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ECOLOGY OF DESERT MULE DEER

IN SOUTHWEST ARIZONA

by

Kurt Robert Rautenstrauch

A Dissertation Submitted to the Faculty of the

SCHOOL OF RENEWABLE NATURAL RESOURCES

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY
WITH A MAJOR IN WILDLIFE AND FISHERIES SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Kurt Robert Rautenstrauch

entitled Ecology of Desert Mule Deer in Southwest Arizona

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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Paul R. Krausman	20 April 1987 Date

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Paul R. Krausman
Dissertation Director

20 April 1987
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ABSTRACT

I evaluated methods of preventing desert mule deer from drowning in the concrete-lined Mohawk Canal, southwest Arizona, and monitored the movements of deer using this canal. A 15 km study section of the Mohawk Canal where most previous drownings occurred was checked 478 times from June 1982 through September 1985 and 5,307 deer-canal interactions (DCI) were recorded. Ninety-eight percent of the DCI were recorded from April through September. Deer fell into this canal $\geq$ 279 times: 116 escaped via steps, 79 via ramps, and 50 escaped unaided. Only 5 deer drowned in sections of the Mohawk Canal with escape structures; 7 deer and 2 bighorn sheep drowned in sections without escape structures. Deer approached the canal to drink, not to cross. Maintaining depths to water of $\leq$ 30 cm will reduce the number of deer falling into the canal. The Mohawk Canal escape structures are adequately designed and spaced to prevent most summer mortalities. Deer use of 2 water catchments built to provide alternate water sources for deer drinking from the Mohawk Canal increased significantly each year. Each time a deer drank from these catchments was one less opportunity for a deer to fall into the canal.

I monitored desert mule deer movements in a xeric region of the Sonoran Desert from October 1982 through November 1984 to determine the influence water availability and rainfall patterns have on deer movements. Ten of 15 radio-collared deer monitored for > 1 year migrated to areas with permanent water in April or May and left those areas soon after summer rains started. Deer did not migrate to areas receiving the most summer rainfall. Home range sizes are larger (annual $\bar{x}$ = 145.2 km^2, range = 47.0 - 566.6 km^2) than any previously reported for mule deer.

INTRODUCTION

Over 12,000 km of concrete-lined canals carry water from rivers and reservoirs to industrial, residential, and agricultural users throughout the western U. S. (Rautenstrauch and Krausman 1986). Unfortunately, thousands of deer (*Odocoileus* spp.) and other ungulates have drowned in these canals while attempting to cross or drink from them. Wild ungulates have drowned in ≥ 21 canals in 9 western states and 1 Canadian province (Rautenstrauch and Krausman 1986).

Concrete-lined canals are hazards to ungulates because canals disrupt movements and are attractive nuisances. Fences, bridges, and alternate water sources have been built to prevent animals from entering canals, and steps, ramps, and directional devices have been developed to allow entrapped animals to escape, but few of these attempts have been successful (Busch, Rorabaugh, and Rautenstrauch 1984)

Desert mule deer (*O. hemionus crooki*) (Furlow 1969, Guenther, Sharpe, and Strauss 1979), mountain sheep (*Ovis canadensis mexicana*) (Gubser 1960), and Sonoran pronghorn antelope (*Antilocapra americana sonoriensis*) (Anon. 1981) have drowned in the Mohawk Canal, southwest Arizona, and other canals in the Wellton-Mohawk Irrigation and Drainage District (WMIDD). At least 170 desert mule deer drowned in WMIDD canals from 1977-1980 (Rautenstrauch and Krausman 1986).

The objectives of the first part of this study were to evaluate the effectiveness of steps, ramps, and directional cables designed to allow entrapped mule deer to escape from the Mohawk Canal, and to determine if alternate water sources would decrease the number of deer using the Mohawk Canal.

To evaluate the effectiveness of methods developed to prevent deer drownings, an understanding of the function the canal has in the ecology of the desert mule deer population is needed. Where do deer entering the canal come from; are they from local populations, passing from one area to another, or are they attracted to the canal from far away? Does the canal create a barrier between areas used by deer? Why do deer in this arid region use the canal; are they attracted to it for water, crops and other green forage, or for some other reason? To answer these questions I also studied the movements of deer using the Mohawk Canal.

To survive in arid environments, large mammals decrease activity and rest in shade during high temperatures (Leuthold 1977, Leopold and Krausman 1987); select forage with high water content (Taylor 1968, 1969, Krausman 1978); and migrate to areas with permanent water, isolated rainfall, or green forage (Western 1975, Newby 1984). Water dependent ungulates in the Sahara Desert (Newby 1984), the Amboseli (Western 1975) and Serengeti (Pennyquick 1975, Maddock 1979) savannahs of east Africa, and the Kalahari Desert of southern Africa (Bothma and Mills 1977) migrate between dry season areas with permanent water and wet season areas with greater forage availability. Red kangaroos (Macropus rufus) (Low et al. 1981), African elephants (Loxodonta africana) (Leuthold and Sale 1973) and North African ungulates (Newby 1984) migrate to areas that recieve isolated rainfall and green forage.

Ungulates inhabiting North American deserts are generally nonmigratory (Dickenson and Garner 1979, Monson and Sumner 1980:127, Krausman 1985), although McLean (1930) and Longhurst and Chattin (1941) suggested that desert mule deer in southeast California migrate to areas receiving geographically isolated rainfall and having the most green forage; however, this has not been documented. Mule deer movements have not been studied in the most xeric mule deer habitats where permanent water sources are widely scattered.

The objectives of the second part of this study were to monitor mule deer movements in an area with low rainfall and few permanent water sources to determine the influence water availability and rainfall patterns have on desert mule deer movements. I hypothesized that desert mule deer inhabitating areas with scattered resources would have large home ranges and would use that part of their home range having the most nutritious and succulent forage.

STUDY AREA

The Mohawk Canal

The WMIDD delivers water year-long from the Colorado River at Imperial Dam, 23 km northeast of Yuma, Arizona, to Dome Valley via the Dome Canal, and to the Mohawk Valley via the Wellton, Mohawk, and Texas Hills Canal (Fig. 1). Most WMIDD deer drownings have occurred during the summer dry season and winter droughts along a 15 km section of the Mohawk Canal that I monitored (Furlow 1969, Guenther et al. 1979, Rautenstrauch and Krausman 1986) (Fig. 1).

The dimensions of the Mohawk Canal along the 15 km study section I studied are relatively small. It has a top width of 10 m for 2.2 km, 8 m for 10.1 km, and 5.5 m for 2.7 km. The side slope is 1.25 horizontal:1 vertical. It has 6 dams, 4 vehicle bridges, and 1 railroad crossing with a siphon.

