

Feature Article

Viewpoint: Benefits and impacts of wildlife water developments

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Abstract

Resource managers in the western United States have long assumed that water was a key limiting factor on wildlife populations in arid habitats. Beginning in the 1940s–1950s, state and federal resource management agencies initiated water development programs intended to benefit game species and other wildlife. At least 5,859 such developments have been built in 11 western states. Most state wildlife management agencies in the western United States have ongoing wildlife water development programs that vary greatly in extent. Ranchers and range managers also have developed water sources for livestock, many of which also are used by wildlife. Recently, critics have suggested that wildlife water developments have not yielded expected benefits, and may negatively impact wildlife by increasing predation, competition, and disease transmission. Based upon a comprehensive review of scientific literature, we conclude that wildlife water developments have likely benefitted many game and non-game species, but not all water development projects have yielded expected increases in animal distribution and abundance. Hypothesized negative impacts of water developments on wildlife are not supported by data and remain largely speculative. However, our understanding of both positive and negative effects of wildlife water developments is incomplete, because of design limitations of previous research. Long-term, experimental studies are needed to address unanswered questions concerning the efficacy and ecological effects of water developments. We also recommend that resource managers apply more rigorous planning criteria to new developments, and expand monitoring efforts associated with water development programs.

Key Words: wildlife management, water requirements, stock-tanks, catchments, guzzlers, tinajas.

The authors thank members of the Arizona Game and Fish Department's Water Development Review Committee (Greg Carmichael, Vanessa Dickinson, Eric Gardner, John Gunn, Russ Haughey, John Hervert, and Ray Lee), who helped prepare a briefing paper that inspired this review. Peggy Bartnicki, Sam Blankenship, Vern Bleich, Doug Bowman, Dwight Bunnell, Bill Gerhart, Rolf Johnson, Lon Kuck, Bruce Morrison, Craig Stevenson, and Don Whittaker provided information on the use of wildlife water developments by state wildlife agencies. Insightful reviews of the draft manuscript were provided by Vern Bleich, Bill Broyles, Paul Krausman, and 2 anonymous reviewers. Special thanks to Susi MacVean for translating the Abstract into Spanish.

Manuscript accepted 12 Sept. 1998.

Resumen

Administradores de recursos en el oeste de los Estados Unidos han por mucho tiempo supuesto que el agua era el principal factor limitante de poblaciones de vida silvestre en hábitats áridos. Empezando en los 1940s–1950s, agencias federales y estatales que manejan recursos naturales iniciaron programas para el desarrollo de aguas construidas, con el objeto de beneficiar a los animales de caza y a otra vida silvestre. Por lo menos 5,859 desarrollos de este tipo han sido construidos en 11 estados occidentales. La mayoría de agencias estatales que manejan vida silvestre en el oeste de los Estados Unidos tienen programas para el desarrollo de aguas construidas. Estos programas varían mucho en magnitud. Rancheros y administradores de pastizales también han desarrollado aguas contruidas para el ganado, muchas de las cuales son usadas por la vida silvestre. Recientemente, críticos han sugerido que las aguas construidas para la vida silvestre no han rendido los beneficios anticipados y que estos desarrollos pueden hacer daño a la vida silvestre debido al aumento en predación, competencia y transmisión de enfermedades. A base de una búsqueda comprensiva de la literatura científica, concluimos que las aguas construidas para la vida silvestre probablemente sí han beneficiado a muchos animales de caza y a otra vida silvestre, pero no todos los proyectos de desarrollo de aguas construidas han rendido aumentos anticipados en distribución y abundancia de animales. Los efectos hipotizados negativos de aguas construidas en la vida silvestre no son soportadas por datos y permanecen altamente especulativos. Sin embargo, nuestro entendimiento de los efectos positivos y negativos de aguas construidas es incompleto, debido a las limitaciones en el diseño de investigaciones previas. Investigaciones a largo plazo, experimentales hacen falta para responder a preguntas sobre la eficacia y los efectos ecológicos de las aguas construidas. También recomendamos que los administradores de recursos apliquen criterios de planificación mas rigurosos a los desarrollos nuevos, y que aumenten esfuerzos de monitoreo asociados con programas para el desarrollo de aguas construidas.

