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Studies of Wildlife Water Developments in Southwestern Arizona: Wildlife Use, Water Quality, Wildlife Diseases, Wildlife Mortalities, and Influences on Native Pollinators

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Summary

Water developments are a widely used wildlife management tool in the arid Southwest. The ecological effects of those facilities have received little study and remain a source of controversy. We studied direct and indirect effects of wildlife water developments in southwestern Arizona from 1999–2003. Our results did not support hypothesized negative impacts suggested by critics of wildlife water development programs. Specifically, we found that water developments were used by a diverse array of wildlife, including at least 1 species (kit fox) previously reported not to need free water. The waters we studied were heavily used by mule deer and game birds, however, the number of visits by nongame species exceeded those by game species. We also found frequent use of catchments outside summer months. Despite frequent visitation by avian and mammalian predators, we observed only a handful of successful predation events at wildlife waters, all of which involved capture of small vertebrates. We did not find significant evidence of water quality problems associated with water chemistry and did not detect toxins produced by blue-green algae. The wildlife water developments we studied did not appear to play a significant role in transmission of the protozoan parasite that causes trichomoniasis or provide larval habitat for biting midges (genus *Culicoides*) that transmit hemorrhagic disease viruses. We documented few instances of animals drowning in wildlife water developments, most of which involved small vertebrates. Africanized honeybees were widely distributed and abundant near wildlife water developments. However, the presence of water developments and large numbers of feral honeybees had no detectable influence on the diversity and abundance of native bees.

Introduction

Wildlife water developments are an important part of wildlife management programs in arid regions of the western United States. Beginning in the 1940s, state and federal resource management agencies initiated water development programs intended to benefit game species and other wildlife. In cooperation with sportsman's groups and other land managers, the Arizona Game and Fish Department has developed and maintained more than 800 water developments throughout the state. Numerous other wildlife waters have been built by federal land management agencies and by private landowners.

Wildlife water development programs have evolved considerably since their inception. Early wildlife water developments were designed to benefit game species, such as bighorn sheep, mule deer, quail, and doves. As human population growth and associated impacts began to affect large areas of wildlife habitat in Arizona, water development projects took on a broader context. Water developments were used to mitigate for water sources that were lost or made inaccessible by development or changes in land use and were designed to provide water for a variety of wildlife species. For many years, the need for water developments in arid habitats was unquestioned, and such developments were considered universally beneficial to wildlife species. Despite the widespread development of water sources for wildlife, the benefits and ecological effects of these facilities have received scant attention. Recently, critics of water development programs have suggested that artificial water sources may not yield expected benefits to wildlife and may actually result in adverse impacts.

In 1999, the Department's Research Branch; U.S. Army Yuma Proving Ground Conservation Program; and U.S. Fish and Wildlife Service, Kofa National Wildlife Refuge initiated a cooperative study of wildlife water developments in southwestern Arizona. This report presents research results and management recommendations from the first 5 years of a planned 10-year study. Focal areas for the first phase of our research were: (1) patterns of catchment use by wildlife, (2) water quality, (3) wildlife diseases and mortalities, and (4) native and nonnative pollinators.

Study Area

We conducted our research on Yuma Proving Ground (YPG), Kofa National Wildlife Refuge, and adjacent areas managed by the Bureau of Land Management (BLM). The study area encompasses about 8,000 km^2 consisting of rugged mountain

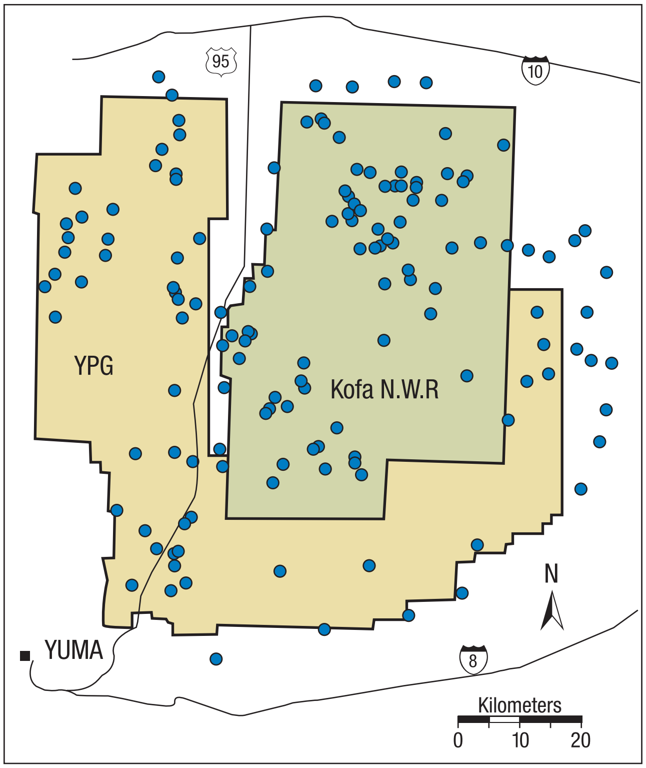


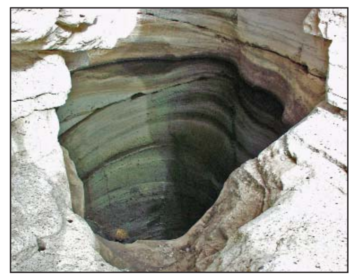
***Figure 1**. Location map of southwestern Arizona study area. Each dot represents a wildlife water development.*

ranges, bajadas, broad valleys, and dry washes. Dominant plant communities are the Lower Colorado River Valley and Arizona Upland subdivisions of the Sonoran Desertscrub biome. Elevations range from 20 m in lower valleys to 1,467 m in montane areas. Long-term average annual precipitation at the 2 nearest weather stations is: 9.3 cm (YPG, Arizona, 105 m elevation) and 17.25 cm (Kofa Mine, Arizona, 584 m elevation). Mean daily minimum (January) and daily maximum (July) temperatures (ºC) at these stations are: YPG (6.3, 41.4) and Kofa Mine (8.0, 39.8).

