2011-01-01

Influence of Orography on the Weather Patterns and Water Availability of a Topographically Complex Chihuahuan Desert Region

Fernanda De La Cerda Camargo
University of Texas at El Paso, fdelacerda@miners.utep.edu

INFLUENCE OF OROGRAPHY ON THE WEATHER PATTERNS AND WATER AVAILABILITY OF A TOPOGRAPHICALLY COMPLEX CHIHUAHUAN DESERT REGION

FERNANDA DE LA CERDA CAMARGO

Environmental Science Program

APPROVED:

Vanessa L. Lougheed, Ph.D., Chair

Jerry D. Johnson, Ph.D.

Thomas E. Gill, Ph.D.

Benjamin C. Flores, Ph.D.
Acting Dean of the Graduate School

INFLUENCE OF OROGRAPHY ON THE WEATHER PATTERNS AND WATER AVAILABILITY OF A TOPOGRAPHICALLY COMPLEX CHIHUAHUAN DESERT REGION

by

FERNANDA DE LA CERDA CAMARGO, BS Environmental Science

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Environmental Science Program

THE UNIVERSITY OF TEXAS AT EL PASO

August 2011

Acknowledgements

This thesis would not have been possible without my family, especially my parents, Idolina Camargo and Jorge De La Cerda, who despite the hardships throughout these couple of years have continued to support me. I would like to thank Dr. Johnson and Dr. Gill for helping me with different aspects of the project as well as being part of my committee. Funding for equipment for this project was provided by The Department of Biological Sciences at UTEP. Completion of this thesis however would not have been possible for me without my wonderful mentor Dr. Vanessa Lougheed; her continuous support, guidance, but most importantly humor, patience, and trust kept me going even when I didn't feel it was possible. Also, I would like to thank Dr. Craig Tweedie for always being ready to offer his help and guidance. I am grateful to Dr. J's Indio Crew for their help and company on those hot field days. Last but definitely not least I would like to thank all of my fellow "Lougheedies" and friends whose constant distraction/motivation and support kept me sane throughout: Mariana Vargas, Gaby Contreras, Christina Hernandez, Sandra Villarreal, Christian Andresen, Ector Martell, Frankie Reyes, Gena Esposito, Bianca Luong, David Lin, Walker Johnson, Ryan Cody, Ari Kassin, Adrian Aguirre, Libia Gonzalez, Jose Herrera, Gesuri Ramirez, Becky Marin, Paul Hotchkins, Hector Riveroll, Clarissa Thomas, Sarah Renteria, Chris Benoit, Will Lukefahr, Chris Billingsley, Claudia Ramirez, Denise Nunez, and Julian Lawler.

Abstract

Arid and semi-arid ecosystems cover a large extent of the planet's land surface and are highly susceptible to/and dependent on resource availability patterns, especially precipitation. Topography affects large scale weather patterns and redistributes precipitation which creates a variety of microclimates in complex landscapes; how these patterns are modified, however, is still not fully understood. Climate change models for arid and semi-arid ecosystems predict a change towards more extreme precipitation events; understanding the mechanisms involved in redistributing precipitation is crucial for the protection of these areas. Indio Mountains Research Station (IMRS) is located in the northern Chihuahuan Desert and seems to exhibit the characteristics of a rainshadow area when comparing its weather to that of surrounding towns. We compared data collected from weather stations at IMRS Headquarters, six permanent or ephemeral water bodies throughout the IMRS property, and publically available data for El Paso, Pecos, Sierra Blanca, and Marfa, TX. Detailed water level data and soil cores were collected from the IMRS water bodies, as well as regional topography and hydrology ArcGIS layers. These data was used to better understand the relationship between large scale weather patterns, topography, soil particle size distribution, size and frequency of rain events, and water availability at IMRS ponds. Contrary to our predictions, IMRS does not receive significantly lower precipitation than surrounding sites, but exhibits lower wind speeds and higher average temperatures; this indicates more of an orographic than rainshadow effect of topography on the area. Temperature patterns inside IMRS were affected by elevation and aspect of each individual site, with cooler sites being at higher elevations and further to the east; also, sites on west facing slopes were warmer than expected. Elevation and orientation of each site with regards to the surrounding landscape also influenced precipitation patterns, with the drier sites being at lower and more southerly locations. Water availability at the ponds was dependent on each pond's morphology, location, soil particle size distribution, and precipitation. Ponds that received more

precipitation and had higher proportion of clay in the soil also held water longer; each pond’s morphology and location influenced the hydrology of the pond.

Table of Contents

List of Tables

List of Figures

Introduction

Arid and semiarid lands cover about one third of the Earth's land surface with an area of about 37,000,000 km^2, of which 25,560,000 km^2 are used as rangelands. Due to their dry, extreme nature, arid and semi-arid ecosystems are greatly susceptible to changes in resource availability, which makes them very fragile and hard to recover from degradation (Whitford, 2002). As more studies are conducted, it is becoming clearer that pulses of essential resource availability, combined with long periods of limited availability, shape the interactions and dynamics of these ecosystems (Schwinning & Sala 2004, Schwinning et al. 2004b, Havstad et al. 2006). Protection attempts for these fragile ecosystems cannot be successful without first understanding the link between precipitation patterns, topography and water availability.

The SW-US is one of the most highly vulnerable regions to climate change due to its high precipitation variability and higher temperatures; spatial distribution of precipitation in this environment is in part governed by topography (Whitford, 2002). Despite the importance of this, little is known about the land and atmosphere interaction of topographically complex areas.

Precipitation patterns are driven by macro- and meso- scale processes, which include the position of jet streams and frontal boundaries, the North American Monsoon (NAM), El Nino Southern Oscillation (ENSO) events, and the Pacific Decadal Oscillation (PDO). The NAM brings a dramatic increase in rainfall to the American Southwest (SW-US) mainly in July and August, as warm humid air currents from the Gulf of California (south) and the Gulf of Mexico (southeast) replace the dry westerlies. ENSO is a coupled phenomenon where a deviation from the long term average sea surface temperature of the tropical Pacific drives changes in atmospheric circulation and precipitation patterns. The PDO is a variation in climate over the North Pacific and North America where the sea surface temperature also deviates from the long term average and causes changes in atmospheric circulation and precipitation patterns (Higgins et al. 1997, Sheppard et al. 2002, Moran et al. 2010). ENSO and PDO effects can amplify each other, increasing annual variability in precipitation over the Southwest (Sheppard et al. 2002).

Even though ENSO and PDO connections with weather are stronger during the winter, they have been showed to influence the timing and large-scale distribution of NAM moisture (Castro et al. 2001).

The larger scale patterns set up by these processes, however, will be modified by topography and type of rainfall, resulting in regional patterns of precipitation timing, magnitude, and variation. Seasonal differences in sources of moisture in the atmosphere, which affects the intensity of rainfall, in conjunction with the topography of the region, orographic and rainshadow effects, will influence the amount of precipitation received by an area (Loik et al. 2004, Havstad 2006, Whitford 2002).

The intermittent availability of water in the desert determines dynamics from the population to landscape level. For example, the pulse-reserve paradigm, one of the most important paradigms in arid land ecology, illustrates the relationship between rainfall and reserves of carbon and energy (Whitford 2002, Reynolds et al 2004). Precipitation pulses of different size and duration will result in a variation of biological and biogeochemical responses. Small events, for example, may only stimulate the activity of soil microbes, while a larger event can affect carbon fixation in plants and even trigger germination of many others. Pulse size will also define whether moisture will be taken up by plants or lost to evaporation. Small events will only wet the upper layers of soil, where a large fraction of moisture is lost by evaporation due to high temperatures and low root densities. Larger events will allow moisture to infiltrate deeper into the soil and be taken up by plants, contributing to their primary productivity (Schwinning & Sala 2004).

Although precipitation is usually perceived as the basis of water availability, it is a poor measure of it because plant growth is dependent on their ability to access soil water (Whitford 2002). For plants and soil biota, water availability in these regions will be greatly influenced by the factors affecting the translation of precipitation to available soil water. In an arid ecosystem, soil characteristics are the second key factor affecting the development of these ecosystems because soil is the only part of the system capable of absorbing and storing nutrients and water.

Soil depth, soil texture, parent material, vegetation type, antecedent moisture, and the presence of soil biotic crusts are some examples of variables that affect the extent to which rain will infiltrate the soil or run off its surface (Yair & Shachak 1982, Driscoll et al 2008, Rango et al 2006, Whitford 2002, Loik et al 2004).

In arid and semiarid environments, runoff generation will depend greatly on conditions preceding the precipitation event. High intensity, low frequency storms will generate runoff regardless of initial soil water content because intensity will be greater than infiltration rates. In contrast, runoff after medium to low intensity events will depend on antecedent soil water content; to produce runoff after less intense storms, saturation of upper soil horizons must be greater than infiltration (Castillo et al 2003). This illustrates another reason why precipitation pulse characteristics are important in this environment. Due to their influence on evaporation, other environmental factors affecting surface water availability aside from precipitation are temperature and wind speed (Allen et al 1998).

In addition to their importance for terrestrial ecosystems, all of these above-mentioned factors, including event size, soil characteristics and run-off, have important implications for the aquatic ecosystems in the desert. Ephemeral ponds, which are basins that hold water for short periods of time each year, are an important ecological feature in the US southwest. These ponds vary in origin, hydroperiod, hydrology, size, morphology, basin to watershed size ratio, geology, salinity, soils, and vegetation. All these variables will affect the organisms and ecosystem processes of the pond when it floods. After flooding, ephemeral water bodies have intense biological activity and often have high species diversity. For example, high diversity of lizards and anurans has been reported to inhabit areas surrounding ephemeral ponds in the Chihuahuan Desert (Havstad 2006). Abundance and diversity of organisms will depend on conditions preceding the flood. As the length of dry periods between flooding events increases, survivorship of adults and eggs decreases (MacKay et al 1990). Following the pulse-reserve paradigm, rainfall pulses will influence primary productivity and thus plant growth, stimulating reproduction, growth, and species richness of animal populations, such as black-tailed jackrabbits (*Lepus*

californicus), desert cottontails (*Sylvilagus auduboni*), and desert grassland breeding birds (Havstad 2006).

