A Novel Approach to Wetland Management in Arid Regions: Harnessing the Power of the Playa

By Tayler A. Rocha

Section 1 – Personal

Living in the intermountain west, I believe that there isn't a more important resource to both humans and wildlife as water. Along with my early childhood interest in science, I have always been concerned about the availability of water, remembering times when our well water was low, barely yielding enough water for bathing due to the diversion of surface water for agriculture, as well as worsening drought conditions. I was also worried about the overuse of water by humans for seemingly trivial reasons, with little regard to wildlife or habitat needs. After I learned about the BLM trying reverse decades of dewatering by reestablishing wetlands in the high mountain valley where I live, I became intensely interested in how both humans and wildlife would benefit from this unique management effort. I saw this as an incredible learning opportunity for me, and a chance to help local biologists make better decisions about the best use and application of this limited and precious resource. This project gave me and other biologists in the region a new perspective on the possibility of managing resources for the benefit of both wildlife and humans. I believe that it doesn't have to be a strict choice of one over the other.

My study examines how temporary wetlands, called playas, can be beneficial to wildlife by serving as a rich food source for migratory birds, as well as a source of groundwater recharge for humans needs. Wetlands, particularly those in the West, have been in sharp decline for many years due to human demands, and are becoming less functional and more disconnected as wildlife habitat. By understanding how wetland habitats and groundwater are interdependent and linked, water application strategies can be developed that can support wildlife as well as the farming needs of humans. I monitored aquatic insects, water quality, and water volumes within a playa basin, providing evidence that infrequent flooding yields an extremely productive wetland while simultaneously recharging local groundwater levels, an important consideration for land managers trying to justify and maximize the use of limited water resources in areas of high demand.

To determine if I had true differences between my samples, I needed to learn about basic statistics, and how to collect enough data to capture the variability of the populations I was sampling. This was a new realization for me, as I had never understood why scientists seemed to "over-collect" data, and perform experiments multiple times. I also had to learn about constructing mathematical models using GIS software, and the type of data I needed to collect to satisfy the parameters of the model.

This project helped to dispel some math anxiety that I had, and expanded my understanding of how math and science are intimately linked.

Math as it is taught in the classroom has not captured my intense interest as has science throughout my years in high school. However, while conducting my research on this project, I realized that math is what allowed me to visualize and deduce my conclusions: it is the tool that validates and describes the differences and findings of any scientific endeavor. The collection and comparisons of any dependent variable are almost always described mathematically, which brought the subject alive for me, and made it much more relevant and meaningful. Understanding the mathematical meaning of a population, a sample, significance, and variability was exciting and gave me a new way to visualize data and new considerations for how to design my experiments. I gained a tremendous amount of confidence when I realized that I had the ability to understand and use math as I conducted science, giving it a much deeper meaning than just textbook examples that were out of context.

If I were to give advice to my peers about conducting research combining science and math, I would recommend starting with topics that matter to them personally, and may not necessarily represent the next "earth shaking" idea. Ask questions that have bearing to your lives, and work to solve problems that help your family, friends, and community. When a research question is personal, it will help you stay focused, kindle interest, and give you the drive to see it to completion. While you might feel that your findings are small-scale, it's remarkable how a "small" idea can morph into something much more global, and make a difference on a much larger scale. I also strongly believe that student researchers must not be afraid to fail. The idea of failure in science is largely an illusion in my opinion; how many "failures" were the precursors to amazing discoveries? The only failure that exists is giving up or not trying at all. If something doesn't work, it's not a failure; you are simply one step closer to finding out what does work.

Section 2 – Research

Abstract

The overall goal of this project was to investigate methods for maximizing biological productivity in wetlands with limited or seasonal water availability. In this study, the initial stages of secondary succession were examined in a newly-flooded playa basin, and its subsequent hydrology was described. Macroinvertebrates and water quality were analyzed and compared to existing mature wetlands in the vicinity in order to establish baseline productivity and serve as a seasonal control. Samples were taken on 8/31 and 9/14/12 from both experimental and control wetlands, and pool perimeters were mapped on 8/31, 9/08, and 9/14/12 using GPS equipment. It was found that most water quality parameters such as dissolved ions and metals increased as time and distance from the inlet pipe increased, and the semi-permanent wetland control (C2) more closely resembled the experimental basin then did the established playa control (C1) in terms of water quality. Macroinvertebrate abundance increased through time, and the greatest diversity was sampled near areas with ancestral playa pans as opposed to areas receiving water for the first time in decades. Overall, biomass was greater in the upper basin but macroinvertebrates in the lower basin were larger, particularly near the ancestral playa areas. Total biomass estimates for the combined basins yield 1015.5 kg of insect forage. It was also found that of the 189996.2 m^3 of delivered water, an average of 38.7% of it remained on the ground throughout the period of active flooding, yielding a maximum basin volume of ~52000 m^3. Water table levels, evaporation rates, timing, and presence of ancestral pans should be factored by land managers to estimate the productivity and hydrologic efficiency of future wetlands projects.

Abbreviations and Acronyms

U1 – Upper Basin Site 1	*U4* – Upper Basin Site 4	*L1* – Lower Basin Site 1	*C1* – Control Site 1
U2 – Upper Basin Site 2	*U5* – Upper Basin Site 5	*L2* – Lower Basin Site 2	*C2* – Control Site 2
U3 – Upper Basin Site 3		*L3* – Lower Basin Site 3	

1. Introduction

1.1 Importance of Playa Wetlands

Playas are a type of ephemeral, or temporary wetland that develop in shallow basins, or "pans" which obtain water from run-off or precipitation and typically last only for a few weeks. Despite the short duration of flooding however, they have a significant impact on the hydrology, soils, plant, and wildlife communities in the vicinity of the playa. They provide important forage and nesting habitat for many species of birds and other wildlife (Nuemberg, 2010) and support a great diversity of plant species that become adapted to the brief flooding cycle. Playas are frequently the only source of standing water in flat areas that have no permanent streams or lakes (epa.gov, 2012), and are also known to help increase local groundwater levels that have been impacted and depleted by industrial or agricultural use, or extended periods of drought.

