AN EVALUATION OF WILDLIFE CROSSINGS OVER THE TUCSON AQUEDUCT

by

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DEDICATION

I dedicate this thesis work to my deceased beloved brother, Stephen Michael Popowski. Stephen was a prominent figure whom I have looked up to during my boyhood in New Jersey. Unpopular in my home area, family interest, and my education, Stephen had taught and inspired me about wildlife subjects in many ways. He bought many wildlife books and put cut out pictures in his bedroom walls. His lifelong dream to work with wildlife ended on 10 March 1985 when he passed away from his long-term fight with muscular dystrophy. Soon after his death, I began my career in wildlife as a volunteer at Everglades National Park, Florida during summer 1986. Since then, I have worked for 3 major natural resources agencies at 7 wonderful places in the country.

When performing my thesis project, taking natural resources classes, and working for natural resources agencies, Stephen has always been in my thoughts and he guides me to work hard that has led me to accomplish many goals. I cannot thank him enough for who I am today.

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ABSTRACT

The Central Arizona Project (CAP) canal system restricts movements of mammals across Avra Valley, Arizona. The Wildlife Mitigation Corridor (WMC) was established to provide access for animals over the Tucson Aqueduct of the CAP, and allow movement across Avra Valley. To determine if animals used the WMC more or less than other canal crossings (i.e., bridges), we recorded tracks of desert mule deer (Odocoileus hemionus crooki), collared peccary (Pecari tajacu), and coyote (Canis latrans) in and out of the WMC from August 1996 through July 1997. We also monitored two water catchments adjacent to crossings within the WMC with cameras to determine if catchments were used by wildlife. Deer and collared peccaries used crossings in the WMC more than those outside of the WMC. There was no significant difference between use of crossings by coyotes. Coyotes used all crossings throughout the year regardless of the availability of water sources. Crossings adjacent to water catchments received the highest use by herbivores.

INTRODUCTION

The Central Arizona Project (CAP) canal system may restrict movement of mammals across Avra Valley, Arizona. The Wildlife Mitigation Corridor (WMC) was established to provide access for animals over the Tucson Aqueduct of the CAP, and allow movement across Avra Valley. I monitored desert mule deer (Odocoileus hemionus crooki), collared peccary (Pecari tajacu), and coyote (Canis latrans) to ascertain their movement characteristics within the WMC. I monitored 6 crossings within and 4 crossings outside the WMC using track plots.

Wildlife use of crossings and corridors has been studied globally. Crossings (e.g., bridges, tunnels, over/underpasses) maintain avenues for wide-ranging animals to emigrate, immigrate, and migrate and to move in response to biological needs and environmental changes.

This thesis will be submitted to a peer-reviewed journal as a feature article. The article consists of a chapter within the thesis that is intended to partially fulfill the requirements for a Master of Science in Wildlife and Fisheries Science in the Graduate College at The University of Arizona. The article is formatted for submission to The Southwestern Naturalist. The writing represent my ideas, analyses, and technical composition abilities. I designed and performed the research and analyses for the manuscript and composed the writing contained herein. I did consult my graduate advisor on design ideas and relied on his input in manuscript preparation.

PRESENT STUDY

The methods, results, and conclusions of this study are presented in the paper appended to this thesis. The following is a summary of the most important finding in the paper.

Our study demonstrated that desert mule deer (Odocoileus hemionus crooki) and collared peccary (Pecari tajacu) used the crossings within the WMC more frequently than crossings outside the WMC but there was no difference in use for coyotes. The odds of deer using the WMC crossings were 18 times higher than the odds of use of crossings outside the WMC. Because of the forage, topography, water availability, and proximity to mountains, the WMC and surrounding areas represent good habitat for desert mule deer.

The odds of peccaries using the crossings within the WMC were 2 times higher than the odds of using the crossings outside of the WMC. Peccaries can tolerate more urbanization than desert mule deer. Peccaries used crossings outside of the WMC on several occasions where urbanization was within 1.2 km to all crossings.

Coyotes are omnivorous generalists, feeding on a diverse array of food. Coyotes are adaptable in their behavior, habitat use, reproduction, and adjustment to urban environments. Although the odds of coyotes using the crossings within the WMC were half the odds of using crossings outside of the WMC, they used crossings regularly throughout the year. They used all crossings more than desert mule deer and collared peccaries.

APPENDIX A

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AN EVALUATION OF WILDLIFE CROSSINGS OVER THE TUCSON AQUEDUCT

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ABSTRACT—The Central Arizona Project (CAP) canal system restricts movements of mammals across Avra Valley, Arizona. The Wildlife Mitigation Corridor (WMC) was established to provide access for animals over the Tucson Aqueduct of the CAP, and allow movement across Avra Valley. To determine if animals used the WMC more or less than other canal crossings (i.e., bridges), we recorded tracks of desert mule deer (Odocoileus hemionus crooki), collared peccary (Pecari tajacu), and coyote (Canis latrans) in and out of the WMC from August 1996 through July 1997. We also monitored two water catchments adjacent to crossings within the WMC with cameras to determine if catchments were used by wildlife. Deer and collared peccaries used crossings in the WMC

more than those outside of the WMC. There was no significant difference between use of crossings by coyotes. Coyotes used all crossings throughout the year regardless of the availability of water sources. Crossings adjacent to water catchments received the highest use by herbivores.

RESUMEN – Las áreas usadas por venados bura (Odocoileus hemionus crooki) y jabalies (Pecari tajacu) se sobreponen a lo largo de sus rangos de distribución en Norte America, pero son pocas las asociaciones documentadas entre estas dos especies. Entre 1996 y 1998 en el Valle de Avra, Arizona, nosotros documentamos observaciones de venados buras y jabalies, estas dos especies fueron observadas dentro de 100 m (rango de distancia = desde menos de 1 m hasta 100 m) de distancia una de otra en siete ocasiones. Asociaciones entre las dos especies ocurrieron en áreas con más cubierto termal (16.7%) que áreas seleccionadas al azar (2.9%). Los venados y jabalies compartieron la sombra pasivamente. La asociación entre las dos especies podra tambien aumentar oportunidades de detectar predatores. Nuestras observaciones fueron hechas en una área plana con vegetación densa causando baja visibilidad. Señales de comportamiento que exhibe uno u otro de las especies al acercarse un predator puede tener ventaja mutua.

