RECON

Conservation of Urban Amphibians in Tucson
Final Report

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Executive Summary

A diverse community of abundant, native amphibians is persisting along waterways of urban and urbanizing Tucson. Community and government leaders in Tucson support the concept of urban amphibian conservation in principle. Meanwhile, concurrent, commingled plans for infrastructure improvements and ecological restoration along major urban riparian corridors are being developed under leadership from Pima County, City of Tucson, and U.S. Army Corps of Engineers. Paradoxically, as this work gets underway, it could impact local amphibian populations – temporarily via direct earth-moving impacts, and permanently via elimination of seasonal waters in which amphibians breed. Pima County wishes to minimize these negative impacts, and to learn how to protect, manage and improve habitat conditions for native amphibians. This report describes means by which—despite complex public health issues—such conservation may be possible with proper planning.

The report is divided into five parts summarizing known conditions for and developing feasible approaches to applied urban conservation:

Part 1.0. Urban Amphibians in Tucson. This section introduces the suite of 13 amphibian species in the Tucson metropolitan area, with annotations describing local distribution, natural history, and ecology.

Part 2.0. Rillito River Ecological Restoration Project. This section details a novel Pima County amphibian salvage-rescue-translocation operation with special emphasis on the activities at the Rillito River Ecological Restoration Project (Area 3) at Columbus Boulevard. Over 600 amphibians of four species were salvaged from Area 3 and translocated to Kino Ecological Restoration Project, West Branch of the Santa Cruz River, and Santa Cruz floodplain near the West Branch. The translocated species were: Couch's spadefoot (*Scaphiopus couchii*, n = 595), Mexican spadefoot (*Spea multiplicata*, n = 60), Great Plains toad (*Bufo cognatus*, n = 4), and Sonoran Desert toad (*Bufo alvarius*, n = 2).

Additional work in the Tucson area resulted in translocation of two additional species, the red-spotted toad (*Bufo punctatus*) and the Great Plains narrow-mouthed toad (*Gastrophryne olivacea*)., In total, 1,317 anurans were translocated, including 523 tadpoles and 794 adults and captive-raised metamorphs. This section presents methods, initial results, prospects for long-term outcomes, and monitoring needs.

Part 3.0. Mosquitoes, Hydroperiod, and Urban Habitat Conservation. This section reviews issues in mosquito ecology and biological control pertinent to amphibian conservation. An updated summary based on published literature is presented for mosquito species present in the region and specifically in Tucson, along with prevalence

of West Nile Virus in the mosquitoes. Information on dispersal of mosquitoes from breeding sites is synthesized. This establishes a basis to evaluate how urban wetland communities might be structured to avoid public health hazards.

Two general approaches are outlined: (1) incorporation of mosquito-eating native fish into summer rain-pool ecosystems, and (2) control of hydroperiods to manage for populations of beneficial mosquito-eating tadpoles and aquatic invertebrates.

Part 4.0. Amphibian Breeding Habitat Design for Ecological Restoration in Infrastructure and Parks. This section presents diagrams and concepts for general classes of urban aquatic systems and elements of the flood-control infrastructure. This establishes an initial basis upon which to engineer solutions that reconcile flood control, public health, and recreational and biodiversity objectives.

Part 5.0. Monitoring Methods and Information Needs. This section summarizes monitoring needed to track outcomes of the salvage-translocation experiments, and discusses monitoring needs related to mosquito issues and habitat design concepts. In addition, information requirements for the design of a successful urban amphibian conservation program are outlined.

1.0 Urban Amphibians in Tucson

1.1 Introduction

Urban sprawl in the Phoenix–Tucson metropolitan area threatens a large area important to Arizona's surprisingly rich lowland desert amphibian fauna. Despite a human population at the million mark, metropolitan Tucson continues to support many tens of thousands of native anurans (frogs and toads) of at least six species. These populations are enjoyed by people in urban parks and other open spaces and contribute to the utility of urban wildlife as an educational resource. The species have demonstrated an ability to thrive in urban areas in the accidental interstices of modern development. As urbanization intensifies, most of these species may disappear, with the same trajectory following in newly urbanizing zones, unless specific conservation considerations are included in urban planning and development.

Although frogs and toads are suffering global decline exceeding those of most other groups of vertebrate animals, the findings reported here show that they remain abundant in Tucson (Figures 1A and 1B). These findings also highlight the centrality of major valley-bottom riparian corridors for both the abundance and species richness of desert amphibians. The rapidly urbanizing Tucson–Phoenix metropolitan corridor occupies much of the richest valley bottom habitat in the northern Sonoran Desert. As such, Sonoran Desert amphibians are facing an increasingly significant threat despite the presence of remaining open valley floors in the Tohono O'odham Nation. Pima County wishes to minimize the negative effects associated with urbanization, as well as learn how to protect, manage and improve habitat conditions for these native amphibians.

Why does Tucson matter to the regional amphibian population? Landscape provides the answer — slope, soils, drainage patterns, and elevation.

Most of the regional abundance and diversity of anurans occur along major riparian corridors on the level mid-valley floors. This is well illustrated by results of the Tucson amphibian survey (Figures 1A and 1B; and P. Rosen, in preparation).

There are marked patterns of amphibian breeding and habitat occupancy on the scale of the characteristic desert landscape structure. Amphibians breed where water collects in montane rock pools (tinajas) carved by powerful canyon flooding, or in canyon springs and perennial or semi-perennial streams. The sloping bajadas surrounding the mountains support few breeding sites for amphibians, as rainfall either runs off into arroyos leading to the valley floor or is absorbed by coarse sandy and gravelly loam soils. On the level valley floors, runoff collects and often stands for weeks, perched on the fine, relatively impervious clays and silts, creating breeding habitat for amphibians. On these valley floors, summer rainpools, pools, and ponds are produced at natural

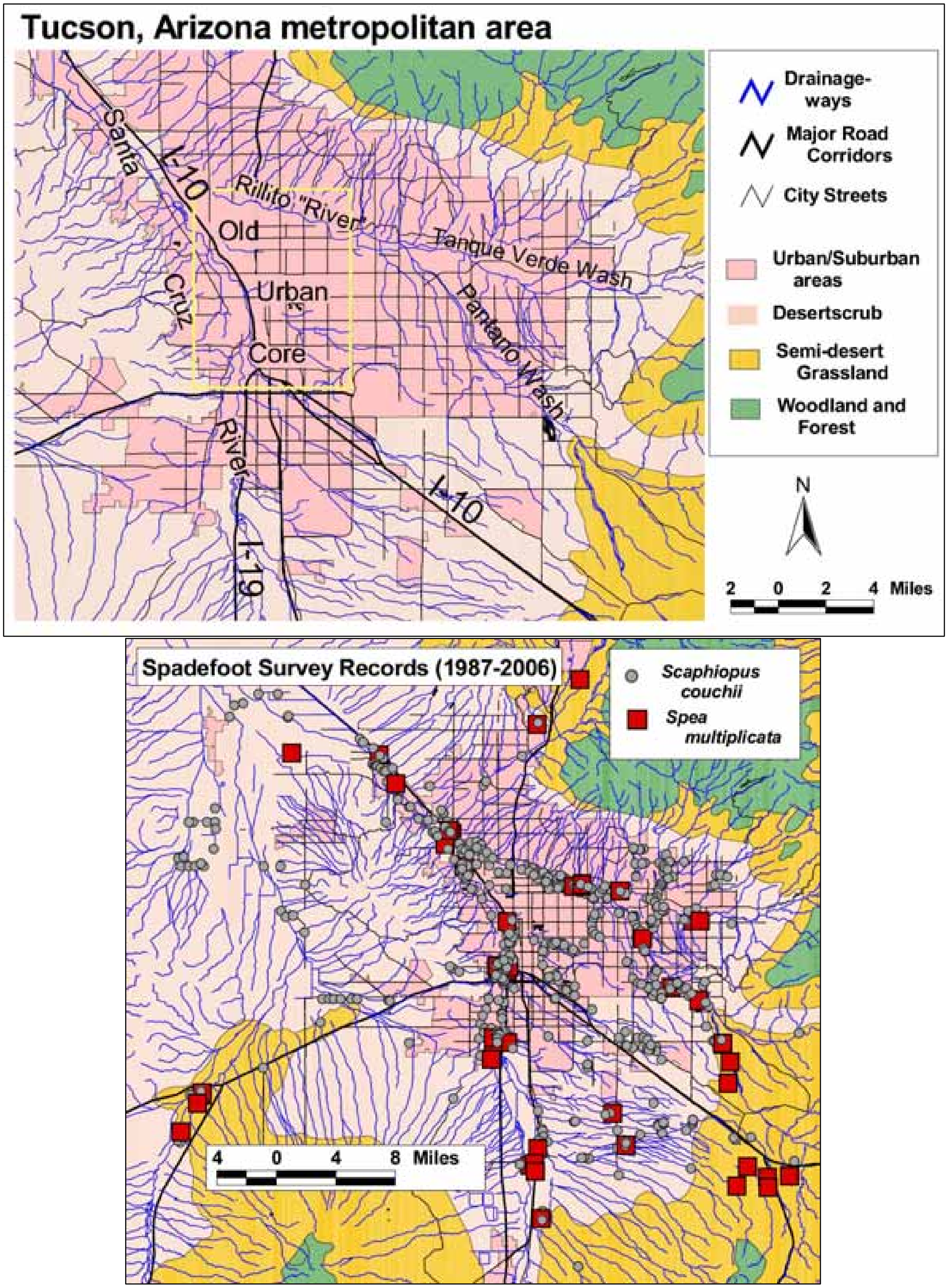


Figure 1A. Location of key features of the Tucson Basin (top map) and distribution of spadefoot toads in the metropolitan area (bottom). Distributional data are based on field survey (P. Rosen, unpublished).

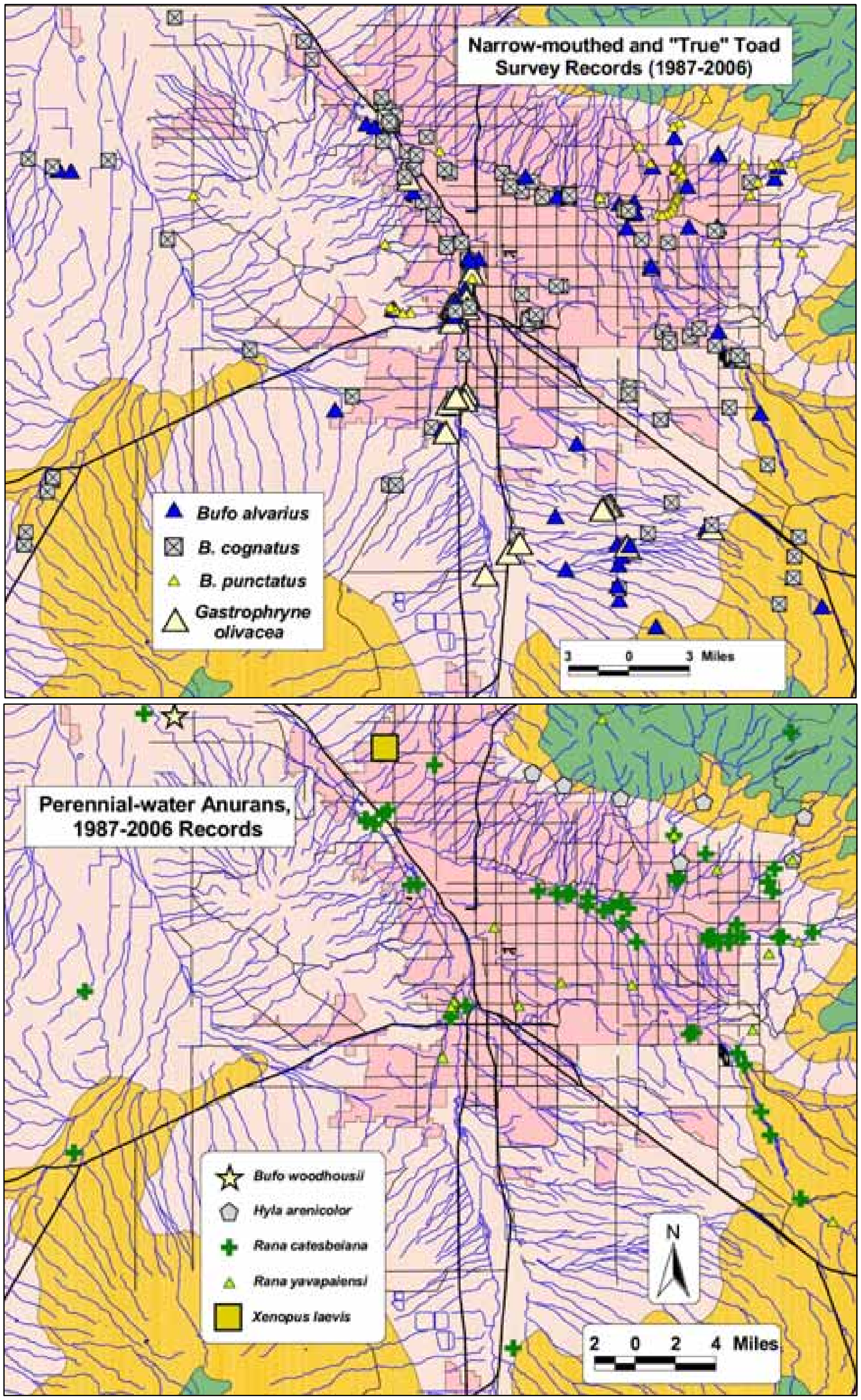


Figure 1B. Distribution of summer-breeding toads (top map) and frogs and toads that may use perennial waters to breed (bottom) based on extensive field survey (P. Rosen, unpublished). Records of the lowland leopard frog in the urbanized area represent populations in backyard or schoolyard ponds. The single record for Woodhouse toad is from 1995.

scour features such as cutoff channels (like the oxbows in major rivers) and scour holes (which form where water pours off hard surfaces onto softer soils), as well as in-stream debris jams. This portion of the landscape is occupied by a diverse regional valley-bottom herpetofauna (the amphibians and reptiles) associated with riparian vegetation, streams, and pools.

Tucson is a significant locality for amphibians for two primary reasons—its large, mesic valley-bottom riparian corridors and the adequate summer rainfall afforded by its geographic location and elevation. To the north and east, temperatures drop and subtropical Sonoran species are lost. Moving north and west down the Santa Cruz and Gila valleys, rainfall diminishes, and the abundance and diversity of amphibians decline. Thus, the Santa Cruz Valley, the Tucson Basin (including the “Tucson Southlands” on the Santa Rita Mountains bajada) host a significant arid-lands amphibian fauna.

In urban Tucson, anurans are surviving in unplanned aspects of infrastructure or in non-urbanized habitat within the urban matrix. The following types of features comprise the vast majority of urban anuran breeding sites:

- Preserved or neglected river bottoms (such as West Branch of the Santa Cruz and the margins of Rillito River),
- Shallow pools in secondary or tertiary drainage channels in the city (such as Arroyo Chico and Arcadia Wash),
- Puddles formed in pits made by off-road vehicles or on dirt roads on valley-bottom soils.
- Rain-filled ponds in the bottoms of abandoned gravel pits,
- Detention and retention basins built along the urban drainageways,
- Scour pools formed incidentally below grade-control structures in major washes (such as in Pantano Wash at Broadway Boulevard), and
- Imperfectly leveled concrete drainage channel bottoms

Because human nature tends to engineer ever-more flawless infrastructure, tending toward the elimination of most of these breeding situations, the persistence of urban amphibians is primarily fortuitous and accidental, and this persistence is threatened by growth, sprawl, and ever-improving infrastructure.

Recent and current distribution of amphibians in Tucson based upon the author’s observations is shown in Figures 1A and 1B. Current and historic distributions are contrasted in Figure 2. For the Tucson Basin, the current distribution maps of summer-breeding anurans are derived from a systematic survey by Phil Rosen, Dennis Caldwell,

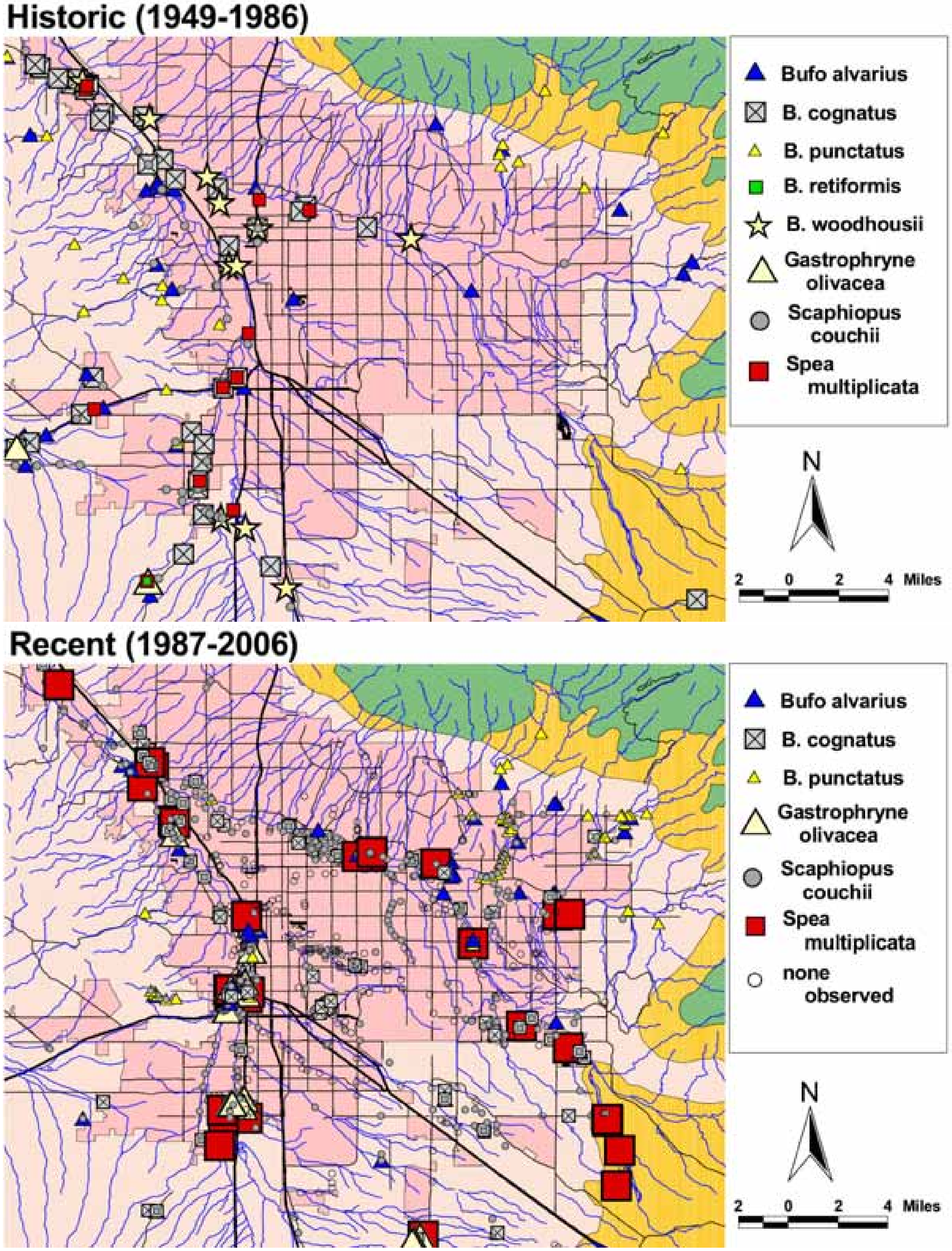


Figure 2. Historic (top, museum data) and recent (bottom, field data) distribution of temporary water-breeding amphibians in the Tucson Basin. Limited data available for mountain canyons are also plotted.

Jay Evenson, and David Lazaroff conducted at night during the breeding seasons of 2002-2006, supplemented by Phil Rosen's earlier observations. For perennial water anurans, the map represents observations of bullfrogs and the catalog of leopard frog populations that remain in natural areas or have been established in schools, back yards, and at other facilities.

As noted, the principal riparian corridors – Santa Cruz River and the Rillito River system – support by far the greatest abundance and species richness of amphibians in Tucson. A second major center of amphibian life was found south of the existing city in the Lee Moore Wash basin of the "Tucson Southlands" region, which is slated for intensive urbanization over the coming 1-3 decades. This report is intended in part to develop concepts and methods to preserve the amphibian biodiversity in the latter region, as urbanization and infrastructure development proceed.

Two species are found in a substantial number of sites outside the principal riparian corridors in the urban core of Tucson: Couch's spadefoot and Great Plains toad (Figure 1A). Certain highly urbanized washes still support extensive breeding populations of Couch's spadefoot, although there are areas, particularly in the old urban core, where apparently suitable washes are unoccupied. The reasons for these empty habitat areas are not known, but may include toxins, enhanced drainage to avoid standing water of sufficient duration for breeding, road mortality, or, perhaps more simply but ominously, long human occupancy. The latter possibility would suggest that urban core populations are declining toward extirpation, though slowly. Population increases in such settings have not been observed, and, anecdotally, some populations seem to be declining, although monitoring has only just begun.