Historical and Current Use of Wildlife Water Developments

In the landmark text *Game Management*, Leopold (1933) articulated 3 fundamental needs of free-ranging wildlife: food,

water, and cover. Since then, the importance of water to wildlife populations has been considered axiomatic. In arid habitats, the scarcity of free-standing water has long been considered a limiting factor for many game species (Roberts 1977). Since the 1940s–1950s, wildlife managers in the western U.S. have expended considerable effort to enhance existing water supplies and develop new water sources for wildlife.

Wildlife water development programs have evolved over time. Early wildlife water developments were intended to benefit upland game birds or ungulates (Glading 1947, Wright 1959). More recently, water development projects have been used to mitigate the loss of naturally-occurring water sources (deVos et al. 1983) and were designed to provide water for a variety of game and nongame species (Sanchez and Haderlie 1990). Broyles (1998) noted that water development projects also provide social, political, and public relations opportunities for resource managers, sportsmen, and user groups.

Development of water supplies also has been an integral part of livestock and range management throughout the arid West (Vallentine 1980). Quantitative information on the number of water developments built for livestock is difficult to obtain; however, livestock water developments outnumber those constructed solely for wildlife. Many livestock waters are used by wildlife, however, the benefits of these facilities to wildlife have been questioned (Scott 1998).

Four primary types of water developments have been constructed in the western U.S., modified natural tanks, artificial catchments, developed springs, and wells. Natural rock tanks (tinajas) that collect precipitation and surface runoff have been modified to increase interception and storage capacity (Werner 1984). Artificial catchments include earthen reservoirs (Halloran and Deming 1958); concrete dams (Halloran and Deming 1958); sand dams (Bleich and Weaver 1983); adits (Parry 1972); and units that incorporate a precipitation collection surface, storage tank, and drinker (Gunn 1990). Existing springs have been developed to increase water flow and availability (Bleich et al. 1982). Horizontal and vertical wells have been used where other types of developments were not practical (Kindschy 1996).

Most western U.S. state wildlife agencies have used water developments as a wildlife management tool; however, the extent of water development programs varied (Table 1). California, Arizona, Nevada, and Oregon had the largest historical and current water development programs, measured by numbers of facilities and expenditures for construction and maintenance. However, agency expenditures on water developments were difficult to estimate, because many projects were built and maintained using donated labor and materials. Water developments also have been built by federal land management agencies such as the USDI Bureau of Land Management (USDI Bureau of Land Management 1964) and USDA Forest Service (Quigley et al. 1989); however, we were unable to obtain region-wide data on these projects.

The Controversy

For many years, the need for water developments in arid habitats was unquestioned, and such developments were assumed beneficial to game and nongame wildlife species. Contemporary resource management references recommend development of new water sources to benefit ungulates and other wildlife (e.g., Kie et al. 1994, Kindschy 1996).

Recently, wildlife water developments have received critical scrutiny. Resource managers have questioned the need for continued development of new water sources (Sanchez and Haderlie 1990). Critics of wildlife water developments have suggested that establishment of new water supplies in arid habitats may

not yield expected benefits, and can have adverse impacts (Broyles 1995, Brown 1998). Economic costs and benefits of wildlife water developments also have been challenged (Broyles 1998).

Wildlife Responses to Water Developments

The underlying assumption of water development programs has been that the scarcity of surface water in arid habitats was a primary factor limiting wildlife populations. Managers anticipated that provision of additional water sources would benefit wildlife populations; by expanding animal distribution, increasing productivity, reducing mortality, and increasing fitness. Here, we present our perspective on the effects of water developments on game and non-game wildlife; derived from an extensive literature review and discussions with resource managers throughout the western U.S.

