# RESPONSES OF MULE DEER TO EXPERIMENTAL MANIPULATION OF WATER SOURCES IN MOJAVE NATIONAL PRESERVE

**Proposal Submitted to the National Park Service**

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## Introduction

State and federal agencies in the western United States have used water developments as an integral component of management of wildlife habitats in arid regions since the 1940's (Rosenstock et al. 1999, Bleich et al. 2005, O'Brien et al. 2006). Where water was perceived to be limiting, considerable attention was focused by early resource managers on developing water sources for wildlife (Krausman et al. 2006). Ranchers and range managers have developed water sources for livestock, many of which also are used by wildlife (Valentine 1980, Rosenstock et al. 1999). Indeed, water catchments remain a widely used management tool in the western United States (Krausman et al. 2006).

Mule deer (*Odocoileus hemionus*) occupy a variety of habitats throughout western North America (Mackie et al. 2003) and require relatively large areas to assure persistence of viable populations, especially in the Chihuahuan, Sonoran, Mojave, and Great Basin deserts (Bleich 2005). Mule deer are dependent upon resources, including water and forage, adequate to meet the demands of growth, reproduction, and lactation (Mackie et al. 2003). Resources that often are assessed to determine the distribution of desert mule deer are availability of forage (Albert and Krausman 1993, Marshal et al. 2005), nutritional quality of forage (Rautenstrauch et al. 1988, Albert and Krausman 1993, Marshal et al. 2005), cover (Ordway and Krausman 1986), mating sites (Scarbrough and Krausman 1988), natal sites (Fox and Krausman 1994), and availability of water (Hervert and Krausman 1986, Marshal et al. 2006). In arid regions, mule deer are dependent on free water (Wolfe 1978:367, Rosenstock et al. 1999), and often are located close to sources of water, particularly during dry seasons

(Rautenstrauch and Krausman 1989, Boroski and Mossman 1996, Rosenstock et al. 1999). Indeed, physiological demands may dictate that during times of water scarcity, ungulates remain close to water rather than ranging widely to forage (Cain et al. 2006). Mule deer in the Sonoran Desert tended to remain close to sources of water during the hot-dry season when water was most scarce, a common occurrence in the southwestern United States (Hervert and Krausman 1986, Rautenstrauch and Krausman 1989, Marshal et al. 2006). Moreover, water developments in Arizona received heavy use by desert mule deer, primarily during hot summer months (Remington et al. 1984, Hervert and Krausman 1986). Thus, distribution, abundance, and seasonal availability of water affect the distribution of mule deer across the landscape (Marshal et al. 2006).

Ungulates use water catchments when they are available; mule deer change distribution and movements relative to catchments and have been observed to use water from catchments as often as 1-2 times per 24 hours during hot-dry weather (Hervert and Krausman 1986, Hazam and Krausman 1988, Rautenstrauch and Krausman 1989, Boroski and Mossman 1996, 1998). Adult females visiting water sources consumed more water than males, likely because of increased water requirements to support lactation (Hazam and Krausman 1988). Moreover, females moved outside of their known home ranges to locate alternative sources of water when denied access to catchments (Hervert and Krausman 1986). Developed water sources that have been present for long intervals tend to receive more use than newly developed sources of water (Marshal et al. 2006b). For example, use of washes near water catchments was greatest after catchments had been in place >3 years (Marshal et al. 2006b). Thus, water sources that have been available for > 3 years receive greater use by mule deer and other species of wildlife than new sources of water (Marshal 2006b).