Twelve species of anurans are currently known from metropolitan Tucson (Table 1). Based on interviews with residents of central Tucson, and on animals they have turned over to the author, adult Sonoran Desert toads, in particular, but probably also Great Plains toads, are found many miles into the urban core – distant from known or presumed possible breeding sties. This probably represents dispersal of young toads recruited from other areas, mostly the Rillito.

Woodhouse's toad apparently disappeared from metropolitan Tucson after the 1960s or early 1970's, most likely after waning for decades following the demise of surface flow in Santa Cruz River. The extirpation and intentional re-establishment of the lowland leopard frog is a larger topic than can be presented here. The current status of the Sonoran green toad could not be established, but it might remain on the San Xavier District of the Tohono O'odham Nation. The two most threatened species that still occur in significant natural populations in metropolitan Tucson are Great Plains narrow-mouthed toad and Mexican spadefoot.

TABLE 1.
THE FROGS AND TOADS KNOWN IN METROPOLITAN TUCSON AS OF 2007

Species	English Name	Status
Bufo alvarius	Sonoran Desert toad	present, widespread
Bufo cognatus	Great Plains toad	present, widespread
Bufo punctatus	red-spotted toad	present, rare in valley
Bufo retiformis	Sonoran green toad	single locality, status unknown
Bufo woodhousii	Woodhouse's toad	extirpated
Gastrophryne olivacea	narrow-mouthed toad	present, restricted distribution
Hyla arenicolor	canyon treefrog	accidental in valley
Rana catesbeiana	American bullfrog	non-native, widespread
Rana yavapaiensis	lowland leopard frog	extirpated, re-established
Scaphiopus couchii	Couch's spadefoot	present, very abundant
Spea multiplicata	Mexican spadefoot	present, restricted distribution
Xenopus laevis	African clawed frog	non-native, single locality

1.1.1 Non-native Anurans in Tucson

Figure 1 demonstrates the extensive distribution for the bullfrog, which may threaten re-establishment of the lowland leopard frog. Many of these records, however, represent small numbers of dispersing juvenile bullfrogs that move down the principal riparian corridors during wet times but probably fail to reach suitable habitat for growth or breeding. Breeding populations of bullfrogs are absent from midtown Tucson, and are generally few and limited in size in most of metropolitan Tucson. A program to remove this species from the city region would seem feasible, although the situation in upper Tanque Verde-Agua Caliente wash basin would require coordination with several private and public landholders.

The African clawed frog was probably established at Arthur Pack Park by a researcher several decades ago, and it remains the only know population in the arid southwest. During rainy periods, large numbers of these frogs are observed moving from the park’s golf course ponds, across roads and, presumably into nearby washes and detention basins where native amphibians occur. Since this species can carry the emerging disease chytridiomycosis, this could represent a future problem for conservation. In addition, non-native tiger salamanders have been found in ponds close to but outside the metropolitan area.

1.1.2 Recent Changes in Tucson’s Anurans

Figure 2 illustrates some important changes that have taken place over recent decades. Although museum collections may reflect collector bias in favor of less common species over the omnipresent Couch’s spadefoot, the magnitude of the increase of this species’ apparent dominance within the assemblage suggests a major shift in species diversity patterns. In the historic museum record, other species were collected at numerous, widely distributed localities in the metropolitan area, but the recent, more intensive and systematic efforts found them at fewer, more dispersed places, and rarely in abundance.

Notes in the University of Arizona herpetology laboratory from the 1960's era work of Dr. Charles H. Lowe and his students, plus specimens they deposited in the UA collection indicate there were very high abundances of bufonid toads in ponds on and adjoining the Santa Cruz River floodplain near Grant Road and Camino del Cerro. Today, at these locations, toad breeding continues but abundances are low. While there seem to be many factors at work, fieldwork suggests that the loss of breeding habitat with suitably long hydroperiod is the most critical factor. It seems highly likely that a conservation plan for this assemblage would be needed to prevent a significant loss of biodiversity in the metropolitan area.

1.2 The Amphibian Species and Their Ecological Characteristics

Following is an annotated list of the amphibians of the Tucson metropolitan area. The species accounts highlight notable characteristics, novel findings, key features of habitat and breeding biology, local distribution, and other information especially relevant to conservation. Although general identification characteristics are not presented, the voice of each species is described in a way that might be useful in the field. A number of recent genus-level changes in accepted scientific names of amphibians are indicated parenthetically for the reader's convenience, but names in long usage are retained until these changes become more firmly established. Unless otherwise noted, photos throughout this document are by P. Rosen.

CLASS AMPHIBIA—Amphibians

ORDER ANURA—Frogs and Toads

FAMILY PELOBATIDAE—Spadefoot Toads

Couch's Spadefoot—*Scaphiopus couchii*

This is the quintessential desert amphibian. It can reach metamorphosis in less than 8 days, from egg-laying to the completion of the water-dependent tadpole stage, making it one of the fastest-developing tadpoles in the world. It is widespread in the warm deserts of North America, including in arid Sonoran desertscrub of the Lower Colorado Valley.

Couch's spadefoot (Figure 3) is most abundant on valley floors and in stock ponds, but extends up into some desert canyons. Adults and juveniles emerge to feed on a variety of insects and other invertebrates on warm, moist nights, as do other toads described here. Breeding occurs almost exclusively in summer, and these spadefoots breed “explosively” in large groups immediately after monsoonal rainpools form. Rapid development allows it to use short-lived puddles, as well as deeper rain-filled ponds and pools.

This is the most abundant amphibian in urban Tucson, with tens of thousands of adults. It can be seen in aggregations of several hundred breeding adults at a number of sites within the city. It occurs in most major washes, within many neighborhoods, as well as along the major riparian corridors. Its breeding call sounds like a bleating sheep, “wa’aanhhh”.

Figure 3. Metamorph and small juvenile (left), and eggs (right) of Couch's spadefoot, from Tucson. Photo at right is by Kathryn Mauz.

Mexican Spadefoot—*Spea multiplicata*

This species—which smells like peanuts when handled—is also sometimes called the southern spadefoot or the New Mexico spadefoot. Its tadpole (Figure 4) is known to be cannibalistic, and readily consume mosquito larvae—up to at least 99 per day for a larger tadpole (P. Rosen, unpublished data).

Figure 4. Mexican spadefoot metamorph (left) and tadpoles (right). Both of these particular tadpoles were carnivorous and fed on mosquito larvae. The one on the lower left was also a cannibalistic morph that ate smaller tadpoles.

The Mexican spadefoot is widespread in the warmer arid lands of North America, including on the Mexican Altiplano. It is most abundant in semi-desert grasslands in our region, and does not occur in the Lower Colorado River Valley. Like Couch's spadefoot, this species breeds explosively in summer rain pools. Its tadpoles reach metamorphosis rapidly (usually 12–19 days, and sometimes longer) but not as quickly as in Couch's spadefoot, and so it normally breeds in ponds or deeper pools, and more rarely in puddles. Its newly metamorphosed toadlet (Figure 3), at about 19 mm, is larger than that of other local toads, which average 11–13 mm (P. Rosen, unpublished).

This species is uncommon to rare in the Tucson region, where it is restricted to major valley floodplain flats. It utilizes stock ponds in the hilly grasslands of Altar Valley and, uncommonly, Pajarito Mountains. In the city, it is mostly found in apparently declining populations at sites where former breeding waters like old gravel pits previously existed. Because its predaceous tadpole may be useful in mosquito control, this species should be a priority for amphibian conservation programs. Its breeding call is a low-pitched snore.

FAMILY BUFONIDAE—"True" Toads

Sonoran Desert Toad—*Bufo alvarius (Ollotis alvaria*)

This species is also known as the Colorado River toad, mainly because it is so large—up to 7.5 inches body length. Its skin glands secrete enough toxins to incapacitate or kill an attacking dog, and reputedly, to send a human drug abuser into orbit. In addition to the usual anuran fare of small invertebrates, this large toad will eat tarantulas, scorpions, other toads, reptiles, and mice.

Figure 5. Recently transformed "metamorphs" of the Sonoran Desert toad (left) and red-spotted toad (right). Although very similar at this age, they can be reliably distinguished. As adults they differ greatly in size and coloration.

This toad is a Sonoran Desert regional endemic, living in the Arizona Upland and other less arid parts of the Sonoran Desert and adjoining tropical environments in Mexico. It occurs in desert canyons and stock ponds, as well as along rivers and streams. It often breeds prior to the monsoons—often just before they arrive—in ponds or stream sections that are fishless but have remained wet through the dry season. However, it also breeds with most of the other toad species in rain-filled ponds. There is little information about the length of the tadpole stage, but in captivity they have transformed in 22-52 days, suggesting a relatively long larval stage (P. Rosen, unpublished data). Its newly metamorphosed toadlet (see Figure 5 above) is tiny—just over half an inch, and only slightly larger than that of much smaller species of *Bufo*.

Because of its large size and toxicity, this species is rightly assumed to be long-lived. Telemetry has demonstrated that individuals regularly hop long distances (D. Beck, personal communication, 1991). This exposes it road mortality, perhaps contributing to the ongoing withdrawal of this species from most of Tucson's urban core. Yet it is abundant at West Branch, apparently avoiding road mortality on adjacent sections of Mission Road. It still breeds in the upper Rillito system, on the Santa Cruz, and in canyons and stock ponds surrounding the urbanized area. Its call is a quiet, rough squawk.

Great Plains Toad—*Bufo cognatus (Anaxyrus cognatus*)

This is a fairly large toad that ranges widely from the Great Plains through the Arizona Upland Sonoran Desert, and down the Gila Valley into the Lower Colorado Valley province of the Sonoran Desert. It can be distinguished from the Woodhouse toad, which is similar in size, stoutness, and general appearance by its paisley spots containing many small warts (Figure 6), and the lack of a light line down the middle of the back.

Figure 6. Great Plains toad adult (left) and eggs (right), from Tucson. The long strands of eggs are typical of most of our true toads (family Bufonidae).

The Great Plains toad occurs in gravel pits, stock ponds, and on valley floors where it attempts to breed in a variety of pools and grassy swales, perhaps often unsuccessfully. Breeding calls are heard in spring when water is available, and large breeding choruses sometimes continue for many days during the summer monsoon. P. Rosen (unpublished data) has recorded the tadpole stage at 17.5–43 days, which is similar to literature reports (17–45 days).

The Great Plains toad is widespread within residential parts of Tucson, second in abundance only to Couch's spadefoot, but it may now be declining as urban breeding habitat is eliminated or stocked with predatory fish. It has the loudest call of any anuran in the region, a long, harsh, pulsating trill that is deafening at close range.

Red-spotted Toad—*Bufo punctatus (Anaxyrus punctatus*)

This widespread toad of the warm, arid regions of North America is somewhat flattened, probably adapting it to sheltering in crevices. It occurs primarily in rocky canyons and foothill arroyos throughout the Sonoran Desert region, as well as the Mojave Desert, where it is usually the only amphibian.

This toad is often associated with tinajas and non-perennial sections of canyon streams and springs. Breeding occurs in spring if water is available as well as explosively immediately following major monsoonal rains. There is little data on the length of the tadpole stage, but P. Rosen (unpublished data) has recorded 17.5–23 days in captive and wild settings in Tucson.

Red-spotted toads are widespread and abundant in the mountains around Tucson. They also breed successfully in several urban valley-bottom sites that simulate natural montane habitat, with rocks, concrete grade-control structures, or concrete-debris and short-lived streams and stream-channel pools. Examples are the Tucson Diversion Channel (Figure 7) and the Broadway Boulevard bridge grade-control structure in Pantano Wash. The voice of this species is a loud, long, musical trill.

Figure 7. Man-made breeding habitat of the red-spotted toad in the Tucson Diversion Channel at the Santa Cruz River, 2006.

Sonoran Green Toad—Bufo retiformis (Anaxyrus retiformis)

This jewel of a toad (Figure 8) is endemic within the Arizona Upland and Plains of Sonora provinces of the Sonoran Desert. It is still abundant on valley floors in the Tohono O’odham Nation, but is reported to have declined markedly in Sonora.

The well-known breeding sites in Arizona are in major stock ponds, usually associated with major arroyos. Its breeding biology is not well documented, but it occurs after major monsoonal rains. Males are reported to call on land at some distance from the water, and intercept females heading toward the breeding ponds, which is unusual among our anurans.

Figure 8. Sonoran green toad from its single known locality in Altar Valley. There is also only a single known species locality in the Tucson Basin. Photo is by Erik Enderson.

A presumably isolated population was found near Black Mountain in a large tank on the San Xavier District, near Tucson, but it is unknown whether the species still persists east of Brawley Wash in northern Altar Valley, where it is rare.

The call is an intense, wheezy buzz, ending abruptly. It is similar to the call of the narrow-mouthed toad (below).

Southwestern Woodhouse’s Toad—*Bufo woodhousii australis (Anaxyrus woodhousii*)

Woodhouse’s toad (Figure 9) is a medium-large toad widespread across the western United States. It can easily be confused with the Great Plains toad if not examined carefully, but it differs ecologically. In the Tucson region it is not found in the desert proper nor in the desert grassland, but along perennial (and formerly perennial) rivers such as the Santa Cruz, Gila, and Colorado and in associated irrigation agriculture.

Figure 9. Southwestern Woodhouse toads from near Florence (left) and Douglas (right) in Arizona. This species has been extirpated from Tucson. Photo at left is by Colby Henley.

It breeds late winter-spring in streams, as well as in perennial ponds with small fish, and during the summer monsoon in rain pools. The tadpole stage is reported to be long, 5–8 weeks.

In Tucson this species occurred at several localities along the Santa Cruz River and the Rillito, but was extirpated after the 1960s. It persists upstream and downstream of the metropolitan region, with a 1995 record from Marana. It might be successfully re-established in larger waters in Tucson’s flood control infrastructure. Its breeding call has been described as a nasal “*wa-a-a-a-ah.*”

FAMILY HYLIDAE—Treefrogs

Canyon treefrog—*Hyla arenicolor*

The canyon treefrog—which lives primarily on boulders, not trees—still thrives in the wetter canyons of major mountain areas of the arid Southwest. It often sits on warm rocks, which its coloration matches with amazing precision (Figure 10). It breeds in semi-perennial to perennial stream pools and rocky runs in early spring to early summer. Its tadpole, which looks like a leopard frog tadpole but is more distinctively spotted, is reported to take 40–75 days to metamorphose.

This treefrog occurs in many Catalina and Rincon mountain canyons, and is especially abundant in Sabino and Bear canyons. It is sometimes seen along Sabino Creek housing areas well below the canyon, but the single museum record for the lower Santa Cruz River in Tucson is probably an abnormal outlier. The species is absent from the Tucson Mountains and similarly arid areas. Its breeding call is a short slow trill, hoarsely metallic, which sounds like it is coming from inside a hollow metal chamber.

Figure 10. A lowland leopard frog (left, from Sonora) and a canyon treefrog (right, from near Tucson), two stream-breeding species living in canyons in the Tucson region. The leopard frog is becoming re-established in backyard and school ponds in Tucson.

FAMILY MICROHYLIDAE—Microhylid Frogs

Great Plains narrow-mouthed toad—*Gastrophryne olivacea*

This strange little frog—rarely over 1½ inches body length—has a narrow, triangular face (Figure 11) that allows it to see the ants and termites it eats up close. Much like the burrowing treefrog (which has never been recorded in the Tucson region) and the Sonoran green toad, this frog is found in current and former desert grasslands of the Arizona Upland province of the Sonoran Desert, and ranges south in semi-desert grassland in the Plains of Sonora province, and in tropical thornscrub of the Sonoran–Sinaloan region of northwestern Mexico.

Although it breeds in many kinds of fishless habitats from March-September over its broad geographic range, in Arizona it has been seen only during the monsoonal rains, when it breeds explosively for a few days after major rains, usually in deeper pools with mesquite and grass. The literature reports a tadpole stage lasting 24–50 days, but P. Rosen (unpublished data) has found it to be shorter in Tucson, from 18–40 days. The tadpole (Figure 10) is a filter feeder, rather than a scraper or predator like most tadpoles. Thus it can feed while stationary rather than while actively moving. It is also very fast to escape when touched or approached, and these two features likely allow it to persist with high densities of tadpole predators.

Figure 11. Narrow-mouthed toad (left) and its distinctive tadpole (right). The tadpole is also unusual in being a filter feeder. Photo at left is by Kathryn Mauz.

This species was thought to have been extirpated from its only known locality in the Tucson region, near San Xavier, but has recently been discovered at several localities along the Santa Cruz River as far north as Columbus Park, and in the Tucson Southlands on floodplains of the northeastern bajada of the Santa Rita Mountains. Its call is an intense, short, wheezy buzz, which is initiated with a very brief, but audible *whit*.

FAMILY RANIDAE—"True" Frogs

Lowland leopard frog—*Rana yavapaiensis* (*Lithobates yavapaiensis*)

Tan, brownish, or light green with darker spots (see Figure 10 above), this regional endemic probably was the most abundant, and certainly the most conspicuous amphibian in downtown Tucson and Sabino Canyon before it was extirpated by a succession of impacts—desiccation of the valley streams, introduction of non-native predatory fishes, bullfrogs, and introduced crayfish, and the emergence of an exotic fungal disease called chytridiomycosis. It inhabits lower mountain canyons and major streams in desert valleys from central Arizona into the lowland rivers and northern Sierra Madre region of northwestern Mexico. It has declined sharply in recent decades, except in upland Sonora, Mexico.

It breeds in late winter-mid spring, secondarily in fall, and occasionally at other times, mostly in perennial streams, springs, and cienegas, especially where fish (particularly larger, mostly exotic, predatory species) are absent or uncommon. Its tadpole is larger than those of all the toads and treefrogs, and has a light cross at the end of the snout.

The length of the tadpole stage has been recorded at 2–9 months, depending on temperature, competition, and probability of desiccation.

Although this species was extirpated in Tucson, and has continued to be progressively confined to ever smaller, more isolated canyons in the region, it is now established at over 10 artificial ponds at schools and residences in Tucson. Its breeding call is a quiet, somewhat musical series of clucks, chuckles, and grunts.

American bullfrog—*Rana catesbeiana* (*Lithobates catesbeianus*) (introduced)

This large frog—to 8 inches body length (Figure 12)—is an invader brought from the eastern United States. It has strong negative impacts throughout the American West on native species in its genus, as well as on other animals. Its diet includes surprises such as small rattlesnakes, large wasps, bats, fish, and large numbers of smaller bullfrogs, as well as the usual invertebrates. Its tadpole is the largest (often >6 inches) of any Southwestern anuran, and is distasteful to most predatory fishes.

Figure 12. American bullfrog from the Santa Cruz River at Marana. This introduced species has known negative impacts on a number of native species in the American West.

Bullfrogs thrive in large, deep, still waters, especially those with cattails and similar vegetation, and especially where fishes reduce populations of aquatic insects that prey on its tadpoles. It does poorly in streams with strong flood regimes and few deep pools. Breeding peaks in May-June, and may continue with decreasing intensity into August, but may occur at other times in warm springs. The tadpole stage develops faster in warm regions like the Southwest, where it lasts roughly 3.5–12 or perhaps 14 months, than in the north (up to 3 yr), but still not fast enough to avoid flood or desiccation hazards in natural streams.

The bullfrog is absent from central Tucson, but occurs in the Kennedy, Columbus, and Fort Lowell park areas, and is widespread in the Tanque Verde—Agua Caliente Park area. It has colonized Sabino Canyon and the Cienega Creek Preserve, but has been eliminated from both places, apparently by floods. Its mere proximity to native frogs is a menace, since it carries, but rarely succumbs to the chytrid fungus disease. The bullfrog call is a loud bellow that sounds something like a bull.

FAMILY PIPIDAE—Tongue-less Frogs

African Clawed Frog—*Xenopus laevis* (introduced)

This strange-looking, large frog (Figure 13)—to over 5.5 inches—was exported from southern Africa starting in the 1930s for use in a human pregnancy test. It became an important laboratory animal, and was released in Tucson and southern California, where it is now established. It lives almost entirely underwater, but disperses overland during wet weather. It eats invertebrates, fish, and other frogs.

Figure 13. African clawed frog. Photo courtesy of National Library of Medicine, Dr. Enrique Amaya.

African clawed frogs live mostly in permanent water ponds without numerous large predatory fishes, but also occupy ditches and many other waters. The breeding ecology is not very well known, especially in the United States, but in Africa adults migrate to newly filled rainpools, primarily in spring but also in most other months, and the tadpole stage is reportedly 10–12 weeks under laboratory conditions.

This species was introduced into numerous locations in southeastern Arizona during the mid-20th century, but has persisted only at Arthur Pack Park, Tucson. It appears likely that this species was the original carrier of chytridiomycosis from Africa, whence it has now spread to threaten frogs with extinction on at least 4 continents. The call is given underwater, and is described as a quickly repeated (up to 100 times per minute) two-part trill, rising and falling in pitch.