Canals transport water to urban and agricultural areas, but can threaten wildlife by altering habitat and restricting movements (Krausman and Hervert, 1984; Rautenstrauch and Krausman, 1989; Carmichael et al., 1991; Krausman and

Etchberger, 1995). The United States Bureau of Reclamation (USBR) implemented mitigation efforts in the late 1980s to address the problem of restrictions to animal movement caused by the Tucson Aqueduct - Phase B of the Central Arizona Project (CAP) canal system. Mitigation efforts included establishment of the Wildlife Mitigation Corridor (WMC) that with several bridges for animals to cross the canal and move between the Tucson Mountains, which include Saguaro National Park and Tucson Mountain Park, and the area to the west of the CAP and Avra Valley to the Roskruge Mountains (Fig. 1).

The CAP is a 541-km long concrete-lined aqueduct that delivers Colorado River water to central and southern Arizona and is one of the largest water projects in the United States (Carmichael et al., 1991). Water from the CAP is used for recreational, industrial, residential, and agricultural purposes (U.S. Dep. Interior, Tucson Aqueduct-Phase B Modification, Phoenix, Arizona, 1987, unpubl. data; Dames and Moore, A review of CAP-related decision from 1965 to present, Tucson, Arizona, 1994, unpubl. data). The Tucson Aqueduct - Phase B section, which begins in Rillito and ends in Tucson, is 76 km long, with 45 km of concrete-lined channel, 31 km of pipeline, and 6 pumping plants. The mean aqueduct depth and width are 3 m and 16 m, respectively. Fences were erected on both sides of the aqueduct to restrict animals from entering the aqueduct to prevent drowning (deVos et al., 1983; Krausman and Hervert, 1984; Rautenstrauch and Krausman, 1989; Krausman and Etchberger, 1995).

When desert mule deer (Odocoileus hemionus crooki) began dying in newly created aqueducts, agencies developed fences, wildlife crossings, and alternative sources for drinking water (e.g., water catchments) along aqueducts for deer and other wildlife (Rautenstrauch and Krausman, 1989; Carmichael et al., 1991; Cashman and Krausman, 1991; Krausman and Etchberger, 1995). The USBR has spent about $10 million on wildlife improvement projects to keep desert ungulates out of the CAP (Krausman and Etchberger, 1995).

Mitigation efforts have been implemented also for the Tucson Aqueduct - Phase B to reduce or eliminate adverse effects of the aqueduct on wildlife. Measures included preserving 11-km^2 of land as an open, undeveloped corridor (the WMC); fencing to exclude wildlife from the aqueduct; crossings over the aqueduct for wildlife; development of wildlife watering sites away from the aqueduct; and revegetation of areas disturbed during canal construction (United States Department of Interior, 1985). The location of the WMC and wildlife crossings were approved by the Arizona Game and Fish Department and the United States Department of Interior (deVos et al., 1983; U.S. Dep. Interior, Tucson Aqueduct-Phase B Modification, Phoenix, Arizona, 1987, unpubl. data). Wildlife crossings, concrete overchutes, underground pipelines and roads are the only areas for terrestrial animals to move across the aqueduct.

Wildlife use of crossings and corridors has been studied globally. Crossings (e.g., bridges, tunnels, over/underpasses) maintain avenues for wide-ranging animals to emigrate, immigrate, and migrate and to move in response to biological needs and environmental change. Mitigation efforts can reduce the negative impact on wildlife from habitat fragmentation due to urbanization and development of roads, above ground pipelines, canals, highway fencing, and logging (Lindenmayer, 1994; Heuer, 1995). Most studies of corridor use are related to mammals or animals with a large home range such as mule deer (Goodwin and Ward, 1976; Carmichael et al., 1991; Cashman and Krausman, 1991; Romin and Bissonette, 1996), elephants (Elephas maximus) and tigers (Panthera tigris) (Johnsingh et al., 1990), predators (Hunt et al., 1987), medium-sized mammals (Hunt et al., 1987), and small mammals (Steer, 1987; Mansergh and Scotts, 1989).

Preserving corridors for movement may result in the connection of wildlife populations in areas fragmented by human activities (Lindenmayer, 1994). The quality of a corridor is based on its ability to provide areas that connect two or more larger tracts of essentially similar habitat and the extent to which it reduces fragmentation of habitats (Henein and Merriam, 1990). The efficacy of corridor is dependent also on surrounding habitat (Wilcove et al.,1986). Corridors and other mitigation efforts can minimize hindrance to movement (Reed et al., 1975; Janzen, 1986; Wilcove et al., 1986; Carmichael et al., 1991; Krausman and Etchberger, 1995); dissection of crucial habitat (Wilcove et al., 1986; Carmichael et al., 1991); reduction of genetic diversity within small subdivided populations (Diamond, 1975; Johnsingh et al., 1990); the probability of local extinction caused directly by small populations (Diamond, 1975; Frankel, 1982; Rautenstrauch and Krausman, 1989); and barriers to re-establishment of local populations through immigration after natural losses (Terborgh and Winter, 1980).

To understand how animals were using the WMC and to determine if it was effective in providing movement across Avra Valley, we monitored use of crossings by desert mule deer, collared peccary (Pecari tajacu), and coyote (Canis latrans). These animals have large home ranges (deVos et al., 1983) and use of crossings within the WMC should be crucial to maintaining movement patterns across the canal. Our objectives were to determine if there was a difference between animal use of crossings located within the WMC and crossings outside of the WMC, determine what habitat variables adjacent to crossings were related to use of crossings by wildlife, and monitor and identify animal activity at two water catchments within the WMC.

STUDY AREA AND METHODS--The study area was located in centrai Pima County, in south-central Arizona (32°12' 15" N, 111°11' 10" W to 32° 18' 00" N, 111° 14' 30" W). The area included 10.9 km of the Tucson Aqueduct - Phase B. The center of the study area was about 26 km west of Tucson. We monitored six crossings within the WMC and four crossings outside of the WMC (Fig. 2). Crossings ranged from 9 to 173 m wide and were 0.2 to 3.1 km apart.

Two water catchments within the WMC (catchment 1 one fed from the Tucson Aqueduct and catchment 2 from a well) provided water to wildlife (Fig. 2).