Sexual segregation outside the mating season is ubiquitous among ungulates, including mule deer (Bleich et al. 1997, Kie and Bowyer 1999, Bowyer 2004, Bowyer and Kie 2004). Differences in spatial distributions of sexes of cervids hold import for understanding the distribution of these large mammals across the landscape (Bowyer 1984, Kie and Bowyer 1999, Stewart et al. 2006). Bowyer (2004) stated that the concept of sexual segregation must be integrated into the disciplines of range and wildlife management and become a standard consideration in designing research and implementing habitat manipulations (Rubin and Bleich 2005, Stewart et al. 2006). Sexual segregation has been well documented in mule deer (Bowyer 1984), and differences in spatial distributions between the sexes of mule deer in Mojave National Preserve may result in some sources of water being used predominately by a single sex outside the mating season when deer are sexually segregated. Thus, for the purposes of this study, we must account for the occurrence of sexual segregation or we may under represent the importance of water sites visited predominately by males if, for example, only the female cohort of the population was marked with radio collars. Nevertheless, because mule deer are polygynous, the female cohort of the population has a more direct effect on survival and reproduction; thus we will equip a greater number of females with radio collars than males.

In arid and unpredictable ecosystems, such as those occurring in the eastern Mojave Desert, availability of forage is strongly influenced by climate (Beatley 1969, Noy-Meir 1973). Forage availability for mule deer is dependent on plant biomass, which is, in turn, influenced by rainfall. This is particularly true in arid regions where there is a close association between rainfall and plant abundance (Beatley 1969, Noy-Meir 1973, Robertson 1987, Polis et al. 1997). Forage quality also is affected by water available to plants; protein content of forage tended to be lowest during seasons with low rainfall and, consequently, low forage growth (Rautenstrauch et al. 1988, Krausman et al. 1990, Bleich et al. 1992, 1997, Marshal et al. 2005). Vegetation surrounding sources of water may access greater quantities of water than vegetation occurring away from water sources, provided there is runoff of water available to the plant community. Thus, vegetation located immediately around water sources may have greater moisture content and higher nutritional quality for mule deer and other wildlife.

Over the past several years, numerous water sources for livestock were deactivated within the Mojave National Preserve. Many of those water sources had been available to native wildlife in excess of 100 years. Deactivation occurred in the absence of any environmental assessment of the potential influences of that action on populations of wildlife, including mule deer, which are widely distributed within the preserve (Bleich and Pauli 1999). The purpose of this investigation is to assess responses of mule deer inhabiting the eastern Mojave Desert to the provision of water at locations where it had been, but is no longer available. Secondarily, we address interactions between mule deer and vegetation as influenced by availability of surface water. Rosenstock et al.

(1999) indicated several areas where research should focus with respect to water developments including: effects of water developments on population performance, distribution and habitat use of game and non-game wildlife species, and secondary effects of water developments on adjacent plant communities. We propose to test several hypotheses relating to responses of mule deer to provision of water, to evaluate effects of deer use on habitats surrounding those water sources, and availability and quality of forage for mule deer with available water compared with similar areas where water sites had been removed (see Marshal et al. 2006c for review).

**EXPERIMENTAL DESIGN**

Many studies examining the relationship between free-ranging species of wildlife and sources of water have been somewhat equivocal. In general crossover experiments, where some water sources are turned on while other are kept off for 2-3 years and then switched (e.g. turn off the ones that were on and vice versa), have been problematic because of stochastic variation among years. The problem with this design is that stochastic variation among years cannot always be separated from the experimental variation among years. Thus, if some sources are available during a high water year, and a drought year occurs after available and unavailable sources are switched, the results of the study are difficult to interpret. In such situations, among-year variation can exceed the variation among the experimental units, which often results in an ability to reject hypotheses because of confounding factors.

We propose a 2-phase experiment with a total duration of 10 years, which includes 2 experiments of 5-year duration on the Mojave National Preserve