ORDER CAUDATA—Salamanders

FAMILY AMBYSTOMATIDAE—Mole Salamanders

Tiger Salamander—*Ambystoma tigrinum* (introduced)

Widely spread as fish bait, introduced forms of this animal (Figure 14) turn up all over the Southwest, despite the presence of endemic native subspecies in the San Raphael Valley and along the Mogollon Rim. This salamander has a complex life cycle in which the aquatic larva, with feathery gills, can take two distinctive forms, normal or cannibal. The cannibal has a big, toothier head and eats its own kind, as well as other animals, yet both the cannibal and normal morphs can mature as aquatic adults with gills or transform into the colorful terrestrial (burrowing) adult.

Figure 14. Tiger salamander from southern Arizona. Photo is by Erik Enderson.

Tiger salamanders live in seasonal to permanent ponds free of medium-sized or large predatory fish. Breeding occurs mostly in late winter to mid-spring, but also sometimes in summer. The larva is predatory, unlike most tadpoles, and takes 10 weeks to several months to transform.

This species was introduced into stock ponds in semi-desert grasslands surrounding Tucson—near the Tortolita Mountains and in Redington Pass—and may be persisting there. It probably occurs as an escape or release in Tucson from time to time. Although not usually lethally affected by chytridiomycosis, tiger salamanders are well known carriers, and they also carry viral diseases that may affect native amphibians. However, they are also one of the few aquatic vertebrates that readily eat bullfrog tadpoles. This species is silent, like all salamanders, with minor exceptions.

1.3 Habitat of Summer Breeding Anurans in Tucson

Breeding habitats are characterized according to degree of urbanization, macrohabitat, and environmental type in Table 2. There is a significant difference between habitat utilized in the urbanized environment and that in the surrounding area, which is mostly represented in Table 2 by surveys in the Lee Moore Wash basin (Tucson Southlands).

1.3.1 Non-urbanized areas

In non-urbanized ranchlands, most of the breeding sites, and an overwhelming number of the breeding individuals are found in temporary ponds constructed as stock tanks. There are a few stock tanks remaining in the urban area; however, and these support numerous species and were visited repeatedly, resulting in numerous occurrence instances shown in Table 2.

In non-urbanized areas, natural floodplain scour pools are also used extensively as breeding habitat, especially by the Couch’s spadefoot, which has a short larval period (minimum 7.5 days) and can use almost any puddle. Natural pools are also used by the Great Plains narrow-mouthed toad and the Mexican spadefoot, and Great Plains narrow-mouthed toad used them frequently and often preferentially over larger stock ponds. For both these species, utilization of this habitat type involved larger, deeper scour pools, whereas the Couch’s spadefoot was able to utilize much smaller pools. In addition, at least one instance of successful breeding in these scour pools by the Sonoran Desert toad was documented; this species, as well as the Great Plains toad, largely uses long-lasting stock ponds, but its breeding habitat is not adequately understood. These factors are reflected in the species richness column of Table 2.

TABLE 2
AMPHIBIAN BREEDING HABITAT TYPES RECORDED IN TUCSON METROPOLITAN AREA SURVEYS 1987-2006

	No. of Instances			
Breeding Habitat	Urban	Non-Urban	TOTAL	Max Species Richness (urban/non-urban)
Temporary Pond (Tank)	72	75	147	6 / 5
Floodplain Scour Pool	28	37	65	3 / 5
Puddle Pool	123	5	128	1 / 2
Drainage Ditch	44	8	52	2 / 2
River/Major Wash Flow Zone	58	3	61	2 / 0
Secondary Wash Flow Zone	146	4	150	1 / 1
Gravel Pit Pond	40	8	48	5 / 2
Pond - other	15	1	16	1 / 1
Backyard Fish Pond	13		13	1 / -
Detention-Retention Basin	66		66	2 / -
Grade Control Structure	7		7	5 / -
Ephemeral Stream (rocky)	3		3	3 / -
Swimming Pool	4		4	1 / -
Grassy Swale	4		4	1 / ?
TOTAL	602	141	743	

Modern infrastructure habitat is in bold font.

1.3.2 Urbanized Areas

In Tucson, the largest number of breeding habitat observations involved puddle-pools of various kinds and pools in the flow zones of secondary washes. Almost all these records involved just one species—Couch’s spadefoot. In contrast, the few natural floodplain scour pools and remaining gravel pit ponds and pools in the city supported moderate to high species richness. Detention basins supported only two species (Couch’s spadefoot and the Great Plains toad) in the city, but this may be because the basins are relatively new, and may have potential to support more species, possibly through translocations (see Section 2.0).

Along the principal riparian corridors in the city, most anuran breeding sites and the overwhelming number of individuals are found on the first terraces above the low- and high-flow channels of the sandbed. However, metamorph Couch’s spadefoot and Sonoran Desert toads are occasionally found on the sandbed suggesting that some breeding may be occurring in this lowest zone.

Although breeding attempts by native anuran have only been documented four times in swimming pools, discussions with homeowners indicate that this is a frequent occurrence. Swimming pools could be an ecological trap for anurans; they may be unable to escape once in them, and the chlorine used to keep them clean would likely kill all anuran eggs or tadpoles.

Some remarkable observations demonstrated anuran utilization of modern infrastructure, including five species breeding at the largest grade control structure on the Pantano Wash (See Section 2.0, Figure 15). The setting of this site is also notable as one of the most important roosting sites for bats in Tucson, and the combination of bats and tadpoles might provide a high-biodiversity example for mosquito control. Other observations include breeding by Couch's spadefoot in trapezoidal concrete channels that held water long enough for tadpoles and predatory aquatic insects to be abundant. The ability of summer breeding anurans to utilize such highly artificial infrastructure offers great promise for urban conservation planning.

2.0 Rillito River Ecological Restoration Project

It should be feasible to sustain most or all species of native amphibians in Tucson if suitable habitat parameters are identified and management actions taken. Most of the original native species are persisting in the early 21st century despite decades of habitat impacts and pollution, and they can utilize modern infrastructure for breeding Biologically, it appears feasible to sustain all the original species in Tucson. Nonetheless, there is already evidence pointing toward widespread declines associated with urbanization trends that are likely to continue.

Among the problems for urban amphibians conservation is how to avoid causing mass mortality at sites that are being re-worked by heavy equipment but may later provide suitable habitat. Secondly, habitat will be destroyed at some sites with amphibians, while new habitat may arise or be created at other sites where natural colonization by amphibians would be slow or non-existent. Salvage and translocation appear to be appropriate methods to deal with these problems, and the added benefit of humanely sparing animals from being crushed or entombed during construction.

2.1 Potential Sites

There are several situations that would be appropriate for salvage, translocation, and repatriation of urban amphibians. They can be categorized as: (1) sites that will be temporarily or permanently damaged; (2) sites suitable as translocation targets; and finally, (3) sites that are drying up for one reason or another, where tadpoles of uncommon or otherwise desirable species that can be salvaged and used elsewhere.

2.1.1 Sites Likely to Sustain Damage

These sites can be divided into two subcategories. First are sites likely to be damaged and then become suitable again. This currently describes the river parks slated for ecological restoration and flood control infrastructure that will be constructed or reconfigured:

- The Rillito River Restoration and Environmental Project
- Santa Cruz River between 29th Street and Ajo Way
- Restoration projects on the Santa Cruz River:
  - Paseo de Las Iglesias restoration project
  - Trés Rios del Norte restoration project
  - Rio Antiguo restoration project on the Rillito

Detention and retention basins on secondary drainages, such as the current Arroyo Chico flood control project might also come under this heading.

A second sub-category includes sites likely to sustain damage that would not only kill resident amphibians but would not likely include suitable habitat in the future. Suitable habitat might be added to some such sites in the future, but they are listed here for the time being:

- Rillito River from Country Club Road to Santa Cruz River
- Santa Cruz floodplain environs near Columbus Park
- Rio Nuevo downtown revitalization area
- El Rio Medio restoration project
- Santa Cruz River floodplain terraces near Irvington Road
- Valencia Road gravel pits at the Santa Cruz River

The Tucson Southlands urban expansion area, on the northwestern bajada of the Santa Rita Mountains, may also belong in this sub-category. Recent surveys (see Section 1) demonstrate that there are many large populations of five species of anurans in this region.

2.1.2 Sites Suitable as Translocation Targets

This category contains the sites that currently appear safest as repositories for animals salvaged elsewhere. It can also be divided into two sub-categories.

First are sites with healthy populations, where salvaged animals of selected species could be stored and might augment existing populations. While various sites on the urban periphery may fit this bill, working relationships are not established with landholders or neighborhoods. At this time, the only such suitable site that is available is:

- West Branch of the Santa Cruz River

The West Branch between 29th St and Ajo Way may be able to host salvaged animals, especially of desirable species such as the Mexico spadefoot.

Secondary sites are those not currently saturated with amphibian species or are likely well below carrying capacity for species already present. This would include newly restored, created, or enhanced habitat. Examples include:

- Kino Ecological Restoration Project (KERP, formerly known as the Ajo Detention Basin)
- Santa Cruz River floodplain at I-10/I-19 interchange
- Brandi Fenton Memorial Park environs and Bingham Historical District
- Completed sites in Rillito River Restoration and Environmental Project
- Other new infrastructure with suitable breeding pools

Infrastructure such as grade control structures may produce scour pools of sufficient size and depth to support amphibians. The most notable example is in Pantano Wash at Broadway, where five anuran species were observed breeding in 2005-6. Another grade control structure that produces a deep scour pool where tadpoles were seen in 2005-6 is about 0.6 mi south of Broadway in Pantano Wash. Most grade control structures are smaller and produce little or no downstream scour. An exception is the one in the Rillito River between Country Club Road and Dodge Boulevard, although thus far native amphibians have not been found there. In cases where tadpoles or metamorphs are available in sufficient numbers, it would be instructive to introduce them to some of these infrastructure sites to see if they become established.

Figure 15. Grade control structures with scour pools supporting breeding amphibians in Pantano Wash, at Broadway (5 species, left) and about 0.6 mi upstream (1 species, right).

2.1.3 Tadpole Salvage from Desiccating Sites

Target species would most likely include the narrow-mouthed toad, Mexican spadefoot, or Sonoran Desert toad, since these are of the greatest interest to people and are also the most in need of management support in Tucson. Tadpoles could be translocated directly or raised through metamorphosis for later release. Such “head-started” animals could then be repatriated to the original salvage site or released elsewhere. Attempts to establish other species in Tucson, such as the Sonoran green toad or Woodhouse’s toad would best utilize this method for obtaining source animals.

2.2 Case Study: Rillito River Ecosystem Restoration Project Salvage Operation

Two general approaches were used during this trial salvage project. First, adults were captured during the explosive breeding choruses immediately following heavy rains, and directly translocated to target sites. The objective was to collect the animals prior to egg-laying. Almost all the adults were transferred to KERP; a few Mexican spadefoots were taken to West Branch just north of 36th Street.

Second, tadpoles were collected when found at high densities in drying pools. These animals were either translocated directly or reared and released as small juveniles. Tadpoles were collected at Area 3 of the Rillito River Ecosystem Restoration and Environmental Project (Area 3), as well as in Pantano Wash just east of Tucson, and at Fraser Pond at West Branch near 36th Street. Releases were at KERP, Fraser Pond, or the Santa Cruz floodplain near the I-10 to I-19 interchange.

Additional tadpoles of selected species were also raised in captivity to study feeding, behavior, and developmental time, and some of these were then released in the same areas.

The objective of the work at Area 3 was to collect at least half the adult anurans to protect them from impacts expected during planned heavy equipment use. The original intent was to translocate them to safe sites where they would later re-establish populations at the original collection site. Holding adult anurans captive for return to a work site may be feasible but risky for long periods, especially in the absence of a firm schedule for completion of the work. Further, it became apparent during the project that redesigned channels at the collection site might be less suitable than the original environment, at least initially, for anuran breeding. Therefore, the focus was on moving anurans to sites where they might establish or significantly enhance populations.

The first attempts at salvage and translocation, which are detailed here, occurred during July-September 2006. Adult anurans were intensively collected from Area 3 breeding pools, which are north and northeast of the end of Columbus Boulevard, on the south side floodplain of Rillito River. Topographic maps show gravel pits at the site decades ago, which probably created anuran habitat. Good floodplain habitat and fair-quality breeding puddles and pools on the floodplain surface and in urban drainages where they reach the Rillito floodplain persisted into the 21st century, At least three species bred there regularly, Couch's spadefoot, Mexican spadefoot, and Great Plains toad, and Sonoran Desert toad and red-spotted toad also occur at the site, and may breed there or nearby.

2.2.1 Health and Safety Protocols

2.2.1.1 Personal Safety

Field personnel should always remain aware of potential dangers inherent in working on anurans under urban conditions. Of course, the greatest danger is probably an automobile accident in transit to the sites.

In addition, urban anuran habitat usually exists along washes and in open space where police presence is limited. Although we have not experienced problems, field personnel should take common sense precautions such as working in pairs, knowing the work areas in daylight, staying attuned to the presence of other persons, carrying cell phones (and possibly self-defense technology), and maintaining composure at all times. At night under wet conditions, encounters with other persons are rare, but nevertheless, it is wise to know ahead of time where homeless camps are found, and to be aware that dry shelters may be densely occupied by the homeless on wet nights.

Field personnel should be wary of deep mud, steep slippery dropoffs into deep water, and rocks or other hard surfaces where they might hit their heads and then fall into water. Major riparian corridors are wide and can suddenly fill with deep, roiling floods. Also, watch out for rattlesnakes, which are active on warm, moist nights in some of the sites in Tucson.

Amphibians have complex skin secretions, many of which are defensive in nature and hence can be irritating and/or toxic. Generally, field personnel should avoid rubbing their eyes after handling toads, although serious illnesses are not known from simply handling our local species. However, people should be ready to recognize symptoms of allergic reaction (sneezing, runny nose, hives, itchy eyes, difficulty breathing), which are supposedly triggered occasionally by spadefoots and perhaps other toads.

As noted in the equipment list, important personal safety equipment to avoid or reduce the effect of various mishaps includes a backup light and a cell phone kept in a waterproof container such as a Ziploc bag.

2.2.1.2 Amphibian Disease Transmission

Collection sites and translocation target sites exist within a matrix of populations of mobile anurans that are likely to share – presently or soon enough – any disease in the area. The species under consideration here (i.e., non-ranid species) are not currently known to be suffering from virulent disease epidemics. Therefore, in the absence of evidence of disease or abnormal mortality episodes (i.e., die-offs), local translocations can be done without quarantine or prophylactic treatments.

This protocol would have to be reconsidered if (1) native leopard frog populations were to be established, since it may be preferable to ensure that the original founders start free of chytridiomycosis; or (2) toads are being moved from sites with tiger salamanders to those without them; or, (3) evidence of disease in source populations of toads if found.

2.2.1.3 Protocols for Establishing Ranid Populations

As an aside, there is some uncertainty regarding the widely held presumption that founders of new ranid frog populations must be free of chytridiomycosis. As KERP is an ideal place to establish the lowland leopard frog (see below), this discussion is relevant here. Several species of ranid frogs (“true” frogs, genus *Rana* in the family Ranidae) in the Sonoran and Madrean bioregions have intra-specifically variable susceptibilities (for reasons yet unknown). Although these species have experienced mortality impacts associated with the disease, each has maintained significant though often apparently reduced populations in the presence of the disease. Perhaps the only ultimate solution to such emerging disease problems is the coevolution of disease resistance and reduced virulence. This cannot occur in uninfected populations—what is required is large populations coevolving with the disease.

There are other points to this debate, but given the presence of bullfrogs in our region, which will likely remain a reservoir for the disease, it is unlikely that we can keep chytridiomycosis out many leopard frog populations. A suitable protocol might still call for starting with uninfected frogs (using an un-infected source or treatment with heat [35^{o} C for 4 hours], itraconazole, or chloramphenicol) to allow a large population to become established, followed by monitoring only. These details would be worked out among experts and responsible agencies of the state and federal government.

2.2.2 Equipment Checklist

The following equipment should be assembled and ready to go (the list is ordered roughly by need; the number needed is given in [brackets]; indispensable materials are marked with an asterisk *). Annotations are given highlighting safety considerations for anurans and field personnel:

- Permits as required by the Arizona Game and Fish Department and any other access permissions required*
- Appropriate field clothing (generally including rain gear and knee-high boots and/or waders) *
- Reliable vehicle capable of transporting muddy containers [at least one per site: generally a pickup or field sport-utility vehicle (SUV); preferably 4-wheel drive] *
- Lights [two per person, generally—at least one backup in case of failure; a preferred arrangement is one headlamp and one small backup, plus at least one powerful spotlight at the site] *
- Five-gallon plastic collection buckets with handle and lid [one per person]*
- Dipnets (at least 5-foot-long, and preferably 10-foot-long, with 1/4 to 1/6” mesh) [one per person] *
- Larger plastic buckets (20–32 gallon) with lids [one total, or more depending on number of anurans to be collected] *
- Notebook and pencil or waterproof pen [1] *
- Keys needed for access to locked field sites *
- Small (~quart size) plastic holding containers (or Ziploc bags) for rare/small species [2]
- Extra buckets for tadpoles, etc. [2]
- Global Positioning System (GPS) unit [1]

- Books and recordings for species identification and sex determination
- Rinse water for animals [3 gallons]
- Drinking water and food
- Extra batteries (one set of each size)
- Camera
- Ziploc bags (to protect equipment from water)
- Fine-mesh aquarium net to sample small tadpoles or other animals
- Measuring and weighing equipment (ruler, spring balances, calipers)
- Cell phone
- Shovel, jack, rope, spare tire, etc.
- Basic first-aid kit
- Maps

2.2.3 Salvage Methods

2.2.3.1 Collection and Translocation of Adults

Summer breeding by most kinds of toads in Arizona occurs at night after runoff from heavy rains fills breeding pools. All of the species may be present during the first night, although some may reach their breeding peak later or continue breeding longer, and some may wait until the heaviest rains to achieve peak breeding.

a. Timing

Correct timing of the work is key. Breeding events vary, but can potentially occur once and only once during a summer, and possibly last as little as two days. For this kind of work, field personnel must remain available on short throughout July, until peak breeding has occurred at least once. Major breeding events can occur from at least 17 June through 19 August. Ideally personnel should be ready and on-call by 17 June if a site must salvaged in a single year.

Rainfall and runoff sufficient to stimulate breeding at a given site in the Tucson metropolitan area can be now be closely monitored using a combination of the online Pima County automated rainfall and runoff monitoring system (http://159.233.69.3/perl/pima.pl), and other online precipitation imagery (http://www.intellicast.com/IcastPage/LoadPage.aspx?loc=ktus&seg=LocalWeather&prodgrp=RadarImagery&product=RegionalRadarLoop&prodnav=none&pid=none; and http://weather.unisys.com/satellite/sat_ir_rad_loop-12.html). Field personnel may also be able to watch electrical storms directly, or receive reports from cooperating observers in areas of work. When a potentially sufficient storm is remotely identified, one of the field team should visit the work site to confirm whether breeding is or will likely soon be occurring.

It is not possible to accurately predict whether breeding is occurring without going to the site every night during which at least 0.2 in (ca. 6 mm) of rain has fallen in the relevant drainage basin. Local events within such smaller rainstorms may exceed the remotely-reported quantity, and runoff from hardened urban surfaces can generate breeding pools sufficient for some species, especially Couch's spadefoot. This occurred during 2006: on 6 July, following heavy rains and breeding the night of 5 July, we found a moderate number of tadpoles already growing at Area 3, although only 0.2 in rain had been previously recorded on 2 July. However, peak breeding and the arrival of other species occurred later, after heavier rains (those exceeding 0.4 in, and especially those totaling 0.75 in or more), as is generally expected.

Breeding may commence at or shortly after dark following heavy daytime rains, and some species may even arrive during daylight. When the stimulatory rains occur at night, breeding can commence after midnight. Almost the entire breeding event can occur the first night even when the rain starts late and therefore the breeding gets a relatively late start. In that case, large numbers of adult anurans would probably remain visible during daylight early the following morning. Therefore, field personnel should be prepared to go to the field site at almost any hour of the night or early morning.

b. Capture and Containment of the Animals

Once at the site, field personnel should listen to the chorus to determine which species are present, and where they are. Field notes should be made about locations, qualitative abundances, rainfall, and habitat conditions, and GPS coordinates should be recorded. This information should be managed and maintained in a simple, reliable, and accessible format, such as an Excel spreadsheet.

Field personnel should enter the breeding choruses netting and hand-catching toads from the banks and by wading. Captured animals should be carried in 5-gallon buckets. Generally all accessible individuals of species to be translocated should be gathered (depending upon protocol), since actually getting them all is apparently far less likely than might be imagined.

When collected animals become crowded in a bucket, they should be spread out among more or larger buckets. For brief periods, conspecifics (members of the same species) can be piled on top of one another at least two or three deep. After transfer from collecting buckets to holding containers, the animals should have access to water about 1-3" deep. Depending upon how crowded they are, they should be rinsed (sometimes more than once) with water from the breeding pool. Toads may secrete or exude skin toxins as a defensive or fear response to capture, handling, and possibly crowding, and there are at least some species whose secretions are toxic to others, and possibly to conspecifics in high enough concentrations. Species should be separated when possible, especially keeping Sonoran Desert toads separate from others. For short-term holding, however, regular rinsing will generally suffice.

