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Final Wetland Demonstration Projects Report

February 2012

SOUTHERN NEVADA WATER AUTHORITY

Las Vegas Wash Coordination Committee

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Las Vegas Wash Project Coordination Team

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ABSTRACT

We conducted two constructed wetlands studies, the Demonstration Wetland at the City of Henderson Water Reclamation Facility (Demonstration Wetland) using treated wastewater, and the Pittman Wash Pilot Wetlands (Pittman Wetlands) using urban runoff. Three species of bulrush (California, SCCA; hardstem, SCAC; and Olney's, SCAM) were planted. Water quality, vegetation and birds were monitored at the Demonstration Wetland between 2004 and 2009. Water quality and vegetation were monitored at the Pittman Wetlands in 2007 and 2008.

We detected significant changes in select nutrients and metals between the inlet and outlet of the Demonstration Wetland. Nitrate and nitrite concentrations were significantly reduced ($p < 0.05$). Ammonia concentrations tended to increase at the outlet and did not have a distinct seasonal trend ($p < 0.05$). Aluminum, chromium, copper, selenium, and zinc concentrations were significantly lower ($p < 0.05$), while manganese concentrations increased at the outlet ($p < 0.05$). Fecal coliforms were reduced. SCCA was the dominant plant species, having the largest mean culm height and diameter, the lowest percentage of dead culms, and the highest cover (~45-55% of the vegetated area), but SCAM had the highest mean culm density and biomass. Harvesting of bulrush from four of 11 hummocks in spring 2008 negatively impacted SCCA height and cover, but it recovered to near pre-harvesting levels by that fall. Spring plant tissue concentrations were significantly higher than fall for total nitrogen ($p = 0.042$), total phosphorus ($p = 0.003$), and selenium ($p = 0.013$). Average abundance exceeded 250 birds per census, but birds do not appear to have negatively impacted removal efficiencies of nutrients and fecal coliforms, demonstrating that constructed wetlands can improve water quality while providing beneficial bird habitat.

The Pittman Wetlands' small size and minimal retention time prevented water quality improvements. The wetland had two cells, a surface flow (SF) cell and a subsurface flow (SSF) cell. In both cells, SCAM had the highest culm densities and dominated cover. Its biomass was highest in the SF cell. Average heights of all species were significantly larger in the SF cell than the SSF cell ($p < 0.001$). SSF cell SCAM had a significantly higher average concentration of selenium than the SF cell ($p = 0.049$). SCAM had a significantly higher total nitrogen concentration ($p < 0.025$) than the other species and was significantly higher than SCCA in total phosphorus ($p < 0.05$). SCAM also had significantly higher concentrations of selenium than the other bulrush species ($p < 0.05$).

Depending on the desired nutrient reductions, a project like the Demonstration Wetland could be useful in the future, and SCCA would likely offer the most benefit. Given the high costs and lack of water quality improvements, a Pittman Wetlands-style project is not recommended for additional trials without changes to size and location. Should such an effort be undertaken in the future, SCAM should be used, as should a surface flow regime.

ACKNOWLEDGEMENTS

We would like to thank Xiaoping Zhou, who designed the Demonstration Wetland water quality monitoring program, oversaw water quality data collection, and analyzed and interpreted past findings, and Paul Kuvelis, who devoted countless hours to the development of the Pittman Wetlands. In addition, we give our thanks to the many other current and former Southern Nevada Water Authority staff members that assisted with these projects. We would also like to thank the Bureau of Reclamation for providing partial grant-funding for select activities at both wetland projects. We thank the City of Henderson Water Reclamation Facility staff who were critical to managing water level and other project activities at the Demonstration Wetland and the City of Henderson staff that helped with maintenance at the Pittman Wetlands. Also, we give our sincere thanks to Joan (Thullen) Daniels and others with the U.S. Geological Survey and Bureau of Reclamation for providing critical assistance with wetland design and implementation at the Demonstration Wetland. In addition, we thank Joan, as well as Seth Shanahan and Keiba Crear for providing critical review of the draft document. Finally, we would like to thank the Research and Environmental Monitoring Study Team and the Las Vegas Wash Coordination Committee for their support of this research and the implementation of the Las Vegas Wash Comprehensive Adaptive Management Plan.

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1.0 INTRODUCTION

1.1 Purpose and Need

The Las Vegas Wash (Wash) is the primary drainage channel for flows originating from the Las Vegas Valley (Valley) watershed located in Clark County, Nevada, and it discharges into Lake Mead at Las Vegas Bay. The flows, which amount to approximately 180 million gallons per day (MGD), are a combination of stormwater, urban runoff, shallow groundwater, and treated wastewater. Treated wastewater contributes approximately 85% of the total daily flow in the Wash and is the only treated component. Urban runoff, which accounts for approximately 10% of the flows, enters the Wash untreated, carrying with it metals, motor oil, pesticides, pet waste and other contaminants. Since 1998, the Las Vegas Wash Coordination Committee, a community stakeholder group, has been implementing the Las Vegas Wash Comprehensive Adaptive Management Plan for the Wash (Las Vegas Wash Coordination Committee 2000), in order to stabilize the channel, restore its ecological functions and improve its water quality. The plan includes 44 action items designed to reach these goals. These action items include conducting additional research and establishing off-channel wetlands with alternate discharge considerations.

Wetlands provide many benefits, improving water quality, providing habitat and minimizing erosion, and a growing body of literature has suggested that wetlands can be constructed for the purpose of providing these targeted benefits in project areas (EPA 1993, 2000, ITRC Wetlands Team 2003, Kadlec and Knight 1996, Moshiri 1993). In order to demonstrate whether constructed wetlands could be used to further improve the water quality of the two primary source components of the Wash, the Southern Nevada Water Authority, the lead agency of the coordination committee, initiated two wetland studies: the Demonstration Wetland at the City of Henderson Water Reclamation Facility (Demonstration Wetland) and the Pittman Wash Pilot Wetlands (Pittman Wetlands). The authority had several partners on these projects including the Bureau of Reclamation, City of Henderson, and U.S. Geological Survey. This document represents the final report for both projects. Zhou and Van Dooremolen (2007), Van Dooremolen and Lane (2007), and Acharya and Adhikari (2010) have reported on these studies previously.

2.0 DEMONSTRATION WETLAND

2.1 Project Description

2.1.1 Goals

The Demonstration Wetland was designed to demonstrate whether constructed wetlands could further polish municipal wastewater treatment plant effluent. Secondary goals were to determine whether water quality improvements could be made while also providing habitat for birds and to identify plant species compatible with the ecological conditions prevalent in Southern Nevada (Zhou and Van Dooremolen 2007). While the overarching goal was to examine whether the wetland could yield any improvement to water quality, particular concerns included nutrients (nitrogen and phosphorus) of which effluent can have elevated concentrations. High nutrient loads are a regional concern as evidenced by the algal bloom on Lake Mead in 2001. Recent voluntary removal efforts by the wastewater dischargers have resolved most of the past concern.

2.1.2 Site and Design Description

The Demonstration Wetland was constructed in 2001 in a pre-existing triangular-shaped pond located in a portion of the City of Henderson Water Reclamation Facility that was also open to the public as a bird viewing preserve. The wetland design devoted 80% of its approximately 2.6 ha surface area to open water, with the other 20% devoted to land. The land component was comprised of 11 emergent vegetation islands, or hummocks, and three bird loafing islands. This design had been shown to improve water quality at other sites, while also limiting the development of overly dense vegetation across the wetland, which can increase internal nutrient loading and mosquito habitat (Thullen et al. 2005).

Several separate plantings were required from 2001 to 2004 to establish emergent vegetation on the hummocks due to water level variation and herbivory by birds. A planting in March 2004 had the greatest impact. The emergent vegetation established and matured across the site and monitoring of birds and water quality commenced that August. The vegetation that successfully established included three species of bulrush: California bulrush (SCCA; *Schoenoplectus californicus*), hardstem bulrush (SCAC; *S. acutus*) and Olney bulrush (SCAM; *S. americanus*).

Treated wastewater from the facility was pumped into the wetland through the inlet on the western side and the outlet from the pond was located on the eastern side (Figure 1). Although the pond originally began as a flow-through wetland, in mid-2006, it became a terminal pond with no outflow. A water level gauge was set in the pond and the water level was generally maintained at approximately 2.2-2.25 m, but ranged from 2.1-2.3 m to allow for management activities. The Demonstration Wetland received secondary treated effluent from the City of Henderson Wastewater lagoon system until April 2007, when denitrified effluent was delivered to the wetland. In September 2007, the inflows changed to partially tertiary treated effluent (a mixture of secondary and tertiary treated wastewater), and by February 2008, tertiary treated effluent was the sole source of inflow into the system.

2.2 Methods

2.2.1 Water Quality

Subsections 2.2.2.1-2.2.2.3 were adapted from Zhou and Van Dooremolen (2007).

2.2.1.1 Sampling Sites

From August 2004 to April 2009, water samples were collected from five sampling sites, including the inlet (DWP-1), the outlet (DWP-4), and three sites inside the wetlands (DWP-2, DWP-3, and DWP-5; Figure 1). Initially samples were collected bi-weekly during the first two complete months of the study and during summer months (May, June and July.) Bi-weekly sampling ceased by 2006 and all sites were monitored monthly thereafter, although some sampling months were missed. A small boat, powered with a 12-volt battery, was used for sample collection and measurements inside the wetland. Both the inlet and the outlet were PVC pipes, accepting flow from the upper pond and draining into the lower pond, respectively. They were used to monitor water quality before and after interaction with the wetland. Site DWP-2, located in the middle of the wetland, was used to monitor water quality changes between the inlet and the outlet. Sites DWP-3 and DWP-5, located at the north corner and at the southeast corner, respectively, showed water quality with less mixing (stagnant) within the wetland.

2.2.1.2 Sampling Methods

Samples were collected for chemical and biological analyses from five sites. A Hydrolab, which measures water temperature, dissolved oxygen (DO), pH, and electrical conductance, was used for field measurements at the inlet and the outlet and for collecting profile data within the water column at one-foot intervals at each site during every sampling event.

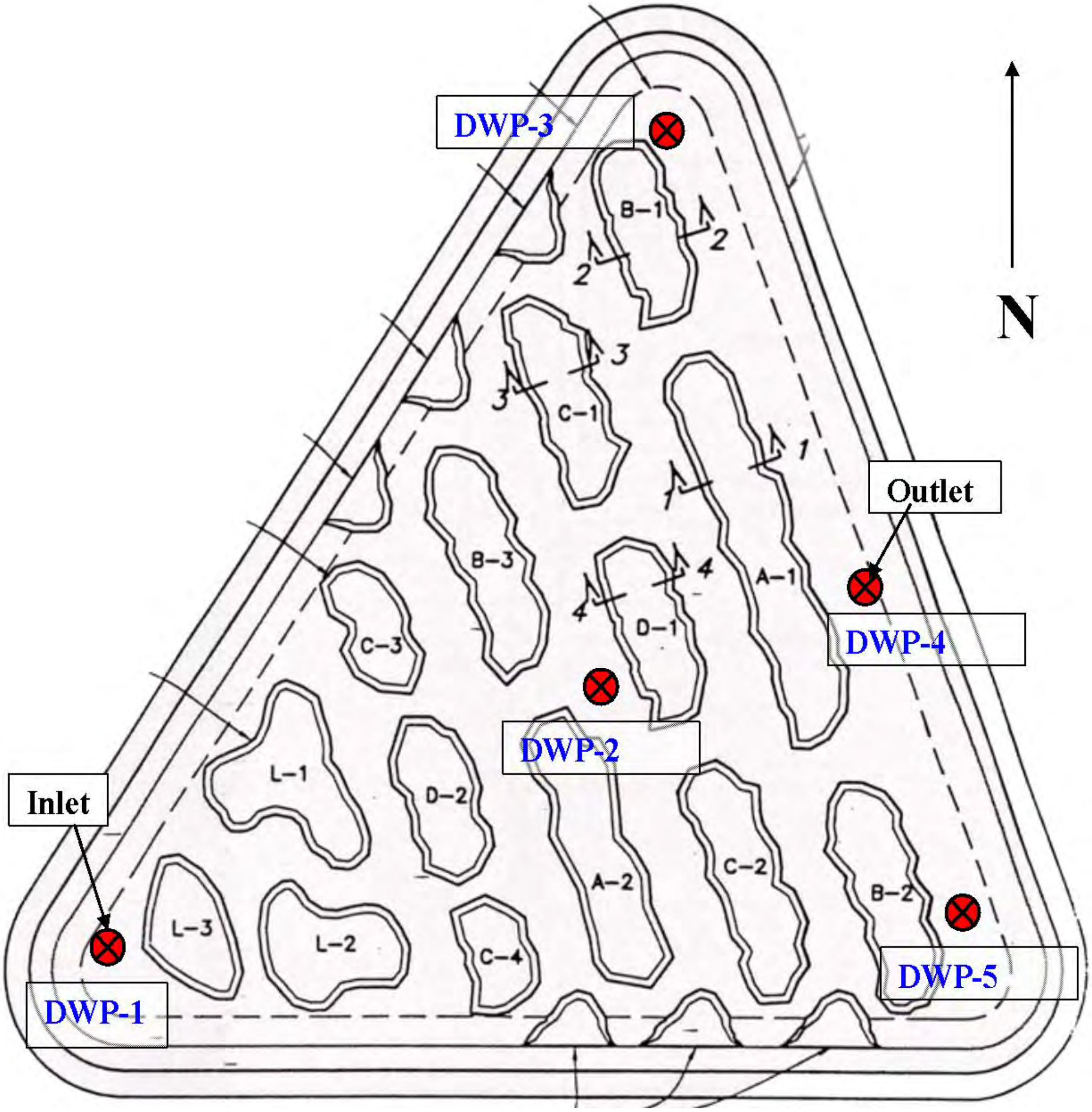

Figure 1: Sampling locations within the Demonstration Wetland.

During each sample event, only one set of samples was collected from both the inlet (DWP-1) and the outlet (DWP-4). Two sets of samples were collected from each of three sites inside the wetlands (DWP-2, DWP-3, and DWP-5), one set from one foot below the water surface, and another set from one foot above the bottom within the water column from August 2004 through November 2006. Beginning in December 2006, only one sample mid-water column was collected at DWP-2, DWP-3, and DWP-5. A Van Dorn sampling device was used to collect samples from different water depths. In addition, one set of duplicate samples were also collected from the outlet (DWP-4Dup) each collection period for quality assurance and quality control.

Sample bottles without acid preservation were rinsed three times with sample water before sample collection. Each site was sampled with pre-labeled bottles prepared in the laboratory. Sample bottles were labeled with site name, sampling location, analysis requested, and date and time of collection. After collection, bacteria samples were kept in a separate cooler of ice to prevent contamination by other samples. The remaining samples were maintained in another cooler of ice at 4°C. Samples were distributed immediately after the sampling event to the designated laboratories and were accompanied by a chain of custody record.

2.2.1.3 Chemical Analyses

In addition to field measurements (temperature, pH, DO, and electrical conductance) collected at each site, water samples were collected monthly from all locations for major ion, metal, nutrient, bacteria, perchlorate, and other analyses (Table 1). Individual water quality parameters were

Analytical Group	Description	Laboratory
Cations and Anions	Ca, Mg, K, Na, SO_4, Cl, HCO_3, F, Br, Hardness as $CaCO_3$, SiO_2, and TDS	Montgomery Watson Harza August 2004 – March 2006 Weck Laboratories, Inc April 2006 – April 2009
Metals	20 metals or metalloids (Al, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Ag, Ti, V, and Zn)	Montgomery Watson Harza August 2004 – March 2006 Weck Laboratories, Inc April 2006 – April 2009
Nutrients	Nitrate Nitrogen (NO_3-N) Nitrite Nitrogen (NO_2-N) Total Kjeldahl Nitrogen (TKN-N) Ammonia Nitrogen (NH_3-N) Total Phosphorus (TP-P) Ortho-Phosphate (OP-P)	City of Henderson
Bacteria	Presence/absence and cell counts of both fecal coliforms, total coliform, and *E.coli*	City of Henderson
Others	ClO_4, BOD_5, TSS, TDS	City of Henderson

Table 1: Water quality parameters for monthly analyses.

analyzed by four different laboratories: City of Henderson, Southern Nevada Water System, Weck, and Montgomery Watson Harza. Montgomery Watson Harza provided analytical services from August 2004 through March of 2006 for cation/anions and metals. Weck Laboratories conducted analyses from April 2006 until the end of the study. Weck Laboratories provided a lower level of detection for some analytes.

2.2.2 Vegetation

Vegetation monitoring was conducted in late fall in 2005 and then in late spring and fall in 2007 and 2008. Spring sampling was conducted in late May/early June and fall sampling occurred in mid to late November (2005 sampling occurred in late November/early December). Cover per species was visually estimated for each hummock using standard categories (<< 1%, < 1%, 1-5%, 5-25%, 25-50%, 50-75%, and 75-100%). One sample per bulrush species was randomly collected from each hummock using 0.06 m^2 quadrats (Note: not all species were present on all hummocks). If the target species was not present at the randomly selected location, the sample location was regenerated until it occurred in the targeted vegetation. Only above-ground material was sampled. To determine culm density, all culms rooted in the quadrat were cut at ground level, harvested and counted. Field staff noted whether each culm was live or dead to establish the average percentage of dead plant material per species. Ten live whole (i.e. unbroken) culms were randomly selected from each sample to determine average culm height and diameter. Length was measured from base to tip and diameter was measured with a caliper at the thickest portion of the culm (near or at the base) and on the widest side and rounded to the nearest millimeter. From these sub-samples, three samples of live above-ground plant tissue were randomly collected for each species and were analyzed for total nitrogen (TN), total phosphorus (TP), and select contaminants of potential concern (COPCs), including arsenic (As), selenium (Se) and mercury (Hg). Total carbon (TC) and hydrogen (TH) were analyzed from samples collected in 2008 only.

To enable biomass calculations and chemical analysis, plant material from the quadrats was dried in an oven for 48 hours at 60° C. In 2005, only a portion of the quadrats of each species was dried. From 2007 forward, all quadrats were shipped to the Bureau of Reclamation laboratory in Denver, Colorado. They dried and weighed the material and wiley-milled samples that were to be analyzed for nutrients and COPCs. The wiley-milled samples were then analyzed by Huffman Laboratories, Inc., in Golden, Colorado.

In the last week of March 2008, a field crew cut and cleared all above-ground bulrush from hummocks 1, 7, and 10, and 50% from hummock 5. This treatment was conducted to determine whether clearing old, decadent vegetation encouraged new growth, and if so, whether new growth accumulated nutrients and COPCs differently than the older growth sampled in prior events. In the May and November 2008 monitoring, culm density, percent dead, height and diameter data were collected separately for both treated and untreated stands using one sample per species per hummock for SCAC and SCCA. SCAM cover was limited on most of the treated hummocks, with only a trace (< 1% cover) on hummock 1, little more than that on hummock 7 and none on hummock 10. So that a minimum of three treated samples were collected for each species treated average, two SCAM samples were collected from hummock 5 and one from hummock 7.

For treated stands, in addition to the ten live whole culms collected per quadrat to determine average culm height and diameter, ≤10 (depending on the number present in the quadrat) dead culm stumps were collected. The heights of the stumps were averaged for each species to calculate the average height above ground at which stands of the species were cut in March.

2.2.3 Birds

Biologists conducted vehicular bird censuses of the pond on non-consecutive days generally surrounding water quality sampling events from August 2004 through July 2009. Up to four surveys were conducted per month depending on the frequency of water quality data collection. Water quality data was not collected in all months; although effort was made to conduct at least one survey in these months, occasionally no surveys were conducted. The survey route consisted of a 0.8-km path around the pond, starting in the southeast corner and traveling north around the perimeter. Two people were required to conduct the surveys; one person identified and counted the birds and one person recorded the data. Binoculars and a spotting scope were used to aid identification. The observer identified all birds seen and/or heard to species, counted the number of individuals present and noted the habitat type being utilized. Four habitat types were identified for analyses: pond edge, loafing island, hummock, and open water. Surveys were conducted during the early morning hours (from sunrise to 10 a.m.) and averaged approximately one hour in duration. Species observations were tallied to generate a total of the number of birds of each species present in the specific habitat types. If a species was heard only, this was noted and another individual of the same species was recorded only if it was clearly a new bird. Birds flying over the pond were recorded; however, they were only included in the analyses if the species was aerially foraging in the pond (e.g., swallows drinking or catching insects) and thus utilizing it as habitat.

2.3 Data Analyses

2.3.1 Water Quality

Data were analyzed using Microsoft Excel and SigmaStat 3.5. Values reported as less than the detection limit were replaced with one-half the detection limit value (Helsel and Hirsch, 2002). Analytes frequently reported below detection limits were not analyzed. Mann-Whitney Rank Sum Test was used to test for statistical differences between DWP-1 (inlet) and DWP-4 (outlet) when the data did not meet the assumptions of normality and equal variance. When data met normality and equal variance assumptions, t-test was used to detect differences between sites.

2.3.2 Vegetation

Using ArcGIS and high resolution aerial imagery from the fall of 2005 and the spring and fall of 2007 and 2008, we calculated the area of each hummock from the outer edge of the vegetation (at the open water interface) inward. Hummock area increased over time as bulrush (typically SCCA but occasionally SCAC, and to a lesser extent SCAM) grew outward into the deeper water areas on the edge of each hummock. The percent cover for a species was calculated by multiplying its mean cover estimate for each hummock by the area of that hummock, summing those values and then dividing by the total hummock area. The sum of each hummock's vegetated area was then divided by the total wetland area (~2.6 ha) to arrive at a total vegetative percent cover for the site.

Average culm height, diameter, density and percent dead were calculated for each species for each sampling event. In 2008, separate averages were calculated for each species for treated and untreated samples to enable comparisons between them. To determine the average height of regrowth for each species following the March treatment, the average height of the dead stumps was subtracted from the average height of the live whole culms. This yielded a conservative measure of culm regrowth as culms may have been new and thus growing from ground level rather than growing from the stumps. Average TN, TP, As, Se, Hg, TC, and TH concentrations were also generated for each species for each event for which values were available. Values reported as less than the detection limit were replaced with the detection limit value. Vegetation data were analyzed separately from water quality data and the difference in methods for dealing with below detection limit values is arbitrary. Both methods are commonly used (Croghan and Egeghy 2003). As with water quality, analytes frequently reported below detection limits were not included in statistical tests.

Biomass was estimated for each species. In 2007 and 2008, the dried weights from all quadrats collected for a species in a sampling event were used to calculate an average kg/m^2 weight per species per event. In 2005, wet weights were collected for all quadrat samples, but only three to four samples per species were dried. From these, the average ratio of dry to wet weight was calculated for each species and used to convert the remaining wet weights into dry weights.

Herein, biomass refers to dried, above ground plant matter, both living and dead. To calculate TN, TP, Se, and As storage per sampling event, we reduced the average biomass of each species by its average percentage of dead culms since only live culms were analyzed for nutrients and COPC concentrations. The resulting average live biomass was then multiplied by the species' average percent concentrations to determine live storage of each across the wetland. 2008 samples were of treated stands only so live biomass was calculated using treated stand dry weights and percent dead.