(Table 1, appendix 1). For the initial 5 years of the experiment we will compare a large area with year-round available water including established wells and developed springs with a large area without permanent (year-round) water (Figure 1). The area around Cima Dome on Mojave Perserve will function as a control and includes developed springs (Deer, Cut, Kessler, and White tank; Figure 1); water sources in this area will not be manipulated for the duration of the study. Our study area with year-around available water will include reestablished wells (Pettit well, Government Holes well, Granite well, Eagle well, and Vontrigger well) and developed springs (Live Oak, Cottonwood, Clark, Cliff Canyon, and Silver Lead); these wells and springs will be monitored and maintained with permanent water for the duration of the study. The study area without permanent sources of water include sites of wells that had been deactivated (Watson's well, Payne well, Caruther's Canyon well, Lecyr well, Barnwell, and Slaughterhouse well; Figure 1). There are 2 developed springs (Bathtub spring and Matt spring located within our no permanent water study area that will be made unavailable to mule deer (Figure 1). Because Bathtub spring occurs in Wilderness, both of these springs will be fenced (2.5 m height) for mule deer only, using t-posts and rolled wire (use of mechanical equipment will not be necessary). Springs and wells (both reinstated and dry locations) in each study area will be equipped with a remote camera to monitor use of those areas by mule deer and other wildlife. These cameras also will be part of the wildlife camera study that is currently underway in MNP. We realize that there are many natural springs occurring throughout the preserve and many are ephemeral. Thus, we will use data sensors to record the presence or absence of water in a substantial sample of these recorded springs. We will test hypotheses regarding habitat selection, movement patterns, and demographics (survival, reproduction, and physical condition) of mule deer by comparing deer in experimental areas with and without available water and an unmanipulated control.

For years 5 – 10 of the study, we propose to reinstate the wells in the no water available study area including: Watson's well, Payne well, Caruther's Canyon well, Lecyr well, Barnwell and Slaughterhouse well (Table 1, Figure 1). Then we will compare responses of mule deer to availability of water in this study area. We will make comparisons of that study area before the wells are reinstated (years 1-5) with 5 years after water is made available in that study area. In addition, we will test hypotheses comparing the area that had permanent water available the first 5 years of the study and will continue as an area with available water during the second 5 years. We will also compare differences in habitats selection and home range size as well as changes in demographics (survival and reproduction)

Table 1. Proposed study areas and treatments for an experiment to understand use of developed sources of water by mule deer in Mojave National Preserve (also see map fig 1).

| Years | STUDY AREAS | | | |
|---|---|---|---|---|
| | Control | Watered | | No Water |
| | Cima Dome | Developed springs | Reinstated wells | |
| 1 - 5 | Deer Spring<br>Kessler spring<br>White tank<br>Cut spring | Cliff Canyon<br>Clark<br>Cottonwood<br>Live Oak | Pettit well, Government Holes well, Granite well, Eagle well, Vontrigger well | No permanent sources of water |
| 5 - 10 | | | | Reinstate wells and develop springs: |
| | Deer Spring<br>Kessler spring<br>White tank<br>Cut spring | Cliff Canyon<br>Clark<br>Cottonwood<br>Live Oak | Pettit, Government Holes, Granite, Eagle, Vontrigger | Watson's well, Payne well, Caruther's Canyon well, Lecyr well, Barnwell, Slaughterhouse well, Bathtub spring, Matt Spring |

**Hypotheses to be Tested**

**H1: Provision of permanent, year around water will be beneficial to mule deer populations.**

**H1a: Fecundity of mule deer will be higher in areas with permanent water available year-round, developed springs and reinstated wells.**

**H1b: Physical condition of mule deer will be greater in areas with available water.**

**H1c: Annual survival is greater in areas where surface water is provided.**

**H1d: Population density of deer will be greatest in areas with permanently available water.**

**Rationale:** Water is thought to be an important limiting resource for wildlife species that rely at least partially on free water to meet their requirements for water in desert habitats (Turner 1973). If water is in fact limiting under some circumstances, then provision of water must increase survival or fecundity for individuals in areas with permanent available water compared to those relying only on ephemeral sources of water. Under this hypothesis, it is also possible that provision of water will attract individuals from areas lacking wells. Thus, we may observe changes in survival and reproduction in areas with permanent, available water and our experimental area without permanent water or changes in distributions of mule deer away from areas without water to those with water available. These changes in distributions, home range size, and movement patterns are most likely during the hot-dry season, which coincides with high water demands, particularly of lactating females.