Chihuahuan Desert Region

According to the World Wildlife Fund (2007), the Chihuahuan Desert is the largest North American desert. It covers an area of about 453,250 km^2, stretching from the Rio Grande Valley in Southern New Mexico and the San Simon Valley of Southeastern Arizona deep into central Mexico to an area just north of Mexico City (Fig 1).

Figure 1. **Chihuahuan Desert Region (map by Christian Andresen).**

The Chihuahuan Desert is bordered by the Sierra Madre Occidental on the west and the Sierra Madre Oriental on the east. A very important aspect of this desert is the presence of the small mountain ranges than run through it, including the San Andres (max elevation, 2,740 m) and Doña Anas (max elevation, 1,449 m) in New Mexico, as well as the Indios (max elevation,

1,600 m) and Franklins in Texas (max elevation, 2,192 m). Large riparian corridors, created by the Rio Grande and Pecos River, are also found in the Chihuahuan Desert (Harris 2005). However, water availability in the Chihuahuan Desert is being compromised by damming of the rivers, destruction of riparian habitats for agriculture, over-pumping of groundwater, and pollution from anthropogenic sources.

In comparison with the other North American Deserts, the Chihuahuan Desert is a fairly dry desert, receiving an average precipitation of 235 mm with a narrow range of variation (67% range is 225-275 mm). While the other deserts get rain both in the summer and the winter, the Chihuahuan Desert receives most of its rainfall from summer monsoon season, from June to October, with only mild rains in early winter, usually December (Worthington et al 2010). Despite these overall regional trends, little is known about fine scale spatial variation in weather patterns and the impacts of Chihuahuan Desert mountain ranges on influencing wind, rain and temperature patterns.

These mountain ranges, and the unique weather patterns they host, have created a variety of distinct habitats throughout the region that has allowed the evolution of many endemic species, especially plants. It’s estimated that there could be up to 1000 endemic species (29%), including at least 16 endemic plant genera in this desert. Taxa with a high level of local endemism include cacti, butterflies, spiders, scorpions, ants, lizards and snakes (World Wildlife Fund 2007). Although the Chihuahuan Desert is one of the most biologically diverse arid regions on Earth, there are still many questions about how the topography of Chihuahuan Desert subregions affects their weather patterns, and thus resource availability; this knowledge is necessary to understand the possible impacts of climate change on the region.

Study Area

Indio Mountains Research Station (IMRS) (30.77688°N, 105.01617°W, elevation 1235 m) is a property of more than 159 km² owned and managed by The University of Texas at El Paso. IMRS is located in Hudspeth County, about 40 km southwest of Van Horn (Fig 1) in the Trans-Pecos region of Texas, which is part of the Chihuahuan Desert Region. The climate of the

Trans-Pecos region is characterized by some of the highest average maximum temperatures in the summer compared to other sites in Texas.

A description of the geology of IMRS, including the formation, stratigraphy, and paleontology of the Indio Mountains can be found in the Biotic Resources of Indio Mountains Research Station (IMRS), Southeastern Hudspeth County Texas: Handbook for Students and Researchers (Worthington et al 2004).

The landscape of IMRS is characterized by desert lowlands and uplands, and its vegetation is typical Chihuahuan Desert scrubland (Creosote-Lechuguilla-Ocotillo-Yucca associations) and Tobosa-Black Grama desert grassland. Extensive biotic surveys at IMRS have surveyed over 375 species of plants, 35 reptiles species, 96 bird species and 35 mammal species (Worthington et al. 2004). Currently, most of the biological research at IMRS is focused on habitat use and phylogeography of rattlesnakes and lizards. This research has shown that biological activity at IMRS tends to increase around water bodies; however, water is rare in this desert landscape. The only permanent water body inside IMRS property is called Squaw Spring, which is connected by Squaw Creek to the Rio Grande; however, Squaw Creek only flows perennially for a few hundred meters downstream of the spring. The only other water bodies at IMRS are several old man-made cattle tanks, which will be referred to as ponds, remaining from when IMRS was a cattle grazing ranch over 25 years ago. Although they are man-made, these ponds are an important feature of IMRS, since they collect water during the rains and therefore serve as microhabitats for the fauna of the area (Johnson 2005).

Understanding how atmospheric and physical variables affect water availability in the ponds can help us understand how climate change can affect resource availability inside IMRS, which in turn is important for better understanding the movement patterns of the organisms of this area. Furthermore, this study can provide insight into the dynamics that affect water availability in areas of similar characteristics. Due to the susceptibility of arid and semi-arid ecosystems to resource pattern changes, understanding these dynamics is necessary to understand

the possible impacts of climate change on these areas and their biodiversity (Gutierrez et al 1988, Wilbur 1997, Kemp 1983, Wilbur 1987).

Methods

Climate and water level data

Weather data has been collected by a Campbell Weather Station (model UT10) adjacent to the Indio Ranch house since 2006, while water level has also been monitored at Squaw Spring since March 2006. In March of 2009, six additional HOBO® weather stations and five additional water level loggers were installed throughout the IMRS property. Five weather station - water logger pairs were located in the vicinity of ponds, while the sixth weather station was installed at Squaw Spring, where a water level logger was already located (Fig 2). Each weather station was set up with the temperature sensor at 1.5 m above ground and oriented to the north. The wind and precipitation sensors were oriented towards the west and east, respectively. Water level loggers in the ponds were enclosed in a PVC case for protection and staked to the center of the deepest area of the pond, along with a staff gauge for monitoring water level.

The location of the weather stations was selected to be as close as possible to each pond, while at the same time considering landscape features that might influence sensor measurements. For example, neighboring hills might influence wind currents or insolation, and short distance from tall vegetation might shade the sensors, which in turn influences temperature measurements.

Weather stations were set up to sample at an interval of 15 sec and log at an interval of 15 min, while water level loggers log at an interval of 30 min. Coordinates and elevation for each weather station and water level logger are specified in Table 1. In addition to the loggers, water level staff gauges were installed at the center of 6 more ponds: Echo Canyon Twin Tanks II, Pirtle Tank, Lonely Tank, West Tank, Rattlesnake Tank, and Red Tank (Fig 2).

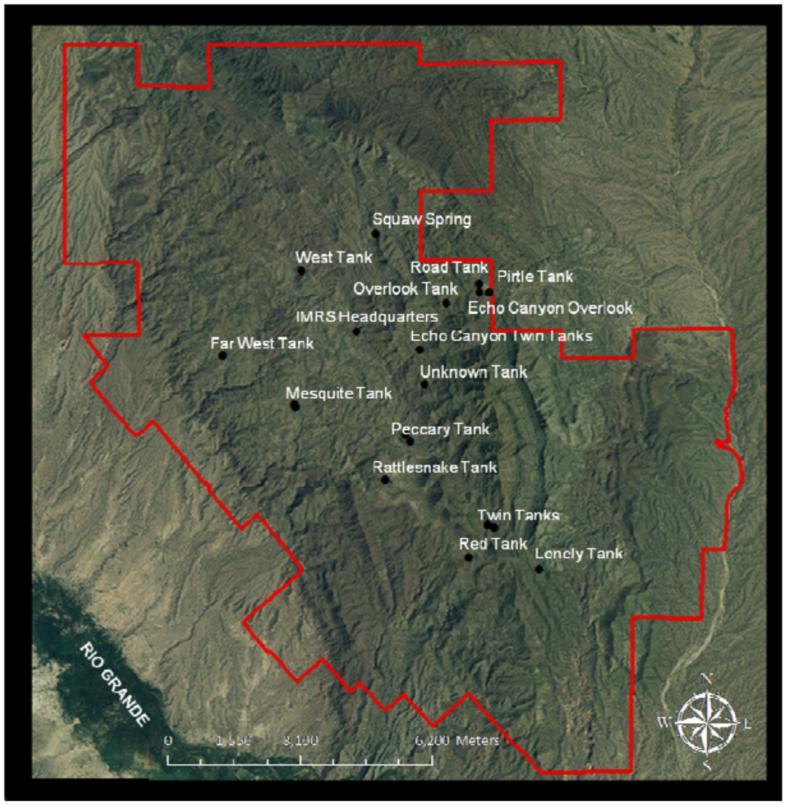


Figure 2. Indio Mountains Research Station Sites

Site selection was determined based on accessibility, location and observed water availability. Pirtle and Road tanks are adjacent to each other and are located right next to the main road; these sites are often observed with water. Echo Canyon Twin Tanks is located at the bottom of Echo Canyon, being most probably greatly influenced by runoff from surrounding hills. Twin Tanks is also located in the drainage area of several hills. This pond and Mesquite Tank are both adjacent to arroyos. Peccary, Rattlesnake and Red tanks were selected due to their accessibility and the fact that they are frequently visited by fellow researchers.

Table 1. Location, elevation and other characteristics of water bodies throughout IMRS, and the presence of weather stations and water loggers.