Game Species

Upland Game Birds

Many early water developments were built for quail; however, the impacts of these facilities on quail populations vary. Gambel's quail (*Callipepla gambelii* Gambel) and scaled quail (*Callipepla squamata* Vigors) can meet most of their water needs by consuming succulent foods (Hungerford 1960, Schemnitz 1994). However, Leopold (1977:183) indicated that desert quail required drinking water to survive periods of sustained heat and drought. Desert quail frequently drank from catchments, particularly during hot and

Table 1. Current wildlife water development programs of 11 western U.S. state wildlife agencies. Information obtained from mail and telephone survey conducted October–December 1997 (Arizona Game and Fish Dept., unpublished).

State	No. developments ¹	Ongoing program	Annual expenditures ²
Arizona	840	yes	\$755,000
California	2,500	yes	data unavailable
Colorado	data unavailable	no	data unavailable
Idaho	data unavailable	yes	data unavailable
New Mexico	43	yes	\$50,000
Nevada	1,000 ³	yes	up to \$110,000
Oregon	1,000	yes	\$75,000–100,000
Texas	135	yes	\$11,000
Utah	250	yes	\$50,000
Washington	6	yes	outside donations only
Wyoming	85	yes	\$14,000

¹Number of developments historically constructed or currently maintained.

²Recent expenditures. Because detailed expenditure records often were unavailable, most figures are rough estimates.

³Includes developments built by other resource management agencies.

dry periods (Elder 1956). Early studies reported that water developments increased quail distribution and abundance (Rahm 1938, Wright 1953). Subsequent research suggested that in some areas, water developments did not substantially increase quail populations or hunter success (Hungerford 1960, Webb and Gallizioli 1963), and were not economically justifiable if constructed for quail alone (Campbell 1961). We concur with Campbell's (1961) suggestion that climatic factors accounted for regional differences in quail use of water catchments, and that these developments were most beneficial in areas characterized by drought during the spring-summer breeding season.

Chukar partridge (*Alectoris chukar* Gray) have been introduced into many arid upland regions of the western U.S., a process enhanced by development of new water sources. In Nevada, installation of guzzlers increased existing chukar populations, facilitated establishment of new populations, and improved hunter distribution and hunt success (Benolkin 1990).

Surface water is required by mourning doves (*Zenaida macroura* L.) and white-winged doves (*Zenaida asiatica* L.), consequently both species likely have benefitted from water developments in arid habitats. Mourning and white-winged doves frequently used water catchments in Arizona (Elder 1956). In Idaho, movements and habitat use of radio-tagged mourning doves suggested that dove populations could be increased by establishing new permanent waters, where distances between existing watering sites were >6 km (Howe and Flake 1988).

Availability of free-standing water appears to be an essential habitat component for Merriam's turkey (*Meleagris gallopavo merriami* L.). In Arizona, turkey population increases were associated with construction of wildlife water developments (Shaw and Mollohan 1992). We concur with current management guidelines recommending that water sources be available within each 2.59 km² of suitable turkey habitat (Hoffman et al. 1993).

Waterfowl

Earthen tanks can provide valuable habitat for migrating and nesting waterfowl. Cutler (1996) observed 6 species of migrant waterfowl using earthen

tanks in Arizona. Nesting habitat suitability of man-made ponds is strongly influenced by water surface area and characteristics of emergent and bank vegetation (Lokemoen 1973, Rumble and Flake 1983). We note that the habitat potential of many stocktanks in the western U.S. has not been realized because of a lack of vegetative cover (Menasco 1986, Scott 1998).

Desert Bighorn

Water is considered a key habitat requirement of desert bighorn (*Ovis canadensis* Shaw) (McCarty and Bailey 1994). Desert bighorn readily use surface water; however, populations of desert bighorn persist in areas where free water is lacking on a seasonal or permanent basis (Krausman and Etchberger 1996). These sheep apparently obtain sufficient water from cacti and other succulent forage items (Warrick and Krausman 1989).

Habitat use by desert bighorn often is positively correlated with proximity to water sources, including water developments. In 6 studies reviewed by McCarty and Bailey (1994), sheep most often were observed within 0.4–3.2 km of a water source. Significant preferences for areas closer to water have been found during hot, dry periods (Wakeling and Miller 1989). Waterholes also may serve as focal areas for social interactions among sheep (Olech 1979). However, in some desert sheep populations, habitat use appears not to be constrained by the distribution of water sources (Krausman and Leopold 1986a, Krausman and Etchberger 1995).