It may take several hours to collect a majority of the animals seen or heard. Male anurans arrive at breeding choruses before females and stay longer. Adult anurans that evade capture by diving may reappear shortly and resume activity. If many females are to be collected, which would be usual, many netting passes through the site will be required.

One person must be assigned as the master of data, and must count or receive accurate counts of all anurans collected and put into buckets for translocation. That person should be completely conversant with species identification and sex determination.

(Generally, male toads can be reliably recognized by their enlarged, cornified thumbs; in some species they can also be recognized by the darkened throat in the area of the un-inflated vocal sac, or by their conspicuously enlarged tympana [external, visible eardrums]; in Couch’s spadefoot the males are more brightly marked with yellow-green; the sexes also differ in size in some species, although there is overlap in this characteristic).

c. Releasing or Holding Adult Anurans for Translocation

At all times, anurans must be protected from overheating, which can occur in minutes in a closed bucket in the sun. As a rule, adult anurans held in closed buckets should never be abandoned, even temporarily, in the sun. Pickup truck beds may have hot spots over the exhaust pipes, catalytic converter, and muffler, which should be avoided during transport. By adding water and opening the buckets, adult anurans of desert species can be protected from overheating using common sense under most conditions in Tucson. Larger toads can float for hours, but if they are excessively crowded, or if large species are kept with smaller ones, animals may be drowned. Anurans can desiccate rapidly on dry soil or other absorbent material.

During transport, it is important that the anurans are packed shallowly in the buckets and driving is as slow and smooth as possible to avoid forceful sloshing. If this is not feasible, pack the animals into many Ziploc bags or transport them on a bed of moist vegetation debris, cotton cloth, or soil.

If possible, adult anurans taken from collection sites should be moved to translocation sites every 2-4 hours during suitable weather, and, in general, they should be released as early as possible during the evening. They should be released into areas with suitable cover in the water or on wet ground to avoid exposing them to predation in the unfamiliar setting of the release site. At the very least, the ground should be thoroughly wet (i.e., soggy) at the release site, so the toads can bury themselves (spadefoots and “true” toads all have spades on their feet for digging) or otherwise hide in vegetation or other cover in wet areas. Optimally, heavy rains have occurred at both the collection site and translocation site, and animals can be translocated directly into water suitable for breeding at the new site. Common sense and awareness must be used to minimize exposure of the anurans to predation or desiccation.

It may sometimes be necessary to hold the anurans in buckets for days (or even weeks) if conditions of moisture, terrain, and cover are not suitable at release sites. Adults can even be held for many months in un-crowded in buckets with moist (not saturated), clean soil (e.g., taken from the collection site).

For a couple of days, a small bit of moist soil or sphagnum to rest on is sufficient. Feeding is unnecessary. If species are kept separate, they can be crowded in with 20 or more in a 20-gallon container. Lids are required, since small, wet amphibians can adhere to and climb smooth vertical surfaces.

If adult anurans are held for weeks, they should have deep, moist soil that is friable enough for easy burrowing. Food can be offered in small amounts (to avoid fouling the container), especially if the project has a mealworm or cricket colony that is not exposed to exotic animals. However, essentially all adult anurans can go for many months at room temperature without food.

If the animals were to be held for more than 3–4 weeks, protocols would need to be developed and tested, and this cannot be recommended on a large scale until without such testing If suitable protocols were to be developed, it might be possible to hold large numbers of toads for a year or more without undue commitment of resources.

2.2.3.2 Collection and Translocation of Tadpoles

Once tadpoles have reached a vigorously swimming stage they are generally durable, and increasingly so as they reach 0.75 inch in total length. Many tadpoles readily gulp air, and can thus be packed into buckets at surprising densities for a short time, but “true” toads (genus *Bufo*, family Bufonidae) cannot, and rapidly deplete oxygen in the water and suffocate if crowded. Most species of desert anurans have tadpoles that can survive temperatures approaching or exceeding 100^o F (38^o C), but tadpoles should be kept below 90^o F (33^o C) during transport.

Identification of tadpoles is an expert task requiring both experience and a key specific to the study area. In cases where there is doubt, samples should be preserved, or tadpoles raised to metamorphosis, at which time they can be more easily identified.

Translocation of tadpoles can be readily accomplished if the following conditions are met: 1) field personnel can identify all potential species, 2) desired numbers animals are accessible for capture, and 3) suitable habitat is present and has received seasonal water input at the translocation site, or 4) provisions are in place for holding captured animals until translocation is feasible.

The best way to obtain tadpoles for translocation is to time return visits to the source site such that the tadpoles have reached a suitable size (2–3 cm, or approaching an inch total length) and when the breeding pool is shrinking as it dries. Tadpoles can sometimes be collected effectively by dipnetting around a pond that is full, and sometimes also by seining.

For anuran conservation work in Tucson, it may at times be desirable to filter out the most common species, Couch's spadefoot, and focus effort on salvaging tadpoles of other species. This can be accomplished using time-since-breeding: Couch's spadefoots usually metamorphose in 8–12 days after eggs are laid, while the Mexican spadefoot requires at least 12 days and the other toads generally require 17 days or more to metamorphose. Generally, after 11 days, it is possible to capture samples containing mostly the less common species.

Tadpoles can easily be raised through metamorphosis with regular attention. They can be kept in tubs or buckets with 4–12 in (10–30 cm) of water, on the ground or on tables in filtered sun or shade. Some species (probably most or all) are tolerant of hot water, apparently at least 40^{o} C (104^{o} F). Tadpoles can thrive in naturally murky, productive water, over natural pond mud or even in bare containers. They can be fed flake fish food, algae pellets, and grated cucumber or squash, or flash-boiled greens. Spadefoot tadpoles can be given extra animal matter (shrimp, for example), but narrow-mouthed tadpoles are filter feeders and may require suspended algae. All of the local species have been raised successfully in captivity using these methods without difficulty (P. Rosen, unpublished).

As metamorphosis approaches, a shallow shoreline is required or the metamorphosing toadlets will mostly drown; alternatively, tadpoles can be netted as soon as their front legs appear, and moved into very shallow holding tanks, carefully protected from overheating.

Metamorphs can be immediately released or fed tiny mealworms, pinhead crickets, or fruit flies. It is usually possible to attract fruit flies to overripe fruit through a 1/8 in mesh lid into an outdoor container with the metamorphs. As with adults, metamorphs should also be released using common sense, only on warm, wet nights, in areas with adequate cover. Metamorphs normally are found in high densities around pond edges, and can find sufficient cover in cracked mud and other debris, as long as moist refuges are accessible. They are tolerant of high temperature, but should not be released into sites where directly insolated soil surfaces cannot be avoided in deep cracks or in shade.

It may also be feasible to translocate eggs. For leopard frogs, eggs are easily handled; egg masses can be cut or gently pulled into smaller pieces, and even express-mailed if protected from temperature extremes. This may also be possible for other species, but it has not been tried. In some species the eggs are deposited singly or are otherwise difficult to locate or handle.

2.2.3.3 Collection and Translocation of Metamorphs

Especially for species with large clutch sizes, which breed in larger ponds where tadpoles may be difficult to net, metamorphs can often be caught in large numbers around the ponds margins after the onset of metamorphosis. This may be the easiest way to obtain Sonoran Desert and Great Plains toads for translocation.

2.2.4 Salvage Results

2.2.4.1 Numbers of Animals Translocated

A total of 1,311 individuals of six species were translocated in 2006 and 6 more in 2007 (Table 3), including 523 tadpoles, 183 metamorphs, three juveniles, one subadult (large, pre-adult juvenile), 451 adult males, and 159 adult females. Animals were translated to three main locations: KERP, Santa Cruz River floodplain near the Interstate 10/Interstate19 interchange (Mesquite Circle Pond), or the West Branch of the Santa Cruz River (this area includes Fraser, Padilla, and Beryl Baker ponds).

a. KERP

KERP/Ajo Detention Basin received 800 anurans (21 Sonoran Desert toads, 4 Great Plains toads, 2 red-spotted toads, 109 Great Plains narrow-mouthed toads, 596 Couch’s spadefoots, and 68 Mexican spadefoots). The majority of the animals comprised the 437 male and 155 female Couch’s spadefoot adults translocated from Rillito Area 3.

The remaining animals were mostly metamorphs or large tadpoles. All of the Mexican spadefoots were captured as tadpoles at three sites, raised in a captive nursery, and released as metamorphs. The narrow-mouthed toads were tadpoles or captive-raised metamorphs salvaged from West Branch.

b. Santa Cruz River floodplain—Mesquite Circle Pond

The Mesquite Circle Pond on the east side floodplain of Santa Cruz River, just north of the Julian Wash-Tucson Diversion Channel, received 447 individuals (three Great Plains toads, 417 Great Plains narrow-mouthed toads, one Couch’s spadefoot, and 26 Mexican spadefoots); all were metamorphs or large tadpoles. During 2001-3 this pond was a breeding site for all these species (except the narrow-mouthed toad) plus the Sonoran

Desert toad, but during 2004-6 1–2 narrow-mouthed toads were observed (2006), with numerous Couch’s spadefoots and Great Plains toads, but not the other species.

c. West Branch—Padilla Pond

All 6 adult Mexican spadefoots taken from Rillito Area 3 were released at Padilla Pond, the most consistent breeding site for the species at West Branch.

d. Other Locations

Translocations from private land at West Branch were carried out when convenient and with the property owners’ permission, using other funds. Early desiccation of the Fraser Pond at West Branch would have resulted in mortality of all the tadpoles taken from there. Mexican spadefoot tadpoles taken from near Pantano Wash, Vail, and Empire Ranch, which were used to study feeding and larval period, were added to the translocation group to diversify the gene pool, and taken to Mesquite Circle Pond and KERP (see Table 1).

TABLE 3
TRANSLOCATION RECORD, TUCSON, 2006-7

Translocation Target Species and Release Site	Source/ Collection Site	UTM Easting	UTM Northing	Coll Date	Rel Date	Rel Time	Total	Stage/Sex
Bufo alvarius—Sonoran Desert Toad								
KERP (NW)	Columbus	506300	3560803	7/6	7/7	23:30	1	1F
KERP (NW)	Columbus	506249	3560694	7/6	7/29	23:34	1	1M
KERP (NW)	Tucson midtown	506249	3560694	7/1	8/1	23:34	1	1 subadult
KERP (NW)	WB-Fraser	506337	3560851	8/14	8/21	20:05	12	12 meta
KERP (NW)	UA Farm	506337	3560851	2007	2007	July	6	5M 1F
Bufo cognatus—Great Plains Toad								
KERP (NW)	Columbus	506224	3560855	7/5	7/6	1:00	1	1M
KERP (NW)	Columbus	506300	3560803	7/6	7/7	23:30	1	1M
KERP (NW)	Columbus	506207	3560787	8/15	8/21	19:51	2	1M 1F
SCR-Mesq Circle Pond	Vail-I10 pond	501354	3561663	8/24	9/7	17:42	3	3 meta
Bufo punctatus—Red-spotted Toad								
Ajo Det Basin (NW)	SCR-Julian Wash	506337	3560851	8/8	8/21	20:05	2	2 meta
Gastrophryne olivacea—Great Plains Narrow-mouthed Toad								
KERP (NW)	WB-Fraser	506205	3560817	8/14	8/14	17:24	100	100 tad
KERP (NW)	WB-Fraser	506337	3560851	8/14	8/21	20:05	9	9 meta
SCR-Mesq Circle Pond	WB-Fraser	501315	3561607	8/14	8/14	16:56	200	200 tad
SCR-Mesq Circle Pond	WB-Fraser	501375	3561629	8/20	8/20	16:57	173	173 tad
SCR-Mesq Circle Pond	WB-Fraser	501354	3561663	8/14	9/7	17:42	44	44 meta
WB-Fraser Mission Rd pool	WB-Fraser	500163	3561918	8/14	8/14	16:42	50	50 tad

TABLE 3
TRANSLOCATION RECORD, TUCSON, 2006-7
(CONT.)

Translocation Target Species and Release Site	Source/ Collection Site	UTM Easting	UTM Northing	Coll Date	Rel Date	Rel Time	Total	Stage/Sex
Scaphiopus couchii—Couch's Spadefoot								
KERP (NW)	Columbus	506307	3560832	7/5	7/5	9:35	192	131M 61F
KERP (NW)	Columbus	506224	3560855	7/5	7/6	1:00	231	180M 51F
KERP (NW)	Columbus	506300	3560803	7/6	7/7	23:30	172	126M 43F 3 juv
KERP (NW)	Tucson	506337	3560851	7/1	8/21	20:05	1	1 meta
SCR-Mesq Circle Pond	Vail-I10 pond	501354	3561663	8/24	9/7	17:42	1	1 meta
Spea multiplicata—Mexican Spadefoot								
KERP (NW)	Empire Ranch HQ	506249	3560694	7/7	7/29	23:34	39	39 meta
KERP (NW)	Columbus	506337	3560851	8/11	8/21	20:05	28	28 meta
KERP (NW)	Vail-I10 pond	506337	3560851	8/24	8/21	20:05	1	1 meta
SCR-Mesq Circle Pond	Columbus	501448	3561740	8/11	8/17	20:00	17	17 meta
SCR-Mesq Circle Pond	Pantano-Valencia	501448	3561740	7/23	8/17	20:00	5	5 meta
SCR-Mesq Circle Pond	Vail-I10 pond	501354	3561663	8/24	9/7	17:42	4	4 meta
WB Padilla Pond	Columbus	500214	3561816	7/6	7/6	1:00	4	3M 1F
WB Padilla Pond	Columbus	500324	3561784	7/6	7/30	22:00	2	2M
WB-Beryl Baker toad pool	Columbus	500189	3561512	8/11	8/17	21:00	9	9 meta
WB-Beryl Baker toad pool	Vail-I10 pond	500189	3561512	8/24	8/17	21:00	5	5 meta

All UTMs are for the release sites (zone is 12S, datum is WGS1984. SCR = Santa Cruz River; WB = West Branch; Columbus = S side of Rillito at Columbus Boulevard (Rillito Area 3), UA Farm = Campbell Avenue south of the Rillito.

2.2.5 Monitoring

Monitoring consists of evaluating the collection site, checking for any evidence of excessive mortality at the translocation target site, and monitoring population establishment, reproductive success, and abundance at the translocation site.

2.2.5.1 Monitoring at the Collection Site

The monitoring objective is to observe whether removal has significantly depleted anuran populations at the collection site. This may be accomplished using observational notes over successive nights or breeding episodes within a season, or by returning in following years (prior to site disturbance by heavy equipment) and repeating observations. For repeat removals within a season, counts (of removed anurans) and estimates (of the number seen but not removed) may be available. This information may be valuable, though quantitatively it must be evaluated carefully, since it is inexact and contains several kinds of bias.

Return visits to Rillito Area 3 showed that collection of 423 adult Couch's spadefoots on 5–6 July 2006 still left the site with hundreds of adults on 7-8 July, when we salvaged 172 additional adults (less than half of those seen).

During the flood-of-record on the Rillito, which occurred 29 July–3 August 2006, floodwaters laden with sand and silt backed up into the breeding ditches used by anurans in Area 3, depositing as much as 0.5 m of sediment in the ditches. The mouth of the main breeding site ditch was plugged with sediment, leaving a deep pool, replicating natural processes that create anuran breeding habitat. However, the plug was soon removed by heavy equipment, presumably eradicating most of the tadpoles from the breeding event.

In the drained channel, which had subsequently dried to small pool, we salvaged the remaining tadpoles from the 29 July–3 August flood/breeding event, including 59 Mexican spadefoots and 34 Great Plains toads. We found 0–3 week-old Couch's spadefoots moderately abundant at the site.

2.2.5.2 Monitoring the Release

The monitoring objective is to observe undesirable effects of the release, such as morbidity, mortality, desiccation, or predation. No well-developed protocols are yet in place to accomplish these tasks. We returned to the release sites periodically (about once per week) in the first month after translocation to make observations.

Evidence of water toxicity was evaluated by watching the anurans as we released them at night into breeding ponds, returning the next day and thereafter to look for dead or moribund anurans in or near the water.

Evidence of predation was evaluated by approaching the release sites circumspectly, watching for active predators. We also canvassed for carcasses, particularly at sites with known predator middens (e.g., burrowing owl burrows at KERP). We noted the anuran breeding choruses at each visit to the released sites.

We observed little evidence of mortality or morbidity affecting translocated animals directly at the target sites, as detailed below.

a. KERP

When we returned to KERP on the night of 6–7 July 2006, we observed a black-crowned night heron active in the shallow lobe of water where we had released a large contingent of Couch's spadefoot adults the previous night. The heron was probably a predator attracted to the amphibians there, since the only available vertebrate prey of this primarily frog- and fish-eating bird would have been the Great Plains toads, which were abundant there naturally, Couch's spadefoots, which were uncommon, and the Couch's spadefoots we had just released. The heron's presence suggests some predation on the translocated animals.

Great Plains toads are moderately abundant at the site, with choruses of 20 or more individuals heard at various times in several of the pools of the detention basin and adults often found on land. All the Great Plains toad tadpoles dipnetted on 22 July 2006 were large and normally developing, and metamorphs were subsequently found. This signifies that this water is suitable for at least some amphibian larvae.

KERP includes several sets of artificial burrows occupied by translocated burrowing owls. KERP staff (Assistant Site Manager David Wise, personal communication 5 July 2006) reported that it is common to find anuran carcasses at burrow entrances. We surveyed all of the artificial burrows on 22–26 July, and found 94 anuran carcasses (61 Great Plains toads, 11 Couch's spadefoot, and 21 unknown anuran species) along with a Mediterranean gecko (an introduced species in the urban Southwest, *Hemidactylus turcicus*; adult, dead but uneaten). A few of the toad carcasses were fresh, especially the juveniles, but the most were mummified, and all appeared partially eaten.

b. Other Sites

The Mesquite Circle Pond on the Santa Cruz River floodplain had a sizable chorus of Great Plains toads, a moderate chorus of Couch's spadefoots, and two Great Plains narrow-mouthed toads calling on the night of 29–30 July 2006, just after it filled. Metamorphic processes and other observations are described below. No dead tadpoles or metamorphs were observed at this site, although the killdeer (*Charadrius vociferus*), which is well known to eat invertebrates the size of metamorph anurans, was extremely abundant at the site during the several daytime visits in summer 2006.

Metamorphs of all three species at the site were found under boards and rocks near the pond during late August and early September 2006, and at least one well-fed, growing individual of each species was observed.

2.2.5.3 Monitoring Reproduction and Population Status

We looked for tadpoles and metamorphs as evidence that water quality was suitable for anuran reproduction. We used dipnets while wading and walking around the ponds at release sites to search for tadpoles and evaluate the compatibility of the invertebrate assemblage for the anuran species being released. We searched for metamorphs at night near pond margins, on wet ground, and on roads.

We will repeat the observations of location and intensity of anuran breeding choruses at future visits to the released sites. The species calling, and their abundance are described within ranked categories according to the following protocol.

Abundance is categorized on a rank scale, where:

0 = absent,

1 = 1–2 isolated individuals calling,

2 = small chorus (i.e., approximately 3–9 separate individuals can be heard)

3 = moderate chorus (i.e., approximately 10–49 individuals estimated), and

4 = large chorus (i.e., $\geq$50 individuals estimated calling or seen).

The numbers of individuals refer to obviously present individuals, but nonetheless are intended only as guidelines for the ranked categories. It is not possible to accurately count anurans quickly under most circumstances. A rough estimate of the number heard and seen can be recorded when the chorus can be approached closely. Visual counts may be especially valuable when they pertain to species with quiet calls or off-season breeding, especially conspicuous ones like the Sonoran Desert toad (*Bufo alvarius*). Data were associated with a GPS time and location, and maintained in an Excel spreadsheet.

2.2.5.4 Invertebrate Community Observations

Dipnetting to characterize the invertebrate fauna was carried out at numerous sites in the Tucson Basin in 2006. Here, results for the two main translocation target sites are presented, along with relevant observations from a few other sites.

a. KERP

The north shallow arms of the two NW ponds of the detention basin were dipnetted from 9:30–12:00 on 22 July 2006, after preliminary dipnetting at various other points in KERP.

Both arms had similar faunas. Small aquatic beetles were abundant, and overall diversity was good diversity, including many *Belastoma* (a genus of predatory giant water bug) including juveniles and adults, a few corixids (water boatmen) and notonectids (backswimmers), and leeches (Table 4). Near the deep lobe of the pool, there were large aggregations of corixids mixed with notonectids. Great Plains toad tadpoles were patchily distributed, and locally abundant in shallows.

In deeper water throughout KERP, corixids and notonectids were very abundant, and in the edges with emergent vegetation we found damselfly and dragonfly nymphs, along with many of the other species found in the shallow arms.

