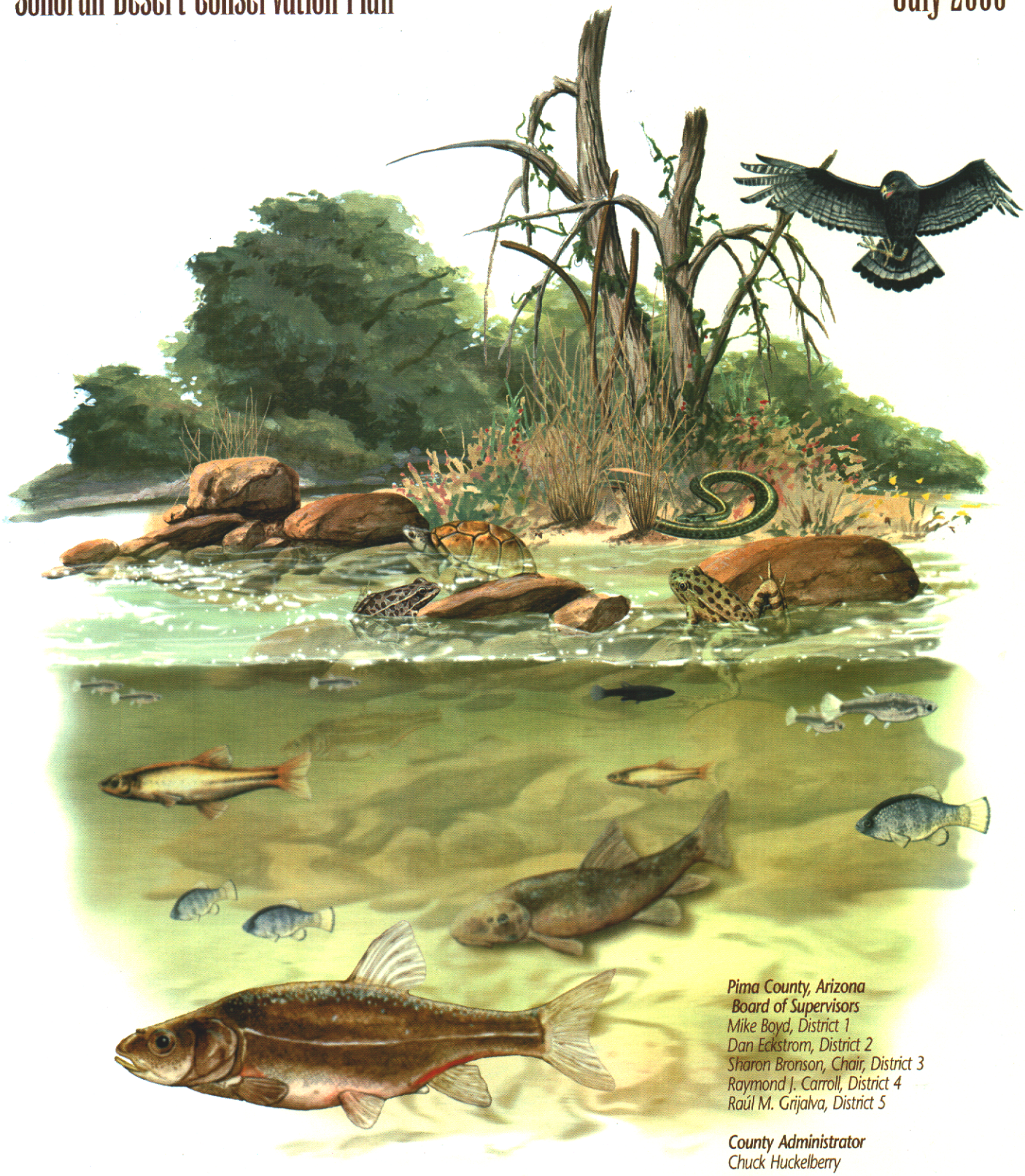
DRAFT

Aquatic Vertebrate Conservation in Pima County

Concepts and Planning Development

Sonoran Desert Conservation Plan

July 2000



Pima County, Arizona
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County Administrator
Chuck Huckelberry

MEMORANDUM

Date: July 10, 2000

To: The Honorable Chair and Members
Pima County Board of Supervisors

From: C.H. Huckelberry
County Administrator

Re: **Aquatic Vertebrate Conservation in Pima County, Concepts and Planning Development**

Overview

Among the many reports that have contributed to the development of the Sonoran Desert Conservation Plan thus far, the attached study by Dr. Philip Rosen on *Aquatic Vertebrate Conservation* stands as one of the most impressive, given the scope of the author's knowledge, and it is one of the most ingenious, given the proposed concepts for restoration and protection of native fish and frogs within the urban Tucson Basin. A three-faceted approach to wetland restoration on the floor of the Tucson Basin includes:

- Creation of in-channel perennial reaches for high-flood systems;
- Creation of spring-fed (or reclaimed water-supplied), quasi-cienega, small channel systems in natural sites with little flooding or with moderate flooding; and
- Creation of ponded habitats where native fishes that can control mosquitos.

Dr. Rosen also discusses the conservation potential of forty key canyons within the ex-urban areas of Eastern Pima County, identifying the presence of both native and non-native aquatic species, and suggesting specific actions ranging from removal of harmful exotics, to reintroduction of natives, to specific management prescriptions, to necessary partnerships and priority acquisitions. The "gazetteer" of key canyons provides alarming insight into the numerous crashes and disappearances that have occurred recently in native frog and fish populations. Stabilizing the aquatic species in isolated canyons is obviously a condition of restoring urban populations. "Ideally," Dr. Rosen writes, "conservation strategies both inside and outside the urban environments of Pima County should look toward both preservation in mountain canyons and restoration of valley floors." (P. 15)

This expert advice and review of the landscape arrives at an important moment. On June 14, 2000, the United States Fish and Wildlife Service proposed threatened status under the Endangered Species Act for the Chiricahua Leopard Frog. The Chiricahua Leopard Frog is just one in the line of native aquatic species that is sliding toward extirpation and extinction, earning, near the very end, status as a listed species, or as a Species of Special Concern. Going beyond a description of the ways in which our aquatic systems are failing, Dr. Rosen's report offers a remarkable gift: a comprehensive, innovative, multi-tiered, and at times aggressive blueprint for how to begin to repair these systems. This memorandum provides a summary of -- and support for -- Dr. Rosen's *Aquatic Vertebrate Conservation* report.

Abstract and Introduction

Pages 3 and 4 of the attached document are the abstract and introduction of Dr. Rosen's report. Highlights include:

- "This document outlines plans for conservation and restoration of native fishes, leopard frogs, Sonoran mud turtles, and garter snakes in Pima County." (P. 3)

- "Restoring natural perennial flow and flooding regimes, and controlling eliminating harmful non-native species are identified as the most important issues. Conservation of native fishes alone will lead to a proliferation of the non-native bullfrog, a predator and competitor which would then defeat conservation efforts for the reptiles and amphibians." (P. 3)

- "Small, in-channel streams segments created and maintained with reclaimed water are proposed to support lowland leopard frogs and fishes. These would be relatively resistant to invasion by harmful non-natives." (P. 3)

- "For natural springs, wastewater sites, and parks and golf courses, management plans are proposed to support a wide diversity of native aquatic species." (P. 3)

- "The native species involved in these plans are as follows: desert pupfish, desert sucker, Gila chub, Gila topminnow, longfin dace, Sonora sucker, speckled dace, canyon treefrog, Chiricahua leopard frog, lowland leopard frog, black-necked garter snake, checkered garter snake, Mexican garter snake, Sonoran mud turtle, and giant spotted whiptail lizard." (P. 3)

- "Introduced species present the greatest physical obstacle to successful re-establishment of native leopard frogs, Mexican garter snakes, Sonoran mud turtles, and native fishes that originally thrived in the Tucson Basin. The problem exotics include especially bullfrogs, catfish, sunfish, bass, and mosquitofish, although other exotics that may become widely involved are crayfish, African clawed frogs, and other fishes (especially carp and cichlids)." (P. 3)

- "Habitat modifications are the primary reason for the potent advantage introduced species over native species. Creation of ponds and lakes creates habitat suitable for bullfrogs and non-native fish. Streams and springs, where are natural habitat here, favor lowland and Chiricahua leopard frogs. Floods tend to favor native fishes, especially longfin dace, over introduced fishes." (P. 4)

- "[Non-native] fish are the easiest aquatic species to control, since they can be eliminated by drying or poisoning, and cannot disperse overland. Crayfish ... have limited dispersal probability, but are much more difficult to eradicate .... Bullfrogs have remarkable overland dispersal capability, are difficult to eradicate, and therefore are the most difficult to control." (P. 4)

Potential Species Recovery in the (Urban) Tucson Basin

Pages 4 through 12 of the *Aquatic Vertebrate Conservation* report outline a three-level plan structure for wetland restoration in the Tucson Basin. Highlights include:

- "Water supplies that can be turned on or off, or at least re-routed to allow drying up of habitat, are ideal for elimination of various exotic fish species that may invade re-establishment sites. Thus, effluents, reclaimed water, and highly managed waters in general, offer a key opportunity for multi-species recovery of our native wetland fauna. This opportunity is not readily available in natural water systems, because the flow is too difficult to regulate, divert, or turn on and off." (P. 4)

- "Placement of the various Tucson Basin core re-establishment sites should be done so that (1) leopard frogs and other amphibians and reptiles may disperse from one site to another during especially good and wet years and thus maintain a metapopulation structure; (2) the metapopulation structure also permits occasional immigration-emigration exchange between the valley floor and surrounding mountain canyons; and (3) fish are positioned in habitats in the landscape at which they can be expected to weather flooding and drying events." (P. 4-5)

- A three-faceted approach to wetland restoration on the floor of the Tucson Basin includes: (1) creation of in-channel perennial reaches for high-flood systems; (2) creation of spring-fed (or reclaimed water-supplied), quasi-cienega, small channel systems in natural sites with little flooding or with moderate flooding; and (3) creation of ponded habitats where native fishes that can control mosquitos. (P. 5)

- **Creation of in-channel perennial reaches for high-flood systems**

  "Dammed-up, non-flowing water systems should be replaced where possible by in-channel streams with longfin dace and lowland leopard frogs. This would likely involve use of reclaimed water. These two species are most tolerant of the powerful flooding that might occur in the major channels of the Tucson Basin. The natural flooding cycle should succeed in maintaining these native species at an advantage over any non-natives that may be present in the system. This kind of habitat generally consists of runs and riffles, with little pool development and little emergent vegetation." (P. 6)

  "Sites should be identified along the length of the major valley floor channels where bank conditions permit a possibility of escape from the floods into eddies or slower water. Eddy structures should be designed into the soil cement banks. These small sites should be about 1 km or more in length, but shorter reaches may suffice initially. The sites should be distributed as a sequential series of stepping stones, to maximize the ability of the native species using them to move on their own, during floods or long periods of higher flow, to other parts of the Tucson Basin." (P. 6)

  "An idealized model of this 'metapopulation' system is shown in Figure 2 [next page] and some possible sites, with existing, planned, or potential water facilities, where native species might survive with in-channel water are shown in Figure 3 [page after next]."

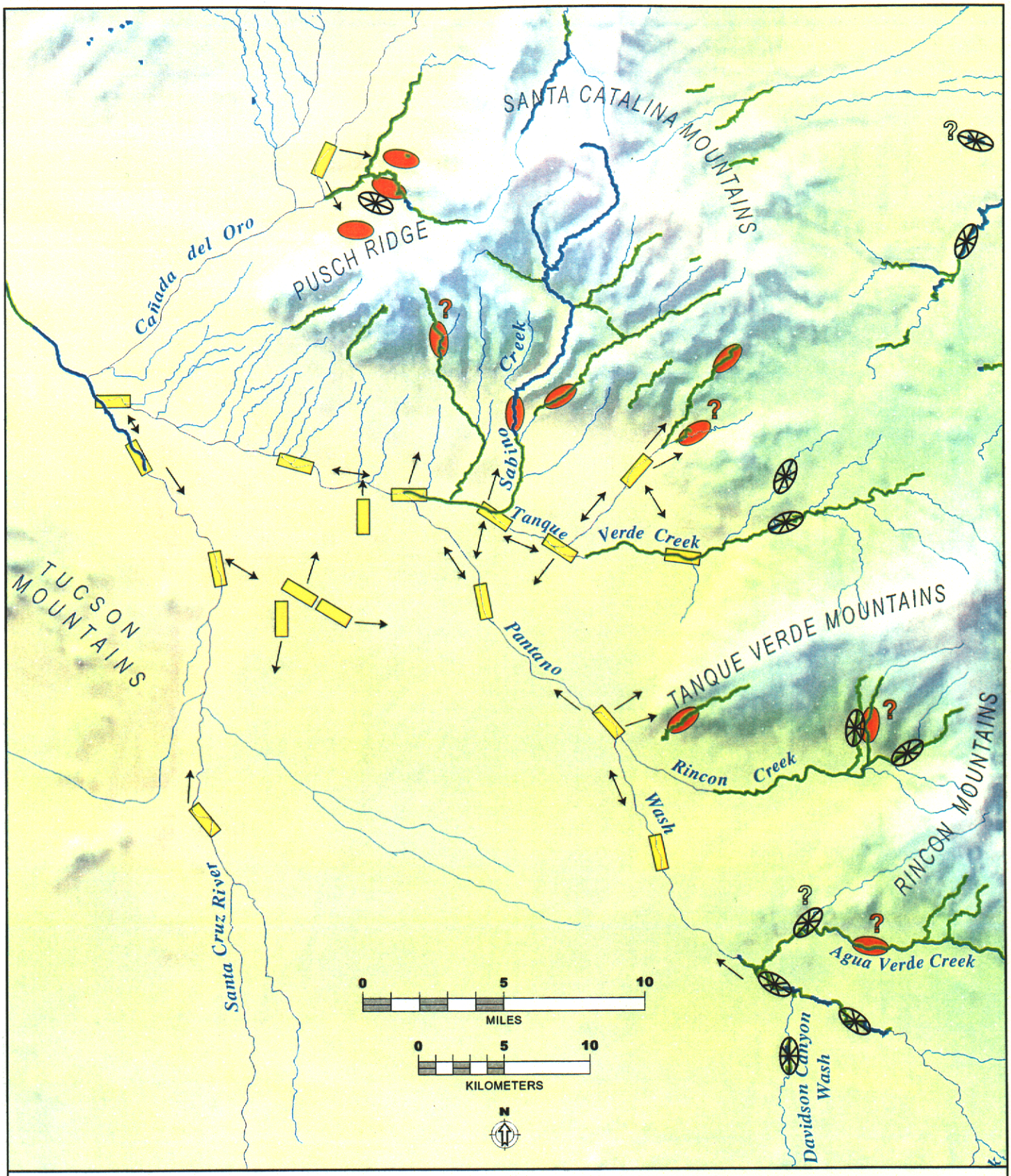

Figure 2.
Ideal Lowland Leopard Frog Metapopulation Structure

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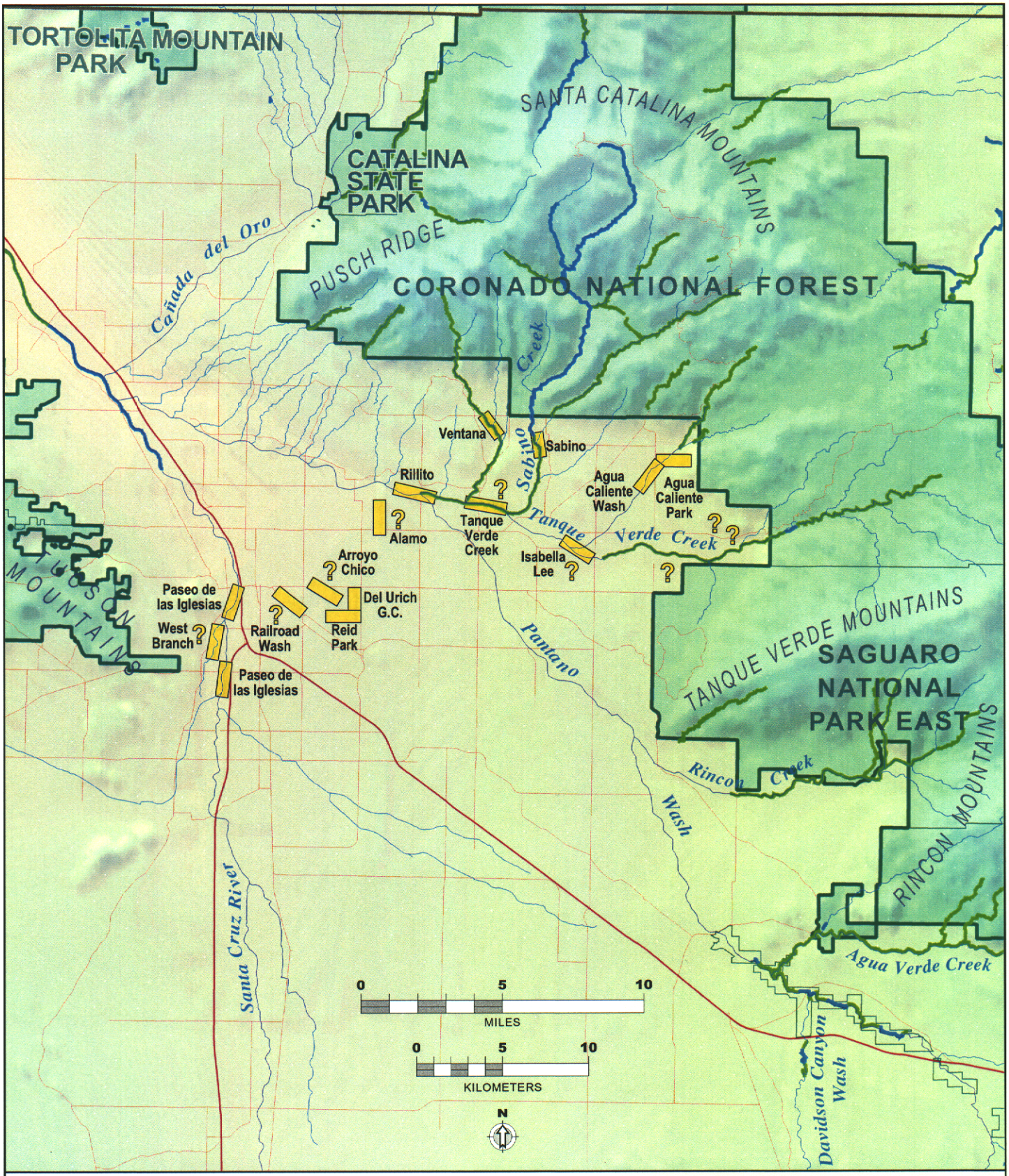

Figure 3.