Water developments have been a centerpiece of desert sheep habitat management throughout the arid West. Use of water developments by desert bighorn is well documented (Graves 1961, Campbell and Remington 1979), but some catchments intended to benefit sheep have received little or no use (Krausman and Etchberger 1995). Bighorn populations have increased after development of new waters (Leslie and Douglas 1979), or declined in response to drying of natural springs (Douglas 1988). However, some authors have argued that desert sheep populations may not benefit from water developments (Broyles 1995, Krausman and Etchberger 1996). We believe that water developments have benefitted some, but not all populations of desert bighorn.

Elk

Elk (*Cervus elaphus* L.) are primarily associated with mesic forest habitats, where water generally is not a limiting factor (Boyd 1980:22). In arid habitats, habitat use by elk is strongly affected by availability of surface water; areas within 0.4–1.6 km of water sources are used most heavily, particularly in dry periods or during lactation (Delgiudice and Rodiek 1984, McCorquodale et al. 1986, Biggs et al. 1997). Close proximity to water (within 0.4–0.8 km) was characteristic of elk calving areas in Arizona (Brown 1994).

Over the last 20 years, elk populations have expanded dramatically in arid shrubsteppe, woodland, and forest habitats of the western U.S. We contend that water developments have played a major role in this expansion. Scarcity of water likely limited prior elk use of these areas, because of the high water requirements of female elk during lactation (Skovlin 1982).

Mule Deer

Mule deer (*Odocoileus hemionus* Rafinesque) in arid regions are dependent upon free water (Wolfe 1978:367). Mule deer typically are found in close proximity to water sources, particularly during dry periods (Rautenstrauch and Krausman 1989a, Boroski and Mossman 1996). In Arizona, water developments received heavy use by desert mule deer, primarily during hot summer months (Remington et al. 1984, Hervert and Krausman 1986). Does visiting catchments consumed more water than did males, perhaps due to increased water requirements associated with lactation (Hazam and Krausman 1988). An apparent dependence of some desert mule deer on water catchments has been demonstrated experimentally (Hervert and Krausman 1986).

There is good evidence that water developments have benefitted mule deer in arid Southwestern habitats. Seasonal desert mule deer ranges in Arizona were occupied year-long after construction of water developments (Wright 1959). Provision of new water sources also increased deer densities in habitats where water previously had been limiting (Bellantoni et al. 1993). deVos and Clarkson (1990) found a positive relationship between mule deer harvest and the number of water developments built

over an 11-year period. Deer numbers increased during a 5-year period following development of wildlife waters in New Mexico (Wood et al. 1970).

White-tailed Deer

Surface water is an essential habitat component for white-tailed deer (*Odocoileus virginianus* Zimmerman) in arid habitats. Habitat use by white-tailed deer in the Southwest is closely tied to the availability of free-standing water (Maghini and Smith 1990).

Water developments have likely benefitted white-tailed deer populations in the Southwest. White-tailed deer regularly visited water developments, particularly during hot-dry seasons (Maghini and Smith 1990). In Arizona, Coues white-tailed deer strongly selected areas within <0.4 km of artificial and natural water sources, avoiding areas >1.2 km away. Availability of supplemental water may increase fawn survival and recruitment when forage moisture is low (Ockenfels et al. 1991).

Pronghorn

The importance of surface water to pronghorn (*Antilocapra americana* Ord) remains a source of debate (Yoakum 1994, Hervert et al. 1998). However, high density pronghorn populations usually occur in habitats with abundant free water, whereas habitats with few water sources support low pronghorn densities (Yoakum 1994). Hervert (1996) observed that Sonoran pronghorn herds that utilized surface water were larger than herds that did not. In some areas, habitat use by pronghorn is related to the availability of surface water. When forage moisture content was lowest, Wyoming pronghorn were found within 4.8–6.4 km of water (Sundstrom 1968, Boyle and Alldredge 1981). In Arizona, pronghorn fawns selected bed sites within 0.4–0.8 km of water, avoiding areas >1.2 km away (Ticer and Miller 1994). In New Mexico, yearling pronghorn remained closer to water than adults (Clemente et al. 1995). Sonoran pronghorn in Arizona and Mexico were located closer to water than expected by chance (Wright and deVos 1986). Other studies have reported that availability of water did not influence habitat use by adult pronghorn (Hughes and Smith 1990, Deblinger and Alldredge 1991, Ockenfels et al. 1994).