There are 8 operational escape structures in the study section located an average of 2.1 km apart. Each dam has a set of deer escape steps built into the north canal wall < 5 m upstream from the dam. One set of stairs are 2 steps deep, the others are 3 deep. Each step is 2.2-3.1 m long and 30 cm wide and deep.

There are 3 deer escape ramps in the study section. The ramps are recessed into the north canal wall at a 25^{o} angle to the direction of water flow, extend to the bottom of the canal, have a slope of 4:1, and

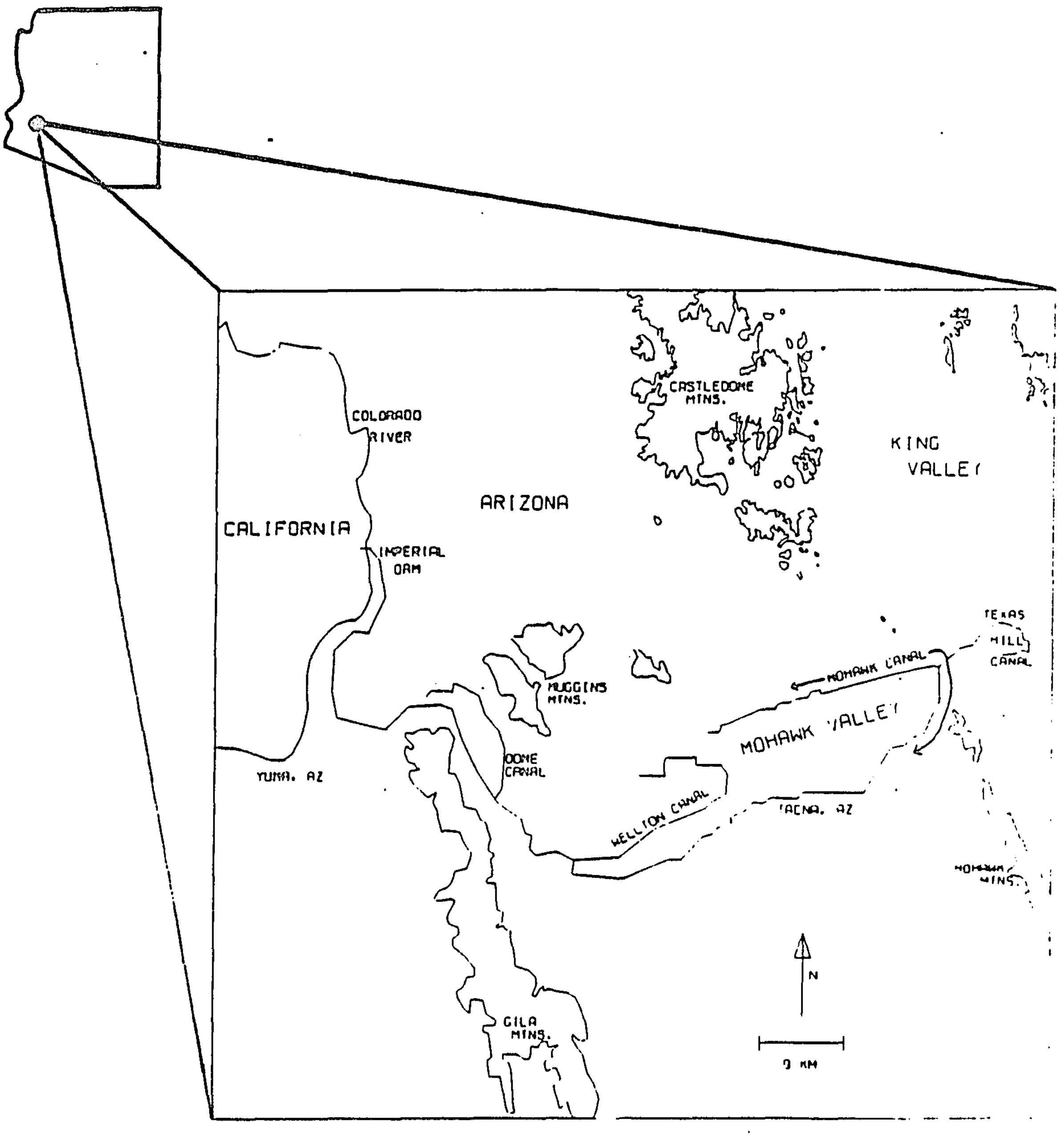

Figure 1. The Wellton-Mohawk Irrigation and Drainage District, southwest Arizona.

are 3 m wide (Appendix A). There is also a 1.3 m wide angle-iron ladder and 7 reinforcement bar maintenance ladders in the study section.

All steps and ramps have a 3 cm diameter wire cable stretched across the canal at water level to direct entrapped deer toward the escape structure. Each cable is at a 45^{o} angle to the direction of water flow. The downstream end of the cable is attached to the downstream end of the steps or ramp. Each cable has $\geq$ 20 plastic floats (20 X 10 cm) attached to keep the cable at water level and increase its visibility.

King Valley

The study section of the Mohawk Canal separates the agricultural fields at the northern edge of the Mohawk Valley from the desert vegetation at the south end of King Valley (Fig. 1). King Valley, elevation 92 - 450 m, is in the Lower Colorado River subdivision of the Sonoran Desert (Turner and Brown 1982). Vegetation in the valley bottom is restricted to the drainages, which are dominated by ironwood (*Olneya tesota*) and palo-verde (*Cercidium* spp.). Areas between drainages have sparse ($\bar{x}$ density = 4 perennial plants/ha) stands of creosotebush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) (Krausman, Rautenstrauch, and Leopold 1985b). The surrounding mountains, maximum elevation 1,487 m, are in the Arizona Upland subdivision of the Sonoran Desert (Turner and Brown 1982).

The Arizona Game and Fish Department built Wellton-Mohawk Catchments 1 and 2 in 1980 and 1983, respectively, < 4 km north of the Mohawk Canal to provide alternate water sources for deer. There are 17 other permanent water sources in the Palomas Plain and mountains surrounding King Valley, but no permanent water sources in the middle of King Valley (Fig. 2).

Climate

This region has hot, dry summers and mild winters. Thirty-six percent of the 11.4 cm average annual precipitation falls during July through September in geographically isolated thunderstorms; 51% occurs during geographically widespread rainfall from November through March. The average daily minimum temperature during December - February is 1.5 C, and the average daily maximum temperature from June - August is 40.9 (Sellers, Hill, and Sanderson-Rae 1985).