A large portion of YPG is used for military research and training activities and closed to public access. Open portions of YPG and the rest of the study area receive relatively little human visitation, primarily by hunters, hikers, and off-road vehicle enthusiasts. Domestic livestock have been excluded from YPG and Kofa National Wildlife Refuge for >20 years, but BLM lands in the easternmost portion of the study area have received some grazing. Small groups of feral burros and horses are present, primarily in the western portion of the study area along and west of Highway 95. Naturally occurring surface water is scarce, consisting of a few perennial springs, mostly ephemeral rock pools (tinajas), and short-duration flows in washes following major rainfall events. To increase availability of water for wildlife, >100 water developments have been built on the study area (Figure 1). These waters include constructed catchments ("guzzlers"), natural tinajas modified to increase water retention and storage capacity, windmill-powered wells, and developed springs.

Older-design catchment with metal collection apron and buried concrete storage tank and trough.

Newer catchment with buried fiberglass storage tank and drinker. Water is collected from a small dam located upstream.



Natural tinaja with steps cut into the rock to allow access by wildlife.

Improved natural tinaja with shade roof to reduce evaporation and raised dam to increase storage capacity.

Methods and Findings

Wildlife Use of Catchments

Video Observations – few studies have directly quantified use of water developments by wildlife. Consequently, use of these facilities has often been inferred from animal sign or limited, anecdotal observations. It has been suggested that wildlife water developments are only for game species and are of limited benefit to nongame wildlife. It has also been suggested that water developments are predation traps where animals visiting to obtain water can be ambushed by predators.

Video camera, infrared illuminator, and weather data logger used to monitor wildlife use of catchments.

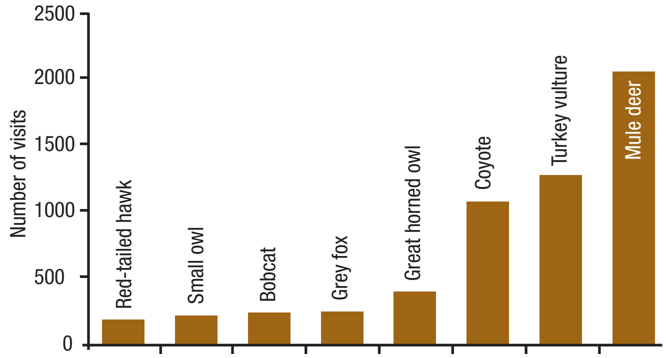
We collected detailed observations of wildlife use at 3 catchments located on YPG (Arizona Game and Fish Department #531, #534, and #535). At each site, we installed a black and white video camera, infrared illuminator for nighttime observations, time-lapse videocassette recorder (VCR), and solar power system (see Appendix A for complete list of system components). The systems recorded 1 picture/second for 3 continuous days each week, from June 2000 to November 2003. At each site, we installed a HOBO Pro® datalogger that recorded hourly measurements of temperature and relative humidity.

We documented date, entry and exit times, species, minimum group size, and activities of owls, humans, and all animals greater than or equal to the size of a black-tailed jackrabbit. We were unable to count individual visits by doves and quail because large groups of these species tended to mill about the water for long periods, passing in and out of the field of view, making it impossible to reliably estimate the number of individuals. Doves and quail were noted as either present or absent during each day of camera operation. The relatively coarse resolution of our black and white video

Table 1. *Wildlife species observed at catchments.*

MAMMALS
Badger (*Taxidea taxus*)
Black-tailed jackrabbit (*Lepus californicus*)
Bobcat (*Lynx rufus*)
Coyote (*Canis latrans*)
Desert cottontail (*Sylvilagus audubonii*)
Grey fox (*Urocyon cinereoargenteus*)
Kit fox (*Vulpes macrotis*)
Mule deer (*Odocoileus hemionus*)
Unknown bat
Unknown ground squirrel
Unknown rodent
BIRDS
American kestrel (*Falco sparverius*)
Burrowing owl (*Athene cunicularia*)
Common poorwill (*Phalaenoptilus nuttallii*)
Common raven (*Corvus corax*)
Cooper's hawk (*Accipiter cooperii*)
Elf owl (*Micranthene whitneyi*)
Gambel's quail (*Callipepla gambelii*)
Gila woodpecker (*Melanerpes uropygialis*)
Greater roadrunner (*Geococcyx californianus*)
Great horned owl (*Bubo virginianus*)
House finch (*Carpodacus mexicanus*)
Loggerhead shrike (*Lanius ludovicianus*)
Mourning dove (*Zenaida macroura*)
Northern mockingbird (*Mimus polyglottos*)
Red-tailed hawk (*Buteo jamaicensis*)
Sharp-shinned hawk (*Accipiter striatus*)
Turkey vulture (*Cathartes aura*)
Western screech owl (*Otus kennicotti*)
White-winged dove (*Zenaida asiatica*)
Unknown bird
REPTILES
Unknown snake
Unknown lizard
AMPHIBIANS
Red-spotted toad (*Bufo punctatus*) [1]
Colorado river toad (*Bufo alvarius*) [1]
[1] Identified by on-site capture.