Possible Lowland Leopard Frog Metapopulation Structure for Re-establishment on Tucson Basin Floor

Pima County Graphic Design 600 ep

- **Creation of spring-fed (or reclaimed water-supplied), quasi-cienega, small channel systems in natural sites with little flooding or with moderate flooding**

"At less powerfully flooded sites, critically imperiled native fish may thrive and native amphibians and reptiles may also persist. These systems would either be managed spring runs, or designed reclaimed water streams in arroyos with moderate flooding. Successful creation of the latter would take some artful hydrological planning and knowledge. In these systems, riffles or runs may alternate with slower or deeper water, and topminnow, pupfish, and chub could thrive." (P. 7)

"The substantial spring flow would be used to create ciénega-run conditions like those found now at the spring source of Agua Caliente. These waters could be landscaped into the existing uses--picnicking, weddings, and so on--in a rather attractive way. They would then be highly suitable for the most endangered species--pupfish and topminnow. A few deeper pools could also support Gila chub. Other native fishes (longfin dace, Sonora sucker, and desert sucker) might also exist, although they are normally found in rocky or more strongly flowing stream habitats. Bullfrogs are not known to thrive in flow-dominated, small-channel habitat types (as opposed to deep pools, ponds, and lakes, where they do thrive), and thus native lowland leopard frogs, Sonoran mud turtles, and Mexican garter snakes could also exist." (P. 7)

"This hypothetical ecosystem, then, could support all of the most critically-declining or endangered wetland vertebrates of the Tucson Basin--pupfish, topminnow, chub, leopard frog, and garter snake--and all in potentially substantial numbers. The spring should be capable of providing a very great linear extent of the habitat type. In fact, I suggest that this spring-run system could be extended to reach the bed of the Agua Caliente Wash itself at this location--which would variously be at about 1/4 to ½ miles from the present spring source. This channel system could then be attached directly to an arroyo-channel habitat type that would also support the native fauna but in a more flood-prone system. This could be the ideal arrangement of things: in wet springs, continuous flow in the major Tucson Basin floor streams would allow fish from the Agua Caliente area to reach and colonize other sites we might create. Regardless of the flood severity in the main arroyo channel at Aqua Caliente, re-colonization could readily occur from the spring-run system I have suggested for the park." (P. 7-8)

"Special and carefully designed measures would be required to sustain anything other than the deep, steep-sided ponds and pools that various exotics would thrive in. Such measures would have to involve either (1) concretized, natural-looking channels (like the one at Quitobaquito, which does, nevertheless, require periodic pulling of the encroaching cattails and tules), (2) periodic re-trenching of earthen runs, or (3) alternate flow channels that would permit drying of some portions of the system to cause the die-off or die-back of the cattails and tules. If such an approach is taken, very careful planning and construction would pay great dividends in the saving of the native fish populations and in efficiency of the maintenance regimen that would be required. .... Proper design of channel gradients and interconnections would allow small channel segments to be isolated and dried out for management purposes." (P. 8)

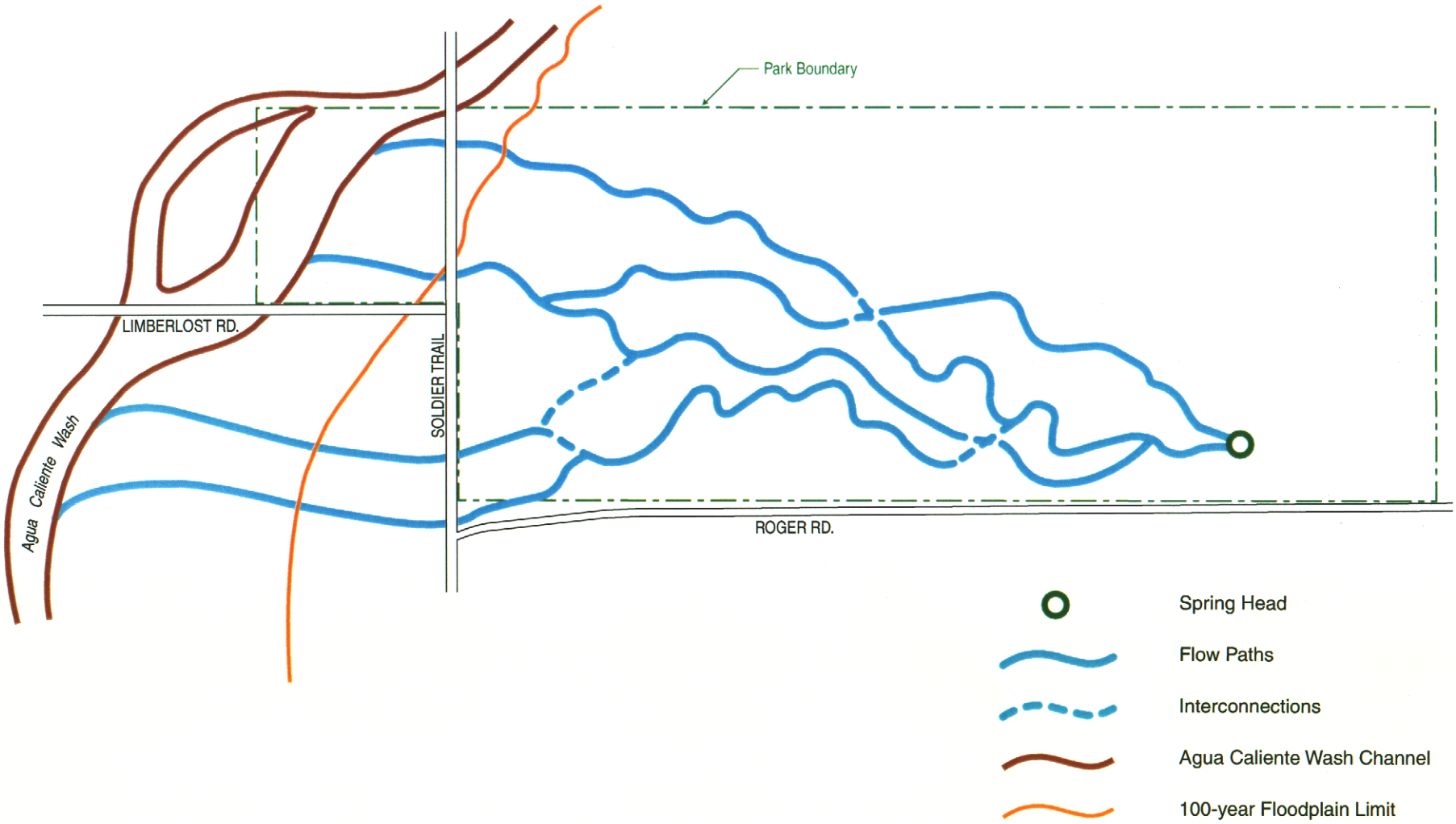

Figure 5.
Agua Caliente Park
Managed Cienega Flow Concept

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Ex-Urban Canyons and Valley Floors

Pages 13 through 22 of the *Aquatic Vertebrate Conservation* report shift focus from the valley floor to the outlying canyons. Highlights from a review of forty canyons include:

- "**Fishes:** Imperiled fishes in Pima County currently occur naturally at upper Ciénega Creek-Empire Ranch (Gila chub, topminnow, longfin dace), Sabino Canyon (Gila chub, and formerly, Gila topminnow), perhaps Buehman Canyon (Gila chub), and potentially in the Santa Cruz River at Arivaca Junction (Gila topminnow, Sonora sucker). Longfin Dace also occur in the County in lower Ciénega Creek, the northeast quadrant of the Santa Rita Mountains (Cave, Gardner, and Fish Canyons), the San Pedro River and some of its tributary canyons, and should be present in the Santa Cruz." (P. 13)

- "**Amphibians:** Lowland leopard frogs are abundant in the perennial stretches of the lower San Pedro and in lower Ciénega Creek (in the County's Natural Preserve). They also occur in the County in good numbers at about 7 isolated canyons in the Rincon, Santa Catalina, and Whetstone Mountains, and they are known in more limited numbers in about 4 additional, also isolated, canyons in these mountains. Canyons confluent with the lower San Pedro probably are the only currently viable population sites, since these and the river appear to form a metapopulation in which local extinction events may be balanced by emigrants or dispersers from other local populations. It is quite possible that the lowland leopard frog may be re-discovered in or near the Altar Valley just north of Buenos Aires National Wildlife Refuge. Otherwise in southern Arizona, this species has been extirpated except at the Muleshoe Ranch Preserve, and two isolated springs, in the Atascosa and Pajarito mountains. Isolated populations of lowland leopard frog have been disappearing at an alarming rate in the mountains around Tucson--at least 6 major populations have disappeared in the last three decades. They have disappeared due to introduced species (3 cases) and short-term drying (2 or 3 cases), and will not be naturally re-established without supportive management." (P. 13)

  "Chiricahua leopard frogs now occur in the County only at Buenos Aires National Wildlife Refuge and vicinity (2 known populations), at Empire Ranch (1 known, tiny population persisting), and in the northern Santa Rita Mountains (where 2 small populations may or may not be persisting). They were formerly widespread and abundant at Arivaca, the Altar Valley, Sierra San Luis, northern Santa Rita Mountains, and upper Ciénega Creek, occurring widely in natural streams, springs, and stock tanks. Major population losses are attributable to exotic species. Both species of leopard frogs are also suffering from a possibly newly acquired disease." (P. 13)

- "**Reptiles:** The Mexican garter snake persists in the County in Ciénega Creek. It formerly occurred, and was presumably extremely abundant, at Arivaca and in all perennial waters of the Santa Cruz, Rillito, Pantano, and Agua Caliente in the Santa Cruz Valley and Tucson Basin. This species is dwindling toward eventual extinction in the United States".

- "Mountain canyons currently contain much of the stock from which we must draw to preserve the native aquatic vertebrate fauna of the County. Gila chub, longfin dace, desert sucker, Sonora sucker, speckled dace, lowland leopard frogs, and Chiricahua leopard frogs are now primarily found in mountain canyons. Without significant efforts to preserve habitat and species in mountain canyons, the Gila chub and the lowland leopard frogs may face extinction--before we have any opportunity to return them to valley floors where they formerly were abundant. Therefore, it will be critical to identify and protect key mountain canyon waters, and to develop and implement conservation strategies in which current and developing land uses may be compatible with species preservation." (P. 14)

- **"Cienega Creek Natural Preserve**, from Pantano to the RR bridge. A well-known, major lowland leopard frog population site, and more recently with numerous records of the Mexican garter snake, this site is recovering from grazing. Under grazing, it was a desert stream with little pool development. Under protection as a county park, deeper and more stable pools have developed, and a ciénega-stream environment is apparently developing.

  "Bullfrogs and non-native soft-shelled turtles were reliably reported at the site starting in about 1995. These and exotic fishes (currently present in clay pit ponds dangerously close to the stream) may do better in the new, more stable conditions, and may pose a significant threat. Clearly, the non-native fish near the stream should be removed. A thorough survey of stock tanks in the region surrounding this critical resource should be initiated. New pond developments in the Pantano floodplain at Vail Valley below the county park threaten to produce a bullfrog explosion that will inundate the leopard frog population in the Natural Preserve. The Rancho Del Lago development situation is highly problematical. This situation should be monitored, and the private developers notified of the implications of what they are doing: perhaps some kind of compromise solution is possible. Local government should consider ordinances that prevent this type of situation from developing again. ... State representatives should be contacted concerning the contradictory nature of state statute and Arizona Game and Fish Department's rules and attitude toward bullfrog possession and introductions. State legislative action is required before the bullfrog can gain its richly deserved status in Arizona--totally prohibited. Currently, it is legal to purchase bullfrogs out of state, and release them on private land. Without legislative action, the Arizona Game and Fish Department cannot correct this situation. A successful, reasoned argument from the SDCP will benefit the entire state."

  "This site may well support a variety of native fish species, most notably the Gila chub and Gila topminnow, which are upstream in the Empire-Cienega Ranch reach of Ciénega Creek. Until very recently, the habitat in the Natural Preserve was shallow runs, with few pools, and unstable banks. Thus, chub and topminnow have probably not had time to recolonize the site. From the standpoint of future recolonization potential in the Tucson Basin, as envisioned in the present plan document, allowing natural downstream colonization processes would be more informative than immediate re-introduction of the species. Assuming the habitat is now suitable, it would be very strange if downstream colonization during floods did not occur, and confirmation would be important." (P 17)

- **"Empire-Cienega Resource Conservation Area -- BLM** (Empire-Cienega Ranch). This is the wetland gem of Pima County, with lowland leopard frogs (rare or extinct), Chiricahua leopard frogs (now rare), bullfrogs (rare), Mexican garter snakes (apparently still widespread and probably not uncommon), Sonoran mud turtles (abundant), longfin dace (abundant), and Gila chubs and Gila topminnows (both superabundant). The excellent wetland management practiced by the Bureau of Land Management, with the cooperation of the grazing permittee, at this site should be recognized. Efforts to eliminate all stock ponds with breeding populations of non-native fish and bullfrogs in the entire basin should be assisted and pursued with vigor." (P. 18)

  "Keeping exotic fish, which have apparently somehow never gained access to Ciénega Creek, out of the system is perhaps the County's highest priority for wetland conservation. There are several million endangered fishes in the system--probably 1-2 orders of magnitude greater than the sum total of all other individuals of Gila topminnow in the U.S., as well as large numbers of Gila chub. Loss of the site through spread of mosquitofish, green sunfish, bass, and bullhead catfish could possibly eliminate the long-term survival prospects for these two fishes. Removal of the offending pond habitat proximal to the stream may make it difficult for bullfrogs to persist in the area, as well."

  "The Chiricahua leopard frog and Mexican garter snake populations in Ciénega Creek are very important, and require study and monitoring. The Mexican garter snake population may be the best one left in the United States." (P. 18-19)

Summary

Pages 25 through 27 summarize the report as follows:

- "The loss of riparian forests, wetlands, and perennial streams is a widely-appreciated problem in Arizona. Less apparent is the spread of introduced, non-native aquatic species (bass, sunfish, catfish, carp, mosquitofish, other fishes, bullfrogs, other frogs, and crayfish). These non-native species have largely eliminated most of the native aquatic species from the remaining perennial waters, and they are a primary obstacle to re-establishment of native species. The impact of non-natives on natives has been greatly exacerbated by habitat modifications: introduced species are typically pond and lake species, and ponds and lakes we have created." (P. 25)

- "The native habitat is flowing water, of a highly variable nature, with sudden, severe flood scour, and, in many areas, drying or near-drying on a seasonal basis. Native species are well adapted to these variable hydrological conditions." (P. 25)

- "To significantly recover our decimated native aquatic fauna will require water, which we can supply upon suitable social consensus. However, it will also require that we plan carefully to eliminate the introduced species, or at least minimize their impacts. This can be done by a combination of traditional removal methods for fish (drying, short-lived toxicants) and habitat management (re-establishment of suitably natural conditions)."