The area was in the Tucson Mountain foothills with elevations ranging from 689 m in the flats near Brawley Wash to 824 m at the northeastern end of the WMC. The area was described as the Arizona Upland Subdivision of the Sonoran Desert (Brown, 1982; Rondeau et al., 1996). This region has long, hot summers, short mild winters, biseasonal rainfall peaks (in winter and late summer), relatively few winter freezes, low relative humidity, and high rates of evaporation. Mean temperatures were 16° and 30 ° C in winter and summer, respectively. Average annual precipitation was 27.9 cm (United States Department of Interior, 1985, 1987). Seasons were classified as spring (Apr-Jun), summer (Jul-Sep), autumn (Oct-Dec), and winter (Jan-Mar). Seasons were defined based on weather patterns and biology of desert mule deer (Krausman, Impacts of the Central Arizona Project on desert mule deer and desert bighorn sheep, Phoenix, Arizona, 1985, unpubl. data); Krausman et al., 1989; Krausman et al., 1990; Tull, 1997).

The WMC (1,017 ha) is close to Tucson Mountain Park, a permanent reserve (7,075 ha) on the east side of the canal. The only man-made developments within the WMC are primitive trails, stock fences, wildlife water catchments, a well, underground gas and telephone lines, and the CAP aqueduct. The Tucson Mountains Wildlife Area overlaps the WMC and Tucson Mountain

Park. North of the WMC, the western boundary of Saguaro National Park West (8,750 ha) is within 1.2 km of all crossings outside of the WMC on the east side of the canal. Lands west of the CAP are developed for housing or farming or are in the Tohono O'odham Nation (i.e., Garcia Strip) with a few parcels of retired farm land with little or no development westward to the Roskruge Mountains. The township of Drexel Heights has gradually spread toward the southern boundary of the WMC and the township of Picture Rocks is scattered on the east side of the canal adjacent to Saguaro National Park.

Washes run westward from the Tucson Mountains toward Brawley Wash. Most of these washes run toward the east side of the canal within the WMC with a few continuing west of the canal. The area outside of the WMC predominantly is flat on both sides of the canal.

The area is comprised of heterogeneous landscape features including bajadas, flats, and large washes, and varied land use retired farms, residential areas and preserve areas. Vegetation associations are: creosote bush (Larrea tridentata) - triangleleaf bursage (Ambrosia deltoidea); bursage - paloverde (Cercidium spp.) - mixed shrubs; and mesquite (Prosopis veluntina) bosque.

Big game species, such as collared peccary and mule deer, and predators, such as bobcat (Felis rufus), cougar (Puma concolor), coyotes, gray fox (Urocyon cinereoargenteus), and kit fox (Vulpes macrotis) reside in the WMC seasonally or pass through it. There were 200 - 400 desert mule deer and 400 - 600 collared peccaries within the game management unit that included the WMC (deVos et al., 1983). The density of coyote in similar setting on the east side of Tucson are as high as 3.2 to $4.6/km^2$ (McClure et al., 1996).

We identified use of crossings by animals by monitoring the presence of tracks of mule deer, collared peccaries, coyotes, and other species O7 days/month from August 1996 to July 1997. We identified animal tracks from a row of circular plots containing fine mortar sand (1-m diameter, < 1 cm deep, 8 m apart) along the width of crossings. Depending on the width of the crossing, there were ≥ 2 and ≤ 22 plots/crossing. We smoothed track plots a with rake < 24 hours prior to recording the presence of animal tracks and after each observation had been made. We inspected track plots within 2 hours of sunrise. Once a week, each plot was sifted to remove debris. Sometimes sifting was more frequent due to weather conditions or other uncontrolled factors. We replaced sand in the plots monthly.

We attempted to check track plots for O 7 consecutive days each month to minimize the difficulty of reading plots due to weather-disturbance; to avoid accumulation of debris; and to avoid overlap of tracks from several days. We checked plots shortly after sunrise when the best lighting conditions for tracking occurred (Fitzhugh and Gorenzel, 1985).

We considered a "set" of tracks to be a line of tracks made continuously by an individual animal (Fitzhugh and Gorenzel, 1985). Tracks separated so widely that there was a possibility that > 1 individual was present, were considered different sets.

We used a binary count (i.e., present/absent) of tracks by species found on the WMC crossings and crossings outside of the WMC and compared both areas (i.e., inside and outside) by species by seasons. We used a 2X2 contingency table and logistic regression to determine if differences in use of crossings were significant and to estimate the probability of use of crossings for each area by species (Hosmer and Lemeshow, 1989).

We recorded vegetation associations, topographic features, proximity to urbanization and water, and crossing description each bridge. We used these parameters to analyze habitat quality (Hall et al., 1997) for desert mule deer, collared peccary, and coyote.

We sampled vegetation from eight areas (within the WMC on the east and west side of the canal, outside of the WMC on the east and west side of the canal, and four areas adjacent to the WMC in each cardinal direction) from May through July 1997. Each area consisted of about 5.2 km^2. We used 50-m line intercept transects (Bonham 1989) to determine vegetation associations for each area. Twenty 50-m transects were run at each area, except for one area that had only 16, 50-m transects. Plants that contributed <1% were not used to determine the vegetation association. Vegetation nomenclature followed Rondeau et al. (1996).

We monitored animal activity at two water catchments using a Trailmaster® 1500 (TM) camera system. The TM 1500, which was connected to a camera (Olympus 35mm), recorded the time and date of animal activity and photographed animals at each water catchment following methods described by Kucera and Barrett (1993). This system operated > 7 days each month. We checked the system each day to ensure that the transmitters, receivers, and cameras were properly aligned and to replace film. Data from the receiver and photos were used in combination.

RESULTS-- The structure of crossings within and outside the WMC varied. Crossings within the WMC contained natural settings with soil and vegetation. Vegetation in crossings was different than surrounding vegetation because of disturbances from canal construction; however, grasses and shrubs were structurally similar to the native plant community. Outside of the WMC, crossings consisted of concrete "overchutes" or "overpasses" where water from a wash passes over the CAP canal. Concrete overchutes usually contained little or no vegetation, and were not developed for wildlife use.