Figure 2. *Total visits to water catchments by most frequently observed species (averaged across all 3 camera sites).*



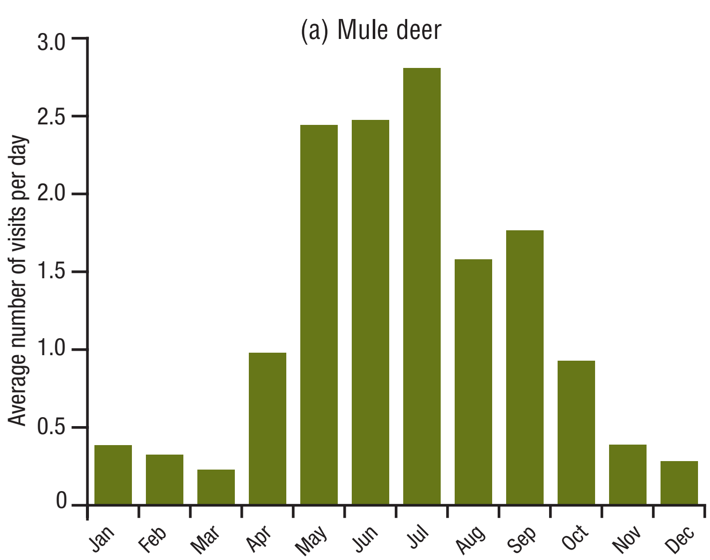
images also made it difficult or impossible to identify and count small, fast-moving animals that were common visitors, including passerine birds, bats, small mammals, amphibians, and reptiles.

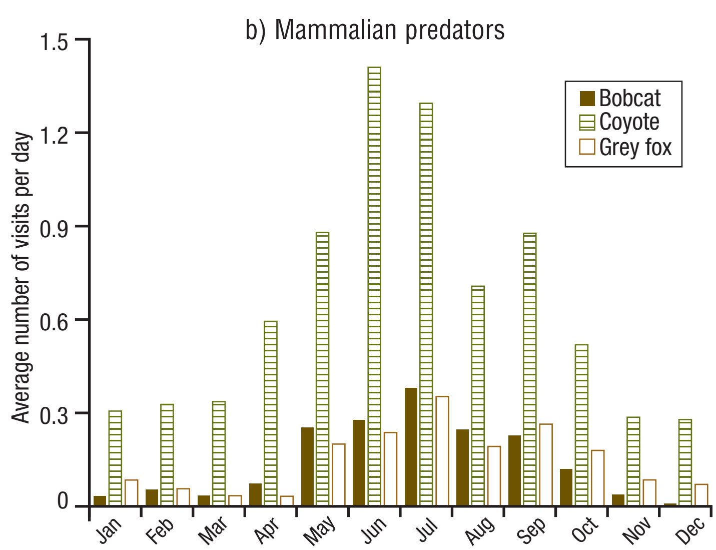
We recorded 37,989 hrs of video observations at the 3 sites, from which we identified 29 species of wildlife (Table 1, previous page). Given the limitations of our video system, this is a conservative estimate of the actual number of species that used these catchments. The most common identified visitors were mule deer, turkey vultures, coyotes, great horned owls, grey foxes, bobcats, western screech owls, elf owls, and red-tailed hawks (Figure 2). Our video-monitored catchments were located on bajadas or valley bottoms away from bighorn sheep habitat, thus visits by sheep were not expected and did not occur. Mule deer and mammalian predators visited catchments during all months of the year, with the highest visitation rates in May, June, and July (Figures 3a, 3b). The majority of visits by raptors and avian scavengers (some of which were migratory) occurred April through September with highest visitation rates in May, June, and July (Figure 4). Mule deer visits increased as mean weekly temperature increased and mean weekly relative humidity decreased (Figure 5).

Table 2. *Total visits and frequency of drinking and bathing by species commonly observed at catchments.*

SPECIES	TOTAL VISITS	% DRANK	% BATHED
Mule deer	6,145	87	2
Turkey vulture	3,843	97	2
Coyote	3,234	86	2
Great horned owl	1,195	98	17
Grey fox	758	85	0
Bobcat	745	95	0
Small owl	682	85	21
Red-tailed hawk	557	98	13
Common raven	270	94	3
Badger	232	91	2
Kit fox	98	76	0
Cooper's hawk	30	93	23

Figure 3. *Monthly visits to water catchments by most frequently observed mammals (averaged across all 3 camera sites).*





Use of catchments by deer decreased somewhat after onset of the summer monsoon, but remained high through the end of October. We also observed regular catchment visits by kit foxes, a species generally considered not to require freestanding water. Kit foxes visited catchments at least 98 times, during at least 8 months of the year (June through January). The amount of time spent at catchments varied considerably among species. Cooper's hawks spent the longest average time at the catchments (average = 14.8 minutes) while kit foxes visited for the shortest average time (average = 1.9 minutes; Figure 6). The majority of animals that visited catchments were observed drinking (Table 2). Bathing was observed much less frequently, most commonly by hawks and owls (Table 2). Doves and quail visited catchments year round, with visitation peaking from April through October. The catchments we observed held water throughout most of the study period and were refilled with hauled water when necessary. We did, however, observe wildlife responses during 4 days in June 2002 when Catchment #531 went dry. Six species (bobcat, coyote, grey fox, mule deer, red-tailed hawk, and turkey vulture) visited the catchment when water was unavailable. Visit duration for 2 species was considerably longer during the dry-up

Figure 4. *Monthly visits to water catchments by most frequently observed raptors and avian scavengers (averaged across all 3 camera sites).*

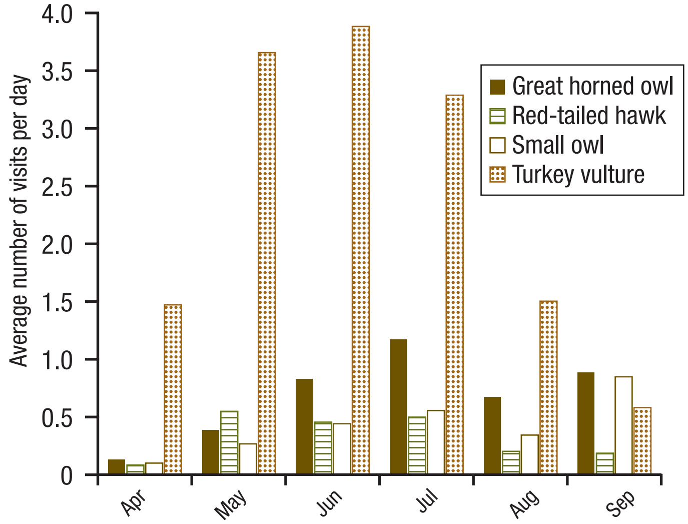


Figure 5. *Visits by mule deer to water catchments in relation to temperature and relative humidity (averaged across all 3 camera sites).*