- "Perennial ponds and lakes may potentially produce massive bullfrog populations that could contaminate large areas of habitat we may be managing for native species. This would be especially true if non-native fishes, which check bullfrog populations, are removed. Efforts to remove bullfrogs from complex wetlands have proven difficult or fruitless. Where pond habitats cannot be avoided, three solutions are possible:

  (1) they can be maintained in areas where bullfrogs will not colonize them (i.e., city parks);

  (2) they can be used for native fishes, which co-exist successfully with bullfrogs, but not for native frogs and garter snakes; and

  (3) they can be located in areas where bullfrogs could reach native species sites, but the bullfrogs might be managed by frequent drying, since bullfrogs have a long tadpole stage." (P.25-26)

- "The native aquatic fauna now persists primarily in isolated mountain canyons and small conservation refugia. These refugia are subject to random extinction processes, and they offer no habitat for many of the most endangered species. Formerly, the fauna's stronghold in Pima County was in the perennial waterways of the Tucson Basin floor--the Pantano, Tanque Verde, Agua Caliente, Rillito, and Santa Cruz. This document describes ways the native aquatic fauna may be re-established in abundance in the original area, the valley floor." (P. 26)

- "Mountain Canyon refugia, and the all-important Empire-Cienega Ranch section of Ciénega Creek, must of course be protected from de-watering. Further, renovations in many of them are needed, specifically the removal of harmful introduced species. This document provides an annotated list of most of the major canyons that support aquatic species in the County. A major step in recovery of the valley floor will be the elimination of upstream, in-drainage populations of introduced species, which otherwise will regularly recolonize downstream areas we are attempting to manage, sharply foreclosing our options." (P. 26)

- "This document focuses on examples of how and where aquatic habitats could be utilized on the valley floor of the Tucson Basin. First, small, in-channel stream segments supported by reclaimed water or natural springflow would permit the re-establishment of lowland leopard frogs, longfin dace, and other members of the original aquatic fauna. Periodic natural flooding in this habitat is expected to prevent non-natives from eliminating the native species, even if non-natives reach the sites." (P. 26)

- "Second, less flood-prone areas, such as natural springs and in-channel water developments in smaller drainages, could be designed to minimize their tendency to support harmful exotics. Non-native fishes can be physically eliminated from such systems to begin with, and the systems could be designed to facilitate dealing with re-introductions of harmful non-natives. By avoiding pond-like habitat, fewer non-native fishes could exist at a site, and the problem of bullfrogs would be minimized."

"Habitats of this kind can be expected to support our most threatened aquatic species--topminnows, pupfish, chubs, and Mexican garter snakes--as well as other species of concern, such as longfin dace, native suckers, lowland leopard frogs, and Sonoran mud turtles. If properly designed, these areas can also supply individuals of these species to the mainstream habitats proposed above, sustaining and augmenting populations there in processes called "metapopulation" dynamics." (P. 26)

- "In addition to detailing some aspects of these proposed restoration efforts, this document identifies and highlights some key immediate or important priorities:

  1. The Empire-Cienega Ranch area must be protected from invasive exotic species, especially fishes, by getting the exotics out of the surrounding drainage basin.

  2. Green sunfish (and a few other exotic fish populations) should be removed from key mountain canyons where they prevent native fish conservation (Romero Canyon; Bear Canyon--including Rose Canyon Lake; Agua Caliente Canyon; Tanque Verde Canyon; Paige Canyon).

  3. A long-term solution should be sought (in cooperation with Buenos Aries National Wildlife Refuge and Arizona Game and Fish Department) to the disastrous situation at Arivaca Ciénega and Arivaca Lake, where non-native species have overwhelmed the Chiricahua leopard frog, Mexican garter snake, and Gila topminnow.

  4. Pima County and the Sonoran Desert Conservation Plan should recognize and assist the development of cooperation between the Buenos Aires National Wildlife Refuge, Arizona Game and Fish Department, and area ranchers interested in conservation and re-establishment of native leopard frogs in ponds and springs in the desert grassland and oak woodland areas of the County." (P. 27)

Conclusion

The approach offered by *Aquatic Vertebrate Conservation* is not only remarkable for its scope and innovative nature. It stands out because it accepts the reality of our aquatic ecosystem and spells out a practical action plan for repairing that system -- improving on many conservation programs by adopting the wisdom that "the best way out is always through.[1]" In order to move forward in developing ideas proposed by Dr. Rosen and pro-actively address the compliance issues that will attach to listings such as the Chiricahua Leopard Frog, Pima County staff is working with the Army Corps of Engineers on an Expedited Reconnaissance Study to investigate and recommend solutions to accomplish ecosystem restoration as presented in concept by Dr. Rosen's blueprint. I have directed staff to work with the Science Team to continue to develop these ideas and to work with other stakeholders to set the stage for implementation and consideration as part of the Sonoran Desert Conservation Plan.

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[1] R. Frost, cited in *General Adjudication of Rights to Use Water, Gila River System*, 1999.

AQUATIC VERTEBRATE CONSERVATION IN PIMA COUNTY:

CONCEPTS AND PLANNING DEVELOPMENT

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4 July 2000

TABLE OF CONTENTS

ABSTRACT

This document outlines plans for conservation and restoration of native fishes, leopard frogs, Sonoran mud turtles, and garter snakes in Pima County. It focuses on mountain canyon preservation and, especially, on habitat and species restoration on the valley floor of the Tucson Basin. Restoring natural perennial flow and flooding regimes, and controlling and eliminating harmful non-native species are identified as the most important issues. Conservation of native fishes alone will lead to a proliferation of the non-native bullfrog, a predator and competitor which would then defeat conservation efforts for the reptiles and amphibians.

Small, in-channel stream segments created and maintained with reclaimed water are proposed to support native lowland leopard frogs and fishes. These would be relatively resistent to invasion by harmful non-natives. For natural springs, wastewater sites, and parks and golf courses, management plans are proposed to support a wide diversity of native aquatic species. This document contains a gazetteer of the aquatic fauna and its needs in Pima County. Drawing up, evaluating, and implementing specific plans based on the concepts in this document will involve collaboration among representatives from a variety of groups and agencies, including from local, university, city, county, state, and federal levels.

The native species involved in these plans are as follows ("i" signifies that the species is federally listed or proposed under the Endangered Species Act, or is a Species of Special Concern identified by Arizona Game and Fish Department): desert pupfish (i), desert sucker, Gila chub (i), Gila topminnow (i), longfin dace, Sonora sucker, speckled dace, canyon treefrog, Chiricahua leopard frog (i), lowland leopard frog (i), black-necked garter snake, checkered garter snake, Mexican garter snake (i), Sonoran mud turtle, and giant spotted whiptail lizard (i).

INTRODUCTION

Our culture in its mainstream development is at cross-purposes with and utterly destructive of native ecosystems. We develop with a scraping motion, replacing native with nouveau, without a thought of the natural order and beauty we are foregoing. The idea of integrating ourselves as a culture of habitat has gone unconsidered. Nowhere is the devastation more stark than in the waters of the arid Southwest.

The objective of the activities proposed herein would be to create and sustain large urban populations of the original native wetland vertebrates, in attractive riparian park-like settings, without any significant public health drawbacks, and to establish these activities in a way that their success would draw support for the continued devotion of water resources to them.

Introduced species (Figure 1; see Appendix A) present the greatest physical obstacle to successful re-establishment of native leopard frogs, Mexican garter snakes, Sonoran mud turtles, and native fishes (Gila topminnow, desert pupfish, longfin dace, Gila chub) that originally thrived in the Tucson Basin. The problem exotics include especially bullfrogs, catfish, sunfish, bass, and mosquitofish, although other exotics that may become widely involved are crayfish, African clawed frogs, and other fishes (especially carp and cichlids).

"Exotic species" are those that are from outside the biogeographic province--in this case outside Southwestern North America and, specifically, the Colorado River Basin (including the Gila, San Pedro, and Santa Cruz and their tributaries).

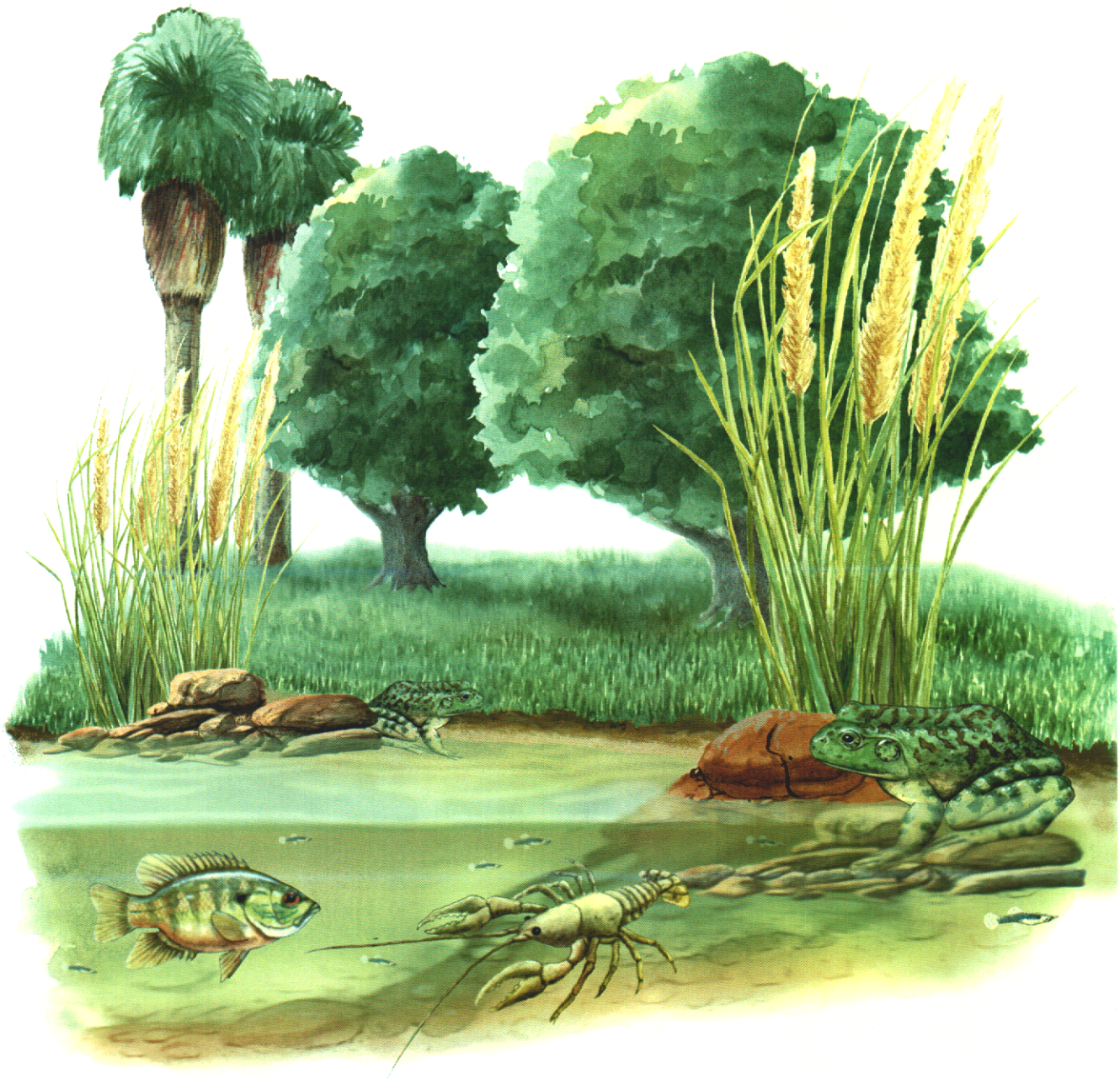

Figure 1.
Exotic species significantly affecting native fish and frogs in Pima County include sunfish, crayfish and bullfrogs (from left to right), as well as many other introduced fishes. These species prefer ponded waters, or systems that are relatively secure from flooding.

Fish are the easiest aquatic species to control (although even this is not simple), since they can be eliminated by drying or poisoning, and cannot disperse overland. Crayfish (none of which occur naturally in Arizona or anywhere in the Colorado River Basin) are in Sabino Canyon (possibly also in Rose Canyon Lake in the adjoining Bear/Sycamore Canyon complex). They are not known from the Tucson Basin floor, but are spreading, and may appear. They have limited dispersal probability, but are much more difficult to eradicate by drying or poisoning. Bullfrogs have remarkable overland dispersal capability, are difficult to eradicate, and are therefore the most difficult to control.

Habitat modifications are a primary reason for the potent advantage of introduced species over native species. Creation of ponds and lakes creates habitat suitable for bullfrogs and non-native fish. Streams and springs, which are natural habitat here, favor lowland and Chiricahua leopard frogs. Floods tend to favor native fishes, especially longfin dace, over introduced fishes.

It is important to consider leopard frogs and native fishes (as well as native aquatic reptiles) together because (1) creation of leopard frog habitat without fish implies a large potential for mosquito problems, (2) habitat conditions and management strategies for native frogs and some of the original native fishes in the Tucson Basin are similar and may naturally coexist, and (3) both groups could significantly benefit from the use of managed urban waters for conservation.

Native fish management in the absence of considerations for native lowland leopard frog and Mexican garter snake management could actually make things worse for the frogs and snakes. Removal of exotic species from un-natural, pond-type habitats is expected to lead to ecological release in the bullfrogs. The bullfrog population will very likely explode in that case, eliminating any possibility for the native frogs and aquatic snakes to persist or be re-established. The expanded bullfrog populations would also be likely to then spill over into other habitats of native aquatic reptiles and amphibians, potentially undermining all efforts to re-establish these in the Tucson Basin.

PART I. POTENTIAL SPECIES RECOVERY IN THE (URBAN) TUCSON BASIN

The Tucson Basin was the core of the wetland ecosystem of Pima County. On its floor, verified museum records demonstrate that it had Gila chubs, Gila topminnows, desert pupfish, longfin dace, Mexican garter snakes, lowland leopard frogs, and Sonoran mud turtles. Only the last mentioned survive there today. These animals must have lived in streams, small pools, spring sources, and ciénegas in the Tucson Basin. Ciénegas, with their swamplike flooding and drying, would create mosquito hazards in the modern setting.

Water supplies that can be turned on or off, or at least re-routed to allow drying up of habitat, are ideal for elimination of various exotic fish species that may invade (or be illegally introduced into) re-establishment sites. Thus, effluents, reclaimed water, and highly managed waters in general, offer a key opportunity for multi-species recovery of our native wetland fauna. This opportunity is not readily available in natural water systems, because the flow is too difficult to regulate, divert, or turn on and off.

Placement of the various Tucson Basin core re-establishment sites should be done so that (1) leopard frogs and other amphibians and reptiles may disperse from one site to another during especially good and wet years (and thus maintain a metapopulation structure--*a metapopulation is a group of subpopulations that support one another (genetically and in reversal of local extinctions) by exchanging immigrants and emigrants*), (2) the metapopulation structure also permits occasional immigration-emigration exchange

between the valley floor and surrounding mountain canyons, (3) fish are positioned in habitats in the landscape at which they can be expected to weather flooding and drying events. It may simply be necessary to avoid placing sites in proximity to exotic species populations that we cannot feasibly deal with.

Further development of this plan would involve synthesis of the professional opinions and knowledge of experts, the sociological limitations or realities reported from the political arena, and the available potential of the existing and foreseeable physical landscape. The fisheries experts with whom I am familiar include Paul Barrett, Rob Bettaso, Heidi Blasius, Doug Duncan, Will Hayes, Dean Hendrickson, Stuart Leon, Paul Marsh, Gary Meffe, W. L. Minckley, John Rinne, Jeff Simms, Sally Steferud, Ross Timmons, Dave Weedman, Kirk Young: there are certainly many others, and I apologize to them for my ignorance of ichthyological circles.

The specific plans for the Basin core would formally identify, map, and plan aquatic habitat structures at individual sites, and would formally consider relationships (distance, drainage connections) among sites. The specific plans would also involve a set of native species lists, one list for each site. These lists would be annotated to describe how each native species should fit into the system. The expertise of experienced fisheries managers, such as those at Arizona Game and Fish Department, would be very important in this.

Interagency relationships, and diverse permitting and other processes, will add substantial complexity to implementing biologically-based plans. The Sonoran Desert Conservation Plan will address many permit issues. Enthusiasm for moving forward on the County's part may help short-circuit what can be very difficult seeming conflicts. But we should be prepared for the multi-jurisdictional reality, within which large numbers of committed individuals are working.

Habitat and Plan Structure for the Tucson Basin

It is important to recognize that the native and exotic species all have unique habitat requirements and preferences (in the sense that each species has different optimal conditions and a different range of absolute tolerance for flooding, temperature, dissolved oxygen, drying, and perhaps even water hardness and organic contamination. Some species require flowing, rocky habitat, others require still, deep pools or ponds. Even among the native fishes, some species are highly adapted to violent flooding, while others may be wiped out by floods; some do very well in flowing water, while others are essentially pool fish. Simply creating ponds or using existing ones is likely to lead to re-establishment of exotic species populations. Simply pouring water into an arroyo may produce populations that are subsequently swept away during major floods. Therefore, I will describe some general approaches to creating good habitat for native fishes and frogs in the Tucson Basin, and flesh out the ideas with hypothetical examples drawn up based on existing important sites that I am familiar with in the Basin.

I propose a three-faceted approach to wetland faunal restoration on the floor of the Tucson Basin:

1. Creation of in-channel perennial reaches with native fishes (especially longfin dace) and lowland leopard frogs, with other native species added as their flood-tolerance permits.