Water developments have been a popular habitat improvement technique for pronghorn, and these developments often receive heavy use when succulent forage is unavailable (O'Gara and Yoakum 1992, Yoakum 1994). Water developments may improve pronghorn distribution in some situations (Beale and Smith 1970, Heady and Bartolome 1977). However, we concur with Deblinger and Alldredge (1991), who cautioned that water developments were not the sole determinant of pronghorn distribution or density.

Mammalian Predators

The literature is equivocal concerning the dependence of mammalian predators on free water. Most can obtain needed moisture from their prey, if additional water is not required for thermoregulation (Schmidt-Nielsen 1964). Some species, e.g., ringtails (*Bassariscus astutus* Lichtenstein) and kit foxes (*Vulpes macrotis* Merriam) are believed not to require free water (Chevalier 1984, Golightly and Omart 1984). However, there are many anecdotal observations of mammalian predators drinking from natural or human-made water sources (Ballard et al. 1998).

There is evidence that water developments attract mammalian predators; however, the effects of these facilities on predator populations are unknown. Cutler (1996) observed 6 species at water developments in Arizona (kit fox, gray fox [*Urocyon cinereoargenteus* Baird], badger [*Taxidea taxus* Schreber], coyote [*Canis latrans* Say], bobcat [*Lynx rufus* Schreber], and mountain lion [*Felis concolor* L.]). Predator observations and sign also were greater at water developments compared to unwatered control sites (Schmidt and DeStefano 1996). In contrast, Smith and Henry (1985) found no difference in predator use at water developments and unwatered control plots.

Non-Game Species

Small Mammals

Terrestrial small mammals found in arid habitats have physiological and behavioral adaptations that minimize or eliminate the need for free water (Mares 1983); consequently these species are relatively unaffected by development of new water sources. In Arizona, water developments had little or no influence

on lagomorphs and rodents (Smith and Henry 1985, Cutler 1996). However, in New Mexico, small mammals were more abundant at water units compared to unwatered comparison plots, a difference attributed to development-related debris and habitat alteration (Burkett and Thompson 1994).

Unlike other small mammals, bats are strongly attracted to water sources in arid habitats. Water catchments are used for drinking, and serve as foraging areas for insectivorous bats (Kuenzi and Morrison 1997). In Arizona, 7–9 species of bats were captured at earthen tanks and other water developments (Cockrum 1981, Cutler 1996). Similarly, bat activity was higher at water developments than at unwatered control sites (Schmidt and DeStefano 1996). Because some bat species are dependent upon surface water (Schmidt and Dalton 1995), water developments likely have expanded bat distribution, particularly in areas where suitable roosts are present (Geluso 1978).

Birds

Birds living in arid environments vary greatly in their dependence on free water (Dawson and Bartholomew 1968). Nevertheless, water developments are heavily used by many bird species, including passerines, shorebirds, waterfowl, and raptors. Gubanich and Panik (1986) observed 40–44 species using waterholes in Nevada. Availability of water affected bird distribution during Summer and Fall dry periods, and a number of species appeared to be “water-dependent.” In Arizona, 150 bird species occurred at or near wildlife water developments, 60 of which were observed drinking water (Cutler 1996). Because bird use peaks during spring and fall migration periods, water developments and associated vegetation “oases” may be important stopover sites for migratory species.

Water developments and associated vegetation provide food, water, and nesting habitat for breeding birds; however, the net effects of these developments on breeding birds vary. In Arizona, total bird abundance and species richness were negatively correlated with distance from wildlife water catchments at 1 of 2 study sites (Cutler 1996). Other studies in Arizona and New Mexico found no difference in

species richness or abundance at water developments compared to unwatered control plots (Smith and Henry 1985, Burkett and Thompson 1994).