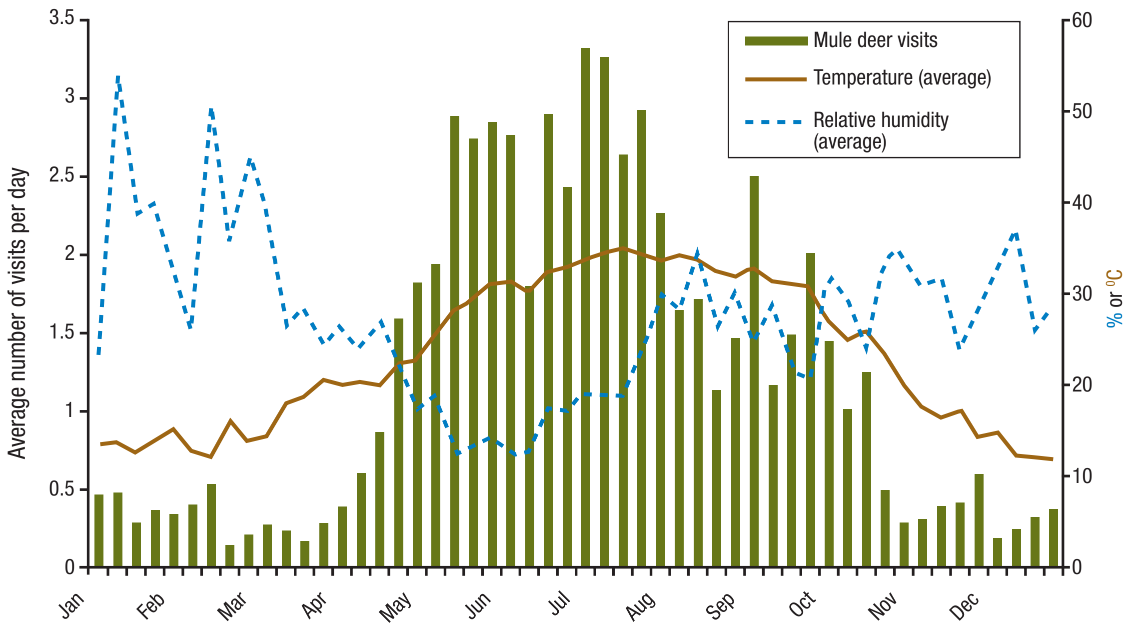
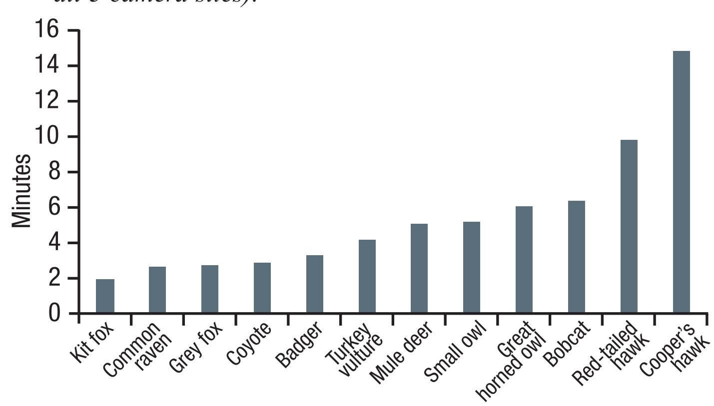


Figure 6. *Average visit duration for species observed most frequently at water catchments (averaged across all 3 camera sites).*



Mule deer, particularly bucks, usually visited catchments during nighttime hours.

event than during periods when water was available. Bobcat visits were 15x longer during the dry-up, during which they were observed entering the buried concrete tank connected to the empty trough. Mule deer visits were 7x longer during dry-up than at other times when water was available. While the catchment was dry, deer were observed licking the empty trough, eating what appeared to be dried algae, and bedding next to the trough for up to 4+ hours at a time.

Table 3. *Bat species captured at wildlife water developments.*

SPECIES	NO. INDIVIDUALS	% TOTAL CAPTURES
Western pipistrelle (*Pipistrellus hesperus*)	187	44
California myotis (*Myotis californicus*)	105	25
Pallid bat (*Antrozous pallidus*)	58	14
Big brown bat (*Eptesicus fuscus*)	31	7
Townsend's big-eared bat (*Corynorhinus townsendii*)	22	5
California leaf-nosed bat (*Macrotus californicus*)	18	4

We observed 8 successful or attempted predation events. Bobcats captured or attempted to capture bats 3 times, a bobcat caught a dove, a red-tailed hawk and Cooper's hawk each captured a dove, a great-horned owl attempted to capture a juvenile grey fox, and a great horned owl grabbed an unknown item out of the water. In addition, we observed 15 events where predators or scavengers (coyote, bobcat, roadrunner, red-tailed hawk, turkey vulture, and raven) consumed dead animals or animal parts that were apparently obtained elsewhere.

Behavioral interactions within and between species occurred in 3% of all visits. Those interactions included kicking and pushing between mule deer, fawns nursing or attempting to nurse from does, mule deer chasing coyotes, 1 species startled by another species arriving at the water, small birds harassing ravens, turkey vultures chasing each other, a bobcat chasing a badger, and coyotes and bobcats reacting to each other.

Bats – bats are strongly attracted to human-made water sources in desert environments, where they drink and forage for insects. Because bats vary in size and maneuverability, different designs of wildlife water developments may be used more readily. A particular concern is the ability of bats to access buried drinking troughs where exposed water can be well below ground level when catchment water levels are low.

We captured bats by mist-netting at various types of water developments in summer 2000 and summer 2001. Study sites included tinajas, wells, and catchments, and were selected to represent different topographic settings of water developments and water configurations available to bats.