Track plots were easily read for deer and collared peccary during dry and non-windy days, however, canids tracks were difficult to detect (Orloff et al., 1993). We checked each track plot 120 times (total = 6,480 readings). Deer and peccaries used crossings within the WMC more than crossings located outside of the WMC (Table 1). Use of crossings in the WMC (x deer/reading/season = 0.06 - 0.11) and crossings outside of the WMC (x deer/reading/season = 0.0 - 0.01) by deer were low. Crossing use by deer differed significantly within and outside of the WMC (x^2 = 27.5, 1 d.f., P = 0.0001). The probability of deer using crossings within the WMC as 18 times higher than the probability of use of crossings outside of the WMC. We recorded deer tracks outside the WMC on only two occasions, but deer regularly used areas within the WMC.

Peccaries used crossings within the WMC significantly more than crossings outside of the area (x^2 = 5.1, 1d.f., P = 0 .0236). The probability of peccaries using crossings within the WMC as two times higher than the probability of using crossings outside of the WMC. The more frequently used crossings (WMC crossing 1-3, Fig. 2) were closer to water catchments, had higher forage quality, and had more cover for herbivores. Coyotes used crossings outside of the WMC more than the WMC crossings throughout the year (x^2 = 0.9, 1d.f., P = 0 .3552). Coyote used crossings within and outside of the WMC regularly throughout the year regardless of season. Coyote used all crossings more than did desert mule deer and collared peccaries. The probability of coyote using crossings within the WMC were one-half the odds of using crossings outside of the WMC.

Vegetation association--Four dominant vegetation associations in the creosotebush - bursage series and the paloverde - mixed cacti series (Brown,

1982) were identified within the study area. We documented 39 plant species from eight areas with an average of 16 species for each area (Table 2). Bursage - paloverde - mixed scrub association dominated from east of the canal within the WMC eastward into the bajadas of the Tucson Mountains. Creosotebush - bursage - mixed scrub association dominated the flat west of the canal within the WMC westward into Brawley Wash. The area east of the canal outside of the WMC also had this association. Creosotebush dominated the flat south of the WMC and had the lowest number of plant species. Creosotebush - bursage - mesquite association dominated from west of the canal outside of the WMC into Brawley Wash.

Use of water catchments--The Trailmaster camera system produced > 536 photographs of identifiable animals (Table 3). There were 75 blank photographs. Nearly all medium to large (lagomorph-sized or larger) mammals known to occur in the Tucson Mountains area were recorded from both catchments. At water catchment 1 and 2, photographs containing identifiable animals were taken during 102 and 103 sampling days, respectively. The total number of photographs does not exhibit the actual number of visitations. Collared peccaries tended to loaf in the area for > 10 minutes and resulted in repeated photographs of the same individual or herd. We used Trailmaster timetable records to determine a separate visit. We considered that a single visit occurred when there was evidence of interruption by a visit by another species or when a species-specific period of elapse occurred: > 20 minutes for deer, > 1 hour for peccaries, and > 45 minutes for coyote.

We classified four activity periods: crepuscular (dusk and dawn), nocturnal (darkness), morning (post-dawn - 0900), diurnal (0900 - presunset). Periods of visitation to water catchments by animals followed predictable patterns (Table 4). Use of both catchments by desert mule deer and collared peccaries followed the expected pattern, with visits increasing during hotter and drier months and decreasing during cooler and wetter months (Hervert and Krausman, 1986; Sowls, 1997). Collared peccaries used water catchment 2, in the bursage - creosotebush association, more than catchment 1, in the bursage - paloverde - mixed scrub association. From October 1996 through April 1997, peccaries used each water catchment on three occasions and use was greater from May through July 1997.

DISCUSSION--Urbanization in Tucson is spreading westward to the Tucson Mountains preventing desert mule deer from moving eastward from the area on the east side of the Tucson Mountains. The Tucson Aqueduct, established in proximity to bajadas at the western slope of the Tucson Mountains, also has reduced the area available for deer and other wide-ranging animals. Historic movement corridors across Avra Valley, particularly to Brawley Wash, used by these species were cut off by the aqueduct (deVos et al., 1983). Mitigation efforts attempted to manipulate movements by these animals by providing access to the area west of the canal. The WMC links Tucson Mountain Park and Saguaro National Park. The addition of two water catchments near canal crossings in the WMC may lead animals to use the crossings and to access areas west of the aqueduct.

What is the benefit-cost ratio of the WMC? The agencies spent about $6,200,000.00 (U.S.) for land acquisition, construction of crossings, and addition of water catchments. It is difficult to determine the overall effectiveness of this mitigation effort or its value to desert mule deer, collared peccary, and coyote. Our study demonstrated that deer and peccaries used the crossings within the WMC more frequently than crossings outside the WMC but there was no difference in use for coyotes.

Habitat quality for each species influenced the use of crossings and use varied throughout the season. Several variables that influence an animal's habitat use are: additional demands for water and nutrients during pregnancy and lactation; use and preference of a vegetation association for forage, thermal cover, or predator avoidance during rearing of young; preference for specific topographic features and elevations; and avoidance of urbanization (Ordway and Krausman, 1986; Bellantoni and Krausman, 1993; Fox and Krausman, 1994).

Our findings differ from Tull (1997) on habitat preference for deer in the Tucson Mountains. Tull (1997) found that female deer generally used the mesquite - burroweed (Isocoma tenuisecta) vegetation association more than it was available and the paloverde - mixed cacti association less than it was available. The vegetation surrounding these crossings consisted of bursage - paloverde - mixed scrub association. Deer in the Tucson Mountains prefer this association (deVos et al., 1983). The bursage - paloverde - mixed scrub association, especially on the east side of canal within the WMC, had the highest concentration of nutritional forage for mule deer (Table 2). Sexual segregation often occurs for mule deer at particular seasons (Fox and Krausman, 1994). It is likely that during pregnancy and lactation females spent more time in bursage-paloverde- mixed scrub association because of higher nutritious forage. The bursage - paloverde - mixed scrub association also provides hiding and thermal cover. The other crossings (WMC crossing 4-6, Fig. 2) were within the transition zone where bursage - paloverde - mixed scrub was interspersed with creosotebush - bursage association. Creosotebush flats had less available forage biomass compared to paloverde - mixed scrub association (Albert and Krausman, 1993, Krausman et al, 1997). This was reflected in the lower use of crossings in this area by deer. Deer rarely used crossings outside of the WMC because of lower quality forage species surrounding the crossings and the lack of water sources. Urbanization east of the canal blocked access to all crossings from the western boundary of Saguaro National Park West.