SITE	Equipment	LATITUDE	LONGITUDE	ELEVATION	ASPECT	Catchment Area (m^2)
Echo Canyon Overlook	Weather Station	30.78267	-104.99493	1397 m	WSW	N/A
Echo Canyon Twin Tanks	Water Logger	30.77309	-105.00076	1273 m		14,820,714
Unknown Tank	Staff Gauge	30.766	-104.99963	1281 m		14,820,714
Far West Tank	N/A	30.77202	-105.04804	1171 m		2,163,661
Lonely Tank	Staff Gauge	30.72794	-104.97209	1193 m		837,923
Mesquite Tank	Weather Station	30.76524	-105.03041	1194 m	E	N/A
	Water Logger	30.76133	-105.04804	1169 m		549,915
Overlook Tank	Staff Gauge	30.78222	-104.99778	1330 m		14,820,714
Peccary Tank	Weather Station	30.75575	-105.00417	1229 m	WSW	N/A
	Water Logger	30.75421	-105.0032	1207 m		314,109
Pirtle Tank	Staff Gauge	30.78512	-104.98428	1337 m		1,946,754
Rattlesnake Tank	Staff Gauge	30.7463	-105.009	1195 m		35,101
Red Tank	Staff Gauge	30.7303	-104.989	1186 m		2,115,959
Road Tank	Weather Station	30.78671	-104.98652	1330 m	ENE	N/A
	Water Logger	30.78735	-104.98651	1330 m		1,946,754
Squaw Spring	Weather Station	30.7948	-105.01445	1268 m	NW	N/A
	Water Logger	30.7972	-105.01125			N/A
Twin Tanks	Weather Station	30.73688	-104.98462	1219 m	WSW	N/A
	Water Logger	30.73651	-104.98315	1193 m		2,122,259
West Tank	Staff Gauge	30.78937	-105.02919	1221 m		2,475,069
IMRS Headquarters (no associated water body)	Weather Station	30.77679	-105.01643	1233 m	SW	N/A

To complement these data since IMRS appears to be in the middle of a rainshadow area, and since data from the Indio weather stations was lost due to technical difficulties for the period

of January 2009 to March 2009, meteorological data from Marfa (southeast), Pecos (northeast), El Paso and Guadalupe Pass (northwest) has been downloaded from Weather Underground.

Catchment size

In order to understand how topography relates to water availability at the ponds, catchment size was calculated using ArcGIS. A digital elevation model (DEM) and Arc Hydro were used to produce layers used to calculate catchment size for IMRS sites (R. Marin, unpubl. data).

Sediment Characteristics

Sediment samples were collected from the center of seven ponds that either regularly held water, or were monitored continually with water level loggers (Road Tank, Echo Canyon Twin Tanks, Mesquite Tank, Peccary Tank, Twin Tanks, Rattlesnake Tank, and Red Tank) at approximately 30 and 60 cm depth. These soils were then dried, homogenized and passed through a 2 mm sieve. A representative 2 g subsample was mixed with 20 ml of Calgon solution (sodium hexametaphosphate) and shaken overnight to breakup any remaining aggregates. These samples were then analyzed for particle size by laser diffractometry with a Malvern Mastersizer 2000. The protocols have been developed at UTEP based on the recommendations of Sperazza et al. (2004) and Zobeck (2004). This data will allow us to evaluate the influence of sediment texture on infiltration and thus surface water availability at the ponds.

Data analysis

Weather station and water level logger data was downloaded from the loggers on a regular basis and imported into a Microsoft Access 2007 database for easy storage and management. Water level for each pond was corrected using a combination of weather station barometric pressure values and further corrections due to the differences in elevation between the weather stations and water level loggers.

For both weather station and water level logger data, monthly and seasonal averages, maximums and minimums were calculated for each site inside and outside of IMRS. Because of the temporally repeated nature of the data, comparisons among sites were made using paired t-

tests. Pearson product moment correlation coefficients (r) were used to measure the temporal coherence of the different meteorological values among sites within IMRS (Benson et al. 2000). This is a measure of the extent to which the meteorological variables at each site vary similarly through time.

The impact of elevation on temperature was determined by calculating expected temperature based on the dry adiabatic lapse rate of 9.8 °C per kilometer of elevation. All expected temperatures were calculated based on elevation and relative to the observed temperature at the lowest elevation site (Mesquite).

Individual precipitation events were identified and analyzed to understand the relationship between size of event and increase in pond depth at the sites. Hourly precipitation totals were calculated and then grouped in precipitation events of 24-48 hrs for each site. A rainfall "event" was defined as any rainfall that accumulated within a 24-hr period, or any rainfall event that was separated by less than 1 hour from another event. For example, rainfall than occurred sporadically every second hour over a 48-hr period could also be defined as an "event". The average depth of each pond for the 24 hr period immediately before the start and after the end of each event was calculated and used to calculate the change in pond depth due to each event. The relationship between event size, as measured by the sum of all precipitation falling during an event, and the mean change in pond depth was analyzed using polynomial regressions and regression trees. Regression trees or partition analysis were used to determine the threshold amount of precipitation needed to cause an increase in pond depth. Average daily loss rates for non-rainy days was also calculated by calculating the change in depth on each 24-hour period (0:00 - 23:59 hours) that rain was not observed. The relationship between average daily loss rates and average pond depth was analyzed using linear regressions. JMP (version 9.0.0) was used for all statistical analyses.

Results

Trends in Climate Data

Plots of monthly temperature averages from the individual sites inside IMRS show consistent patterns through time, with peak temperatures being reached in July 2009 and June 2010 at all sites (Fig 3a). In contrast, there was more variation among sites with respect to average precipitation and wind. Seasonal trends in average wind speed are less obvious, and there is a great deal of difference in the mean wind speed among sites (Fig 3b). An obvious seasonal trend in precipitation was observed at all sites with the highest monthly precipitation values observed during the summer, with July being the wettest month on average for both years (Fig 3c). However, the greatest divergence in trends was observed in summer 2009, when sites in the northeast (Road, Echo Canyon) experienced an increase in precipitation, while all other sites declined.

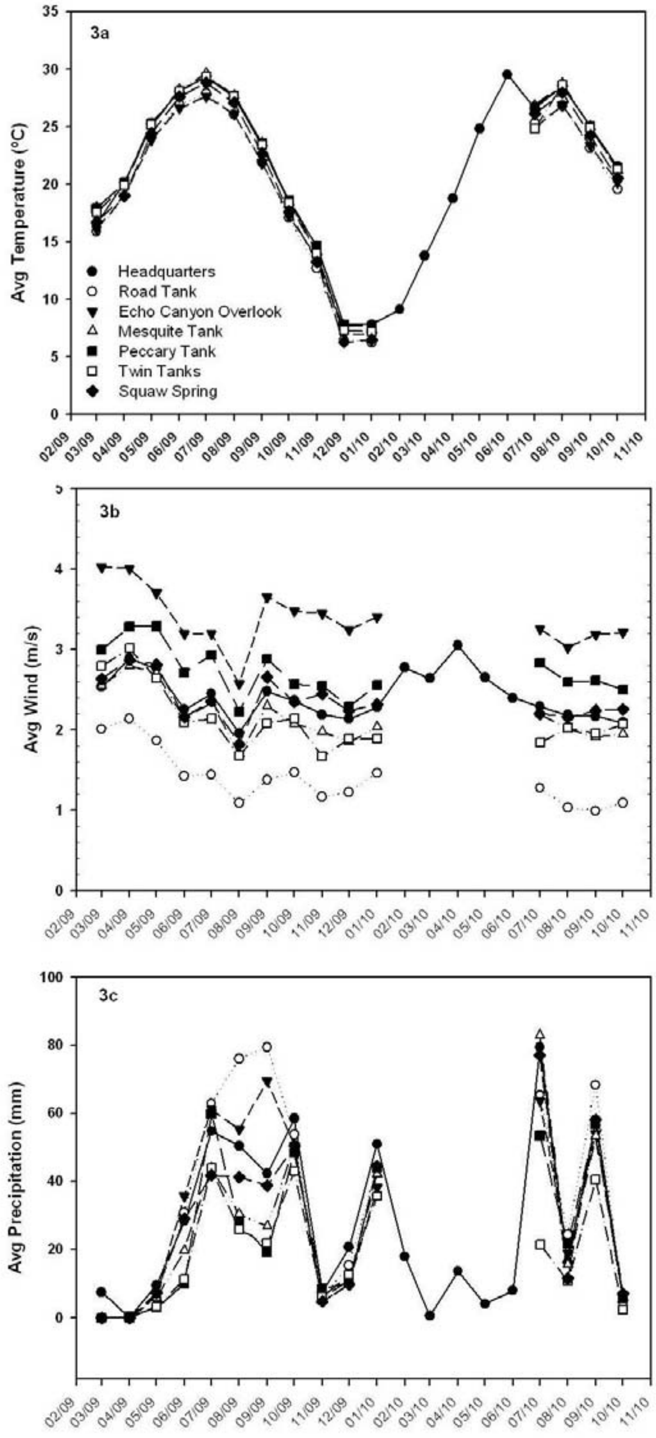


Figure 3. Monthly averages of temperature, wind and precipitation for weather stations at IMRS. Note: Due to technical difficulties, all weather stations except the Headquarters are missing data for 5 months in 2010.

Temporal coherence calculations confirmed the trends observed in Figure 3. We found very high correlations among average, minimum and maximum monthly temperatures among

sites inside IMRS (average r > 0.99), while wind and precipitation patterns were less synchronous among sites (average r <0.90) (Table 2). This lower coherence for wind and precipitation can be observed in the different monthly patterns among sites (Fig 3b-c).

Table 2. Average correlation coefficients for temperature, wind, and precipitation at 6 weather stations inside IMRS. The asterisk indicates that all correlation co-efficients used in calculation of the average were significant (p<0.05).

