Title
Impacts of Delayed Drawdown on Aquatic Biota and Water Quality in Seasonally Managed Wetlands of the Grasslands Ecological Area

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Impacts of Delayed Drawdown on Aquatic Biota and Water Quality in Seasonally Managed Wetlands of the Grasslands Ecological Area

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ABSTRACT

The 178,000-acre Grassland Ecological Area in California's San Joaquin Valley is managed to provide overwintering habitat to waterfowl on the Pacific Flyway. The major management activity is the fall flooding and spring drawdown of wetlands, timed to optimize the availability of forage vegetation and invertebrates for ducks and shorebirds. Wetland drainage contains salt, boron, and trace elements that are largely derived from imported surface water but concentrate during storage in the wetland impoundments and contribute to occasional water quality violations in the San Joaquin River (SJR) during dry years. Compliance with water quality objectives may be improved by timing wetland drawdown to coincide with high SJR salt assimilative capacity during mid-March to mid-April when reservoir releases are increased to aid salmon migration.

The experimental sites chosen were three pairs of matched wetland basins (20-100 acres each) that are part of the larger Modified Hydrology Study. For each wetland pair, one was managed with a traditional March drawdown; while the drawdown was delayed up to one month for the other to coincide with the period of high SJR assimilative capacity. Two additional drainage sites were added to the second year of sampling to better characterize drainage flowing to the SJR. Soil and water column samples were collected during the flooded periods at the inlets, outlets, and along transects within the wetlands. Water quality analyses included total/volatile suspended solids, conductivity, nitrogen (NH4+, NO2-+NO3-, organic), phosphorus (total, $PO4^{3-}$), total organic carbon, alkalinity, turbidity, temperature, and pH. Planktonic and benthic invertebrates were identified and enumerated. Data were collected between February and April in 2007 and again in 2008.

Identified phytoplankton were predominantly chlorophytes and diatoms. Zooplankton that feed on phytoplankton were found in abundance and consisted mostly of Cladocera. Benthic invertebrate densities were also measured to help explain the differences in algal concentrations between ponds. Benthic invertebrates were found to be predominantly *Chironomidae*.

Seasonal loads of volatile suspended solids, total dissolved solids, and total organic carbon were estimated at the two aggregate drainage sites and at one delayed drawdown wetland during the 2008 season. For volatile suspended solids, the discharged load was 1500 lbs at the Buttonwillow drainage site, 2500 lbs at the Los Banos 38 drainage site, and upstream of those sites, 770 lbs were discharged from the Mud Slough 4b wetland. For total dissolved solids, the discharged load was 293 tons, 524 tons, and 26 tons, respectively, for the same locations.

Of the factors potentially limiting phytoplankton concentrations, invertebrate grazing was likely the most important. Nutrients were not limiting in either the traditional or modified wetlands, as indicated by sufficient N and P content in the algae biomass. Likewise, inorganic C was not limiting, as indicated by pH (most <9.0 pH). Sunlight intensity was not significantly attenuated by water depth or turbidity, and thus light limitation was not indicated.

ACKNOWLEDGEMENTS

This report is largely derived from the MS thesis research of Kyle Poole who was employed at UC Merced under funding from the UC Salinity Drainage Program. The original idea to investigate impacts of delayed wetland drawdown on algae and other aquatic biota was Tryg Lundquist's who helped to write the research proposal while a graduate research associate at Berkeley National Laboratory in the HydroEcological Advanced Decision Support (HEADS) Group. This research project was conceived as an extension to a large State Water Resources Control Board Project to improve wetland salinity drainage load management and a CALFED funded study to look at the biological consequences of adopting delayed drawdown practices. When Dr Lundquist graduated and took a Faculty position at California State Polytechnic University, San Luis Obispo he continued his involvement in the project and provided laboratory support to Kyle Poole. Other equipment, not acquired for the project, was supplied by the HEADS research group at Berkeley National Laboratory.

The study team would like to acknowledge the generous support of the UC Salinity Drainage Program for funding the project and the cooperation of the Grassland Water District and the California Department of Fish and Game. Special thanks to Ric Ortega, John Beam, Bill Cook and Lara Sparks for their assistance in project design and their review and helpful comments on the draft project report.