**Methods:** Assessment of this hypothesis will entail applying radio collars to mule deer. We will capture 30 female and 10 male mule deer in the area which has permanent water available including developed springs and wells reinstated by NPS and 30 female and 10 male mule deer in areas without permanent, developed water sources each year. Capture effort will be concentrated on female mule deer, and males will be equipped with radio collars opportunistically. Individuals will be captured either using netguns from a helicopter or clover traps placed near water sources. All individuals also will be uniquely marked with eartags and will be fitted with a small standard VHF transmitter and a subsample of individual females will be equipped with additional GPS radio collars to record their locations up to 7 times/day. VHF collars on animals equipped with GPS collars will remain on the individual after the GPS collar drops off of the animal.

Radio-tagged individuals will be located weekly throughout the year from the ground by NPS personnel, field technicians, and graduate students, and monthly by air, to record mortality. Remote cameras at each well and developed spring will be used to ascertain the presence of young during and following the birthing season; such data can be used to generate recruitment information (Marshal et al. 2006a). Survival probabilities will be estimated using known fate analyses implemented in Program Mark (White and Burnham1999). We will use information theoretic model selection approaches (Burnham and Anderson 2002) to assess hypotheses about variation in survival. Basically, these approaches use Akaike's Information Criterion (AIC) to rank models of survival based on the combination of the fit of models to data and model complexity. Parameter estimates and their 95% confidence intervals (CI) from the most parsimonious models will provide the second stage of assessment of hypotheses. For example, presence of a treatment effect (water available or no water) on survival depends not only on performance of a model containing this effect but a parameter estimate for the treatment whose CI does not overlap zero.

Models that allow survival probability to vary among the experimental areas (Figure 1) will be the most general models of spatial variation in survival. Of particular interest to this hypothesis, we will contrast survival probabilities of all deer in the area with permanent water to the area without developed water (Figure 1). Survival in these two groups likely is influenced by precipitation; however, by maintaining this experimental design over a 5 year period stochastic variation in rainfall among years will affect both the experimental and control areas simultaneously. We will assess and control for inputs of precipitation on survival. We anticipate that effects of precipitation on survival will differ between the area with developed springs and wells versus that without permanent sources of water. Our design should be robust against this type of variability among years. This possibility also will be examined by the performance of models containing an interaction between treatment areas (water and no water) and a covariate measuring local rainfall. In the most general forms of all models described above, survival probability will be allowed to vary among seasons and years of this investigation.

Producing a fawn is a binomial event and we will run multistate capture-recapture approaches to estimate the probability that a female produces a fawn, conditioned on (1) her reproductive status in the previous year and (2) treatment (permanent water versus no water). At the time of capture, we will use ultrasonography (Stephenson et al. 2002) to determine body condition, and ultrasonography (Stephenson et al. 1995) or hormonal assays (Drew et al. 2001) to ascertain pregnancy and fetal rates. We will use cameras located at each water site in both control and experimental areas to determine if individual females have fawns at heel as an index to recruitment. Fawns also will be located using radio signals of their mothers. We will compare fawn survival between treatment and control areas using known fate analyses similar to those for adults. Models of fawn survival and assessment of hypotheses will be approximately the same as those for adults.

**H2: Provision of water at historic wells will not be detrimental to habitat for other wildlife species.**

**Rationale:** Vegetation represents a key aspect of the habitat for many wildlife species, because vegetation provides either cover or food (Bowyer et al. 1998). Water alone does not sustain ungulate populations in areas where forage availability is insufficient; thus, forage availability near water sources could be a significant draw for mule deer in those areas (Marshall et al. 2006c). Increased numbers of mule deer using reestablished wells have the potential to impact shrubs through their browsing activity or by mechanical disturbance. In years of adequate rainfall, forbs are an important part of the diet for many wildlife species, including mule deer (Marshal et al. 2004). Increased numbers of mule deer at wells might lead to increased interspecific competition for herbaceous plants near these sites. In addition, graminoids present near sources of water also may be suitable forage for mule deer, particularly during early stages of growth. Thus we will sample shrubs and herbaceous plants occurring near water sources or sites without available water.