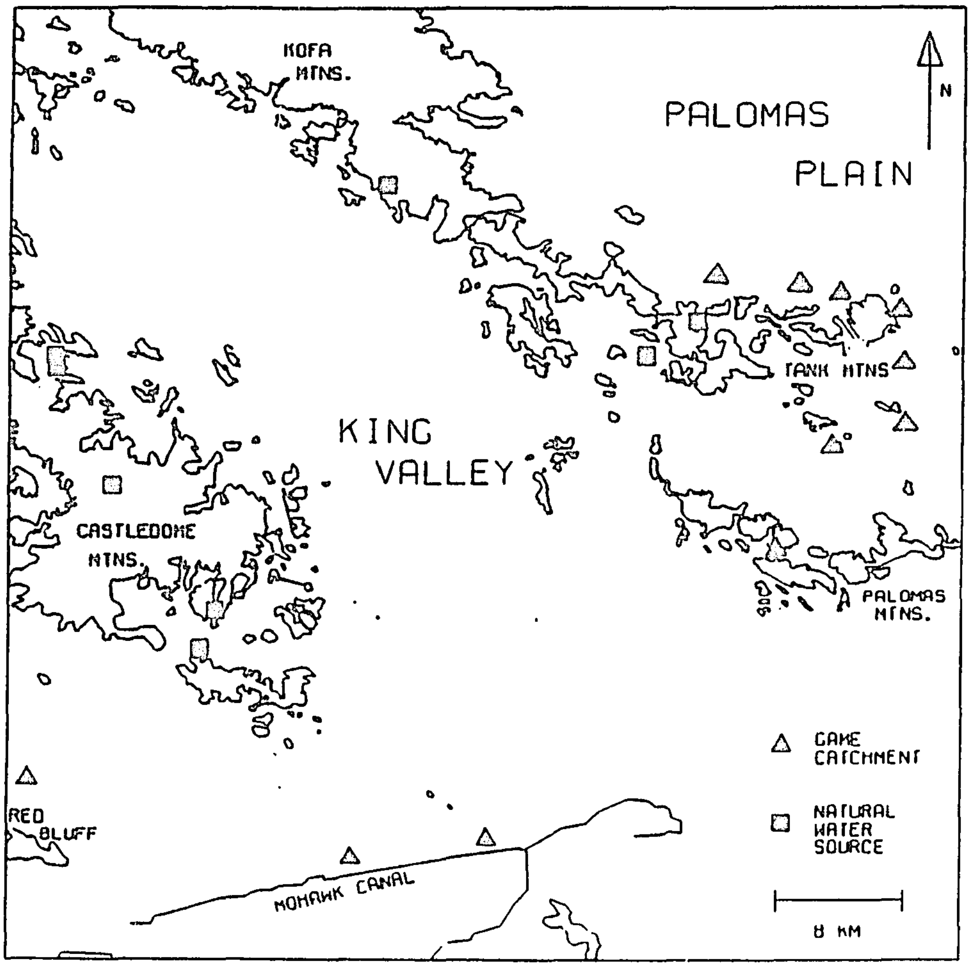

Figure 2. Permanent water sources accessible to mule deer in the region surrounding King Valley, southwest Arizona, in 1983 - 1984.

METHODS

Deer-Canal Interactions

From June 1982 through September 1985, I monitored deer activity along the 15 km study section of the Mohawk Canal by driving the north maintenance road looking for deer tracks. I checked the study section daily when deer were using the canal and every 3 days when they were not. When tracks were found I recorded the location of the deer-canal interaction (DCI), the number of deer, and the depth to water (cm of exposed concrete lining from the top of the canal lining to the water level, i.e. freeboard) if I was sure the DCI occurred within the past 24 hours. I also determined if the deer (1) walked along the north canal road < 20 m before drinking, (2) walked along the north canal road > 20 m before drinking, (3) did not drink, (4) fell in the canal, or (5) used a bridge or dam to cross to the south side of the canal. The Kruskal-Wallace multiple sample comparison test was used to determine if depth to water differed among these behaviors. When a deer fell in the canal I recorded the depth to water if I was sure the DCI had occurred within the past 24 hours, and the location where the deer escaped if it could be accurately determined.

To determine if entrapped deer die after escaping from the Mohawk Canal, I radiocollared 5 deer after rescuing them from the canal. Four of these deer and 2 previously radio-collared deer seen in the canal were located $\geq$ 1 time/2 hours for the first 12 hours after they escaped, $\geq$ 1 time/6 hours for the next 2 days, and weekly for $\geq$ 2 months. This technique can overestimate post-escape survival because rescued deer may spend less time in the canal and have a smaller possibility of injury than other entrapped deer.

Deer Use of the Mohawk Catchments

I used track plots to determine the time of year that deer were drinking from the Wellton-Mohawk Catchments. The track plots were checked and cleared at least weekly. I used Kodak Analyst Super 8 movie cameras programmed to expose 1 frame/minute during daylight hours to index deer use of the catchments from 15 May to 31 August each year. I recorded the number of deer photographed/camera day as described by Remington et al. (1984). A 2-way analysis of variance (ANOVA) of deer/camera day x month x year was used to determine if deer use of the catchments varied between years. Deer/camera day was transformed by the square root to achieve homogeniety of variances.

Deer Movements

I used a Bell Jet Ranger helicopter to capture seven male and nine female mule deer in King Valley in 1982 and 1983. Deer were drugged with etorphine plus azaperone (Krausman et al. 1986) administered with a Cap-Chur rifle, dart, and projectile syringe (Palmer Chemical and Equipment Co., Inc., Douglasville, GA) (deVos and Remington 1981) or captured with a net gun (Krausman, Hervert, and Ordway 1985a). Three females and one male were radiocollared after being rescued from the Mohawk Canal. Radio-collared deer were located weekly from a fixed-wing aircraft (Krausman, Hervert, and Ordway 1984) from November 1982 through October 1984.

The Fourier method (Anderson 1982) was used to calculate minimum area vs. 75% probability (MAP[0.75]) home range size estimates to compare home range size among seasons and between sexes. I used this method because it makes no assumptions about the probability distribution of an animal's use distribution, sample size bias is limited, and it omits areas within the perimeter of an animal's home range that are rarely used (Anderson 1982). I also present minimum convex polygon (MCP) (Southwood 1978:338) estimates of home range size to compare with other studies. MAP(0.75) estimates were transformed by ln to achieve homogeniety of variances and a multiple ANOVA was used to test for differences in MAP(0.75) among seasons and between sexes and years. Home ranges were only calculated when individual deer were located $\geq$ 8 times/season.

A multiple ANOVA of season by sex by year was used to test for differences in the straight line distance from deer locations to permanent water. Distances from water were transformed by the square root to achieve homogeniety of variances. One-tailed *t*-tests were used to compare average seasonal distances from water to the average distance from an equal number of random points in the study area to water.

Deer were considered migratory if their winter and summer dry season MCP home ranges did not overlap. Distance migrated was calculated as the straight line distance between the geometric centers of 2 seasonal home ranges.