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CHAPTER 1: INTRODUCTION

The 178,000-acre Grassland Ecological Area (GEA) in California’s San Joaquin Valley provides over-wintering habitat to waterfowl on the Pacific Flyway, a 10,000 mile migratory pathway from Alaska to South America (Grassland 2008). Wetlands in the GEA are home to millions of waterfowl and shorebirds, a diverse community of moist-soil vegetation, and other common and endangered wildlife (Mason, 1969; Cogswell, 1977; Grassland Water District, 1986). Wetlands in this area are a component of the Western Hemisphere Shorebird Reserve Network and are now internationally recognized for their importance to shorebirds (Grassland 2008). However, discharge from these wetlands contributes to water quality concerns downstream, which hinder populations of other aquatic wildlife.

The San Joaquin River (SJR) has been listed as an impaired water body by the California Water Quality Control Board. Pollutants of concern include salinity and biochemical oxygen demand BOD. These pollutants can be detrimental to aquatic wildlife and agricultural uses downstream. A potential source of salinity and BOD are managed seasonal wetlands of the Central Valley. These managed seasonal wetlands receive the largest portion of their annual water supply from the Sacramento-San Joaquin Delta – a water supply that is elevated in salinity. During the late fall and winter seasons direct evaporation from the wetlands and evapotranspiration from emergent moist soil plants further concentrates these salts. Decaying algae, respiring algae, detritus and ammonia discharged from the wetlands contribute to BOD downstream. Real-time management of annual drainage discharges from seasonal wetlands has been proposed as one means of improving water quality conditions in the San Joaquin River during sensitive periods for downstream irrigators such as during agricultural crop germination. An equitable balance needs to be developed between actions to minimize water quality impacts on the SJR and actions necessary to maintain the essential function of managed seasonal wetlands as wildlife habitat.

One proposed real-time management scheme is to improve scheduling of drawdown from seasonal wetlands to coincide with reservoir releases into the SJR – especially during dry seasons, when water pollution concerns are greatest. Reservoir releases are made during the VAMP (Vernalis Adaptive Management Program) period (April 15 – May 15) to aid the migration of anadromous fish such as salmon. During these periods significantly more water flows into and along the river increasing the River’s assimilative capacity for salinity and BOD. The secondary impacts of these modifications to wetland hydrology and ecology are largely unknown.

This project supplements a much larger scale, multi-year Modified Hydrology Study led by multiple institutions that is studying the impacts of delayed wetland drawdown on water quality, moist soil plant productivity, and wetland ecology. The current project attempts to quantify the rate of algae biomass increase during the delayed drawdown period and determine the factors that affect final algae biomass concentrations at selected sites within the study area.

Delaying wetland drawdown is one of several practices available to better manage salt in the SJR - the true merit needs to be assessed by measuring the direct and indirect secondary impacts of its implementation at all levels of the wetland ecosystem. Along with other information from a State Water Resources Board study (Quinn, 2005) and associated CALFED-sponsored Modified Hydrology Study (Ortega, 2006) the current project will lead to an improved understanding of the consequences of delayed drawdown on wetland water quality and aquatic biota. A consequence could be a set of guidelines as to where and when delayed seasonal wetland drawdown might be employed with minimal risk to wetland habitat resources and associated river ecosystems.

CHAPTER 2: BACKGROUND

2.1 San Joaquin River Water Quality

The San Joaquin River (SJR) has been listed by the California Water Quality Control Board (CWQCB) as an impaired water body. Pollutants contributing to water quality problems include mercury, metals, pesticides and salinity. In addition, one of the most important water quality problems is the intermittent low dissolved oxygen (DO) within the San Joaquin River Deep Water Ship Channel (DWSC) near Stockton. These low DO periods can inhibit anadromous fish migration – salmon are thought to require a dissolved oxygen concentration of at least 6 mg/l for optimal health. Among the major factors contributing to the DO sags are transport of oxygen-consuming substances from the upper SJR into the DWSC. These substances, together measured as biochemical oxygen demand (BOD), include detritus, respiring and decaying phytoplankton, and ammonia. The factors contributing to low DO become critical during periods of low flow and warm weather (SJVDA 2003).