**Methods:** We will monitor vegetation to assess potential impacts of increased wildlife use in control and treatment areas near each sampling location (developed spring, reinstated wells, or dry wells). Shrub cover will be estimated within 200 m of sampling locations in both treatment and control areas by establishing 10, 50 m transects within 200 m of each site. Shrub cover will be estimated annually within each transect using the line intercept method (Bonham 1989). Treatments with and without water and control sites will be compared using a repeated measures design, with specific locations treated as random effects. Differences between treatments with and without permanent sources of water for shrub cover will be interpreted as evidence for an impact on shrub habitat.

To asses potential impacts on herbaceous plants (forbs and graminoids), we will use 5, 1-$m^2$ moveable exclosures. We will clip vegetation inside and outside each moveable exclosure using a 1m2 plot frame, one time per season to estimate cover and biomass of herbaceous plants by forage category (Bonham 1989). Difference in percent cover between exclosed and control plots for each herbaceous species present will provide the response variables. Potential impacts of water developments on herbaceous plants also will be assessed using a multivariate repeated measures analysis of variance, with location as a random effect and treatment (water source, well or natural, or site with no water, well or natural and exclosed) and year as fixed effects. Herbaceous species present at all sites will define the elements of the response vectors. Presence of a treatment by year interaction (greater responses to exclosures at sites with permanent water versus sites with no water) as time progresses will be interpreted as evidence that vegetational differences at wells may result from use by mule deer.

It is noteworthy that vegetation studies proposed here also will provide basic information on spatial-temporal dynamics of vegetation at water sources in Mojave National Preserve. These data, therefore, have the potential to inform managers in the Preserve beyond their role in this study.

**H3: Availability and quality of forage for mule deer and other species will be greatest in areas around developed water, seeps, and springs than away from sources of water or water catchments that are not functional.**

**Rationale:** During conditions when water is most scarce in arid environments, water content of forage is also at its lowest (Bleich et al. 1992, 1997; Marshal et al. 2005). Levels of crude protein in plant material is generally associated with higher rates of forage growth and is associated with the anabolic processes that occur during the production of plant tissues, which decrease as plants reach vegetative maturity (Greenwood and Barnes 1978, Marshal et al. 2005). Desert trees and shrubs responded quickly (<1 week) to adequate rainfall by producing new foliage and died back during dry periods (Marshal et al. 2005). Thus, it is likely that shrubs located near sources of water are higher in quality and maintain growth longer than those not associated with sources of water. Moreover, springs, seeps, and developed catchments, with overflow, likely have more forbs and graminoids. Water catchments that are no longer functional will no longer have secondary effects on the surrounding vegetation. When those sites are redeveloped, however, forage quality of the surrounding vegetation will likely increase and maintain higher moisture content through the dry season, provided there is some additional water available to the plant community.

**Methods:**

We will sample biomass of forbs and shrubs 2 times per year (spring-wet and summer-dry season) in the immediate location of sampling sites (wells, developed springs) in control site, treatment sites, and vegetation also will be sampled in random sites located a minimum distance of 250 m from any sampling location (Figure 1). We will sample biomass in 10 points around each sampling point, using a 1-$m^2$ plot frame to estimate biomass of herbaceous plants and shrubs. We will confine our sample of shrubs to current annual growth. Treatment and random sites will be compared using a repeated measures design, with specific locations treated as random effects. Differences between treatment and control sites in trend for shrub cover will be interpreted as evidence for an impact on shrub habitat. We will use repeated measures ANOVA to test for differences in forage quality and availability and moisture content before and after water sites are turned on. Furthermore, we will use a subsample of those plants to test for forage quality at each sampling point. We will analyze plant samples by forage category (or species if necessary) for crude protein and *in vitro* dry matter digestibility and Van Soest fiber analysis. All analyses of forage quality will be conducted by the Chemical Nutrition Laboratory in the Institute of Arctic Biology at the University of Alaska Fairbanks.

We will collect fecal pellets of mule deer opportunistically, around any sampling location or at any random sites that we sampled vegetation. Pellets will be collected monthly to obtain data on seasonal differences in use of forage plants by mule deer. We will analyze fecal pellets for species composition using microhistological analysis and for fecal N as an index of diet quality. All analysis of fecal material will be conducted and the Oregon State University field station in Union County, Oregon.