Humans can have a great impact on ephemeral wetlands. Often times, humans drain these ponds to prevent them from becoming mosquito breeding grounds, whereas others may turn them into permanent bodies of water for recreation, fishing, or other purposes. Increasing demands for water (both surface and groundwater) for agricultural and domestic use often reduces the size and extent of flooding of playas (epa.gov, 2012). These modifications alter the water cycle that playa species are adapted to and depend upon, which ultimately changes the functionality of the playa and the suite of plant and animal species that live there.

1.2 Significance of Wetlands in the San Luis Valley

From the Pleistocene period to present day, there has been significant wetlands within the San Luis Valley, a large intermountain valley filled with deep sediments creating a substantial, saturated aquifer. Since the early 1900's, heavy use of surface water and depletion of groundwater for agricultural purposes has dewatered these wetlands (photo 1), lowered groundwater tables, and seriously degraded artesian water sources. For the past several years, the San Luis Valley Bureau of Land Management has worked with other state and federal agencies to begin the process of restoration of this network of historic wetlands that linked surface water across a 60 mile corridor on the valley floor. In 2012, biologists obtained approval, built the infrastructure and equipment, and exchanged surface water rights with the goal of wetting a playa basin that has been limited to brief precipitation events for at least the last 70 years (Lucero & Swift-Miller, Personal Interview, 2012).

Photo 1. Comparison of surface water availability at Mishak Lakes (The Nature Conservancy), one of dozens of dewatered wetlands within the San Luis Valley, Colorado.

1.3 Application of LiDAR Data

The water application area of this project was mapped prior to flooding using a technology called LiDAR (Light Detection And Ranging). This highly precise mapping technique uses laser light to detect sub-meter elevation differences along the ground and vegetation, and can give detailed and accurate 3D measurements of the ground surface (Andersen, July 31, 2006). The lasers units are mounted on the underside of an airplane, and send laser signals to the ground at 100,000 pulses per second. The amount of time it takes for the light beam to bounce back to the plane is recorded by an onboard computer, and slight differences in the reflection time correspond to slight elevation differences, which are then used to model subtle topography and create highly detailed maps of ground surfaces.

Access to these detailed ground elevation maps allowed for the derivation of precise calculations of volume for each flooded basin over time. This information is critical for understanding hydrological processes that by nature are difficult to quantify, and are frequently “ball-parked” by land managers due to a lack of accurate elevation maps. By combining the water input flow rate (from the flow meter on the supply pump), average evaporation rates for the area (wrcc.dri.edu, 2013), and the accurate basin topography and volumes from GIS modeling and LiDAR, a rate of “ground-soak” was derived for the basins. This information can be used to model and plan future water application projects in similar areas, and potentially save land managers time and money by creating accurate water budget forecasts.

1.4 Objectives of this Study

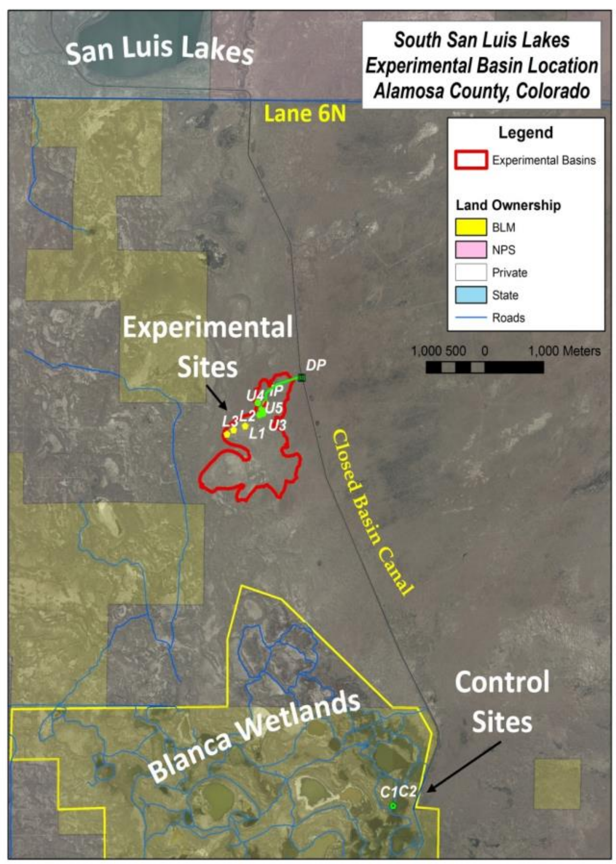
Biological productivity (macroinvertebrates), abiotic factors (water quality), and hydrology (GIS LiDAR) were monitored and analyzed during a unique flood event of an experimental playa basin. The goal of this study is to help wetland managers see trends and correlations between water quality and macroinvertebrate communities, which will help with future decisions about the location, timing, amount, and duration of water application. This information will be critical for the designing and re-establishing of historic wetlands, as well as providing greater insect productivity and forage opportunities for migratory and nesting birds.

2. Materials and Methods

2.1 Description of the Study Area

The main experimental basins are located approximately five km south of San Luis Lakes State Wildlife Area and approximately two km north of Blanca Wetlands. The source water for these basins was piped from the Closed Basin Canal (Bureau of Reclamation) as part of a larger water exchange with other state and federal agencies. Within the Experimental Basin area (figure 1), three small basins were identified as potential flood sites. Specific locations within these basins were chosen as sample sites based on the degree and depth of flooding, and varied between sample periods. Two mature wetlands (a playa and a semi-permanent wetland) were also selected from the Blanca Wetlands complex to serve as a concurrent sample site for comparisons of water quality and macroinvertebrate species.

Figure 1. Water quality and macroinvertebrate sample sites on Nature Conservancy lands and Blanca Wetlands, Alamosa County, Colorado.



2.2 Field Collection of Water Samples

Two samples were collected from each basin during each sample period. Samples were collected every two weeks until water was no longer available in the basin due to evaporation, soil porosity, and/or water pump failure. Each water sample was collected with two acid- rinsed 500 mL high density linear polyethylene bottles which were labeled with the location, time, temperature, and pH of the sample. Water samples, pH, and temperature were taken onsite in water columns not disturbed by foot traffic. Sample bottles were primed before samples are collected by rinsing at least twice with sample water. Samples were taken from middle of the water column, and two bottles from each site as a back-up. Samples were collected at various distances from the inlet and at different locations within the test basin, as well as from mature wetlands located on Blanca Wetlands. Samples were stored in coolers until analysis and acidification to reduce biotic activity which may affect the results.