PARAMETER	AVG CORRELATION Co-efficient	AVG P-VALUE
Avg Temperature	0.999	<.0001*
Max Temperature	0.992	<.0001*
Min Temperature	0.997	<.0001*
Avg Wind Speed	0.868	<.0016*
Max Wind Speed	0.624	0.043
Total Precipitation	0.882	<.0003*

Matched paired t-test analysis of monthly temperature, wind speed, and precipitation averages allowed us to look at statistical differences among sites (Fig 4). Mesquite, Peccary, and Twin Tanks were the warmest sites, while Squaw Spring, Road and Echo were the coolest (Fig 4a). Mesquite Tank reached the highest maximum temperature, while Squaw Spring, Echo, and Road Tanks reached the lowest minimum temperatures (Fig 4b and 4c). Wind speed averages confirmed that Echo Canyon Overlook was the windiest site, followed by Peccary, Squaw and Headquarters, Mesquite and Twin, and Road Tank (Fig 4d). Analysis of maximum wind speed values showed very similar results to those from wind speed averages (Fig 4e). Precipitation averages indicated that Headquarters, Road, and Echo Canyon Overlook were the wettest sites, but only Headquarters was significantly higher than the other four sites. These wetter sites were the most northeasterly weather stations in our study and Road is located outside of the mountain ranges surrounding IMRS.

Further analysis indicated that average temperature was likely influenced by a combination of site elevation and aspect. While average temperature declined with elevation (r^2=0.878, p=0.015), all sites had warmer temperatures than expected from elevation effect alone (Fig 5). The sites with the largest difference from expected, as calculated based on a dry adiabatic lapse rate, tended to have southerly or south-westerly aspects (Peccary, Headquarters, Echo).

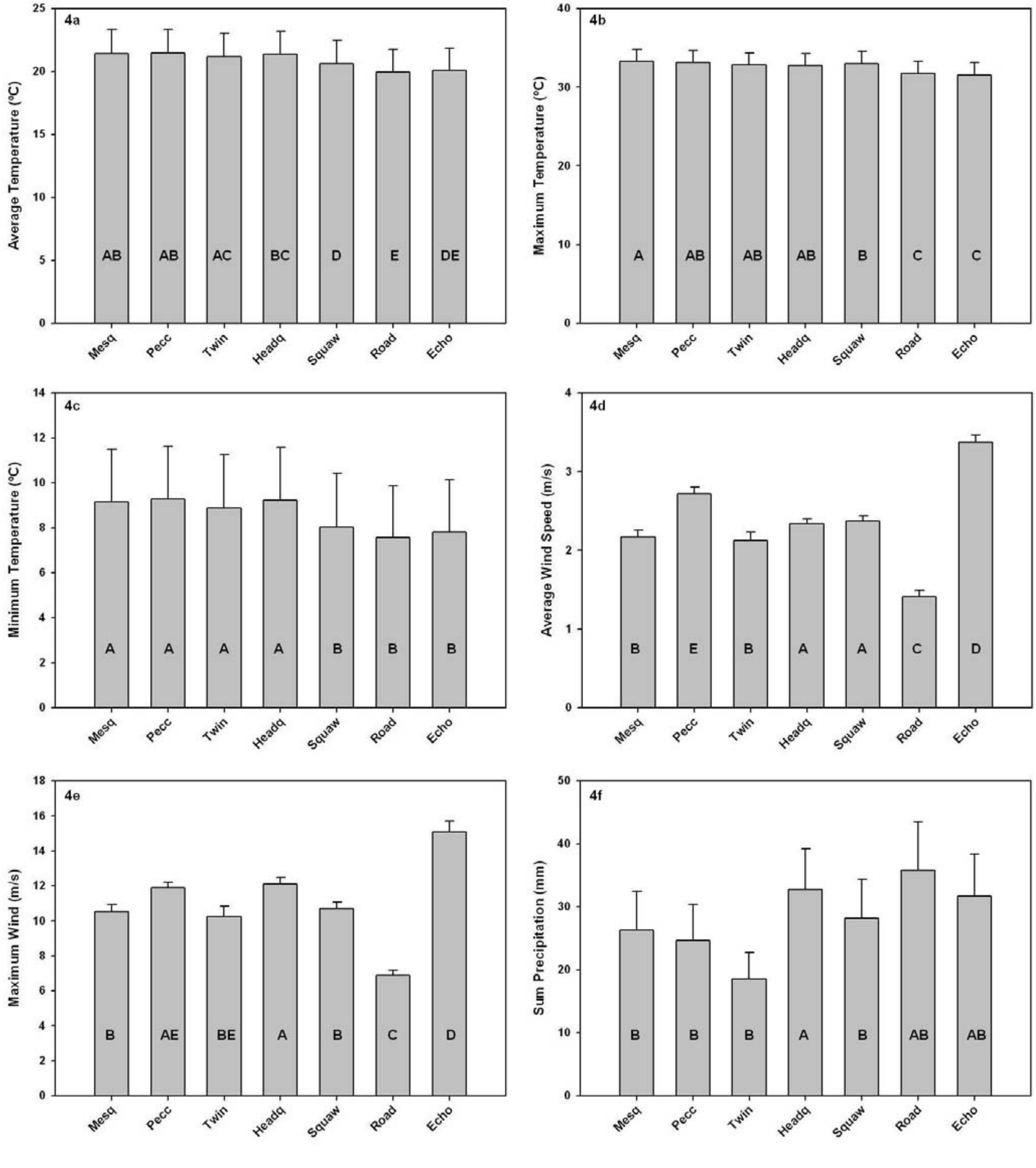


Figure 4. Comparisons of average temperature (4a-4c), wind speed (4d-4e), and precipitation (4f) among IMRS weather stations. Letters illustrate statistical similarities among sites (paired t-test, $p<0.05$). Sites are ordered from lowest to highest elevation.

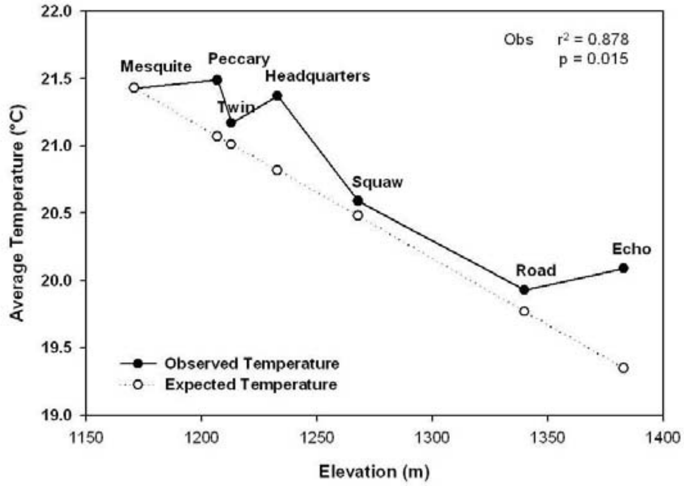


Figure 5. Relationship between weather station elevation and average temperature of IMRS sites. Expected temperature was calculated based on the dry adiabatic lapse rate.

Seasonal averages and maximums were calculated for Headquarters data from 2006-2010, and compared to those from El Paso, Pecos, Guadalupe Pass, and Marfa TX. Headquarters showed significantly higher average and minimum temperatures (Figs 6a and 6c), as well as lower wind speeds (Fig 6d and 6e), than all other sites. The only significant differences in precipitation totals was that Pecos, TX was significantly drier that all the other sites (Fig 6f).

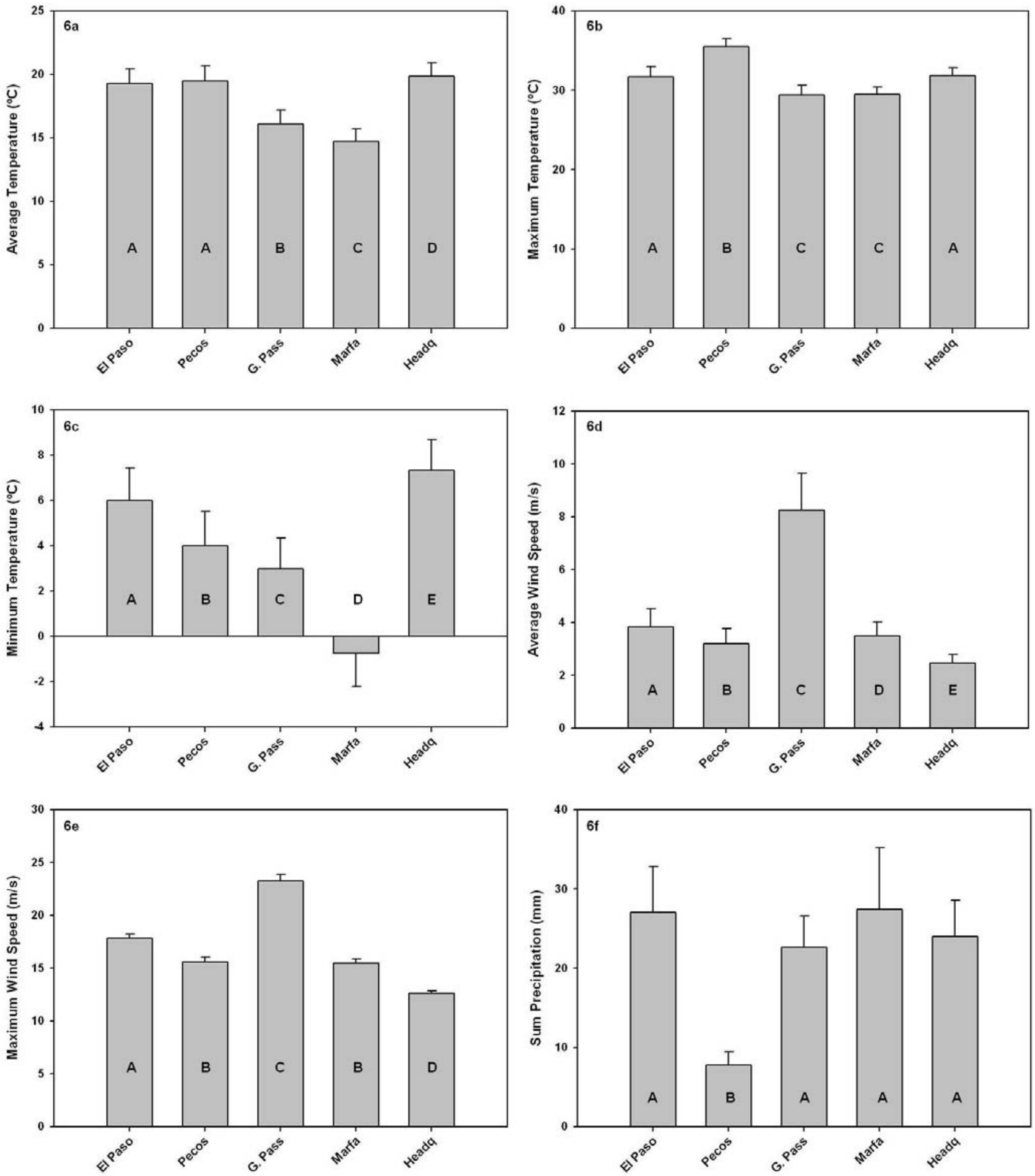


Figure 6. Comparisons of average temperature (6a-6c), wind speed (6d-6e), and precipitation (6f) for the region.