**H4: Mule deer will actively select for areas near permanent sources of water and home range size of mule deer will be smaller in areas with permanently available water.**

**Rationale:** Habitat selection is defined as areas used greater than their availability (Krebs 1999). Mule deer likely select for areas with permanent sources to fulfill their needs for free water and to obtain forage that is more available and of greater quality (Marshal et al. 2006). In addition, movement patterns of mule deer likely differ seasonally and home ranges may be smallest during the hot-dry season when deer remain closer to permanent sources of water as ephemeral sources become less available (Rautenstrauch and Krausman 1989). In the control area, without permanent sources of water, mule deer likely move farther and have larger home ranges to include several ephemeral sources of water and spend more time searching for available water. Conversely in areas with permanent sources of water, home ranges of mule deer likely are smaller as deer remain close to those water sources, particularly during the hot-dry season when physiological demands for water are greatest (e.g. lactation). In addition home range size likely differs among males and females and some water sources may used more by one sex than the other during the period of sexual segregation outside the mating season (Bleich et al. 1997).

**Methods:** We will use locations obtained from radio-collars on adult females and adult males (see Hypothesis 1) to estimate selection of water sources compared with locations of mule deer in control areas, and treatment areas with and without permanent sources of water (Figure 1). We will use those locations in combination with a GIS database maintained by the National Park Service. We will obtain random locations in each of the study areas and compare variables such as vegetation type, slope, aspect, elevation, distance to permanent water, distance to developed and undeveloped springs, in locations randomly selected from the GIS database to locations obtained from mule deer in each study area. Random locations will be used to characterize availability of habitats and locations of mule deer will characterize those used by mule deer. Because random locations may be used by deer without being documented, this estimate is conservative (Stewart et al. 2002). We will use stepwise logistic regression to estimate habitat selection; the dependent variable is location (used =1, random =0), and independent variables will include vegetation type, slope, aspect, elevation, cover, and distances to estimate habitat selection in treatment and control study areas. We will control for availability of water, such as springs, wells, etc. in each study area using analysis of covariance with water availability as a co-variate in those analyses. In addition we will use fixed kernel analysis to estimate home range size of mule deer in treatment and control areas. We will compare size of home ranges of deer of each sex seasonally, and among study areas to examine changes in home ranges and distributions of mule deer in response to seasonal changes in availability of water and physiological demands.