The area east of the canal and the WMC had more topographic features than the area west of the canal. Extensive washes occur throughout the WMC area and most of these washes lead to crossings. Washes serve as essential travel lanes for desert mule deer, especially during hot, dry periods (Krausman, Impacts of the Central Arizona Project on the desert mule deer and desert bighorn sheep, Phoenix, Arizona, 1985, unpubl. data; 1993). Deer probably took advantage of these washes as travel routes in the WMC. Our data showed lower use of crossings by deer in the WMC during fawning season. Females with young probably remained on the slopes of the mountains east of the canal. The higher elevation attracts females to these areas (Ordway and Krausman, 1986; Fox and Krausman, 1994). Predator avoidance might be the reason for this behavior and the resultant low use of crossings during fawning. The area west of the canal generally was flat with less cover than the area east of the canal except for mesquite bosque in Brawley Wash. In general, females avoid creosotebush and males generally use open areas with lower quality forage during the non-breeding period of the year (Ordway and Krausman, 1986).

Water is important for desert mule deer during hot, dry seasons. Two water catchments were adjacent to the two crossings used most frequently by herbivores (WMC crossing 1 and 3, Fig. 2). Water catchments might be an attractant to deer. Deer used water catchment 1 more than catchment 2. Catchment 1 was within bursage - paloverde - mixed scrub association which provides more hiding cover than in creosotebush - bursage association. Also catchment 1 was within better habitat quality on cover and forage on the boundary between the WMC and Tucson Mountain Park. Deer have smaller home ranges in summer than throughout the year as a result of greater dependence on available water (deVos et al., 1983; Ordway and Krausman, 1986; Fox and Krausman, 1994). Water catchment 1 was close to numerous large washes that provided cover and travel lanes.

Crossings provided male deer a means of dispersing during sexual segregation. Without crossings, the canal potentially interrupts natural sexual segregation and eventually may increase deer density in some areas. Restricting dispersal of males may lead to higher density of deer in some areas and could negatively impact availability of quality forage for female deer and could impact fawn survival.

Peccaries also used WMC crossings 1-4 near water catchments more frequently than any other crossings. This is similar to the pattern of use of crossings by deer. Most of the preferred foods of peccaries are in the bursage - paloverde - mixed scrub association (Knipe, 1957; Leopold, 1959; Eddy, 1961; Sowls, 1997). Peccaries also use washes as travel lanes and for bedding during the day in summer (Bellantoni and Krausman, 1993). Peccaries use similar vegetation associations as those used by deer but can tolerate urbanization to a greater degree (Bellantoni and Krausman, 1993; Sowls, 1997). Peccaries used crossings outside of the WMC (overchute 1 and 4) on several occasions where urbanization was within 1.2 km. Human-provided food and water often attracted peccaries to urban areas east of Tucson (Bellantoni and Krausman, 1993). Peccaries may receive the same treatment in the Tucson Mountains.

Elder (1956) reported that water was necessary for peccaries during the driest part of the year but not essential when succulent plants were available. The bursage - creosotebush association consists of less succulent plants compared to bursage - paloverde - mixed scrub association. Peccaries that use areas with less succulent plants, such as creosotebush during the hot, dry period, are more likely to benefit from the provision of water catchments. Peccaries were generally closer to water sources during the summer than in winter (deVos et al., 1983).

Coyotes in deserts are more flexible than desert mule deer and collared peccary to environmental changes. Coyotes are omnivorous generalists, feeding on a diverse array of food (Elliot and Guetig, 1990; McClure et al., 1995; Sanabria et al., 1995). Coyotes are flexible in their behavior, habitat choice, reproduction, and adjustment to humans and urban environments (Bekoff, 1978; Bounds and Shaw, 1994, 1997; Goldlightly, 1997).

Coyotes may have used crossings outside of the WMC more frequently than within the WMC crossings because of their proximity to urbanization. Suburban and urban developments often increase coyote numbers by providing abundant anthropogenic foods including garbage, pets, and pet food (Howell, 1982).

Mitigation efforts within the WMC appear to benefit the small populations of desert mule deer and collared peccary. Both herbivore species used all crossings in the WMC throughout the year. Water catchments were used during hot, dry seasons. Beside the two water catchments within the WMC, there are numerous catchments in Tucson Mountains Park, Saguaro National Park, and several other locations. All of these catchments are on the east side of the canal. The low use of all crossings probably reflects the presence of few water catchments on the west side of the CAP. If an objective of the placement of water catchments is to get animals to move to the mountains west of Avra Valley or to make crossings more attractive, managers need to put catchments near crossings on the west side of the CAP. Water catchments appear to attract animals to the crossings.

MANAGEMENT IMPLICATIONS

Designing wildlife corridors has always been a difficult task due to the mosaic of land ownership, lack of funding for land acquistion, and insufficient biological information on habitat requirements and movement patterns of species targeted for conservation. However, careful planning by landscape planners and wildlife managers could result in positive outcomes from corridor developemnt.

The movement corridors used by desert mule deer, collared peccary and other mammals in Avra Valley were identified prior to selection of the WMC and crossing locations. It is not necessarily true that the high use of crossings within the corridor indicates that natural movements of animals were not disrupted. An underground pipeline for the CAP water may have been better than an open aqueduct that required crossings for wildlife within the WMC. With a buried pipeline, wildlife could move freely throughout the WMC and use the general area within the corridor.

Mitigation efforts should be based on 10 to 20- year plan that includes protection of areas surrounding the WMC. The WMC will provide maximum benefit if the surrounding area does not undergo extensive development. The long-term status of lands surrounding the WMC is uncertain due to complex land ownerships (Tull, 1997). The level and type of human activity sourrounding the WMC can affect its use by wildlife. Development on Tohono O'odham lands and private lands nearby eventually will probably reduce habitat quality for desert mule deer and collared peccary (Tull, 1997). If the ongoing process of housing development surrounding the WMC continues to occur, the WMC will become less effective in providing movements across the aqueduct for wide-ranging animals..