Water Availability at Ponds

Field observations reveal that the ponds that tended to contain water most often were Road Tank, Twin Tanks, and Echo Canyon Twin Tanks, while Pirtle, Red and Rattlesnake ponds would collect water for only brief periods of time before they emptied, and Peccary and Mesquite did not collect water at all (Table 3). Water level logger data confirmed manual observations; however, the continuous monitoring was able to record that Peccary did retain water for brief periods and time (0.06), while Twin Tanks only retained water for 20% of the time. Field measured values may be inflated relative to actual frequency of water, as site visits were often planned after rain events or during the rainy season. Since the completion of this study, a water level logger was moved from Mesquite Tank to Red Tank to obtain more detailed data from that site.

Table 3. Frequency (proportion of visits) where standing water was observed at a tank. N/A indicates that a water logger was not installed at the site.

SITE	FREQUENCY OF OBSERVED WATER	FREQUENCY OF LOGGED WATER
Echo Canyon Twin Tanks	0.45	0.46
Echo Canyon Tank II	0	N/A
Lonely Tank	0	N/A
Mesquite Tank	0	0
Peccary Tank	0	0.06
Pirtle Tank	0.36	N/A
Rattlesnake Tank	0.27	N/A
Red Tank	0.36	N/A
Road Tank	0.73	0.75
Twin Tanks	0.55	0.20
West Tank	0	N/A

Most sites had very similar soil particle size distribution among the 30 and 60 cm depths, as indicated by the clustering of points around a 1:1 line (Appendix A & B). Road and Mesquite tanks tended to deviate most from this line, with a greater proportion of sand at 60 cm in Mesquite tank, and a greater proportion of silt at 60 cm in Road tank. On average, there were high percentages of silt at all of the sites (average = 68%); Mesquite, one of our driest sites, had the highest percentage of sand from all of the ponds.

Soil particle size distribution seems to have a strong influence on water retention. In particular, the frequency of water standing in the ponds was strongly dependent on the percentage of clay in the sediment for both field measurements (r^2 = 0.57, p = 0.05) and data from the water level loggers (r^2 = 0.92, p < 0.05). However, there was no relationship with the percentage of sand or silt (p>0.05) (Figure 7).

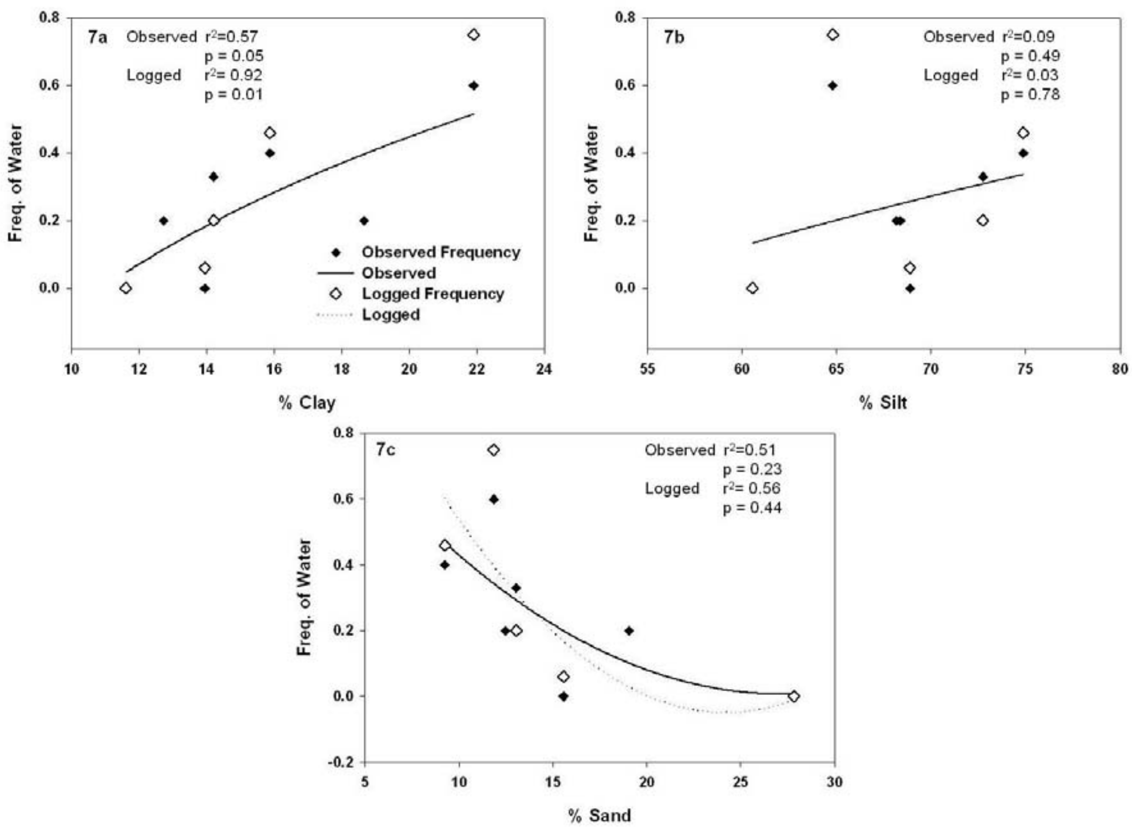


Figure 7. Relationship between the frequencies of observed and logged water in the ponds, and percentage soil composition of a) clay, b) silt, and c) sand.

Analysis of 24-36 hr precipitation events and water level logger averages for each pond indicated that all sites received a threshold of 13-20 mm of precipitation before the depth in the tanks changed abruptly, although there was variability among sites. Echo Canyon Twin Tanks and Twin Tanks for example, both had a higher threshold level of precipitation (17-20 mm) than the other two sites (13 mm). Echo Canyon Twin Tanks had a 2 to 3 times higher mean depth change (1.07 m) than the other tanks (0.3-0.4 m) (Fig 8).