Species, years, and seasons were compared for differences in growth parameters (i.e., height, diameter, culm density, percent dead, biomass) and concentrations of nutrients and COPCs. Spring and fall 2007 chemical analyses were compared with 2008 spring and fall results to determine whether there were differences between pre- and post-treatment samples by comparing consecutive years.

Treated samples were excluded from all growth-parameter related analyses except those specifically examining treatment effects. Statistical tests were performed with SigmaStat 3.5 and the significance level was set at $p < 0.05$. If data met assumptions of normality and equal variance, they were tested parametrically with t-tests or Analysis of Variance (ANOVA), and if not, Mann-Whitney Rank Sum Tests or Kruskal-Wallis ANOVA on Ranks were performed. If ANOVA results were significant, pairwise multiple comparison procedures isolated the significant relationships. Parametric tests test means, while non-parametric tests test medians. For simplicity, all reported values are means.

Due to smaller sample sizes for culm density and percent dead ($n = 7\text{-}10$ per species per monitoring event), power to perform statistical tests was lower and reported as an issue by SigmaStat when failing to reject the null hypothesis on parametric tests. When comparing treated stands to untreated stands, sample sizes were smaller still with only 3-4 samples for treated stands per species and 6-7 samples per species for untreated stands. Therefore, care should be taken when interpreting non-significant results. Sample sizes were also small for tissue concentrations (n = 3 per species per monitoring event).

2.3.3 Birds

Data were summarized overall (for each year) and for the breeding and non-breeding seasons. The breeding season was defined as April 1 through August 31. (Note: the 2004 breeding season was excluded from analyses since April-June data were not collected that year, and the 2009 breeding season does not include data for August as the study was discontinued at the end of July). The non-breeding season was defined as October 1 through March 15. The latter half of March and all of September were excluded from seasonal analyses due to the overlap in breeding and non-breeding species that occurred at each seasonal transition. Migrant species moved through the area during the breeding season, so not all species recorded during that period actually breed at the site. Migrants also used the site as a stopover during the non-breeding season but to a lesser extent.

Total species richness and abundance (i.e., the number of unique species and the number of total detections, respectively) were generated for each study year (August through July) and for the breeding and non-breeding seasons. Species richness and abundance were also calculated for each census, and then used to generate annual overall and seasonal means. Numbers of dependent young and juveniles were reported separately from adults and only in the breeding season; overall and non-breeding season numbers do not include them. Average chick and juvenile species richness were calculated. Average abundance was also calculated for both; once using all surveys in the breeding season and then again using only the number of surveys in which they were detected.

Mean species richness and abundance for each study year overall and its seasons were then compared using ANOVA to determine whether differences were statistically significant. If data met assumptions of normality and equal variance they were tested parametrically, and if not, Kruskal-Wallis ANOVA on Ranks was performed. All reported values are means. Statistical tests were performed with SigmaStat 3.5 and the significance level was set at $p < 0.05$.

The most frequently detected species (75-100% of all surveys) were reported to highlight common birds at the site. ANOVAs were conducted on species detected on at least 40% of the surveys for a given time period (sufficient to detect statistical differences but otherwise arbitrarily selected) to determine whether they had undergone significant changes in abundance over the five-year study. Individual species abundances were also generated for each study year and the breeding and non-breeding seasons using the average number of detections per survey. The percentage of aquatic birds (i.e., wading, swimming, and diving birds, examples of which include herons, ducks, and cormorants), the most dominant group present at the site, was also generated, as was the percentage of detections contributed by the three most abundant species.

Finally, the percentage of detections occurring in each of the four habitat types (hummock, island, open water, and pond edge) was reported for each time period.

2.4 Results and Discussion

2.4.1 Water Quality

2.4.1.1 Temperature

Seasonal fluctuations were seen in temperature data collected at the Demonstration Wetland. The small area and shallow depth (6-8 ft) of the wetland allowed for temperature exchange throughout the pond and at depth (Zhou and Van Dooremolen, 2007). Slight stratification is seen during summer months (June and July), with very little temperature variation between the surface and bottom temperatures (< 3°C.) Monthly mean temperature data from all locations within the wetland show increased temperatures during summer months (Figure 2).

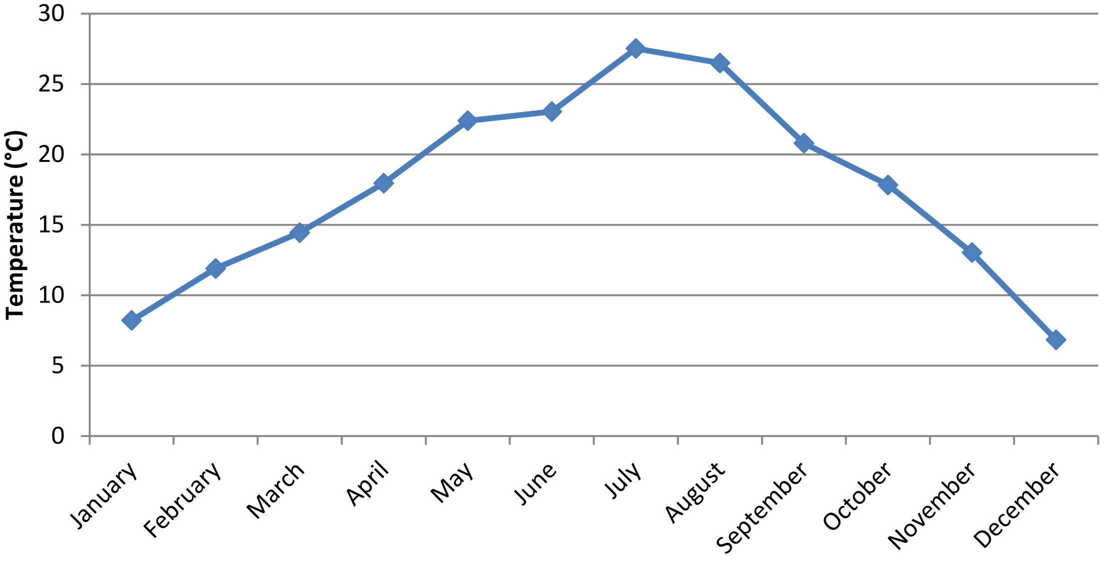

Figure 2: Demonstration Wetland temperature data from 2004-2009.

2.4.1.2 Electrical Conductance

Electrical conductance was measured at all locations within the Demonstration Wetland. Electrical conductance was typically lower at DWP-1 (inlet) and increased slightly at other locations within the pond. Monthly averages show an increase in conductance during the warmer months, due to the effects of evapoconcentration and lower inflows into the system during the summer months. Figure 3 shows the monthly averages from the Demonstration Wetland. Electrical conductance increased beginning in February and peaked at approximately 2,600 µS/cm in mid June.

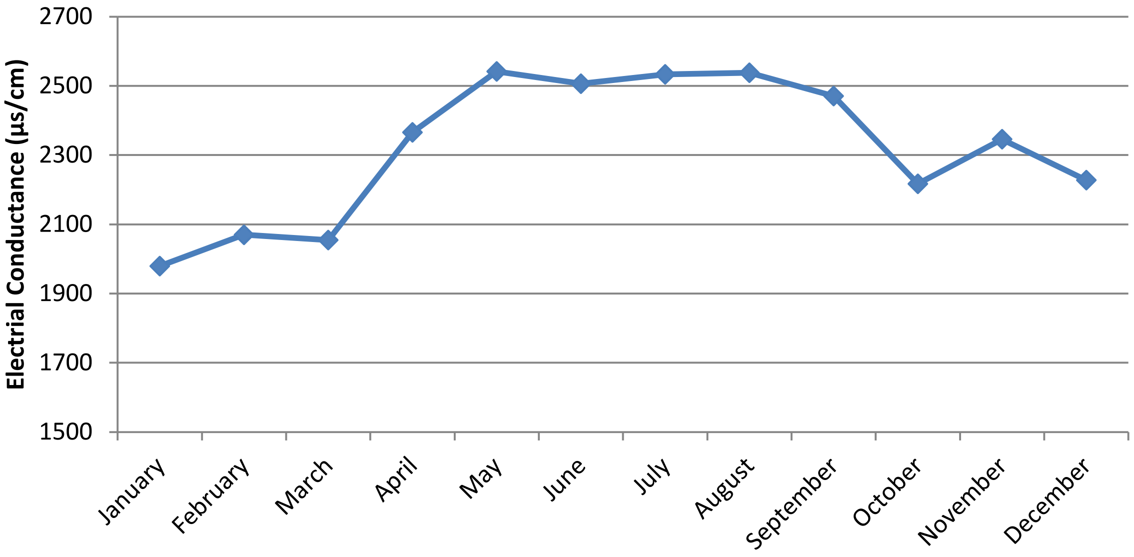

Figure 3: Demonstration Wetland electrical conductance data from 2004-2009.

2.4.1.3 pH

In general, water in the Demonstration Wetland tended to be neutral to basic, although, pH values exhibited slight seasonality. Monthly averages display an increase in pH values during the winter months and during late summer or early fall months (Figure 4). Changes in pH are associated with photosynthesis, respiration, and decomposition (Reddy 2008). Increased algal productivity was observed during winter and late summer/early fall months increasing photosynthesis and increasing pH. The subsequent decline in pH following winter and late summer months may be caused by decomposition (T. Tietjen, pers comm.). These current pH data show only limited representation of the pH in this wetland system, as pH can have high diurnal fluctuations in response to photosynthesis during the photoperiod (Reddy 2008). These values only capture early morning conditions during sampling events.

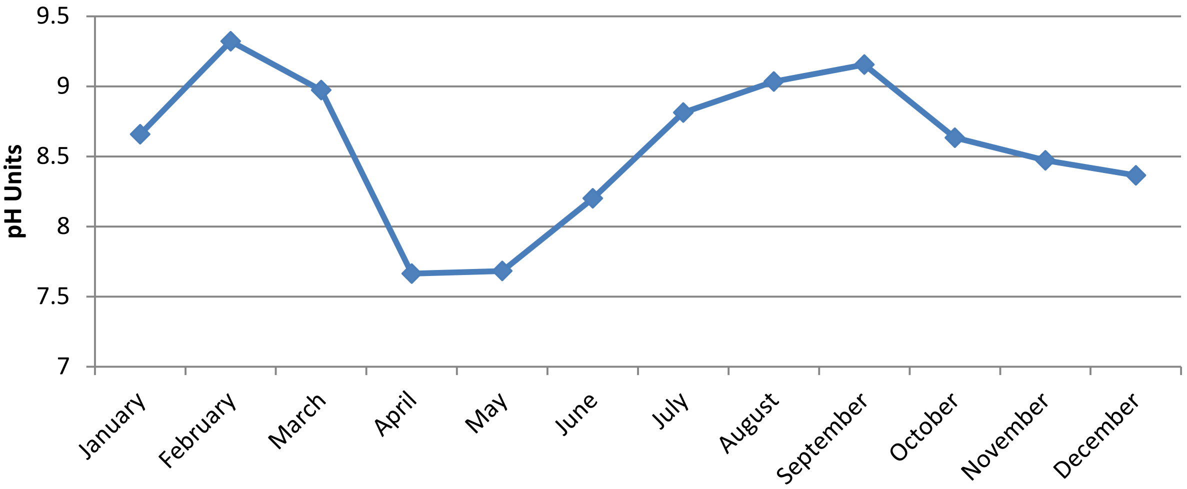

Figure 4: Demonstration Wetland pH data from 2004-2009.

2.4.1.4 Dissolved Oxygen

DO levels in the Demonstration Wetland showed seasonal fluctuations. Annualized data show a decrease in DO during the summer months and super saturated conditions during the winter months (Figure 5). These trends appear in all sampling locations in the wetland system. In addition, DO was greater near the surface and declined with increasing depth. The decline in the water column is caused by many factors including, decreased interaction with the atmosphere, oxygen consumption/respiration by organisms and plants, and decomposition of detritus and organic material near the bottom of the wetland (Reddy 2008). The decomposition of organic matter consumes available oxygen and results in decreases in oxygen levels (Reddy 2008). DO levels appear near anoxic conditions near the bottom of the wetland during the summer months.

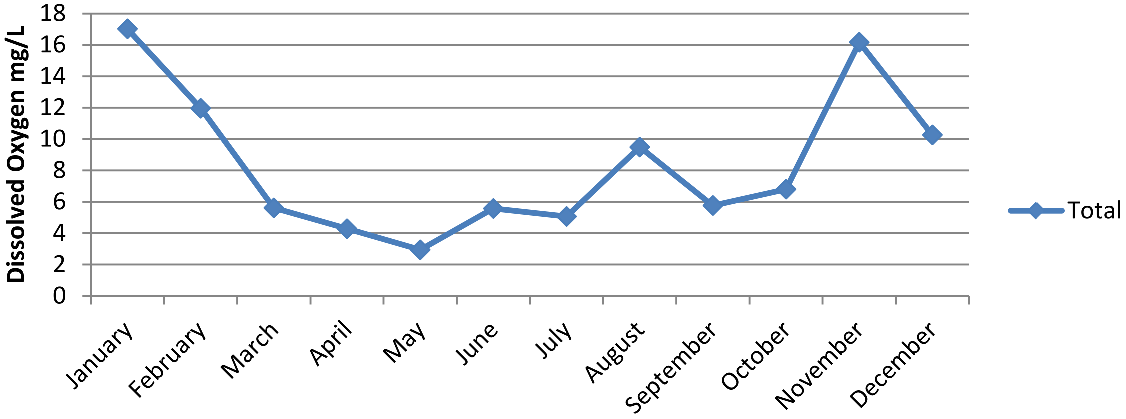

Figure 5: Demonstration Wetland dissolved oxygen data 2004-2009.

2.4.1.5 Nutrients

Nutrient concentrations are of unique interest at the Demonstration Wetland, as it was sited within an operational wastewater treatment plant and received treated effluent from the City of Henderson Wastewater Facility. Water quality monitoring during the study period characterizes changes in effluent quality and the wetland's response to these water quality changes. Increased nitrogen and TP concentrations can augment plant productivity in a wetland and simultaneously help reduce effluent concentrations. Statistical summaries and temporal trends of ammonia, nitrite, nitrate, orthophosphorus, and TP characteristics were analyzed for the Demonstration Wetland. Average, maximum, and minimum concentrations of the analytes before and after effluent treatment changes are summarized in Table 2. Of the constituents analyzed during the study, only ammonia, nitrate and nitrite showed significant increases or decreases ($p < 0.05$, Mann-Whitney Rank Sum) between DWP-1 (inlet) and DWP-4 (outlet) during the study.

Ammonia concentrations showed a significant ($p < 0.05$) increase at the outlet (DWP-4 = 3.52 mg/L) when compared with the inlet concentrations (DWP-1 = 2.99 mg/L). Concentrations increased during spring months, although the increases were not statistically significant ($p > 0.05$ Kruskal-Wallis). The seasonal ammonia concentration increases are most apparent prior to June 2007 (Figure 6) and are likely resultant from mineralization of organic material, which occurs in low oxygen conditions. Abundant organic nitrogen combined with low oxygen conditions prevent nitrification and can increase ammonia concentrations (Maine et al. 2006). The peak in ammonia concentrations coincides with low DO concentrations within the wetland. The significantly higher peaks in ammonia concentrations are probably due to effluent quality, but some ammonia may be produced during the denitrification process (Seelig and DeKeyser 2006). After June 2007, ammonia concentration peaks are much lower. There are not any statistical differences between DWP-1 and DWP-4 ammonia concentrations or seasonal trends when analyzing pre and post effluent change data. Although ammonia concentrations appear to peak again in spring 2008, without further data it cannot be determined if the peak was related to nitrogen cycling processes or external sources.

During the first half of the project, organic nitrogen concentrations decreased at DWP-4 by ~22 and ~55% while receiving secondary effluent as a flow through and terminal wetland system, respectively. The removal efficiency of organic nitrogen decreased once the wetland received mixed and tertiary treated effluent. Average organic nitrogen concentrations were reduced to 2.73 and 2.21 mg/L at DWP-1 and DWP-4 once the Demonstration Wetland started receiving tertiary treated effluent. Mineralization of organic nitrogen is the most likely cause for the reduction in organic nitrogen concentrations and the increase in ammonia concentrations in the Demonstration Wetland (Reddy 2008).

Nitrate concentrations significantly decreased at DWP-4 ($p < 0.05$) during the study period (Figure 7). Overall, average nitrate concentrations were reduced at the outlet. Table 3 displays the removal efficiency (RE) of the wetland system during different hydrological regimes (flow through versus terminal) and effluent quality delivered to the system. The RE for nitrate ranged from 0 to 99%. There are two notable exceptions to the reduction of nitrate; as a terminal wetland during both secondary and mixed tertiary effluent treatment periods, there was a 325% and 17% increase in nitrate concentrations at DWP-4. The 325% increase was based on one data point, and when compared to the rest of the dataset, does not adequately describe the general reduction of nitrate seen in the entirety of the dataset. Denitrification is the common process cited in nitrogen reductions in wetland systems (Maine et al. 2006). Average nitrite concentrations decreased significantly ($p < 0.05$) at DWP-4 before and after treatment effluent changes but did not demonstrate seasonal changes.

		Ammonia mg/L		Nitrite mg/L		Nitrate mg/L		Orthophosphorus mg/L		Total Phosphorus mg/L		Organic Nitrogen mg/L	
Flow Regime	Effluent Quality	DWP-1	DWP-4	DWP-1	DWP-4	DWP-1	DWP-4	DWP-1	DWP-4	DWP-1	DWP-4	DWP-1	DWP-4
Flow through wetland	Secondary Treatment												
	Mean	3.15	4.35	0.60	0.23	4.83	1.30	1.42	1.89	2.91	2.62	6.80	5.34
	SE	1.66	1.48	0.10	0.04	0.84	0.28	0.20	0.21	0.22	0.21	1.55	1.43
	Min	0.00	0.23	0.11	0.02	0.10	0.02	0.02	0.02	1.02	1.25	0.00	0.00
	Max	22.00	17.00	2.05	0.78	15.64	4.71	3.23	3.98	4.59	4.80	24.97	24.00
	N	14	14	22	22	22	22	22	22	22	22	14	14
Terminal wetland	Secondary treatment												
	Mean	2.48	3.69	0.33	0.22	2.08	0.47	1.11	1.16	2.35	1.81	11.13	5.03
	SE	2.38	3.21	0.14	0.13	0.72	0.25	0.43	0.36	0.55	0.44	3.60	1.32
	Min	0.00	0.14	0.02	0.02	0.02	0.02	0.21	0.27	0.83	0.68	3.30	2.50
	Max	12.00	16.50	0.96	0.86	4.13	1.58	2.78	2.83	3.94	3.81	27.00	11.00
	N	5	5	6	6	6	6	6	6	6	6	5	5
	Mixed treatment												
	Mean	1.97	2.01	0.65	0.28	4.72	0.63	0.97	0.93	1.69	1.65	7.18	7.35
	SE	1.67	1.27	0.33	0.12	1.28	0.21	0.40	0.35	0.62	0.46	3.15	1.82
	Min	0.10	0.26	0.12	0.02	0.86	0.02	0.02	0.15	0.21	0.83	1.61	0.94
	Max	12.00	9.55	2.55	0.76	10.66	1.66	2.84	2.72	4.79	4.07	25.00	14.89
	N	7	7	7	7	7	7	7	7	7	7	7	7
	Tertiarty treatment												
	Mean	0.72	1.04	0.25	0.12	6.28	1.23	0.22	0.29	0.51	0.44	2.73	2.21
	SE	0.25	0.26	0.04	0.04	2.22	0.60	0.05	0.08	0.08	0.08	0.28	0.25
	Min	0.14	0.10	0.08	0.02	0.79	0.02	0.02	0.02	0.02	0.02	1.10	1.00
	Max	3.10	2.60	0.48	0.41	24.00	6.20	0.56	0.81	0.79	0.96	4.12	3.50
	N	12	12	12	12	12	12	12	12	12	12	12	12

Table 2: Mean, minimum, maximum and standard error of mean for DWP-1 and DWP-4 hydrological and effluent quality phases.

DWP-1 was located at the inlet to the wetland system.

DWP-4 was located at the outlet of the wetland system.

Mixed treatment was a blended treatment of denitrification, secondary and tertiary effluent.

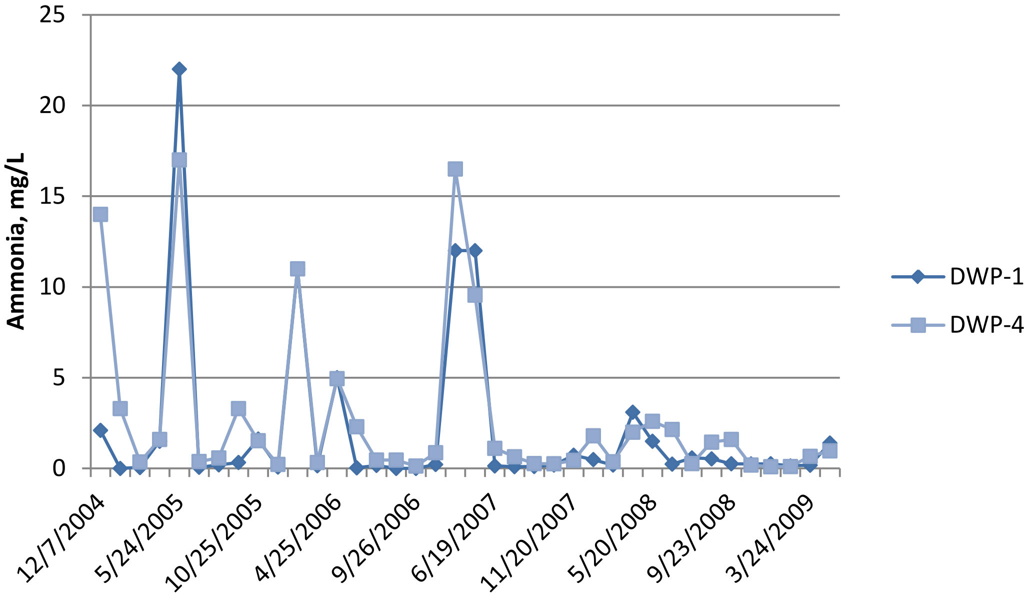

Figure 6: Demonstration Wetland ammonia data.