In terms of ecosystem management, it is important to look at a larger context, and to realize the impact of loss of connectivity at a local scale for

Tucson Mountains. A corridor alone is insufficient as a strategy for conservation. The continuity of natural desert environments within and surrounding the WMC and the Tucson Mountains region must be maintained if the full spectrum of native species is to be preserved. We considered wildlife movement at a very local scale. Collaboration among the land owners and managers of the area is needed to develop the Avra Valley landscape management plan, including extension of the buffer zone outside the WMC. Community education and open communication among land managers and land owners must occur.

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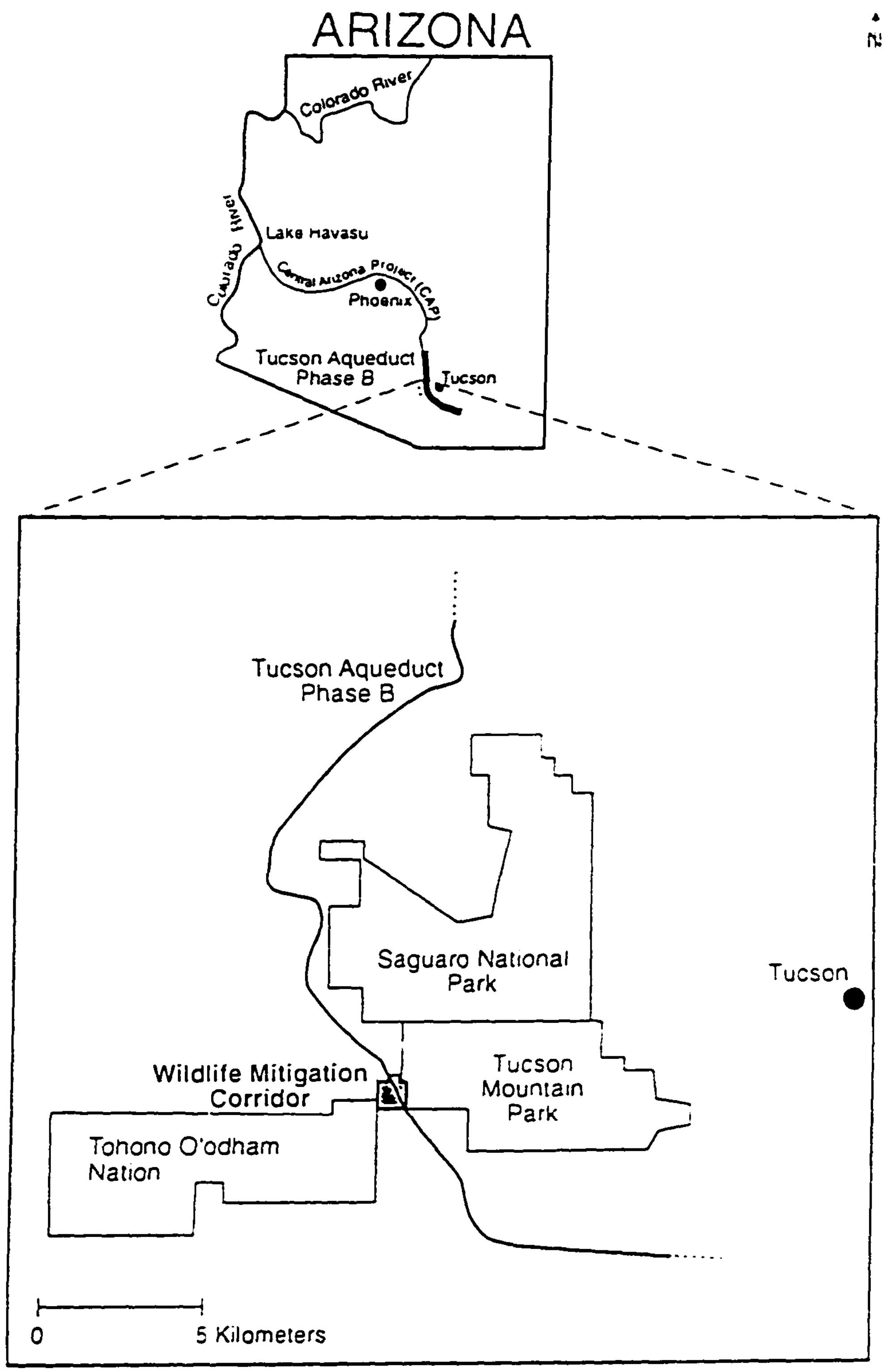

Figure 1. The locations of study area and the Wildlife Mitigation Corridor along the Central Arizona Project, Avra Valley, Arizona, 1996-1997.