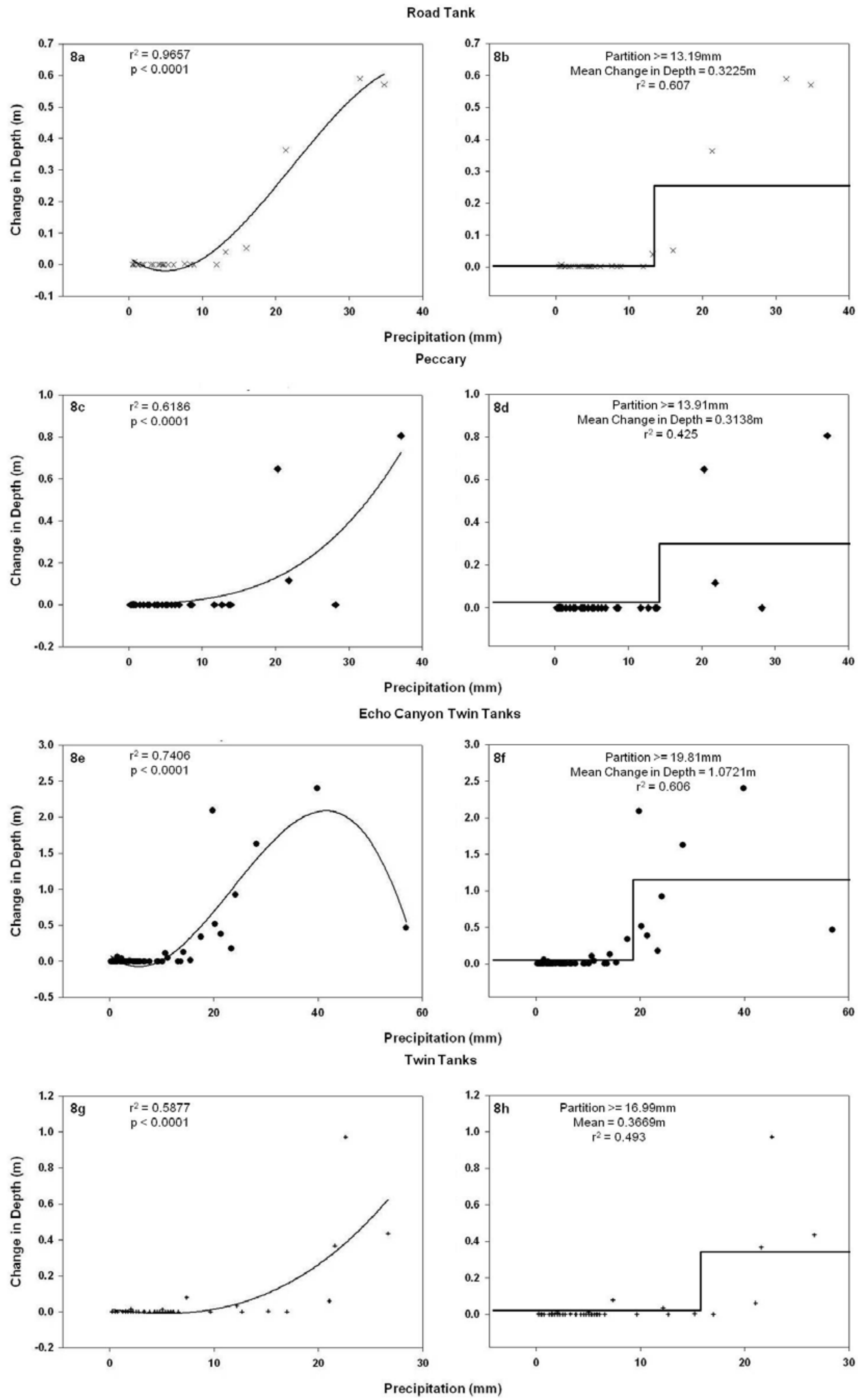


Figure 8. Analysis of 24-36 hr precipitation events and mean change in depth for IMRS ponds.

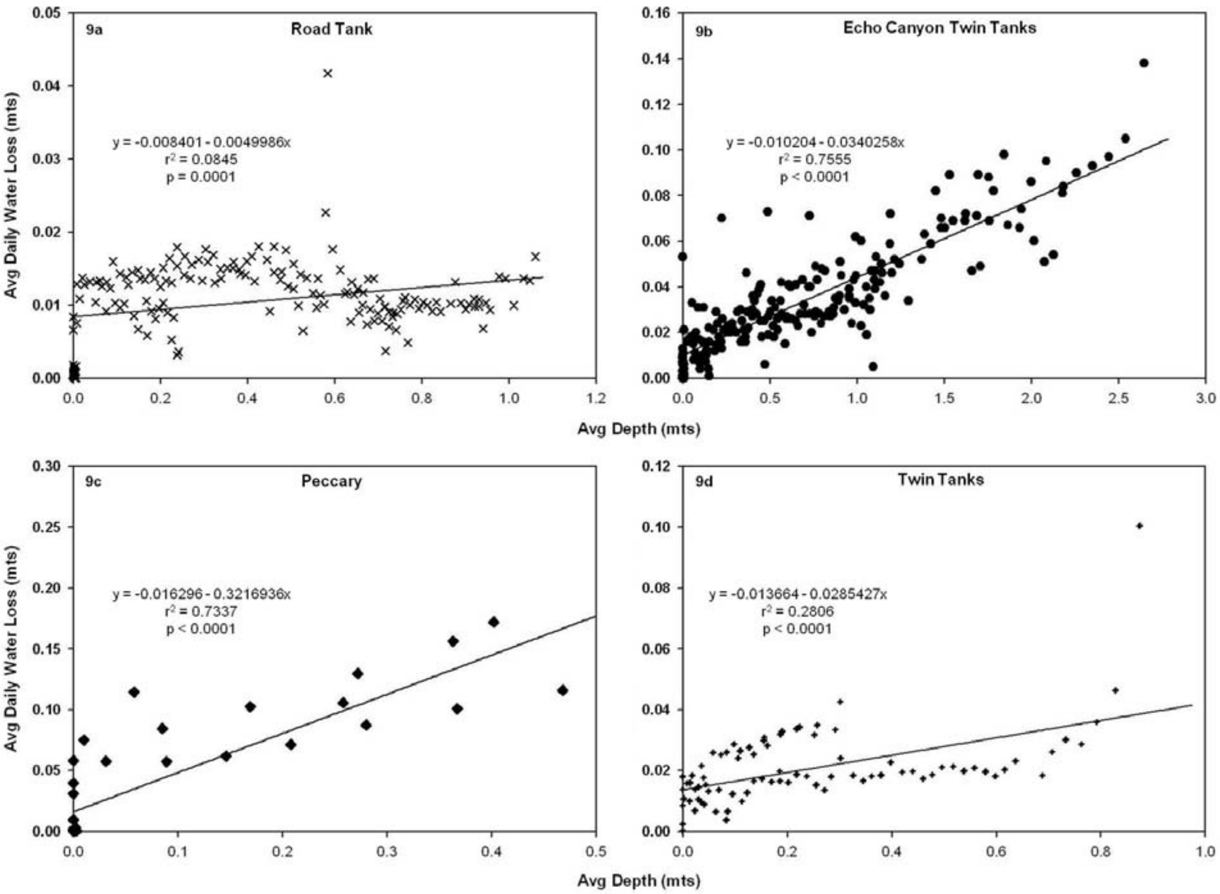


Figure 9. Analysis of average daily water loss on non-rainy days and average depth for IMRS ponds.

Analysis of average daily water loss and average depth for all IMRS ponds showed a very strong significant relationship (Fig 9). The highest rate of loss was observed at Peccary Tank, while the lowest rate of loss was observed at Road Tank.

The relationship between catchment area, calculated using ArcHydro for ArcGIS, and the mean depth change as calculated using partition analysis was highly significant (Fig 10). Echo Canyon Twin Tanks, with the largest catchment area, recorded the largest changes in depth after each rain event, while the other 3 tanks have much smaller catchment areas and depth changes.

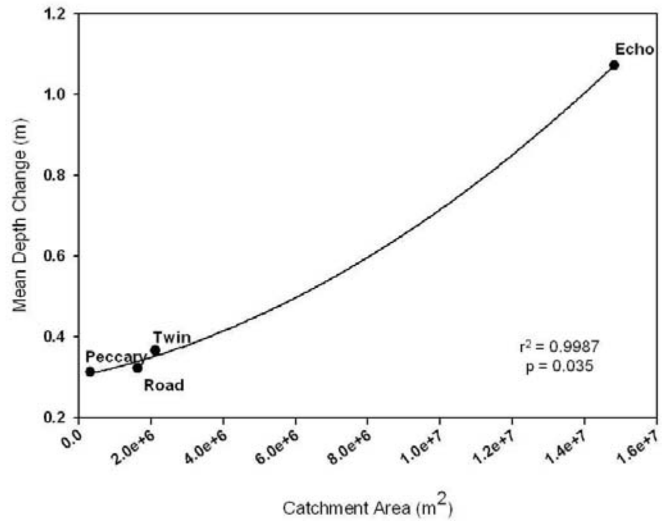


Figure 10. Relationship between mean depth change, partition, and catchment area.

Discussion

While temperature patterns among IMRS sites were very similar, precipitation and wind patterns were more variable. For example, during August 2009 the difference between the hottest and coolest site was 1.5 °C while the difference between the driest and wettest site was 50.2 mm of precipitation. Other studies of ecosystems with scattered mountain ranges found that one of the controls for the spatial distribution of precipitation is elevation. For example, (Gebremichael et al. 2010) found that high elevation areas receive more rain than low elevation areas in a topographically complex river basin in Ethiopia. Similarly, (Gebremichael et al. 2007) observed decreased precipitation at lower elevations and sites at the southern end of their study area in the Sierra Madre Occidental in northwest Mexico. Similarly, in the Indio Mountains, we also found that lower elevation and more southern sites tended to have reduced levels of precipitation.

Topography will also affect the temperature patterns of the region due to differences in elevation and other spatial variations such as orientation. Although most forecasts of mountain temperatures are determined based on either a standard or calculated lapse rate (Martinec and Rango 1986, Lundquist and Cayan 2007) found that accounting for other spatial variations, such as orientation with regards to a mountain range, yields better results for temperature. For example, when comparing sites on the east/west of a mountain range, strong winds coming from the west were associated with cooler west and warmer east sites; weaker westerly winds, however, were associated with the opposite. At IMRS sites elevation and aspect also had an influence on temperature; sites at lower elevations had higher temperatures, and those sites with western aspect deviated the most from the expected average temperature. Although elevation had a greater effect on temperature, location and distance of sites with regards to the surrounding mountains indicates a larger scale effect of topography on temperature; for example sites that were further to the east were also cooler.

IMRS weather also appears to be influenced by its surrounding topography when compared with sites outside of the mountain range, as can be observed by its lower wind speeds.

Lundquist and Cayan (2007) found that in regions with complex terrain, sites that were exposed to higher wind speeds had a lower temperature. Similarly, IMRS average wind speeds were significantly lower than those from nearby sites, and it had significantly warmer average temperatures. However, contrary to our prediction, IMRS headquarters did not have significantly lower precipitation when compared to other sites in the region. This indicates that IMRS is influenced mostly by an orographic effect instead of a rainshadow effect from the surrounding topography.

The influence of topography in combination with the NAM, El Nino/La Nina Southern Oscillation (ENSO) and/or the Pacific Decadal Oscillation (PDO), can create a lot of inter-annual climate variability in the SW-US (Molnar and Ramirez 2001, Sheppard et al. 2002, Arriaga-Ramirez and Cavazos 2010) that impact local climate, ecosystem function, and water resources (Vera et al. 2006). Most weather patterns within IMRS were similar in both 2009 and 2010; however, analysis of precipitation patterns among IMRS sites shows summer 2009 to have greater variation when compared to the rest of the sampling period. A possible explanation for this variation could be a combination of ENSO and PDO effects on both summers influenced by the topography of the area and location of the sites. However, the absence of data from early 2010 makes generalizations regarding inter-annual variability difficult.