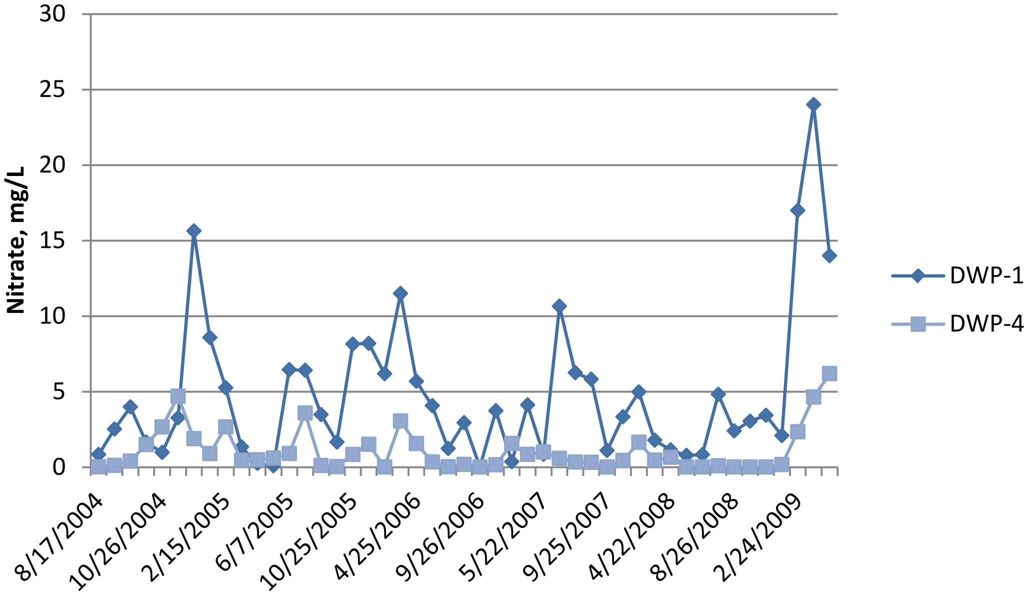

Figure 7: Demonstration Wetland nitrate data.

			Removal Efficiency % [a]				
Flow Regime	Effluent Quality	Month	Ammonia	Nitrite	Nitrate	Ortho-phosphorus	Total Phosphorus
Flow through wetland	Secondary treatment	January	-29.98	87.50	93.74	-36.73	4.98
		February	-592.31	13.64	49.14	-67.26	6.87
		March	-16.97	45.08	72.61	-534.21	21.24
		April	1.00	22.97	72.41	-25.38	41.81
		May	12.41	3.61	67.12	-43.06	0.73
		June	-474.63	2.36	65.02	-50.76	-47.49
		July	-632.08	92.95	96.90	-62.30	24.01
		August		88.70	96.41	-185.73	-35.16
		September		81.59	91.83	-13.72	33.42
		October	5.56	68.92	53.53	16.25	23.33
		November	-181.25	72.92	45.74	-1.96	25.00
		December	-566.67	93.57	87.88	-138.32	-35.84
Terminal wetland	Secondary treatment	February		-514.29	-325.68	65.83	53.93
		April	-37.50	71.35	79.30	-36.47	2.31
		June	-173.53	93.10	97.18	-126.67	22.97
		July	-23150.00	52.94	93.56	-68.48	8.44
		September	-6650.00	0.00	0.00	-266.67	-34.34
		November	-295.45	80.00	95.59	50.91	46.43
Terminal wetland	Mixed treatment	May	20.42	-16.15	-17.44	4.23	15.03
		June	-692.86	71.18	94.47	-3.16	9.79
		July	-545.00	61.11	94.41	-77.94	-14.73
		August	-145.45	85.71	94.34	-650.00	-297.62
		September	-36.84	86.67	98.20	-800.00	-155.41
		November	38.36	74.00	86.53	64.38	35.71
		December	-267.35	-66.67	66.83	-41.67	1.19
Terminal wetland	Tertiary Treatment	February	-44.55	27.38	84.94	50.00	7.14
		March	-272.22	52.08	80.63	73.91	-275.00
		April	34.00	-33.64	54.69	16.48	15.43
		May	-73.33	81.82	97.47	-43.75	-20.89
		June	-795.83	90.00	97.62	-3950.00	-21.62
		July	53.45	95.83	97.93	13.33	15.00
		August	-173.58	88.24	99.17	-442.86	-3.41
		September	-515.38	90.48	99.34	-138.46	38.97
		October	24.00	91.67	99.42	92.00	54.86
		December	62.69	75.00	91.43	0.00	38.60

Table 3: Nutrient removal efficiency at the Demonstration Wetland.

[a] Reductions in concentration are displayed with positive numbers and increases in concentration are noted with a minus symbol.

TP concentrations ranged between 0.21 to 4.80 mg/L at the inlet and outlet of the Demonstration Wetland and declined after effluent quality changed in the wetlands, consequently reducing the range to 0.02 to 1.61 mg/L. While TP concentrations did tend to decrease at the outlet, the reduction was not significantly different between DWP-1 and DWP-4 ($p > 0.05$) in any phase of effluent quality. TP concentrations were reduced near the end of the study period but the reductions resulted from the change in effluent quality not wetland performance. TP concentrations began to decrease after a peak in May 2007 at both the inlet and outlet of the wetland. Soon after, the City of Henderson Water Reclamation Facility began delivering a mix of secondary and tertiary treated effluent to the pond lowering the magnitude of subsequent peaks. Tertiary treated effluent was fully supplied to the pond by February 2008, and TP concentrations continued to diminish. RE of TP ranged from 0.73 to 55%.

Orthophosphate concentrations were not significantly reduced or increased during either effluent treatment periods. Orthophosphate concentrations at DWP-1 and DWP-4 during the secondary treatment phase ranged from 0.02 to 3.98 mg/L. Average orthophosphate concentrations were 1.33 mg/l and 1.68 mg/l at DWP-1 and DWP-4, respectively. Once tertiary treated effluent was delivered to the system, the maximum orthophosphate detected was 1.53 mg/L. The average concentration at DWP-1 and DWP-4 were 0.31 mg/L and 0.33 mg/L.

2.4.1.6 Metals

The average, maximum, and minimum concentrations of metal analytes are found in Table 4. Beryllium, cadmium, Hg, and thallium were not regularly detected during the study and were excluded from analysis. Several of the analytes show average concentration reductions over the study period. However, only aluminum, chromium, copper, manganese, Se and zinc showed significant changes ($p < 0.05$) between DWP-1 and DWP-4. Analyte concentrations did not change when effluent quality supplied to the wetland transitioned to tertiary treatment and average concentrations were determined using data gathered during the complete extent of the study.

	DWP-1					DWP-4					% removal
Analyte	Mean	Max	Min	±SE	N	Mean	Max	Min	±SE	N	
Aluminum (µg/L)	79.00	210.00	19.00	8.47	39	51.89	145.00	11.50	5.82	38	34.31
Antimony (mg/L)	0.81	1.90	0.25	0.06	39	0.72	2.10	0.25	0.05	39	11.15
Arsenic (µg/L)	2.72	4.80	1.00	0.14	39	2.37	3.85	1.00	0.13	39	12.75
Barium (µg/L)	89.41	170.00	35.00	4.55	39	95.12	160.00	41.50	4.10	39	-6.38
Chromium (µg/L)	0.46	2.30	0.10	0.06	39	0.34	1.10	0.10	0.04	39	26.12
Copper (µg/L)	10.31	19.00	3.80	0.83	39	5.43	16.50	0.65	0.70	39	47.30
Iron (µg/L)	71.64	240.00	20.00	7.88	39	96.35	370.00	19.00	13.19	39	-34.48
Lead (µg/L)	0.33	1.40	0.10	0.05	39	0.37	2.00	0.10	0.07	39	-11.72
Manganese (µg/L)	21.19	64.00	4.70	1.98	39	53.95	99.50	17.50	3.43	39	-154.57
Molybdenum (µg/L)	12.05	20.00	3.20	0.61	39	11.41	19.50	3.05	0.65	39	5.31
Nickel (µg/L)	5.66	12.00	2.50	0.36	39	6.55	14.50	2.50	0.41	39	-15.77
Selenium (µg/L)	2.07	2.90	0.89	0.08	39	1.60	2.50	0.22	0.11	39	22.65
Silver (µg/L)	0.17	1.10	0.10	0.03	39	0.11	0.32	0.10	0.01	39	34.51
Vanadium (µg/L)	1.91	5.60	0.25	0.20	39	1.82	4.80	0.25	0.22	39	4.35
Zinc (µg/L)	49.43	130.00	7.90	3.43	39	33.66	83.00	5.35	3.18	39	31.90

Table 4: Mean metal concentrations at the Demonstration Wetland from 2004-2009.

Aluminum concentrations ranged from 19 µg/L to 210 µg/L at the inflow to the Demonstration Wetland. Aluminum concentrations were significantly lower at DWP-4, ranging between 51 µg/L and 145 µg/L and averaging 51.89 µg/L. There were no significant seasonal differences in the data set ($p > 0.05$ Kruskal-Wallis); however, aluminum concentrations peaked at both the inlet and outlet around April of every year. Aluminum concentrations appear to gradually increase over the study period (Figure 8). Copper concentrations were reduced from inlet to outlet of the wetland and at DWP-1 ranged between 3.80 µg/L and 19 µg/L and averaged 10.31. The average copper concentrations at DWP-4 was 5.43 µg/L and ranged between 0.65 µg/L and 16.5 µg/L (Figure 9). No seasonal trends in concentration data were detected.

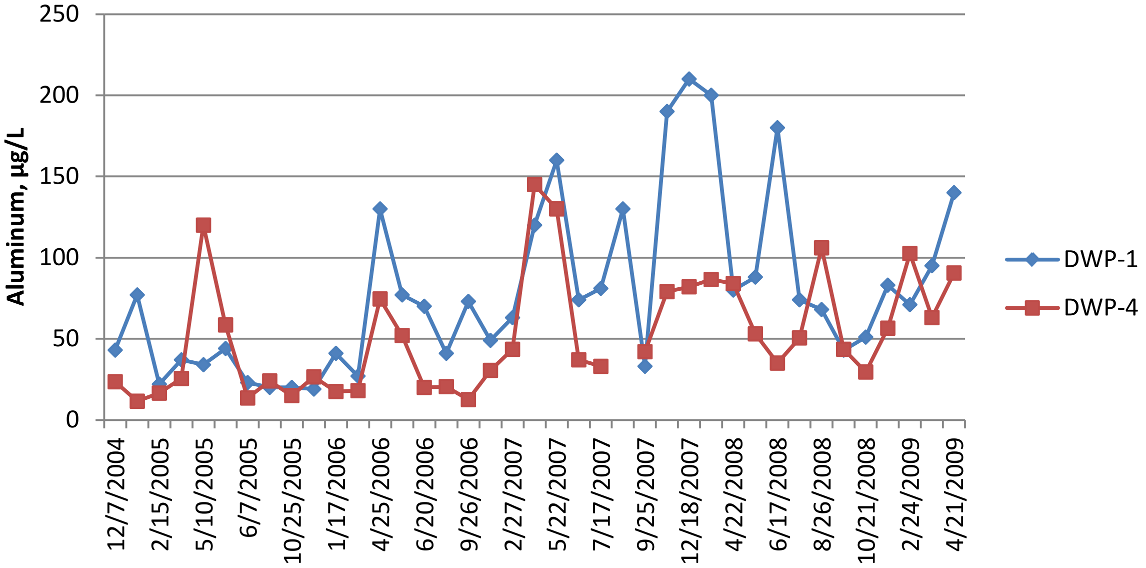

Figure 8: Demonstration Wetland aluminum concentrations 2004-2009.

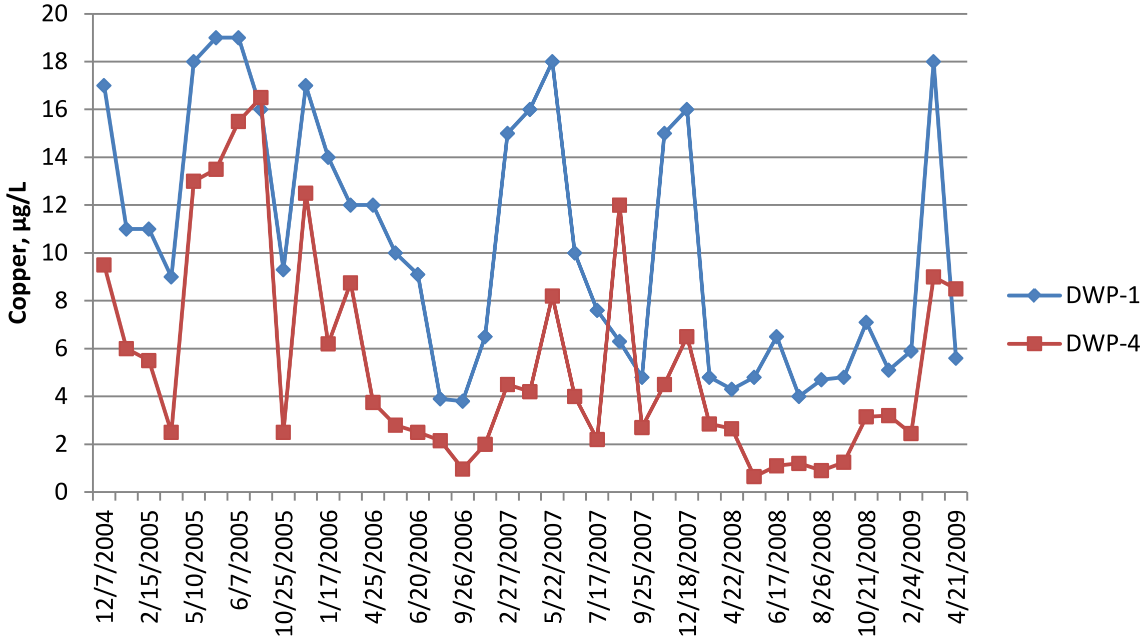

Figure 9: Demonstration Wetland copper concentrations 2004-2009.

Manganese concentrations were significantly greater at DWP-4 than DWP-1 ($p < 0.05$). Average manganese concentrations rose by nearly 157% at the outlet of the wetland. Although no significant seasonal difference was detected, manganese concentrations appear to increase in April at DWP-1 and DWP-4 (Figure 10). Some literature has cited declines in redox cycling, organic matter, and temperature as potentially releasing trace metals from wetland systems (Kerr et al. 2008). Although iron concentrations were not significantly different between DWP-1 and DWP-4, average concentrations did increase at the outlet and followed a similar spring pattern to manganese concentrations. Redox cycling within the wetland may help explain the seasonal increases in manganese and iron concentrations.

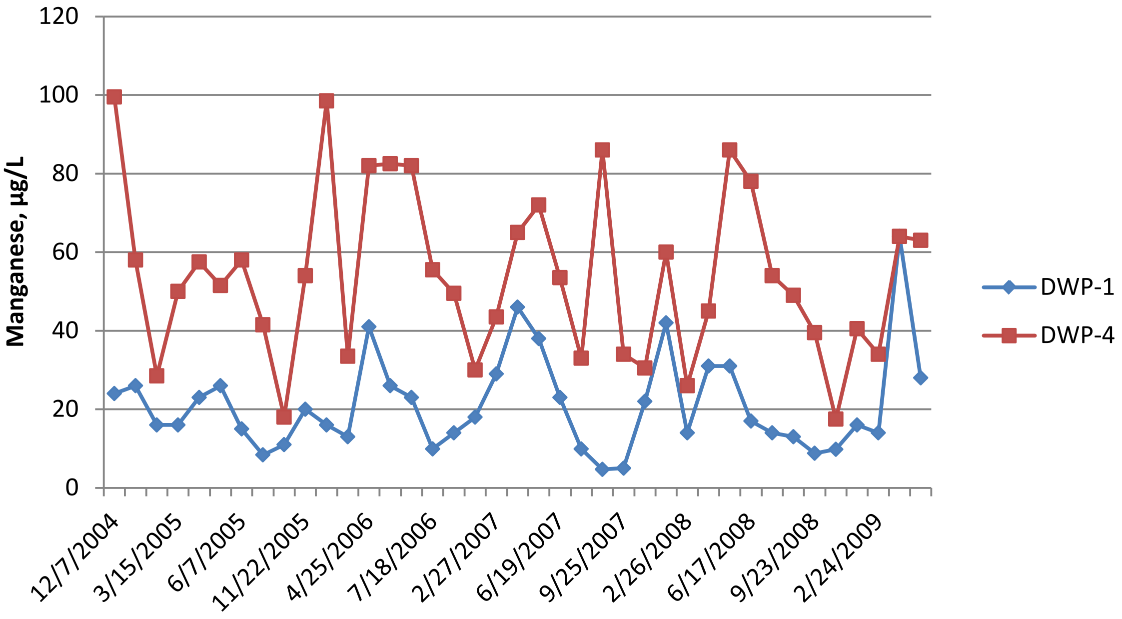

Figure 10: Demonstration Wetland manganese concentrations.

Se concentrations were below the detection limit (5 µg/L) until March 2006. These data were excluded from analysis since values set at half the detection are greater than the concentrations measured in the Demonstration Wetland. Se concentrations ranged from below detection limit (< 5 ppb) to 2.90 µg/L. Average concentrations at DWP-1 were 1.90 µg/L and 1.25 µg/L at DWP-4. There was a statistically significant reduction in Se concentrations at the outlet of the wetland ($p < 0.05$). Se concentrations appear to decline during the study (Figure 11). Inflow Se concentrations remained well below the 5 µg/L standard to protect aquatic wildlife but the wetland system was still able to significantly reduce concentrations.

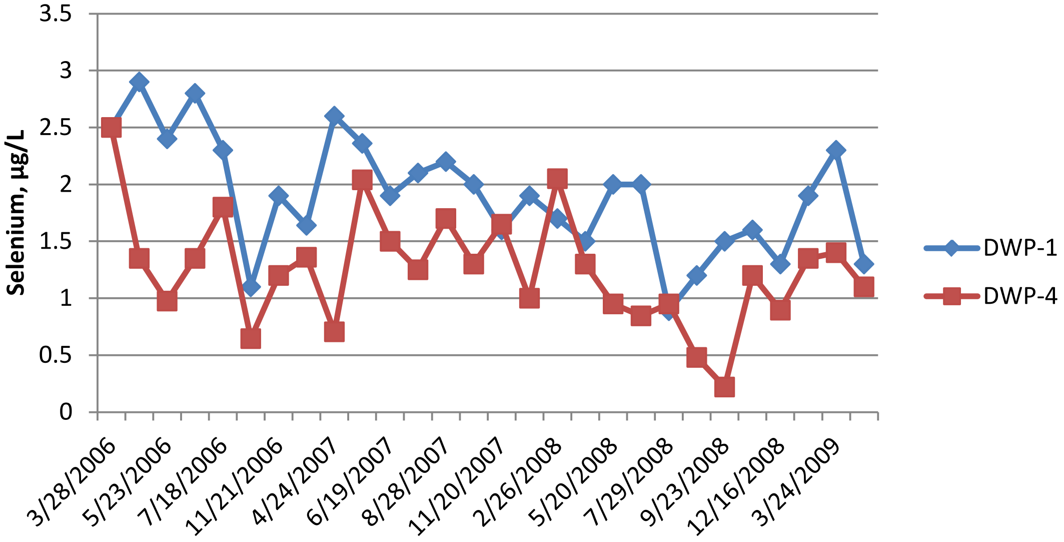

Figure 11: Demonstration Wetland selenium concentrations from 2006-2009.

During the first year of the study, zinc concentrations were below the 50 µg/L detection limit. These values were removed from the dataset for analysis. Values set at half of the detection limit were still greater than the actual values measured once detection limits were lowered. Figure 12 shows zinc values from 2006 through 2009. Average zinc concentrations were significantly reduced at DWP-4, although in some instances zinc concentrations were greater at the outlet (DWP-4). Zinc concentrations at DWP-4 were approximately 32% lower than DWP-1. Average concentrations at DWP-1 were 49.43 µg/L and 33.66 µg/L at DWP-4.

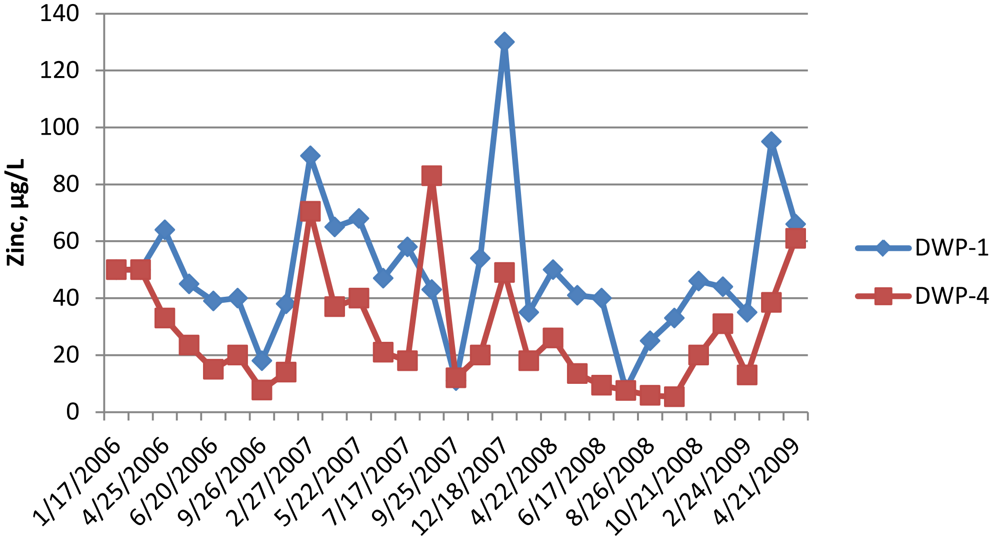

Figure 12: Demonstration Wetland zinc concentrations from 2006-2009.

2.4.1.7 Total Dissolved Solids and Total Suspended Solids

Total dissolved solids (TDS) significantly increased in the Demonstration Wetland between DWP-1 and DWP-4. TDS concentration at DWP-1 averaged 1,350 mg/L and ranged between 1,100 mg/L and 1,800 mg/L. TDS ranged between 1,150 to 2,600 mg/L at DWP-4 and averaged 1600 mg/L. Although there were no significant seasonal trends, the lowest TDS concentrations were measured in February and concentrations tended to increase in the following months (Figure 13). After effluent quality changed in February 2008, TDS concentrations decreased and continued to decline thereafter. High values post February 2008 were much lower than peak values recorded in prior years. Chloride and sulfate concentrations showed a similar positive increase until February 2008 and began to decline after effluent quality changes were implemented. Increases in TDS, sulfate and chloride may be attributed to the effects of evaporation during warmer months. Total suspended solids (TSS) were significantly reduced in the Demonstration Wetland. Mean TSS was 40 mg/L at DWP-1 and 23 mg/L at DWP-4 during the study (Figure 14). The Demonstration Wetland's slow to stagnant water movement allowed for particles to settle before reaching the outlet of the wetland. There was little disturbance in the wetland and disturbance of sediments was limited.