2.3 Lab Analysis of Water Samples

Filtration:

Half of a 500 mL was filtered into a 500 mL vacuum flask mounted with a magnetic filter funnel and a 47mm diameter (45 µm pore size) prewashed filtration membrane. Filter and flask was primed before each filtration with approximately 50 ml of sample water. During the process, the tip of the magnetic filter funnel was not touched by any surface to avoid contamination and water levels did not reach above 150 mL within the funnel to avoid contamination of the sample. A blank was created by filtering deionized water using the protocol described above. The blank and the filtered/non filtered 250 mL water samples were acidified with 0.5 mL of concentrated nitric acid, which preserved the samples and gave them a pH of approximately 2.0.

Total Dissolved Solids:

Glass beakers were heated in a drying chamber, and the starting dry weight of the beakers was determined using a calibrated electronic scale accurate to 0.0001 g. Sample water was used to prime a 50 mL pipette, and three beakers were filled with 50 mL of sample (3 replicates). Blanks made from deionized water and a quality control sample of a known TDS was also measured. Samples were dried once again, with a final two hours at 180°C to drive off all moisture. Samples were then placed in the desiccator to cool to room temperature. When beakers reached a constant temperature (approximately 21°C), they were weighed. The two weights were subtracted to get the total dissolved solids.

Conductivity:

Conductivity was found by using a conductivity meter. The probe is stored in deionized water (D.I.) until use, when it is then rinsed twice with D.I. and then placed into sample water. The sample used to find conductivity was not filtered or acidified since this may cause inaccurate results. Conductivity is measured in microsiemens per centimeter (µS/cm).

Alkalinity:

Alkalinity was found using a Metrohm Auto-titrator. Samples were placed into plastic test cups in a specific sequence required by the titrator (tap water, two D.I. rinses, a quality control alkalinity standard solution, a D.I. blank, several water samples, a sample duplicate of the last sample, and another blank D.I.). The titrator automatically rotated through the test cups in a specific interval of time, and the data was stored electronically and retrieved.

Metals:

For the analysis of dissolved metals, an acidified portion of the filtered water sample was analyzed directly. Samples were pretreated with nitric to help determine the total recoverable metals in water samples. The method involved identifying the signature of each type of metal by using an inductively coupled plasma-mass spectrometer (ICP). Sample solutions are pneumatically nebulized (changed into a mist) into a radio-frequency plasma where ionization occurs. The metals ions are extracted from the plasma through a vacuum interface and separated on the basis of their mass-to-charge ratio by a quadruple mass spectrometer. Separated ions were detected by an electron multiplier, and instrument drift must be corrected with the use of fixed internal standards.

2.4 Macroinvertebrates

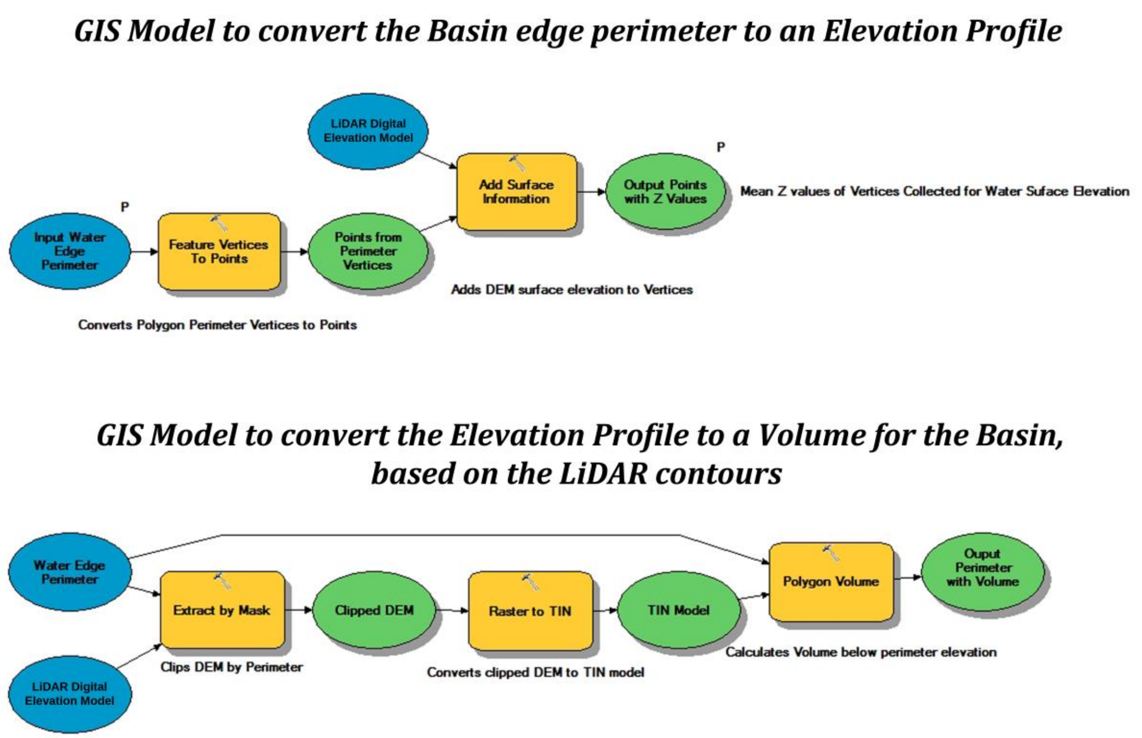
In conjunction with water sample collection, there was at least two macroinvertebrate samples collected from each basin during each sample period. Samples were collected every two weeks until water was no longer available in the basin due to evaporation, soil porosity, and/or water pump failure. Macroinvertebrates were collected at specific points in time to see how abiotic factors affect biotic factors in the flooded basin. Once the locations for samples within the basin were determined, a large round plastic tub with its bottom removed was placed securely in the mud to isolate the insects within the water column and bottom substrate. Since the tub was essentially a cylinder, the diameter at the water's surface, as well as three depths within the bucket, were measured in centimeters, which will yield an overall volume. The entire water column was removed from the bucket with a small plastic cup and filtered through a 250 micron sieve until there was no standing water left inside the bucket. The macroinvertebrate sample was rinsed and condensed, and placed into plastic 1L sample bottles with 100% ethanol alcohol for preservation. The sample from each site was then sorted by Order or Family, and placed into separate vials. Each insect group was then measured for length using a random sub-sample of the group. This was accomplished by using a petri dish with a 1cm x 1cm grid marked on the back, placing the sample on the plate, and measuring the lengths of individual insects within randomly selected grids. Each group of insects was then counted within each sample.