Rainfall was measured at 20 rain gauges located approximately 5 km apart in King Valley and the Palomas Plain. These gauges were checked 1 time/2 weeks during the summer rains and 1 time/month during other seasons. I kept 1 cm of mineral oil in each gauge to prevent evaporation. Long-term weather data are from the Tacna (1969 - 1982) and Kofa Mine (1952 - 1982) weather stations at the extreme south and north ends of King Valley, respectively (Sellers et al. 1985).

Seasons were based on rainfall and temperature patterns and deer's water requirements. Seasons were defined as follows: winter = November - January, spring = February - the day before deer began drinking from the water sources at the south end of King Valley (Rautenstrauch and Krausman 1986), summer dry = the first day deer drank from the water sources at the south end of King Valley (19 May 1983 and 5 May 1984) - the day before the first summer rain in the study area, summer wet = the first summer rain (24 July 1983 and 1 July 1984) - October.

I tested if forage quality differed between areas used by deer during the wet and dry seasons by measuring the nutritional quality of 7 plants frequently eaten by deer (Rautenstrauch and Krausman, unpubl. data). Each species was collected bimonthly in 2 areas from September 1983 to August 1984. One area was 2 - 3 km north of the Mohawk Canal in washes frequently used by radio-collared deer during the dry season but rarely used during the rest of the year. The second area was in washes in the middle of King Valley, 9 -10 km from permanent water, where radio-collared deer were located in all seasons except the summer dry season. At least 150 g of plant material/species were collected from ≥

10 individual plants and analysed for dry matter, protein, ether extract, cell solubles, cellulose, hemicellulose, and lignin (Assoc. of Official Agric. Chemists 1980). Repeated measures ANOVA of each nutritional parameter was used to determine if these parameters differed between sites.

PREVENTING MULE DEER DROWNINGS IN THE MOHAWK CANAL, ARIZONA

I monitored the Mohawk Canal 478 times from June 1982 through September 1985 and recorded 5,307 DCI. Most (98%) DCIs occurred from April through September; 96% occurred before the start of the summer rains.

Seventy one percent of the DCI were from deer that drank from the canal and returned to the north. Deer did not drink or I was unable to find where they drank in 23% of the DCI. Only 27 (0.5%) of the DCI were from deer that crossed the canal.

The average depth to water for DCI when deer drank was significantly less than when deer did not drink or when they fell in (Table 1, $\underline{P} < 0.001$). The number of DCI where deer drank and returned to the north decreased at depths to water > 30 cm. Eighty percent of the DCI where deer fell in or did not drink occurred at depths to water > 30 cm.

Deer fell into the 15 km study section of the canal $\geq$ 279 times (5% of all DCI). Of these deer, 116 escaped via steps, 79 via ramps, 8 via metal ladders, 10 were pulled out alive, 50 escaped unaided, and I was unable to determine where 16 escaped. The average distance deer swam before escaping via escape structures was 947 m (SE = 51.07, range = 1 - 3770). Deer swam over or under cable directors 11 times.

Twelve deer and 2 mountain sheep drowned in the WMIDD during our study. Only 3 of these deer drowned in the study section; all 3 were

Table 1. The $\bar{x}$ depth to water (cm) recorded for each of 4 deer-canal interaction types in the Mohawk Canal, Arizona, from 1982 through 1985. Averages with the same capital letter are not different at alpha = 0.05, as determined by the Kruskal-Wallace multiple sample comparison test.

	Deer-canal interaction type			
	1[a]	2[b]	3[c]	4[d]
$\bar{X}$ depth to water	29A	34B	58C	56C
N observations	1,681	557	585	129

[a]Deer approached canal from north, drank, and returned directly to north.

[b]Deer walked along canal road or bank for > 20 m before or after drinking.

[c]Deer did not drink or evidence of drinking was not found.

[d]Deer fell in the canal.

found at dams equipped with steps. Three dead deer were found at dams 1.2 km and 2.8 km west of the study section. There are 2 step escape structures at these dams, but 1 set of steps did not have a cable director. Six deer drowned in the Texas Hill Canal and the 2 mountain sheep drowned in the Dome Canal. There are no escape structures in these 2 canals.

All radio-collared deer monitored after escaping unaided from (N = 2) or being rescued from (N = 5) the Mohawk Canal bedded down $\leq$ 6 hours after escaping and were active again the next evening. All survived $\geq$ 2 months after escaping from the canal.

The number of deer/camera day increased significantly each year at Catchment 1 (P = 0.03), from 0.3 in 1981 to 6.0 in 1985. I found deer tracks in the Catchment 1 track plots only during those months when > 40 DCI were recorded at the canal. Deer/camera day also increased significantly every year at Catchment 2 (P = 0.001), from zero in 1983 to 2.6 in 1985. Tracks were found at this catchment during every month in 1984 and 1985 that > 40 DCI were recorded at the canal except September 1984, when no tracks were observed at the catchment.

Discussion and Management Implications

The first step in determining how to prevent ungulates from drowning in a canal is to find out why they are attracted to and fall into that canal. Ungulates may drown while attempting to reach water in or forage near canals, or while attempting to cross canals that interfere with their movements (Busch et al. 1984).

Four facts suggest that most deer fall in the Mohawk Canal while attempting to drink. First, 96% of the deer activity along the Mohawk Canal occurred from April to the start of the summer rains, when desert mule deer are most stressed for water (Hervert and Krausman 1986). Second, I began observing deer activity at the canal in 1983 and 1984 at the same time radio-collared deer made long movements to water sources surrounding King Valley. Third, deer crossed the canal only 27 times. Many deer passed bridges while walking on the north canal road before drinking or returning to the north. Fourth, only 2 of the 50 deer that escaped unaided exited on the canal's south side.

Because deer rarely crossed the Mohawk Canal, building additional bridges will probably not reduce deer drownings. The best ways to prevent deer from drowning in the Mohawk Canal are to prevent deer from entering the canal and to provide escape structures for entrapped deer.

Evaluation of Escape Structures

The steps and ramps with cable directors are effective escape structures. At least 195 deer used these structures to escape and only 4 deer drowned in sections equipped with complete escape structures. The cable and float directors are an important part of these structures. The Mohawk Canal steps were not effective before the directors were added (Guenther et al. 1979). Although deer can swim over and under these cables, they rarely did during this study. The cables are inexpensive, easy to maintain and replace, and do not interfere with water delivery.

The Mohawk Canal escape structures are adequately located and spaced to prevent most summer mortalities. To allow all entrapped deer to escape from a canal, every section starting and ending with a dam, siphon, or pump station must have $\geq$ 1 escape structure, preferably just upstream from the dam or siphon.

Although steps and ramps are both effective, each has certain advantages. Steps can be cut into an already existing canal wall without disturbing the adjacent berm or maintenance road and may be less expensive to build. If ramps and steps are equally effective, it would be better to build more steps placed closer together than fewer ramps.