2. Creation of spring-fed (or reclaimed water-supplied), quasi-cienega, small-channel systems in natural sites with little flooding (such as at Agua Caliente Park or smaller springs), or with moderate flooding (as in side drainages like Alamo Wash, Arroyo Chico, or the West

Branch of the Santa Cruz River. By keeping these systems free of deep ponded habitats and exotic species, numerous native fishes and reptiles and amphibians may be established in them.

3. Use of necessary ponded up habitats (like Roger Road Waste Water Treatment Plant ponds and wetlands) for native fishes (especially Gila topminnow and desert pupfish) that can control mosquitos where water quality is adequate for the fishes. Sonoran mud turtles will also thrive in these ponds, and should be fostered and protected in them. In regions (like Reid Park) that may be protected from bullfrog invasion, lowland leopard frogs may also be established in the system.

Details of this three-faceted approach are outlined below.

Habitat Type 1. High-Flood Systems In-Channel

First, dammed-up, non-flowing ("lentic") water systems should be replaced where possible by in-channel streams ("lotic" water systems) with longfin dace and lowland leopard frogs. This would likely involve use of reclaimed water. These two species are most tolerant of the powerful flooding that may occur in the major channels of the Tucson Basin (Santa Cruz, Rillito, Pantano, Agua Caliente). The natural flooding cycle should succeed in maintaining these native species at an advantage over any non-natives that may be present in the system. This kind of habitat generally consists of runs and riffles, with little pool development and little perennial emergent vegetation like tules and cattails. Native suckers may also utilize this habitat, and with adequate eddying during flood stage, so might the Gila topminnow.

Sites should be identified along the length of the major valley floor channels where bank conditions permit a possibility of escape from the floods into eddies or slower water. "Eddy structures" should be designed into the "soil cement" banks. These small sites should be about 1 km or more in length, but shorter reaches may suffice initially. The sites should be distributed as a sequential series of stepping stones, to maximize the ability of the native species using them to move on their own, during floods or longer periods of higher flow, to other parts of the Tucson Basin. An idealized model of this "metapopulation" system is shown in Figure 2, and some possible sites, with existing, planned, or potential water facilities, where native species might survive with in-channel water are shown in Figure 3.

An exemplar model of this type of system is the lower San Pedro River (Cascabel to Dudleyville; Figure 4). I use it as the evidentiary basis that such a system can work and sustain itself with native species despite the input of exotic species, which fail to thrive under the flood regime seen there. Garter snakes and mud turtles, and possibly other native fish, may also utilize this habitat type if it is established in the Tucson Basin, although this habitat is probably not stable enough for them to thrive in large populations. The dace and other fish should control mosquito problems that would otherwise arise in fish-free perennial waters. Flood-stage eddies or backwaters that could be designed into the system would enhance the number of native species likely to persist in this habitat type.

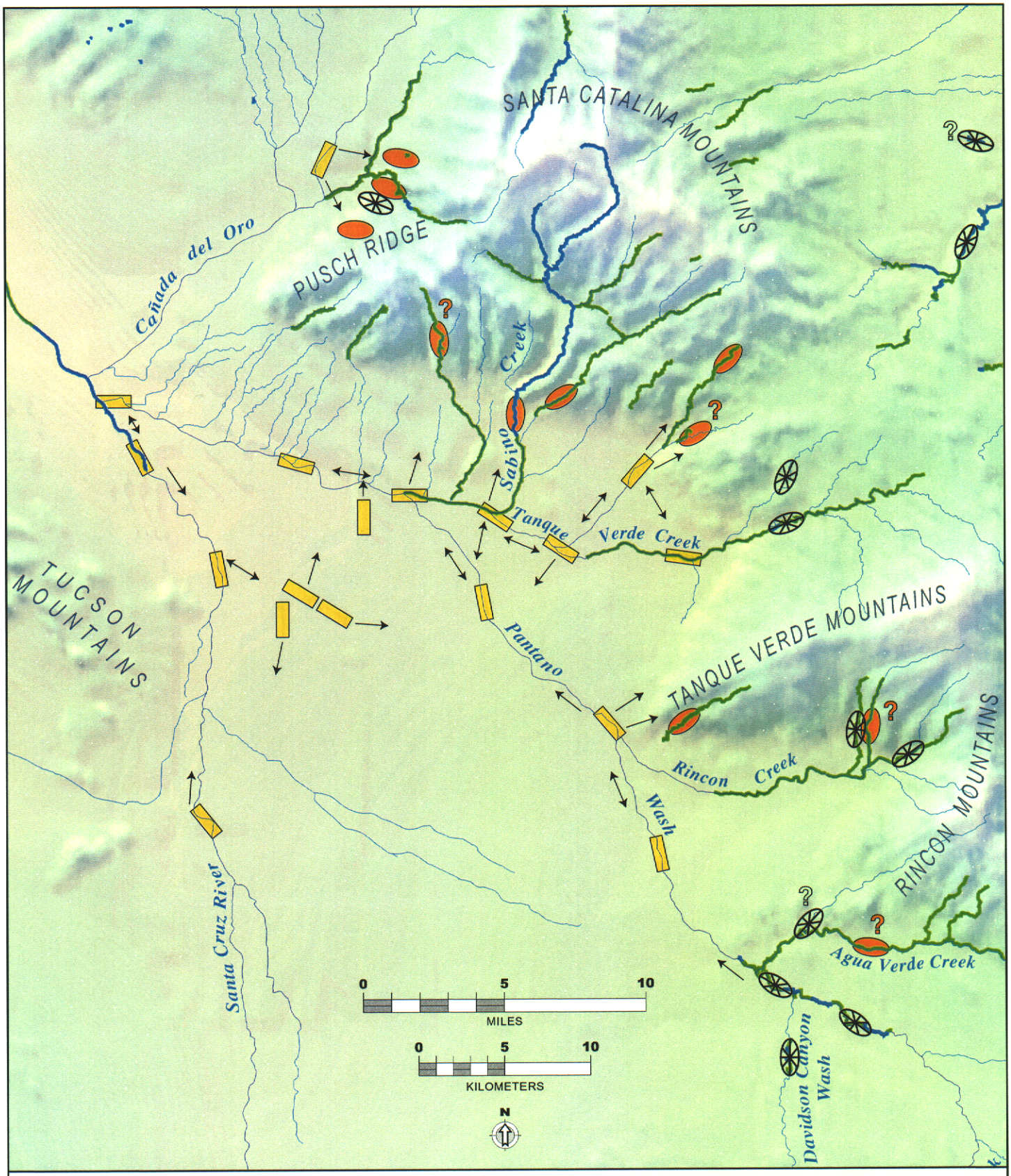

Figure 2.
Ideal Lowland Leopard Frog Metapopulation Structure

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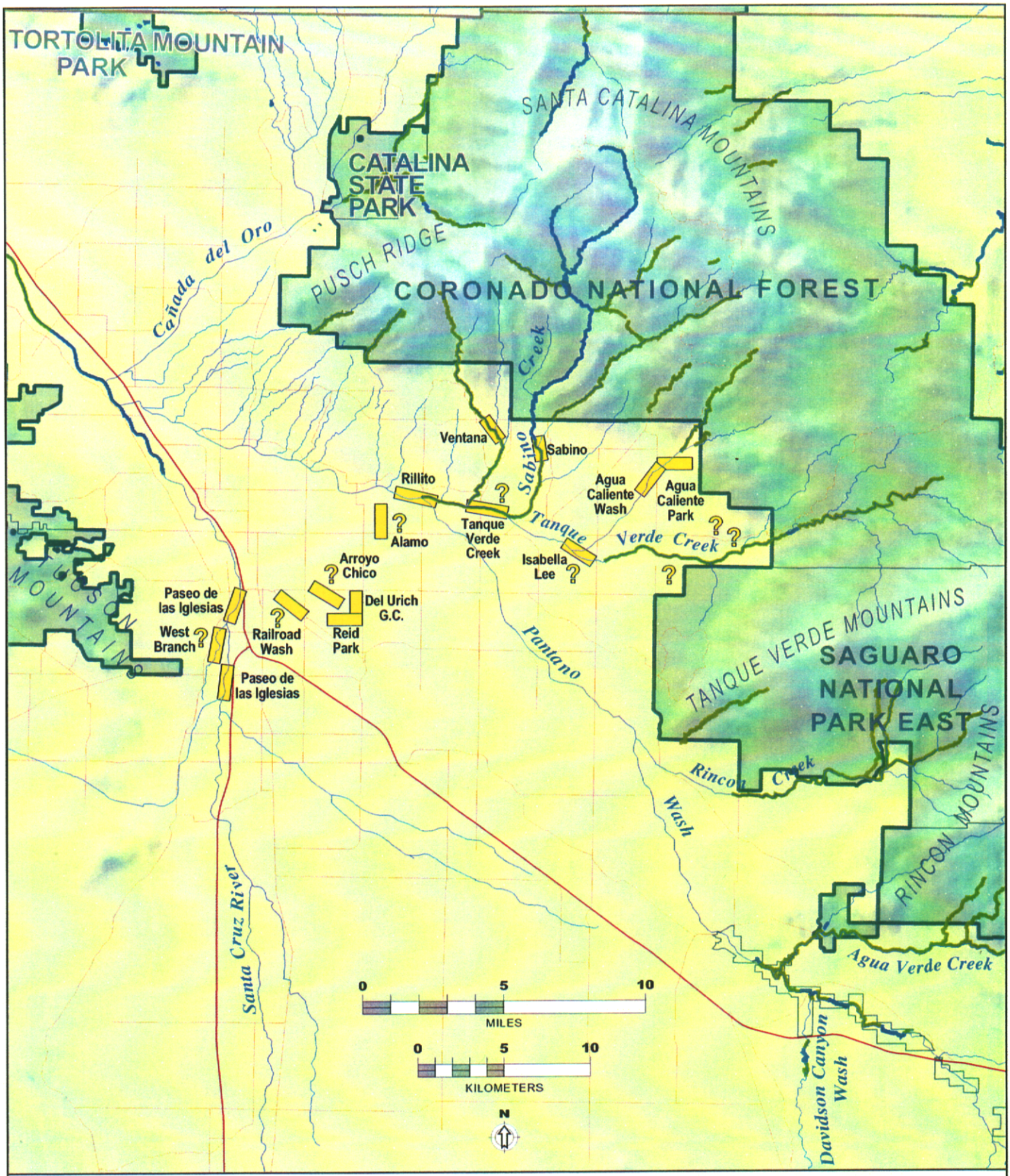

Figure 3.

Possible Lowland Leopard Frog Metapopulation Structure for Re-establishment on Tucson Basin Floor

Existing Reserves

Perennial Streams

Intermittent Streams

Ephemeral Streams

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Figure 4
The lower San Pedro River (Cascabel-Dudleyville) as an exemplar of a scour-prone lowland desert stream, where native species thrive despite the regional presence of numerous harmful exotic species.

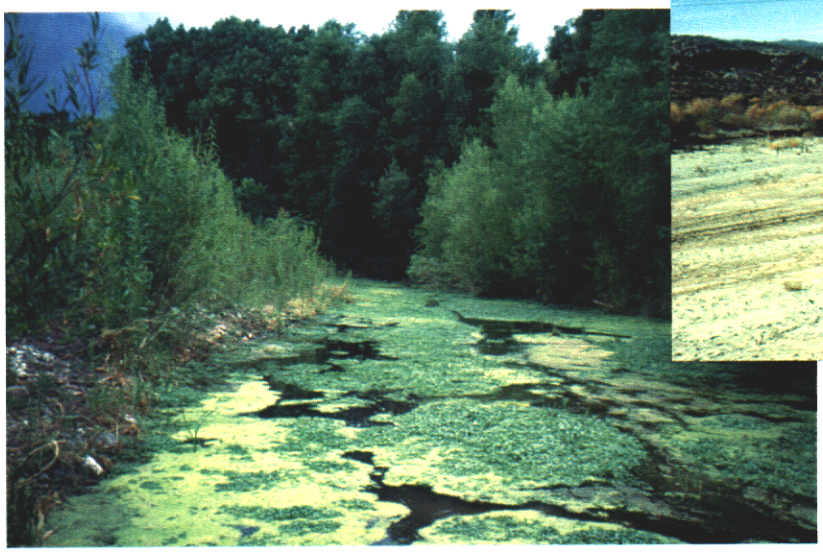

Figure 4A.
Productive, pre-flood conditions at Cascabel, with lowland leopard frogs and longfin dace.

Figure 4B.
A dry reach, showing the effects of scour, as seen along most of the lower San Pedro.

Figure 4C.
Flood conditions at Cascabel which presented no challenge to native frog or fish populations.

Figure 4D.
An exterior view of conditions suitable for native species.

Habitat Type 2. Low-Flood Systems

2A. Second, at <u>less-powerfully flooding sites</u>, critically imperiled native fishes may thrive and native amphibians and reptiles may also persist. These systems would either be managed spring runs, or designed reclaimed water streams in arroyos with moderate flooding. Successful creation of the latter would take some artful hydrological planning and knowledge. In these systems, riffles or runs may alternate with slower or deeper water, and topminnow, pupfish, and chub could thrive. Successfully creating and maintaining this habitat type will be more difficult than the first, and so I will go into some detailed expansion and description of the issue.

I envision the following as an example, which may be modified to fit other, more readily available sites of which I am currently unaware. A thorough discussion of the potential approaches to native aquatic faunal recovery at Agua Caliente County Park will serve to illustrate the complications that can be anticipated (I will not treat the political or social aspects of this), and how they might best be resolved.

The large spring at Agua Caliente creates three or more quite large ponds in a setting reminiscent of Quitobaquito Springs at Organ Pipe Cactus National Monument, where something like 15,000 desert pupfish thrive in about 1/10th the water volume. Also at Quitobaquito, the pupfish thrive exceptionally in small dirt and concrete channels of flowing water.

At Agua Caliente, one might imagine simply removing the exotic fishes and substituting natives. However, the result would almost certainly be a massive explosion of the bullfrog population, and loss of any existing or potential occurrence of native aquatic amphibians and reptiles. One conceivable alternative would be to utilize the largest natural predator in Arizona's native fish fauna--the Colorado squawfish (now called the pikeminnow in recognition of the mean connotation of "squaw"). However, it is not known to eat or regulate bullfrogs; the other native fishes apparently do not. It might make an attractive addition from a public perspective, since it is a large, impressive animal. Its presence might certainly help mitigate the perception of loss of the fine, though clearly troublesome, populations of exotic fishes--koi, grass carp, largemouth bass, bluegill sunfish, and various African cichlids. However, Pima County is outside the area defined by the recovery plan established for the pike-minnow under the Endangered Species Act, and its use in this area may be problematical.

From a more thoroughly integrated ecosystem perspective, however, a different approach would be preferred. This approach would more closely mimic natural habitat conditions and species occurrences. The substantial spring flow would be used to create ciénega-run conditions like those found now at the spring source of Agua Caliente. These waters could be landscaped into the existing uses--picnicking, weddings, and so on--in a rather attractive way. They would then be highly suitable for the most endangered species--pupfish and topminnow. A few deeper pools could also support Gila chub. Other native fishes (longfin dace, Sonora sucker, and desert sucker) might also exist, although they are normally found in rocky or more strongly flowing stream habitats. Bullfrogs are not known to thrive in flow-dominated, small-channel habitat types (as opposed to deep pools, ponds, and lakes, where they do thrive), and thus native lowland leopard frogs, Sonoran mud turtles, and Mexican garter snakes could also exist.

This hypothetical ecosystem, then, could support all of the most critically-declining or endangered wetland vertebrates of the Tucson Basin--pupfish, topminnow, chub, leopard frog, and garter snake--and all in potentially substantial numbers. The spring should be capable of providing a very great linear extent of the

habitat type.

In fact, I suggest that this spring-run system could be extended to reach the bed of the Agua Caliente Wash itself at this location--which would variously be at about 1/4 to 1/2 miles from the present spring source. This channel system could then be attached directly to an arroyo-channel habitat type that would also support the native fauna but in a more flood-prone system. This could be the ideal arrangement of things: in wet springs, continuous flow in the major Tucson Basin floor streams would allow fish from the Agua Caliente area to reach and colonize other sites we might create. Regardless of the flood severity in the main arroyo channel at Aqua Caliente, re-colonization could readily occur from the spring-run system I have suggested for the park.

However, this last aspect of the scenario points to an inherent difficulty in using spring sources like Agua Caliente, Quitobaquito, and presumably other available springs around the mountain bases in the Tucson Basin. The natural tendency of springs like this, which are not in scouring canyons or arroyos, is to form broad wet meadows with little or no open water. Cattails (*Typha*) and tules (*Scirpus americanus* -- also called *Scirpus olneyi*) grow over, close off, and choke open-water ponds and even small channels with amazing rapidity in the warm climate of Arizona. Special and carefully designed measures would be required to sustain anything other than the deep, steep-sided ponds and pools that various exotics would thrive in. Such measures would have to involve either (1) concretized, natural-looking channels (like the one at Quitobaquito, which does, nevertheless, require periodic pulling of the encroaching cattails and tules), (2) periodic re-trenching of earthen runs, or (3) alternate flow channels that would permit drying of some portions of the system to cause the die-off or die-back of the cattails and tules.