We caught 6 species of bats (Table 3), among which western pipistrelle, California myotis, and pallid bats were most common. Other species captured were big brown bats, Townsend's big-eared bats, and California leaf-nosed bats. The highest diversity was found at large tinajas in rocky upland areas, the lowest at catchments with buried concrete vault drinkers. Smaller species, such as western pipistrelles and California myotis, were able to use all the waters we studied, included buried vaults with water below ground level. However, less-maneuverable species, such as big brown and pallid bats, were captured only at tinajas. There was also a strong positive correlation between water surface area and total number of bats captured.

Water Quality

Desert water developments have characteristics that could adversely affect water quality, including high water temperatures, high evaporation rates, and infrequent flushing. Those factors are most pronounced during summer periods when desert water developments are heavily used by a variety of game and nongame wildlife. Hypothesized water quality problems at wildlife water developments include high levels of mineralization, chemical toxins, and toxic blooms of blue-green algae.

Catchment trough with accumulated algae, dead honeybees, and other detritus. Preventing such accumulations of organic matter will improve water quality.

Water Chemistry – we collected water samples from 5 different types of water developments: natural tinajas (n = 14), modified tinajas (n = 9), catchments (n = 6), wells (n = 3), and developed springs (n = 3). Four sets of samples collected in 2000 and 2001 were analyzed for arsenic, barium, calcium, chloride, chromium, copper, fluoride, iron, lead, mercury, nitrate (as N), nitrite, selenium, silver, sulfate, zinc, alkalinity (as $CaCO_3$), and total dissolved solids (TDS) by an Environmental Protection Agency-certified lab (Turner Labs Inc., Tucson, Arizona) following standard procedures. If samples had detectable sulfur odor, we measured dissolved hydrogen sulfide (H_2S) using a reagent test kit (#HS-C, Hach Industries, Loveland, Colorado). Because published water quality standards and guidelines are lacking for wildlife, we relied primarily on those developed for domestic cattle, horses, sheep, goats, swine, and poultry (Table 4).

Results of water quality analyses are given in Table 5 (next page). Seven constituents (barium, cadmium, chromium, copper, mercury, selenium, and silver) were absent or below detection thresholds in all samples. Eight others (calcium, chloride, iron, lead, nitrate, nitrite, sulfate, and zinc) were present in 1 or more water samples, but at levels well below guidelines. Levels of arsenic above the most conservative guideline (0.02 mg/liter), but well below the higher published guideline (0.5 mg/liter), were found in 8 samples from catchments, 2 samples from tinajas, and 1 sample from a spring. Levels of fluoride above the most conservative guideline (1.0 mg/liter) were found in 12 samples from catchments, 3 samples each from wells and springs, and 1 sample from a tinaja. Hydrogen sulfide was detected infrequently (3% of samples) and occurred in all water developments except wells, most frequently in tinajas. Concentrations of H_2S ranged from 0.1 to 0.7 mg/liter, well below the 25 mg/liter recommended guideline. Values of alkalinity (as $CaCO_3$) were slightly to strongly alkaline and varied among types of water developments, with the highest

Table 4. *Published guidelines used to evaluate water quality at wildlife water developments.*

CONSTITUENT	GUIDELINE (mg/liter)
Alkalinity (as $CaCO_3$)	500[4]
Arsenic	0.02[2], 0.025[6], 0.2[5], 0.5[3,4]
Barium	300[4]
Cadmium	0.02[3,4], 0.05[2,5], 0.08[6]
Calcium	700 – 1,000[4], 1,000[3,6]
Chloride	15,000[4]
Chromium	1.0[2,3,4,5]
Copper	0.5[2,5], 5.0[3], 0.5 – 5.0[4,6]
Fluoride	1.0 – 2.0[6], 2.0[2,3,4,5]
Iron	5.0[6]
Lead	0.1[2,3,4,5,6]
Mercury	0.01[2,5], 0.003[3,4,6]
Nitrate (as N)	100[2,3,4,5,6]
Nitrite	10[2,3,4,5,6]
Selenium	0.05[2,3,4,5,6]
Silver	0.05[6]
Sulfate	1,000[3,4,6]
Sulfide (as H_2S)	25[4]
Total Dissolved Solids	3,000[2,3,4,5,6], 5,000[1]
Zinc	24[5], 25[2], 50[3,6]

[1]O'Gara and Yoakum (1992)
[2]Runyan and Bader (1995)
[3]Dupchak (1999)
[4]Peterson (1999)
[5]Soltanpour and Raley (1999)
[6]CCME (2002)