Ramps have some advantages in canals that are seasonally empty or have greater water velocities than the Mohawk Canal. Deer trapped in fast water can be swept past steps before they can use them; ramps cut deep into a canal wall create an area of slower water velocity. Deer may not be able to reach steps if the water level is below the lowest step; deer can escape via ramps that extend to the canal bottom even when the canal is empty. Ramps also provide a safe place for deer to drink in sections of a canal where water levels are always low.

Escape structures only 2 steps deep may not be as effective as those with 3 steps. Four of the 6 deer that drowned in the Mohawk Canal were found in sections with 2 step escape structures. The second step may be too shallow for deer to reach with their back legs. I recommend that step-type escape structures have $\geq$ 3 steps.

I also recommend that metal maintenance ladders be built only where necessary for human safety in canals near ungulate populations. Deer rarely used these ladders to escape and could easily slip off of one and break a leg.

I was unable to determine if the Mohawk Canal escape structures will prevent deer drownings or hypothermia induced mortality during winter droughts. There were no winter droughts during this study. Deer, especially fawns, that fall into the Mohawk Canal during the winter may have a higher mortality rate than deer falling in during the summer (Rautenstrauch and Krausman 1986). Forty, 32, and 48 deer drowned during winter droughts in 1968 (Furlow 1969), 1979, and 1980 (WMIDD, unpubl. data), respectively. It may be necessary to place escape structures closer together in canals in colder climates so deer can quickly escape from the colder water.

Preventing Deer From Entering the Mohawk Canal

The 2 most efficient ways to prevent deer from entering the Mohawk Canal are to maintain high water levels and provide alternate water sources. Fencing would probably not work along this canal because the canal access roads are frequently used by the public; therefore, it would be difficult to keep gates closed. Fences must completely seal a canal section to be effective.

Maintaining Water Levels. I recommend that managers maintain depths to water $\leq$ 30 cm in places where deer frequently drink from canals. Deer drink from the Mohawk Canal by sliding their front hooves down the canal wall as they lower their heads. Deer fall in if they lose control while sliding or if they lean too far forward to reach water. Most (89%) of the deer that approached the canal when the depth to water was < 30 cm drank and returned to the north. Only 27 deer fell into the canal when the depth to water was ≤ 30 cm. Maintaining a high water level will, therefore, reduce the number of deer falling in and will also allow some entrapped deer to escape unaided. Guenther et al.1979) stated that deer are unable to escape unaided unless the water is within 31 cm of the top of the canal lining.

Alternate Water Sources. Because most deer fall in the Mohawk Canal while attempting to drink, providing alternate water sources should reduce deer use of the canal. Although deer use at the catchments increased each year, the number of DCI at the canal just south of the catchments did not decrease. The King Valley deer herd had unusually high fawn survival during this study (Ariz. Game and Fish Dep., 1985); therefore, the increased use of the catchments may have been due to an increase in the deer herd or to a change in the watering habits of some deer. However, even if the increased catchment use was caused only by an increase in the deer herd, there was less activity along the canal than there would have been without the catchments. Any deer that drank from the catchments would have had to drink from the canal if it remained at the south end King Valley during the dry season.

I recommend that any new catchments built in the south end of King Valley be ≥ 10 km north of the Mohawk Canal. The average distance radio-collared deer were located from water during the summer dry season was 4.6 km. At least 2 radio-collared deer that spent the summer dry season at the south end of King Valley drank from both Wellton-Mohawk Catchment 1 and the canal. Building catchments > 10 km from the canal will, therefore, prevent most deer from using both the catchment and the canal. Because deer were located most often in washes > 50 m wide (Krausman et al. 1985b), catchments should be built in the largest available wash.

Deer in King Valley have much larger home ranges than those reported for other mule deer and some deer in King Valley have knowledge of > 1 water source. Two radio-collared deer moved from the canal to water sources 42 - 44 km away during the middle of the summer, and 3 other deer that used the canal spent the winter and spring closer to water sources other than the canal. The 2 mountain sheep that drowned in the Dome Canal were radiocollared for other studies 72 and 95 km north of that canal. Therefore, all of the water catchments and natural tanks surrounding King Valley may influence the number of deer using the Mohawk Canal, and new water sources built within 50 km of the Mohawk Canal should reduce the number of deer using this canal.

MOVEMENTS AND HOME RANGE SIZE OF DESERT MULE DEER

All rain gauges had > 10 cm rainfall from winter 1982 through spring 1983, 70% greater than the long-term winter average. The first 1983 summer rain recorded was a 1.0 cm isolated shower at the north end of King Valley and in the Kofa Mountains on 24 July. It did not rain again in the area until 7 August. By 14 August all rain gauges had $\geq$ 2.5 cm rain, the amount necessary to cause desert plant growth (Beatley 1974). The northeast quarter of King Valley received the most summer rain ($\underline{x}$ = 5.3 cm) and the southeast received the least ($\underline{x}$ = 3.3 cm).

All rain gauges had < 4 cm rainfall during winter 1983 through spring 1984, 45% less than the long-term average. The first 1984 summer rain was on 1 July in the southwest corner of the study area and all gauges had > 2.5 cm rain by 15 July. The south end of King Valley received the most rain; however, the 1984 summer rainfall was the largest recorded to date and all gauges had > 10 cm.

The general annual pattern of movements for radio-collared deer was to use the middle of King Valley during the summer wet, winter, and spring seasons and migrate to permanent water or restrict movements to that part of their home range that contained permanent water during the summer dry season. Ten of 15 deer monitored for > 1 year used nonoverlapping areas during the winter and summer dry seasons, and 6 of these deer used nonoverlapping areas during the summer dry and summer wet through spring seasons. These 10 deer migrated an average of 14.2

km (range = 8.8 - 23.5) from the middle of King Valley to water sources surrounding the valley. No migratory deer's summer wet through spring home ranges had permanent water.

Four of the 5 deer that did not migrate spent the entire year at the south end of King Valley < 15 km north of the Mohawk Canal. These 4 does spent most (80% of 182 locations) of the summer wet through spring seasons > 5 km north of the canal and restricted most (71% of 60 locations) activity during the summer dry season to within 5 km of the canal. The fifth deer spent the entire study period within 9 km of a catchment in the southwest corner of the study area.

All migratory deer moved to their summer dry season home ranges from 30 days before to 10 days after the start of the summer dry season both years. No deer were found in the middle of King Valley > 8 km from water 10 days after the start of that season. Most migratory deer left their summer dry season ranges immediately following the start of the summer rains; 2 stayed near their summer ranges for > 1 month. All deer returned to the same areas they were in during the previous winter and spring, and the 8 deer monitored for 2 years generally used the same seasonal home ranges both years.