TABLE 4
SUMMARY OF TADPOLE-INVERTEBRATE ASSOCIATION OBSERVATIONS 7-21/23-2006

WP	Date-time	SCCO	SPMU	BUCO	Mosquitoes	Other invertebrates	Site description
CMSQPD	21-Jul-06	abund	0	0	abund	few sm beetles, bugs, clam shrimp	Main rd puddle-pool nr Rita Detention Basin (RDB)
CMSQPD	21-Jul-06	0	0	0	v. abund	few sm beetles, bugs	Secondary rd-puddle pool nr RDB
CMSQPD	21-Jul-06	0	0	0	v. abund	few sm beetles, bugs	Secondary rd-puddle pool nr RDB
CMSQPD	21-Jul-06	0	0	0	0	clam shrimp, tadpole shrimp	V. shallow rd-puddle pool nr RDB
TSMP1	21-Jul-06	0	0	0	0	Abund tadpole shrimp	Shallow puddle on rd to Pant-Rita Det Basin (RDB)
CPUD2	21-Jul-06	v abund	0	0	0	no data	Secondary rd-puddle pool nr RDB
CMSQP2	21-Jul-06	abund	0	0	mod. abund	no data	Secondary rd-puddle pool nr RDB
CTWDDT	21-Jul-06	v abund	0	0	v. abund	few sm beetles	Grassy det basin floor of Rita Detention Basin
CTWDDT	21-Jul-06	rare	0	rare	super abund	2 *Eretes* dytiscids, few sm beetles	Grass-open det basin floor w pools in RDB
NOTPND	21-Jul-06	0	0	0	abund	few notonectids	Julian Wash deep pool nr (N of) RDB
CPUD3	21-Jul-06	abund	0	0	no data	no data	Secondary rd-puddle pool nr RDB
AjoDet1	22-Jul-06	0	0	uncommon	0	sm beetles, corixids; Belastoma, notonect, leech few	Ajo Det Basin 1st SCCO rel site arm
AjoDet2	22-Jul-06	0	0	common	0	sm beetles, *Belastoma*, corixids, notonect; leech, snail few	Ajo Det Basin 2nd (W-most) SCCO rel site arm
RACA1	23-Jul-06	0	0	0	0	few sm beetles, corixids	Shallow mud flat pool Pantano Wash at Valencia
BAMETA	23-Jul-06	0	0	0	0	sm beetles, corixids, beetle larvae	Shallow mud flat pool Pantano Wash at Valencia
COMUTD	23-Jul-06	abund	common	0	uncommon	sm beetles	stabilized Pantano Wash channel pool at Valencia
COMSQ3	23-Jul-06	v abund	0	0	super abund	few sm beetles, clam shrimp, rare fairy shrimp	cul-de-sac pool Pantano Wash nr Valencia
NOTADQ	23-Jul-06	0	0	0	abund	few sm beetles	Willow-Cttnwd Pond big SSCO chorus on 7-18

These are representative observations consistent with others under similar conditions elsewhere in the Tucson Basin during 2004-6. Waypoint (WP) identifiers are retained here for reference purposes only. The anuran species are represented by acronyms composed of the first two letters or genus and species.

In summary, KERP had moderately high aquatic insect abundance and moderate diversity. Mosquitoes were not evident during the night-time work, and larvae were not found in the water. However, Assistant Site Manager Wise reported use of *Bt* (*Bacillus thuringensis*) for mosquito control at KERP.

b. Santa Cruz floodplain—Mesquite Circle Pond

On 8 August 2006, water was 0.4 m deep in the mesquite-lined east end, with a moderate abundance of *S. couchii* tadpoles (2 cm; about 7–10 days old) and a small hoard of metamorphs ("metamorphs" are small, newly transformed toadlets, which are often extraordinarily numerous) under a board. The larger, shallower, less shadednorthwest sector of the pond had a moderate abundance of 1.5 cm (presumed 8 d-old) Great Plains toad tadpoles in water that was quite warm (41° C in shallow water, 40 in the deeper water, 38 on the bottom muck, and 36 ° C at 3 cm into the muck). The tadpoles were certainly tolerating 40° C, (104° F) body temperature. Throughout this pond arthropods were very abundant: fairy shrimp, tadpole shrimp, predaceous diving beetle (dytiscid) larvae (all about 1.5–2.25 cm long and of a single kind, probably *Eretes*), plus a 6-mm dytiscid diving beetle, and a 4-mm non-dytiscid diving beetle (all listed in order of abundance). In addition, 1 *Eretes* ("Charlie Brown" diving beetle) and 1 *Belastoma* adult were netted. No mosquitoes were observed.

Subsequent sampling at this site confirmed the general picture. On 17 August 2006 we sampled *Triops* (the tadpole shrimp) and found adult *Eretes* beetles extremely abundant. Libellulid dragonfly nymphs were additionally abundant at that time.

In summary, Mesquite Circle Pond had very high abundance and moderately high diversity of predatory aquatic invertebrates, along with moderately high tadpole densities. Mosquitoes were scarce: no larvae or adults were seen or heard.

2.2.6 Discussion: Evaluation and Recommendations

2.2.6.1 Numbers Salvaged and Total Anuran Abundance

The number of Couch's spadefoots collected (595) included 447 adult males, and clearly many, certainly more than 150, were left at the collection site (Rillito Area 3) based on visual observations. Assuming an equal sex ratio for the population, this suggests an adult population at Area 3 of at least 1,200. In most years, there would also likely be several hundred juveniles from previous years' breeding, so we may roughly estimate the population at around 2,000, not counting eggs, tadpoles, or metamorphs. Numerous comparable Couch's spadefoot populations occur in Tucson, including several within 2 miles of the collection site.

Previously, we estimated about 300 adults (mostly males) breeding at a single time in ditches at the north end of Columbus (P. Rosen, 26 July 2003, unpublished), which is lower than, but generally consistent with what we found during the salvage/translocation effort. Those observations did not include observations throughout the site, so even though they are low, and based on a snap estimate, they agree reasonably well with the removal observations.

During 2004-6, surveys resulted in 18 sites where Couch's spadefoot was categorized as very abundant (80-800 breeding adults seen) in developed urban and suburban Tucson. These larger choruses of adults comprised 49.77 percent of the total for estimated numbers of breeding adults observed. Using these numbers without modification produces an estimate of 72,339 Couch's spadefoot, not counting outlying open space such as Southlands, Avra Valley, and areas near Vail to the west and east, and not counting tadpoles or metamorphs. It is unlikely that we found over ¾ of the large choruses because of timing and access issues. A rough estimate of around 96,000 or more for the species is more reasonable. Couch's spadefoot accounted for 75.0 percent of estimated numbers of breeding adults of all species. Based on this it is reasonable to suggest there are over 100,000 anurans living in the city, with numbers peaking in the millions when tadpoles and metamorphs are present.

2.2.6.2 Level of Effort Required

In 2006, summer rains in Tucson were timely and plentiful, allowing for a relatively efficient salvage and translocation operation. We were probably able to collect and translocate about 50–65 percent of the male Couch's spadefoots at Rillito Area 3 with two people in two full nights (plus volunteer assistance on one of the nights). One night of work requires approximately 7 hours (from about 1900 hr through at least 0300 hr). This timeframe represents a best case scenario, and in more typical years, we would expect to spend more time monitoring weather conditions prior to the onset of breeding activities.

Although collection of the animals can be accomplished in a few hours, other tasks also require adequate time-budgeting: field preparation, handling, recording information, and transporting and releasing animals. The nature of the task requires that field personnel monitor weather conditions closely and remain "on-call" for fast mobilization as the amphibians emerge to breed.

For the effort at Rillito Area 3 in 2006, 14 person-hours were spent tracking storms, performing site reconnaissance to assess field conditions and determine if breeding had occurred, processing communications, and other miscellaneous activities. In total (exclusive of permitting, scope development, planning, and acquiring equipment) the salvage work required roughly 50 person-hours. It should also be noted that the site-specific knowledge required to conduct this work efficiently was developed over several years; more time would be required if the team were not as familiar with the site. Similar results could require as many as 75 person-hours, depending on additional preparation needs, site familiarity, and/or cooperation of weather conditions.

Even with this level of effort, the result was less than optimal. Not all the males were collected, and a doubling of effort would be required to capture the majority of them. Meanwhile, the females moved into the breeding chorus in a relative trickle, where they produced eggs and left promptly. Even though we attempted to preferentially catch females we captured 2.8 males per female. We suspect it would require a quadrupling of effort to collect most of the adult females, and not all females may actually breed every year.

Monitoring was performed opportunistically, and for this project comprised approximately 12 hours. This seemed inadequate and we estimate that approximately 32 hours would have been more appropriate. Therefore, in total, it is plausible to budget 110 person-hours for a salvage and translocation project with similar circumstances. A quadrupling of the collecting effort to catch a greater number of females would add about 80 person-hours, for a total of 190 person-hours.

While our work intensity was probably adequate for Couch’s spadefoot, it was more difficult to obtain other species, which are less tightly timed to the first rains. We found that collecting tadpoles, as described above, was the most efficient means of obtaining the Mexican spadefoot for translocation. Approximately 6 hr was dedicated to this effort, beyond that recorded above. More generally, adding this component to the work would raise the estimate for total time investment to 130–210 person-hours. Using only tadpole translocation would involve much less effort, perhaps by half or more, so tadpole translocations are more time-efficient than moving adults as a means to establish new populations of desired species.

2.2.6.3 Anuran Translocation Monitoring Recommendations

The outcome of the salvage and translocation work cannot be determined without follow-up monitoring. Minimal monitoring recommendations are as follows:

Recommendations: Collection Site: Rillito Area 3

1. Monitor to determine if many adults return to breed in 2007 and 2008 and to determine if some of the un-translocated population has survived.

Recommendations: Translocation Sites: KERP and Mesquite Circle Pond

1. Continue the auditory monitoring for at least two years.

2. Continue the dipnet, carcass canvas, and metamorph-search monitoring effort for at least one more year.

3. It would be preferable to triple these projected monitoring time horizons, if feasible and useful.

4. Monitoring both KERP and Mesquite Circle Pond concurrently would not double the effort, since planning, gearing up, and travel for the two sites would cost little more than travel to just one.

2.2.6.4 Aquatic Insect Discussion and Recommendations

Several lines of evidence discussed here and in the next section indicate that current management, which is harmful to amphibians and aquatic biodiversity overall, may not be the best or only ways to minimize mosquito breeding in Tucson.

At Rillito Area 3, management over the past 5 yr or more has reduced the hydroperiod of standing water, apparently favoring the Couch's spadefoot and mosquito larvae over the mosquito-eating Mexican spadefoot and tadpole shrimp that were seen more abundantly in 2003–4 than 2005–6. Initial observations in 2003 (P. Rosen, unpublished) found tadpole shrimp but not mosquito larvae in puddle pools that had predominantly mosquito larvae and Couch's spadefoot tadpoles in 2005–6. These and other observations prompted us to examine the relationships among management, biological diversity, and mosquito breeding in standing water during the amphibian breeding season at several local sites.

At Mesquite Circle Pond on the Santa Cruz floodplain we did not observe mosquitoes of any life stage during several visits in 2006. We documented high abundance of larvae of the medium-sized predaceous diving beetle (the dytiscid *Eretes*), which can be aggressive mosquito larva predators in captivity; and we documented high abundance of the tadpole shrimp (*Triops longicaudatus*), which is a filter feeder (rather than an active predator like *Eretes*), but nonetheless consumes substantial numbers of small mosquito larvae. Other aquatic invertebrates were also abundant, and could also have been preying on or competing with mosquito larvae. It is unlikley that there was active management of mosquitoes at this site, and similar observations have been made in less detail at remote stock ponds. In this case, it is reasonable to hypothesize that both *Triops* and *Eretes* were key to mosquito control, consistent with what has been seen at remote ponds.

Recommendations:

1. Evaluate the potential effectiveness of natural mosquito control provided by mosquito-eating anurans, aquatic crustaceans, and insects using:

   a. Non-urban stock ponds, and
   b. Laboratory and large-scale microcosm experiments utilizing species potentially viable in the city.

2. Model and monitor the hydroperiod behavior of sites that support these mosquito-eating species.
3. Evaluate impacts of efforts to avoid standing water on the aquatic invertebrate community in the city.
4. Apply these findings to places like Area 3, KERP, and others.

These problems are discussed further below.

2.2.6.5 Suitability of Sites as Translocation Targets

Aquatic invertebrates were very abundant at KERP, and we suspect that not all the native anurans could thrive with the predation pressure this entails. The Mesquite Circle Pond and West Branch areas appeared more advantageous for the Mexican spadefoot and Great Plains narrow-mouthed toad.

a. Mesquite Circle Pond

Mesquite Circle Pond, which is on publicly owned land, appeared to be suitable for the species already established there (Couch's spadefoot, Great Plains toad). The hydroperiod after filling may be about 15–20 days, so if more than a single rainfall event occurred during a two-week period, there would be adequate time for most of Tucson's anurans to reach metamorphosis. Couch's spadefoot also were breeding successfully in numerous puddle pools within a 0.25-mile radius. The environs of the pond support small stands of mesquite trees, but in general are barren compared to most areas that support abundant anurans. Monitoring is needed to determine whether the Mexican spadefoot and narrow-mouthed toad become established.

The site could be substantially enhanced by: (1) installing a headgate to increase and regulated the depth of filling; (2) analyzing the environs to optimize runoff delivery to the pond; and (3) encouraging recruitment or planting new perennial plants to enrich the terrestrial environment.

b. KERP

This site had less ephemeral water than desirable for spadefoots, and more small predatory aquatic insects than optimal for other anurans such as the Great Plains toad and Sonoran Desert toad. Short-term and long-term site suitability for the anurans now living there is questionable, especially for Couch's spadefoot, and should be evaluated by monitoring.

The underlying issue is that the hydroperiod at KERP is longer than optimal for most of Tucson's anurans. However, the site appears to be optimal for the lowland leopard frog and small mosquito-eating fish like the Gila topminnow (which would essentially eliminate mosquito problems in the perennial waters of the basin). Another species of interest that may be ideal for KERP is the Southwestern Woodhouse toad, *Bufo woodhousii australis*. This species was extirpated from Tucson, but can breed in ponds and streams with aquatic insects and small fish. All three species—lowland leopard frog, Woodhouse toad, and Gila topminnow—are readily available with suitable genetic stock. Their addition to KERP could be part of a program to increase the animal diversity at the site.

3.0 Mosquitoes, Hydroperiod, and Urban Habitat Conservation

3.1 Introduction

Many people have a generally good regard for anurans, and relatively few have negative or hostile feelings toward them. Many would generally support or at least not oppose inexpensive anuran conservation projects within Tucson. The principal problem for the summer-breeding toads in Tucson is that they must breed in standing water that is normally fish-free and can potentially be habitat for mosquito larvae. Under some conditions, fishless waters produce tremendous numbers of mosquitoes, which can then disperse far enough to affect people. Even with predatory native fish (e.g., Gila topminnow, desert pupfish, longfin dace, Gila chub), standing water may produce mosquitoes, although not regularly, and in very low abundance.

People may react strongly and negatively to water perceived as mosquito breeding habitat within the city, even when the actual threat is insignificant. Thus, both real health issues and citizen perception of mosquito problems are critical issues facing anuran conservation within the city. The problem is both scientific and sociopolitical. First, we need adequate factual information on mosquito ecology and public health.

The public health issue has three primary aspects:

- The kinds of mosquitoes and the diseases they carry;
- The distance of breeding pools from people and the dispersal distances of mosquitoes from these breeding pools; and

- The abundance of maturing mosquito larvae under varied ecological conditions.

Together, these factors determine the potential for diseases to be present in the mosquitoes and the potential for people to be infected.

Hydroperiod of standing waters is a principal determinant of the kinds of mosquitoes likely to be present. The community of mosquito predators—species composition, abundance, and timing of colonization and population cycling—is likely to play the principal role determining mosquito abundance. If mosquito species and abundance can be understood and managed, public policy could permit amphibian breeding habitat to remain within the urban landscape. Under these conditions, public education could succeed in generating solid support for management and conservation of anurans in the city.

3.2 Mosquitoes

The nexus of anuran breeding waters to mosquitoes, public health, and nuisance issues complicates the prospect for urban amphibian conservation. In a wetter climate (e.g., Ostergaard and Richter 2001), managers might be forced to rely on fish to manage mosquitoes, which can be expected to dramatically reduce (but not entirely eliminate) amphibians. The approach may be different in arid regions, where the elimination of all fishless standing water is at least conceivable. Current policy attempts to reduce the hydroperiod of standing floodwaters to $\leq$3 days, which would theoretically preclude successful mosquito breeding, and also would certainly prevent successful reproduction of amphibians.

3.2.1 Regional Mosquitoes and Mosquito Issues

There are about 174 taxa of mosquitoes in North America north of Mexico (Darsie and Ward 2005) and about 48 species in Arizona (Darsie and Ward 2005; Willott 2003). A majority of the Arizona species occur in the Tucson region, and twenty Arizona species are known carriers of West Nile Virus (WNV; CDC 2005) (Table 5). Not all species that might carry WNV have been adequately tested, so there may be additional carrier species here.

Species ecology is critical for public health issues. Carriers of WNV must bite birds, and to transmit disease to people the species must also bite mammals often and be abundant around people. An individual mosquito must bite an infected bird, become infected itself, and then bite a person to transmit WNV. These factors point to mosquitoes in the genus *Culex* as the key vector.

TABLE 5

MOSQUITO SPECIES KNOWN FROM ARIZONA AND PIMA COUNTY, AND CONFIRMED POSITIVE FOR WEST NILE VIRUS ACCORDING TO CDC (2005)

Species	Present in Pima Co.	WNV+	Annotations	Breeding Habitat
Aedes aegypti	Y	Y		R
(Aedes cinereus)	na	N	Probably extralimital (mapped by D)	(unk)
Aedes vexans	Y	Y		OFIe
(Anopheles barberi)	na	N	Not in AZ - listed in W,M	TR
Anopheles franciscanus	Y	Y		OPSRpe
Anopheles freeborni	Y	Y	Previously listed, Syn. of *An. hermsi*?	Pp
(Anopheles hermsi)	na	N	Not in AZ - previously listed	ODPp
Anopheles judithae	Y	N	Syn. of *Anopheles hermsi* (part)?	Tp
(Anopheles punctipennis)	na	N	Tabled, not mapped by D	POSRp
(Coquillettidia perturbans)	na	N	Tabled, not mapped by D	(unk)
Culex apicalis	Y	N		PSp
Culex arizonensis	Y	N		S
Culex coronator	Y	Y		FOR
Culex erythrothorax	Y	Y		POp
Culex nigripalpus	N	Y		RIOPpe
Culex peus	Y	Y	Not listed by W, reason unknown	OPRD
Culex quinquefasciatus	Y	Y		DORPSIpe
(Culex restuans)	na	N	Tabled, not mapped by D; listed in W,M	DPSOR
(Culex stigmatosoma)	na	na	Syn. of *Cx. peus*	
Culex tarsalis	Y	Y		DORPSIpe
Culex territans	Y	Y		SPp
Culex thriambus	Y	Y		S
Culiseta incidens	Y	N		OPDSRpe
Culiseta inornata	Y	Y		PIFR
Culiseta particeps	Y	N		O
(Ochlerotatus atropalpus)	na	N	Not mapped, listed questionable by W	Se
Ochlerotatus burgeri	N	N	(nr. kompi in McDonald et al, 1973)	T
Ochlerotatus cataphylla	N	N		M
Ochlerotatus dorsalis	Y	N		Fie
Ochlerotatus epactius	Y	N	Not listed by W, reason unknown	(unk)
Ochlerotatus fitchii	N	N		PS
Ochlerotatus hexadontis	N	N	Tabled, not mapped by D	(unk)
Ochlerotatus implicatus	N	N	Not listed by W, reason unknown	(unk)
Ochlerotatus increpitus	N	N	Not listed by W, reason unknown	(unk)
Ochlerotatus monticola	Y	N		T
Ochlerotatus muelleri	Y	N		(unk)
Ochlerotatus nigromaculis	N	N		MI
Ochlerotatus papago	Y	N		T
Ochlerotatus pullatus	Y	N	Syn. of *Oc. purpureipes*	T
Ochlerotatus schizopinax	N	N	Possibly extralimital	(unk)
Ochlerotatus sollicitans	N	N		saltmarsh

TABLE 5
MOSQUITO SPECIES KNOWN FROM ARIZONA AND PIMA COUNTY, AND CONFIRMED POSITIVE FOR WEST NILE VIRUS ACCORDING TO CDC (2005)
(CONT.)

Species	Present in Pima Co.	WNV+	Annotations	Breeding Habitat
Ochlerotatus taeniorhynchus	N	N		saltmarsh
Ochlerotatus thelctor	Y	N		FOIe
Ochlerotatus trivittatus	Y	N	"(infirmatus. misidentification in Arnell, 1976?)"	FOe
Ochlerotatus varipalpus	Y	N		TR
Ochlerotatus ventrovittis	N	N		O(mtn)e
Orthopodomyia kummi	N	N		TRp?
Orthopodomyia signifera	Y	Y		TRp
Psorophora columbiae	Y	Y	"and subspecies confinnis"	FOPIe
Psorophora discolor	Y	N		OSI
Psorophora howardii	Y	Y		OI
Psorophora signipennis	Y	N		Oe
Toxorhynchites moctezuma	N	N	As "moctezume" in W	TRp
Uranotaenia anhydor	N	N		p?
Total Arizona species	46			
Total Pima Co. species	31			
Total WNV +		16		
WNV + in Pima Co.		15		

Sources, in order of authority are Darsie and Ward (2003; D; maps, tables), Willott (2003; W), Kingsley and Llewellyn (2005) and Kingsley (2002; K; highest weight for occurrence in-county), and McDonald et al. (1973; M). Species in parentheses are considered not present in Arizona, but are listed by some of the sources. Annotations from previous lists are in quotation marks. Breeding habitat categories are given as P, S, M, I, O, or F (pond, stream, meadow, irrigation overflow, pools, or floodplain), D (decompositional or stagnant pools), R (small receptacles), T (treeholes), and "p" or "e" (perennial/long-lived or ephemeral/short-lived), with the order reflecting degree of association.