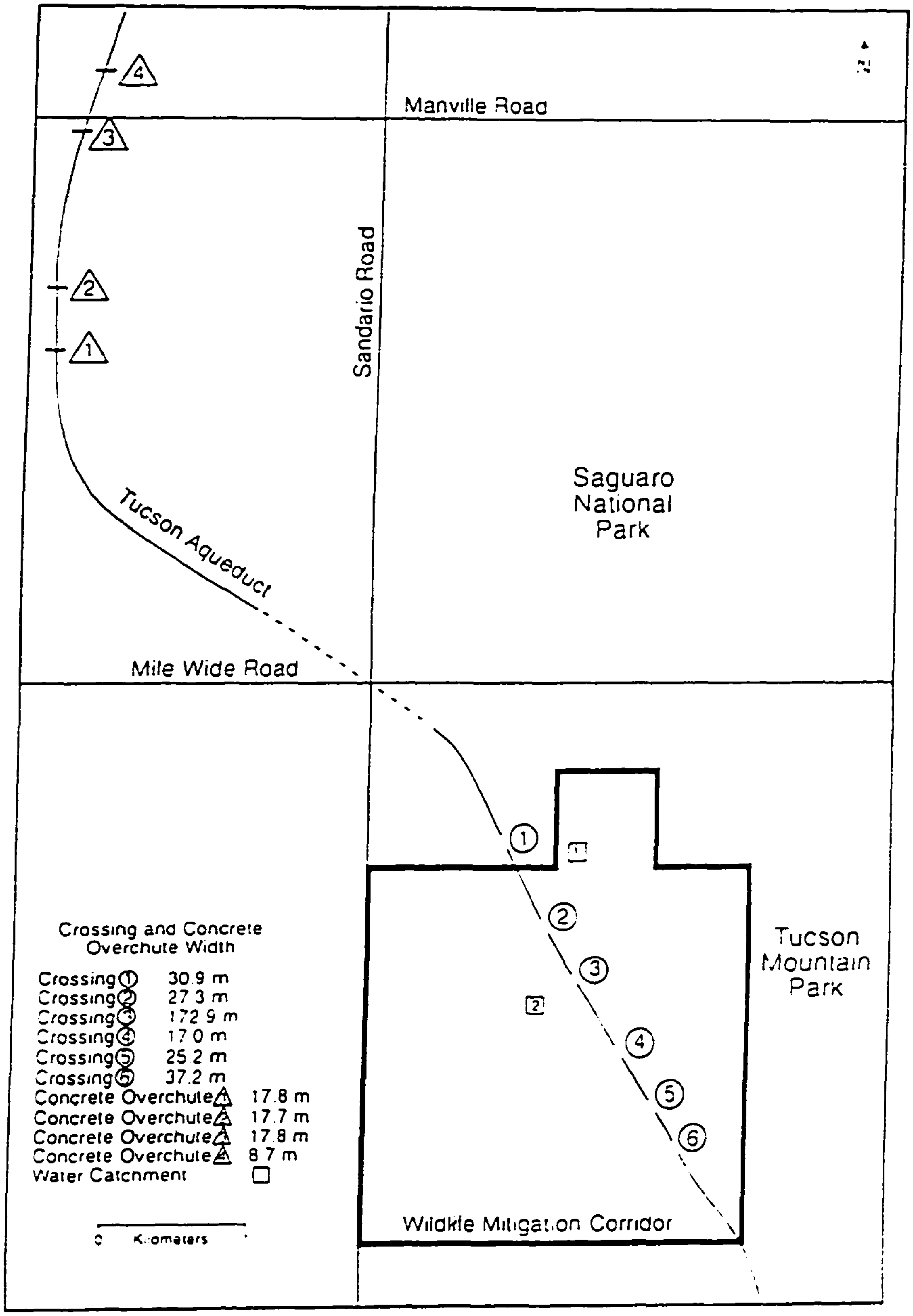

Figure 2. Crossings (O) and concrete overchutes (△) locations inside and outside the Wildlife Mitigation Corridor, Central Arizona Project, Avra Valley, Arizona, 1996-1997

Table 1 Mean number (binary count) of tracks/reading/season inside and outside the Wildlife Mitigation Corridor for autumn (Oct - Dec, n = 31), winter (Jan - Mar, n = 27), spring (Apr - Jun, n = 30), and summer (Jul - Sep, n = 29), from Avra Valley, Arizona, 1996-97

	Within WMC							Outside of WMC				
Crossing number	1	2	3	4	5	6		1	2	3	4	
Crossing width	30.9	27.3	172.9	17.0	25.2	37.2	$\bar{x}$	17.8	17.7	17.8	8.7	$\bar{x}$
Desert mule deer												
Autumn	0.12	0.16	0.03	0.03	0.07	0	0.07	0	0	0	0	0
Winter	0.07	0.03	0.14	0.03	0.06	0	0.06	0	0	0	0	0
Spring	0.20	0.17	0.13	0	0.07	0.10	0.11	0	0	0.03	0	0.01
Summer	0.13	0.08	0.22	0.08	0	0.06	0.10	0	0.3	0	0	0.01
Collared peccary												
Autumn	0.23	0.13	0.06	0.36	0.06	0.06	0.15	0.03	0.10	0.10	0.07	0.08
Winter	0.39	0.13	0.30	0.22	0.09	0.10	0.21	0.30	0.09	0.03	0.24	0.17
Spring	0.17	0.20	0.17	0.17	0.07	0.10	0.15	0.23	0.10	0.07	0.10	0.13
Summer	0.17	0.21	0.33	0.07	0.03	0.06	0.15	0.08	0.03	0	0.13	0.06

Table 1 Continued

	Within WMC							Outside of WMC				
Crossing number	1	2	3	4	5	6		1	2	3	4	
Crossing width	30.9	27.3	172.9	17.0	25.2	37.2	$\bar{x}$	17.8	17.7	17.8	8.7	$\bar{x}$
Coyote												
Autumn	0.46	0.16	0.36	0.26	0.23	0.29	0.29	0.55	0.33	0.36	0.23	0.37
Winter	0.61	0.09	0.45	0.52	0.59	0.43	0.45	0.45	0.48	0.63	0.81	0.59
Spring	0.37	0.50	0.57	0.47	0.40	0.37	0.45	0.77	0.37	0.43	0.63	0.55
Summer	0.23	0.27	0.36	41	0.15	0.28	0.28	0.42	0.30	0.23	0.30	0.31

Table 2 Percent composition of plant species for areas in the Wildlife Mitigation Corridor and surrounding areas, Avra Valley, Arizona Each area consists about 5 2 km^2

	Within WMC		Outside of WMC		Adjacent to WMC			
Species	West	East	East	West	South	West	North	East
Larrea tridentata[1]	10 2	2.9	8.5	7.1	20 8	6 9	8 7	9 3
Ambrosia ambrosioides			0.01					
A deltoidea[1]	13 0	14 6	9 1	4 5		0 7	11 8	13 4
Cercidium spp[2]	3 0	5 9	0 5	0 5			5 6	7 2
Cacti spp.[2, 3]	2.0	2.9	1.4	0.6	0 2	0 1	4 9	3 5
Krameria erecta[2]	0 7	0 2					0 4	1 7
Acacia greggii[2]	0 8	0 1	0 1	0 3		0 2		
A constricta[2]	0 2	0 1	0 1			0 3	0 1	0 4
Olneya tesota[2]		0 6	1 1	0 7			1 2	0 2
Prosopis velutina[2]	0 3		0 9	8 4	1 0	7 2		
Fouquieria splendens[2]		0.4					0 2	0 4
Jatropha cardiophylla[2]		0 3					0 4	1 2
Trixis californica[1]		0 1						
Amaranthus fimbriatus[1]			0.1	0 1				
Baccharis sarothroides			2 3					
Euphorbia hyssopifolia			0 1					
Isocoma tenuisecta			0.1	0 3	2 5	0 5		0 3
Ziziphus obtusifolia				0 1				