If such an approach is taken, very careful planning and construction would pay great dividends in the saving of the native fish populations and in efficiency of the maintenance regimen that would be required. The ability to rapidly and thoroughly dry wetland sites will greatly reduce the difficulty of dealing with invasions or illegal re-introductions of the harmful exotics. Deep, muddy pools and ponds, often having subsurface spring inflow, are quite difficult to dry and rid of exotics--often requiring long efforts and multiple poison applications. Proper design of channel gradients and interconnections would allow small channel segments to be isolated and dried out for management purposes.

It seems to me that this proposal is a feasible one--not cheap, but not overwhelmingly costly either. It is a proposal with a rather high probability for a successful outcome, given the water quality, amount, and the experience we have already had under similar circumstances at Quitobaquito. Making such a project attractive at several levels is, however, simply a costly must-do for a place like Agua Caliente.

In Figure 5, we illustrate what Agua Caliente Park might ideally look like under this scenario. In Figure 6, we identify some spring sites that might also have some potential for redesign to benefit native species.

2B. A somewhat similar approach might be developed using reclaimed water in **small urban feeder arroyos**. Examples of what I have in mind here might include Arroyo Chico in the NW quarter of the Reid Park block, and Arcadia Wash north of Speedway near Swan Road. Another possibility is the West Branch of the Santa Cruz River south of Silverlake Road (Figure 7). In these systems, enough reclaimed water might be added to sustain longfin dace, topminnow, or pupfish, with which lowland leopard frogs could also co-exist, and the systems could be kept small enough that natural flooding might control the tendency of the systems to choke with cattails, tules, and other grasses. The vegetation might

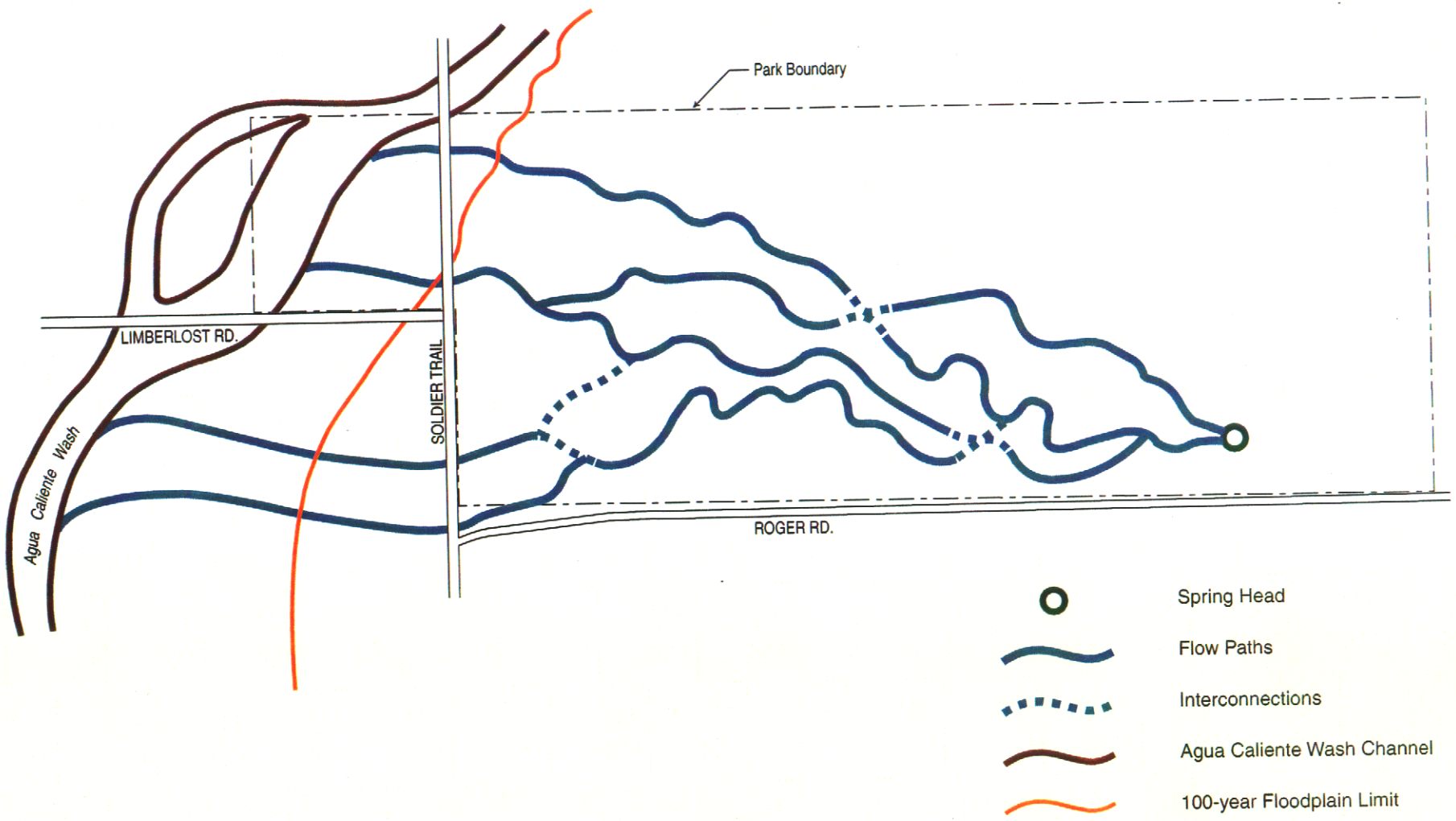

Figure 5.
Agua Caliente Park
Managed Cienega Flow Concept

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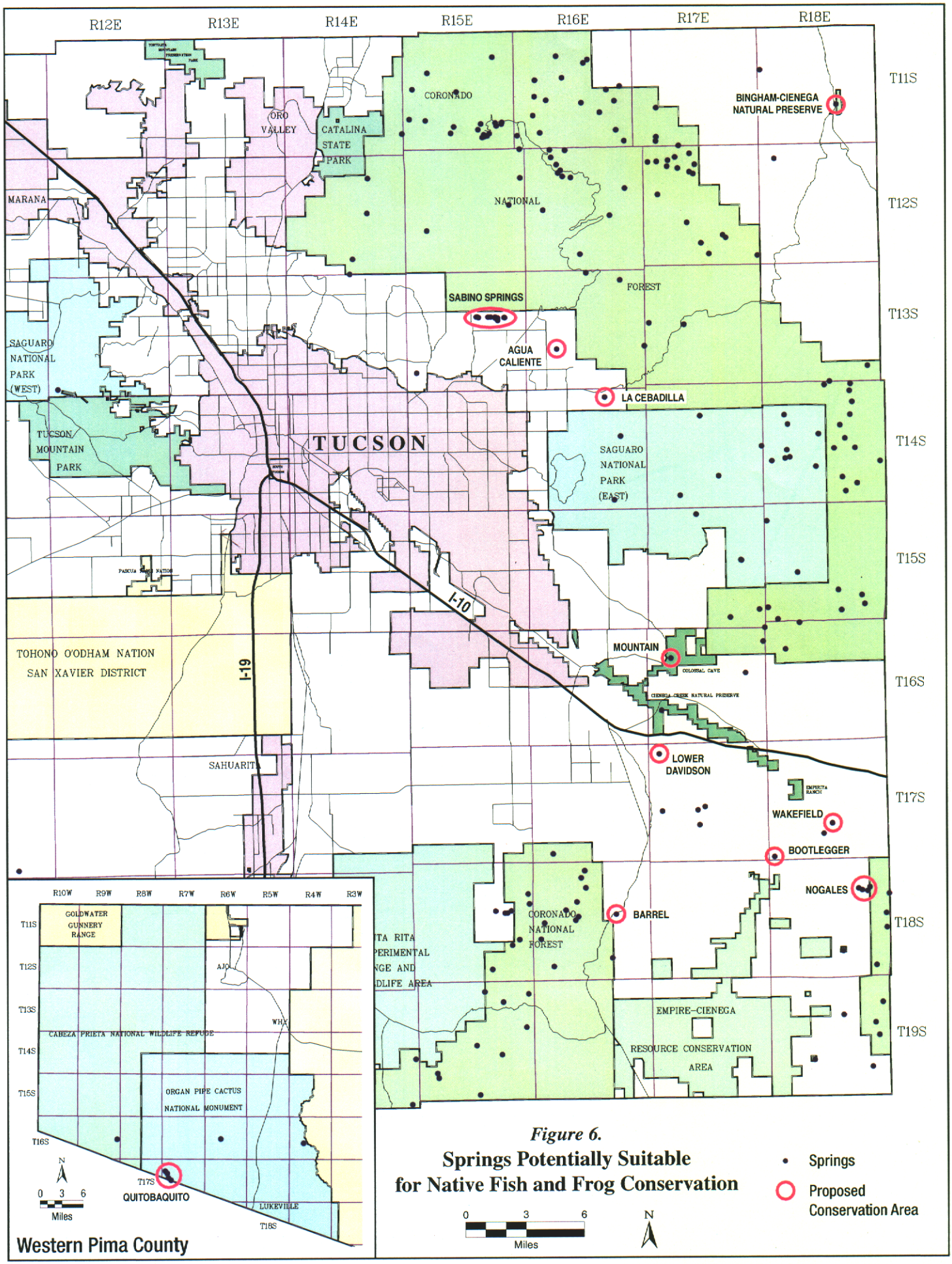


Figure 6.

Springs Potentially Suitable for Native Fish and Frog Conservation

Western Pima County

Pima County Graphic Design 6/00 ep

Figure 7.
West Branch of the Santa Cruz River near Silverlake Road. (P. Rosen photo, May 2000)

also be managed by shifting the location of the water at appropriate intervals. This would require dealing with saving the fish, however, or some other provisions would have to be developed.

The West Branch of the Santa Cruz River, which is actually a feeder arroyo and not a braid of the main channel, is an attractive site for two pre-existing reasons. First, it is near or part of a proposed Paseo de las Iglesias park, and riparian or aquatic enhancements could fit nicely into this downtown-related revitalization project. Second, it supports the last-known valley floor population of the giant spotted whiptail lizard, which is identified as a species of concern in the Sonoran Desert Conservation Plan, as well as by Arizona Game and Fish Department and U.S. Fish and Wildlife Service. This is quite a large, active, attractive greenish and reddish lizard that would, for many, significantly contribute to a Tucson parks experience. Natural vegetation enhancements and restoration along the Santa Cruz from Xan Xavier and Martinez Hill to the downtown area would allow the relict population to expand into formerly occupied areas.

Habitat Type 3. Pond or Lake Systems

The third general habitat type I outlined is pond and marsh sites--either those that are required for various reasons, or those that we may choose to experiment with for ecological restoration in its own right--may be used for native aquatic species. I recognize two situations--(A) one with and (B) one without bullfrogs. There are two clear caveats that must be appreciated for conservation use of ponds in the Southwest. First of all, any pond is open to re-introduction of exotic fishes that will exterminate desirable native fishes. Such ponds should be designed to permit drying to eliminate the unwanted species, especially introduced fishes. Therefore, every such site that is to be used for native fish restoration must have provisions for prompt, timely, and cost-efficient drying to eliminate exotic fishes. Otherwise, we would simply lose the battle to those who would, for various reasons, release their favorite sport fish or liberate their unwanted pets. The drying process could be made relatively simple, although we should gather the native fish to be saved and re-stocked, a labor-intensive process.

The second caveat is that bullfrogs are good colonizers, better than we think, using both humans and their own vaunted legs as dispersal agents. In general, we will probably not be able to prevent bullfrogs from colonizing most ponds in the Tucson Basin under current conditions. Bullfrog numbers might be controlled by pikeminnow (it's worth a research experimental effort, anyway), or even some relatively tolerable exotic like the softshell turtle, but bullfrogs will not be eliminated. However, such species will probably also strongly affect native fish species that we wish to propagate. These same native fishes are the ones that best control mosquitos by eating mosquito larvae (avidly, with relish).

A possibility is that at very high natural population densities, Sonoran mud turtles may exclude or at least limit bullfrogs: this appears to be true at certain localities in southern Arizona, at which native fishes survive (fishes are more agile swimmers than tadpoles). Native leopard frogs will not be able to establish successful breeding populations in pond or marsh habitats that bullfrogs have access to, since any predator able to limit bullfrogs in this habitat type will almost surely also eliminate leopard frogs.

These two caveats lead to a pair of specific considerations: regarding (1) draining techniques and facilities, and (2) utilization of existing zones that lack bullfrogs; and a pair of examples: (1) Roger Road Waste Water Treatment Facility (WWTF; Figure 8) with the associated effluent Santa Cruz River; and (2) the Reid Park complex of ponds (Figure 9).

Figure 8 A.
Looking across Sweetwater Wetlands at the Roger Road Wastewater Treatment Facility

Figure 8B.
Turtle Pond at the Roger Road Wastewater Treatment Facility, which may be utilized for native fishes

In both situations the ideal shape of a pond that must be drained to eliminate exotic fish would slope down to the drain point--whether that be a physical drain or simple irrigation-type gate--so that almost all the water can be removed rather quickly, with the native fish then available to be gathered from a shallow remaining pool.

3A. **Roger Road WWTF (Figure 8) and other facilities where ponds are required.** There is no apparent biological obstacle that I know of that would prevent successful use of small native fish (topminnow and pupfish) for mosquito control. (Presumably, some ponded water must exist that is too foul for fish, and in those cases other mosquito control approaches will still be required). But where water quality is adequate, and exotic fish predators or competitors can be eliminated, pupfish and topminnows should suffice for mosquito control except where there is dense, shallow-water vegetation impenetrable by the fish. In such habitat, twice-weekly drying (total elimination of open surface water) may control the mosquitos while still preserving the vegetation for use by birds.

The existing pond or ponds north of Roger Road at the WWTF appear suitable for fish and completely amenable to mosquito control by the fish. Perhaps the wetlands south of Roger Road do not have adequate water quality (experimental tests are badly needed on this), or have so much vegetation that the fish could persist but not control the mosquitos. But wherever fish can thrive, they are perhaps the most effective known mosquito control solution ever devised.

3B. **Reid Park (see Figure 9)** presents simpler opportunities, because as of now there are not bullfrogs there, or near there, as far as I can determine. The Reid Park/Randolph Golf Course could become a model for use of urban park settings for native aquatic species conservation. Existing ponds at the golf course (a City of Tucson facility) presumably have non-native fishes of various kinds in them; presumably they can be dried singly or all at once, as needed, to remove the non-natives. At that point, they could be stocked with Sonoran mud turtles, lowland leopard frogs, perhaps some kind of garter snake, Gila topminnow, desert pupfish, Gila chub, and perhaps some other fishes, such as suckers or dace. The first steps, however, would be approaching the City and golf course managers, and conducting an inventory of the ponds' biota. There are existing national programs that fund nature conservation projects on golf courses.

The public park ponds at Reid Park are an "urban fishery" where stunted sunfish are caught. If the plumbing allows it, one of the ponds might be isolated and converted to a "Gila chub" or other native species fishery to test the waters of public reaction. Reid Park Zoo may be approached with an inquiry about the possibility of using small native fish in their numerous water channels and pools, which, as far as I know, do not now contain fish. Other urban parks may have facilities that could similarly be incorporated into a plan for large, widely scattered native fish populations in Tucson.

A voluntary, backyard pond program in tandem with this would help create public awareness, and would also help minimize the chance that the public would inadvertently contaminate park systems with bullfrogs that might escape from their ponds. Of course, bullfrogs are noisy, and easy to detect, and probably not very suitable for urban neighborhoods. Lowland leopard frogs make pleasant chuckling and quiet trills, and would be accepted readily by many people, who like the idea of having frogs in the yard. Here is where the "ecology of co-existence" of compatible species could best be communicated to the public, and would need to be communicated. This would go a long way toward eliminating the neighborhood mosquito problems that originate in ponds, fountains, and the like.

Figure 9.
Golf course ponds, like this one at Reid Park, could be managed for native species rather than exotic species. Photo by N. Connolly, June 2000.

I suppose native species for backyards could be distributed by commercial vendors licensed to obtain them from City, County, or State personnel that would obtain them from prescribed sites, such as Roger Road or Agua Caliente. In any case, suitable oversight, control, and attention to lineage and pedigree will be necessary throughout any native species restoration program.

The Santa Cruz River below Roger Road

Use of the Santa Cruz River effluent system for native fishes should similarly require that the system could be dried out--once initially to remove exotic fish species, and, subsequently, whenever re-invading exotic fishes threaten the natives. Since this water cannot be turned off, a concrete drain canal on the river bottom, would be necessary. In my opinion, a large and deep system like the Santa Cruz River from Roger Road to Avra Valley Road requires the capacity for drying to control exotic fishes. There are currently too many exotics in the Tucson Basin to suppose that there will not be contamination, such as from former gravel pits (Figure 10). On the other hand, the challenges this poses (in cost and complexity) do not necessarily outweigh the reward--re-establishment of truly large populations of the original fishes, in their original place, under conditions comparable to those found in the original streambed. An array of species might well be supported: longfin dace, topminnows, pupfish, Gila chubs, Sonora suckers, flannelmouth suckers, and possibly desert suckers. Such benefits would be substantial in terms of the Endangered Species Act listings, and the costs actually pale before the likely costs of such assemblage-wide re-establishment anywhere else in the Colorado River Basin.

