.

Creel Database
This georeferenced database was created for this project from existing AGFD Region I and II creel survey information.

The database provides general fish species and angler use data summarized by water by year.

Management Actions Database
This georeferenced database was created for this project.

The database lists management actions for all management units. It categorizes various types of management actions (i.e. fisheries surveys, species repatriations, habitat improvement needs, etc.) and provides a mechanism to sort out those units that are considered to be high priority for implementation of any given type of action.

Notes Database
This georeferenced database was created for this project.

The database contains information of past events and condition (i.e. fishkills, renovations, drought conditions, etc.) for specific geographic locations. The information primarily comes from AGFD Region I and II personnel field notes.

Stream and Lake Management Unit GIS Covers
These GIS covers were created for this project.

The associated databases contain much of the information, in an electronic format, that is found on the Units Summary forms.

PROJECT CHRONOLOGY

This section is included as a way to help the reader understand the evolution of both process and plan.

August 1995 - Conceptualization
The earliest documents to describe the project included the following elements and ideas:

- Two goals: integration of native and sportfish management, and fisheries management planning on a large, geographically meaningful scale
- The idea that the plan would incorporate three activity types: inventory, monitoring, and management
- The idea that the plan's framework would consist of individual management units with corresponding unit summaries. These summaries would contain at a minimum: name, physical description, species assemblage, management emphasis, current land use,

current condition, desired condition (including species assemblage), and management actions

- Specified that GIS be used as a tool to help determine management emphasis
- Described coordination between regional personnel and Nongame Branch to determine needs for inventory, monitoring and management on an annual basis

June 1996 - Arizona Game and Fish Commission approves the project

September 1996 - First full-time staff is assigned to the project

October 1996 - First draft work plan written. Incorporated all of the elements from early conceptualization documents but lacked criteria for emphasis determination

October 1996 - Solicitation of LCR fish surveys and other fish information (creel, stocking, museum and so on) from other branches of the Department

October 1996 to Present - Data entry, creation and/or modification of georeferenced databases: creel, fish, museum, stocking, and others

November 1996 - Other states solicited for their approaches, if they existed, to watershed-based fisheries management of both native and non-native species (see Appendix F)

February 1997 - Project coordinator hired

April 1997 - Nongame GIS specialist hired

April 1997 - Solicitation of LCR fish surveys and other fish information from other governmental and non-governmental organizations, and museums

1997 - Series of internal meetings with regional fisheries personnel, Nongame Branch, Habitat Branch, and Research Branch personnel to discuss project approach, data collection, and so forth

September 1997 - Second full-time project employee hired

September to December 1997

- Plan development process mapped
- Unit evaluation procedure developed
- New needs identified: angler needs and native fish needs within the LCR watershed
- Work plan finalized, unit summary format refined

September 1997 to Present - Inventory of fish species for previously unsurveyed streams as time permitted

January 1998 to April 1999

- Unit summaries compiled, management emphases determined, and management recommendations written, one hydrologic unit at a time, at monthly CMPG meetings
- Upper LCR fish habitat data analyzed
- GIS models for suitable native fish habitat created

October 1998 - Gathering of native fish experts from within and outside the agency to define and agree upon acceptable "native fish needs" within the LCR

June to August 1999 - Writing and revisions of the final draft document of the plan

## Discussion

From the start, project leaders (Kirk Young and Jim Novy) intended that steps taken and decisions made in the development of this process and plan be both transparent and repeatable, so that others, using our methodology and data would reach similar conclusions. Often, however, the lack of data and subjective nature of certain questions required that decisions be made by informed judgment. Although decisions reached using this approach may not coincide with decisions another group would have reached given the same information, we attempted to document our decisions and difficulties, in hopes of maintaining standards of repeatability and transparency.

Of the responses received from the 50 states solicited for their efforts at integrated fisheries management, none were found to be suitable models on which to base such an effort in Arizona (see Appendix F). The reasons for this ranged from inherently different characteristics of fish in those states (unlike in Arizona, in many other states sportfish are also native fish; some states must include for consideration commercial fisheries, many states do not consider water to be a limiting factor in distribution and abundance of fish, and so on) to the development in some states of plans with much more inclusive goals, such as watershed management, which this plan was not intended to undertake.

The results of the nationwide solicitation therefore, led project leaders to conclude that Arizona would be developing a unique plan. Because discrete management actions are usually carried out at geographically limited scales, it made sense to divide the watershed into individual, readily identifiable, and geographically defined management units. This concept surfaced early on in the conceptualization of the plan, and is its central tenet: management units and their respective summaries are the building blocks of the plan.