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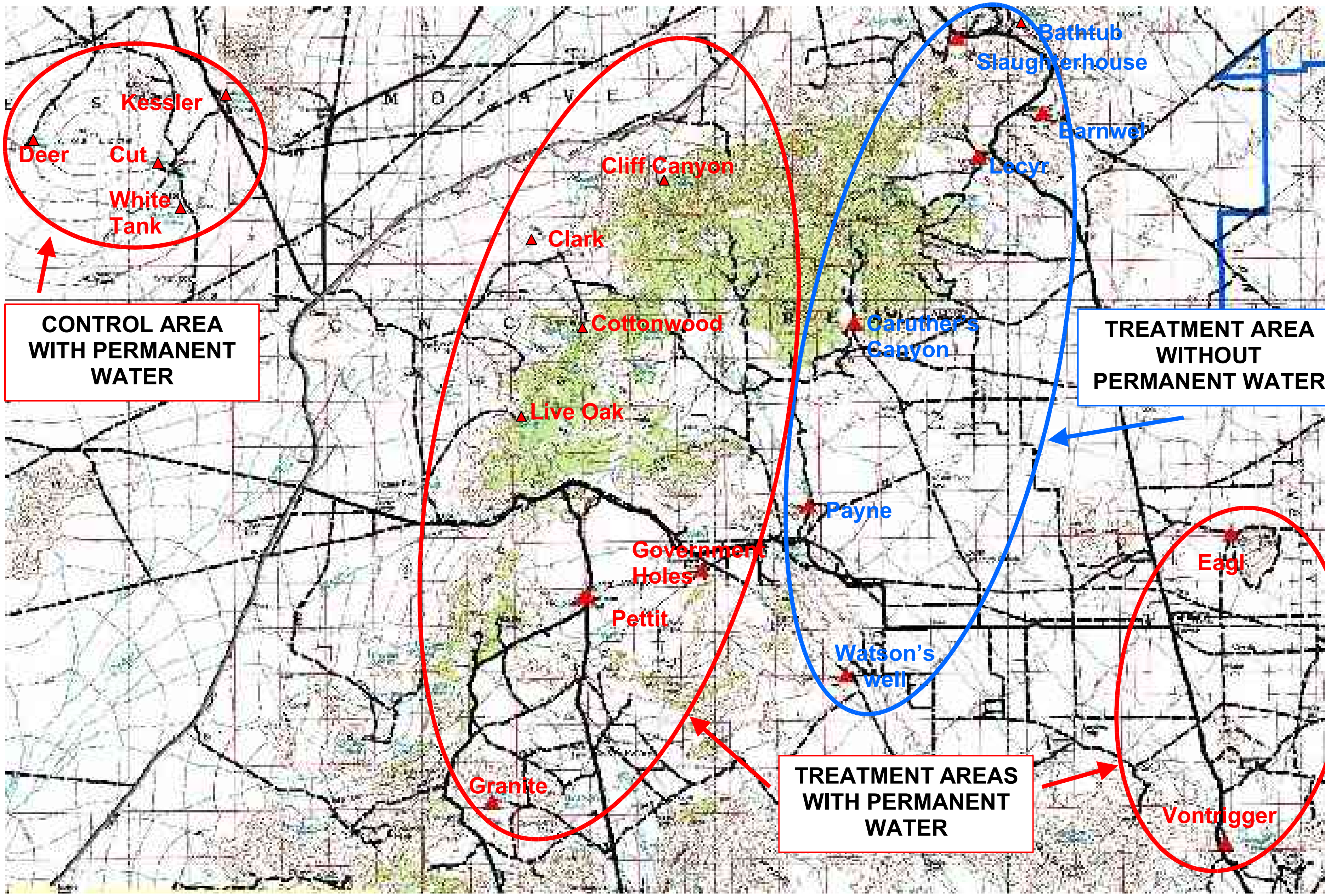
Appendix 1. Timeline and responsibilities for implementation of study and data collection for mule deer project in Mojave National Preserve.

| Time | Event | Responsibility |
|---|---|---|
| Dec 2007 -June 2008 | Reinstate wells in treatment areas. | National Park Service (NPS) |
| January 2008, 1 time / year (years 2-10) | Capture Deer and Apply Radio collars | California Department of Fish and Game |
| Years 1-10 | Monthly sampling of vegetation and monitoring locations of mule deer. Collection of mule deer pellets. | Univ. Nevada Reno (UNR) graduate students and technicians. |
| Years 1-10 | Capture mule deer with clover traps | UNR students & technicians. NPS personnel |
| Years 1-10 | Monitor and maintain sensors for water in springs | UNR students & technicians NPS personnel |
| Years 1 – 10 | Monthly aerial flights to monitor mule deer for mortality | To be determined |
| Years 1 - 10 | Camera maintenance and collection of data | NPS personnel |
| Years 1 - 10 | Maintenance of wells and developed springs in treatment areas with available water. | Local Sportsman's Groups |

Figure 1. Location of treatment and control study areas in Mojave National Preserve, San Bernardino County, California. Control sites are areas with no permanent sources of water, such as developed springs (or springs that are unavailable to mule deer) and wells that have not been reinstated. Treatment areas include sites with permanently available water, including reinstated wells and developed springs.

Figure 1.


Kessler
Deer
Cut
White Tank
CONTROL AREA WITH PERMANENT WATER
Cliff Canyon
Clark
Cottonwood
Live Oak
Government Holes
Pettit
Granite
Bathtub
Slaughterhouse
Barnwel
Lecyr
Caruther's Canyon
Payne
Watson's well
TREATMENT AREA WITHOUT PERMANENT WATER
Eagl
Vontrigger
TREATMENT AREAS WITH PERMANENT WATER
M O J A V E