Although many sources report that mosquitoes in the genus *Culex* are the main carriers of WNV, CDC reports positive WNV tests for 60 species in 10 mosquito genera. According to National Biological Information Infrastructure (NBII) Wildlife Disease Information Node:

> The most common carrier of West Nile is the *Culex pipiens* (Northern house mosquito). Other carriers include *Culex restuans, Aedes albopictus, Culex quinquefasciatus* (Southern house mosquito), and *Aedes vexans*.

Of these species, the last two listed are likely of great importance in Tucson. The species of regional concern include: the western encephalitis mosquito (*Culex tarsalis*), which is also found near people; the southern house mosquito (*Culex quinquefasciatus*), which is abundant around Tucson homes along with the yellow fever mosquito (*Aedes aegypti*, which is not frequently a WNV carrier); and the floodwater mosquito (*Aedes vexans*) which prefers briefly flooded meadows and is reported to achieve larval densities of 100 million/hectare. The floodwater mosquito feeds only secondarily on birds, but may be strongly attracted to humans (Andreadis et al. 2004), and is a potential vector for WNV (Gingrich and Williams 2005), second primarily to species of *Culex* (Kilpatrick et al. 2005). Among the WNV carriers, the floodwater mosquito and the dark ricefield mosquito (*Psorophora columbiae*) are probably among the main beneficiaries of detention and retention basins in Tucson that are too shallow to support a diversity of predatory aquatic animals (see below).

3.2.2 Mosquito Dispersal Distances

Mosquitoes are not strong fliers and are highly vulnerable to predation by birds and bats when they do fly to disperse. Nonetheless, dispersal from breeding sites is normal, and may extend further than expected. Mosquitoes can be wafted in wind currents, and females (which must bite to obtain the blood meal they require for egg production) may disperse over significant distances if a food source is not close to their breeding site. Dispersal varies among different species and genera of mosquitoes, with measured maxima for species varying at least from 2.5 to 22 km (summarized in Becker et al. 2003). These distances imply that at least some mosquitoes will essentially always be present in cities.

Many species present in Tucson have been reported to fly at least 0.6–1 km (0.4–0.6 mi)/night (Schreiber et al. 1988; Reisen et al. 1991), with maximal dispersal distances often given in the range of 3-8 km (2–5 mi) (summarized by Kingsley 2002). One important species in Tucson, the floodwater mosquito, is reported to fly as much as 1 km (0.62 mi)/night and to disperse up to 15 km (10 mi) (see Becker et al. 2003; but see below). In contrast, the yellow fever mosquito (*Aedes aegypti*), an Old World exotic that became re-established in 1994 in Tucson after a 4-5 decade hiatus (Engelthaler et al. 1997), is generally found to disperse no more than several hundred meters (Harrington et al. 2005). It lives in common backyard water-holding receptacles, so despite its relatively limited dispersal it is one of the most common mosquitoes biting Tucsonans; and although it is not known as an important WNV vector, it is notorious for transmission of dengue fever as well as its namesake.

Other reports often place mosquito dispersal at much greater distances (see Becker et al. 2003, and, e.g., Kramer et al. 1995; Bryan et al. 1992). Although *Aedes aegypti* is sedentary, one study found dispersal to 2.5 km (1.75 mi) (Wolfinsohn and Galun 1953). Mosquitoes of more immediate local health concern for WNV (*Culex* species [Reisen and Lothrop 1995; Reisen et al. 1991; Tietze et al. 2003; Walton et al. 1999], *Aedes vexans*, and others; Becker et al. 2003) or other forms of encephalitis and, potentially, malaria (e.g., *Anopheles* species [Cho et al. 2002]) have regularly been reported to disperse greater distances. What these distance values mean in practical terms is not immediately obvious.

Actual dispersal is best envisioned as analogous to the brightness of light or loudness of sound. In its most simple form, this process follows an inverse-square probability density function, which is densest adjoining the breeding site and falls off rapidly with distance moved away from the breeding source. Both the intensity of mosquito presence near the breeding site and the chance that one or a few will be experienced by a person at a great distance from the site are strongly affected by the production of adults at the breeding site. (Analogously, the louder the sound, the further you can hear it, but as you move away, the loudness decreases much faster than your distance increases.)

Although the literature indicates that this “model” of dispersal processes can be modified significantly by things like wind and the availability of prey for a blood meal, everyday experience indicates that this simple inverse-square model is usefully applicable in reality. If you are near a major mosquito breeding site, the experience is intense, but move away a few score meters and it diminishes tremendously. As an example, Harrington et al. (2005; Figure 16) presented the following figure summarizing the dispersal of *Aedes aegypti*, indicating that most dispersal is limited to about 122 m (133 yards), or under 2/3 of a typical city block, especially for females:

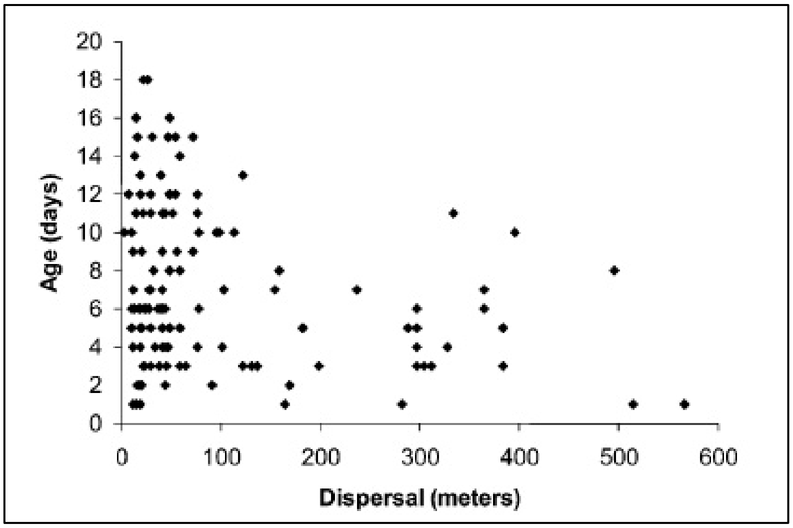


Figure 16. Dispersal of flying yellow fever mosquitoes in a Thailand study, as indicated by age since emergence. This graphic is a reproduction of Figure. 6 in Harrington et al. (2005).

It is also of interest to compare large estimates for maximum and long-distance dispersal in the literature for *Culex* mosquitoes and *Aedes vexans* (as cited above) with data reported by Ba et al. (2005) over 12 days (Figure 17):

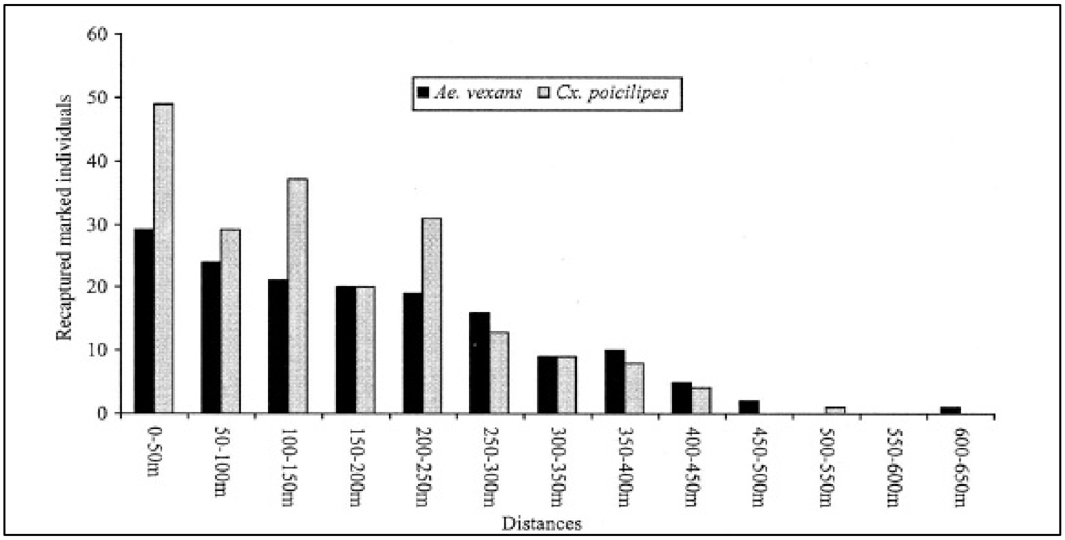


Figure 17. Number of floodwater mosquitoes and *Culex* recaptured as a function of dispersal from a release site. Reproduced from Figure 2 of Ba et al. (2005)

As with the data for the usual movements of *Aedes aegypti*, these results suggest that the greatest proportion of dispersal is far less than maximum values measured, usually under 450 m (0.3 mi) rather than several km. Thus, maximum dispersal values reported for mosquitoes should be interpreted carefully and in context; they are most directly relevant to site colonization but less so to overall abundance, direct public health, and nuisance issues.

Although anuran sites with small numbers of mosquitoes in very close proximity to homes will likely add noticeably to people's annoyance and, perhaps, risk, the literature suggests that impacts would be very limited at distances ≥0.5 km [0.3 mi]).

In the urban context, few existing or potential anuran breeding sites are more than 250–300 m (about 0.15–0.2 mi) from residential areas. This suggests that if these breeding sites are not prevented from producing mosquitoes, people would be at least somewhat affected. If anurans are to be preserved in newly urbanized parts of the Tucson region, preserving bottomlands about 0.9–1 km (0.5–0.6 mi) across would provide a partial distance barrier to mosquito impacts.

Detention and retention basins are mostly within 500 m (0.3 mi) of residences. We observed that they often consist of broad areas with shallow water and short hydroperiods that supported mosquitoes but few of their predators or competitors during surveys in 2006. Some of these sites would likely generate fewer mosquitoes if they were re-designed to have longer hydroperiods and support species that prey on or compete with mosquitoes. Details are provided in the following sections.

3.3 Hydroperiod and Anurans

Section 1.0 presented estimates for the hydroperiod required by each anuran species for development from egg to tadpole to metamorphosis. Without sufficient hydroperiod, species will be extirpated. The shorter the maximum hydroperiod in an area, the fewer species of anurans present.

Short hydroperiod waters, which last for a few to several days after a heavy rainfall, are abundant on valley-bottom flats, and many support Couch's spadefoot, occasionally even in completely channelized concrete drainages. In some detention basins, the broad grassy floor of the basin also supports a short hydroperiod, and some of these sites may permit abundant proliferation of floodwater mosquitoes (see below, and Table 2 above).

Longer hydroperiods are found in deeper scour pools, such as those at the foot of grade control structures in Pantano Wash (Figure 14), or at man-made ponds, like the one at West Branch on the Padilla property. Up to five or six anuran species may occur in these sites. Larger ponds with longer hydroperiods, which in many years may last through the foresummer drought, are important sites for the Sonoran Desert toad and are also used by other species.

Perennial waters often have fishes—many of which completely extinguish toad tadpole survivorship—or high densities of predatory insects—which are believed to reduce but usually not eliminate tadpole survival.

3.3.1 Observations on Hydroperiod, Aquatic Communities, and Mosquitoes

Although there is considerable information on mosquito occurrence, including in the Tucson region, there is a lack of specificity. In particular, the literature does not sufficiently distinguish larval sources – which ultimately determine mosquito abundance – from sites where concentrations of adults are detected. Available larval data, including authoritative published summaries, are indicative do not guarantee we can adequately translate general knowledge to the local sites and regional environments that specifically concern us here. Therefore, observations from the Tucson region are presented here, with the caveat that more quantitative and taxonomically focused information is required.

The same hydroperiod-habitat gradient that affects anuran communities also affects aquatic insects. Minimum mosquito larvae developmental periods for some species are slightly faster than for the fastest developing tadpoles (Couch's spadefoot, at $\geq$7.5 days).

Most anurans and most predatory aquatic invertebrates have life cycles or larval periods significantly longer than those of mosquitoes. A generalized picture is that short-lasting waters (4–10 days) often support dense populations of mosquito larvae. Longer lasting waters can also support mosquitoes, especially if the water is polluted, fetid, and anoxic, but the published literature suggests that invertebrate predators can reduce mosquito abundance to low levels. Our experience is that the abundance of flying mosquitoes is usually low at sites with longer hydroperiods and healthy aquatic insect populations. However, a thorough evaluation is needed.

Although aquatic ecosystems completely dominated by small fish like topminnows normally *produce* essentially no mosquitoes, they may *attract* mosquitoes by providing a moist, shady environment. Fishless waters tend to be dominated by aquatic invertebrates that would tend to be eliminated by fish. The published literature contains a substantial number of examples in which assemblages of aquatic invertebrates severely depress the abundance of mosquito larvae. Microcosm experiments in and near Tucson have revealed a complete suppression of mosquito breeding in fishless tanks with abundant notonectids (backswimmers—P. Rosen unpublished).

There is a successional progression of aquatic species in fish-free biotic communities in the Tucson region. Upon filling, these waters may be rapidly colonized by mosquitoes and other small flying dipterans (the order of flies, mosquitoes, midges, and gnats – Diptera). In addition, bacteria, protozoa, and algae lying dormant may be immediately activated. In deeper pools, toads may deposit eggs immediately, and dormant eggs of crustaceans like tadpole shrimp, fairy shrimp, and clam shrimp rapidly hatch. The initial stage in succession is presumably set by previous years' history, determining the kinds and amounts of eggs and spores lying dormant, as well as the kinds of adult animals in the area that are likely to arrive early and deposit eggs or take up residence. Details of mosquito production in these initial successional stages have not been scientifically evaluated with respect to hydroperiod and aquatic community structure.

Our observations indicate that shallow water (only a few inches) with abundant newly submerged grass can produce huge numbers of mosquitoes. These sites generally have few toads reaching metamorphosis, no predatory tadpoles, and few or no predatory insects or crustaceans. Constructing retention basins with sloping floors to convey water down to a deeper area with a longer hydroperiod might provide more effective for mosquito control than current attempts to limit the hydroperiod to ≤3 days.

Deeper pools and puddles, even muddy puddles in dirt roads made by trucks and off-road vehicles, support more tadpoles and crustaceans, and many fewer mosquito larvae. Nonetheless, many of these short-lived waters produce at least some mosquitoes. These are the most numerous anuran breeding sites in the Tucson region, and the principle species that thrives in them is Couch's spadefoot, with its rapid larval development.

For rainpool waters with longer hydroperiods, successional processes are rapid, and different communities result (Figure 18). Adult insects fly in and deposit eggs, producing ecologically important larvae, which in turn become adults with wings that can escape as desiccation proceeds. If the Mexican spadefoot is present, it may produce eggs right after the pool fills, and the tadpoles may hatch at or rapidly achieve a size at which they consume mosquito larvae (up to 99 or more per night; P. Rosen, unpublished). Over several days, tadpole shrimp hatch and grow to sizes at which they eat smaller (1st and 2nd instar) mosquito larvae, and over a few weeks additional generations of tadpole shrimp are produced (Figure 19). The community structure apparently is heavily influenced by predatory species, many of which actively consume large numbers of mosquito larvae. These ponds typically have very few or no mosquito larvae present, but more rigorous observations are essential to rigorously evaluate this key matter.

Even in waters with small fish, which are the most effective biological control for mosquitoes, it is often possible to find a few mosquito larvae if enough effort is made. There is little reasonable expectation that anuran breeding waters could be designed to never produce any mosquitoes, but the available evidence strongly suggests that mosquito problems can be minimized with biological control by native species of fishes, crustaceans, insects, and toad tadpoles. Learning how to accomplish this in an urban setting remains a challenge.

At intermediate hydroperiods or successional stages of the temporary water aquatic ecosystem, deeper pools usually produce few mosquitoes. However, in secondary and tertiary washes, water depths vary locally, and where there are deeper pools there are often shallower ones, with few predators, where small swarms of mosquitoes can develop. Under these conditions, some mosquitoes will be produced, and if people live within 50–100 meters they are likely to be affected at least somewhat. In designed ponds or pools (see Section 4), this could potentially be avoided.

Fishless waters that are long-lived (a few to several months, or permanent) normally sustain sufficient populations of predatory insects so that few mosquitoes are produced, and the potential for human health problems arises infrequently.

Therefore, the most important waters for amphibian abundance and diversity in Tucson, which would have average hydroperiods of about one month to one year will likely produce some, but not many mosquitoes, particularly if they were designed to support desired species.

While it is theoretically possible to reduce hydroperiods to eliminate all breeding by mosquitoes in the flood control infrastructure, our observations suggest that in practice this approach still permits large mosquito populations to develop. Further, most mosquito problems in the city probably originate in fountains, untended swimming pools, discarded tires, potted plant saucers, and other domestic standing waters. An alternative approach that would preserve biodiversity would involve careful design of waters with longer hydroperiods, allowing rich predator assemblages to minimize mosquito abundance and permit amphibians to thrive.

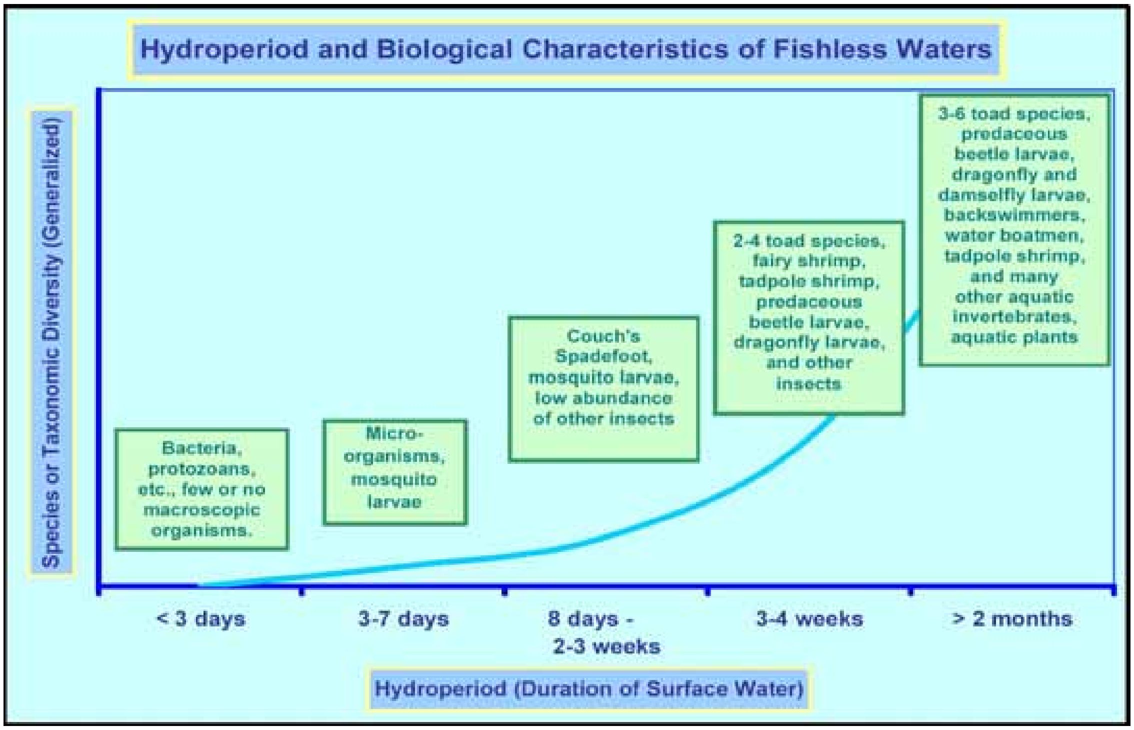


Figure 18. Tucson area temporary pool and pond communities in relation to hydroperiod. This diagram represents existing communities found in pools that usually have approximately the hydroperiods shown. It does not imply that the successional development of the animal community in an individual pool of water would go through the stages shown over time, although in some aspects that can occur.

Figure 19. A tadpole shrimp (a crustacean, Triops longicaudatus, left) and a predaceous diving beetle (an insect, Eretes sticticus, right), two predatory aquatic invertebrates that eat many mosquito larvae in the Tucson region.

Local flood control infrastructure, especially retention (flood holding) and detention (flood attenuating), basins and overbank flood storage areas, would be an appropriate arena for some of the necessary applied research to occur. This could involve:

- Design and construction (or selection) of study locations with desired hydroperiod conditions;
- Establishment of a desirable animals assemblage to support desired ecosystem processes and outcomes;
- Monitoring of mosquito larvae and other animal populations in the water, as well as flying mosquitoes;
- Comparison of results to other flood control sites; and
- Detailed observations at reference sites exemplifying unmanaged mosquito control, such as floodplains and stock ponds in Altar Valley and Tucson Southlands.