Macroinvertebrate samples were then dried in pre-weighed beakers at the Bureau of Reclamation water testing lab in a drying chamber (65°C until ethanol is evaporated, then 90°C for 24 hours). After cooling, the beakers were then weighed and the biomass of each insect group was recorded.

2.5 Mapping, LiDAR Imagery and GIS

Using a Trimble GPS unit (Geoexplorer 2004), the perimeter of the water edge was mapped periodically for each basin to monitor how much water remained on the ground after the effects of evaporation and absorption by the substrate. A GIS model based on the LiDAR imagery was constructed (figure 2) to determine the average pool elevation (z value) for the flooded basins, which was then used to derive the volume for the complex ground topography of each basin (figure 8). Rates of evaporation were obtained from average pan evaporation data (Alamosa, Colorado, 1948-2005) from the Western Regional Climate Center (wrcc.dri.edu, 2013) for the month of September. A profile of standing water volumes through time was derived from direct basin volume measurements, inlet flow rates, and evaporation rates, yielding an estimation of water loss due to ground-soak.

Figure 2. GIS model to derive basin volumes from LIDAR surface topography and pool perimeters.



3. Results

3.1 Macroinvertebrates

Figure 3a. Total Species abundance of all sample sites – 8/31 – 9/14

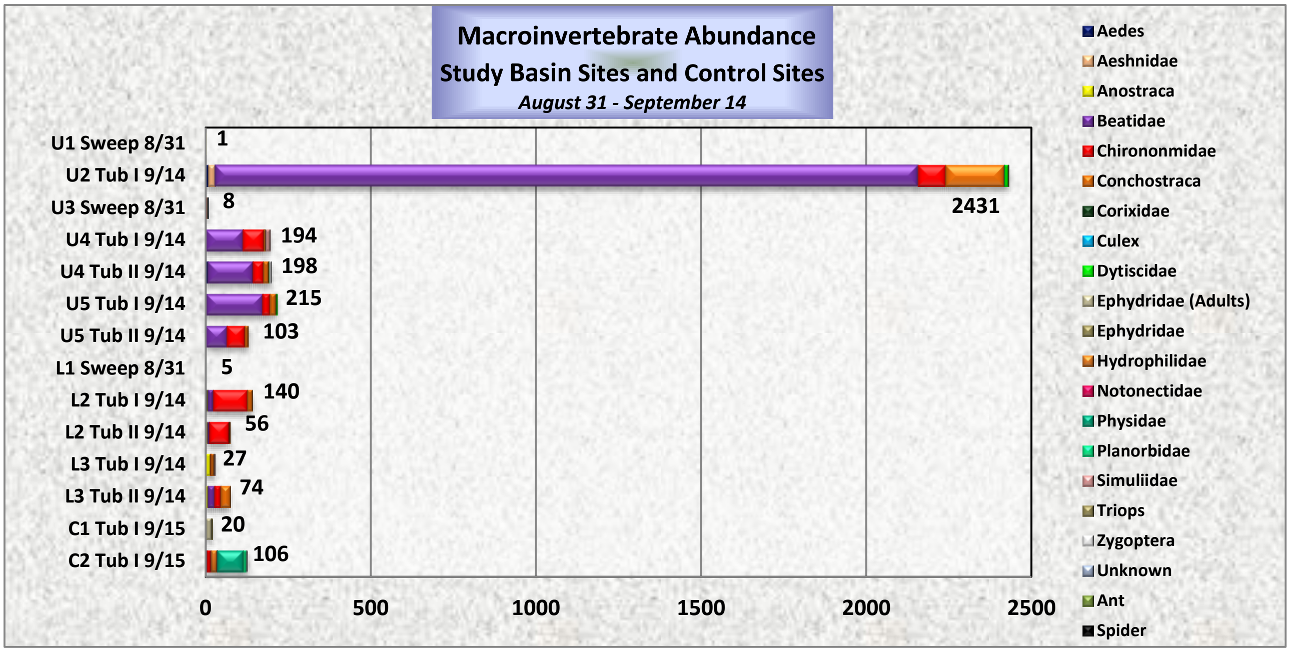


Figure 3b. Total Species abundance of all sample sites – 8/31 – 9/14

(U2 Tub 1 removed to see smaller sample size detail)