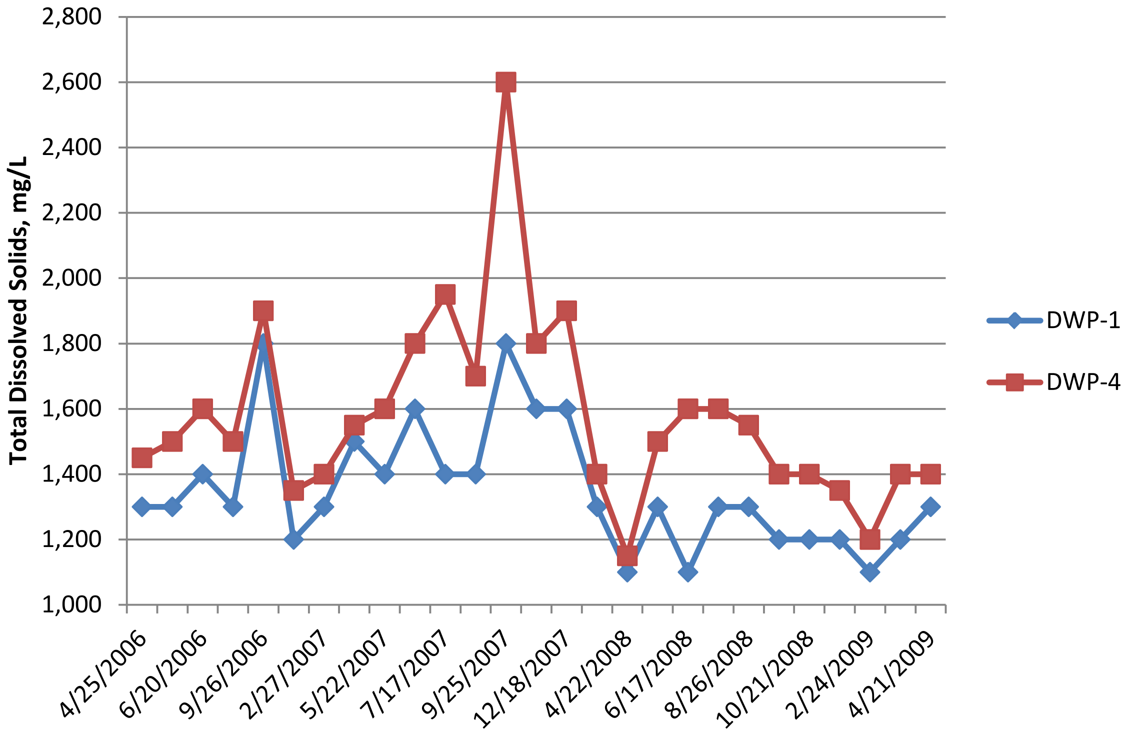

Figure 13: Demonstration Wetland TDS concentrations 2006-2009.

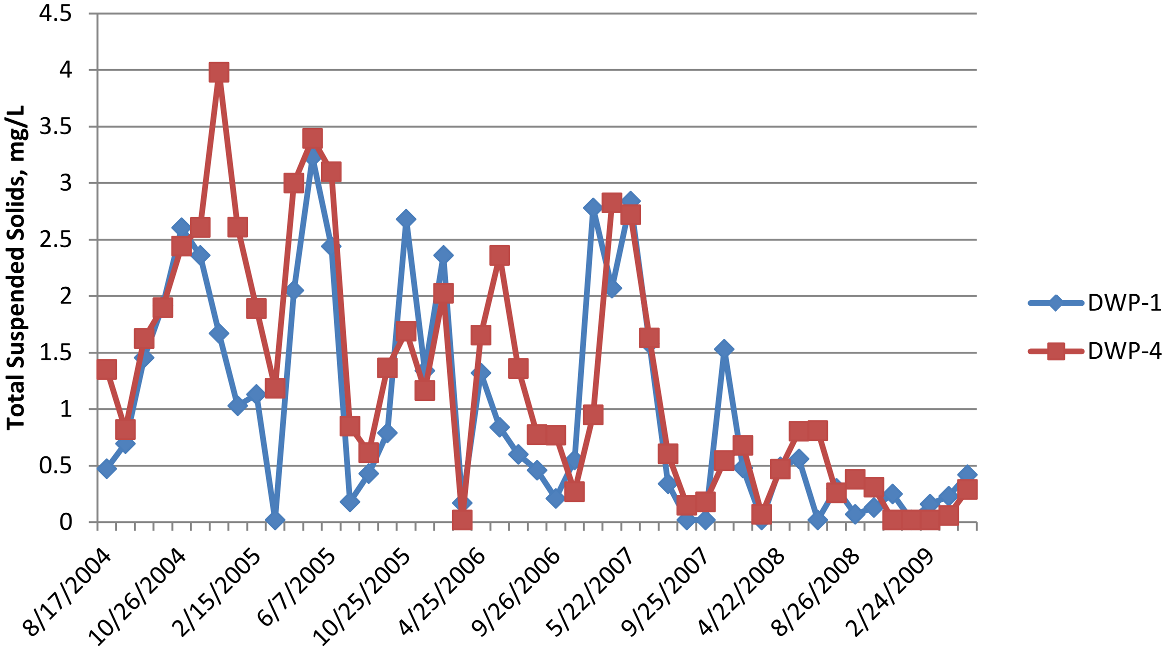

Figure 14: Demonstration Wetland TSS concentrations from 2004-2009.

2.4.1.8 Fecal Coliforms

Fecal coliforms were used in analysis because the group includes bacteria from warm-blooded animals including birds and mammals. Bacteriological groups such as fecal coliforms are commonly used as an indicator of pathogenic organisms in water. The Demonstration Wetland received secondary and tertiary treated effluent and provided attractive bird habitat, both factors warranting observation for potential impact to wetland functions. Fecal coliform monitoring was conducted to quantify the efficiency of the wetland to reduce potential pathogenic organisms and to detect if bird populations increased fecal concentrations in the pond. Fecal coliform content in the Demonstration Wetland varied greatly, ranging from 2 to 50,000 CFU/100 mL. Average concentrations at DWP-4 (1,032 CFU/100mL) were much lower than the DWP-1 (2,501 CFU/100mL). While overall average fecal coliform content was reduced at the outlet of the system, there were periods when DWP-4 fecal coliform concentrations exceeded the inflow (Figure 15). Effluent is treated to low levels prior to being discharged by the wastewater treatment facility. The higher levels of fecal coliforms measured in the Demonstration Wetland exceeded discharge levels. The potential relationship between these periods and bird use of the site are discussed in Section 2.4.3.5.

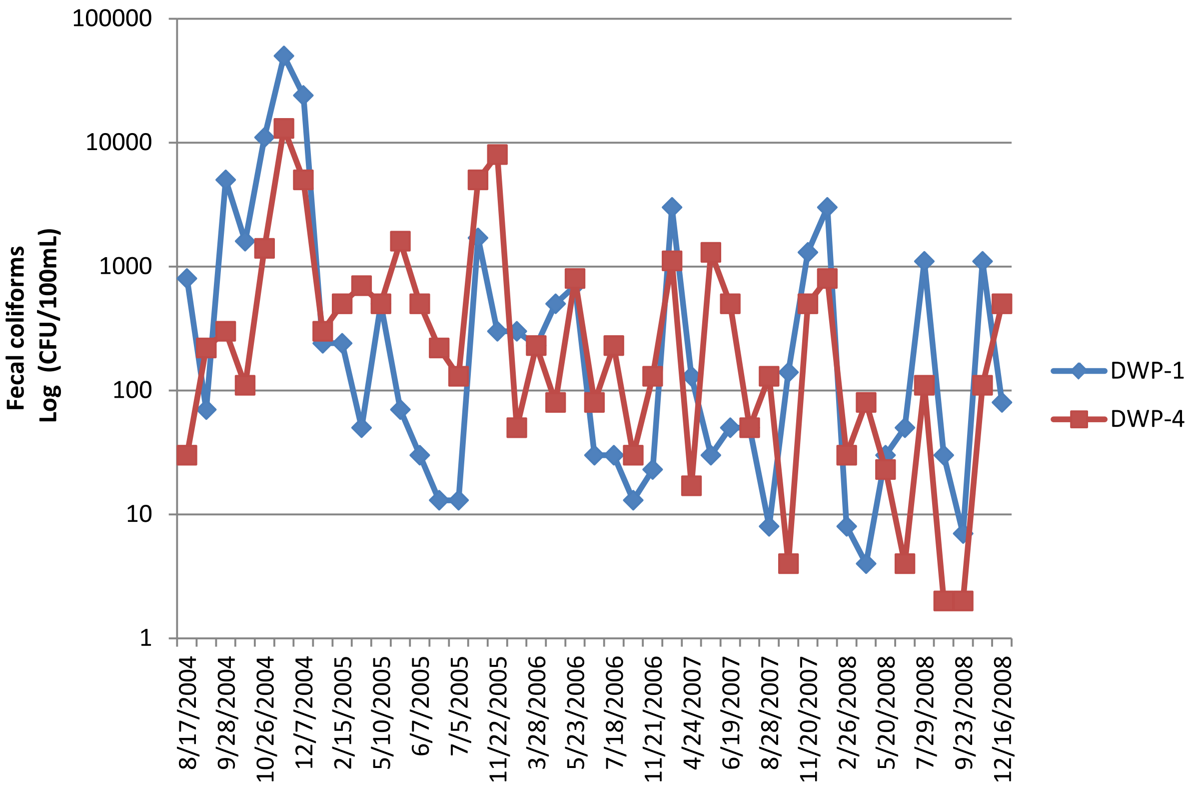

Figure 15: Demonstration Wetland fecal coliform concentrations.

2.4.2 Vegetation

2.4.2.1 Average Culm Height, Diameter, Density, and Percent Dead

SCCA and SCAC were found on 10 of the 11 hummocks in all sampling events, while SCAM was present on 7-9 hummocks. Average culm density, height, diameter, and percentage of dead culms for each species are presented in Table 5. The three species were significantly different from each other in all physical parameters ($p < 0.05$). SCCA was the most robust having the largest culm height and diameter and the lowest culm density and percent dead culms, SCAM had the reverse, and SCAC had intermediate values.

Within species, ANOVA identified significant differences in height among sampling events. Pairwise comparisons found that mean heights were significantly greater in November 2005 than in any other sampling event for all species ($p < 0.05$) except SCCA, for which it was not significantly different than May 2007. In addition, SCCA height in May 2007 was significantly greater than in both November 2007 and 2008. For SCAM, May 2007 mean height was significantly taller than May 2008, which was in turn, significantly shorter than November 2008. Mean culm diameter changed over time for all species, decreasing significantly for SCAC ($p < 0.05$) and declining but then rebounding for SCAM and SCCA.

Species	Year	Month	Avg Ht (m)	±SE	Avg Diam (mm)	±SE	Avg Culm Density (#/m^2)	±SE	Avg % Dead (#/m^2)	±SE	Avg Dry Wt (kg/m^2)	±SE
SCAC			1.96	0.03	12	0.1	1114	71	32%	4%	6.90	0.53
	2005	November	2.32	0.05	14	0.3	1214	100	30%	4%	14.20	1.93
	2007	May	1.97	0.06	12	0.4	893	118	19%	6%	5.93	1.54
		November	1.91	0.04	12	0.3	934	142	23%	7%	4.60	0.66
	2008	May	1.90	0.05	11	0.3	1351	248	40%	9%	4.87	0.77
		untreated	1.92	0.08	12	0.4	1432	275	51%	9%	5.55	1.03
		treated	1.86	0.07	10	0.4	1189	582	17%	16%	3.53	0.71
		November	1.86	0.05	10	0.3	1203	143	50%	8%	4.68	0.67
		untreated	1.87	0.07	10	0.3	1266	198	49%	10%	5.04	0.92
		treated	1.83	0.06	10	0.4	1056	121	50%	13%	3.83	0.55
SCAM			1.51	0.02	8	0.1	5045	444	48%	3%	13.71	1.37
	2005	November	1.83	0.05	9	0.2	3612	524	27%	5%	19.17	3.04
	2007	May	1.57	0.07	7	0.2	5879	1557	51%	7%	14.81	4.10
		November	1.47	0.05	7	0.2	6316	1261	56%	7%	15.69	3.92
	2008	May	1.23	0.04	6	0.2	5712	625	50%	8%	10.07	1.71
		untreated	1.23	0.05	6	0.2	6368	677	61%	8%	12.68	1.69
		treated	1.25	0.05	7	0.2	4400	1050	27%	9%	4.86	0.68
		November	1.59	0.05	9	0.3	3872	723	52%	8%	9.90	1.85
		untreated	1.55	0.06	8	0.3	4563	962	59%	8%	11.51	2.55
		treated	1.67	0.10	10	0.3	2491	462	40%	16%	6.67	0.90
SCCA			2.46	0.03	19	0.2	808	44	15%	3%	10.97	0.69
	2005	November	2.92	0.06	22	0.5	835	109	2%	1%	13.21	1.07
	2007	May	2.74	0.07	17	0.4	614	54	12%	3%	9.77	0.89
		November	2.37	0.06	18	0.4	840	110	13%	5%	12.12	2.62
	2008	May	2.31	0.06	17	0.4	875	63	32%	7%	9.50	1.01
		untreated	2.49	0.07	18	0.6	797	41	27%	11%	9.26	0.83
		treated	2.01	0.07	15	0.4	992	135	38%	10%	9.90	2.68
		November	2.46	0.06	19	0.5	875	125	16%	7%	9.94	1.16
		untreated	2.48	0.06	20	0.6	896	203	19%	12%	10.59	1.68
		treated	2.42	0.11	17	0.9	844	118	11%	5%	8.97	1.60

Table 5: Average culm height (Avg Ht), diameter (Avg Diam), culm density, percent dead (Avg % Dead), and biomass (Avg Dry Wt) with standard errors (±SE) for the Demonstration Wetland.

Average culm density and percent dead also varied over the course of monitoring for each species (Table 5). Species-specific changes in mean culm densities were not found to be statistically significant ($p \geq 0.110$); standard errors were high. The percentage of dead culms increased for all species over the course of the study, but not all differences were statistically significant. ANOVA showed some differences between sampling events for SCAM and SCAC, but none for SCCA. Percent dead SCAM was significantly higher in both May and November 2008 than in November 2005 ($p < 0.05$). For SCAC, May 2008 percent dead was significantly higher than May 2007 ($p < 0.05$).

2.4.2.2 Biomass

The average dry weights of both SCAM and SCCA were significantly greater than SCAC ($p < 0.05$) when pooled across sampling events (Table 5). Pooling species, there was no relationship between season and biomass ($p = 0.106$), but year was found to be a significant factor, with average dry weight greater in 2005 than in both 2007 and 2008 ($p < 0.05$). Within species, SCAC's 2005 average dry weight was significantly higher than in both 2007 and 2008 ($p < 0.05$). For SCAM and SCCA, no significant difference among years was found ($p \geq 0.056$). No statistically significant seasonal difference was found within any of the species ($p \geq 0.108$).

2.4.2.3 Treatment Effects

Approximately 5,300 kg (almost six tons, wet weight) of bulrush were harvested from four hummocks in late March 2008. Measurements taken during vegetation monitoring two months later showed substantial regrowth with SCCA and SCAC growing an average of 1.5 m or more and SCAM growing approximately 1 m. Comparisons of treated samples to untreated samples showed no significant differences in mean culm density or percent dead ($p > 0.067$). However, results were likely impacted by small sample sizes and high standard errors. Although not statistically significant, there were some substantial differences, with treated SCAC and SCAM average culm densities and percent dead lower than their untreated counterparts, and treated SCCA average culm densities and percent dead higher than untreated samples (Table 5). Mean height only differed significantly for SCCA, with the treated samples nearly 0.5 m shorter than those from uncut hummocks ($p < 0.05$). Mean diameter also differed for SCCA with treated samples more than 2.5 mm thinner ($p = 0.005$). SCAC also exhibited a significant difference in mean diameter between treated (10 mm) and untreated (12 mm) samples ($p = 0.014$).

Comparing May to November 2008, no significant differences were detected in culm densities or percent dead, either in comparing the treated and untreated samples to each other or to themselves ($p > 0.067$). However, once again some substantial differences occurred (Table 5). SCAM average culm densities continued to be dramatically different between treatment types. Treated sample means equaled just over 50% of untreated sample means, and both averages declined substantially from their May values. SCCA densities for treated and untreated samples were similar and the percentage of dead culms declined. Mean height and diameter increased significantly for SCAM from May to November for both treated and untreated samples ($p < 0.05$), but again, no significant differences were found when comparing the two treatments to each other. Average height increased significantly for treated SCCA between May and November ($p < 0.05$), so that there was no longer a difference between the mean heights of the treated and untreated samples. Average diameter increased significantly only for untreated samples ($p = 0.013$). As a result, treated and untreated mean diameters for SCCA continued to be significantly different in November (p = 0.010). For SCAC, mean height remained unchanged, but mean diameter actually decreased significantly when comparing untreated samples from May to November (p = 0.008). The mean diameter of treated samples increased slightly, although not significantly, and was no longer significantly different than untreated samples (p = 0.463).

Pooling May and November results, average biomass for treated samples was significantly lower than untreated samples for SCAM (p = 0.028). SCAC and SCCA exhibited no significant difference (p ≥ 0.273) between treatment types.

2.4.2.4 Cover

SCCA dominated cover through the life of the project varying from 44-55% of hummock vegetative cover (Table 6). SCAC accounted for approximately 25% of vegetative cover, and SCAM accounted for approximately 20% of the cover. The lowest value for SCCA (and for total hummock cover) occurred in May 2008 and can be attributed to the harvesting of bulrush that March. Estimated cover of the species decreased substantially on two of the harvested hummocks but rebounded to near pre-treatment level by November 2008.

	2005	2007		2008			
	November	May	November	May		November	
				Treated	Total	Treated	Total
SCAC	24%	24%	25%	42%	25%	41%	25%
SCAM	19%	21%	21%	5%	19%	5%	20%
SCCA	55%	55%	54%	36%	44%	49%	51%
Hummock Vegetative Cover	98%	100%	100%	83%	88%	95%	98%
Wetland Vegetative Cover	12%	13%	14%	4%	12%	5%	15%

Table 6: Bulrush cover values. Percent cover for a species was calculated by multiplying its mean cover estimate for each hummock by the area of that hummock, summing the values and then dividing by the total hummock area. Hummock vegetative cover is the sum of species cover. In 2008, treated values apply to the 3.5 hummocks where bulrush was harvested that March. Wetland vegetative cover equals the vegetated hummock area divided by the area of the pond.

After summing the mean cover estimates for all species present, an individual hummock's cumulative vegetative cover could and often did exceed 100% given the extent to which bulrush had already filled in by the time monitoring commenced in the fall of 2005. As a result, total hummock vegetative cover approached or equaled 100% in all monitoring periods, with the exception of May 2008 (Table 6). Total wetland vegetative cover increased over the three-year period from 12% to 15%.

Cover by invasive species was limited. Common reed (*Phragmites australis*) was discovered on a single hummock in June 2007. While its percent cover on that hummock increased in subsequent monitoring periods, it never reached 1% of total hummock vegetative cover.

Species	Year & month	Avg TN%	±SE	Avg TP (µg/g)	±SE	Avg Se (µg/g)	±SE	Avg As (µg/g)	±SE	Avg Hg (µg/g)	±SE	Avg TC%	±SE	Avg TH%	±SE
SCAC		1.46	0.21	2071	284	0.21	0.05	0.09*	0.02	0.01*	0.00	41.67	0.67	5.66	0.06
	2005	0.97	0.06	1893	347	0.16	0.01	0.08	0.01	0.02	0.00	n/a	n/a	n/a	n/a
	November	0.97	0.06	1893	347	0.16	0.01	0.08	0.01	0.02	0.00	n/a	n/a	n/a	n/a
	2007	1.60	0.13	1922	186	0.27	0.06	0.11	0.02	0.01*	0.00	n/a	n/a	n/a	n/a
	May	1.76	0.12	2163	153	0.27	0.06	0.09	0.02	<0.01		n/a	n/a	n/a	n/a
	November	1.45	0.08	1680	67	0.27	0.07	0.13	0.02	0.01*	0.00	n/a	n/a	n/a	n/a
	2008	1.56	0.20	2308	324	0.18	0.03	0.06*	0.01	0.02	0.00	41.67	0.67	5.66	0.06
	May	1.51	0.21	2567	404	0.22	0.03	0.08	0.01	0.01	0.00	40.84	0.10	5.58	0.00
	November	1.61	0.23	2050	180	0.13	0.01	<0.05		0.02	0.00	42.49	0.66	5.74	0.03
SCAM		1.30	0.15	1872	473	0.22	0.04	0.13*	0.03	0.02*	0.00	41.50	0.57	5.67	0.09
	2005	1.18	0.05	2113	308	0.18	0.05	0.11	0.02	0.02	0.00	n/a	n/a	n/a	n/a
	November	1.18	0.05	2113	308	0.18	0.05	0.11	0.02	0.02	0.00	n/a	n/a	n/a	n/a
	2007	1.28	0.16	1495	234	0.22	0.03	0.18	0.02	0.01*	0.00	n/a	n/a	n/a	n/a
	May	1.22	0.18	1773	182	0.24	0.02	0.18	0.02	<0.01		n/a	n/a	n/a	n/a
	November	1.34	0.18	1216	160	0.20	0.04	0.17	0.02	0.01	0.00	n/a	n/a	n/a	n/a
	2008	1.38	0.16	2091	637	0.24	0.04	0.09*	0.02	0.02	0.01	41.50	0.57	5.67	0.09
	May	1.64	0.09	3197	348	0.27	0.02	0.10	0.00	0.02	0.00	40.99	0.47	5.53	0.04
	November	1.18	0.05	1263	113	0.21	0.04	0.08*	0.02	0.02	0.01	41.88	0.52	5.77	0.06
SCCA		1.14	0.13	1822	322	0.20	0.05	0.09*	0.03	0.01*	0.00	41.32	0.53	5.59	0.09
	2005	1.15	0.19	2397	266	0.14	0.01	0.05*	0.01	<0.01		n/a	n/a	n/a	n/a
	November	1.15	0.19	2397	266	0.14	0.01	0.05*	0.01	<0.01		n/a	n/a	n/a	n/a
	2007	1.10	0.10	1658	235	0.21	0.05	0.12	0.03	0.01*	0.00	n/a	n/a	n/a	n/a
	May	1.11	0.09	1933	226	0.21	0.07	0.12	0.01	<0.01		n/a	n/a	n/a	n/a
	November	1.09	0.14	1383	104	0.21	0.04	0.12	0.05	0.01*	0.00	n/a	n/a	n/a	n/a
	2008	1.18	0.15	1698	351	0.22	0.07	0.08*	0.03	0.02*	0.00	41.32	0.53	5.59	0.09
	May	1.21	0.09	1933	275	0.19	0.02	0.11	0.03	0.01	0.00	40.99	0.61	5.49	0.08
	November	1.16	0.22	1462	421	0.24	0.10	<0.05		0.02*	0.00	41.65	0.47	5.68	0.06

Table 7: Average (Avg) plant tissue concentrations of nutrients and COPCs in the three species of bulrush at the Demonstration Wetland.

< # - all values in the average were below the detection limit.

* - ≥ 1 value in the average was below the detection limit and was set as the detection limit for the purpose of calculating the average.

n/a – not analyzed.