Other Issues Related to Exotic Species in the Tucson Basin

A related issue is the widespread presence of exotic species in the Tucson Basin. Where possible, efforts should be made to eliminate habitat for exotic species. For example, there are a number of old gravel pits around town (Figure 11) that harbor exotic species in ponds at the bottom of the pits. Bullfrogs live in these, for example, and I presume that various non-native fishes are also there. Many of these are in the major floodplains, and are therefore potential source of biological contamination for any serious efforts to restore the native aquatic fauna. These places should be filled with dirt to a level above the water table, or they should be carefully treated with drying to remove exotics and establish native species.

Other efforts should be made to eliminate sources of dispersing exotics. Voluntary cooperation should be sought with private golf courses and country clubs, specially those close to the major drainages. These places might agree to dry existing ponds to replace exotics with natives, or to other beneficial changes. It is simply necessary for everyone concerned to recognize that ponds and lakes are highly detrimental to the native fauna and to efforts to recover it.

Urban sport fisheries with non-native fishes can still be integrated into this conservation plan. See "Sport Fisheries and Native Species Conservation", below.

Coupled with education, a planned ability to deal efficiently with illegal distribution (by disgruntled or uninformed people) of exotic species to conservation sites would allow a harmonious change in the fisheries management in the Tucson Basin. It should be made clear that wildcat introduction of non-natives will result in draining of sites, and sport fishery sites should be designed with this in mind.

Figure 10A.
An in-channel former gravel pit on the Santa Cruz River near Cortaro Road, which may serve as a source of harmful exotic species. Aerial view.

Figure 10B.
Santa Cruz River north of Camino del Cerro. Ground level view at site of bullfrog population near the "Tres Rios" site.

Figure 11.
Another example of gravel pit habitat (here, Pantano Wash above Houghton Road) that harbors exotic species.

Signage

Interpretive signs will play a role in public education with regard to aquatic faunal conservation issues. Other approaches (news media, pamphlets) should also have a significant role. General information about the harmful effects of non-native species and the undesirability of spreading them should be an educational focus.

Another key aspect of signage, which probably should be utilized at all important wetland sites, should explain the great importance of not introducing pets into the water. This is especially critical for crayfish, which people are fond of catching and bringing home or to class, and then releasing. Explanatory cautions against the release of crayfish will probably not fall on deaf ears, and do a world of good for public education as well. The signs could also note the lesser, but still significant issue of releasing pet fish into Arizona's waters.

Moving Forward from the Conceptual Plan to Implementation

I have drawn up this plan based on what I know and input generously given on short notice from many quarters. Even the concepts are not finished. The specific ideas I have discussed in Part I were intended primarily as examples, and are subject to revision in concept. They are not nearly at the stage of suitability for implementation.

An **Implementation Team** consisting of representatives from all pertinent regulatory, funding, and conservation agencies, as well as other appropriate participants, should convene to more efficiently pool knowledge of the landscape--both ecological and political. One goal of this team, or committee, will be to achieve active, creative resolution of contentious or difficult legal matters. I have tried to skirt these issues in an attempt to focus on biologically sound ideas that we can work toward within the many other constraints that may arise.

As a starting point, I suggest the following logical structure, based on the discussion in Part I and drawing upon the gazetteer material presented in Part II. Our work focus would start with (1) exotic species removals in stock ponds, small natural springs, tinajas, and stream segments in the drainage areas facing the Tucson Basin floor: Agua Caliente Canyon, Tanque Verde Canyon, the Rincon Creek-Chimenea-Madrona basin, and the Ciénega Creek Natural Preserve area. Then (2), we would proceed toward establishment of native fishes in those areas made suitable for them. Starting with these two actions will minimize the input of exotic species into downstream sites we want to manage, and establish native fishes in places from which they may enter the Tucson Basin. The next logical priorities will be (3) to establish sites in-channel on the valley floor, and (4) negotiate to find solutions at sites where ponds and springs currently support non-native species on private or public property on the valley floor. At the same time, we can (5) pursue species restoration work in relatively isolated areas (ecologically speaking, e.g., Reid Park) or in relatively tractable areas (politically speaking, e.g., Agua Caliente Park).

PART II. EX-URBAN CANYONS AND VALLEY FLOORS

Most aquatic species of amphibians and reptiles, as well as fishes, which were formerly abundant in the Tucson Basin persist in reduced and low numbers in mostly isolated habitats in mountain canyons (see Figure 12, for one example) in the mountains of Pima County. The Rincon, Santa Catalina, Galiuro, Santa

Figure 12.
An example of mountain canyon stream habitat. This habitat type supports isolated, natural populations of native frogs, fish, and turtles at a number of sites in Pima County.

Rita, Baboquivari, and San Luis Mountains (and perhaps the Sierritas) all support at least one native aquatic species that is currently in danger of extinction.

Fishes

Imperiled fishes in Pima County currently occur naturally at upper Ciénega Creek-Empire Ranch (Gila chub, topminnow, longfin dace), Sabino Canyon (Gila chub, and formerly, Gila topminnow), perhaps Buehman Canyon (Gila chub), and potentially in the Santa Cruz River at Arivaca Junction (Gila topminnow, Sonora sucker). Longfin Dace also occur in the County in lower Ciénega Creek, the northeast quadrant of the Santa Rita Mountains (Cave, Gardner, and Fish Canyons), the San Pedro River and some of its tributary canyons, and should be present in the Santa Cruz. Native suckers occur in low numbers in the lower San Pedro (below Benson), and may also occur in the County in the lower reaches of Redfield Canyon, in which Gila chub and speckled dace also occur. For native fishes, occurrence in and distribution within individual mountain canyons of the Santa Catalina, Rincon, and Santa Rita Mountains remains to be precisely determined.

The San Pedro River originally supported at least 13 species of native fishes, and the Santa Cruz Basin originally held at least 8 species. The present fish fauna contains little more than a shadow of the original diversity and abundance.

Amphibians

Lowland leopard frogs are abundant in the perennial stretches of the lower San Pedro and in lower Ciénega Creek (in the County's Natural Preserve). They also occur in the County in good numbers at about 7 isolated canyons in the Rincon, Santa Catalina, and Whetstone Mountains, and they are known in more limited numbers in about 4 additional, also isolated, canyons in these mountains. Canyons confluent with the lower San Pedro probably are the only currently viable population sites, since these and the river appear to form a metapopulation in which local extinction events may be balanced by emigrants or dispersers from other local populations.

It is quite possible that the lowland leopard frog may be re-discovered in or near the Altar Valley just north of Buenos Aires National Wildlife Refuge. Otherwise in southern Arizona, this species has been extirpated except at the Muleshoe Ranch Preserve, and two isolated springs, in the Atascosa and Pajarito mountains.

Isolated populations of lowland leopard frog have been disappearing at an alarming rate in the mountains around Tucson--at least 6 major populations have disappeared in the last three decades. They have disappeared due to introduced species (3 cases) and short-term drying (2 or 3 cases), and will not be naturally re-established without supportive management.

Whereas the lowland leopard frog persists in canyons above desert valley streams, the Chiricahua leopard frog persists around areas that once supported grassland valley wetlands--often ciénegas. Chiricahua leopard frogs now occur in the County only at Buenos Aires National Wildlife Refuge and vicinity (2 known populations), at Empire Ranch (1 known, tiny population persisting), and in the northern Santa Rita Mountains (where 2 small populations may or may not be persisting). They were formerly widespread and abundant at Arivaca, the Altar Valley, Sierra San Luis, northern Santa Rita Mountains, and upper Ciénega Creek, occurring widely in natural streams, springs, and stock tanks (Figure 13). Major population losses

Figure 13.
Stock pond habitat, which would be suitable for lowland or Chiricahua leopard frogs in the absence of harmful exotic species such as bullfrogs, sport fish, and crayfish.

are attributable to exotic species. Both species of leopard frogs are also suffering from a possibly newly acquired disease.

A variety of ephemeral water amphibians (canyon treefrogs, narrow-mouthed toads, and various species of spadefoot toads and true toads) and introduced tiger salamanders remain abundant over large sections of Pima County, both in mountain canyons and on valley floors.

Reptiles

Sonoran mud turtles remain widespread and relatively abundant below about 5000 feet elevation in the Santa Catalina, Rincon, Galiuro, and San Luis Mountains. They also persist in numbers at Arivaca Ciénega, and are found in the Altar Valley, lower San Pedro River, and Santa Cruz River (including in Tucson) in small numbers. This species is tolerant of exotic fishes and bullfrogs, but populations can be devastated by drying and bulldozing unless measures are taken to protect them.

The Mexican garter snake persists in the County in Ciénega Creek. It formerly occurred, and was presumably extremely abundant, at Arivaca and in all perennial waters of the Santa Cruz, Rillito, Pantano, and Agua Caliente in the Santa Cruz Valley and Tucson Basin. This species is dwindling toward eventual extinction in the United States, with a few good localities around the Canelo Hills and Camp Verde, and marginal, disappearing, or already-extinct populations in New Mexico, Cochise County, the White Mountains, and sub-Mogollon mountains.

Other garter snakes maintain relatively intact populations in the smaller or less perennial habitats they occupy in Pima County. The black-necked garter snake is abundant in many rocky canyons and draws in the Rincon, Santa Catalina, Galiuro, Whetstone, San Luis, and possibly the Baboquivari, Cerro Colorado, and Sierrita Mountains. The checkered garter snake occurs along the Santa Cruz River and elsewhere in Tucson, and at Arivaca, where the Mexican garter snake was formerly most abundant. It is also known in semipermanent ponds in desert grasslands in the Avra-Altar Valley, and in the agricultural region of Marana.

Along with the beaver, muskrat, and a variety of waterfowl and wading birds, this constitutes the aquatic vertebrate fauna of Pima County.

Conservation Strategies and Values for Mountain Canyons

This document summary assumes that there will be a focus on protecting and enhancing (by exotic species removal) remaining natural canyon and stream segments with perennial water. The document will identify important priorities, as well as treat specific aspects of important sites.

Mountain canyons currently contain much of the stock from which we must draw to preserve the native aquatic vertebrate fauna of the County. Gila chub, longfin dace, desert sucker, Sonora sucker, speckled dace, lowland leopard frogs, and Chiricahua leopard frogs are now primarily found in mountain canyons. Without significant efforts to preserve habitat and species in mountain canyons, the Gila chub and the lowland leopard frogs may face extinction--before we have any opportunity to return them to valley floors where they formerly were abundant. Therefore, it will be critical to identify and protect key mountain canyon waters, and to develop and implement conservation strategies in which current and developing land

uses may be compatible with species preservation.

The current problem with using isolated canyons as conservation refuges for native frogs and fish are that (1) they are too unpredictable and varying (drying, flash-flooding) for some species, and (2) they are so isolated that they are vulnerable to random extinction processes. Thus, ideally, conservation strategies both inside and outside the urban environments of Pima County should look toward both preservation in mountain canyons and restoration of valley floors.

Gazetteer of Key Canyons for Conservation Attention

I present here the beginnings of an annotated list of the major canyons of concern, with description of what actions (purchases, agreements, active management) Pima County or others may want to pursue in relation to each.

Cañada del Oro, interior of Santa Catalina Mountains. Removal of the harmful exotic green sunfish may be required. A decision to establish native ranid frogs or fish may be considered, following further historical inquiry.

Cargodera Canyon, Santa Catalina Mountains. Lowland leopard frogs, which disappeared after a 1989 drought, may be re-established by translocation at this site.

Romero Canyon, Santa Catalina Mountains. Lowland leopard frogs were present in this canyon in about 1980, but were gone, and green sunfish were abundant, by 1986 or 1987. Removal of green sunfish is required. Lowland leopard frogs from adjoining Montrose Canyon may re-colonize. This site might be considered as a native fish site (longfin dace, Gila chub, Gila topminnow). This site, like Cañada del Oro, requires careful evaluation to select appropriate species for re-establishment.

Montrose Canyon, Santa Catalina Mountains. The lowland leopard frog population appears to be in the throes of a major, new disease epidemic, and should be closely monitored and studied from a research perspective vis a vis global amphibian declines.

Alamo Canyon, Santa Catalina Mountains. Lowland leopard frogs, which disappeared after a recent drought, may be re-established by translocation at this site.

Ventana Canyon, Santa Catalina Mountains. The possibility of establishing lowland leopard frogs in the mountains or on the bajada, and topminnow on the bajada, should be investigated, in consultation with Arizona Game and Fish Department, USDA Forest Service, and private landholders.

Sabino Canyon, Santa Catalina Mountains. The removal of green sunfish should be completed, and a solution to the problem of the crayfish infestation should be sought. There is currently no known solution. Leopard frogs may not be able to exist at this site, where they were once abundant, until the crayfish are controlled. It is believed that the crayfish are also threatening a damselfly that is endemic at Sabino Canyon. Depending on the situation and prognosis for water in Sabino Canyon in the foothills, this stream should be a suitable site for reintroduction of Gila topminnow.

Following elimination of green sunfish in 1999 in Sabino Canyon, and flooding in summer 1999 that may have reduced the crayfish population, lowland leopard frogs were detected (in numbers) in early

June 2000, after an absence of 1.5 to 2 decades.

Bear Canyon, Santa Catalina Mountains. Green sunfish were introduced into Rose Canyon Lake, which was intended only as a trout fishery: these threaten conservation efforts in Bear Canyon, Sycamore Canyon, and Sabino Canyon, and points downstream as well. It has or had crayfish, and has a large bullfrog population, as well as other exotic fishes, probably including mosquitofish. The common snapping turtle has been found at the lake, and is capable of establishing breeding populations in Arizona. Removing the green sunfish, and letting sediment fill the lake up would be the first choice from solely a native species perspective, although it is overly ambitious and unlikely. However, the current AGFD and USDA Forest Service concept for refurbishing this site seems insufficient to me. And unfortunately, once that plan is carried out, in its currently-reported form, it will become much more difficult to do the job correctly for a variety of reasons.

A trout fishery in Rose Canyon Lake should pose little threat to native species anywhere away from the lake, and is probably the only acceptable compromise that can be reached. The lake itself will remain an attractive nuisance that people will tend to stock with more harmful species. For that reason, I would not favor deepening the lake at this time--not until it becomes politically unavoidable.

Whether the deepening is done or not, removal of the exotic species remains important both for biodiversity conservation and for re-establishment of a good trout fishery. The idea of pumping and siphoning the place is entirely sound. But current plans do not require that the place be totally, thoroughly dried to ensure that all green sunfish, mosquitofish, bullfrogs, and crayfish are eliminated. Because of the magnitude and public inconvenience of the project, a halfway effort now will be worse than nothing. The site needs to be dried out early--as soon as the area is closed for the winter, and then left dry or re-emptied and left dry during April-June. Even then, active measures should be taken to physically remove as many bullfrogs and crayfish as possible during the drying operation. If this protocol is not followed, the management will fail to remove all of the exotic species.

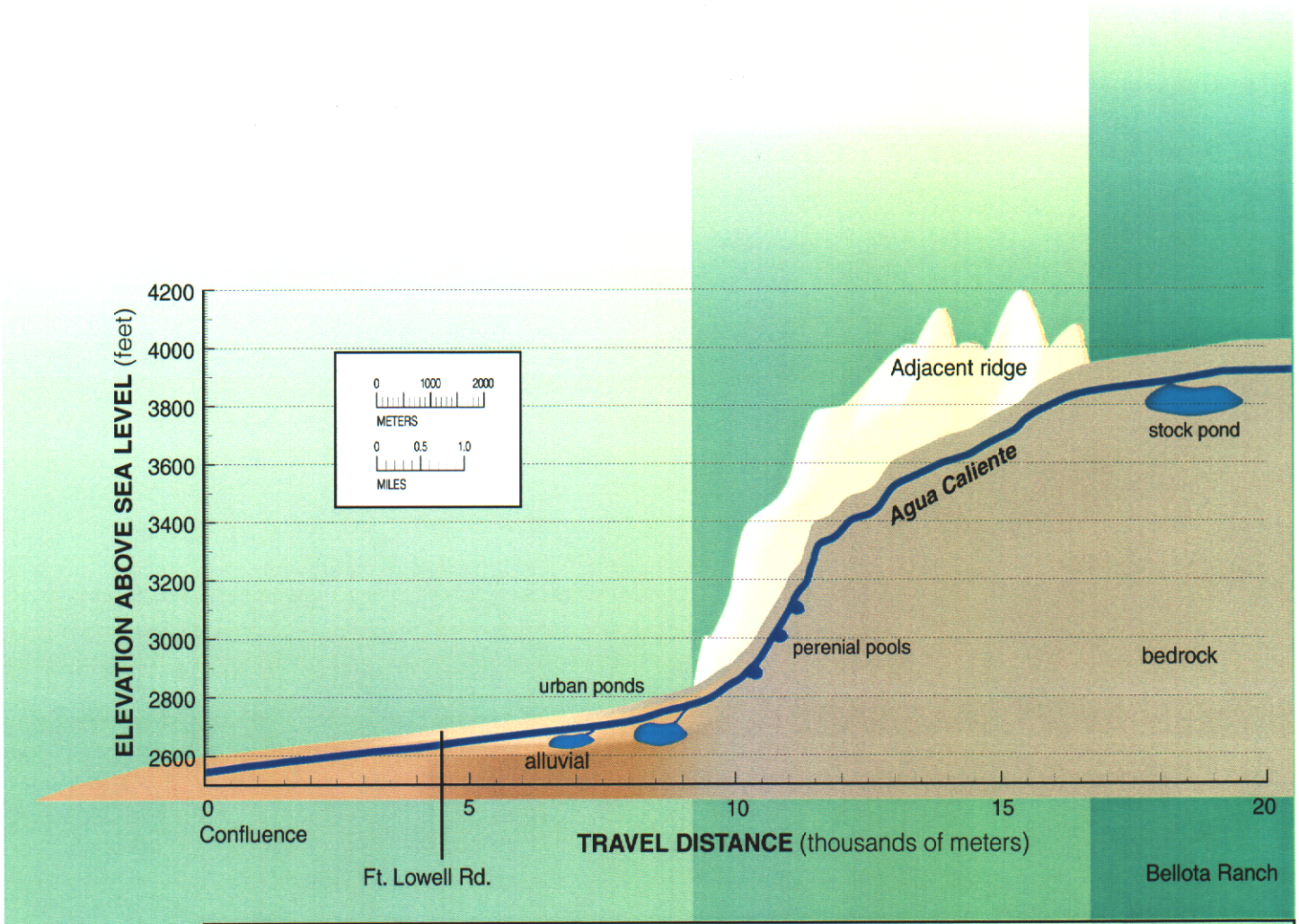
Lowland leopard frogs were known from this canyon system, but are thought to be gone now.