Raptors appear to benefit from water developments, particularly in desert habitats. Developments and associated structures or vegetation provide water for drinking and bathing, perches, nest substrates, and foraging areas with concentrations of potential prey (Kochert et al. 1988, Cutler 1996). In Arizona and New Mexico, raptor sign was more abundant at water developments than at unwatered control plots (Burkett and Thompson 1994, Schmidt and DeStefano 1996). Mesquite trees (*Prosopis glandulosa* Torr.) established at stocktanks provided roosting, nesting, and winter habitat for long-eared owls (*Asio otus* L.) (Kochert et al. 1988, Cutler 1996). Harris' hawks (*Parabuteo unicinctus* Temminck) require free water during the breeding season; water developments have allowed population expansion into previously unoccupied Sonoran desert habitats (Dawson and Mannan 1991).

Herpetofauna

Many reptiles found in arid habitats will drink water when it is available; however, most species are believed not to require free water (Mayhew 1968). Studies in the southwestern U.S. generally have reported that water developments did not affect reptile abundance or species richness (Smith and Henry 1985, Cutler 1996). However, in New Mexico, snakes and lizards were more abundant at watered sites, a difference attributed to the presence of development-related debris (Burkett and Thompson 1994). One snake species found in the southwestern U.S., the wandering garter snake (*Thamnophis elegans* Baird and Gerard), opportunistically inhabits aquatic habitat provided by stocktanks (J. Howland, Ariz. Game and Fish Dept., pers. comm.).

In the Southwest, earthen tanks and other water developments provide extremely valuable habitat for amphibians. Stocktanks in New Mexico supported breeding populations of 5 toad species that also occurred on a nearby, intermittently flooded playa (Cruesere and Whitford 1976). In Arizona, Jones (1988) found 8 amphibian species that occurred only in stocktanks and other

permanent surface waters. Studies in Arizona and New Mexico found 2–4 species of amphibians at water developments, species that were absent on unwatered control plots (Smith and Henry 1985, Burkett and Thompson 1994). In Arizona, one amphibian, the Sonora tiger salamander (*Ambystoma tigrinum stebbinsi* Green) currently is found only in livestock stocktanks (Collins 1998). Stockponds and earthen tanks represent the bulk of occupied habitats for ranid frogs (*Rana* spp) widely extirpated from natural habitats (Rosen et al. 1995, Sredl and Howland 1995). These artificial habitats are managed as refugia and source populations for future frog reintroductions (Rosen and Schwalbe 1998). Sredl and Saylor (1998) found similar reproductive success in frog populations occupying human-made ponds and natural habitats.

Water developments also provide habitat for turtles. In Arizona, Sonoran mud turtles (*Kinosternon sonoriense* LeConte) were considerably more abundant in stocktanks than in stream pools (van Loben Sels et al. 1995). Yellow mud turtles (*K. flavescens* Agassiz) also were commonly found in stocktanks (Menasco 1986).

Adverse Impacts of Wildlife Water Developments

Critics suggest that water developments may adversely affect wildlife expected to benefit from these facilities. Four potential adverse impacts are commonly cited: predation, competition, direct mortality, and health problems resulting from poor water quality or disease transmission. Here, we evaluate the evidence supporting these contentions.

Predation

As reported elsewhere in this paper, avian and mammalian predators are attracted to water developments, leading some to suggest that these facilities may function as "predation sinks." The literature does contain references to predation at natural waterholes or water developments; typically anecdotal observations of individual predation events, inferences based upon indices of predator use, or discoveries of prey remains (Ballard et al. 1998, Cutler 1996). However, data on predator abundance

and predation rates at water developments versus unwatered areas are lacking. Consequently, the "predation sink" effect remains an untested hypothesis.