3.3.2 The Literature on Mosquito Control in Fishless Waters

In spite of the clear evidence that mosquito reproduction is, or at least can be minimal in waters with well-developed aquatic invertebrate populations (see e.g., Bay 1974; Walton 2001; Becker et al. 2003), there remains a common perception that:

> “There are no effective avian, mammalian, amphibian, reptilian, or insect predators that will provide natural or biological control of mosquito populations. There are species of these predators that will feed on mosquito larvae and adults but not to the extent that they will control the population.“ http://www.michigan.gov/emergingdiseases/

Perhaps this perception correctly describes what happens in some regions or at some times, or perhaps it is a misperception based on inadequate management and the presence of fetid or short-hydroperiod waters, or an artificial dearth of aquatic predators.

Natural biological control of mosquitoes primarily includes predation, although competition must also play a role. The use of bacterial biocontrol of mosquito larvae using *Bacillus thuringensis* (“*Bt*”) and *Bacillus sphaericus* (“*Bs*”), which are recent, effective adjuncts for mosquito control, will not be discussed in detail here. These methods require ongoing monitoring and management without, in themselves, contributing to biodiversity. If we can establish reasonable controls with minimal maintenance using self-sustaining natural biodiversity, management might be reduced, and *Bt* or chemical methods could be used supplementally as needed.

Evidence suggests that incomplete control of mosquitoes by insect predators (Stout 1982) reflects ecological limitations that could be overcome by habitat design and assembly of urban ecological communities. Although the control of mosquito larva abundance by predatory aquatic insects and other invertebrates has been described for some decades (summarized in Becker et al. 2003), practical progress in capitalizing on this has been slow, and applied research and testing are sorely needed (Kumar and Hwang 2006). A more in-depth consideration of the literature and direct observations in the local area are needed to clarify the situation.

3.3.3 Non-native Species

Non-native species threaten urban amphibians in two principal ways—through pre-emption of habitat for perennial-water species like leopard frogs and by temporary pre-emption of ephemeral waters close to perennial waters. The second situation is illustrated by spillover from urban fishing lakes, (e.g., Lakeside Park) of crayfish, bluegill sunfish, shade, and other species. These animals are flooded into Tucson's waterways during floods, become stranded in pools, and eventually die, but not before pre-empting the breeding habitat of native anurans and aquatic insect. This situation also exists in Arroyo Chico below Randolph–Reid Park, from where mosquitofish are washed into the drainage, apparently suppressing anuran reproduction (Rosen 2006).

4.0 Amphibian Breeding Habitat Design for Ecological Restoration in Infrastructure and Parks

Amphibians are diverse and abundant in flood channels and open space lands along the major riparian corridors of urban Tucson. They have ecological and aesthetic significance, and can serve as a resource for education and recreation. Because these animals require standing water for breeding and development, ecological restoration (e.g., KERP, Rillito Riparian, Tres Rios del Norte, Paseo de Las Iglesias) and infrastructure projects provide a unique opportunity to enhance amphibian habitat. This section provides preliminary design considerations for low-maintenance, amphibian-friendly habitats that also discourage mosquito infestations and non-native invasive species.

Preliminary ideas for such habitat focus on ephemeral water situations that could promote breeding by most of the native amphibian species. One principle underlying these concepts is the use of natural processes and forces to maintain physical habitat and minimize the need for its active maintenance, including management of mosquitoes and non-native invasive species. Testing would be required to monitor biological processes in the designed habitats. Engineers, hydrologists, and biologists will need to coordinate and revise these conceptual models on a site-specific basis to ensure that they function as envisioned and do not create major maintenance and public problems.

At least four general classes of habitat settings with different problems should be considered:

- **Primary channels** of the major riparian corridors (i.e., the Pantano, Rillito, and Santa Cruz channels);
- **Higher-degree tributary channels** (e.g., Alamo Wash or Arroyo Chico);
- **Retention and detention basins** along secondary tributaries (e.g., Arroyo Chico or Julian Wash);
- **Constructed or natural ponds** on the floodplains of major riparian corridors.

Each of these categories will contain variations in habitat size, characteristics, and function. There will likely be situations that are intermediate between categories, as well. The designs proposed here do not encompass all of the possibilities. Any design that is constructed will be adapted to meet specific requirements defined by its local setting.

4.1 Guidelines and Considerations for Successful Amphibian Habitat Design

4.1.1 Mosquito Habitat

Mosquitoes and public health concerns would be at the forefront of any habitat design; the suggested approach is use a two-pronged design approach that both optimizes the presence of mosquito-controlling animals and minimizes successful breeding of mosquitoes.

In some cases this might involve creating small areas of permanent water with fish and beneficial predatory aquatic insects that could immediately occupy floodwater pools and prevent an early flush of mosquito breeding. In other cases, mosquito breeding may be of little concern, adequately limited by flood, habitat conditions, and ephemeral water animals like Mexican spadefoot tadpoles, tadpole shrimp, and the predatory larvae of insects such as dragonflies and diving beetles.

The following guidelines may help minimize mosquito problems while enhancing amphibian diversity:

- Flattened channel slopes where pooling may occur, and scour pools associated with tributary confluences and grade controls should be established at a safe distance from residential areas.

- Amphibian breeding sites should be should be in open, sunny sites, without large amounts of decaying organic matter or trash fouling the water. This will discourage mosquito presence.

- Dense grasses and other partially submerged vegetation should be avoided when mosquito predators are not present.

4.1.2 Amphibian Breeding Habitat

The following general guidelines on amphibian breeding habitat are based on preliminary observations and should be adjusted as new information becomes available:

- Amphibian diversity will be supported where hydroperiods of three or more weeks exist.

- Some amphibians will do best where hydroperiods are even longer, or where ponds may last for many months.

- Designed hydroperiods of 4-8 weeks are a reasonable target for initial projects for amphibians and mosquito-eating aquatic invertebrates.

    - Foraging habitat for juvenile frogs and toads near the breeding habitat would be desirable, but specific information regarding the Tucson region is lacking.

4.1.3 Substratum

Amphibians and beneficial aquatic insects have been found in a variety of pools, including those with natural floodplain soil bottoms, those on the sandbed of drainage channels, and even trapezoidal concrete-bottomed channels in which water pools and small amounts of sediment and debris accumulate. Although natural substrata would be generally preferable, these observations suggest that including impervious, concrete basements might be beneficial in certain instances.

4.1.4 Permanent Water

Designs that include permanent water to support small baseline populations of fish and predatory insects, should consider the following:

- Native Gila topminnow and desert pupfish feed voraciously on mosquito larvae, can tolerate high temperatures (37-47 C, depending on species and acclimation) and low oxygen, but are only moderately flood resistant.
- A USFWS Safe Harbor Agreement should be pursued to prevent potential conflicts between conservation legalities and operations requirements for endangered Gila topminnow and desert pupfish.
- Native longfin dace also feed voraciously on mosquito larvae, but are less tolerant of high temperature (33-38 C) and low oxygen, but are highly flood resistant and well adapted to small streams that flood intensively.
- Longfin dace are not endangered and can be included following consultation with the Arizona Game and Fish Department.
- Native fish can survive flood events in small refugium pools or streams, from which they would emerge to forage when waters are expanded after rainfall and flood events.
    - Refugia should be not less than 1 meter (3 feet) deep if in full sun during May–June and late summer, but can be much shallower if flowing and in partial shade. Planning should accommodate the following:
        - Total annual evaporation in the Tucson valley is about 7–8 feet, and about 0.5–1 inch per day during the hottest, driest times of year.
        - Additional water may be lost by infiltration and seepage.
        - Water may be provided artificially or maintained based on depth of filling, or both.

  - Several hundred to over a thousand fish can survive in a refugium pool of a few thousand gallons measuring around 10-feet square and varying in depth from 0.5–3 feet.

  - Design should avoid creating features that could trap and desiccate excessive numbers of fish when waters recede.

- Most predatory aquatic insects can fly as adults, but only backswimmers and some kinds of diving beetles are effective mosquito predators as adults. The other kinds are predatory as larvae (or "nymphs") which normally would develop from eggs deposited shortly after rains and floods fill breeding areas with water. There is very little experience using these animals to control mosquitoes, and research into this topic must be part of a program to design and construct amphibian breeding habitat.

4.1.5 Non-native Invasive Species

Amphibian, fish, and aquatic insect habitat may be invaded by harmful non-native invasive species such as crayfish, bullfrogs, and sport fish. The following considerations may help avoid or mitigate these problems:

- Some areas of Tucson lack bullfrogs, including most of the urban core centered on Reid Park.

- Bullfrogs are uncommon and local in most other areas of metropolitan Tucson and could be eliminated and kept out at areas like Kennedy Park and Fort Lowell Park without very much effort.

- Bullfrogs may invade ephemeral waters, but will not become established in them, and will not likely cause problems while they are present. If they invade small perennial waters, they can be removed by trapping.

- Crayfish in Tucson probably are restricted to Lakeside Park and Fort Lowell Park, and should be removed there.

- Sport fish that may be washed into conservation areas in the floodwater channels are not likely to be numerous, will be less flood resistant than native fishes, and should be removed from fish refugia as necessary. However, when sport fish are located close to and upstream from conservation areas with permanent water pools, ongoing management actions should be anticipated.

- Mosquitofish will invariably eradicate the Gila topminnow, and should be replaced with Gila topminnows in all public waters as soon as possible. Mosquitofish are somewhat less flood resistant than topminnows, but not more effective at mosquito control.

4.1.6 Scour

In in-channel scour pool habitat, natural flood scour will provide some part of the maintenance needed to eliminate exotic species and control community composition.

- Native fish and aquatic insects are more flood resistant than harmful non-natives.

- Amphibian tadpoles will readily be scoured out by successive floods, but the species in Tucson do not depend on each cohort of eggs and tadpoles surviving. Adult amphibians survive and breed over several years.

- However, excessive scour would also eradicate native fish, tadpoles, and aquatic insects. The frequency and force of scour should be optimized to permit native species to persist while minimizing habitat suitability for exotics. Particular design parameters to achieve this are currently unknown and will have to be generated as more experience is gained in this arena .

4.2 Design Scenarios

4.2.1 Primary Channel Scour Pools

The flood force in major channels can be so powerful that options are limited. However, grade controls on Pantano Wash at Broadway and between Broadway and 22nd Street (see Figure 15) provide examples that could be enhanced or replicated elsewhere. The general processes producing such pools are shown in Figure 20.

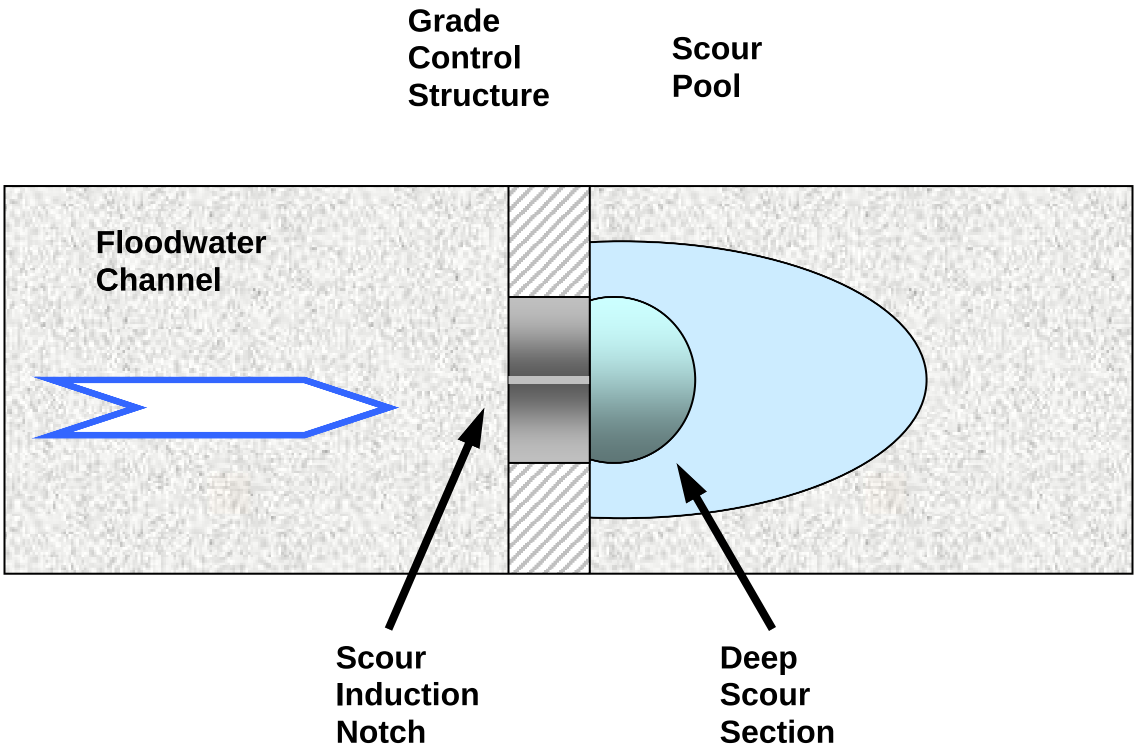


Figure 20. Base diagram showing induction of scour pool below grade control in an urban waterway. In this diagram, there is also a secondary notch, which would focus scour force and create a deep section of the scour pool.

Current management practices may involve attempts to eliminate the scour pools and kill mosquitoes at these sites, however this may be unnecessary as mosquitoes have not been observed in them. A high priority should be given to monitoring these sites for the presence of mosquitoes, invasive non-native animals from Lakeside Park, and the success of amphibian breeding. Based on results of such a study, wildlife values of these structures could be evaluated and ideas for their improvement could be generated.

Patterns of scour could be manipulated to produce pools of desired depths and locations by using hardened aprons in some areas to avoid scour and installing notches at the top of the grade control in other areas to encourage scour below, in softer substrata.

Grade control structures could be installed at angles other than 90^{o} to adjust the position and intensity of scour force. Grade control structures could also be designed so that the beginning of a flood front lands not on the deepest scour pool, which might serve as a refugium for aquatic animals, but instead is directed through a lower zone and lands elsewhere, on hard substrata that resist the formation of scour pools. Waters would then begin rising at the base of the grade control before the brunt of scour force hit animals (such as fish in a drought refugium, for example) in the deepest scour holes, allowing them to move to less turbulent sites where they could survive the flood peak. Some of these ideas are illustrated in Figure 21.

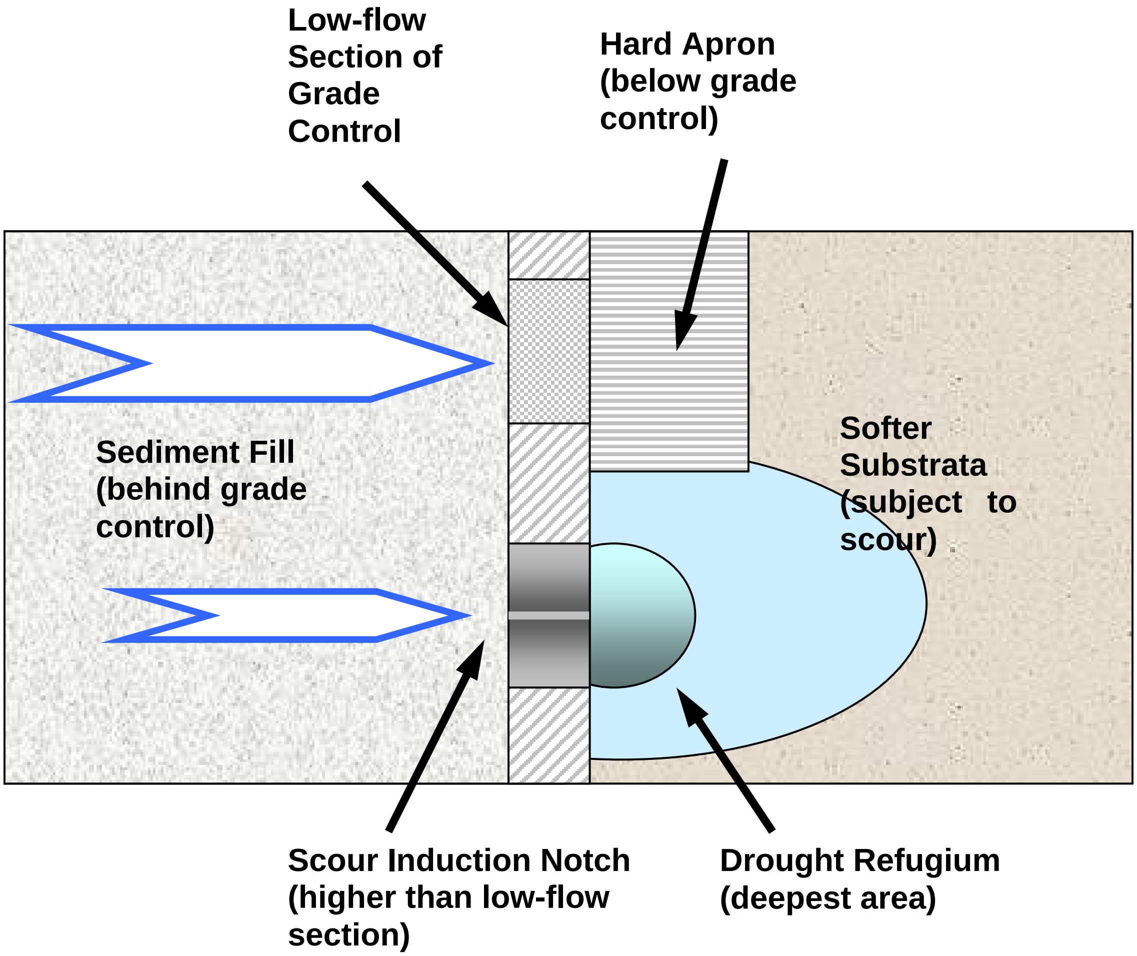


Figure 21. Modifications to a grade control that could provide benefits to aquatic wildlife, as described in text.

4.2.2 Higher-Degree Tributary Channels

The concepts diagrammed in Figures 20 and 21 apply to smaller channels as well as the primary channels of the major urban riparian areas. In smaller channels, however, flood forces are less overwhelming, and there would be lower costs of experimenting with different configurations that might be beneficial to aquatic wildlife.

It would be easier, for example, to test non-right angle or even wedge-shaped designs in secondary or tertiary urban drainages. One option that would offer protection for aquatic animals could include flood refugium designed as side-pockets partly or largely protected from the brunt of scour force. Another option would be to mimic the bouldercrevice structures found in Sabino Canyon in which, remarkably, the Gila chub apparently managed to weather the massive challenges of ash, suspended sediment, and landslides during the epic floods in recent years.

In the smaller drainages, head-gate structures might be included at the lower end of the scour pools inhabited by aquatic animals during the experimental learning phase of this potential conservation project. The structures could be removed or lowered manually after the pool filled if it became necessary to drain the pool for such reasons as eliminating mosquitoes. A head-gate structure might permit adjustment of the depth to which pools filled, in order to achieve a desired the hydroperiod. Head-gates could also be removed or lowered completely outside the amphibian breeding season. Some of these possibilities are diagrammed in Figure 22.

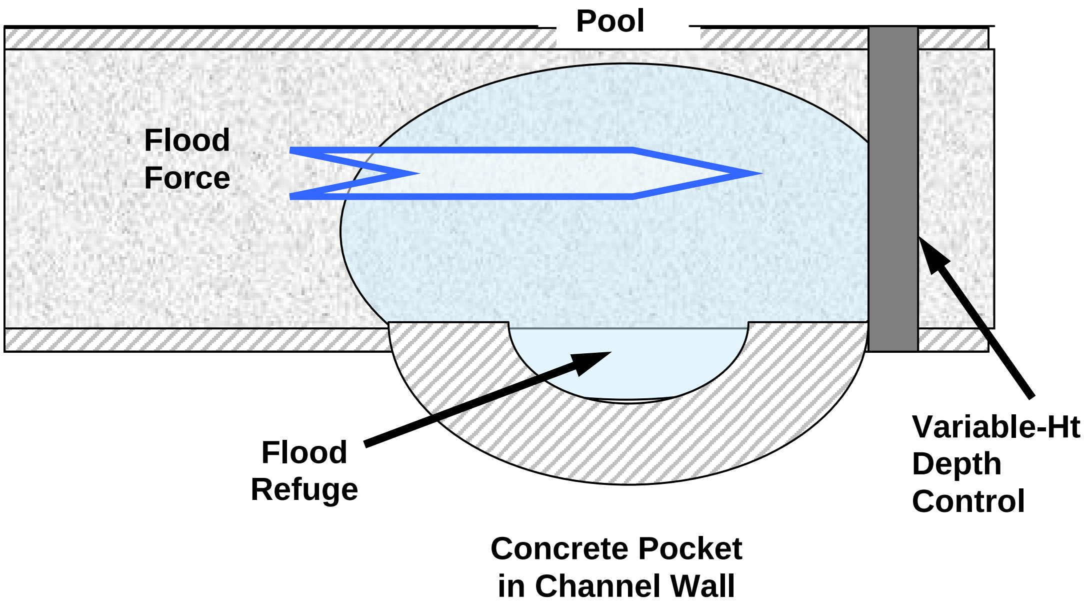


Figure 22. Options that might be utilized experimentally in smaller urban channels (see text).