Molino Canyon, Santa Catalina Mountains. Lowland leopard frogs were known from this site, but disappeared, possibly due to drought. Historical and other considerations should be applied to determine if re-establishment of these frogs in Molino is feasible and justified.

Agua Caliente Canyon, Tucson (see Figure 14). Lowland leopard frogs disappeared within 1 or 2 years of establishment of green sunfish at this site in about 1998. Leopard frogs and sunfish, and other native and introduced aquatic vertebrates, are presumably scattered in a variety of upstream tinajas and stock tanks, in the Bellota Ranch/Redington Pass area. Green sunfish should be immediately removed from the small area of natural perennial water, which is in lower Agua Caliente Canyon. All stock tanks in the drainage should be immediately surveyed, and harmful exotic species removed from them by drying, starting at the head of the drainage basin and working down. Leopard frogs can then be re-established in the lower canyon or we might wait for natural recolonization. As far as I know, this appears to be a naturally fish-free canyon, and might be left that way as a refugium for leopard frogs and other frogs and toads.

Tanque Verde Canyon, Tucson. Lowland leopard frogs formerly abounded at this site, but disappeared long ago, presumably due to the presence of various introduced fish. The situation here is much like that in Agua Caliente, and the same prescription applies. However, the perennial reach is larger and much more heavily used for human recreation. Thus, the mainstream part of the prescription should be delayed at least until results from Agua Caliente are in. However, the stock tank part of the prescription should be pursued

Representative Stream Profile, Agua Caliente Wash



	Valley	Canyon	Headwater
Natural Flow Conditions	Intermittent, becoming ephemeral, except at Agua Caliente Spring	Intermittent with persistent bedrock pools	ephemeral
Stream Gradient	Gentle	Steep with occasional falls	moderate
Hydrologic Modifications	Groundwater pumping, urban lakes and ponds	none	stock tanks

Figure 14.
Diagrammatic illustration of a representative drainage profile

vigorously: there are known, viable, populations of lowland leopard frogs in the upper basin that inevitably must be threatened by spreading exotics there. There is enough water in Tanque Verde Canyon to support native fishes, including at least the longfin dace, and quite probably others, at least including Gila chub.

Saguaro National Monument, Rincon Mountains (about 4 lowland leopard frog sites). These sites should be carefully monitored, as they are the only sites in the Tucson region where the new disease ("chytridiomycosis") has not yet been confirmed. Thus, they may offer critical clues about the epidemiology of this apparently devastating fungal disease of frogs. These populations also should be studied as examples of natural population processes, since they are unaffected by exotic species. Thus, they now are our best "control" sites. Landowners in Rincon Valley should be alerted to the problems that may arise if they import bullfrogs to their properties, and these bullfrogs escape into Rincon Creek, and Chimenea and Madrona Canyons. Bullfrogs might damage the leopard frog populations by competition, predation, or as vectors of the disease.

Gila topminnows originally occurred in a site in this area, which therefore would be an ideal target for their re-establishment.

Chimenea Canyon, Rincon Mountains. This is an outstanding and highly isolated population site for lowland leopard frogs, Sonoran mud turtles, canyon treefrogs, black-necked garter snakes, and giant spotted whiptail lizards--perhaps the most natural and intact site that exists. There is a mandate for the Arizona Trail to be routed through the site, that the County and Park Service should request be altered. This is the only site we can observe where there is essentially no direct human presence to effect the behavior and physiology of the frogs, which here have not displayed any of the disease symptoms that have appeared almost everywhere else.

Madrona Canyon, Rincon Mountains. The site may also have some representation of the species seen in Chimenea.

Rincon Creek, Rincon Mountains. The site may also have some representation of the species seen in Chimenea, or be equivalent to it in quality.

Agua Verde Creek, Rincon Valley. Leopard frogs are known from this site, and other important species will certainly be found there. This site might have the Mexican garter snake, which is a critically imperiled, but yet unlisted species. Purchase of private holdings, conservation easements, and/or management agreements here and in Posta Quemada may appropriately be a County wetlands conservation priority.

Chimney Canyon, Rincon Mountains. The site might have some representation of the species seen in Chimenea.

Distillery Canyon, Rincon Mountains. The site might have some representation of the species seen in Chimenea.

Cienega Creek Natural Preserve, from Pantano to the RR bridge. A well-known, major lowland leopard frog population site, and more recently with numerous records of the Mexican garter snake, this site is recovering from grazing. Under grazing, it was a desert stream with little pool development. Under protection as a county park, deeper and more stable pools have developed, and a ciénega-stream environment is apparently developing. The original name of the site was Pantano, which means "marsh".

In 1995, lowland leopard frogs were found dying at Pantano, and subsequent research demonstrated chytrid fungus disease as the cause. This was the first documented case in North America of a disease now implicated in mysterious frog and toad population collapses in the Rockies and Sierra Nevada.

Bullfrogs and non-native soft-shelled turtles were reliably reported at the site starting in about 1995. These and exotic fishes (currently present in clay pit ponds dangerously close to the stream) may do better in the new, more stable conditions, and may pose a significant threat. Clearly, the non-native fish near the stream should be removed. A thorough survey of stock tanks in the region surrounding this critical resource should be initiated. New pond developments in the Pantano floodplain at Vail Valley below the county park threaten to produce a bullfrog explosion that will inundate the leopard frog population in the Natural Preserve. The Rancho Del Lago development situation is highly problematical. This situation should be monitored, and the private developers notified of the implications of what they are doing: perhaps some kind of compromise solution is possible. Local government should consider ordinances that prevent this type of situation from developing again.

Working through The Friends of Ciénega Creek, the County should foster education raising awareness about the significance of harboring exotic species near Ciénega Creek. Here also the ordinance approach might be considered. State representatives should be contacted concerning the contradictory nature of state statute and Arizona Game and Fish Department's rules and attitude toward bullfrog possession and introductions. State legislative action is required before the bullfrog can gain its richly deserved status in Arizona--totally prohibited. Currently, it is legal to purchase bullfrogs out of state, and release them on private land. Without legislative action, the Arizona Game and Fish Department cannot correct this situation. A successful, reasoned argument from the SDCP will benefit the entire state.

This site may well support a variety of native fish species, most notably the Gila chub and Gila topminnow, which are upstream in the Empire-Cienega Ranch reach of Ciénega Creek. Until very recently, the habitat in the Natural Preserve was shallow runs, with few pools, and unstable banks. Thus, chub and topminnow have probably not had time to recolonize the site. From the standpoint of future recolonization potential in the Tucson Basin, as envisioned in the present plan document, allowing natural downstream colonization processes would be more informative than immediate re-introduction of the species. Assuming the habitat is now suitable, it would be very strange if downstream colonization during floods did not occur, and confirmation would be important.

Empire-Cienega Resource Conservation Area -- BLM (Empire-Cienega Ranch). This is the wetland gem of Pima County, with lowland leopard frogs (rare or extinct), Chiricahua leopard frogs (now rare), bullfrogs (rare), Mexican garter snakes (apparently still widespread and probably not uncommon), Sonoran mud turtles (abundant), longfin dace (abundant), and Gila chubs and Gila topminnows (both superabundant). The excellent wetland management practiced by the Bureau of Land Management, with the cooperation of the grazing permittee, at this site should be recognized. Efforts to eliminate all stock ponds with breeding populations of non-native fish and bullfrogs in the entire basin should be assisted and pursued with vigor.

Keeping exotic fish, which have apparently somehow never gained access to Ciénega Creek, out of the system is perhaps the County's highest priority for wetland conservation. There are several million endangered fishes in the system--probably 1-2 orders of magnitude greater than the sum total of all other individuals of Gila topminnow in the U.S., as well as large numbers of Gila chub. Loss of the site through spread of mosquitofish, green sunfish, bass, and bullhead catfish could possibly eliminate the long-term survival prospects for these two fishes. Removal of the offending pond habitat proximal to the stream may make it difficult for bullfrogs to persist in the area, as well.

The educational and political recommendations under the Ciénega Creek Natural Preserve section

apply here, as well, in full.

The Chiricahua leopard frog and Mexican garter snake populations in Ciénega Creek are very important, and require study and monitoring. The Mexican garter snake population may be the best one left in the United States.

Wakefield Canyon, Whetstone Mountains. The lowland leopard frog population at this site should be secured. I am not familiar enough with this site to know the parameters. Purchase of private holdings and easements, and management agreements in this area should be considered.

Northern Santa Rita Mountains. The set of canyons with Chiricahua leopard frogs is not entirely in Pima County, but these probably function as a loose metapopulation, or two metapopulations. Thus, they should be treated as a unit for management purposes, and the County should work with USDA Forest Service to transcend the political border here. In addition, individual Chiricahua leopard frogs have been found in various drier canyon sites, again pointing to substantial dispersal and thence, to potential metapopulation dynamics. A similar situation is seen in the northern part of the Chiricahua Mountains.

None of the Santa Rita ranid frog populations are secure. The best site has been surveyed twice in recent years with no frogs seen: it is a small population site susceptible to random extinction effects. The other canyon complex population also appears vanishingly small, or gone, at times, but reappears strongly for brief periods. For these reasons, I suspect there is at least one unknown stock pond population supplying it with frogs. There may be little the County can do directly in this area of USDA Forest Service ownership, but encouraging the further survey of the area for frogs is entirely in order as a County priority.

Outreach describing aquatic conservation activities under the Sonoran Desert Conservation Plan should be produced for ranchers and other residents in the area. They might then be willing to remove exotics. For example, at the formerly best site, there are exotic fish in steel-rimmed tanks about 1/2 mile below the leopard frog spring: those could invade, and conversely, the leopard frogs might utilize the well site if the sunfish and goldfish were removed.

At this point, status surveys are badly needed for this area, and a clearer picture of the frog population dynamics in this area is required. The frog habitat also supports what is probably Pima County's only population of the mountain skink, one of the more beautiful lizards in Arizona, as well as some other unique, dry tropic scrub amphibians and reptiles.

Mainstream San Pedro River, and Bingham Ciénega. Avoid impoundments and ponds.

Gessaman Canyon, Santa Catalina Mountains. This site is not well known, but may contain important riparian faunal elements. It is probably not a high priority site for the County.

Alder Canyon, Santa Catalina Mountains. This site is not well known, but may contain important riparian faunal elements. It is probably not a high priority site for the County.

Edgar Canyon, Santa Catalina Mountains. This site is not well known, but has supported lowland leopard frogs and is suitable for fish, probably longfin dace. This would be a suitable purchase or easement target priority for the County.

Buehman (and Bullock) Canyon, Santa Catalina Mountains. This site is not as well known as it should be, but supports lowland leopard frogs and native fish. Acquisition and protection of this site by the County

should be the highest priority for wetland habitat purchase by the County in the Santa Catalina, Rincon, and Santa Rita area. This site may support suckers, chubs, topminnows, and dace, at least.

Youtcy Canyon, Santa Catalina Mountains. This site is not well known, but has supported lowland leopard frogs and is suitable for fish, probably longfin dace. This would be a suitable purchase or easement target priority for the County. This site is within the City of Tucson's A7 Ranch, so the County may wish to encourage or assist the City in the area of exotic species control.

Espiritu Canyon, Santa Catalina Mountains. This site is not well known, but has supported lowland leopard frogs and may be suitable for fish. Green sunfish are present in this system, and should be removed. This would be a suitable purchase or easement target priority for the County. This site is within the City of Tucson's A7 Ranch, so the County may wish to encourage or assist the City in the area of exotic species control.

Deer, Turkey, Miller Creeks, Rincon Mountains. Poorly known non-perennial canyon drainages. These may support small pockets of lowland leopard frogs, but probably do not require County attention at this time.

Paige Canyon, Little Rincon and Rincon Mountains. This area supports lowland leopard frogs and green sunfish. The sunfish should be eliminated if possible. This is a large enough stream to support one or more species of native fishes, though in relatively limited numbers. Pima County should purse the matter of exotic species removal, as well as developing a collaborative relationship with the local ranchers, or at least purchase of inholdings or conservation easements therein.

Ash Creek, Rincon Mountains. Poorly known non-perennial canyon drainages. Canyon treefrogs are known from this site, which might also support small pockets of lowland leopard frogs. This site probably does not require County attention at this time, at least from the perspective of wetland fauna.

Arivaca Ciénega. This site may originally have been fishless, but Gila topminnows were introduced there, and subsequently were eliminated by introduced mosquitofish. Presently there are mosquitofish, sunfish, bass, probably catfish, and crayfish.

Originally, the site supported a very large population of Chiricahua leopard frogs, and may also have had lowland leopard frogs, at least at times. It also had a Mexican garter snake population, probably a very large one. Now, bullfrogs are extremely abundant at the site, leopard frogs and Mexican garter snakes are extinct; Sonoran mud turtles (abundant), checkered garter snakes, and black-necked garter snakes are present.

Removal of the bullfrogs can be considered intractable at present. The best solution would be to allow the artificial ponds that have been dug into the flat ciénega to fill in naturally with cattails and tules, eliminating fish and bullfrog habitat, and hope this leads toward elimination of exotic species in the perennial reach of stream below the ciénega proper. Perhaps exotic fishes could be eliminated from this stream then by poisoning, and native fishes introduced. The bullfrog and crayfish situation might remain intractable at this site.

Plans that might involve elimination of Arivaca Lake, which is in-drainage upstream, and serves as a source for all of the listed exotic species, should be pursued with an eye toward long-term restoration of native species and relatively natural habitat conditions at Arivaca Ciénega and Arivaca Creek.

Most of the ciénega and creek is under U.S. Fish & Wildlife Service ownership, with management

by Buenos Aires National Wildlife Refuge (BANWR). County support for consolidation of ownership under, or cooperative management with, BANWR would be a reasonable and efficient approach.

The idea of allowing the Arivaca Ciénega to revert back to a wet meadow, with little open water (which is the natural state of springs on valley flats that don't have erosive flooding to create scour pools), has not been presented to BANWR yet, but will shortly be, in the form of a management plan for leopard frogs and other anurans.

San Luis Mountains, SW margin of Altar Valley. These are low mountains supporting a dry tropic scrub with some oak woodland. They support a number of plant and animal species with much more southerly distribution, and are a special resource for the County, State, and Nation. Most of the range is grazed under USDA Forest Service ownership, and some is privately held. These mountains are connected with the Tumacacori-Atascosa-Pajarito complex, which supports remarkably high biodiversity.

From the wetland faunal perspective, exotic species and (probably) introduced disease are the major problems in the area. Bullfrogs are widespread in artificial ponds, including stock ponds, and in Arivaca Lake. Several species of exotic fish are equally widespread but occur in fewer--more exclusively perennial--places. Crayfish are apparently currently restricted to the Arivaca Lake-Arivaca Ciénega area, but could easily become much more widespread, with devastating effects. Introduced tiger salamanders are also very widespread, and dominate some stock ponds to the apparent exclusion of other amphibians; however, they appear to coexist with leopard frogs at other sites.

The portion of the Atascosa and Tumacacori Mountains in Pima County are not well surveyed, but may well support populations of the Chiricahua leopard frog and habitat suitable for re-establishment of the Tarahumara frog. Pima County would be peripheral to such efforts, except that populations of exotic fishes in Pima County may potentially preclude successful management of key drainages (Sycamore Canyon, Peck Canyon, Peña Blanca Canyon) in Santa Cruz County.