Table 5. *Water quality parameters at wildlife water developments.*

PARAMETER	WATER TYPE	% SAMPLES > DETECTION LIMIT	% SAMPLES > GUIDELINE [1]	RANGE (mg/liter)
TDS	Catchment	100	0	56 – 1,700
	Natural tinaja	100	0	74 – 1,756
	Modified tinaja	100	0	34 – 440
	Spring	100	0	230 – 2,500
	Well	100	0	58 – 1,200
ALKALINITY	Catchment	100	4	42 – 1,400
	Natural tinaja	100	0	62 – 450
	Modified tinaja	100	4	62 – 520
	Spring	100	33	210 – 780
	Well	100	0	120 – 270
ARSENIC	Catchment	67	33	0.001 – 0.071
	Natural tinaja	0	-	-
	Modified tinaja	32	8	0.005 – 0.100
	Spring	83	8	0.005 – 0.036
	Well	25	0	0.011 – 0.018
CALCIUM	Catchment	100	0	17 – 67
	Natural tinaja	100	0	19 – 219
	Modified tinaja	100	0	17 – 88
	Spring	100	0	26 – 68
	Well	100	0	11 – 100
CHLORIDE	Catchment	100	0	12 – 360
	Natural tinaja	100	0	7 – 410
	Modified tinaja	100	0	8 – 83
	Spring	100	0	69 – 360
	Well	10	0	9 – 390
FLUORIDE	Catchment	54	50	0.9 – 4.2
	Natural tinaja	0	-	-
	Modified tinaja	4	4	1.6 [2]
	Spring	33	25	1.0 – 2.7
	Well	19	19	6.4 – 7.1
IRON	Catchment	13	0	0.32 – 0.68
	Natural tinaja	17	0	0.32 – 1.18
	Modified tinaja	32	0	0.31 – 2.30
	Spring	25	0	0.32 – 0.49
	Well	0	-	-
LEAD	Catchment	0	-	-
	Natural tinaja	0	-	-
	Modified tinaja	0	-	-
	Spring	0	-	-
	Well	0	-	-
NITRATE	Catchment	21	0	1.00 – 5.30
	Natural tinaja	41	0	0.05 – 6.13
	Modified tinaja	16	0	1.00 – 2.80
	Spring	25	0	1.50 – 2.40
	Well	44	0	1.20 – 8.10
NITRITE	Catchment	4	0	0.10 [2]
	Natural tinaja	6	0	0.10 [2]
	Modified tinaja	8	0	1.60 – 1.90
	Spring	0	-	-
	Well	25	0	0.11 – 0.64
SULFATE	Catchment	96	0	7.0 – 250.0
	Natural tinaja	64	0	0.4 – 573.0
	Modified tinaja	68	0	6.1 – 54.0
	Spring	100	0	33.0 – 320.0
	Well	88	0	7.1 – 240.0
ZINC	Catchment	58	0	0.06 – 0.49
	Natural tinaja	4	0	0.27 [2]
	Modified tinaja	0	-	-
	Spring	17	0	0.10 – 0.19
	Well	69	0	0.04 – 0.28

[1] Most conservative guideline used if >1 available.
[2] Single observation.

values observed in catchments. Alkalinity exceeded the recommended guideline (500 mg/liter) in 4 samples from springs and 1 sample each from 1 tinaja and 1 catchment. TDS levels were well below recommended guidelines at all types of water developments.

The source of water had a strong influence on water quality. Arsenic and fluoride occurred primarily at springs, wells, and catchments that were fed by groundwater or received hauled water from wells, all of which contained high natural levels of those elements. Levels of arsenic were well below the higher guideline and likely did not present a meaningful risk. Levels of fluoride above recommended guidelines for domestic animals were not uncommon, however, the implications of observed concentrations to wildlife are uncertain. Though well below guidelines, sites using groundwater also had the highest values for TDS, particularly during summer months when high evaporation rates concentrated soluble salts. Alkalinity levels that we observed represent a relatively minor concern (concentrations >500 mg/liter can have a laxative effect).

Blue-Green Algae – we collected monthly samples of surface algae, benthic algae, and phytoplankton from 5 different types of water developments (natural tinajas, modified tinajas, catchments, wells, and developed springs) from January to December 2001. Algae cells were identified to the genus level and counted. We conducted monthly tests (April through October, 2002–2003) of water samples from those sites for the toxins microcystin (variants LR, LA, RR, and YR) and nodularin, using an enzyme-linked immunoassay (ELISA) test (#ET-022, Envirologix, Inc., Portland, Maine).

Wildlife water developments supported diverse algal communities. We found 82 genera in the Divisions Chlorophyta (39 genera), Cyanophyta (20 genera), Chrysophyta (17 genera), Euglenophyta (4 genera), and Pyrrophyta (2 genera). We found 8 genera of blue-green algae (*Oscillatoria, Lyngbya, Microcystis, Nostoc, Phormidium, Anabena, Gleotrichia, and Schizothrix*) that contain toxin-producing species. However, because algae were identified only to genus, it is unknown whether toxin-producing species were actually present.

Blue-green algae occurred in all types of water developments, but most frequently in springs, catchments, and tinajas. Relative abundance of blue-green algae was low compared to other algae that were present. Drinking troughs and tinajas with shade roofs had significantly lower total algal growth and abundance of blue-green algae than did similar unshaded waters.

Despite the prevalence of blue-green algae, associated toxins were absent. All water samples were negative for microcystin and nodularin (below ELISA detection limit of 0.3 parts per billion). Wildlife water developments do not appear to provide suitable conditions for development of toxic blooms that can cause poisoning of animals. Reported wildlife mortalities have occurred on lakes and other large bodies of water that had near-permanent, heavy standing crops of blue-green algae during summer months. Such conditions did not occur at wildlife waters we studied, which had small surface areas and very low abundance of blue-green algae. Dense surface mats of filamentous algae were common and persistent at some wildlife waters; however these algae do not produce toxins that pose a risk to wildlife.

Wildlife Diseases and Mortalities

Hemorrhagic Disease Vectors – biting midges (genus *Culicoides*) are vectors of viruses that cause the hemorrhagic diseases bluetongue (BTV) and epizootic hemorrhagic disease (EHDV) in mule deer, desert bighorn sheep, and other ungulates.

Known hemorrhagic disease vector (Culicoides sonorensis) and potential vector (Culicoides mohave). Wildlife water developments appear to have little, if any, influence on the distribution and reproduction of these biting midges.

Because larval *Culicoides* develop in saturated sand or soil, it has been suggested that wildlife water developments may provide developmental habitat for midges and also facilitate spread of diseases among ungulates using these facilities.

We captured and identified adult *Culicoides* at wildlife water developments and unwatered comparison areas from April through October 2001–2003. Female midges of known or suspected vector species were tested for BTV and EHDV using polymerase chain reaction (PCR) and virus isolation. We collected saturated substrate samples (sand, mud, or coarse sediments) from tinajas and other potential larval development sites (waste-water and water storage ponds) from June through October 2002–2003. Any larvae present were extracted and reared to adults for identification (different species of *Culicoides* cannot be reliably distinguished in their larval forms).

We captured 5 species of *Culicoides*, including a known vector for BTV and EHDV (*C. sonorensis*), a suspected vector (*C. mohave*), and 3 non-vector species (*C. cacticola, C. cochisensis,* and *C. stonei*). *C. sonorensis* and *C. mohave* were widely distributed and locally abundant at both watered and unwatered sites, primarily in the western portion of the study area. Both species occurred >20 km from known or suspected larval development sites, a far greater dispersal distance than previously reported.