4.2.3 Retention And Detention Basins

Retention basins retain floodwaters in ponds that may last for variable periods of time. Examples are the Rita Ranch Detention Basin and KERP. The Rita Ranch site is shallow, and may function as an ecological trap that attracts amphibians to breed in its large, but highly ephemeral water body. It also hosts a massive breeding population of mosquitoes. KERP contains numerous deep ponds in which toads breed, aquatic insects abound, and mosquitoes are rare. However, *Bt* is currently used to control mosquitoes there, so the impact of predatory insects on the mosquitoes has cannot be directly evaluated.

Detention basins are designed to absorb large pulses of floodwater, which are particularly characteristic of arid environments. The pulse is gradually released, with the basins designed to drain completely in 3 days or less to avoid becoming breeding habitat for mosquitoes. Examples include the Countryside Detention Basin (Figure 23) and the Massingale Detention Basin, both in the northwest part of metropolitan Tucson.

Figure 23. Countryside Detention Basin (Overton Road) in northwest Tucson, with the water detention area and sediment trap (left) with an overflow dike perforated by a culvert leading to a concrete overflow pool that functions as an apron preventing erosion (right). Water detained in the basin flows out through the shallow apron pool, where numerous tadpole shrimp, which eat mosquito larvae, and Couch's spadefoots were found in summer 2006.

In 2006, no mosquitoes were observed near the overflow of the Countryside basin, where the concrete pool may retain water long enough for beneficial invertebrates to thrive. At the Massingale basin, it appeared the natural scour that is unavoidable in the upstream half to two-thirds of the basin floor created enough breeding pools to support a substantial mosquito population, as well as a few Couch’s spadefoots. This seems to indicate that even a modern, well-engineered detention basin supports mosquitoes. Inevitably, it will be argued that creating breeding habitat for amphibians creates potential mosquito breeding habitat. To the contrary, observations suggest that similar or higher numbers of mosquitoes may result with existing designs that support few or no amphibians.

As currently designed, most retention and detention basins flood-irrigate large grassy areas that support significant to large mosquito populations as well as regionally common native mammals such as coyotes and cottontail rabbits and numerous desert-adapted birds, but few amphibians or riparian birds or reptiles. The large size and relatively abundant water supply in these basins might be utilized to increase biodiversity of amphibians by establishing local, longer-hydroperiod pools in the basins. If permanent waters with fish and predatory aquatic insects, or suitably long-hydroperiod waters with aquatic insects and predatory tadpoles and tadpole shrimp and were incorporated, this approach could possibly reduce existing mosquito problems.

Flood control basins might be managed for biodiversity without producing mosquito problems or incurring large and frequent maintenance costs, if the following, to some extent competing problems could be resolved:

- Avoid the frequent creation of short-lived waters, which could generate mosquitoes after every minor flood.

- Create and maintain deeper pools that will tend to fill during major flood events and last long enough to support beneficial insect, crustacean, or fish populations.

- Allow sediment deposition to occur away from the deeper water catchment areas (pools) so they are not continually buried, rendering them too shallow or requiring frequent maintenance.

The Countryside Detention Basin fulfills these criteria to some degree, but the created waters are small and shallow, and the biodiversity gains are limited. The concept might be scaled up as diagrammed in Figure 24. The key elements in this proposed design are:

(1) Avoid the frequent creation of short-lived waters, which could generate mosquitoes after every minor flood.

Ranch tanks often have “sediment trap” ponds that are shallow and capture sediment before the water enters the main pond, but these may create shallow, highly ephemeral water that is undesirable in urban settings. In urban retention basins it may be better to separate the functions of sediment deposition and flood scour attenuation into two distinct functional areas.

The first stage of a retention basin (the entry point; Figure 24) might consist of a fan-shaped apron of hard consolidated material or concrete that will not erode into scour holes where the concentrated flood force enters the basin inflow from the floodwater channel. As the water spreads and loses velocity as well as erosive energy, sediment deposition would begin (Stage 2 in Figure 24), but by design the hydraulic energy at this stage should be too high for accumulation and aggradation.

(2) Allow sediment deposition to occur before water reaches the deeper water catchments (the pools in Stage 3) so they are not continually buried, rendering them too shallow to support aquatic biodiversity or requiring frequent maintenance.

This second stage of the basin would consist of a broad, level, absorptive apron consisting of fairly solid material that will resist erosion into scour holes as floodwaters move from the hardened, Stage 1 apron to the absorptive and depositional Stage 2 area fan.

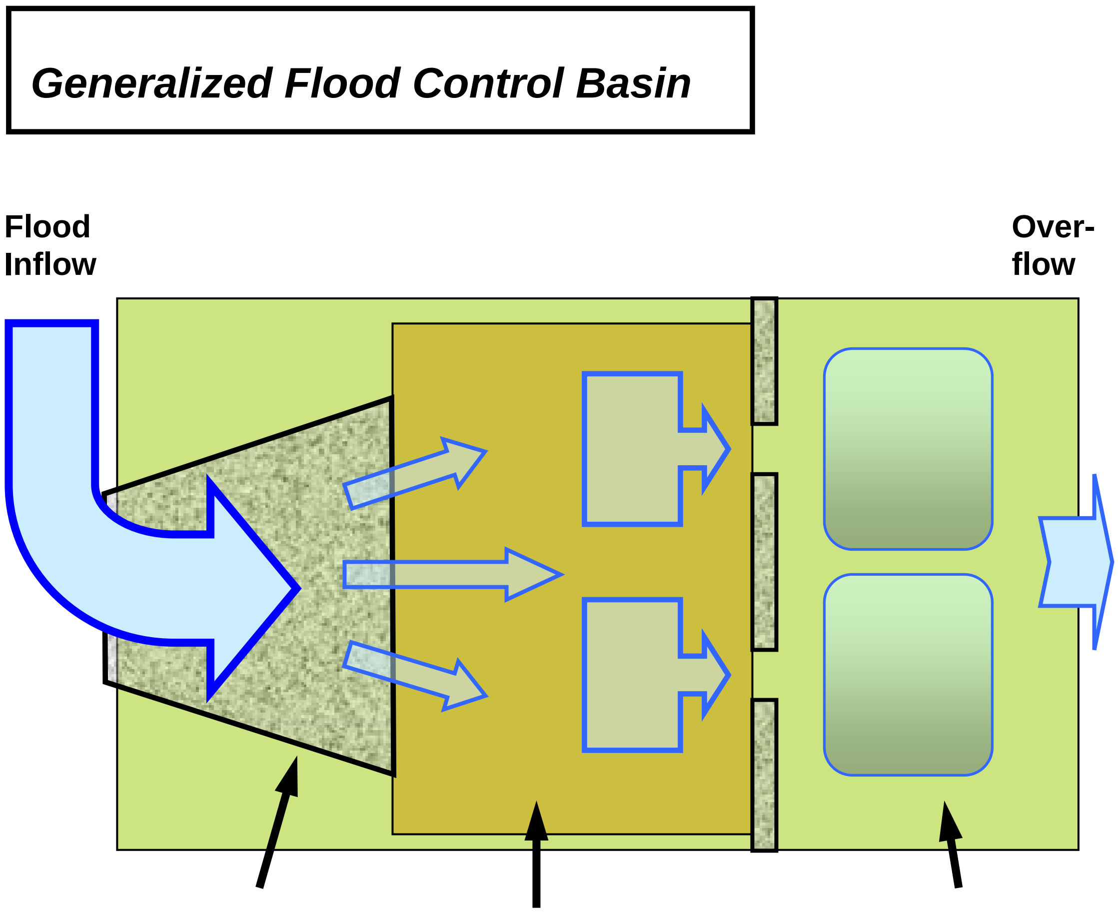
Water should completely drain slowly and directly toward and into the Stage 3 pools (see Figure 24). During low flows, it may be desirable to have all of the water absorbed by the Stage 2 fan.

(3) Create and maintain deeper pools near the outlets that will fill substantially during major flood events and last long enough to support beneficial populations of aquatic animals.

Medium to large floods would exceed the Stage 2 capacity and fill one or more deeper pools in Stage 3 (Figure 24).

The hydrological computations required to accomplish these desired outcomes require knowledge of several physical variables, including frequency distribution and timing of various rainfall amounts, the slope of the basin, hardness of apron and fan substrata, absorptive parameters of the fan and pool bottoms, seasonal evaporation rates, depth of the pools, and the amount and composition of sediment entering the basin with floodwater. Suitable hydroperiods could then be designed into the system, and an expected maintenance schedule and cost projection could be developed.

Deep pools may be established through excavation and concrete lining (e.g. Countryside Basin; Figure 23), by scour force at contact zones between harder and softer substrata, or simply by excavating a suitably large and deep “tank” like a cattle pond at the desired position. Re-excavation to eliminate sediments might be required every 10 – 30 years, as it is with many tanks on Arizona cattle ranches, but presumably any detention or retention basin would require maintenance with or without a design like that suggested in Figure 24.



Stage 1: Hardened Inflow Fan (dissipation of erosive force)

Stage 2: Shallow Collection Basin (sedimentation and infiltration zone, designed to drain toward Stage 3)

Stage 3: Deeper Collection Basin(s) (water storage, with planned hydroperiod and species)

Figure 24. Diagrammatic concept for a floodwater retention or detention basin designed to encourage the proliferation of aquatic invertebrates that reduce mosquito larva abundance while providing habitat for native amphibians that breed in summer rainpools. The optimal hydroperiod for Stage 3 collection basins remains to be determined, but they should retain water for at least 4 weeks when full.

Where feasible, water lines (reclaimed or potable) could be installed to sustain the Stage 3 pools. The pools could be used to support native fish, amphibians, and beneficial predatory aquatic insects.

If large populations of suitable and beneficial predatory aquatic insects were living in the deeper pools, the flying adults might rapidly colonize scour holes that may develop on the Stage 2 fan. This should be tested, but it might result in better mosquito control than could be achieved without the deeper pools. It is worth noting that none of the predatory aquatic invertebrates discussed here are known or suspected to be harmful to humans.

4.2.4 Existing or Constructed Floodplain Ponds

Deeper pools or ponds including cattle tanks, abandoned gravel pit ponds, or large natural scour pools support the largest and most diverse aggregations of breeding amphibians both inside and outside the metropolitan area. Some of these ponds that currently have hydroperiods less than three weeks may also support large breeding populations of mosquitoes. This suggests that they should be re-designed to support predatory animals that live in longer-lasting or perennial waters, such as backswimmers and fishes, or long-duration ephemeral waters, such as tadpole shrimp, diving beetle larvae, and dragonfly and damselfly nymphs.

The feasibility of converting these mosquito breeding areas to predatory invertebrate-dominated waters should be assessed with field observations and experimental research. This section presents a design in which native fishes might be tested in situ in one or more amphibian breeding sites at West Branch where hydroperiod has become attenuated and mosquito abundance is high. The approach would involve establishing a small perennial pool housing native predatory fishes, such as the Gila topminnow, in the bottom of the ephemeral pond (Figure 25). Flood scour would not be a consideration, but sediment deposition in the fish refuge would need to be limited or avoided. Thus, the design should include a depositional catchment area where most sediment will fall before getting near the fish refuge pool.

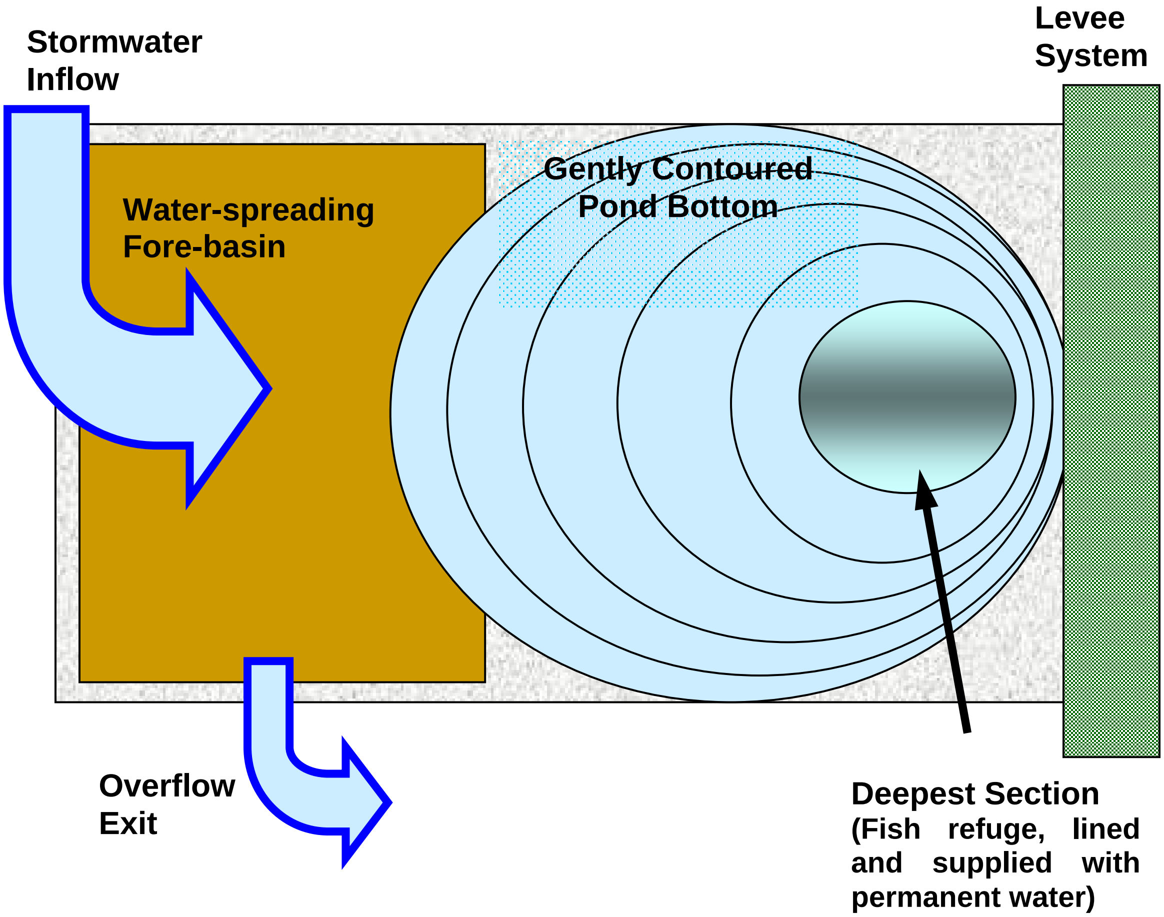


Figure 25. Diagrammatic concept for a runoff-filled, non-permanent floodplain pond that summer rainpool-breeding amphibians could utilize. It includes a small permanent-water pool to sustain Gila topminnows, which could emerge from the pool when the pond filled and prevent successful breeding by mosquitoes. Gila topminnows at the low densities in which they would populate the newly filled pond would probably have little negative impact on the amphibians, although this has not been tested. The fill-depth of the pond could be regulated by a headgate or similar structure (not shown).

In addition to avoiding accumulation of sediment and trash in the fish refugium, it would be essential to ensure positive drainage toward the perennial pool to avoid trapping fish in isolated puddles as the ephemeral water recedes. This applies to any of the design scenarios discussed here that involve fish.

The objective of this design is for the native fish, which should aggressively eat small animals but not impact tadpoles, to exist at moderate-high density in their refuge pool but at low density when they spread out into the freshly filled amphibian breeding pool. Because food would not be very plentiful in the early amphibian pool stages after a flood, and because mosquito wrigglers are extremely attractive and vulnerable to fish, it is plausible to expect that fish might control mosquitoes without seriously impacting amphibian breeding in this configuration.

4.3 Testing the Designs

If the urban habitat designs and biodiversity-based mosquito control methods outlined here are to be utilized, design concepts should be vetted by a team including engineers, hydrologists, and biologists. Designs should be tested experimentally, by observation at existing sites analogous to those that would be constructed, and by carefully monitoring small applied trials at selected locations. For the use of endangered fish, permitting issues would need to be resolved using a Safe Harbor Agreement or an existing research permit.

Field testing sites for novel methods of mosquito control, such as those employing predatory aquatic insects, should be conducted at relatively remote sites, where minor mosquito breeding, if it occurs, does not create public liability. One such site might be the Kolb Road Detention Basin, northwest of Rita Ranch.

The Kolb Road site may be appropriate for a replicated experimental approach using small, 300 gallon water tanks as model ecosystems. If effective control of mosquitoes can be achieved experimentally at a remote site, testing could be extended into the urban area itself, to see how lighting (which might have an impact on night-flying adults of aquatic insects, for example) and a different suite of species (e.g., more grackles, raccoons, etc.) might affect outcomes.

Experiments alone cannot provide the answers needed. Monitoring of natural systems will be necessary to understand the processes affecting mosquito larvae under the impact of predation. This should occur at key existing urban sites such as the grade controls on Pantano Wash, pools and ponds near West Branch, and the detention and retention basins discussed in this report. A greater range of information should also be obtained by extending a monitoring-observational study to a selected set of earthen stock ponds, such as in the Tucson Southlands region, Buenos Aires NWR, or elsewhere.

Some of the key biological questions that should be addressed are discussed below in Part V. Fundamentally, we need to learn how effectively mosquito control can be achieved in ways that are compatible with amphibian breeding. This represents a novel attempt to design integrated pest management (IPM) approaches for urban mosquito control to benefit public health and biodiversity conservation.

5.0. Monitoring Methods and Information Needs

5.1 Monitoring Methods for Amphibian Salvage and Translocation

5.1.1 Adequate Proportion Salvaged

Observations in 2006 during the Rillito Area 3 salvage effort indicated that most likely over half the adult spadefoots were salvaged. The site should be re-monitored during the peak of toad breeding in 2008; heavy construction will have been completed for approximately 8 months at that time.

5.1.2 Fate of Non-salvaged Individuals

Re-monitoring during the first summer breeding seasons after the heavy equipment and other work has been done on the site (2008) will provide an indication of how severe the impact of the work was, and whether salvage might be a beneficial undertaking for other projects. The method to be used would be as in 2006—tracking storms and visiting the site to make visual and dipnet observations—but without capture and translocation. Some previously monitored areas not subject to heavy equipment work should be simultaneously re-monitored as calibration, in view of natural variation independent of the restoration work.

5.1.3 Outcome of Translocations

Two release sites should be monitored, KERP and Mesquite Circle Pond at Santa Cruz Lane. In both cases, adult populations would be monitored during the summer of 2008 by seeking breeding choruses after suitable rains, as described above.

At both sites, monitoring should also focus on locating late-stage tadpoles at low water or large pulses of metamorphs of the translocated species starting about 3.5 weeks after breeding rains.

This monitoring at KERP should be supplemented by counts of carcasses found at the mouths of the artificial burrows of burrowing owls two or three times during the first year to see if and when carcasses are rapidly accumulating. During our initial efforts, this activity required only 2–4 hours of time, including travel.

5.2 Other Information Needs

Including amphibian conservation in modern ecological restoration in urban contexts presents challenges in infrastructure design and construction. There are large gaps in each part of the biological knowledge base needed to develop and implement cost-effective programs. Some of the broad research needs are enumerated in Section 3.0 of this report. Here, basic issues requiring study and resolution are outlined.

5.2.1 Mosquitoes

The most immediate need is to obtain a firm grasp of mosquito problems associated with surface water in the city:

Which species of mosquitoes occur as larvae and in what abundance?

- In what sequence following initial pool filling?
- In what macro-environments (natural pools, stock ponds, flood basins, etc.)?
- What is the relationship between larval abundance and adult mosquito abundance as a function of distance from breeding sites?

***What bio-control measures are feasible and effective*?**

- In what sequence do predatory invertebrate populations develop following initial pool filling?
- When is predatory regulation of mosquito larvae effective?
- Can assemblages that control mosquitoes be successfully established and sustained?
- Can fish and invertebrates be combined to control mosquitoes in floodwaters?
- Can supplemental treatments with *Bt* or insecticidal materials be added in a useful, cost-effective way?
- What level of monitoring and maintenance will be required?
- Will construction costs be in a feasible range?

Formal investigation is needed on these points under a research and testing program that would be initiated in the field in the context of active conservation, with ancillary controlled research experiments.

5.2.2 Amphibian Ecology

There is a second dimension to the problem of managing amphibian conservation that applies both in Tucson and elsewhere: what are the characteristics that permit a high diversity of amphibian species to persist? There is virtually no regionally appropriate published information available on this subject that could be applied to local management concerns. The following key research needs are offered as knowledge requirements for successful, active conservation of amphibians in urban environments:

Obtain species-specific data that is lacking on basic larval characteristics, especially:

- Length of larval period (including mean, variance, range and controlling factors)
- Larval diet
- Larval ability to evade predation

Document species-specific habitat occupancy, especially for breeding habitat, with quantitative reference to:

- Hydroperiod and the assemblage of co-existing predatory and competing invertebrates.
- Competition with tadpoles of other species.
  - ➢ Develop a working model based on information from (3) and (4) to understand and predict how amphibian communities and co-occurring aquatic invertebrate communities are dynamically assembled.
  - ➢ Conduct trials based on this working model in replicated laboratory and outdoor microcosm experiments as well as via small scale conservation trials under field conditions

This research program will require support from various branches of local, state, and federal government.

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