For Pima County, the main aquatic fauna focus in this region should be the major drainages of the San Luis: Wilbur Canyon, San Luis Canyon, Canoa and Fresnal Washes at Cumero Mountain, and Fraguita Canyon. A major effort is underway at BANWR to re-establish and preserve the Chiricahua and lowland leopard frog (see also below), with efforts centered in the southern and eastern part of the refuge for bullfrog control. It would appear feasible to temporarily dry the stock ponds listed below to remove the bullfrogs.

Bullfrogs threaten this effort--by providing disperses to waters being prepared for leopard frogs and, potentially, to the last leopard frog populations--e.g., from Alamito Tank, Las Encinas Tank, and Unnamed Upper San Luis Canyon Tank. The County should (1) support efforts by BANWR to acquire any of these areas, (2) urge the USDA Forest Service to support removals of bullfrogs from these key areas, and (3) facilitate positive relationships between local ranchers, the County, and conservationists (including at BANWR).

Palo Alto Ranch, Altar Valley. This ranch adjoins BANWR to the north, in the center of the Altar Valley, extending east into portions of the Peñitas Hills area where lowland leopard frogs were found as recently as the early 1980's and might still occur. This ranch is for sale, and presents an important opportunity for re-establishment of lowland leopard frog populations that once occurred in the Avra-Altar Valley.

BANWR is developing a lowland leopard frog restoration plan for the north part of the refuge, based on use of existing wells and stock tanks. The refuge is interested in adding Palo Alto Ranch to the management efforts for native leopard frogs and other imperiled animals and plants. Identification by the Sonoran Desert Conservation Plan of the potential importance of this site may significantly increase the availability of USFWS funds for protection and management of this large area. Thus, I recommend it be

given high acquisition priority by the County from the standpoint of wetland faunal recovery.

Cerro Colorado, north of Arivaca. This area is unknown faunistically, and needs to be surveyed. There would seem to be a good possibility that lowland leopard frogs persist in it, and that special-interest tropical species (Sinaloan narrow-mouthed toad, green rat snake, vine snake, thornscrub hooknosed snake, giant spotted whiptail, cactus ferruginous pygmy owl) occur there.

Sierritas. This area is poorly known faunistically, and needs to be surveyed. There would seem to be a good possibility that lowland leopard frogs persist in it, and that special-interest tropical species (Sinaloan narrow-mouthed toad, green rat snake, vine snake, thornscrub hooknosed snake, giant spotted whiptail, cactus ferruginous pygmy owl) occur there.

Baboquivari Mountains. This is a large and diverse (topographically and biotically) mountain complex of great interest and with tremendous conservation potential. Tropical species at the northern end of their range are well known to occur, as is the Chiricahua leopard frog, which reaches its western limit here.

It is critical that the County and BANWR develop and sustain good relationships with the local ranchers and other residents of the area, and include them and their concerns in the development and implementation of management strategies. The Tohono O'odham Nation encompasses lands west of the crest of these mountains, and may be a suitable management partner at the District and Tribal levels.

Key needs are (1) land acquisition, (2) bullfrog removal on the bajadas, and (3) survey for leopard frogs and other fauna in the mountains.

PART III. ISSUES RELATED TO AQUATIC BIODIVERSITY CONSERVATION

Strategies for Public-Private Cooperation for Frog Conservation

I identify 6 generally important categories for public-private cooperation for leopard frog and native fish conservation:

1. Public support for acquisition of land, easements, and cooperative agreements for biodiversity protection

2. Public support for appropriate use of public water supplies for native wetland fauna.

3. Voluntary cooperation of developers and major private landholders in avoiding the creation of exotic habitat types (ponds, lakes) and in preventing occupation of such habitat by exotic species. This concept may well extend to fully terrestrial systems, in which exotic plantings favor urban-associated and otherwise exotic species of birds over native birds, and also ultimately lead to elimination of other major components of the native biota, over time, in all developed lands.

4. Use of backyard ponds for native fish and/or frogs.

5. Supervision of and programs for suppliers of fish, frogs, crayfish, and plants for aquaria and ponds.

6. Development of appropriate means and funding sources for ranch-based conservation.

Ranchers and Frog Conservation

Bullfrogs, exotic fishes, mud turtles, desert and semi-desert anurans (frogs and toads), various native birds, mammals, and cattle use tanks that are or can be used by native leopard frogs. In many areas, these ponds are all that has prevented local extinction of the leopard frogs, and thus, indirectly, ranch management has already been important in preserving native leopard frogs. Similarly, ranching could be compatible with restoration of a variety of native aquatic species in ranch water developments.

Stock tanks are managed waters where control of exotic species may be much easier than in natural surface waters. At the same time, however, ranch waters are usually suitable for, and often occupied by, harmful exotic species that not only preempt the sites for native species, but also threaten to contaminate nearby waters.

Many ranchers deserve our thanks for leaving the land in better condition than with any other non-recreational economic activity. At the same time, if ranchers wish to maintain a positive position within the ever-increasing conservation movement, they must recognize the importance of biodiversity conservation on their areas. For our purposes here, this suggests a responsibility to cooperate in controlling and removing harmful exotic species from stock waters. Assuming such cooperation, it is imperative that we put aside the historical and social issues on which hinge much of the existing enmity between the ranching and conservation communities.

Ranchers are a small minority in Arizona and throughout the West, and have become vulnerable to criticism and legal attacks emanating from urban populations eyeing the lands they are managing. Although somewhat vulnerable, they are also an admirably capable, hard-working group. Taking advantage of this minority status, and deploying the full array of statutory and legalistic weapons available will be, in the long view, unethical and unfair, as well as counterproductive. For example, removal of grazing leases from their ranches seems to be a totally fair approach based on high-bidding by conservation interests. But anyone familiar with ranching knows this is a sentence of bankruptcy for the private ranch that is geographically bound to the allotment. I suggest that respect for the rights and economic needs of ranchers, and most particularly family-based ranching, will be both fair, and ultimately, in the scheme of things, only trivially costly in financial terms. The urban public's leadership should recognize the needs of fair policy for all involved in the transitions underway based on new, widespread, conservation values.

Ranchers should be compensated when society-at-large places new demands on them in a local area. Conservationists would, in my opinion, do well to avoid depriving individuals of their traditional livelihoods, especially without making all due provisions that are possible. I do not believe that conservation can thrive as a movement without an inherently humane ethic. For ranchers, this could involve subsidies or purchase of conservation easements, offers of land purchase at fair price, and co-development of water or fencing projects. Moreover, ranchers could take part in local conservation, potentially on a paid basis as land managers and guardians.

Sport Fisheries and Native Species Conservation

Arivaca Lake is the largest sport fishery lake in the County (see above). For sport fisheries to co-exist with native fish and frog preservation and restoration, sport fisheries probably should be located at sites from which biological contamination of native species locations is minimal. While this is possible and feasible,

it has not been given enough serious or detailed consideration. All of the large lakes in southern Arizona are solely for sport-fishing of exotic species; and all of them are ecologically disastrous, from the native species standpoint. From these lakes come the broadest, and most intractable, exotic species problems.

The developed lakes in southern Arizona represent a significant investment by the angling public and the Arizona Game and Fish Department. They support a multi-million dollar economy. It will take time to design and build support for acceptable solutions to the problems these lakes pose, but I suspect that many or most of them should, ultimately, be removed from the landscape. Consideration of and planning for this, and for alternative sport-fishing sites as desired by the public, needs to be seriously countenanced. Here I offer some compromise suggestions, most of which reflect ideas that came from reviewers of drafts of this document.

Urban sport fishing lakes can be maintained at places suitably removed from drainages through which fish might disperse. Lakeside Park is a possible example, but it is on a side drainage, and might thus be subject to overflow of exotic species into the Pantano Wash. Kennedy Park is a more ideal example, where escape of exotic species is unlikely even in a major flood. Columbus Park on the Santa Cruz floodplain is an example of a poor place for exotic species. Perhaps it could be stocked for sport fishing using species native to the Colorado River Basin. Given the will to resolve this issue, I see no insurmountable obstacles: simply by choosing isolated sites and keeping them that way, the problem could be resolved.

Two other alternatives have been presented in discussion with County Flood Control personnel. First, a situation in the Avra Valley, where (1) much habitat is already degraded, (2) CAP water is already present, and thus (3) chances of further downstream contamination by exotics is small, might be a relatively innocuous place to relocate sport fisheries. An even more simple solution would be to focus urban sport fisheries on species unlikely to have an impact if they escaped: stocked trout are an ideal example. Perhaps some other exotic fishes may be unlikely to persist if they escape into the Rillito or Pantano, but others, such as green sunfish, mosquitofish, and bullhead catfish should be regarded as extremely likely to become established and harm native species recovery efforts.

Similarly, there is a possibility that certain lake fish, especially largemouth bass, may not be able to escape from the fishing lakes in southeastern Arizona and successfully colonize the smaller natural streams and springs. Largemouth bass might be used in lakes like Arivaca or Parker Canyon that do not closely connect to suitable habitat for it. Perhaps this fish could be combined with certain native fishes in such places to create a sport fishery, although this has not been tested.

However, the difficulties facing such a program would be substantial. It would require that major efforts be approved for removal other exotic species from the lake, and all of it's surrounding drainage. It would be necessary to totally eliminate bullfrog and crayfish populations, which would otherwise recolonize the lake, multiply in it, re-disperse (precluding most aquatic conservation work for native species in the surrounding region), and then continue their apparently inexorable spread to the far corners of the environment. Finally, planners would have to be prepared to dry the lake again if and when illegal and harmful introductions were made.

The Buenos Aires National Wildlife Refuge as a Major Cooperator in Frog Conservation

Conservation of frogs at BANWR includes a southern Chiricahua leopard frog zone, and a northern refuge area as a lowland leopard frog zone. The existence of U.S. Fish and Wildlife Service refuges can be a major benefit to conservation in an area. The Service has interest in developing local cooperative plans (although such interest may not always be clearly translated). The Service also has substantial funds for active management and land acquisition. Most importantly, the presence of a refuge can allow a cohesive, unified, exclusively conservation-based management system to be deployed in at least an important part of a local or regional landscape. The importance of BANWR in this sense should be recognized by the County, and neither County nor State should unnecessarily allow the development of jurisdictional conflicts.

The Importance of a Significant Educational Campaign

Recovery of native wetland species cannot succeed without public support. Thus, education--mostly through news media, published books, and signage at conservation sites--is at the crux of the program. Key issues are (1) non-native species, (2) habitat modification, (3) spread of emerging diseases, (4) groundwater supplies, and (5) aesthetics. For the public to accept the programs proposed in this document, they must be able to understand these key issues, and that requires clear and repeated communication.

SUMMARY

The loss of riparian forests, wetlands, and perennial streams is a widely-appreciated problem in Arizona. Less apparent is the spread of introduced, non-native aquatic species (bass, sunfish, catfish, carp, mosquitofish, other fishes, bullfrogs, other frogs, and crayfish). These non-native species have largely eliminated most of the native aquatic species from the remaining perennial waters, and they are a primary obstacle to re-establishment of native species. The impact of non-natives on natives has been greatly exacerbated by habitat modifications: introduced species are typically pond and lake species, and ponds and lakes we have created. The native habitat is flowing water, of a highly variable nature, with sudden, severe flood scour, and, in many areas, drying or near-drying on a seasonal basis. Native species are well adapted to these variable hydrological conditions.

To significantly recover our decimated native aquatic fauna will require water, which we can supply upon suitable social consensus. However, it will also require that we plan carefully to eliminate the introduced species, or at least minimize their impacts. This can be done by a combination of traditional removal methods for fish (drying, short-lived toxicants) and habitat management (re-establishment of suitably natural hydrological conditions). This document describes the issues of habitat management and recreation in detail. It provides specific examples of how and where these works might well be carried out.

Perennial ponds and lakes may potentially produce massive bullfrog populations that could contaminate large areas of habitat we may be managing for native species. This would be especially true if non-native fishes, which check bullfrog populations, are removed. Efforts to remove bullfrogs from complex wetlands have proven difficult or fruitless. Where pond habitats cannot be avoided, three solutions are possible: (1) they can be maintained in areas where bullfrogs will not colonize them (i.e., city parks); (2) they can be used for native fishes, which co-exist successfully with bullfrogs, but not for native frogs and garter snakes; and (3) they can be located in areas where bullfrogs could reach native species sites, but the bullfrogs might

be managed by frequent drying, since bullfrogs have a long tadpole stage.

The native aquatic fauna now persists primarily in isolated mountain canyons and small conservation refugia. These refugia are subject to random extinction processes, and they offer no habitat for many of the most endangered species. Formerly, the fauna's stronghold in Pima County was in the perennial waterways of the Tucson Basin floor--the Pantano, Tanque Verde, Agua Caliente, Rillito, and Santa Cruz. This document describes ways the native aquatic fauna may be re-established in abundance in the original area, the valley floor.

Mountain Canyon refugia, and the all-important Empire-Cienega Ranch section of Ciénega Creek, must of course be protected from de-watering. Further, renovations in many of them are needed, specifically the removal of harmful introduced species. This document provides an annotated list of most of the major canyons that support aquatic species in the County. A major step in recovery of the valley floor will be the elimination of upstream, in-drainage populations of introduced species, which otherwise will regularly recolonize downstream areas we are attempting to manage, sharply foreclosing our options.

This document focuses on examples of how and where aquatic habitats could be utilized on the valley floor of the Tucson Basin. First, small, in-channel stream segments supported by reclaimed water or natural springflow would permit the re-establishment of lowland leopard frogs, longfin dace, and other members of the original aquatic fauna. Periodic natural flooding in this habitat is expected to prevent non-natives from eliminating the native species, even if non-natives reach the sites.

Second, less flood-prone areas, such as natural springs and in-channel water developments in smaller drainages, could be designed to minimize their tendency to support harmful exotics. Non-native fishes can be physically eliminated from such systems to begin with, and the systems could be designed to facilitate dealing with re-introductions of harmful non-natives. By avoiding pond-like habitat, fewer non-native fishes could exist at a site, and the problem of bullfrogs would be minimized. Habitats of this kind can be expected to support our most threatened aquatic species--topminnows, pupfish, chubs, and Mexican garter snakes--as well as other species of concern, such as longfin dace, native suckers, lowland leopard frogs, and Sonoran mud turtles. If properly designed, these areas can also supply individuals of these species to the mainstream habitats proposed above, sustaining and augmenting populations there in processes called "metapopulation" dynamics.

In addition to detailing some aspects of these proposed restoration efforts, this document identifies and highlights some key immediate or important priorities for wetland species conservation:

1. The Empire-Cienega Ranch area must be protected from invasive exotic species, especially fishes, by getting the exotics out of the surrounding drainage basin.

2. Green sunfish (and a few other exotic fish populations) should be removed from key mountain canyons where they prevent native fish conservation (Romero Canyon; Bear Canyon--including Rose Canyon Lake; Agua Caliente Canyon; Tanque Verde Canyon; Paige Canyon). This would be in cooperation with the Arizona Game and Fish Department and USDA Forest Service effort that has already been initiated.

3. A long-term solution should be sought (in cooperation with Buenos Aries National Wildlife

Refuge and Arizona Game and Fish Department) to the disastrous situation at Arivaca Ciénega and Arivaca Lake, where non-native species have overwhelmed the Chiricahua leopard frog, Mexican garter snake, and Gila topminnow.

4. Pima County and the Sonoran Desert Conservation Plan should recognize and assist the development of cooperation between the Buenos Aires National Wildlife Refuge, Arizona Game and Fish Department, and area ranchers interested in conservation and re-establishment of native leopard frogs in ponds and springs in the desert grassland and oak woodland areas of the County.

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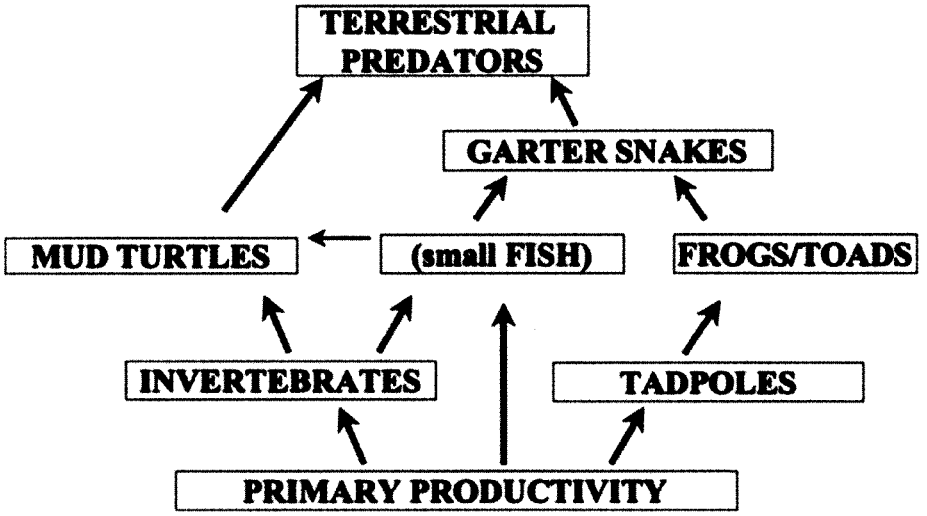
Appendix A

Natural Spring Food Web



Altered Spring Food Web