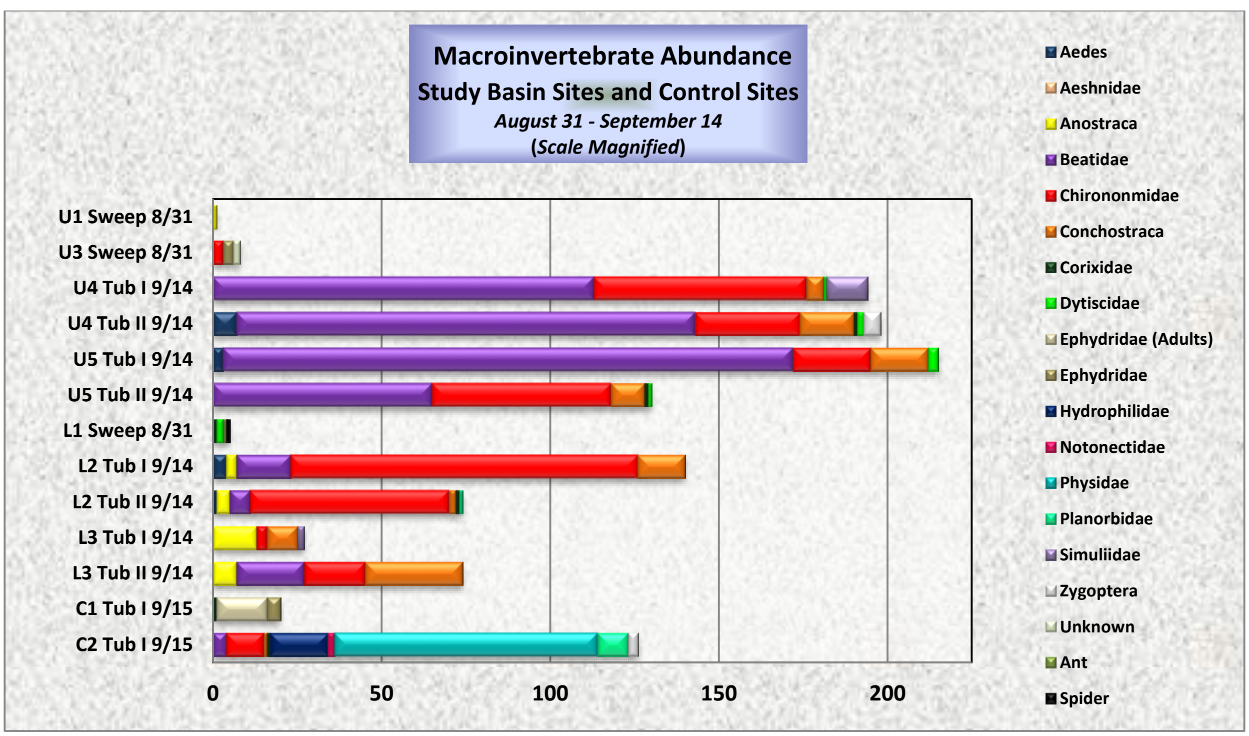


Figure 4. Average Length of Macroinvertebrates - Aedes, Baetidae, & Chironomus – 8/31 and 9/14

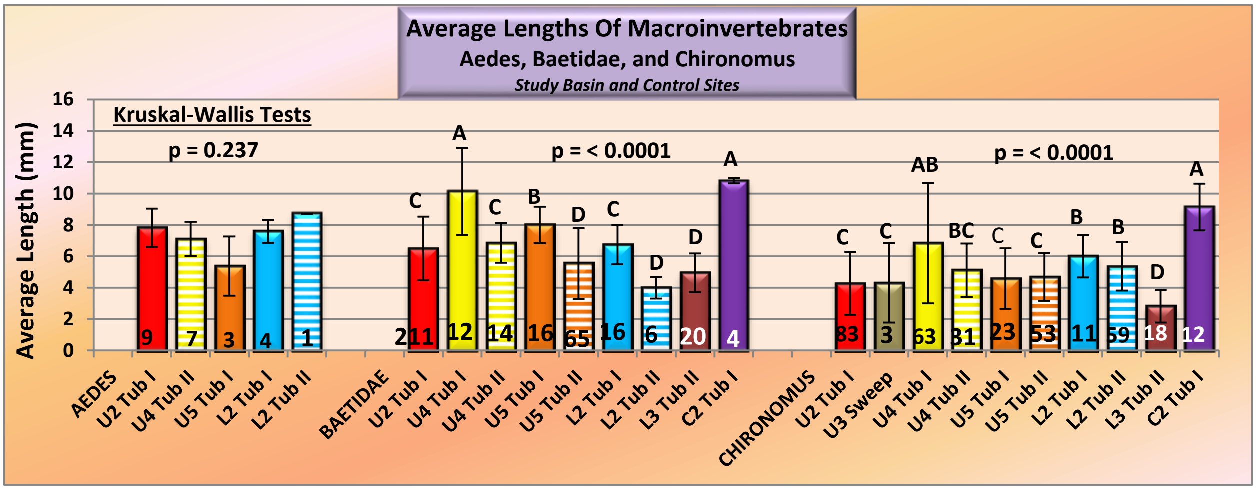


Figure 5. Average Length of Macroinvertebrates – Dytiscidae, Corixidae, Hydrophilidae, Ephydridae & Zygoptera – 8/31 and 9/14