The distance from permanent water was significantly different among seasons ($\underline{P} < 0.001$) but not between sexes ($\underline{P} = 0.210$) or years ($\underline{P} = 0.893$). In all seasons the distance from random locations to water was significantly different from the distance of deer locations from water ($\underline{P} < 0.05$). The mean deer location distance was less than the mean random distance in the summer dry and greater in all other seasons (Fig. 3).

Deer in King Valley have large home ranges; the mean annual MCP home range size was 145.17 km^2 (Table 2). Home range size differed significantly among seasons (P = Ø.Ø29) and between sexes (P = Ø.Ø49) but not years (P = Ø.339) (Table 1). Males had larger home ranges than females in all seasons except the summer dry season, when 1 and 2 females moved 42 - 44 km between permanent water sources in 1983 and 1984, respectively.

Only 1 (ether extract) of 7 nutritional parameters measured differed significantly ($P \leq$ Ø.Ø5) between the dry season and wet season collection sites. I conclude that the nutritional quality of forage did not differ between these 2 areas.

DISCUSSION

Mule deer popuations studied to date are either nonmigratory (Severson and Carter 1978, Dickenson and Garner 1979, Krausman 1985) or migrate to avoid deep snow (Gruell and Papez 1963; Robinette 1966; Loft, Menke, and Burton 1984). This is the first mule deer population studied that migrates to find drinking water. Because wildlife management agencies have built game catchments and improved natural water sources in most desert mule deer habitat (Tueller 1976; Wallmo, LeCount, and Brownlee 1981), there are probably few other mule deer populations in the United States that must now migrate to find water.

No radio-collared deer migrated to the areas receiving the greatest summer rainfall instead of returning to their spring home

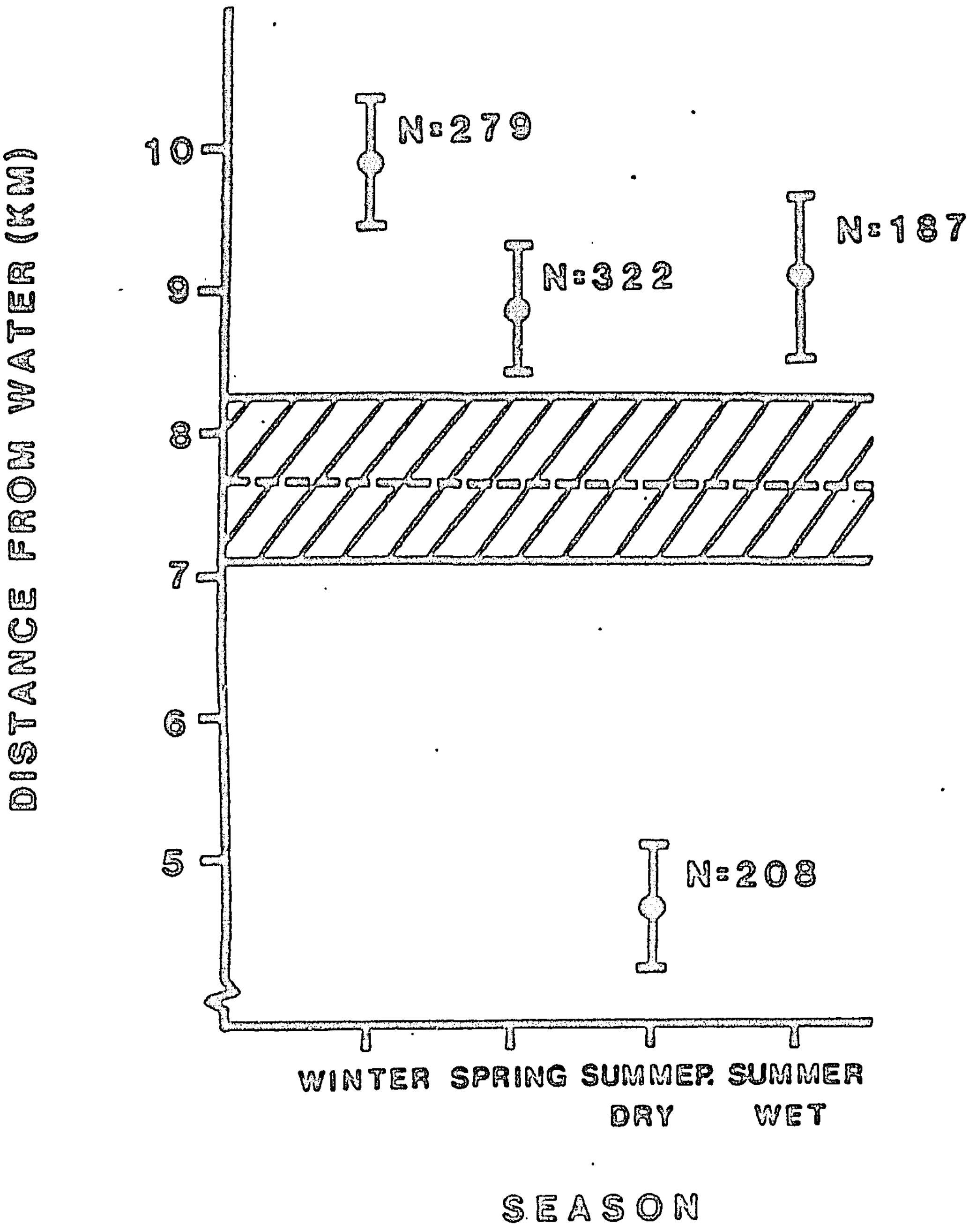

Figure 3. Seasonal distance from permanent water ($\bar{x} \pm$ 95% CI) for desert mule deer and 300 random points (shaded area) in King Valley, Arizona.

Table 1. The $\bar{x}$ annual and seasonal minimum convex polygon (MCP) and MAP(Ø.75) (Anderson 1982) home range size (km^2) of desert mule deer in King Valley, Arizona. MAP(Ø.75) was transformed by ln for a multiple analysis of variance (F = 1.95, P = Ø.Ø28). Values with the same letters are not significantly different at alpha = Ø.Ø5, as determined by Tukey's (1953 in SAS Inst., Inc. 1985) multiple comparison test.