2.4.2.5 Plant Tissue Concentrations of Nutrients and Contaminants of Potential Concern and Storage

Concentrations of tested nutrients and COPCs from November 2005 through November 2008 are provided in Table 7. A few statistically significant species and seasonal differences were detected. Two-Way ANOVAs comparing the effects of species and season on TN and TP found SCAC had significantly higher TN than SCCA ($p = 0.002$) and found spring to have significantly higher values than fall for both TN ($p = 0.042$) and TP ($p = 0.003$); no interactions between species and season were detected (TN, $p = 0.423$; TP, $p = 0.328$). Se data could not be normalized, so non-parametric tests were used. ANOVA on Ranks found no difference between species ($p = 0.513$), but a Mann-Whitney Rank Sum Test found spring to have significantly higher concentrations than fall ($p = 0.013$). Given the seasonal differences in TN, TP, and Se concentrations, ANOVAs including year were not conducted due to the lack of spring sampling in 2005. Concentrations of Hg, and to a lesser extent As, were often below detection limits, preventing meaningful statistical analyses, and analyses were not conducted on TC and TH, which were only collected in 2008.

Comparisons of 2007 to 2008 to look for differences between pre- and post-treatment tissue concentrations yielded some interesting results. A Three-Way ANOVA of species, season and year for TN once again showed SCAC to have significantly higher concentrations than SCCA ($p < 0.001$), but season was no longer significant ($p = 0.228$); year was not found to be significant ($p = 0.519$), nor were any interactions ($p \geq 0.077$). The same test on TP once again found spring to have significantly higher concentrations than fall ($p < 0.001$), but also found 2008 concentrations to be significantly higher than 2007 ($p = 0.01$); no interactions were significant ($p \geq 0.058$). Comparing these parameters for effects and interactions on Se concentrations identified no significant differences or interactions ($p \geq 0.214$), unlike the 2005-2008 analyses in which spring had higher concentrations than fall.

Species	Year	Month	Avg Live Dry Wt (kg/m^2)	TN (g/m^2)	TP (g/m^2)	Se (mg/m^2)	As (mg/m^2)
SCAC			4.64	61.59	9.35	0.96	0.40
	2005	November	10.01	97.07	18.95	1.63	0.80
	2007	May	4.82	84.75	10.44	1.30	0.45
		November	3.52	51.00	5.91	0.96	0.45
	2008*	May	2.91	44.11	7.48	0.63	0.22
		November	1.93	31.01	3.96	0.26	0.10
SCAM			7.12	89.93	13.39	1.49	0.93
	2005	November	13.91	163.64	29.39	2.50	1.48
	2007	May	7.19	87.76	12.76	1.75	1.27
		November	6.94	93.05	8.44	1.38	1.21
	2008*	May	3.53	57.97	11.28	0.95	0.36
		November	4.02	47.25	5.08	0.85	0.32
SCCA			9.26	105.27	17.17	1.78	0.81
	2005	November	12.94	148.82	31.02	1.81	0.65
	2007	May	8.63	95.77	16.68	1.81	1.06
		November	10.58	115.36	14.63	2.19	1.30
	2008*	May	6.11	73.75	11.82	1.18	0.65
		November	8.01	92.67	11.71	1.90	0.40

Table 8: Storage of TN, TP, Se, and As in live biomass at the Demonstration Wetland. Note that Se and As are reported in mg/m^2.

Table 8 presents the estimated storage of TN, TP, Se, and As in the live, above-ground biomass of each species. SCCA averaged the highest nutrient and Se storage while SCAM had the highest storage of As.

2.4.2.6 Discussion

The Demonstration Wetland was a very productive habitat for all bulrush species as shown by the high average culm heights, diameters, and densities. Culm densities in the wetland were high relative to those of the project on which our hummock design was based, the 9.9-ha Eastern Municipal Water District Multipurpose Demonstration Wetland in the Hemet/San Jacinto Valley Regional Water Reclamation Facility (Thullen et al. 2002). They were also high relative to the results of DRI's study that included the Demonstration Wetland (Acharya and Adhikari 2010), which was conducted from summer 2008 to summer 2009, although they too found the wetland very productive. The difference may be due at least in part to the sampling method. While quadrat placement was randomly chosen for our study, they were targeted at each species. If the species was not at the randomly selected location, the quadrat location was re-selected until it occurred within the targeted species of bulrush. The resulting samples were then representative of culm densities where the species occurred, rather than across the wetland landscape, as calculated in Acharya and Adhikari (2010), and should be considered in association with the species' percent cover. However, Thullen et al. (2002) adjusted their culm densities based on cover and our values were still a few times higher than theirs for SCCA (the only species reported in their study). Our targeted sampling method led to several samples being taken at or near the core, or densest part of the plant, which could be a reason for the difference.

SCCA performed the best in the wetland, with impressive average height and diameter, a high percentage of live material, large biomass and nutrient storage, and the dominant percent cover. In addition, the majority of SCCA remained green and upright year-round as the species does not senesce in the relatively mild winters of southern Nevada. SCAM typically had larger biomass values than SCCA and significantly higher culm densities, but it also had a significantly greater percentage of dead culms than the other species. Also, SCAM does senesce in the winter. Dead and senesced culms grow limp and fall into the water where they decompose and release stored nutrients, which contributes to internal loading (Sartoris et al. 2000). This may have implications for SCAM's use in constructed wetlands designed to remove nitrogen and phosphorus.

Biomass values in November 2005 were higher than in any later sampling event. This was the event where biomass was estimated using the ratio from just a handful of dried samples to convert all wet sample weights. The resulting values were high for SCAM and SCCA, but the difference was most dramatic in SCAC, whose estimated biomass was more than twice any amount achieved in later years, even though some higher culm densities were recorded. These differences may point to a flaw in the method and should be interpreted with caution.

Differences in average height and diameter among the species were within known ranges ('eFloras 2011). That their average heights declined significantly from 2005 to 2008 is more curious. The decline occurred primarily between November 2005 and November 2007, with each species shrinking ~ 0.36 m or more. There are several possible contributing causes for this trend. Changes to wetland hydrology and inflow water quality (i.e., decreased nutrients) may have impacted vegetation growth and contributed to some of the observed differences. It may have also been influenced by the hummock design, which limited the expansion of bulrush. Additionally, when monitoring began, the vegetation was already well established. Average diameter and height for each species were at their highest values in fall 2005, at which time the vegetation had been growing in the more nutrient-rich inflows of secondary-treated wastewater for 18 months or more. By fall 2007, the plants were several years old and the percentage of dead material was starting to increase; an increase which became dramatic by spring 2008.

No seasonal patterns were identified in growth parameters. However, seasonal patterns did appear in the concentrations of TN, TP, and Se when analyzing the entire 2005-2008 dataset, with spring having significantly higher concentrations than fall. Interestingly, these differences were no longer significant for TN and Se when comparing 2007 and 2008 to look for differences following harvesting.

Considering the changes in inflow water quality in 2007 and 2008, it is notable that plant TN and TP concentrations did not decrease. While culms analyzed in 2007 were older and grew in the higher nutrient effluent, 2008 culms grew in partial to 100% tertiary-treated effluent and yet actually had higher concentrations of TP than in 2007, suggesting that new growth concentrates higher TP than older growth.

In March 2008, bulrush was harvested from approximately one third of the hummocks. Results from May vegetation monitoring suggest that harvesting impacted SCCA the most of the three species in terms of average height, diameter, and cover (interestingly, biomass and culm density were not significantly different between the treatment types and were in fact slightly higher in treated samples). However, within eight months the impacted parameters had rebounded to at or near pre-treatment levels. SCAM biomass was significantly lower and culm density was substantially lower in treated stands, indicating an effect. This is curious because average treated height, diameter, and cover were similar, if not slightly higher, than untreated values. Results may have been impacted by the fact that treated samples were collected in part from a hummock where the species was barely present (hummock 7), and so may have been less representative.

2.4.3 Birds

2.4.3.1 Overall

We detected a total of 107 species during the five-year study, with an additional three species (Cooper's hawk, ash-throated flycatcher, and common raven) recorded as flyovers only. From year to year, total richness varied from 68 to 78 species, with the highest value recorded in the first year and the lowest in the second year (Table 9). Average species richness increased over the course of the study, from 19.4 to 24.2 species per visit (Table 9). The increase was significant, with years three and five having significantly greater average species richness than the first year ($p < 0.05$). Average abundance varied among years, rising and then declining, but differences were not statistically significant ($p = 0.084$; Table 9).

A total of 21 species were detected on at least 40% of all surveys, but only American coot, ruddy duck, and common gallinule were detected on every survey. Mallard was detected on nearly every survey and pied-billed grebe, eared grebe, cinnamon teal, marsh wren and great-tailed grackle were recorded on 75-85% of all censuses.

Although overall abundance did not change significantly over the five-year period, certain species experienced significant declines and increases between years one and five, or in the years in between. Species that increased between years one and five include: mallard, cinnamon teal, Virginia rail, and marsh wren ($p < 0.05$). Species that ultimately declined in abundance between years one and five include ruddy duck, eared grebe, American coot, and great-tailed grackle ($p < 0.05$). Species such as common gallinule and gadwall experienced more complicated changes, increasing significantly in the first few years and then decreasing again, so that abundance values from years one and five were not significantly different.

Year	# Censuses	# Species	Average Species Richness	Species Richness, Min. & Max.	Total Detections	Average Abundance	Abundance, Min. & Max.	% Detections by 3 Most Abundant Species
1	33	78	19.4 ±1.02	9, 29	9,934	301.0 ±29.1	126, 720	56%
2	26	68	21.8 ±1.00	13, 31	9,861	379.3 ±45.2	150, 1154	56%
3	19	74	23.8 ±0.77	16, 29	7,040	370.5 ±48.1	150, 922	55%
4	18	69	23.1 ±0.77	15, 28	6,007	333.7 ±41.1	150, 688	54%
5	22	74	24.2 ±0.61	20, 31	5,880	267.2 ±37.8	116, 855	50%

Table 9: Overall bird values for the Demonstration Wetland, by study year. Average richness and abundance values are ± standard error.

The bird community within the pond was largely composed of aquatic birds, which accounted for 82-87% of annual detections. In all years the three most abundant species, northern shoveler, American coot and ruddy duck, accounted for approximately 50-56% of all detections. Northern shoveler is a winter species and so is generally either absent or present in very low numbers for approximately half of the year, but was still the most abundant species in all years. Both ruddy duck and American coot are year-round residents. Average abundance for all species is provided in Appendix A.

Detections by habitat type are presented in Figure 16. Birds were most commonly detected in open water and on the loafing islands. Pond edge accounted for the fewest detections in years one and two, while hummock habitat accounted for the fewest in the remaining years.

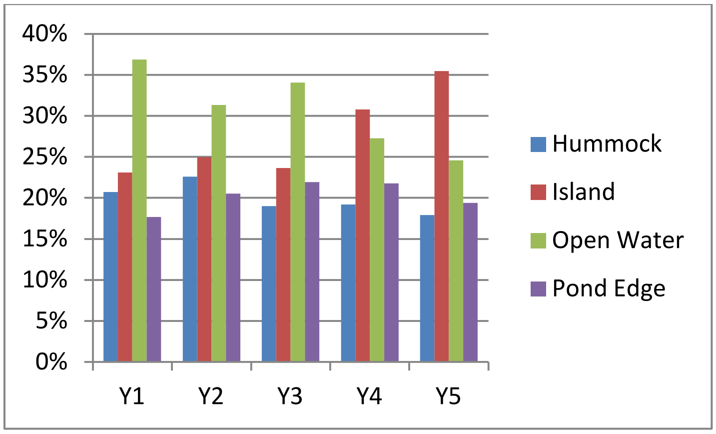

Figure 16: Percentage of overall detections by habitat type.

2.4.3.2 Non-Breeding Season

A total of 81 species were detected during the non-breeding season. Total richness varied annually from 44 to 57 species, with the highest richness again being recorded in the first year and the lowest in the second (Table 10). Average species richness varied insignificantly ($p = 0.575$), ranging from 22.9 to 25.3 species per visit (Table 10). Average abundance also varied between years, first increasing and then decreasing, but these changes were not found to be statistically significant ($p = 0.285$; Table 10). In the first three years, average abundance was significantly higher in the non-breeding season than in the breeding season ($p < 0.004$).

We detected 24 species on at least 40% of the censuses. In addition to those mentioned in the overall section, northern shoveler was detected on every survey, and gadwall, green-winged teal and yellow-rumped warbler were detected on most (> 77%).

Year	# Censuses	# Species	Average Species Richness	Species Richness, Min. & Max.	Total Detections	Average Abundance	Abundance, Min. & Max.	% Detections by 3 Most Abundant Species
1	13	57	23.6 ±1.02	18, 29	5,881	452.4 ±45.5	216, 720	63%
2	8	44	24.5 ±1.02	19, 27	4,057	507.1 ±60.8	268, 760	61%
3	7	45	25.3 ±0.64	24, 29	3,956	565.1 ±83.0	303, 922	63%
4	8	52	23.4 ±1.21	18, 27	3,498	437.3 ±68.4	150, 688	66%
5	8	51	22.9 ±0.95	20, 28	2,781	347.6 ±86.8	120, 855	62%

Table 10: Non-breeding season bird values for the Demonstration Wetland, by study year. Average richness and abundance values are ± standard error.

Once again, although changes in average abundance were not statistically significant, there were significant changes to the abundance of individual species. Virginia rail and marsh wren increased, eared grebe and ruddy duck decreased ($p < 0.05$), and common gallinule increased and then decreased significantly, with no significant change between years one and five. Black-crowned night-heron increased significantly from years one through three and although it then declined again, the changes were not significant. Red-winged blackbird abundance was significantly different between years two and four ($p < 0.05$).

The percentage of aquatic birds in the community was higher in the non-breeding season than overall, ranging from 86-96%. The three most abundant birds were the same as overall, but ruddy duck displaced American coot as the second most abundant in four of five years. The three species accounted for 61-66% of annual detections. Average abundance for all species for the non-breeding season is provided in Appendix B.

Birds were typically most commonly detected in open water and on the loafing islands, but in a few years pond edge was among the highest contributors to detections (Figure 17). Birds were detected the least in hummock habitat in all years.

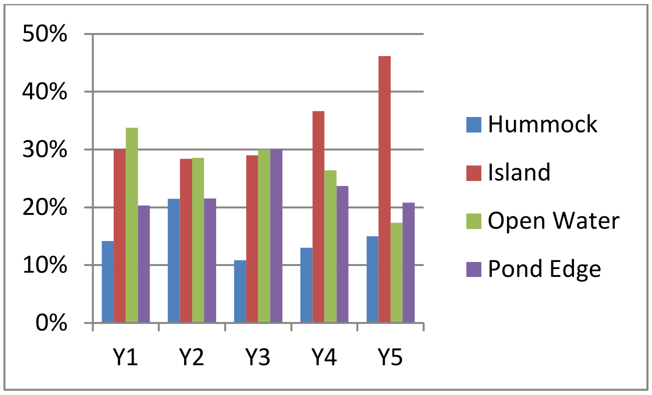

Figure 17: Percentage of non-breeding season detections by habitat type.

2.4.3.3 Breeding Season

Eighty species were detected in the breeding season. Although total annual richness again varied (from 46 to 57 species), the first year exhibited the lowest richness while the third year had the highest (Table 11). Average species richness increased significantly ($p < 0.001$)) over the five-year period, from less than 16 species per visit in year one to nearly 24 species per visit in year five (Table 11). Average abundance varied from year to year (Table 11) but changes were not statistically significant ($p = 0.090$).

Year	# Censuses	# Species	Average Species Richness	Species Richness, Min. & Max.	Total Detections	Average Abundance	Abundance, Min. & Max.	% Detections by 3 Most Abundant Species
1	16	46	15.9 ±1.52	9, 31	3,165	197.8 ±16.7	126, 360	67%
2	12	54	19.1 ±1.48	13, 29	2,859	238.3 ±23.8	150, 442	58%
3	9	57	21.8 ±1.12	16, 28	2,343	260.3 ±28.8	186, 457	54%
4	9	53	23.9 ±1.49	15, 31	2,377	264.1 ±35.2	181, 474	46%
5*	9	50	23.8 ±0.62	20, 27	1,899	211.0 ±25.8	120, 373	47%

Table 11: Breeding season bird values for the Demonstration Wetland, by study year. Average richness and abundance values are ± standard error.

* - missing August – surveys discontinued at the end of July.

Sixteen species were detected on at least 40% of the surveys. In addition to those highlighted in the overall section, black-necked stilt and redhead were detected on nearly every census and American avocet was detected on approximately 75%.

As in the other time periods, some species experienced statistically significant changes in abundance even though changes to total abundance were not significant. Increasing species include gadwall, mallard, cinnamon teal and marsh wren and decreasing species include ruddy duck, American coot and great-tailed grackle ($p < 0.05$). Common gallinule's pattern of increasing and then decreasing continued.

Aquatic birds comprised a lower percentage of the community than in the overall and non-breeding time periods, ranging from 73-80%. The three most abundant birds varied somewhat. American coot was always the most abundant, and ruddy duck was the third most abundant species in four of five years. In the first three years, the second or third most abundant species was great-tailed grackle, but by the fourth year it was displaced by mallard. The latter two species are year-round residents although grackle numbers typically increased substantially in the breeding season. The percentage of

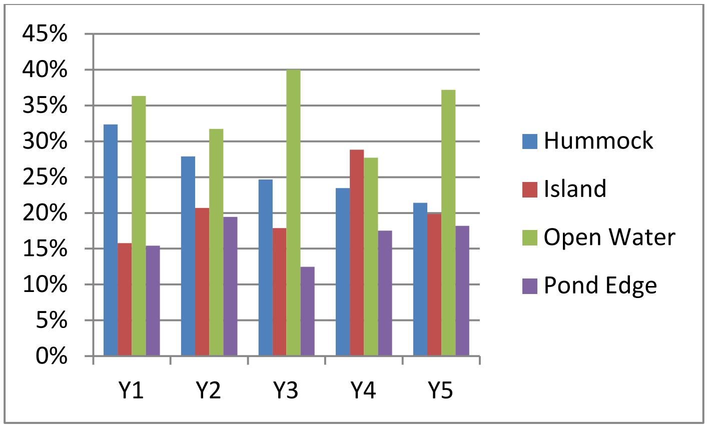

Figure 18: Percentage of breeding season detections by habitat type.

annual detections for which the three most abundant species accounted varied generally downward, starting at 67% in year one and ending the study at 47% in year five. Average abundance for all species for the breeding season is provided in Appendix C.

Birds were generally most commonly detected in open water and hummock habitats, with the loafing islands only making it into the top two types in year four (Figure 18). Pond edge accounted for the fewest detections in all years.

2.4.3.4 Notes on Breeding Activity

Annual chick and juvenile richness and abundance information for the breeding season is provided in Table 12. Chicks were typically present May-August, and the highest chick abundance was recorded between June 10 and June 22 each year. Juveniles were most abundant in July and August. We recorded 15 species with dependent young over the course of study (Table 13). The number of species with dependent chicks ranged from as low as 5 in the second year to a high of 11 in the fourth year (Table 12). Chick abundance was highest in the first year and lowest in the second, declining significantly ($p < 0.001$) from an average of 51.8 to just 8.1 chicks per census (Table 12). The remaining years showed no significant differences. One additional species, marsh wren, was confirmed breeding through observations of nests rather than young. Although not recorded during censuses, Bird Viewing Preserve staff also noted least bittern, Virginia rail, and sora with young in the pond (J. Branca, pers.comm.). Other species considered possible (but not confirmed) breeders include yellow-headed blackbird, detected in every breeding season, and common yellowthroat. We also observed green heron and black-crowned night-heron in the pond with juveniles, and although we consider it unlikely that they actually nested in the pond, the two species were using the wetland's resources to nourish their young. Juveniles of both species are able to fly to foraging sites with adults when still dependent.

Year	# Censuses	Chick Species Richness	# Chick Detections	Avg Chick Abundance - All Surveys (Detected Only)	Chick Min. (non-zero) & Max.	Juvenile Species Richness	# Juvenile Detections	Avg Juvenile Abundance - All Surveys (Detected Only)	Juvenile Min. (non-zero) & Max.
1	16	8	829	51.8 (55.3)	5, 127	5	178	11.1 (29.7)	19, 47
2	12	5	89	8.1 (11.1)	1, 38	6	52	4.3 (13)	4, 19
3	9	9	328	36.4 (40.8)	1, 80	4	79	8.8 (19.8)	8, 29
4	9	11	242	26.9 (30.8)	22, 46	5	63	7 (10.5)	2, 17
5*	9	6	204	22.7 (22.7)	3, 82	5	53	5.9 (17.7)	1, 34

Table 12: Breeding season chick and juvenile values for the Demonstration Wetland.

* - missing August – surveys discontinued at the end of July.

Only American coot, common gallinule, and mallard were documented with chicks in all years (Table 13). However, ruddy duck was the most prolific breeder in most years. Interestingly, although the species averaged more than 30 chicks (in surveys in which chicks were detected) in the 2005 breeding season, no chicks or juveniles were reported in 2006. Ruddy ducks produced chicks in all other years, averaging ten or more chicks per census in which they were detected. Chicks were produced by all other major breeders in 2006, but the average number of chicks per census was the lowest of all years (8.1). We observed redheads, American avocets, and black-necked stilts with chicks in three of five years (Table 13). All other species were reported with chicks in two years or less, although they may have nested more frequently (one example would be great-tailed grackle which nested in great numbers, but did so in the dense hummock vegetation where it was difficult to observe dependent young).

2.4.3.5 Discussion

The wetland averaged ~100-150 birds per ha (birds/ha) year-round, ~75-100 birds/ha in the breeding season and ~130-215 birds/ha in the non-breeding season (calculated as average abundance divided by the area of the pond), and by the end of the study, an average of 24 species were detected per census. While this seems representative of productive habitat, little information was available in the peer-reviewed literature with which to compare it. In their investigation of inland wetland quality indicators, Adamus and Brandt (1990) state that southwestern herbaceous wetlands are among the least-studied in terms of wetland bird communities; they also state that from a seasonal perspective, little is known about wintering bird populations in wetlands. We found that research often pertained to a type of wetland that was not applicable to the current study (e.g., prairie pothole and bottomland forested wetlands of the eastern United States) or was limited to one or a few targeted species, such as the white-faced ibis. However, we were able to compare our results with those of the project on which our wetland design was based (Anderson et al. 2003), and species richness and abundance (once adjusted for differences in wetland area) appear similar.

Species	# Years w/Chicks Detected	# Chicks Detected in 5 Breeding Seasons
American Avocet	3	12
American Coot	5	537
Black-Necked Stilt	3	13
Canada Goose	2	10
Cinnamon Teal	2	5
Common Gallinule	5	81
Eared Grebe	2	10
Gadwall	1	8
Gambel's Quail	2	35
Great-tailed Grackle	1	1
Killdeer	2	9
Mallard	5	133
Pied-Billed Grebe	2	4
Redhead	3	50
Ruddy Duck	4	791

Table 13: Species with dependent young.