Competition

Several authors have suggested that water developments may exacerbate competition, particularly among native and exotic ungulates. Feral burros (*Equus asinus* L.) are strongly attracted to water developments, where they often deter use by desert bighorn (Weaver 1973). Consequently, many wildlife water developments are fenced to exclude burros and domestic livestock (Brigham 1990). In some areas, water developments have increased abundance of deer and burros, perhaps creating competition with desert bighorn for a limited forage base (Krausman and Leopold 1986b). Because desert bighorn are poor competitors (Geist 1985), such competition could adversely impact sheep populations. We note that the influence of water developments on competitive interactions among wild and domestic ungulates has not been directly studied. Consequently, presumed impacts of increased competition remain an untested hypothesis.

Direct Mortality

Water developments have caused direct mortality of wildlife that become trapped in these facilities. Mortalities of birds and small mammals in livestock troughs and other water facilities have been widely reported (Schemnitz et al. 1998, Scott 1998). Hoover (1995) found desert tortoise (*Gopherus agassizii* Cooper) remains in guzzlers in California. Mule deer and bighorn sheep have died after becoming trapped in earthen tanks and tinajas (Baber 1983, Arizona Game and Fish Dept., unpubl. data). Similar entrapment mortalities also occur in natural water catchments (Halloran and Deming 1958, Mensch 1969). Construction of access and escape ramps can reduce wildlife mortalities in natural and man-made water catchments (Wilson and Hannans 1977, Schemnitz et al. 1998). Detailed studies of wildlife mortality at water developments have not been conducted; however, we suggest that these mortalities are probably negligible from a population perspective. In some situations, water developments may reduce wildlife mor-

talities. Provision of alternative water sources reduced drowning of mule deer and other ungulates attracted to deep, concrete-lined canals (Rautenstrauch and Krausman 1989b).

Hunters also harvest wildlife at water developments. Species commonly taken at these facilities include: deer, elk, band-tailed pigeon (*Columba fasciata* Say), Merriam's turkey, and waterfowl (S.R., J.D., pers. obs.). Ethical aspects of hunting at water developments have been a source of debate among some sportsmen; however, to our knowledge, adverse biological impacts have not been identified or suggested.

Water Quality

Poor water quality is a significant concern at some water developments; however the impacts on wildlife are largely unknown. In summer, some Arizona catchments contained potentially toxic algae, bacteria, hydrogen sulfide, and ammonia (Kubly 1990, Schmidt and DeStefano 1996). Modification of tinajas to increase storage capacity can prevent flushing during runoff events, and may exacerbate water quality problems (Kubly 1990). Consumption of water-borne toxins has been suggested as a potential explanation for desert sheep mortalities near waterholes, as well as sudden, unexplained sheep dieoffs (deVos and Clarkson 1990, Broyles 1995). However, data supporting these hypotheses are lacking. High levels of dissolved minerals may reduce water quality in some water developments, particularly those fed by groundwater (Kubly 1990). In Wyoming, pronghorn avoided water with >5000 ppm total dissolved solids (O'Gara and Yoakum 1992).

It has been suggested that desert water developments facilitate transmission of wildlife diseases, but there are limited data supporting this contention. We found only 1 documented case of wildlife mortality caused by disease spread from a water development (Swift 1996). In California, desert bighorn lambs drowned in the storage tank of a water catchment, apparently while trying to obtain water. The decomposing carcasses provided a substrate for *Clostridium botulinum* bacteria. Subsequent release of botulinum toxin into the drinker resulted in the deaths of ≥45 sheep. Broyles (1995) speculated that water developments might facilitate

spread of *Trichomonas gallinae*, a protozoan parasite that causes avian trichomoniasis. Trichomoniasis outbreaks have occurred in urban areas where birds concentrate at feeders and birdbaths; however, transmission of trichomoniasis via wildlife water developments has not been documented (Arizona Game and Fish Department 1988, Brown 1989:267). A recent study (Hedlund 1996) suggested that water-borne transmission of *Trichomonas* may not be as common as previously thought.