	Season				
	Winter	Spring	Summer dry	Summer wet	Annual
MCP	53.82	68.38	48.65	34.86	145.17
MAP(Ø.75)					
Males	48.7Ø	65.48	32.Ø4	3Ø.53	99.6Ø
Females	34.52	54.27	35.73	22.16	6Ø.22
ln(MAP(Ø.75))	3.42AB	3.77A	3.ØØBC	2.72C	
N	29	28	25	24	22
SE[a]	Ø.14	Ø.15	Ø.23	Ø.22	

[a] Standard error of transformed seasonal home range sizes.

range, as some mammals in other arid region do (Leuthold and Sale 1973, Maddock 1979). However, the entire study area received > 2.5 cm rainfall both summers. In years when only few isolated summer storms occur deer may migrate to areas recieving those storms as McLean (1930) and Longhurst and Chattin (1941) suggested. The movements of 2 radio-collared deer may indicate that deer can detect and react to distant rainfall. By 27 July, 1983, 1 doe returned 32 km from the Palomas Plain, where it had not rained, to the area at the north end of King Valley where it rained on 24 July. A second doe, captured in the Mohawk Canal in June 1983, moved 25 km north of the canal to the area where it had rained by 27 July, and spent the next 8 months in that area; it did not rain within 10 km of the canal until 7 August. Red kangaroos (Low et al. 1981) and elephants (Leuthold and Sale 1973) may also be able to detect distant rainfall.

Deer avoided the south end of King Valley in all seasons except the summer dry season. Migratory radio-collared deer that used that area during the summer dry season left soon after the summer rains started, and the nonmigratory deer spent most of the summer wet through spring seasons > 5 km north of the canal. In November 1982 I saw 1 deer in King Valley ≤ 10 km north of the Mohawk Canal during 5 hours of helicopter flight and 53 deer during 9 hours flying > 10 km north of the canal. Radio-collared deer that used other summer dry season areas also left those areas soon after the summer rains started.

Deer are not migrating away from their summer dry season areas to find a different type of habitat or more nutritous forage. The vegetation composition at the south end of King Valley is similar to the rest of the valley and forage nutritional quality did not differ between the 2 areas sampled. Deer concentrating near permanent water sources during the summer dry season may decrease forage availabiltiy in those areas, making it advantageous for deer to migrate when water becomes available in other parts of the valley.

Mule deer in King Valley have larger home ranges than those reported for mule deer in Utah (Robinette 1966), California (Dasmann and Taber 1956), Oregon (Miller 1970), New Mexico (Eberhardt and White 1985), Texas (Dickenson and Garner 1979), South Dakota (Severson and Carter 1978), and central Arizona (Krausman 1985). This supports McNab's (1963) hyothesis that animals have larger home ranges in deserts and other areas where resources are scattered. Because deer habitat in King Valley consists of long, narrow washes and their associated vegetation separated by wider bare areas, deer must move long distances to forage in a relatively small area of habitat.

APPENDIX A

Diagrams of the Mohawk Canal Deer Escape Ramps

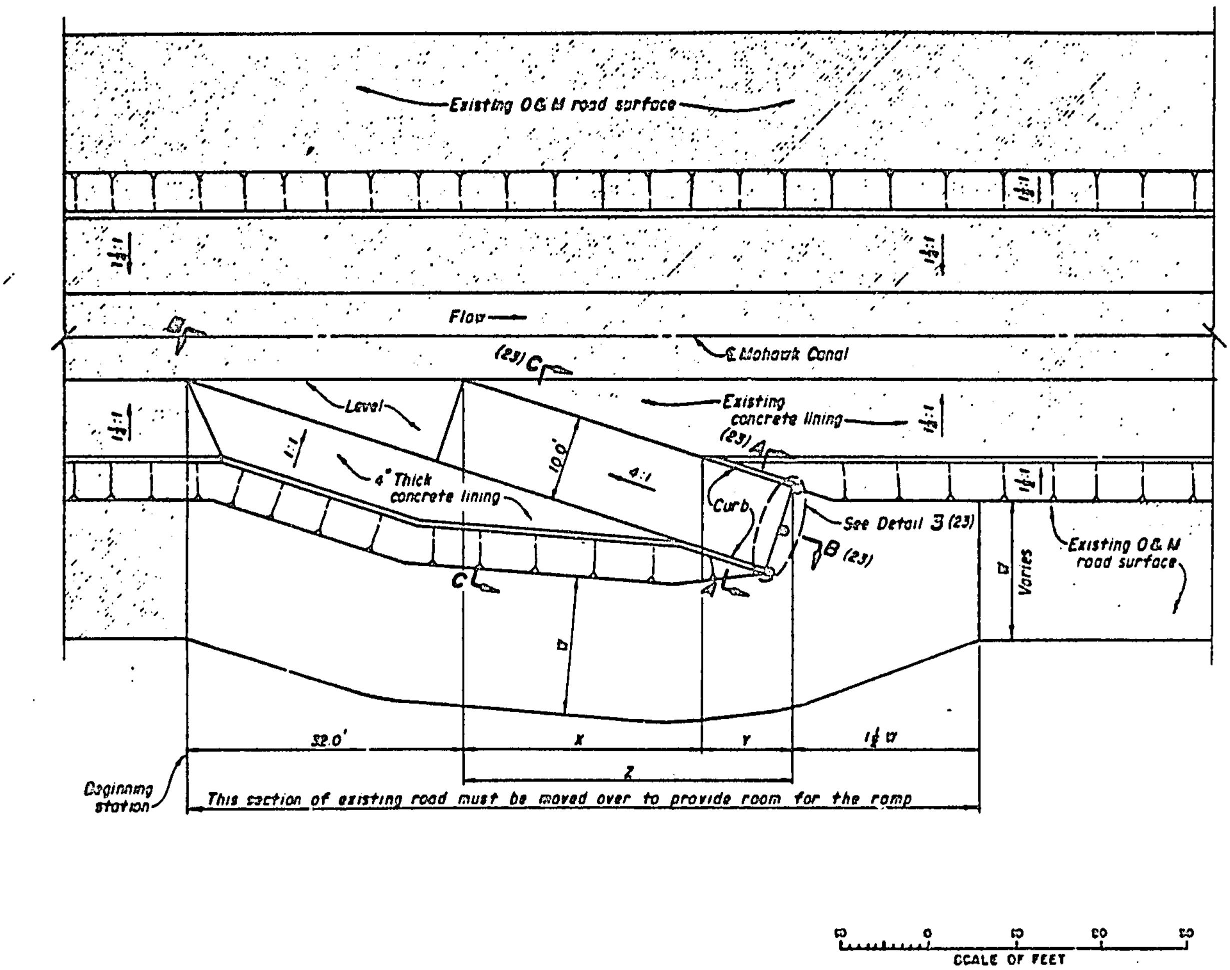

Figure 1. Schematic diagram of the Mohawk Canal, Arizona, deer escape ramps. A-A, B-B, and C-C refer to the cross-sectional diagrams in Figures 2, 3, and 4, respectively (W = 16.0 ft., X = 25.5 ft, Y = 6.1 ft, Z = 31.5 ft).