Table 2 Continued

Species	Within WMC West	Within WMC East	Outside WMC East	Outside WMC West	Surrounding WMC South	Surrounding WMC West	Surrounding WMC North	Surrounding WMC East
Boerhaavia spp.[1]					0 5		0 1	
Atriplex canescens[1]						[illegible]		
Lycium spp [1]						0 2		0 1
Celtis pallida[2]							0 5	
Simmondsia chinensis[2]							0 3	
Aristida adscensionis	0 1		2 9	1 1	0 1	0 [illegible]	0 2	
Bouteloua aristidoides[1]			0 4					
Digitaria spp	0 4		0 1					
Leptochloa spp			0.1					
Muhlenbergia porteri				0 1	0 4	0 [illegible]	0 1	
Panicum obtusum						0 2		
Sorghum halepense					5 3			
Sporobolus spp	0 1		0 6	1 4				

[1] = Reported as food of desert mule deer in trace amounts, < 1% (Krausman et al . 1997)

[2] = Reported as food of desert mule deer pending on seasons (Krausman et al . 1997)

[3] = Cacti spp includes Carnegiea gigantea, Ferocactus wislizenii, Opuntia arbuscula, O bigelovii, O phaeacantha, O fulgida, O leptocaulis, and O versicolor.

Table 3 Total number of photos and visitation by species at two water catchments within the Wildlife Mitigation Corridor, Avra Valley, Arizona, 1996-1997.

Species	Catchment # 1 Photo	Catchment # 1 Visitation	Catchment # 2 Photo	Catchment # 2 Visitation
Desert mule deer	82	77	12	11
Collared peccary	25	14	27	20
Coyotes	32	32	30	27
Gray fox	85	n/a	26	n/a
Mountain lion	3	n/a	8	n/a
Bobcat	5	n/a	2	n/a
Desert cottontail (<u>Sylvilagus</u> <u>audubonii</u>)	1	1	0	0
Skunks (<u>Mephitis</u> spp.)	16	n/a	18	n/a
Ringtail (<u>Bassariscus</u> <u>astutus</u>)	1	1	0	0
Turkey vulture (<u>Cathartes</u> <u>aura</u>)	55	n/a	8	n/a

Table 4. Percentage of activity periods by species at two water catchments within the Wildlife Mitigation Corridor, Avra Valley, Arizona, 1996-1997.

Species	Catchment =	Crepuscular	Nocturnal	Morning	Diurnal
Desert mule deer	1	14.6	35.6	24.4	25.6
	2	16.7	50.0	25.0	8.3
Collared peccary	1	0	100	0	0
	2	14.8	81.5	0	3.7
Coyote	1	9.4	18.8	25.0	46.9
	2	16.7	20.0	26.7	36.7

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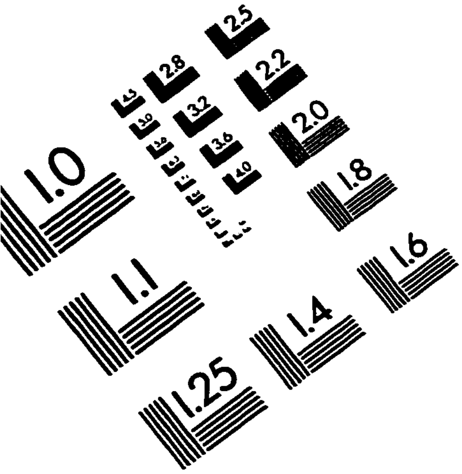
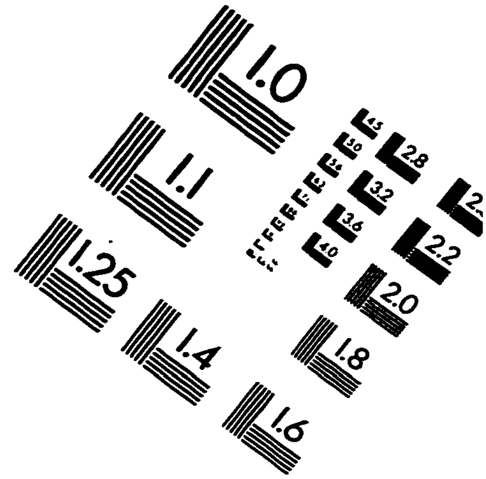
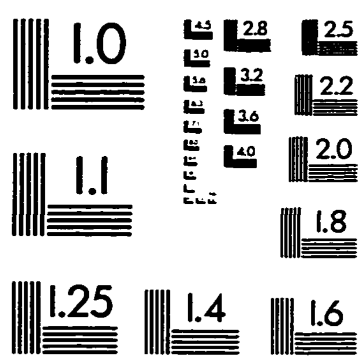
IMAGE EVALUATION TEST TARGET (QA-3)







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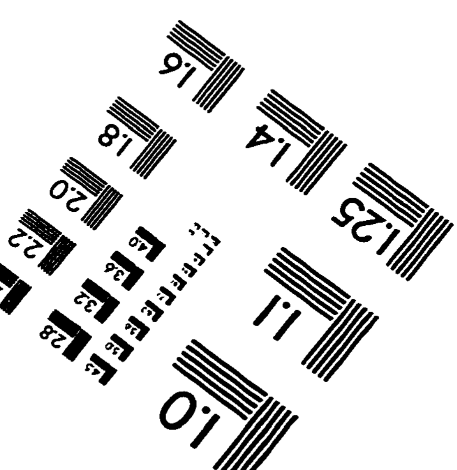

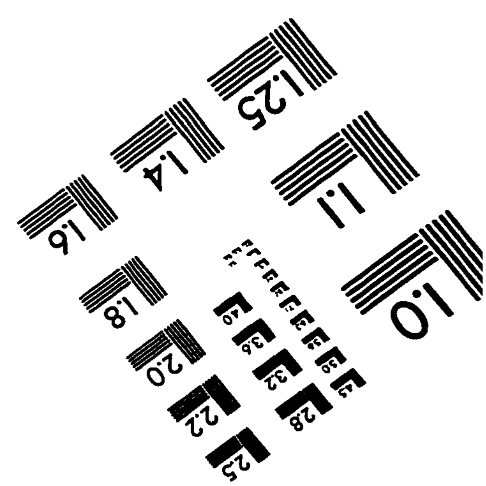

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