All tests for BTV and EHDV in the known vector *C. sonorensis* were negative. A large proportion (39%) of *C. mohave* samples yielded PCR-positives for EHDV. However, subsequent sequencing of PCR products did not confirm these results and all virus isolations were negative. Consequently, the role of *C. mohave* as an EHDV vector remains unknown.

Optimum larval development habitat for *C. sonorensis* consists of fine silt or mud at the margins of standing water that is brackish or heavily enriched with animal manure (e.g., from domestic livestock). Larval *C. sonorensis* were abundant in water treatment brine ponds that provided the former condition. A few *C. sonorensis* larvae were found in 1 sample from a tinaja that had abundant fine silt at the water margin. However, the other tinajas we sampled did not provide suitable larval development habitat, having water with low levels of dissolved salts, mostly rock or coarse gravel substrates at the water margins, and minimal inputs of animal feces, primarily from mule deer or desert bighorn. We found a west-east gradient in the abundance of adult *C. mohave*, with the highest concentration in the westernmost portion of the study area. Preliminary evidence suggests that larval development habitats for this species are located in wetlands along the Gila and Colorado Rivers, and adults are dispersing long distances with prevailing westerly and southwesterly winds.

Water-borne Pathogens – during epizootic outbreaks of trichomoniasis, large numbers of dead and dying doves are sometimes found near water sources, particularly in urban areas. Birdbaths and other backyard water sources can harbor the causative organism, the protozoan parasite *Trichomonas gallinae*. Thus, it has been suggested that wildlife water developments in wildland areas could also play a role in spreading that disease.

We collected monthly water samples (April through October 2002–2003) from wildlife water developments on the study area (natural tinajas, modified tinajas, catchments, wells, and developed springs) and tested them for *Trichomonas*. In summer 2003, we collected water samples from wildlife water developments in west-central Arizona (Kingman area), where sick and dying mourning doves were found during a trichomoniasis outbreak. Samples were cultured using InPouch™ TF test pouches (BioMed Diagnostics, San Jose, California) and examined for presence of trichomonads (motile protozoans).

All cultures for *Trichomonas* were negative. The protozoan was absent in all water samples from the southwestern Arizona study area as well as those collected during the Kingman area trichomoniasis outbreak. Our results and those of other studies suggest that wildlife water developments may not provide suitable environments for persistence and transmission of *Trichomonas*. Under experimental conditions, trichomonads do not appear to survive in water for periods >24 hours. Mortality from

Mountain lion-killed mule deer found near tinaja. Wildlife mortalities from predation or drowning at wildlife waters were very uncommon.

exposure to ultraviolet radiation and predation by other microorganisms are 2 factors that may limit persistence of *Trichomonas* in wildlife water developments and other aquatic environments.

Wildlife Mortalities – published literature contains anecdotal observations of mule deer, bighorn, and other animals that apparently became entrapped and drowned in wildlife water developments. Thus, it has been suggested that these developments may represent a significant risk to animals that visit them.

Over the course of our research (1999–2003), we conducted >600 visits to wildlife water developments located on the study area. Visits occurred year round, but were concentrated during summer months when wildlife use of developed waters was greatest. During each visit, we inspected the water itself and the surrounding area for dead animals or animal remains.

We recorded 19 incidents of wildlife mortalities. There were 5 mortality events of large mammals (3 involving 1–3 mule deer, 1 involving a bighorn sheep, and 1 involving a coyote), all of which occurred at natural or modified tinajas. The remaining mortality events involved birds, small mammals, and reptiles and occurred at various types of wildlife waters. Those mortalities included 1 woodrat, 1 pocket mouse, 2 unidentified bats, 5 mourning doves, 2 northern flickers, 1 house finch, and 4 unidentified lizards. We did not necropsy recovered animals, but all were found floating in the water and presumed to have drowned. Natural tinajas with steep sides can entrap and cause mortalities of desert bighorn and other vertebrates. Such "trap tanks" are relatively uncommon and usually modified by installation of escape steps or ramps after mortalities are documented. Our sample did not include known trap tanks, however, the small number of observed mortalities suggests that non-trap tinajas and other types of water developments do not present a significant drowning risk to wildlife. Because some animals visiting catchments bring in prey or scavenged food, previous studies that counted animal remains in drinkers may have overestimated drowning events.

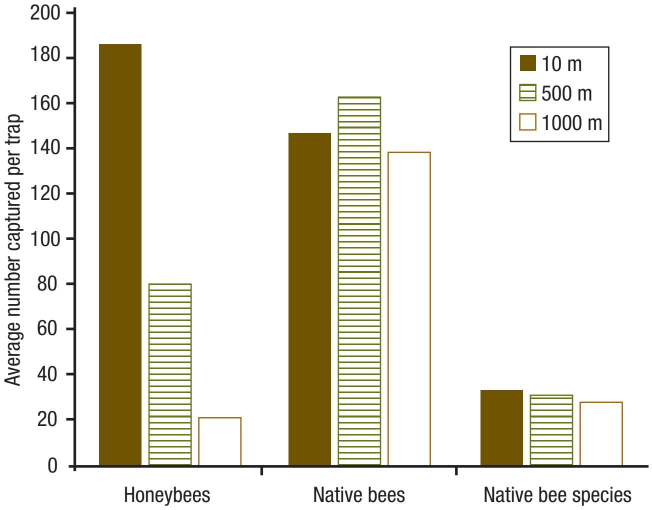
Native And Nonnative Pollinators

The addition of human-made water sources is believed to have increased abundance of non-native honeybees in southwestern U.S. deserts. Water transported by worker bees is used to cool the hive during hot summer periods and is critical to survival of the colony. Expansion of the range of feral honeybees, particularly the Africanized variety, may have important consequences for native bees because of potential competition for nectar and pollen resources.