Net Benefits of Wildlife Water Developments

We contend that water developments have benefitted some wildlife populations in arid habitats of the western U.S. Increased availability of surface water has increased the distribution and or abundance of popular and economically important game species such as mule deer, white-tailed deer, elk, chukar, and Merriam's turkey, and has increased opportunities for wildlife observation and harvest. Water developments also benefit nongame wildlife, particularly birds, bats, and amphibians. Perceived negative impacts of water developments on wildlife resulting from predation, competition, direct mortality, and disease are not supported by data and remain largely speculative. However, we recognize that the ecological effects of water developments are poorly understood, and in some cases, expected benefits to game species and other wildlife have not occurred.

Management Implications

Given the high cost of water development construction and maintenance, we believe that resource management agencies should invest more effort in planning, monitoring, and managing these facilities.

In the past, water developments were considered inherently beneficial to wildlife, wherever they were constructed. Following decades of effort by resource managers, we believe that many suitable locations for wildlife water developments have been utilized, and in many areas, scarcity of water no longer limits wildlife populations. Merely

adding new water sources to the landscape is no longer adequate justification for new projects. Therefore, we recommend that future wildlife water development projects should: (1) have a solid biological basis, (2) reflect clearly articulated management objectives, and (3) include a formal economic benefit:cost analysis. We also recommend that managers consider options to enhance the habitat value of existing water developments, particularly earthen tanks.

Monitoring is a key component of modern resource management, and in our opinion, an under emphasized element of water development programs. Six of the western U.S. state wildlife agencies we contacted had conducted resource monitoring associated with water developments. Monitoring was typically of limited duration and intensity, and focused on water availability, water quality, and observations of animals visiting these facilities.

We recommend that resource management agencies expand formal monitoring of wildlife water developments. Well-designed monitoring would facilitate data-driven management of water development programs and more efficient use of labor and capital resources. Monitoring efforts should reflect clearly defined management objectives, and use standardized methods to measure resource outputs such as: wildlife distribution, population performance, harvest rates, hunter-days, and hunter success. We also recommend that resource managers conduct regular, site-specific assessments of individual water developments; to decide if they should be maintained in their existing state, modified, abandoned, or removed.

Research Needs and Design Considerations

Despite the tremendous investment in wildlife water developments, there have been few studies examining their ecological effects. Recent studies have furthered our understanding of water development impacts on non-game wildlife; however, most information on the response of game species is anecdotal, observational, or derived from research designed to address other questions. Studies of wildlife water developments frequently have been compromised by 1

or more design weaknesses, including: lack of replication, non-independence of watered and unwatered sampling units, small sample sizes, short study periods, and potential confounding by weather and other effects. In addition, many studies used animal abundance as a response variable, a potentially misleading indicator of habitat quality (VanHorne 1983). Because of these limitations, our knowledge of wildlife water development effects rests on a shaky foundation.

Clearly, there are important, unanswered questions concerning the ecological impacts of water developments, as well as their efficacy in meeting wildlife management objectives. We believe that research on wildlife water developments should be a high priority. Specifically, we suggest that researchers focus on 5 topic areas: (1) effects of water developments on the population performance, distribution, and habitat use of game and non-game wildlife species; (2) effects of water developments on mammalian predator population performance, distribution, habitat use, and predation rates; (3) water quality in catchments versus natural water sources; (4) secondary effects of water developments on adjacent plant communities; and, (5) the role of water developments in transmission of wildlife diseases.

Future studies of water developments need to be long-term, capturing an adequate range of variation in climatic conditions and other temporal phenomena affecting wildlife populations (deVos et al. 1998). In the southwestern U.S., we believe that studies ≥ 10 years in duration would likely be required to distinguish "natural" variation from treatment effects. Such studies also need to be conducted at a spatial scale appropriate to the research questions and species of interest.

To develop clear cause-and-effect relationships, researchers must experimentally manipulate water developments. We envision 2 general types of experiments, each testing a different hypothesis and management option. The first type of experiment would test effects of water addition, by constructing new water sources in areas previously lacking such developments. The second type would test effects of water removal, by manipulating water availability at existing developments. We acknowledge that attaining true replication of experimental treatments will be

difficult or perhaps impossible in some cases. In such circumstances, alternative approaches developed for impact assessment studies, such as the Before-After-Control-Impact-Pairs design (Stewart-Oaten et al. 1986, 1992) could be used.

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