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# Testing a model for the prediction of isolated waters in the Sonoran Desert

Joseph C. Drake [a], Jeffrey S. Jenness [b], Jordan Calvert [a], Kerry L. Griffis-Kyle [a,*]

[a] Department of Natural Resources Management, Texas Tech University, Box 42125, Lubbock, TX 79409, USA
[b] Jenness Enterprises, 3020 N. Schevene Blvd, Flagstaff, AZ 86004, USA

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ABSTRACT

Water is an extremely limiting resource in arid regions and wildlife managers need accurate inventories of water sources to better manage natural resources. Many of the water sources in the Sonoran Desert are tinajas, solid rock-bottom pools of varying sizes. These and other isolated and ephemeral water resources are essential for desert wildlife. We developed an approach to predict the location of unidentified ephemeral waters in the Sonoran Desert of Arizona, USA. We used Mahalanobis distance based on topographic wetness and slope to indicate groups of pixels in GIS that are the most similar in these aspects to locations of currently known waters. We tested this model in southwestern Arizona at the U.S. Air Force's Barry M. Goldwater Range - East by comparing polygons of predicted waters with random polygons. Seventy-four percent of standing surface water features found were attributed to the predicted polygons derived by our model. The model found a significantly larger water capacity in predicted polygons than in random polygons. This modeling technique could provide a new tool for researchers and land managers to better estimate potential water resources for wildlife conservation objectives in arid landscapes.



## 1. Introduction

Water is a critically limiting resource for many species of wildlife, especially in arid regions. In the Sonoran Desert, ephemeral and isolated waters can be found in intermittent streams, rock pools (tinajas), springs, and seeps. Biodiversity in arid lands tends to be concentrated around these areas of water, even if that water is very ephemeral in nature (Souza et al., 2006). These sites are recognized as rare, patchily distributed (Shepard, 1993), and having cultural and biological value (Burke et al., 2002). Isolated desert springs, which provide more persistent sources of waters, can be as far as 100 km apart and are difficult for many types of organisms to move between (Shepard, 1993). Hence, expanding the knowledge of surface water types and localities is very important for wildlife management. Isolated and ephemeral waters in arid lands often are home to endemic and rare species of vertebrates and invertebrates (Hendrickson and Minckley, 1985). These resources are literal oases in the landscape, but are considered threatened and sensitive to changes in precipitation, rising temperatures, and other climate change impacts (Glick and Stein, 2010; Field et al., 2007).

Climatic shifts are projected to reduce water availability in the southwestern United States due to a reduction in precipitation and increased evaporation as a result of the increased temperature (Karl et al., 2009; Seager et al., 2007; Field et al., 2007). Less precipitation means less water will be available to recharge aquifers and as a result springs will dry (Field et al., 2007). Groundwater extraction has already contributed to a reduction in water tables across the southwest (Carpenter, 1999; Konikow, 2013) and to available surface water at seeps, springs, and other historically wet areas (Patten et al., 2008). Continued urban population expansion (Swanson, 1989) and agricultural need (Karl et al., 2009; Ackerman and Stanton, 2011) will continue to enhance groundwater depletion and the reduction of reliable surface waters available to both humans and wildlife.

Other sources of surface water in arid environments will be impacted by climate change and anthropogenic influence too. Water available for wildlife will be reduced by several related mechanisms. Ephemeral water sites such as charcos, tinajas, and

* Corresponding author.
*E-mail addresses:* joseph.drake@ttu.edu (J.C. Drake), jeffj@jennessent.com (J.S. Jenness), jordan.goetting@ttu.edu (J. Calvert), kerry.griffis-kyle@ttu.edu (K.L. Griffis-Kyle).

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intermittent streams are dependent on precipitation. Rain events are projected to occur less frequently with a higher intensity of precipitation per event (Karl et al., 2009). Tinajas (rock-bottom pools) hold a limited amount of water, and once they are filled excess water runs off into the surrounding soil. As fewer rain events occur it is more likely that these ephemeral waters will dry completely between each rain event. These shortened hydroperiods will only be exacerbated by the increased evaporation caused by increasing temperature regimes (Glick and Stein, 2010; Field et al., 2007). The smaller the reservoir of water, manmade (Goodrich and Ellis, 2008) or natural, the greater the impact reduced rain frequency and increased evaporation incurs upon them. Increased intensity of rainfall events in the southwest also increase the risk of flooding and the sedimentation caused by floodwater runoff. Reduced capacity for water-storage could occur in tinajas, charcos, and intermittent streams. Wildlife will have less water available in an already water limited environment.