The increase in birds in the non-breeding season highlights the importance of the wetlands to overwintering waterfowl. Northern shoveler was the most abundant species when averaged year-round, even though it was only present about six months of the year. The pond also provided breeding habitat with 15 species observed with dependent chicks and a few others observed nesting or with dependent juveniles. While it is possible that some of the species confirmed with young nested elsewhere and only foraged in the Demonstration Wetland, the pond still clearly offered valuable habitat to breeding birds.

A few species experienced significant declines and increases in abundance over the course of the study, and this is not unusual. Species that declined and those that increased were fairly balanced both in number and type (i.e., waterfowl family, rail family, passerine). Overall and individual abundances do not appear to have been impacted by the vegetation harvesting in March 2008. There were some species that decreased that breeding season, but others increased that used the same habitat (see Appendix C), so the variations likely were not related to the harvesting. Another argument in favor of no effect is that average species richness and abundance actually increased slightly that breeding season.

The importance of different habitat types varied based on the time period and year. Birds were most commonly detected in open water and on the loafing islands year-round, and typically in the non-breeding season. However, in some years, birds were detected on the pond edge in the non-breeding season in significant numbers, and in most years, hummock habitat was among the two types with the most detections in the breeding season. Therefore, it is likely that bird abundance in the pond benefitted from having the four different types available. The periodic upsurge in detections on the pond edge can be attributed to its function as a second loafing habitat, with up to hundreds of winter waterfowl identified there on several censuses. In the breeding season, the hummocks offered structure for nesting as well as cover and food with easy access to water. It is not surprising that open water dominated habitat use, given that it represented ~80% of the surface area of the pond. Likewise then, it is not surprising that the bird community was dominated by aquatic birds, which represented more than 70% of detections in any given time period.

The Demonstration Wetland showed the ability for a constructed wetland to provide valuable habitat for birds while still improving water quality. While ammonia did increase significantly in the pond, this appears to have been related to chemical processes rather than bird inputs, as the pattern of ammonia concentrations did not mimic that of bird abundance. In fact, some of the lowest concentrations recorded at the outflow in a given year correspond to dates with the highest bird abundances. In addition, nitrate and nitrite both decreased significantly in the wetland. Average fecal coliforms also decreased. There were sampling events where concentrations at the outflow exceeded those at the inflow, but these did not generally correspond with peaks in bird abundance. These events often occurred in the summer when bird abundances were typically at their lowest. Peaks in inflow concentrations (> 1,000 CFU/100 ml) in the fall and winter months often corresponded to higher bird abundances (≥ 600 birds) in the pond, but outflow concentrations were still reduced by 60% or greater, arguing against a significant effect by birds on removal efficiency. While the birds in the Demonstration Wetland would not impact inflow concentrations, they are a proxy for increased abundance on the ponds through which the water flowed on its way to the constructed wetland.

3.0 PITTMAN WETLANDS

3.1 Project Description

3.1.1 Goals

The primary purpose of this pilot project was to determine whether constructed wetlands could improve the water quality of urban runoff. Other goals included evaluating the feasibility of operating constructed wetlands in an urban flood control channel (addressed in Van Dooremolen and Lane 2007), identifying challenges associated with this type of setting (addressed in Van Dooremolen and Lane 2007), optimizing design and construction techniques, and comparing the effects of different wetland flow regimes.

3.1.2 Site and Design Description

Figure 19: Pittman Wetlands with Pittman Wash in the foreground, taken July 3, 2008. The SSF cell is adjacent to the tributary channel.

The Pittman Wetlands were constructed in the Pittman Wash channel (Figure 19) adjacent to the Arroyo Grande Sports Complex in Henderson. Construction was originally completed in May 2005, and the site planted that June. However, the site had to be rebuilt twice due to storm damage (see Van Dooremolen and Lane 2007). The final construction and planting was completed in February 2007. The project covered approximately 0.1 ha of the floodplain adjacent to the dry flow channel. There were two cells, each approximately 0.02 ha in size, one with a surface flow (SF) regime, and another with a subsurface flow (SSF) regime (Figure 19). The SF cell had alternating open water zones (depth of 0.75-1 m) and bulrush-vegetated beds. The SSF cell was filled with 2-cm gravel, and the entire surface was planted. The same three species of bulrush used at the Demonstration Wetland (SCCA, SCAC and SCAM) were planted in alternating bands in each wetland cell. Both cells were lined with 10 cm of clay to keep groundwater from influencing wetland water chemistry. Earth berms bordered the cells and another berm separated the cells. Flows from the main channel entered the site via two 7.5-cm pipes in the concrete wall bordering the channel. Water from these pipes entered a small channel at the top of the site. In this channel, each cell had a diversion structure through which the water entered and then flowed through the given cell. Water exited each cell into a similar small channel and then returned to the main channel.

3.2 Methods

3.2.1 Water Quality

The Pittman Wetlands were sampled at three locations: the inlet, the surface flow outlet (surface outlet), and the outlet. Water samples were collected each month from February 2007 through January 2009, and analyzed for nutrients, cations/anions, and metals. During each sampling event, field parameters (including pH, DO, conductance, and temperature) were recorded using a Hydrolab multi-probe water quality instrument. Hydrolab measurements were taken at the three water quality sampling locations and at four other sites within the wetlands, including three sites in the SSF cell and an additional site in the SF cell.

As one of the primary goals was to determine the impact of the pilot wetlands on normal (dry weather) urban runoff, sampling was not conducted for at least two days following storm events. Clark County Regional Flood Control District has several rain gauges in place along the Pittman

Wash channel, including one less than 0.33 km downstream of the pilot project site. These gauges allowed accurate estimates to be made regarding the timing and amount of rain impacting the site.

3.2.2 Vegetation

Vegetation monitoring was conducted in the spring and fall (May and November) of 2007 and 2008. Methods used were similar to those used at the Demonstration Wetland. Total vegetative cover and cover per species were visually estimated for each cell, using the standard categories (<<1%, <1%, 1-5%, 5-25%, 25-50%, 50-75%, and 75-100%). For the SSF cell, where the three species were present in distinctly separate bands, three samples of each of the three species of bulrush were randomly selected, yielding a total of nine samples. However, these bands rapidly disappeared in the two planting beds within the SF cell, as SCAM invaded the SCAC and SCCA zones. Therefore, 2-3 samples were randomly selected in each of the two planting beds, yielding a total of 4-6 samples comprised of various species. As with the Demonstration Wetland, three subsamples per species were analyzed for nutrients and select COPCs. In addition to the bulrush, we also sampled and analyzed volunteer species that accounted for ≥15% cover in the SF cell or ≥25% cover in the SSF cell during at least one sampling event.

3.3 Data Analyses

Statistical analyses were similar to those used for the Demonstration Wetland for both water quality and vegetation, with a few exceptions for the latter. Comparisons of physical parameters and tissue concentrations among species were made using only SSF cell data as that was the only cell in which all bulrush species were sampled in all monitoring events. As only SCAM was sampled in both cells in all monitoring events, differences in physical parameters and tissue concentrations between the hydrologic regimes were analyzed using only SCAM data. To identify differences in tissue concentrations between the two cells, we ran Two-Way ANOVAs comparing the effects of flow regime and season on the concentration of each COPC. Linear regression was also used.

Sample sizes for culm density, percent dead, and tissue concentrations were small ($n = 3$ per species per monitoring event in the SSF cell, and $n = 2$-6 for SCAM and $n = 0$-3 for other species per monitoring event in the SF cell). As a result, power to perform statistical tests was lower and reported as an issue by SigmaStat when failing to reject the null hypothesis. Therefore, care should be taken when interpreting non-significant results.

Average culm density and percent dead were calculated somewhat differently for each cell based on the differences in quadrat collection. In the SSF cell, each species' average culm density and percent dead was calculated from the three quadrats collected for that species. Since quadrats were not species-specific in the SF cell and thus all species had an equal chance of being discovered in those quadrats, average culm density and percent dead for each species were calculated using the total number of quadrats collected in that cell during a given monitoring event. For SCAC and SCCA, which typically occurred in just one to a few quadrats per event, this yielded average percentages of dead culms that appeared low. For example, in the November 2008 instance in which only one culm of SCAC was found in six quadrats and it was dead, the average percentage of dead culms was calculated as 100%/6 or 17%. Frequency, herein defined as the proportion of quadrats in which the species was found, was also calculated for the SF cell. Biomass and TN, TP, Se and As storage were calculated using the method described in Section 2.3.2.

Bird surveys were not conducted at the Pittman Wetlands, but anecdotal observations were made and are reported.

3.4 Results and Discussion

3.4.1 Water Quality

3.4.1.1 Temperature, Electrical Conductance, pH, and Dissolved Oxygen

Water temperature at the Pittman Wetlands trended closely with ambient air temperature. Temperatures ranged from 11.47°C to 29.46°C, with the highest temperatures measured during the warmer summer months. Conductivity was very consistent and ranged between 3,662 and 4,056 µS/cm throughout the study. The pH values ranged from 6.85 to 8.3 and were neutral to basic. DO levels remained high in the summer months and ranged from 3.55 mg/L to 9.72 mg/L, and remained similar at all three locations within the wetlands. Overall, DO levels remained well above anoxic conditions.

3.4.1.2 Nutrients

Water samples at the Pittman Wetlands were analyzed for ammonia, TKN, nitrate, nitrite, orthophosphate, and TP. Nitrate was the only nutrient regularly detected at the Pittman Wetlands with average nitrate concentration ranging from 7.8 mg/L to 10 mg/L. The remaining analyte concentrations were below the detection limit or detected infrequently and were excluded from analysis. Average nitrate concentrations at the inlet were 9.0 mg/L and 8.9 mg/L at the outlet. Nitrate concentrations were similar at the inlet and outlet at the Pittman Wetlands, resulting in no discernable reduction in nitrate concentrations.

3.4.1.3 Metals

Chromium, vanadium, aluminum, Se, molybdenum, As, nickel, cobalt, and barium concentrations were consistently detected in the Pittman Wetlands. Other metals (thallium, lead, Hg, iron, manganese, beryllium, copper, zinc, silver, cadmium, and antimony) were sampled for but were not detected or were detected infrequently during the sample period and were excluded from this report. Table 14 displays the mean, minimum, and maximum concentration for metals analyzed at the Pittman Wetlands. Metal concentrations remain very similar with no statistical change between the inlet and outlet concentrations.

Analyte (mg/L)	Site	Mean	Min	Max	±SE	RE %
Molybdenum	Inlet	13	11	15	0.24	1
	Outlet	13	11	15	0.22	
Nickel	Inlet	2.02	0.005	5.9	0.50	3.23
	Outlet	1.96	0.005	5.9	0.52	
Selenium	Inlet	10.38	7.5	12	0.27	2.10
	Outlet	10.16	7.5	12	0.30	
Aluminum	Inlet	33.58	0.05	160	10.16	-27.91
	Outlet	42.95	0.05	460	24.87	
Arsenic	Inlet	13.52	8	16	0.47	-2.88
	Outlet	13.91	8.4	18	0.47	
Barium	Inlet	43.82	38	51	0.85	-4.10
	Outlet	45.61	39	65	1.58	
Chromium	Inlet	1.6	1.2	1.9	0.05	8.70
	Outlet	1.4	1.1	2.1	0.07	

Table 14: Pittman Wetlands metal means, maximum, minimum, standard error, and removal efficiency.

3.4.1.4 Total Dissolved Solids

The high TDS in the Pittman Wetlands is reflective of water found in urban tributaries in the Valley. The flood conveyance channels are typically shallow during non-storm events, carrying irrigation runoff and resurfacing shallow groundwater. Increasing major ions are common in summer months due to increased evaporation, especially in desert environments. The Pittman Wetlands had low flow and coupled with increased temperatures and conductance, high TDS is expected. TDS does not appear to increase during summer months and concentrations remained between 2,100 and 3,600 mg/L throughout the sampling period (Figure 20). Average TDS concentrations were 3,000 and 2,938 mg/L at the inlet and outlet, respectively.

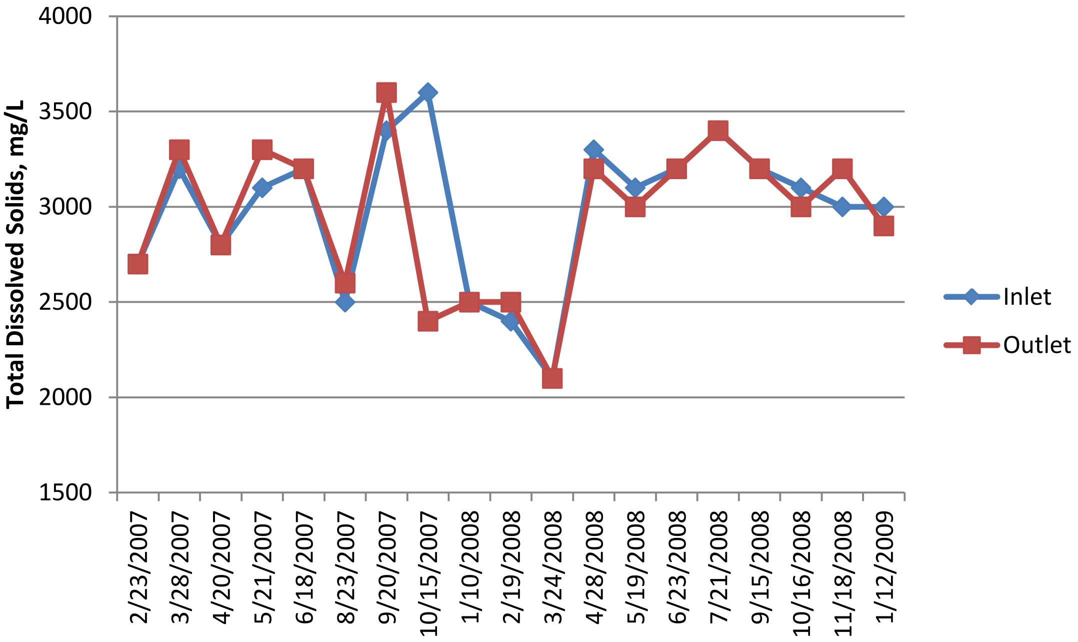

Figure 20: Pittman Wetlands TDS.

3.4.2 Vegetation

3.4.2.1 Average Culm Height, Diameter, Density, and Percent Dead

Average culm height, diameter, density, and percentage of dead culms for the SSF cell are presented in Table 15. The three planted bulrush species differed in physical parameters, although not all differences were statistically significant. SCAC averaged significantly taller than both SCCA and SCAM (with particularly high values in spring 2008; $p < 0.05$), and the mean culm diameter of both SCAC and SCCA was significantly higher than SCAM ($p < 0.05$). Average height within species varied throughout monitoring, as did diameter to a lesser extent.

SCAM had the highest mean culm density in all sampling events ($p < 0.05$; Table 15) in the SSF cell, but linear regression shows density decreasing significantly from May 2007 to November

Species	Year	Month	Avg Ht (m)	±SE	Avg Diam (mm)	±SE	Avg Culm Density (#/m^2)	±SE	Avg % Dead (#/m^2)	±SE	Avg Dry Wt (kg/m^2)	±SE	Avg Cover & Range
SCAC			1.04	0.04	8	0.2	1011	126	49%	8%	1.96	0.26	26%
	2007	May	0.89	0.05	8	0.4	795	205	19%	7%	1.56	0.19	5-25%
		November	0.85	0.04	7	0.4	1413	324	46%	11%	2.26	0.40	25-50%
	2008	May	1.43	0.05	7	0.3	1152	105	43%	5%	2.94	0.41	25-50%
		November	0.91	0.09	10	0.7	683	146	86%	5%	1.06	0.29	5-25%
SCAM			0.82	0.03	5	0.1	2779	540	54%	5%	1.39	0.17	32%
	2007	May	0.65	0.04	4	0.2	4261	1106	41%	3%	1.28	0.15	5-25%
		November	1.05	0.05	6	0.3	3723	1382	53%	8%	2.19	0.68	25-50%
	2008	May	0.82	0.04	5	0.3	1739	444	51%	15%	1.10	0.21	25-50%
		November	0.75	0.04	5	0.2	1392	184	73%	5%	1.24	0.14	5-25%
SCCA			0.86	0.03	7	0.3	751	97	54%	4%	1.30	0.21	12%
	2007	May	0.85	0.04	8	0.4	683	267	48%	9%	1.63	0.48	1-5%
		November	0.76	0.06	6	0.4	747	101	40%	11%	0.95	0.13	5-25%
	2008	May	0.86	0.07	7	0.6	651	166	63%	1%	0.86	0.58	5-25%
		November	1.00	0.06	7	0.5	923	275	63%	4%	1.62	0.48	5-25%
SSF			0.90	0.02	6	0.1	1513	237	52%	3%	1.38	0.13	75%
Total	**2007**	May	0.80	0.03	6	0.3	1913	676	36%	5%	1.49	0.16	50-75%
		November	0.88	0.03	6	0.2	1961	610	46%	6%	1.75	0.30	50-75%
	2008	May	1.04	0.04	6	0.3	1180	211	52%	5%	1.30	0.36	75-100%
		November	0.88	0.04	6	0.3	999	147	74%	4%	1.11	0.18	75-100%

Table 15: Average culm height (Avg Ht), diameter (Avg Diam), culm density, percent dead (Avg % Dead), and biomass (Avg Dry Wt) with standard errors (±SE), and cover for the SSF cell of the Pittman Wetlands.

2008 ($r^2 = 0.503$, $p = 0.010$). SCCA and SCAC densities were not significantly different ($p > 0.05$) and underwent no significant changes during monitoring. No statistically significant differences were found for the average percentage of dead culms between species ($p = 0.759$). However, percent dead did increase for all species, averaging ~36%-46% the first year and ~52-74% the second. Linear regressions show this trend was significant for both SCAC ($r^2 = 0.699$, $p < 0.001$) and SCAM ($r^2 = 0.349$, $p = 0.043$).

Average culm height, diameter, density and percentage of dead culms for the SF cell are presented in Table 16. SCAM had significantly higher values than the other species in all

Species	Year	Month	Freq-uency	Avg Ht (m)	±SE	Avg Diam (mm)	±SE	Avg Culm Density (#/m^2)	±SE	Avg % Dead (#/m^2)	±SE	Avg Dry Wt (kg/m^2)	±SE	Avg Cover & Range
SCAC			0.31	1.48	0.09	8	0.3	64	26	17%	8%	0.12	0.07	4%
	2007	May	0.50	1.48	0.10	8	0.3	140	86	14%	12%	0.29	0.17	5-25%
		November*	0.33	1.39	n/a	8	n/a	51	48	32%	21%	0.19	0.18	< 1%
	2008	May	0.25	1.49	0.26	7	0.9	64	64	20%	20%	0.03	0.03	1-5%
		November**	0.17	n/a	n/a	n/a	n/a	3	3	17%	17%	< 0.01	< 0.01	<< 1%
SCAM			0.96	1.71	0.03	7	0.2	1306	156	38%	6%	3.44	0.40	63%
	2007	May	1.00	1.48	0.06	7	0.3	1140	305	15%	6%	2.11	0.57	50-75%
		November	1.00	1.80	0.04	8	0.3	1347	312	43%	9%	4.15	0.83	50-75%
	2008	May	1.00	1.83	0.06	7	0.4	1568	443	42%	10%	4.17	0.96	50-75%
		November	0.83	1.71	0.05	7	0.3	1171	280	54%	11%	3.12	0.67	50-75%
SCCA			0.40	1.54	0.06	10	0.3	193	65	19%	7%	0.79	0.31	12%
	2007	May	0.25	1.27	0.07	10	0.8	60	60	5%	5%	0.14	0.14	1-5%
		November	0.33	1.24	0.07	9	0.5	171	122	14%	10%	0.49	0.35	5-25%
	2008	May	0.50	1.91	0.10	10	0.8	364	223	21%	16%	1.81	1.23	5-25%
		November	0.50	1.72	0.12	9	0.6	176	105	38%	18%	0.82	0.54	5-25%
SF				1.65	0.03	8	0.1	1542	134	46%	5%	4.35	0.39	69%
Total	**2007**	May		1.45	0.05	8	0.2	1340	324	17%	6%	2.54	0.65	50-75%
		November		1.64	0.04	8	0.2	1568	260	48%	7%	4.84	0.65	50-75%
	2008	May		1.84	0.05	8	0.4	1996	327	44%	10%	6.01	0.94	50-75%
		November		1.71	0.05	8	0.3	1347	188	64%	3%	3.95	0.29	75-100%

Table 16: Frequency; average culm height (Avg Ht), diameter (Avg Diam), culm density, percent dead (Avg % Dead), and biomass (Avg Dry Wt) with standard errors (±SE); and cover for the SF cell of the Pittman Wetlands.

* - a single live culm was found in the 6 quadrats, all others were dead.

** - a single, dead culm was found in the 6 quadrats.

n/a - not applicable.

parameters but diameter ($p < 0.05$) in the SF cell. Its average height increased slightly (but not significantly) over the course of monitoring, while average diameter remained approximately the same (7-8 mm). SCAC was not consistently detected but height remained about the same in those periods in which it was. Linear regressions showed an increasing trend in SCCA average height from May 2007 to November 2008 ($r^2 = 0.251$, $p < 0.001$), and also showed the increase of nearly 40% in percent dead for SCAM to be significant ($r^2 = 0.244$, $p = 0.027$).

Comparing averages between the two cells, average heights in the SF cell were significantly taller for all species ($p < 0.001$) and average diameters were significantly larger for SCAM and SCCA ($p < 0.001$). SCAM average culm density was significantly smaller ($p = 0.010$) in the SF cell. Average percent dead was smaller in the SF cell as well, but the difference was not significant ($p = 0.095$). While SCAC and SCCA could not be tested due to their low rate of occurrence in samples from the SF cell, culm densities were substantially lower in that cell as well.

3.4.2.2 Biomass

In the SSF cell, SCAC had the largest average biomass when averaged across years (Table 15). A Three-Way ANOVA of species, year, and month found species to be a significant source of variation, but a significant interaction between year, month, and species ($p = 0.002$) impacted SigmaStat's ability to interpret main effects. Possibly as a result, no intra-specific differences were identified as significant in pairwise multiple comparison procedures. At the main effects level of species, May average dry weight was found to be significantly higher than November for SCAC ($p = 0.005$) and 2007 average dry weight was significantly higher than 2008 for SCAM ($p = 0.049$).

In the SF cell (Table 16), ANOVA on Ranks found that SCAM average dry weights were significantly higher than both SCAC and SCCA ($p < 0.05$) when pooled across all sampling events. Pooling species across events, no relationship was found between either season or year and biomass ($p > 0.842$). Likewise, within each species, no relationship was found between season or year and biomass ($p > 0.124$).

Comparing averages among the two cells (once again using SCAM data only), biomass was significantly higher in the SF cell ($p = 0.002$).