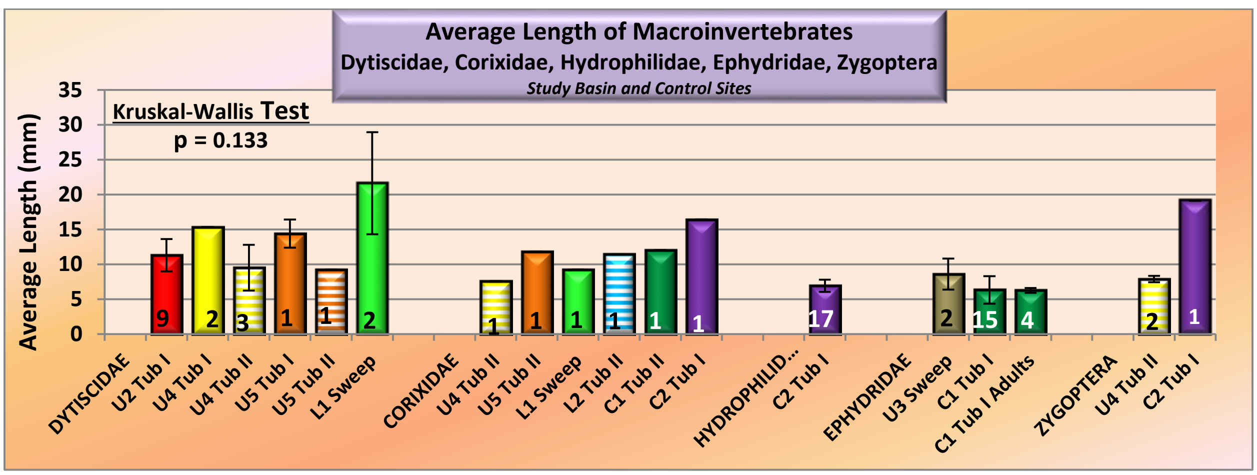
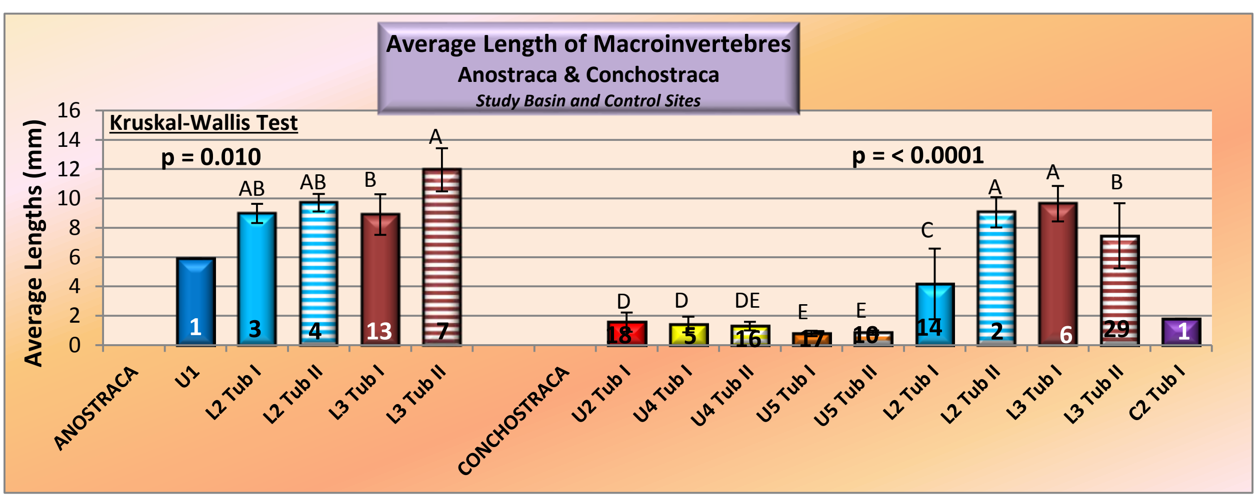
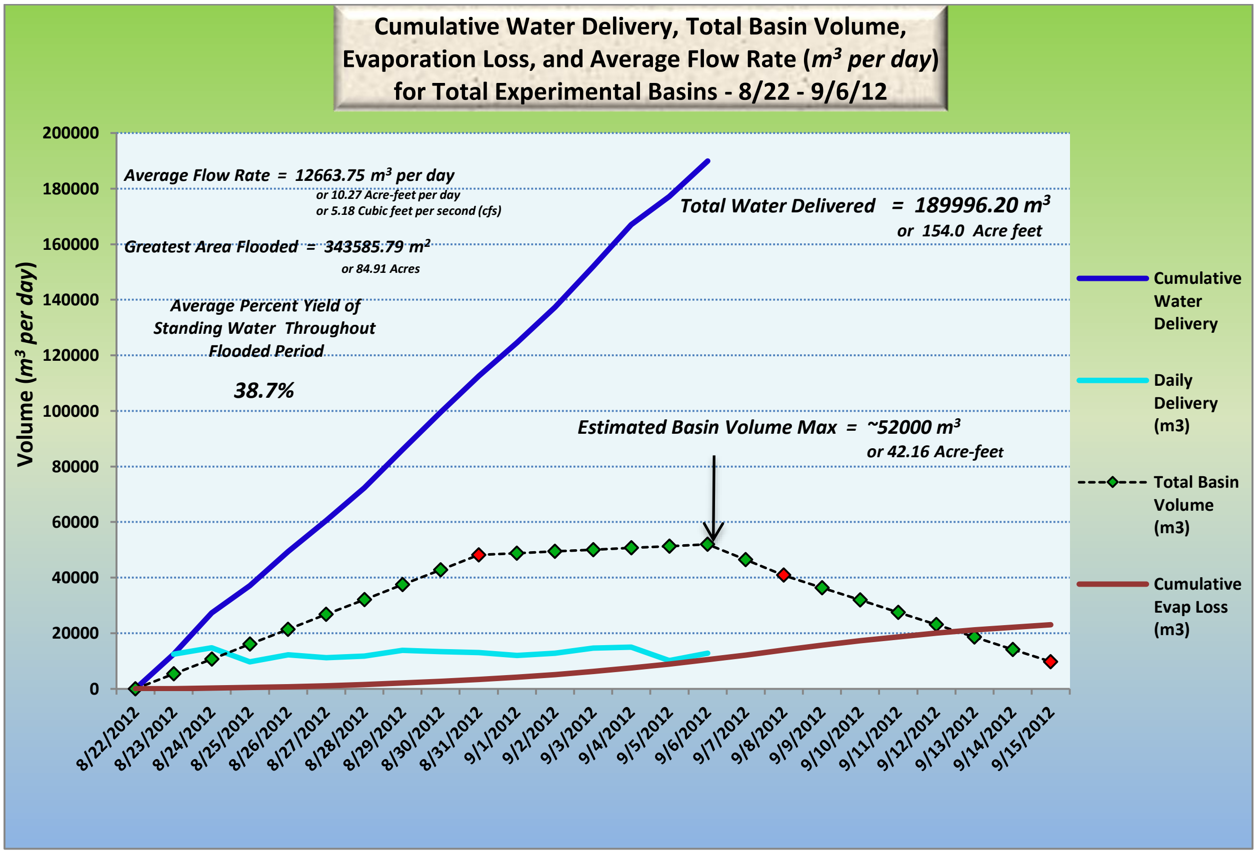


Figure 6. Average Length of Macroinvertebrates- Anostraca & Conchostraca – 8/31 and 9/14



3.3 LiDAR & Hydrology

Figure 7. Cumulative water delivery, total basin volume, evaporation loss, & average flow rate (m3 per day) for all flooded basins combined.



4. Discussion

4.1 Water Quality

Temperature, pH, salinity, conductivity, total suspended and dissolved solids, alkalinity, hardness, bicarbonates and all metals with the exception of barium and magnesium either remained stable or increased as the sampling distance from the inlet increased and time passed between 8/31 and 9/14 sampling dates. An initial water sample directly from the pipe inlet (site U1) served as a baseline, and allowed for comparisons of distance from the pipe, as well as through time from 8/31 to 9/14/12, when the last water samples of this study were collected.