Since the 1940's, natural resource managers have been monitoring existing water sites and constructing new developments for wildlife in the desert southwestern United States (Rosenstock et al., 2004; Wright, 1959). Active management of water for wildlife can help offset reduced access to water caused by factors such as landscape fragmentation and climate change (Rosenstock et al., 2004). Locations that already have water are arguably the best places for conservation efforts such as future water developments. Focusing conservation efforts at these known water locations (currently or historically) could provide managed waters that are less ecologically abrasive, or are less likely to illicit a negative ecological consequence within the natural stochasticity of the spatial extent of interest, than novel catchments. Natural waters appear not to experience some of the problems associated with artificial waters (Griffis-Kyle et al., 2014). These known waters would be less “out-of-place” within the natural context of the area. The conservation of sites that already have water is an effective step in maintaining biodiversity in arid environments (Minckley et al., 2013; Unmack and Minckley, 2008).

Permanent springs and ephemeral pools are often difficult to find when hidden in rugged desert terrain (Shepard, 1993). There is also some speculation by experts that many of the springs that do exist are not currently known (Stevens and Meretsky, 2008). For example, the number of springs mapped in the steep topography of the Colorado Plateau, north of our study area, might be as low as 25 percent (Burke et al., 2002). Because these sites provide wildlife with a critically limiting resource, resource managers need a thorough and accurate inventory to make the most informed and effective decisions.

Management of isolated and ephemeral waters will become increasingly important as climate shifts stress surface-water availability. We created a model that predicts the location of water sites based on topological and geographic features including topographical wetness and slope. This model provides a tool for land managers in the Sonoran Desert and other arid regions to better understand and evaluate the availability of aquatic resources.

## 2. Methods

### 2.1. Study area

This work was conducted at the Barry M. Goldwater Range – East (BMGR-E) in southwestern Arizona, USA on land managed by the U.S. Air Force's 56th Range Management Office (Fig. 1). The area is actively managed for wildlife conservation and game species that depend on water. This is a expanse of Sonoran Desert that includes six mountain ranges separated by basins – elevations range from approximately 60 m–1220 m above mean-sea level. Habitat and vegetation varies between mountain ranges, with creosote bush, mixed-cacti, paloverde trees, and other mixed-scrub common (Hardy and Morrison, 2000) along with patches of semi-arid grasses occurring (Shreve, 1942). The range receives less than 12.7 cm (5 inches) of rain annually, often coming in one or a few patchy events (BMGR INRMP, 2012). Summer temperatures frequently reach and exceed 43 °C (110 °F) and were recorded in the field using iButton Hygrochron dataloggers (Maxim Integrated). They recorded temperatures in part sun/part shade reaching over 56 °C (134 °F; unpublished data, J.C. Drake & J. Calvert, 2013). Because of these high temperatures evaporation potentials exceed rainfall (BMGR INRMP, 2012). Most surface water is available in tinajas or desert wildlife catchments, which are constructed water troughs connected to reservoirs of water (BMGR INRMP, 2012).

### 2.2. Predicted polygon generation

#### 2.2.1. Generalized approach

To generate the predicted polygons we created a model using Mahalanobis Distance analysis of spatial aspects of the landscape. Mahalanobis distance can be used to quantitatively measure landscape variables against ideal criteria to determine how closely they resemble the ideal (Jenness, 2003). The ideal criteria in our analysis are based on locations that already contain water. To create our list of known existing waters, we combined water source point data from the military base's datasets, excluding points that were either unlabeled or labeled “catchment.” Because these points indicated unknown and artificial water sources respectively, they did not fit our criteria of confirmed natural water sources. We excluded all of Arizona Game and Fish “Wildlife Waters” points because they were all labeled “catchment.” The final sample point dataset contained 148 points, each indicating an individual, naturally-occurring water site. Spatial calculations were performed in Esri's ArcGIS 9.3 software suite. The inputs to create the Mahalanobis Distance values were derived from Topographic Wetness Index (TWI), and Longitudinal and Cross Sectional Curvature rasters sampled at interpolated water location points in a region around the BMGR-E. We then calculated the mean vector and covariance matrix for variable values at known tinajas and modified tinajas on the study area. Next, we calculated Mahalanobis Distance surfaces, showing the similarity of all points on the landscape to the mean vector and covariance matrix of TWI, Longitudinal Curvature and Cross-Sectional Curvature for the known water sites. We identified the $\leq$5% of the BMGR with the greatest similarity to the mean vector of TWI and Curvature values. These are the regions with the lowest Mahalanobis Distance values, meaning they are the most similar to the water sites.

#### 2.2.2. Correction of locations

Upon visual comparison of the sampled points in the GIS database with aerial imagery (Esri's World Imagery map service and Microsoft's Bing map service, both viewed in May, 2010), we observed that many sites were shifted in various directions and distances (max approximately 60 m) from visible water locations in the imagery. This meant that either the coordinates of the waters sites were inaccurate, the imagery was inaccurate, or the sites had been moved since they were mapped. If the point locations are inaccurate the method that we used, Mahalanobis distance would use an incorrect underlying raster value. To correct for this, we sampled the raster values around a point. We interpolated the 4 closest cells using a bilinear method to interpolate values vertically then horizontally (Fig. 2). This was used to calculate both TWI and curvature values.