3.4.2.3 Cover

Average cover for the SSF cell increased from 63% in May 2007 to 88% in November 2008, including cover from volunteer species (Table 15). Cover for SCAM increased from 5-25% to 25-50% in the first year but declined again in the final monitoring event (Table 15). While SCAC cover increased from 5-25% in the first monitoring period to 25-50% in the second and third, it too declined again in the fourth. SCCA increased from 1-5% to 5-25% cover in the first year and remained there through the second year of monitoring. We also identified several other species during monitoring as the wetlands location within an urban flood control channel made it particularly susceptible to invasion by weeds and escaped ornamentals. The few volunteer species that exceeded the trace cover class (< 1%) more than once included: alkali aster (*Aster subulatus),* Bermuda grass *(Cynodon dactylon),* Mexican sprangletop *(Leptochloa fusca),* rabbitsfoot grass *(Polypogon monspeliensis),* and dock *(Rumex stenophyllus).*

Average cover for the SF cell also increased from 63% in May 2007 to 88% in November 2008 (Table 16). Although the three bulrush species were planted in roughly equal amounts in February 2007, by that May, SCAM covered 50-75% of the surface area of the cell and remained in that cover category for the life of monitoring (Table 16). In May 2007, SCAC provided 5-25% of the cover for the cell; by November 2008, hardly any SCAC culms were found. As with the SSF cell, SCCA increased from a nominal 1-5% to 5-25%. Volunteer species also established within the cell over the course of monitoring. Those that exceeded the trace category more than once included: alkali aster, Bermuda grass, and cattails *(Typha domingensis).* Cattails established in the center pond by May 2007, filling in the open water areas (~1 m). SCAM also spread into the open water, growing at depths not seen at the Demonstration Wetland.

3.4.2.4 Plant Tissue Concentrations of Nutrients and Contaminants of Potential Concern and Storage

Concentrations of tested nutrients and COPCs from May 2007 through November 2008 are provided for the SSF and SF cells in Tables 17 and 18, respectively. When comparing flow regimes (using only SCAM data), there were some differences in average concentrations between the two cells, but only Se was statistically significant. A Two-Way ANOVA comparing the effect of flow regime and season on Se found SSF cell SCAM had significantly higher average Se than the SF cell ($p = 0.049$). Additionally, the average concentration of Se was significantly higher in fall than in spring ($p = 0.008$). No interaction between flow regime and season was identified ($p = 0.244$).

When making comparisons among species, each had significantly different average TN ($p < 0.025$), with SCAM having the highest concentration. SCAM was also significantly higher than SCCA in TP ($p < 0.05$). While SCAC had a higher average concentration than both at 607 µg/g, it had a standard error of 136 µg/g, and was not statistically different than the others. SCAM also had significantly higher concentrations of Se than the other bulrush species ($p < 0.05$). Pooling species, only As was found to have a statistically significant difference between years with 2007 concentrations higher than 2008 ($p < 0.001$). Average TP concentration was higher in the fall than in the spring for all species, but the difference was not statistically significant ($p \geq 0.080$); standard errors were relatively high. Se was higher in fall 2008 than at any other point in sampling, but seasons were not found to be significantly different when pooling species and years. However, SCAM was found to have significantly higher fall Se concentrations than spring ($p = 0.047$), which is consistent with the finding under the flow regime comparison. Concentrations of Hg were often below detection limits, preventing meaningful statistical analyses, and analyses were not conducted on TC and TH, which were only collected in 2008.

We also analyzed cattails (TYDO) from the SF cell (May and November 2008) and rabbitsfoot grass (POMO; May 2008) and Bermuda grass (CYDA; November 2008) for the SSF cell (Table 15). To identify any significant differences for TYDO, we compared it to all other species collected in the SF cell in May and November 2008 ($n = 6$ for all but SCAM for which $n = 7$). The only significant relationship identified for TYDO was for TP in a Two-Way ANOVA with species and season. TYDO had significantly higher concentrations (868 ±53 µg/g in May and 1,225 ±281 µg/g in November) than SCAM and SCCA ($p < 0.018$; SCAC was not included in the analyses as it was only sampled in May 2008) and concentrations were significantly higher for all tested species in the fall than in spring ($p = 0.0361$). To identify any significant

Cell & Species	Year & Month	Avg TN%	±SE	Avg TP (µg/g)	±SE	Avg Se (µg/g)	±SE	Avg As (µg/g)	±SE	Avg Hg (µg/g)	±SE	Avg TC%	±SE	Avg TH%	±SE
SSF		1.06	0.15	489	175	0.86	0.38	0.32	0.10	0.01*	0.00	41.68	0.87	5.63	0.08
SCAC		1.05	0.12	607	272	0.50	0.13	0.28	0.09	0.01*	0.01	42.37	0.80	5.67	0.10
	2007	0.99	0.12	398	47	0.40	0.06	0.39	0.07	0.01*	0.00	n/a	n/a	n/a	n/a
	May	1.13	0.10	374	55	0.42	0.01	0.28	0.03	<0.01		n/a	n/a	n/a	n/a
	November	0.84	0.06	422	43	0.38	0.10	0.50	0.02	0.01	0.00	n/a	n/a	n/a	n/a
	2008	1.10	0.13	816	354	0.59	0.16	0.16	0.05	0.02*	0.01	42.37	0.80	5.67	0.10
	May	1.05	0.15	464	149	0.37	0.03	0.11	0.02	0.03	0.01	41.25	0.43	5.54	0.07
	November	1.16	0.13	1168	409	0.82	0.11	0.22	0.05	0.01*	0.00	43.48	0.38	5.80	0.03
SCAM		1.29	0.12	521	86	1.37	0.48	0.39	0.12	0.02*	0.00	41.13	0.38	5.67	0.05
	2007	1.20	0.08	444	80	1.04	0.13	0.55	0.08	0.02*	0.00	n/a	n/a	n/a	n/a
	May	1.17	0.11	354	78	0.87	0.07	0.63	0.08	<0.01		n/a	n/a	n/a	n/a
	November	1.23	0.06	534	42	1.22	0.07	0.47	0.04	0.02	0.00	n/a	n/a	n/a	n/a
	2008	1.38	0.14	598	71	1.70	0.64	0.23	0.05	0.02	0.00	41.13	0.38	5.67	0.05
	May	1.28	0.03	585	14	0.95	0.18	0.19	0.05	0.02	0.00	40.97	0.54	5.66	0.06
	November	1.47	0.20	610	111	2.45	0.64	0.27	0.05	0.01	0.00	41.30	0.20	5.69	0.05
SCCA		0.86	0.09	341	53	0.70	0.22	0.30	0.08	0.01*	0.00	41.54	1.22	5.56	0.09
	2007	0.88	0.08	346	36	0.57	0.14	0.40	0.05	0.01*	0.00	n/a	n/a	n/a	n/a
	May	0.98	0.04	333	38	0.70	0.17	0.37	0.05	<0.01		n/a	n/a	n/a	n/a
	November	0.79	0.08	359	40	0.44	0.05	0.42	0.07	0.02*	0.00	n/a	n/a	n/a	n/a
	2008	0.83	0.11	336	70	0.84	0.27	0.21	0.08	0.01*	0.00	41.54	1.22	5.56	0.09
	May	0.76	0.02	256	22	0.46	0.08	0.26	0.10	0.02	0.00	40.56	1.62	5.46	0.10
	November	0.90	0.15	415	74	1.21	0.19	0.16	0.04	0.01*	0.00	42.51	0.40	5.66	0.01

Table 17: Average (Avg) plant tissue concentrations of nutrients and COPCs in the three species of bulrush in the SSF cell of the Pittman Wetlands.

< # - all values in the average were below the detection limit.

* - ≥ 1 value in the average was below the detection limit and was set as the detection limit for the purpose of calculating the average.

n/a – not analyzed.

differences for POMO and CYDA, we compared them to all species collected in the SSF cell in May and November 2008 (n = 3 for POMO and CYDA, n = 6 for bulrush species). At 1.30 ±0.12 µg/g, POMO had significantly higher concentrations of As than all other species ($p < 0.001$), and CYDA had significantly higher concentrations of As than the bulrush species ($p \leq 0.006$) with 0.48 ±0.06 µg/g. No other significant relationships could be detected.

Tables 19 and 20 present the estimated storage of TN, TP, Se and As in the live, above-ground biomass of each bulrush species for which information was collected in the SSF and SF cells. In the SSF cell, SCAC provided the largest storage of nutrients while SCAM stored more Se; the two had the same average storage of As. In the SF cell, SCAM provided the largest storage of all constituents, and the SF cell had larger storage than the SSF.

Cell & Species	Year & Month	Avg TN%	±SE	Avg TP (µg/g)	±SE	Avg Se (µg/g)	±SE	Avg As (µg/g)	±SE	Avg Hg (µg/g)	±SE	Avg TC%	±SE	Avg TH%	±SE
SF		1.15	0.08	671	61	0.83	0.08	0.28*	0.03	0.02*	0.00	40.02	0.42	5.52	0.04
SCAC															
	2008														
	May	1.22	0.25	923	317	0.97	0.53	0.10	0.02	0.01	0.00	41.04	0.39	5.65	0.06
SCAM		1.31	0.11	710	77	0.94	0.10	0.35	0.05	0.02*	0.00	38.89	0.67	5.44	0.07
	2007	1.35	0.13	832	93	0.90	0.13	0.37	0.05	0.01*	0.00	n/a	n/a	n/a	n/a
	May	1.39	0.06	846	27	0.74	0.13	0.45	0.03	<0.01		n/a	n/a	n/a	n/a
	November	1.32	0.22	824	169	1.00	0.20	0.32	0.06	0.02	0.00	n/a	n/a	n/a	n/a
	2008	1.28	0.18	623	108	0.96	0.15	0.33	0.08	0.02	0.00	38.89	0.87	5.44	0.09
	May	1.00	0.26	524	207	0.69	0.16	0.35	0.17	0.02	0.00	38.98	1.02	5.39	0.10
	November	1.50	0.22	697	122	1.17	0.20	0.32	0.07	0.02	0.00	38.82	1.46	5.48	0.15
SCCA															
	2007														
	November	0.63	0.02	394	9	0.30	0.05	0.20	0.02	0.01	0.00	n/a	n/a	n/a	n/a
	2008	1.07	0.15	565	116	0.85	0.11	0.23*	0.04	0.02	0.00	40.83	0.82	5.56	0.08
	May	0.86	0.16	362	115	0.65	0.08	0.30	0.05	0.01	0.00	41.07	1.31	5.55	0.10
	November	1.28	0.19	767	116	1.05	0.12	0.16*	0.08	0.02	0.01	40.59	1.25	5.56	0.14

Table 18: Average (Avg) plant tissue concentrations of nutrients and COPCs in the three species of bulrush in the SF cell of the Pittman Wetlands. Data is shown only for sampling events where it was collected.

< # - all values in the average were below the detection limit.

* - ≥ 1 value in the average was below the detection limit and was set as the detection limit for the purpose of calculating the average.

n/a – not analyzed.

3.4.2.5 Discussion

There were clear differences in performance between the flow regimes and the bulrush species. The two regimes differed in percent cover by species, culm size, density, and percent dead. SCAM thrived in the SF cell, demonstrating significantly taller average height, biomass, and substantially higher cover than in the SSF cell. It also dominated the cover in the SF cell and expanded into deeper water areas (≥0.5 m) than would be expected for the species. While SCCA increased somewhat in cover in the SF cell, it never thrived in the SSF cell. This is likely due to hydrology (i.e., lack of surface water). SCAC underperformed in the SF cell and was effectively excluded from it by the end of the study. The species originally showed promise in the SSF cell, dominating in terms of average biomass, nutrient storage, height, and diameter, but by the end of the study, it had declined significantly. This can likely be attributed to storm damage. In August 2008, storm flows flattened the vegetation and impacted hydrology. The negative impacts can be seen in the November 2008 data, with the highest percent dead recorded for all species in the two-year period, the decline in cover and culm density for SCAC and SCAM, and the substantial decline in SCAC average height from spring. New SCAM shoots were observed coming through the flattened vegetation indicating recovery potential, but no new SCAC shoots were seen.

Average Se concentration was significantly higher in the SSF cell, but storage of Se, as well as TN, TP, and As were substantially higher in the SF cell due to its overall higher biomass and generally greater percentage of living material. SCAM once again outperformed the other bulrush, having significantly higher concentrations of TN, TP (versus SCCA-only), and Se.

Based on these results, SCAM was the most successful species on the site and surface flow was the most successful hydrologic regime.

3.4.3 Birds

No bird surveys were conducted at the Pittman Wetlands. However, we recorded several species anecdotally. Virginia rail, killdeer, and marsh wren nested within the site. Several others used the site for foraging, cover, or loafing, including mallard, ruddy duck, white-faced ibis, green heron, black-crowned night-heron, black-necked stilt, willet, Wilson's snipe, song sparrow, yellow-headed blackbird, and great-tailed grackle, among others.

Species	Year	Month	Avg Live Dry Wt (kg/m^2)	TN (g/m^2)	TP (g/m^2)	Se (mg/m^2)	As (mg/m^2)
SSF							
SCAC			1.08	10.97	0.48	0.43	0.29
	2007	May	1.26	14.27	0.47	0.53	0.35
		November	1.22	10.32	0.52	0.46	0.62
	2008	May	1.68	17.58	0.78	0.62	0.18
		November	0.15	1.71	0.17	0.12	0.03
SCAM			0.66	8.33	0.33	0.81	0.29
	2007	May	0.76	8.84	0.27	0.66	0.48
		November	1.02	12.56	0.55	1.25	0.48
	2008	May	0.54	6.93	0.32	0.51	0.10
		November	0.34	4.99	0.21	0.83	0.09
SCCA			0.58	5.13	0.20	0.43	0.18
	2007	May	0.84	8.25	0.28	0.59	0.31
		November	0.57	4.48	0.20	0.25	0.24
	2008	May	0.32	2.44	0.08	0.15	0.08
		November	0.59	5.36	0.25	0.72	0.09

Table 19: Storage of TN, TP, Se, and As in live biomass in the SSF cell of the Pittman Wetlands. Note that Se and As are reported in mg/m^2.

Species	Year	Month	Avg Live Dry Wt (kg/m^2)	TN (g/m^2)	TP (g/m^2)	Se (mg/m^2)	As (mg/m^2)
SF							
SCAM			2.01	25.54	1.44	1.77	0.72
	2007	May	1.80	24.87	1.52	1.33	0.80
		November	2.37	31.29	1.95	2.37	0.75
	2008	May	2.43	24.39	1.27	1.68	0.85
		November	1.45	21.61	1.01	1.69	0.46
SCCA							
	2007	November	0.42	2.67	0.17	0.13	0.09
	2008	May	1.43	12.27	0.52	0.93	0.42
		November	0.51	6.55	0.39	0.54	0.08

Table 20: Storage of TN, TP, Se, and As in live biomass in the SF cell of the Pittman Wetlands. Note that Se and As are reported in mg/m^2. SCAC was excluded due to limited live biomass and no concentration data was collected for SCCA in May 2007.

4.0 COMPARISON AND DISCUSSION OF THE PROJECTS

4.1 Water Quality

4.1.1 Nutrients

Organic nitrogen was the dominant form of nitrogen in the Demonstration Wetland. The wetland had 11 vegetated hummocks that provided an additional source of organic nitrogen in the wetland system; as vegetation senesced and attracted wildlife, detritus and other organic matter accumulated in the wetland. Increases in ammonia concentrations at the outlet may have been caused by ammonification of organic nitrogen to ammonia. While the Demonstration Wetland was not effective at reducing ammonia concentrations, reductions in both nitrate and nitrite were detected. Denitrification is the primary process by which nitrate is reduced to N_2 gas and requires anoxic conditions. Reduction of nitrates within the Demonstration Wetland suggests that vegetation requirements and redox conditions were suitable for the denitrification process.

Unlike nitrogen, there is no gaseous loss of phosphorus in wetland systems. It is either transformed and/or retained within the system (Reddy 2008). Accumulation of phosphorus depends on residence time within the wetland system. Generally, short-term accumulation occurs in vegetation and long-term shortage occurs in the soils (Reddy 2008). The Demonstration Wetland may have provided beneficial short term and long term removal of phosphorus, although retention time was not measured to calculate residence time within the wetland. Vegetation establishment was dramatic and offered substantial potential for phosphorus removal in plant tissue. A more complete analysis of phosphorus accumulation needs to include mass loading and soil storage within the wetland system.

Only nitrate concentrations were detected in the Pittman Wetlands system. Nitrate concentrations were similar between the inlet and outlet indicating that nitrate was not reduced in any substantial way. The Pittman Wetlands maintained high concentrations of DO throughout the year and this may have limited the role of nitrogen cycle processes. The relatively short residency time also may have limited nitrate removal.

In both instances, the Wash is, and could be, the receiving waters for these wetland projects. The beneficial use criteria for the Wash as listed in Nevada Administrative Code 445A.201 sets nitrite and nitrate standards at 10 and 100 mg/L respectively. Neither of the wetland projects examined had concentrations near the limit described for the Wash. TDS concentrations in the Demonstration Wetland were below the 3,000 mg/L beneficial use criteria for the Wash listed in Nevada Administrative Code 445A.201. A major concern regarding use of treatment wetlands is the potential increase in TDS, and while concentrations did increase at the outlet of the wetland system, the increase did not surpass the standard level.

4.1.2 Metals

Some metals are needed for biological activity in small amounts but can be harmful at high concentrations. Metals found in the Demonstration Wetland and the Pittman Wetlands mostly come from anthropogenic sources. However, local geology plays another role in the abundance and prevalence of some metal species. Geological characteristics can give rise to local concerns.

In the Valley, Se occurs naturally in the local geology and necessitates concern over its ability to accumulate and interfere in wildlife reproduction. Sediments can act as a source or sink for metals (Lesley et al. 2008), depending on the oxidation/reduction rates of the sediment as well as the soil pH (Miao et al. 2006). Sediment pH and redox strongly influence the water solubility of metals and nutrients (Miao et al. 2006). Miao et al. (2006) found that changes in soil pH and redox could alter the nutrient and metal exchange in the sediment and could increase iron, manganese, and phosphorus concentrations in the water column.

Chromium, vanadium, aluminum, Se, molybdenum, As, and barium were the only metals regularly detected in the Pittman Wetlands. Sources of these metals are commonly from geology and the combustion of fossil fuels. These parameters remained similar between sites and during the first year of sampling suggesting a consistent flow of metals through the system. The data indicate that the Pittman Wetlands did not reduce the metals. Similar conditions, reducing environments, are needed to remove or sequester metals as are needed for nutrient reductions from water. The Pittman Wetlands did not provide the necessary environmental or hydrological conditions needed to reduce metal concentrations. Increased residence time was likely needed to create suitable conditions for biochemical reactions that drive most water quality improvements.

The Demonstration Wetland was effective in sequestering most metals from the water column. Reductions were found in eleven metals with significant decreases in Se, copper and zinc. Increases in metal concentrations were slight except for manganese. A 40% increase was calculated in average manganese concentrations. Manganese is an essential trace element required for living organisms and can have a significant impact on ecological functions. Excessive concentrations of dissolved manganese can be toxic to plants, decrease the availability of plant nutrients through precipitation reactions and reduce microbial processes that regulate organic matter decomposition (Reddy 2008).

4.1.3 Conclusion

The Demonstration Wetland provided some water quality improvements through concentration reduction in nutrients and metals. Due to the ongoing changes to effluent quality, it was necessary to evaluate the data according to flow regime and treatment quality of effluent supplied to the wetland. Changes in effluent quality were detected in water quality trends, most noticeably in the ammonia dataset. Overall, nitrate and nitrite concentrations were significantly reduced during the study period, while ammonia concentrations increased, although there were some instances where ammonia decreased when compared on a monthly basis. Most concentrations of metals detected during the study decreased but only aluminum, chromium, copper, Se, and zinc showed significant decreases. Manganese significantly increased. Improvements in water quality were only detected at the Demonstration Wetland. No significant decreases in concentrations were measured at the Pittman Wetlands.

4.2 Vegetation

4.2.1 Average Culm Height, Diameter, Density, Percent Dead, Biomass, and Cover

There were several significant differences between the growth parameters of the two projects. Demonstration Wetland SCAC and SCCA culms were significantly taller and wider than culms from the SF and SSF cells ($p < 0.05$). However, SF cell SCAM was significantly taller than that of the Demonstration Wetland ($p < 0.05$) and not significantly different in diameter ($p > 0.05$).

Culm densities were significantly higher at the Demonstration Wetland for all species when compared to the SF cell, and were also higher than the SSF cell for SCAM ($p < 0.05$). Percent dead SCCA was significantly lower at the Demonstration Wetland than in the SSF cell ($p < 0.05$).

The Demonstration Wetland had significantly higher biomass than both Pittman cells ($p < 0.001$). Living biomass (Live Dry Wt; Tables 8, 19 and 20) at both sites appeared to be similar to that calculated by Acharya and Adhikari (2010), adjusting for the fact that they also included below ground plant material in their calculations. The biomass of bulrush species at the Demonstration Wetland was, as they reported, similar to those from very productive constructed wetlands.

SCAM represented the highest cover in both cells at the Pittman Wetlands, but accounted for only about 20% of the cover at the Demonstration Wetland, where SCCA was dominant, accounting for approximately 50% of the vegetative cover throughout the life of the project.

Differences in nutrients and salinity likely played a role in plant production and species performance between the two wetlands. Plants can take up large amounts of nutrients, increasing production and biomass (Krebs 1972, Cronk and Fennessy 2001). Consequently, biomass was highest at the Demonstration Wetland, where nutrients were available in higher concentrations than at the Pittman Wetlands. While SCCA dominated the lower salinity, nutrient-rich Demonstration Wetland, SCAM outperformed it in the higher salinity, lower nutrient environment of the Pittman Wetlands. SCAM occurs in brackish, as well as freshwater marshes, in soil salinities of 2-17 parts per thousand (ppt; Uchytil 1992) and is considered a halophyte (Aronson 1989). SCAC was outcompeted by SCAM in higher salinity environments in Utah (Esser 1995), and SCCA's salinity tolerance is just 0-6 ppt (USDA NRCS 2007).

4.2.2 Plant Tissue Concentrations of Nutrients and Contaminants of Potential Concern and Storage

The Demonstration Wetland had significantly higher concentrations of TN and TP ($p < 0.001$), while the Pittman Wetlands had significantly higher concentrations of As and Se ($p < 0.001$). The differences in concentrations between the two projects were expected given their respective inflow water quality. Stranger is the difference in seasonal patterns between the two wetlands. While the seasonal pattern was not significant in TP, averages were substantially higher in fall than in spring at Pittman, and Pittman SCAM had significantly higher Se concentrations in the fall than in the spring. Yet, at the Demonstration Wetland, TP was significantly higher in spring (as were Se and TN when comparing 2005-2008). Interestingly, Achyut and Adhikari (2010) reported higher Se concentrations in their winter samples (collected in late December, approximately one month after our fall samples) than in any other season for both projects. Likewise, they cited Pollard et al. (2007) as finding Se plant tissue concentrations to be higher in the culms in fall than in spring or summer at the Clark County Wetlands Park Nature Preserve. However, Achyut and Adhikari (2010) reported higher TP concentrations in their summer samples (collected in July, approximately 5-6 weeks after our spring samples) than any other season for both projects.