Although most elements contained in the early conceptualizations of the project can be found in this plan, some were dropped, while new ones were developed. As with any project of this size and ambition, we found the devil to lay in the details. For instance, one early document confidently stated that management unit summaries should contain "Species Assemblage: fish species present, invertebrates, etc." We made every effort to include all fish information we had. But information on invertebrates was scarce, and where available, we were confounded by how to present it. Should we include density? Do we include invertebrates as prey base for fish, or as harmful predators (crayfish)? What other aquatic species should we include in the "Species Assemblage"? Do we list amphibians in general, sensitive amphibians, or predatory non-native amphibians (bullfrogs)? What about other riparian dependent species, or other sensitive species which may occur in the area? Other important questions also quickly surfaced: how will we measure the success of this plan? How can we make this plan as useful as possible to as many resource management entities as possible? How do we decide whether a management unit better serves native fish conservation efforts or the needs and desires of anglers? How do we incorporate and disseminate new information? How do we prioritize management actions for 251 management units? How do we deal with conflicting management recommendations within management units and between adjacent units? We attempted to answer each of these questions, with varying degrees of success.

An important early realization was that in order to measure the success of the project, somewhat nebulous goals (recovery of sensitive native fish, reduction of conflict between native fish and sportfish) would have to be translated into more tangible questions, such as exactly how many populations of each native species would we like to see in the LCR watershed? And what, exactly, are the needs and desires of anglers within this watershed in terms of the different types of fisheries available to them (feature species, wildfish, blue ribbon, warmwater, and so on)?

The former question we decided to answer with the aid of a group of experts on Arizona native fish from various institutions including the Fish and Wildlife Service, the Bureau of Reclamation, universities, and also from within the Department. The goals we had in mind for this group, which proved mostly unattainable, were to define "population" precisely, to determine the minimum numbers of individuals that could constitute a population, and to agree upon a range of numbers of populations of each species needed for that species' needs to be considered met within the watershed.

The outcome, although not what we had envisioned going into this process, proved more than adequate; a single number of populations for each of the major basins in the watershed (Clear Creek, Chevelon, Silver Creek and the upper LCR). In retrospect, it doesn't seem as if the first two goals were all that important, and another goal, which we had not formally expressed, surfaced and was unanimously agreed upon: native fish, regardless of their status of endangerment, should be managed in mixed assemblages, according to their habitat preferences. In the end, we are satisfied with the assessments of the native fish expert group, and emphasize that such a gathering be made a part of the five year, comprehensive review process, so that new information can be incorporated into the discussion as it surfaces.

Determining the analogous needs and desires of anglers in the watershed proved to be impossible. None of the previous statewide angler surveys (Pringle 1994; Pringle in prep.) could answer questions on the scale at which we were asking them. What, for example, is the angler demand for stream fish angling days in the Little Colorado River watershed? For this iteration of the plan, at least, we relied instead on the assertion by Department fisheries personnel that current angler demand is being met, and that with no net loss in angling days, demand would continue to be met (to the extent possible given the watershed's resources).

On the subject of management unit delineation, there was considerable debate on what should constitute a criterion for breaking a stream reach or lake into an individual unit. Some favored strictly biological or physical characteristics, but this was rejected because it excluded factors important to our ability to carry out management actions such as land ownership. In general, we selected criteria for their ability to define an area to which we could apply relevant, site-specific management actions.

The management unit summaries, as well as determination of desired fish species and management recommendations, were completed by basin (geographically) as opposed to being completed "as sufficiently complete data sets become available" (as an early draft work plan suggested). This shift allowed the CMPG to work more efficiently through entire geographic regions at a single sitting, instead of addressing a mix of management units. Aside from being a more clerically manageable approach, it forced us to recognize and deal with the fact that data for a number of management units would simply not become available within the lifetime of the pilot project. It also prevented some initial conflicts in species assemblages and management recommendations between adjacent units by allowing the CMPG to address issues for one management unit with the decisions for adjacent units and those within the same basin still fresh in mind.

We excluded from management unit summaries certain elements identified in early conceptualization documents. Habitat condition, water rights, stream gage data, vegetation composition, average water width and depth, and primary substrates were omitted because of their general paucity of data. By extension, we also did not include opinions on desired habitat conditions for the future. Other data were not included in an effort to streamline summary forms, because it was not deemed particularly useful to our endeavor, or because it was at an inappropriate scale (for example fish management area, game management area, wildlife management district, latitude and longitude - replaced with UTMs - watershed area, and others).

We used information included in unit summaries to evaluate units' relative values to native fish conservation and angling. We realized early on that in order for this process to remain repeatable, we would have to come up with a precise mechanism for the evaluation of the units. First attempts included scorecards with criteria for both native fish and sportfish. We rejected this because numerical values seemed arbitrary relative to data. We also found it easier to completely decouple evaluations for native fish and sportfish. The end result was two decision flowcharts with relative rankings, designed to be applied independently to a given unit. Continuous modifications to the flowcharts were necessary as previously unanticipated circumstances were encountered. Flowcharts, like the process as a whole, will undoubtedly have to be further modified as we plan for other watersheds, but we are satisfied that the current mechanism legitimizes our decisions and that where deviations from the flowcharts were unavoidable, we documented our reasoning for such deviations (see Appendix C).