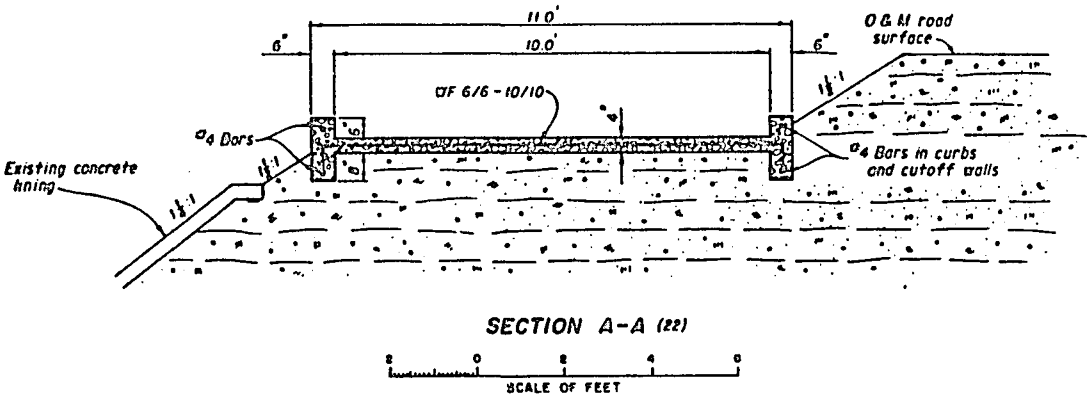

Figure 2. Cross-sectional diagram of the top of the Mohawk Canal, Arizona, deer escape ramps.

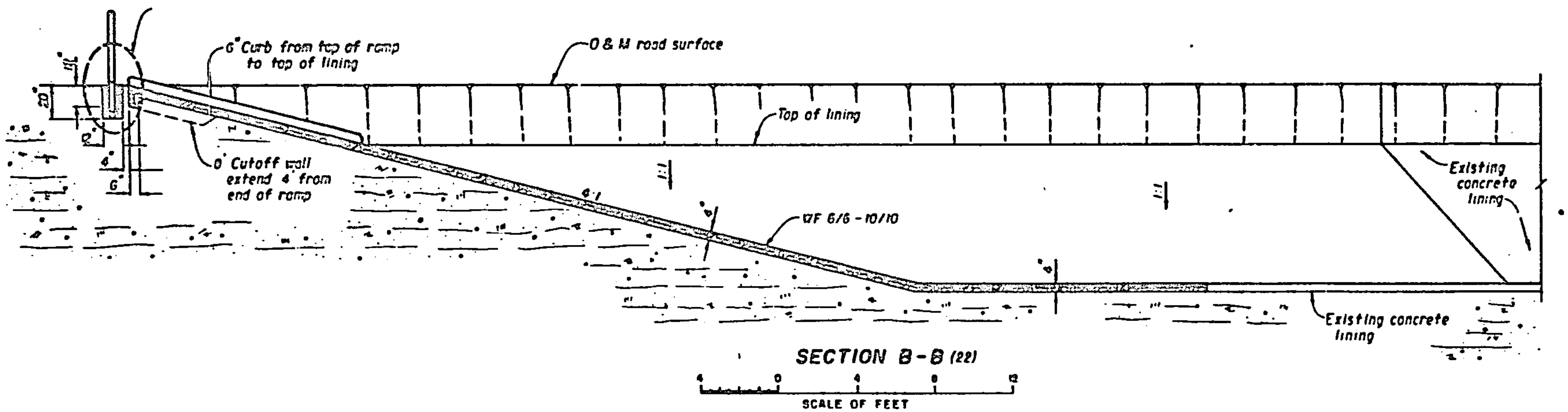

Figure 3. Longitudinal cross-sectional diagram of the Mohawk Canal, Arizona, deer escape ramps.

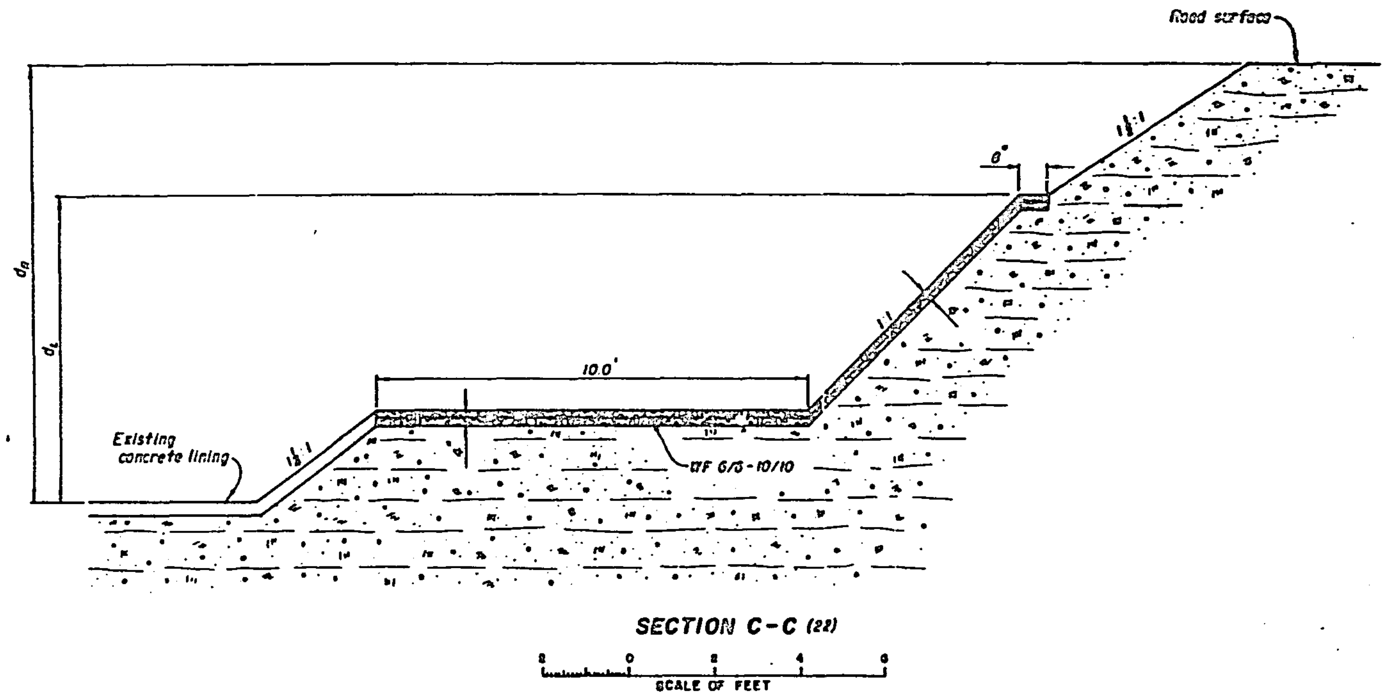

Figure 4. Cross-sectional diagram of the Mohawk Canal, Arizona, escape ramps, 30 feet down from the top of the ramp (d_r = 9.0 ft, d_l = 7.1 ft).

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