We examined nutrient, Se, and As storage in standing live material within both projects. Nutrient storage was substantially higher at the Demonstration Wetland, which was not surprising. However, given its massive living biomass, it also often had higher storage of Se and As than either cell at Pittman. Storage values for TN were typically lower than those calculated by Acharya and Adhikari (2010) for the Demonstration Wetland, which ranged from 135.7-170.2 g/m^2 TN, but were similar to those they reported for TP (6.6-16.0 g/m^2). Our values were also similar to those they reported for the Pittman Wetland, which ranged from 15.8-44.7 g/m^2 TN and 0.5-2.2 g/m^2 TP. Given that they also included storage in roots in their calculations, the proximity of our estimates is surprising. They found that the bulrush stores more TP in the roots than the shoots (culms) and more TN in the shoots than the roots, which opposes the differences in our calculations (TN values differing but TP values similar). Our nutrient storage values were within the range of the literature they cited.

4.3 Birds

As stated previously, the results from the Demonstration Wetland suggest that bird use of the site did not negatively impact wetland function, as nitrate and nitrite and average fecal coliforms all decreased. These results concur with other research at constructed wastewater treatment wetlands. Anderson et al. (2003) examined the effects of bird use on nutrient removal in a constructed wastewater treatment wetland in southern California (the project on which the Demonstration Wetland was based) and found that nutrient removal was best explained by water temperature rather than bird-loading. When the same research team examined the impact of different vegetation configurations via small test cells in Thullen et al. (2002), they found all configurations reduced total coliforms by 97%. Our fecal coliforms were reduced by a lesser percentage, but were still reduced significantly.

Since no quantitative data were collected at the Pittman Wetlands, the two projects cannot be rigorously compared; however, it can be said that each provided valuable habitat for birds. Monitoring at the Demonstration Wetland showed high species richness and abundance, and nesting by several species. Despite its small size, we anecdotally recorded several species at the Pittman Wetlands, some of which nested and others that foraged, loafed, or found cover there.

5.0 MANAGEMENT RECOMMENDATIONS

We have several recommendations for the management of constructed wetlands systems in southern Nevada as a result of our research.

We examined nutrient, Se and As storage in standing live plant material within both projects. However, bulrush detritus stores a tremendous amount of nitrogen and phosphorus before it decomposes and releases it back into the water (J.S. Thullen, unpublished data). It also stores more Se and As than live culms (J.S. Thullen, unpublished data). This should be considered when determining if and when in a constructed wetlands' lifetime, above-ground vegetation should be harvested in order to remove nutrients and/or COPCs. Timing of maximum tissue concentration for the target nutrient and/or COPCs should also be taken into consideration, where applicable. A balance between maximum biomass, percent dead culms, and maximum tissue concentration may yield the best results. Another issue to consider is cost. In our Demonstration Wetland experiment, harvesting was expensive, costing ~$2.83/kg (wet weight) of vegetation removed. While costs were likely increased because of having to transport the cut material by a small boat, increasing labor costs, this is still excessive. In the future, prescribed burning should be explored as a potential alternative.

Certain species appear better suited for use in constructed wetlands projects, depending on the targeted nutrient or COPC. Due to its high biomass and storage potential in nutrient-rich environments, SCCA is our recommended species for use in constructed wetlands for removal of TP and TN from wastewater effluent, as long as salinities are similar to the Demonstration Wetland and the project has a surface flow hydrologic regime. Although the species was negatively impacted from harvesting at first, it rebounded fully within eight months.

TYDO also showed some promise for use in constructed wetlands. Although we only sampled it at Pittman in 2008, its average tissue concentrations of TP exceeded SCAM and SCCA by more than 400 μg/g, and concentrations of TN were not significantly different. TYDO is the most common emergent in the Valley's tributaries, and it readily volunteers on sites, as it did here. However, it should be noted that although average concentrations of TYDO did not differ significantly for Se and As, they were lower than SCAM and given the low sample size, statistical power was not strong.

SCAM demonstrated potential for use in constructed wetlands to treat urban runoff. The species' thrived in the higher salinity of the Pittman Wash and had higher concentrations of Se (significant) and As at Pittman, which was also found by Acharya and Adhikari (2010). It performed very well in the SF cell, with significantly greater biomass and a lower percentage of dead culms than in the other cell, and it outperformed the other species. However, there were issues with SCAM. At all our sites, it developed high percentages of dead material, typically having the highest percentage of any species. By November 2007, just eight months after planting, both Pittman cells had at least 40% dead material.

While POMO and CYDA had significantly higher As concentrations than all bulrush species, given their low biomass, they are likely not suited for deliberate inclusion in a treatment wetland. Rather, if they volunteer, such as they did in our project, they can be left in place and removed with the target vegetation if and when the decision is made to harvest.

As for the value of future projects of the types researched here, depending on the desired nutrient reductions, a project like the Demonstration Wetland could be useful, and as mentioned above, SCCA would likely offer the most benefit. In regards to the Pittman project, the challenges of operating a highly designed constructed wetland in an urban flood control channel were found to be high and may be prohibitive. It requires not only a significant commitment in the form of upfront costs, but also in long-term maintenance. It is our recommendation following the Pittman Wetlands project, that if tributary treatment wetlands are considered again in the future, either off-channel locations should be selected, or the wetlands should be more natural-state and low maintenance (i.e., leaving TYDO in place, encouraging its expansion, and removing it during annual flood control operations). SCAM would be the most beneficial bulrush species to use in more actively managed projects. In regards to flow regime, we recommend surface flow hydrology for any future project, given the significantly higher biomass and nutrient, Se and As storage. Additionally, cell size should be increased. The Pittman cells at just 0.02 ha each were insufficient to improve water quality. Although targeting wastewater effluent, Thullen et al. (2002) were able to achieve water quality improvements using 0.1-ha research cells, demonstrating this as a possible minimum size for future projects.

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Appendix A

Average Annual Abundance for Bird Species Detected at the Demonstration Wetland

Species	Y1 (n=33)	Y2 (n=26)	Y3 (n=19)	Y4 (n=18)	Y5 (n=22)
Northern Shoveler	81.91	109.27	99.11	90.83	72.41
American Coot	45.82	62.19	59.05	59.61	32.09
Ruddy Duck	40.21	40.15	43.68	29.06	28.73
Great-tailed Grackle	22.64	38.38	17.21	13.44	9.05
Mallard	14.36	10.92	12.11	15.33	25.64
Green-winged Teal	12.09	7.35	11.79	13.78	10.45
Ring-Billed Gull	10.27	7.50	8.89	9.28	1.86
Eared Grebe	8.48	3.23	6.37	6.11	3.27
Swallow sp.	5.91	1.54	0.16	4.44	0.23
American Avocet	4.58	4.31	5.11	4.44	3.14
Common Gallinule	4.18	14.23	11.95	11.83	7.27
Red-Winged Blackbird	4.00	9.65	1.32	2.83	3.73
Yellow-Headed Blackbird	3.70	4.38	6.68	9.22	2.32
Gadwall	3.61	2.88	10.21	5.78	4.23
Black-Necked Stilt	3.18	6.04	4.05	3.00	2.73
Bufflehead	2.82	3.23	1.63	1.72	1.41
Cinnamon Teal	2.76	5.27	3.37	6.44	8.82
Yellow-rumped Warbler	2.73	7.15	2.68	3.17	3.82
Pied-Billed Grebe	2.61	3.27	6.58	5.61	4.09
Redhead	2.36	5.96	7.63	6.56	4.41
White-Faced Ibis	2.30	3.12	0.42	1.39	2.50
Long-Billed Dowitcher	1.91	1.35	1.11	4.72	0.77
Least Sandpiper	1.61	1.27	0.16	0.28	0.18
Northern Rough-Winged Swallow	1.48	0.08	-	1.56	1.86
Greater Yellowlegs	1.33	-	-	0.28	0.50
Mourning Dove	1.18	0.58	0.26	0.33	0.50
Snowy Egret	1.12	1.12	0.58	0.50	0.91
Killdeer	1.09	1.88	1.42	1.28	2.14
Marsh Wren	0.94	1.58	3.89	6.67	9.05
Brown-Headed Cowbird	0.67	0.77	0.21	0.17	0.18
Lesser Scaup	0.64	0.54	1.00	0.56	0.23
Great Egret	0.58	0.73	0.42	0.33	0.14
Ring-Necked Duck	0.58	6.04	12.05	1.33	0.32
American Wigeon	0.55	0.54	0.42	0.33	0.45
Northern Harrier	0.42	0.15	0.37	0.33	0.18
Blue-Winged Teal	0.39	0.04	-	0.11	0.18
Black Phoebe	0.36	0.12	0.16	0.17	0.05
Northern Pintail	0.36	0.73	0.37	0.33	0.50
Common Goldeneye	0.33	-	0.05	0.28	-
Pectoral Sandpiper	0.33	-	-	-	-
Western Meadowlark	0.33	-	-	0.06	-

Lesser Yellowlegs	0.30	0.04	-	-	0.09
Snow Goose	0.30	-	0.32	-	-
Gambel's Quail	0.24	0.88	0.16	1.67	2.00
Canvasback	0.18	-	0.53	-	-
Double-Crested Cormorant	0.15	0.04	0.16	-	0.36
Sora	0.15	0.31	0.32	0.11	0.45
American Pipit	0.12	0.15	-	0.11	0.05
California Gull	0.12	-	-	-	-
Caspian Tern	0.12	-	-	-	-
Belted Kingfisher	0.09	-	-	-	-
Black-Crowned Night-Heron	0.09	2.50	3.84	0.61	1.50
Bonaparte's Gull	0.09	-	0.05	-	-
Canada Goose	0.06	0.19	0.84	1.67	2.91
Cattle Egret	0.06	0.08	0.32	0.06	0.14
Great Blue Heron	0.06	0.27	0.11	0.06	0.05
Say's Phoebe	0.06	-	-	-	-
Violet-Green Swallow	0.06	-	-	-	0.45
Western Grebe	0.06	-	0.26	0.17	0.23
Wood Duck	0.06	0.12	0.68	0.17	0.14
Yellow Warbler	0.06	-	-	-	-
American Kestrel	0.03	-	-	0.06	0.05
Bank Swallow	0.03	-	0.11	-	0.05
Brewer's Blackbird	0.03	0.08	0.11	-	-
Common Tern	0.03	-	-	-	-
Franklin's Gull	0.03	0.23	0.11	-	-
Greater Roadrunner	0.03	-	0.11	0.06	0.23
Least Bittern	0.03	0.23	0.26	0.22	0.86
Peregrine Falcon	0.03	-	0.05	-	-
Red-Tailed Hawk	0.03	-	-	-	-
Ruby-Crowned Kinglet	0.03	-	-	0.06	-
Sharp-Shinned Hawk	0.03	-	-	0.06	-
Song Sparrow	0.03	0.50	0.68	0.56	0.45
Spotted Sandpiper	0.03	0.15	-	-	-
Turkey Vulture	0.03	0.04	-	0.06	0.36
Virginia Rail	0.03	0.27	1.26	0.78	1.05
Western Sandpiper	0.03	0.58	-	-	-
Western Tanager	0.03	-	-	-	-
Wilson's Phalarope	0.03	1.96	0.37	-	0.23
Abert's Towhee	-	-	0.11	-	0.14
American Bittern	-	-	-	-	0.05
American White Pelican	-	0.04	0.11	-	-
Barn Swallow	-	-	8.00	-	0.91
Black Tern	-	0.08	-		0.18

Black-Chinned Hummingbird	-	-	-	-	0.05
Black-Tailed Gnatcatcher	-	0.04	-	0.06	0.05
Clark's Grebe	-	0.12	-	-	-
Cliff Swallow	-	0.19	2.32	0.28	
Common Yellowthroat	-	0.12	0.21	-	0.23
Forster's Tern	-	-	0.05	-	-
Greater Scaup	-	0.04	0.05	0.06	-
Green Heron	-	0.27	0.37	0.44	0.68
Hooded Merganser	-	-	-	-	0.09
Horned Grebe	-	-	0.05	0.11	-
House Finch	-	-	-	0.11	-
Lincoln's Sparrow	-	0.35	0.11	-	0.09
Long-Billed Curlew	-	-	0.05	-	0.05
Marbled Godwit	-	-	0.37	-	-
Northern Flicker	-	-	-	0.06	-
Orange-Crowned Warbler	-	0.08	0.21	0.06	0.05
Rock Pigeon	-	-	-	-	0.05
Savannah Sparrow	-	-	-	0.11	0.05
Tree Swallow	-	-	3.58	-	1.36
Verdin	-	-	0.05	0.28	0.45
Western Kingbird	-	0.12	-	-	-
White-Crowned Sparrow	-	1.27	0.26	0.44	0.73
Willet	-	0.04	1.37	1.33	-
Wilson's Snipe	-	-	0.05	0.06	-

Appendix B

Average Non-Breeding Season Abundance for Bird Species Detected at the Demonstration Wetland

Species	Y1 (n=13)	Y2 (n=8)	Y3 (n=7)	Y4 (n=8)	Y5 (n=8)
Northern Shoveler	191.85	206.75	261.14	197.88	152.38
Ruddy Duck	51.08	55.25	56.86	33.63	34.88
American Coot	42.08	47.75	36.71	56.75	26.38
Green-winged Teal	29.77	22.88	31.71	28.75	24.50
Ring-Billed Gull	21.31	7.13	21.29	20.13	4.25
Mallard	15.69	6.50	14.43	9.50	15.63
Great-tailed Grackle	10.23	16.63	7.00	3.50	6.63
Swallow sp.	10.00	-	-	6.25	0.63
Eared Grebe	9.00	4.88	6.00	5.50	3.00
Gadwall	7.31	7.25	22.29	9.88	7.00
Red-Winged Blackbird	6.92	25.63	2.00	1.88	6.63
Yellow-rumped Warbler	6.77	20.25	6.71	6.75	8.88
Bufflehead	6.46	7.25	4.14	3.75	2.13
Common Gallinule	5.38	16.88	17.43	15.38	8.88
Pied-Billed Grebe	4.69	5.50	10.43	7.75	7.00
Cinnamon Teal	3.00	5.88	2.71	6.38	5.50
American Avocet	2.62	0.63	-	-	1.50
Least Sandpiper	2.38	-	-	0.13	-
Greater Yellowlegs	2.00	-	-	0.25	0.88
Long-Billed Dowitcher	1.92	-	-	0.88	0.25
White-Faced Ibis	1.69	1.38	-	-	-
Redhead	1.62	4.13	3.14	1.00	0.75
American Wigeon	1.38	1.63	1.00	0.38	0.88
Ring-Necked Duck	1.23	17.25	32.00	2.75	-
Snowy Egret	1.15	1.38	0.57	0.63	0.25
Lesser Scaup	1.00	1.38	2.29	1.00	-
Northern Harrier	1.00	0.50	0.71	0.63	0.38
Northern Pintail	0.92	0.63	0.71	0.50	1.25
Great Egret	0.85	1.13	0.57	0.25	0.13
Western Meadowlark	0.85	-	-	0.13	-
Pectoral Sandpiper	0.77	-	-	-	-
Snow Goose	0.77	-	0.86	-	-
Marsh Wren	0.69	2.50	2.71	4.00	6.00
Killdeer	0.62	0.25	-	0.50	0.50
Mourning Dove	0.46	-	0.43	-	-
Black Phoebe	0.38	0.25	0.29	0.25	0.13
Common Goldeneye	0.38	-	0.14	0.25	-
Double-Crested Cormorant	0.38	0.13	0.14	-	0.25
American Pipit	0.31	0.50	-	0.25	-
Northern Rough-Winged Swallow	0.31	-	-	-	-
Black-Necked Stilt	0.23	-	-	-	-

Canvasback	0.23	-	1.43	-	-
Sora	0.23	0.25	0.57	-	0.63
Gambel's Quail	0.15	-	-	0.13	4.13
Violet-Green Swallow	0.15	-	-	-	-
Wood Duck	0.15	0.38	1.71	0.38	0.25
Yellow-Headed Blackbird	0.15	-	-	-	-
American Kestrel	0.08	-	-	-	0.13
Belted Kingfisher	0.08	-	-	-	-
Black-Crowned Night-Heron	0.08	7.38	9.57	0.88	3.88
Brewer's Blackbird	0.08	0.25	-	-	-
Greater Roadrunner	0.08	-	-	-	-
Lesser Yellowlegs	0.08	-	-	-	0.25
Peregrine Falcon	0.08	-	0.14	-	-
Red-Tailed Hawk	0.08	-	-	-	-
Ruby-Crowned Kinglet	0.08	-	-	0.13	-
Song Sparrow	0.08	1.38	0.86	1.13	1.00
Western Sandpiper	0.08	-	-	-	-
Abert's Towhee	-	-	0.29	-	-
American Bittern	-	-	-	-	0.13
Black-Chinned Hummingbird	-	-	-	-	0.13
Black-Tailed Gnatcatcher	-	0.13	-	0.13	0.13
Canada Goose	-	-	1.00	2.00	1.75
Cattle Egret	-	-	0.14	-	0.25
Cliff Swallow	-	-	-	0.63	-
Great Blue Heron	-	0.50	-	-	0.13
Greater Scaup	-	0.13	0.14	-	-
Green Heron	-	0.25	0.29	0.63	0.63
Hooded Merganser	-	-	-	-	0.25
House Finch	-	-	-	0.25	-
Least Bittern	-	0.13	-	0.25	0.88
Lincoln's Sparrow	-	1.13	0.29	-	0.25
Northern Flicker	-	-	-	0.13	-
Orange-Crowned Warbler	-	0.25	-	0.13	-
Savannah Sparrow	-	-	-	0.13	0.13
Sharp-Shinned Hawk	-	-	-	0.13	-
Tree Swallow	-	-	-	-	1.25
Turkey Vulture	-	-	-	0.13	-
Verdin	-	-	0.14	0.38	0.13
Virginia Rail	-	0.75	1.71	1.25	2.00
Western Grebe	-	-	0.14	0.13	0.13
White-Crowned Sparrow	-	4.13	0.29	1.00	1.88

Appendix C

Average Breeding Season Abundance for Bird Species Detected at the Demonstration Wetland

Species	Y1 (n=16)	Y2 (n=12)	Y3 (n=9)	Y4 (n=9)	Y5 (n=9)
American Coot	51.94	59.00	78.33	63.78	41.00
Great-tailed Grackle	40.75	50.58	26.11	24.11	13.89
Ruddy Duck	38.94	28.92	36.78	27.67	27.67
Eared Grebe	9.00	2.25	7.78	6.89	4.11
American Avocet	8.00	6.58	9.78	10.67	2.67
Black-Necked Stilt	7.69	11.25	6.33	9.22	2.89
Mallard	5.06	16.00	12.00	30.00	31.22
Redhead	5.06	7.00	13.44	11.78	8.44
Common Gallinule	4.38	11.25	7.22	6.22	6.00
Ring-Billed Gull	3.56	0.58	0.89	0.56	0.56
Yellow-Headed Blackbird	3.00	-	12.22	10.56	1.22
Cinnamon Teal	2.31	4.42	5.44	7.33	9.67
Red-Winged Blackbird	2.31	0.67	2.33	2.33	1.22
Killdeer	1.44	3.50	2.22	2.89	3.56
White-Faced Ibis	1.31	4.25	0.44	7.33	0.44
Northern Shoveler	1.13	1.42	0.56	1.44	12.11
Pied-Billed Grebe	1.13	1.92	2.67	2.00	1.67
Snowy Egret	1.13	0.42	0.89	0.33	1.22
Great Egret	1.00	0.08	0.11	0.33	0.11
Long-Billed Dowitcher	0.88	0.83	1.89	9.56	-
Blue-Winged Teal	0.81	0.08	-	0.22	-
Marsh Wren	0.81	1.25	5.78	9.22	14.11
Gambel's Quail	0.69	1.00	0.22	1.67	0.22
Mourning Dove	0.69	0.58	0.33	0.44	1.22
Least Sandpiper	0.63	2.67	0.78	0.33	
Lesser Scaup	0.50	-	0.33	0.56	0.11
Brown-Headed Cowbird	0.44	1.83	0.22	0.22	0.33
California Gull	0.25	-	-	-	-
Caspian Tern	0.25	-	-	-	-
Common Goldeneye	0.25	-	-	0.33	-
Gadwall	0.25	0.58	2.22	2.56	3.44
Black-Crowned Night-Heron	0.19	0.08	0.22	0.22	0.22
Bonaparte's Gull	0.19	-	0.11	-	-
Bufflehead	0.19	-	-	0.11	0.33
Cattle Egret	0.19	0.17	0.33	-	-
Great Blue Heron	0.19	-	-	0.11	-
Green-winged Teal	0.19	0.08	0.22	-	2.11
Least Bittern	0.19	0.33	0.33	0.22	0.89
Sora	0.19	0.33	-	0.22	0.33
Black Tern	0.13	-	-	-	-
Canada Goose	0.13	0.17	0.89	1.56	4.00

Spotted Sandpiper	0.13	0.25	-	-	-
Black Phoebe	0.06	-	0.11	-	-
Franklin's Gull	0.06	0.42	0.22	-	-
Greater Yellowlegs	0.06	-	0.11	0.33	-
Wilson's Phalarope	0.06	-	0.78	2.44	-
Abert's Towhee	-	-	-	-	0.33
American Pipit	-	-	-	-	0.11
American Wigeon	-	0.08	0.22	0.22	0.33
Bank Swallow	-	-	0.22	0.11	
Barn Swallow	-	-	4.67	0.44	2.22
Clark's Grebe	-	0.08	-	-	-
Cliff Swallow	-	0.42	1.56	-	-
Common Yellowthroat	-	0.17	0.44	-	0.56
Double-Crested Cormorant	-	0.08	-	0.33	0.11
Forster's Tern	-	-	0.11	-	-
Greater Roadrunner	-	0.17	-	0.11	0.44
Greater Scaup	-	-	-	0.11	-
Green Heron	-	0.42	0.33	0.44	0.44
Horned Grebe	-	-	0.11	0.22	-
Lesser Yellowlegs	-	0.08	-	-	-
Long-Billed Curlew	-	-	0.11	-	0.11
Marbled Godwit	-	-	0.78	-	-
Northern Harrier	-	-	0.22	-	0.11
Northern Pintail	-	1.08	0.11	0.33	-
Northern Rough-Winged Swallow	-	0.17	-	3.33	4.33
Orange-Crowned Warbler	-	0.25	-	-	-
Ring-Necked Duck	-	0.67	0.22	0.22	0.78
Song Sparrow	-	0.25	0.11	0.11	0.22
Swallow sp.	-	0.08	3.67	-	-
Tree Swallow	-	0.08	3.11	-	0.56
Turkey Vulture	-	-	-	-	0.89
Verdin	-	-	-	0.33	0.89
Virginia Rail	-	0.17	0.44	0.56	0.44
Western Grebe	-	1.25	0.11	0.56	-
Western Kingbird	-	4.67	-	-	-
Western Sandpiper	-	0.08	-	-	-
Willet	-	7.17	2.89	-	-
Wilson's Snipe	-	-	-	0.11	-
Wood Duck	-	-	0.11	-	0.11
Yellow-rumped Warbler	-	-	0.11	-	0.89