Although the flowcharts were designed to cleanly arrive at a management emphasis of either native fish or sportfish, we found the reality to be a bit more complex. Although we include primary management emphasis (which, incidentally, can also include "no emphasis", or "unknown") in unit summaries, we made a conscious decision to de-emphasize this variable in favor of the "desired species assemblage" variable. This allowed us to better handle those fish species that are both native fish and sportfish (Apache trout, and roundtail chub), and to advocate a mix of native and sportfish in certain management units where we believe they can co-exist, and where the removal of one or the other is either not feasible or does not make any sense.

At certain times, it seemed the entire house of cards would collapse upon us, as we encountered situations in which previous actions and decisions could not guide us. Such was the case for the upper portion of the Show Low Creek drainage, above Fool Hollow Lake. Here, the drainage is characterized by a series of important sportfishing lakes interspersed with private inholdings, and a high degree of urbanization. Our confusion came with determining emphasis, desired species assemblage, and management recommendations for those stretches of stream in between the reservoirs. These stream reaches, with limited access, were not obvious candidates for sportfish management areas. But the likelihood of movement of non-native sportfish from reservoirs into the streams during times of high flow is high, making renovation impractical. This would not necessarily make the stream reaches good candidates for native fish conservation either. To exacerbate the situation, recent surveys throughout the drainage only located a handful of native speckled dace in one tributary to Show Low Creek. We assume, but cannot confirm, that the absence of native fish from the drainage is due to long ago chemical renovations (see Appendix G). Fortunately, common sense prevailed, and we decided that only further enlightenment could result from translocating native fish back into those stream reaches. The success or failure of these transplants, in the presence of non-native fish that might have migrated from above or below, will guide future decisions under similar circumstances.

Success or failure of this project, as measured by the achievement of the goals for native fish and sportfish within the watershed, will depend on the soundness of the management unit recommendations, the usability of the resources developed here (with emphasis on the electronic, georeferenced databases), the extent to which recommendations can be and are implemented, and ultimately on the success or failure of those management recommendations to achieve the desired results. The five year review period should include an examination of these questions.

This report, with the accompanying management unit summaries, is intended as a tool/resource for fisheries, wildlife, and land management personnel of all agencies. It is also intended to serve as the fish management module of more comprehensive watershed management plans developed. Although this project focuses on fish resources in the LCR watershed, the importance of the effect of land management practices throughout the watershed on fish within the watershed cannot be overstated.

## RECOMMENDATIONS

### GENERAL

- Data collection methods and data entry codes should be standardized to the greatest extent possible. Databases should be centralized and frequently updated with the most recent data available. Strict mechanisms for quality control and documentation must be developed and implemented

- Fish collection and stocking locations should be recorded as UTM coordinates rather than reaches whenever possible. Stocking records should be verified by Regional personnel on a yearly basis, with feedback to Fisheries Branch

- A standardized archival system should be developed and implemented (for fisheries Department wide) for the storage of original data sheets, field notes, slides, and photographs, so that they may be quickly and easily accessed

- More emphasis needs to be placed on recording and archiving of field notes. This is critical to helping current and future managers in understanding events and conditions which led to the current state

- Formal mechanisms to coordinate field activities and to assure inclusion of all fisheries data from other agencies and academia need to be developed and implemented

- The Perennial and Intermittent Hydrology covers need to be improved upon. This includes the creation of an Interrupted Perennial cover to make them more accurate and useable for fisheries management

- Angler needs and desires for each watershed must be better understood to ensure the Department is meeting them within the constraints of available habitat

- The Department should evaluate the potential of "adopt a stream" and "adopt a lake" programs to improve habitat conditions

- The Department should explore new ways to prevent illegal introduction and distribution of aquatic organisms

PROCESS SPECIFIC

- The Department should actively pursue participation in watershed management plans being developed throughout the state, providing the fisheries management component of these plans

- The process developed here must remain dynamic and capable of incorporating valuable feedback from the users of this resource. The process will undoubtedly need modification in subsequent watersheds as circumstances unique to those watersheds are encountered

- The package of management recommendations developed in this plan will require regular review. Periodic modifications to some of the recommendations will be necessary as additional data become available, and watershed conditions change. The plan must remain sufficiently adaptable to allow for the implementation of innovative solutions and the exploitation of new opportunities, as they become available

- Project staff should consider the following changes to management unit summary forms:
    - Create separate forms for lakes and streams
    - Add "region" as a field to indicate jurisdictional responsibility
    - Add a "date updated" field
    - Develop a mechanism to identify and archive those management actions completed upon revision of the project
    - Add "funding source(s)" as a field to identify potential sources to fund the recommended management actions

- To remain valuable, databases and management unit summaries will require continuous maintenance.

## LITERATURE CITED

Apache Trout Recovery Team. In prep. Apache Trout Implementation Plan. Pinetop, Arizona.

Pringle, T.W. 1994. Statewide surveys of 1986, 1989, and 1992 Arizona Anglers. Fisheries Branch, Arizona Game and Fish Department, Phoenix, Arizona. 212 pp.

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APPENDICES A-G: SEE ENCLOSED CD

CD not delivered to GCMRC library.
SCW