Baseline concentrations of conductivity were at 478 uS/cm (from the pipe inlet, site U1). This was the lowest value for the study basin. However, all samples within the study basin were less then what was sampled for the control ponds, which ranged from 1706 uS/cm on the playa (C1) and 614.6 uS/cm on the semi-permanent wetland (C2). Conductivity increased as sampling distance from the inlet increased, and throughout time from 8/31 to 9/14. These values ranged from 482.3µs/cm at site U3 to 693.98µs/cm at site L3. Conductivity was also sampled in Prodrabsky's study and it was found that this parameter increased when salinity was higher, and also in places where temperature was elevated (Podrabsky et.al, 1998).

Salinity levels remained low and fluctuated only slightly in amount as time and distance from the pipe inlet increased. Values ranged from 0.1 ppt at U1 to 0.3 ppt at L3, whereas the control playa (C1) had the highest valued measured at 10.5 ppt, which again demonstrated that the study basin more closely resembled the control semi-permanent wetland and not the control playa. Total dissolved solids (TDS) were found to be higher than the total suspended solids (TSS) for all sample sites. TSS and TDS increased throughout the basin as sampling distance increased from the inlet, and from 8/31 to 9/14. TDS ranged from 370µg/L at site U1 to 480µg/L at L3. Site C1 was the highest by far, with a value of 1400 µg/L. For TSS, values within the experimental basin ranged from 315µg/L at U1 to 447 µg/L at L3. Control sites ranged from 399µg/L at C2 to high value of 1196 µg/L at C1.

Trace metals also showed a range of variability over time and with distance from the inlet, depending on the metal. Trace metal concentrations that generally showed an increase include Al, Be, Cd, Co, Pb, Se, Cr, Cu, Mo, and Zn. Trace metals that generally decreased were Ba, Mn, U, and V. Trace metals that were variable or had little change were Sb, Ag, Tl, Th, As, and Ni. The control playas showed larger differences; with the playa (C1) having much greater levels for almost all trace metals, and the semi-permanent wetland (C2) more closely resembles the experimental basins. Prodrabsky found that metals were in higher in playas and lower in fresh water, which caused different plants and macroinvertebrates to inhabit the water (Podrabsky et.al, 1998).

Most major anions showed little change or weak increases with time and distance from the inlet, with the exception of site C1, which continued its trend of having much higher values compared to all other sites. Baseline samples of nitrate and nitrite were initially high, and decreased with time and distance from the inlet.

Major cations showed a range of variability over time and with distance from the inlet, depending on the ion. Cation concentrations that generally showed an increase include B, Fe, K, Na, and Ammonium. Cations that generally decreased were Si and Ca. Cations that were variable or had little change were Mg and Li. The control playa had wildly higher cation values compared to the experimental basin or the control semi-permanent wetland, which continued to resemble the study basin in terms of water quality.

Changes in alkalinity, hardness and bicarbonate were evident between the upper and lower basins, which aligns well with the hypotheses of this study. There was a general increase in all three parameters from the upper basin to the lower basin, and mixed range of variability at control sites. Alkalinities ranged from 140 mg/L at site U3 to 355 mg/L at site L2; hardness ranged from 103 mg/L at site U2 to 140 mg/L at site L3; and bicarbonate values ranged from 150 mg/L at site U2 to 240 mg/L at site L1.

4.2 Macroinvertebrates

Overall population numbers were greatest in the northern basin where water quality more closely resembled baseline levels (figures 3a and 3b). Numbers also increase through time as hatches of insects occurred between 8/31 and 9/14. However, important differences in species cohorts were discovered depending on where the samples were collected in the basins.

It is apparent that hatches were only beginning on 8/31, as the sites sampled yielded very few insects (U1 = 1, U3 = 8, and L1 = 5, figures 3a & 3b). However, numbers increase substantially on the 9/14 samples. For the upper sites, site U2 had 2431, site U4 had 194 and 198 respectively (Tub 1 and Tub 2), and U5 had 115 and 130 respectively (Tub I and Tub II). For the lower basin sites, site L2 had 140 and 74 respectively (Tub 1 and Tub 2), and L3 had 27 and 56 respectively (Tub 1 and Tub 2).

The types of species found varied greatly from site to site, indicating a wide range of diversity within the basins (figures 3a & 3b). In general, upper sites were dominated by mayflies, followed by chironomids, clam shrimp, black flies, and mosquitoes. Lower sites had more variability depending on the site, and tubs sampled within a site. Site L2 had some consistency between the tubs sampled, with chironomids being the dominant species, followed by mayflies, clam and fairy shrimp, and mosquitoes. Site L3 had a vastly different species cohort, with the order of dominance being fairy shrimp, clam shrimp, chironomids, and black flies for Tub 1. Tub 2 was dominated by clam shrimp, followed by mayflies, midges, and finally fairy shrimp. This increase in diversity and presence of fairy shrimp and clam shrimp indicates that the L3 area is part of an ancestral playa that receives enough periodic moisture to maintain the life cycle of these insects. In the Guide to Common Freshwater Invertebrates of North America, it states that mayflies prefer fresh water and shrimp species prefer more alkaline and salty conditions (Voshell, 2002). In the control basins, insect numbers were similar to the experimental basin. However, the suite of species was quite different, indicating that these areas are at a different successional stage and water quality state than the experimental basins. At C1, brine flies were 95% of the total insect type, and water boatmen were the other 5%. Site C2 had a species cohort typical of a semi-permanent wetland, dominated by physid snails, water scavenger beetles, planorbid snails, and chironomids. Macroinvertebrate lengths generally increased from the upper basin to the lower, with the exception of Baetidae (mayflies), which had larger lengths in the upper basin (figures 4-6).