To assess the prevalence of Africanized bees, we collected feral honeybees at 54 wildlife water developments located across the study area in June 2000. We determined genetic origin of the bees using mitochondrial DNA (mtDNA). To assess water effects on feral honeybees and native bees, we established arrays of bee traps at varying distances

Feral Africanized honeybees watering at catchment trough. While abundant near wildlife waters, feral honeybees do not appear to exclude native bees.

Figure 7. Effect of distance to water on feral honeybees and native bees.



from 4 wildlife water developments from February 2001 through February 2002. The traps simulated the appearance of a large flower, capturing and preserving both feral honeybees and native bees.

Africanized bees were present at all collection sites. The majority of bees collected (87%) possessed African mtDNA, and non-Africanized strains were relatively uncommon. Western European, Eastern European, and Egyptian mtDNA were present in 6%, 4%, and 3% of collected bees, respectively.

Pan trap used to sample pollinators. Feral honeybees and native bees are attracted to the large yellow funnel that mimics the appearance of a flower.

The study area supported an extremely diverse native bee community, 1 of the richest documented to date in North America. Our trapping effort yielded >200 species, including several not previously described. Not surprisingly, honeybees showed a strong relationship with water, being most abundant near wildlife water developments and diminishing rapidly with increasing distance from water (Figure 7). However, the diversity and abundance of native bees was unaffected by distance from water developments (Figure 7). If competition occurred between feral and native bees, we would have expected fewer species and individuals of native bees close to water where honeybees were most abundant and could have dominated available floral resources (nectar and pollen). No such relationship was apparent.

Management Considerations

Wildlife water developments are an effective and appropriate wildlife management tool in arid environments, particularly during periods of drought. The importance of water developments is likely to increase as urbanization, highways, and other developments continue to fragment wildlife habitats and populations. We offer the following recommendations for resource managers involved in planning, construction, and maintenance of wildlife water developments:

1. Wildlife water developments are used by a broad variety of game and nongame wildlife, which should be a consideration when locating these facilities. Characteristics of the surrounding habitat are particularly important to bats; water sources in rocky uplands and canyon areas will receive the greatest use.
2. Water surface area and accessibility are important to bats and likely other species as well. We recommend additional work to examine how bats and other species use deep, buried troughs at newer design, passive flow (non-float valve) catchment systems.
3. Wildlife water developments are used year round, with peak visitation by wildlife during the months of May, June, and July. We encourage managers to design and maintain waters in a manner that ensures year-round availability of water, particularly during periods of drought. Newer catchment designs can maximize water collection and storage efficiency and minimize evaporative loss. Such systems, when properly designed, typically do not require supplemental water hauling, except during prolonged drought. Reducing or eliminating use of supplemental hauled water will improve overall water quality and reduce potential problems associated with arsenic, fluoride, dissolved salts, and other groundwater constituents.
4. Tinajas and potholes should be designed in a manner that allows easy ingress and egress, thus

minimizing potential water quality problems associated with entrapment and decomposition of large animals. Steep-sided basins should be equipped with ramps or steps.

5. Frequency of flushing is an important factor affecting water quality in tinajas and potholes. Where elevated dams and gabion structures are used, they should be designed in a manner that allows regular flushing during runoff events and reduces accumulation of organic matter.
6. Where compatible with visual objectives and other planning considerations, we suggest placing shade roofs over troughs and tinajas to reduce algae growth and water loss to evaporation. Where roofs cannot be used, we recommend shading using natural features present on-site and orienting troughs to minimize solar radiation input.
7. Organic debris, dead animals, floating algae, and accumulated sediment should be regularly removed from water development troughs. A preferred approach is to drain the trough and shovel out accumulated material. Where this is not feasible, much of the suspended and settled organic material can be removed using a pool skimmer and shovel.
8. To reduce habitat suitability for larval *Culicoides*, modified tinajas and other types of wildlife water developments should be designed and maintained in a manner that reduces accumulation of silt and mud at the water margin.
9. Africanized honeybees are widely distributed in wildland areas of southwestern Arizona. Individuals working or traveling in remote desert areas should assume that all honeybees encountered are Africanized and use appropriate caution.

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For More Information

Electronic copies of this report in Adobe Acrobat PDF format can be obtained from the senior author (srose@azgfd.gov). Printed copies can be obtained by written request from the Arizona Game and Fish Department, Research Branch/WMRS, 2221 W. Greenway Rd., Phoenix, AZ 85023. Complete results of research efforts summarized in this report have been submitted for publication in scientific journals. Citations and reprints of those articles will be available from the senior author after publication. Information on this and other Research Branch projects can be found on the Department web site (www.azgfd.gov).

Appendix A. *Components of video systems used to monitor wildlife use at water catchments.*

COMPONENT	MODEL #	SPECIFICATIONS AND MANUFACTURER
Video camera	CB-01	Black and white, 2.9 mm or 4.3 mm focal length Opticom Technologies, Inc., Burnaby, British Columbia, Canada
Infrared illuminator	IRI-2060	12-volt Scopus Inc., Naples, Florida, USA
Timer switch	DIGI 42E	12-volt, 24-hr, 7-day programmable Grasslin Controls, Inc., Mahwah, New Jersey, USA
Videocassette recorder	SVT3050 or SVT168	168 hour, VHS format, time-lapse capable Sony Corp., New York, New York, USA
Gel cell batteries (2)	SG-90	12-volt, 90 amp-hr Trojan Battery Co., Santa Fe Springs, California, USA
Solar panels (2)	SP75	12-volt, 75-watt Siemens Solar Industries, Camarillo, California, USA
Charge controller	Sunsaver 20L	12-volt, 20-amp Morningstar Corp., Washington Crossing, Pennsylvania, USA
DC-AC inverter	Statpower Notepower PW-50	12 volt, 50-watt Xantrex Technology, Burnaby, British Columbia, Canada
Weather data logger	HOBO Pro H08-032-08	Onset Computer Corp., Pocasset, Massachusetts, USA

Arizona Game and Fish Department Mission

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

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