Isolated wetlands occur in different areas of the United States and their characteristics resemble those of IMRS manmade ponds. These are small seasonal precipitation-fed depressional wetlands, with no permanent connection to another surface water body (Brooks 2005, Smith and Verril 1998, Bauder 2005). Hydrology and hydroperiod of isolated wetlands has been shown to be affected by topography, geologic location and morphology of each individual pool (Brooks 2005, Bauder 2005); and climate patterns, especially precipitation (Brooks 2004, Brooks 2005, Bauder 2005) and temperature related evapotranspiration (Bonner et al 1997, Broooks 2005, Bauder 2005). Other studies of seasonal ponds also show these to have soils consisting of less permeable silt and clay (Kantrud et al 1989, O’Driscoll & Parizek 2003, Zedler 1987, Gamble & Mitsch 2009). Variation among individual IMRS ponds also indicates an

influence of all of these factors on their hydrology. In particular, sites with a greater proportion of clay substrates hold water for longer periods of time, and the rate of filling is dependent on rainfall intensity and watershed size. Much as the pulse-reserve paradigm describes how pulse size determines fluxes of carbon and energy in arid terrestrial ecosystems (Whitford 2002, Reynolds et al 2004), the size of a rainfall event can also affect the development of ephemeral aquatic ecosystems in the desert. While small events may stimulate microbial activity in the dry pond beds, larger events result in pooling of water and elevated levels of primary production by both algae and wetland plant communities. This vegetation can in turn influence soil type, soil formation, and distribution of atmospheric and soil moisture, which influences precipitation patterns.

Weather in the Trans-Pecos is dependent on the influence of topography on synoptic phenomena, as can be observed by the warmer, less windy weather of IMRS when compared to that of nearby sites. Topography and location will also affect temperature and precipitation patterns at a microscale, as seen with the location of cooler IMRS sites at higher elevations, for example. These variables, combined with the physical and geological characteristics of the area will dictate the hydrology and water availability of the site.

Conclusion

Arid and semi arid lands cover about one-third of the Earth's surface, are used mostly as rangelands and are highly susceptible to changes in resource availability, especially precipitation. Due to their dry nature, precipitation patterns shape the interactions and dynamics of these ecosystems from the microscopic to the landscape level. Weather and precipitation patterns of a region are dependent on the region's topography and the changes in larger scale oceanic and atmospheric conditions; despite this, the local effect of topography on the redistribution of larger scale precipitation patterns is not fully understood. It is now widely accepted that anthropogenic emissions into the atmosphere are causing drastic changes in the planet's oceanic and atmospheric temperatures, which causes changes in weather and climate patterns all over the globe. Climate change models predict arid and semi-arid ecosystems to experience longer dry periods and less frequent yet more extreme precipitation events. This study contributed to the understanding of the mechanisms influencing weather patterns, precipitation events, and thus water availability at a microscale.

Future Directions

- In order to better understand the impacts of large scale wind patterns on smaller scale weather patterns, a wind direction sensor should be added to Echo Canyon Overlook station, as well as another weather station also equipped with wind direction on the western slope of the western range; this would help understand how topography affects wind direction and thus precipitation patterns at this microscale.
- An additional water level logger at Rattlesnake Tank, as well as soil moisture sensors at Peccary, Twin, and Road Tanks would help further understand the relationship between soil moisture and water availability at the ponds.
- Bathymetric measurements of each pond should be added to continued aboveground water level measurements to better understand the relationship between pond morphology and water availability.
- Additional water level loggers In addition to aboveground measurements, description and monitoring of the water table would help understand the translation of weather patterns into water availability in this topographically complex region.
- Analysis of primary production and nutrient dynamics during small and large rain events would allow the expansion of the pulse-reserve paradigm into arid ephemeral pond ecosystems.

References

Allen, Richard, Luis S. Pereira, Dirk Raes, and Martin Smith. “Chapter 1: Introduction to Evapotranspiration.” Crop evapotranspiration: Guidelines for computing crop water requirements. 1998. FAO. <http://www.fao.org/docrep/x0490E/x0490e04.htm>

Arriaga-Ramirez, S. and T. Cavazos. 2010. Regional trends of daily precipitation indices in northwest Mexico and southwest United States. Journal of Geophysical Research-Atmospheres 115.

Bauder, E. T. 2005. The effects of an unpredictable precipitation regime on vernal pool hydrology. Freshwater Biology. 50:2129–2135.

Benson, Barbara J., John D. Lenters, John J. Magnuson, Maryan Stubbs, Timothy K. Kratz, Peter J. Dillon, Robert E. Hecky, and Richard C. Lathrop. “Regional Coherence of Climatic and Lake Thermal Variables of Four Lake Districts in the Upper Great Lakes Region of North America.” Freshwater Biology. Vol 43. 2000: 517-527.

Bonner L.A., Diehl W.J. and Altig R. 1997. Physical, chemical and biological dynamics of five temporary dystrophic forest pools in central Mississippi. Hydrobiologia 353: 77–89.

Brooks, R. T. 2004. Weather-related effects on woodland vernal pool hydrology and hydroperiod. Wetlands 24:104–114.

Brooks, R. T. 2005. A review of basin morphology and pool hydrology of isolated ponded wetlands: implications for seasonal forest pools of the northeastern United States. Wetlands Ecology and Management 13:335-348.

Castillo, V.M., A. Gomez-Plaza, and M. Martinez-Mena. “The Role of Antecedent Soil Water Content in the Runoff Response of Semiarid Catchments: A Simulation Approach.” The Journal of Hydrology. Vol 284. 2003: 114-130.

Castro, C. L., T. B. McKee, and R. A. Pielke. 2001. The relationship of the North American monsoon to tropical and North Pacific Sea surface temperatures as revealed by observational analyses. Journal of Climate 14:4449-4473.

Driscoll, Michael, and Richard R. Parizek. “Geological Controls on Seasonal-Pool Hydroperiod in a Karst Setting.” Wetlands. Vol 28. 2008: 1004–1017.

Gamble, D. L., and W. J. Mitsch. 2009. Hydroperiods of created and natural vernal pools in central Ohio: a comparison of depth and duration of inundation. Wetlands Ecology and Management 17:385–395.

Gebremichael, M., F. A. Hirpa, and T. Hopson. 2010. Evaluation of High-Resolution Satellite Precipitation Products over Very Complex Terrain in Ethiopia. Journal of Applied Meteorology and Climatology 49:1044-1051.

Gebremichael, M., E. R. Vivoni, C. J. Watts, and J. C. Rodriguez. 2007. Submesoscale spatiotemporal variability of North American monsoon rainfall over complex terrain. Journal of Climate 20:1751-1773.

Gutierrez, Julio, Oswaldo A. Da Silva, Maria I. Pagani, Danforth Weems, and Walter G. Whitford. "Effects of Different Patterns of Supplemental Water and Nitrogen Fertilization on Productivity and Composition of Chihuahuan Desert Annual Plants." American Midland Naturalist. Vol 119. 1988: 336-343.

Harris, Arthur. "Chihuahuan Desert Homepage." 2005. The University of Texas at El Paso. <http://museum.utep.edu/chih/chihdes.htm>

Havstad, Kris M., Laura F. Huenneke, and William H. Schlesinger. eds. "Structure and Function of a Chihuahuan Desert Ecosystem: The Jornada Basin LTER." Oxford (United Kingdom): Oxford University Press, 2006.

Higgins, R. W., Y. Yao, and X. L. Wang. 1997. Influence of the North American monsoon system on the US summer precipitation regime. Journal of Climate 10:2600-2622.

Johnson, Jerry. "Indio Mountains Research Station." 2005. The University of Texas at El Paso. <http://research.utep.edu/Default.aspx?alias=research.utep.edu/indio>

Kantrud H.A., Krapu G.L. and Swanson G.A. 1989. Prairie basin wetlands of the Dakotas: a community profile. USDI Fish and Wildlife Service Biological Report 85 (7.28). Washington D.C., USA.

Kemp, Paul. "Phenological Patterns of Chihuahuan Desert Plants in Relation to the Timing of Water Availability." The Journal of Ecology. Vol 71. 1983: 427-436.

Loik, M. E., D. D. Breshears, W. K. Lauenroth, and J. Belnap. 2004. A multi-scale perspective of water pulses in dryland ecosystems: climatology and ecohydrology of the western USA. Oecologia 141:269-281.

Lundquist, J. D. and D. R. Cayan. 2007. Surface temperature patterns in complex terrain: Daily variations and long-term change in the central Sierra Nevada, California. Journal of Geophysical Research-Atmospheres 112.

MacKay, William P., Steven J. Loring, Thomas M. Frost, and Walter G. Whitford. "Population Dynamics of a Playa Community in the Chihuahuan Desert." The Southwestern Naturalist. Vol 35. 1990: 393-402.

Martinec, J. and A. Rango. 1986. Parameter Values for Snowmelt Runoff Modeling. Journal of Hydrology 84:197-219.

Molnar, P. and J. A. Ramirez. 2001. Recent trends in precipitation and streamflow in the Rio Puerco Basin. Journal of Climate 14:2317-2328.

Moran, M. S., E. P. Hamerlynck, R. L. Scott, J. J. Stone, C. D. H. Collins, T. O. Keefer, R. Bryant, L. DeYoung, G. S. Nearing, Z. Sugg, and D. C. Hymer. 2010. Hydrologic response to precipitation pulses under and between shrubs in the Chihuahuan Desert, Arizona. Water Resources Research 46.

O'Driscoll M.A. and Parizek R.R. 2003. The hydrologic catchment area of a chain of karst wetlands in central Pennsylvania, USA. Wetlands 23: 171–179.