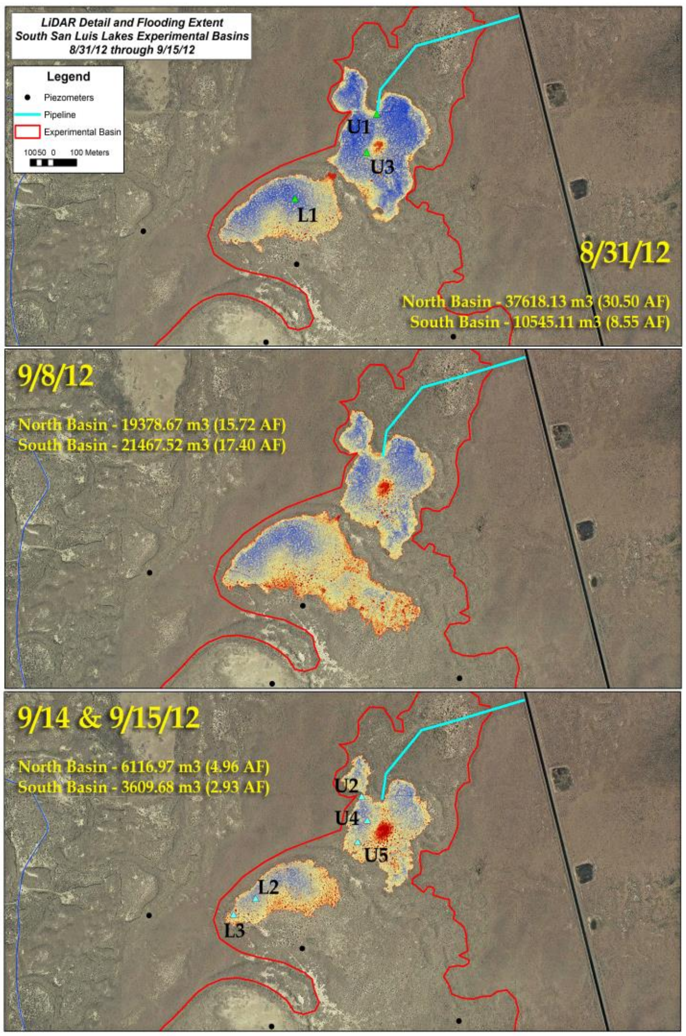
Statistical analysis using a Kruskall-Wallis two-way analysis of variance (XLStat) showed significant differences in size for Baetidae (mayflies, $p < 0.0001$), Chironomidae (midges, $p < 0.0001$), Anostroca (fairy shrimp, $p = 0.010$), and Conchostraca (clam shrimps, $p < 0.0001$. There were no significant differences for Aedes (mosquitoes, $p = 0.237$) or Dytiscidae (predaceous diving beetles, $p = 0.133$). For the other macroinvertebrate groups, numbers were too low to derive trends or statistical differences based on insect length.

Biomass in the experimental basins had great variability, with L2 having only 56.3 mg, and U2 having the highest biomass at 1046 mg, mostly due to high numbers of mayflies, tadpole shrimp, and predacious diving beetles. The length of insects between basins showed similar patterns of size change from species to species. Size class for a given species in the upper basin generally showed a difference when compared to the same species in the lower basin, indicating that different cohorts were present. This means that since water filled the upper basin and then flowed into the lower basin at a later time, the macroinvertebrates in the lower basin were younger, making them separate cohort from the macroinvertebrates in the upper basin. When average biomass per tub is extrapolated to the volume of the basins, over 1015.5 kg (2238.8 lbs) of insect matter is available for forage.

4.3 LiDAR & Hydrology Data

The precise ground mapping of the area made it possible to collect accurate perimeters of the standing water (figure 8), and then derive a volume for the basin, even with its complicated ground topography and dendritic edges. This data was analyzed using ArcGIS software models designed to make these calculations figure 8), and will be extremely useful to land managers planning future water application projects. The total volume of water delivered from 8/22 to 9/6 was 189996.20 m3 (154 acre-feet), creating a total basin maximum volume of ~52000 m^3 (42.16 acre-feet), and yielding an average of only 38.7 % of standing water volume during that time period (figure 7). That means that ~60% of the water was mostly absorbed by the ground at any given time, which is evident by increases in local groundwater piezometers (up to 2 feet near the basin; Lucero & Swift-Miller, 2013). Losses due to evaporation were relatively low (estimated at 1%) with the cooler

Figure 8. LiDAR elevation detail, perimeter locations, basin volume, and extent of flooding in the experimental basins, August 31 – September 15, 2012.



temperatures of early September, based on average pan evaporation data collected in Alamosa (1948-2005) by the Western Regional Climate Center (wrcc.dri.edu, 2013). Within approximately two weeks after shut-off, the pools dwindled rapidly and the remaining water essentially disappeared into the ground.

5. Conclusion

Based on all parameters analyzed in this study, there are a few key points that wetland managers may take into consideration when planning water budgets for wetlands. First, when putting water onto dry ground, the majority of the water will be lost to ground soak, especially if water tables are low in the surrounding area. To deliver a specific amount of water to a basin, knowledge of water table levels and local evaporation rates would be needed to calculate the amount of water needed to maintain a specific depth goal. It is also important to note the presence of established, historic pans that may contain a high-quality, high-biomass food such as fairy and tadpole shrimp, compared to hydrological "stable" ponds that have lower biomass values because of their lack of successional change. Another critical consideration is that playas offer large blooms of macroinvertebrates and contain great diversity compared to more stable ponds. Timing and amount of water application would be an important factor in managing a macroinvertebrate bloom, and wetlands could be designed to meet the demands of migrating waterfowl at different points in the growing season while still maintaining the integrity of the playa basin with a short-duration water application.

Future studies could potentially investigate effects of time of year, geographic location of the basin, and topographic differences between basins for the parameters investigated in this study. It would be predicted that time of year would greatly affect the suite of species present and the amounts of biomass measured. In turn, this could affect the number and type of migratory waterfowl that visit the area. The location of the water application could greatly impact water chemistry depending on the type of soils present, causing an increase or decrease in metals concentrations which subsequently effect conductivity and salinity concentrations in the water. This would ultimately effect the types of macroinvertebrates that exist in the basin (freshwater vs. brackish species), and would draw in different types of birds with different food preferences and feeding strategies. The topography would not only affect the species suite in the area, but also the productivity of the macroinvertebrates and how much water would be lost due to evaporation and ground-soak. There are indications that varied topography creates greater biomass and species diversity due to greater variation of "microhabitat" created by the variable terrain. Additional sampling and a broader experimental design could provide some valuable insight to this hypothesis, and be used by land managers to plan water application projects to sites that would yield the greatest potential of biomass and diversity possible for migratory and nesting waterfowl, while also boosting local water tables which will enhance surface water longevity.

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