Rango, A., S.L. Tartowski, A. Laliberte, J. Wainwright, A. Parsons. "Islands of Hydrologically Enhanced Biotic Productivity in Natural and Managed Arid Ecosystems." Journal of Arid Environments. Vol 65. 2006: 235-252.

Reynolds, James F., Paul R. Kemp, Kiona Ogle, Roberto J. Fernandez. "Modifying the 'Pulse-reserve' Paradigm for Deserts of North America: Precipitation Pulses, Soil Water, and Plant Responses." Oecologia. Vol 141. 2004: 194-210.

Schwinning, Susanne, Osvaldo E. Sala. "Hierarchy of Responses to Resource Pulses in Arid and Semi-arid Ecosystems." Oecologia. Vol 141. 2004: 211-220.

Schwinning, Susanne, Osvaldo E. Sala, Michael E. Loik, James R. Ehleringer. "Thresholds, Memory, and Seasonality: Understanding Pulse Dynamics in Arid/semi-arid Ecosystems." Oecologia. Vol 141. 2004b: 191-193.

Sheppard, P. R., A. C. Comrie, G. D. Packin, K. Angersbach, and M. K. Hughes. 2002. The climate of the US Southwest. Climate Research 21:219-238.

Smith D.W. & Verrill W.L. 1998. "Vernal pool-soil-landform-relationships in the Central Valley, California." In: Ecology, Conservation, and Management of Vernal Pool Ecosystems—Proceedings from a 1996 Conference (Eds C.W. Witham, E.T. Bauder, D. Belk & W.R. Ferren, Jr), pp. 15-23. California Native Plant Society, Sacramento, CA.

Sperazza, M., Moore, J.N., Hendrix, M.S., 2004. High-Resolution Particle Size Analysis of Naturally Occurring Very Fine-Grained Sediment Through Laser Diffractometry. Journal of Sedimentary Research 74: 736-743.

Vera, C., W. Higgins, J. Amador, T. Ambrizzi, R. Garreaud, D. Gochis, D. Gutzler, D. Lettenmaier, J. Marengo, C. R. Mechoso, J. Nogues-Paegle, P. L. S. Dias, and C. Zhang. 2006. Toward a unified view of the American Monsoon Systems. Journal of Climate 19:4977-5000.

Whitford WG (2002) Ecology of Desert Systems. Cambridge University Press, Cambridge

Wilbur, Henry. “Experimental Ecology of Food Webs: Complex Systems in Temporary Ponds.” Ecology. Vol 78. 1997: 2279-2302.

Wilbur, Henry. “Regulation of Structure in Complex Systems: Experimental Temporary Pond Communities.” Ecology. Vol 68. 1987: 1437-1452.

Woodward, Bruce. “Predator-Prey Interactions and Breeding-Pond Use of Temporary Pond Species in a Desert Anuran Community.” Ecology. Vol 64. 1983: 1549-1555.

World Wildlife Fund. "Chihuahuan desert." 2007. Encyclopedia of Earth. <http://www.eoearth.org/article/Chihuahuan_desert>

Worthington, R. D., C. S. Lieb, and W. Anderson. 2004. Biotic Resources of Indio Mountains Research Station (IMRS), Southeastern Hudspeth County Texas: Handbook for Students and Researchers. Continually Reviewed and Updated by J. D. Johnson. The University of Texas at El Paso, Privately Printed. El Paso, Texas. 86 pp.

Yair, A., and M. Shachak. “A Case Study of Energy, Water and Soil Flow Chains in an Arid Ecosystem.” Oecologia. Vol 54. 1982: 389-397.

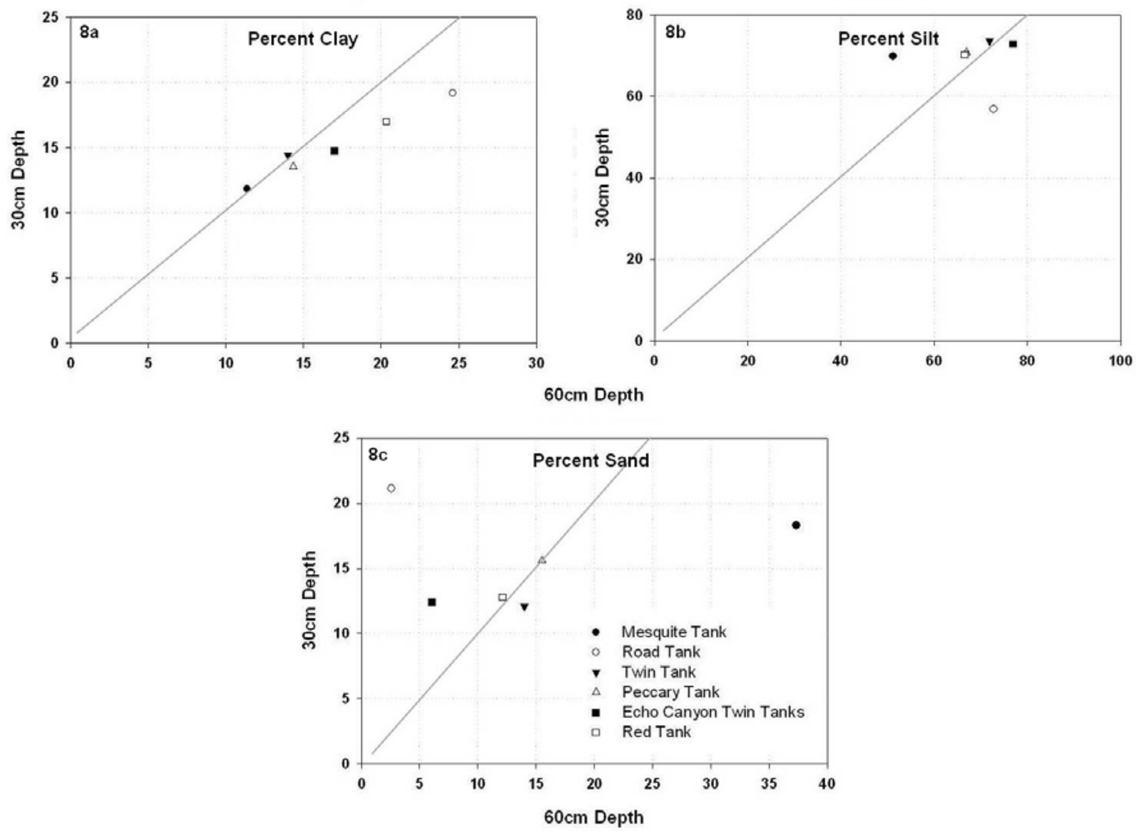
Zedler P.H. 1987. The ecology of southern California vernal pools: a community profile. USDI Fish and Wildlife Service Biological Report 85 (7.11), Washington D.C., USA.

Zobeck, T.E., 2004. Rapid Soil Particle Size Analyses Using Laser Diffraction. Applied Engineering in Agriculture 20: 633-639.

Appendix

Appendix A. Sediment grain size distribution analysis results. All samples were collected on DATE.

SITE	% CLAY	% SILT	% SAND	SOIL TEXTURE
Echo Canyon Twin Tanks 30cm	14.75	72.85	12.4	Silt Loam
Echo Canyon Twin Tanks 60cm	17	76.91	6.07	Silt Loam
Mesquite Tank 30cm	11.83	69.88	18.3	Silt Loam
Mesquite Tank 60cm	11.38	51.22	37.36	Silt Loam
Peccary Tank 30cm	13.54	70.85	15.6	Silt Loam
Peccary Tank 60cm	14.36	66.9	15.51	Silt Loam
Rattlesnake Tank 30 cm	12.73	68.17	19.06	Silt Loam
Red Tank 30cm	17.01	70.18	12.81	Silt Loam
Red Tank 60cm	20.33	66.57	12.13	Silt Loam
Road Tank 30cm	19.18	56.8	21.13	Silt Loam
Road Tank 60cm	24.64	72.79	2.57	Silt Loam
Twin Tanks 30cm	14.41	73.51	12.08	Silt Loam
Twin Tanks 60cm	14	71.96	14.01	Silt Loam



Appendix B. Comparison of percentages of a) clay, b) silt, and c) sand at 30 and 60cm depth in tanks at IMRS. The grey line indicates a 1:1 of percent composition at each depth.

Vita

Fernanda De La Cerda was born in Mexicali, BC, Mexico. After moving to Chihuahua City at the age of 8, she graduated from the Instituto La Salle de Chihuahua in the spring of 2002 and entered the University of Texas at El Paso that same fall. While pursuing her Bachelor's Degree in Environmental Science, she worked as a student research assistant on a molecular project to assess heavy metal effects on the lifecycle of *E. dilatata*, a species of rotifer. In fall of 2006 she started working in Dr. Vanessa Lougheed's lab helping graduate students with their field work at Rio Bosque Wetlands Park, as well as conducting small in lab experiments related to these projects. For her internship, Fernanda worked at a PRONATURA Hawksbill turtle camp in the Yucatan Peninsula monitoring nests and tracking hatchlings as they left the shore. By the end of her bachelor's degree in fall 2007 she started working with a contracting company doing vegetation field surveys for Ft. Bliss and continued for a semester after starting her graduate studies also at The University of Texas at El Paso in spring 2009. Fernanda started working as a TA teaching introductory biology and environmental science labs in the fall of 2009 and continued until the end of her graduate studies. Throughout both her undergraduate and graduate studies, Fernanda also attended and/or presented at the Society for the Advancement of Chicanos and Native Americans in Science, Ecological Society of America, and Sustainability on the Border Conferences, as well as the UTEP Geological Sciences Colloquium.

Permanent address: 3411 Maine
Chihuahua, Chih, 31250
or
fdelacerda@miners.utep.edu

This thesis/dissertation was typed by Fernanda De La Cerda.