Approximately 10% of the SJR's annual flow and up to 30% of its annual salt load, as measured at the Vernalis compliance monitoring station passes through wetlands within the Grasslands Basin, which includes the Grassland Water District (Grober et al., 1995; Quinn et al., 1997; Quinn and Karkoski, 1998). Despite the major habitat importance and the influential salt discharge of the wetland refuges, few studies have considered how management for decreased salinity in the SJR might affect the wetland habitat and other water quality constituents in wetland drainage such as phytoplankton concentrations.

The CRWQCB has encouraged water contracting agencies such as Reclamation to promote salinity management schemes including timed discharges, real-time monitoring, and source control for all agricultural and wetland dischargers of salt to the SJR. To date, Grassland Water District and Berkeley National Laboratory have developed the only pilot system capable of meeting the CRWCB definition of real-time wetland monitoring and management. A large multi-agency, cross-disciplinary study on six paired wetlands in Grassland Water District and in the Los Banos Wildlife Management Area has been active since 2005. This study implemented a modified schedule of discharges from one of the paired wetlands at each study site. Monitoring of influent and effluent flow and water quality was performed to develop salinity budgets and remote sensing techniques developed to measure impacts of the modified wetland hydrology on soil salinity and the abundance of certain moist-soil plant associations that provide important waterfowl overwintering habitat. The pilot study focuses on individual ponds ranging in area from 20 acres to 100 acres allowing more intensive monitoring and improving the ability to make realistic water and salinity balances. Concerns have been raised by several wetland managers that promotion of delayed drawdown practices, while improving salinity conditions in the SJR, could lead to irrecoverable changes to the wetland landscape and a potential loss of function in these wetlands as an overwintering sanctuary for waterfowl.

2.2 Real Time Water Quality Management

The San Joaquin River Management Program (SJRMP) was conceived in 1990 as a stakeholder group dedicated to improving flow, water quality and the riparian ecology of the San Joaquin River. One of the SJRMP's mandates was to reconcile and coordinate the various uses and competing interests along the river. Real-time water quality management (RTWQM) was a proposal that was championed and further developed by SJRMP in association with Berkeley National Laboratory, the California Department of Water Resources and the Regional Water Quality Control Board (Grober et al., 1995; Quinn et al., 1997; Quinn and Karkoski, 1998). The basic concept of RTWQM is that by coordinating Sierra reservoir releases with west-side drainage releases, river water quality could be improved for the benefit of migrating fish, south Delta irrigators, and other riparian users.

Recognizing that adaptive seasonal wetland drainage management had potential as component of a comprehensive program of manipulating west-side drainage to coincide with SJR salt assimilative capacity - Berkeley National Laboratory was successful in obtaining a number of consecutive research grants to further explore the concept. Increased surface water allocations under the Central Valley Project Improvement Act have provided opportunities for increased coordination between agencies as well as a need to address salt and boron water quality issues, given the additional imported salt loads associated with the more reliable wetland water supply. Although manipulation of wetland drainage schedules include both earlier drainage release (followed by subsequent re-flooding) as well as delayed drawdown – delayed drawdown was chosen as the easier scenario to explain and to implement in practice. Early drawdown and re-filling also requires additional water supply – water supply can be constrained during dry and critically dry years. From an experimental point of view the impacts of an earlier drawdown may be more difficult to quantify – especially during wet years when pond evaporation losses are low.

The delayed drawdown scenario chosen required wetland drainage to occur after April 15 at a time when the VAMP purchases water supply from east-side water districts to provide steady and consistent river flows annual in support of salmon migration. The typical result of these releases is a significant increase in salt assimilative capacity at the Vernalis compliance monitoring station.

2.3 Grasslands Basin Seasonal Wetlands

Preservation and enhancement of wetlands in California's Central Valley is important to ensuring wildlife and habitat diversity. The regional wetlands are home to millions of waterfowl and shorebirds, a diverse community of moist-soil vegetation, and other common and endangered wildlife (Mason, 1969; Cogswell, 1977; Grassland Water District, 1986). The 178,000-acre Grassland Ecological Area in California's San Joaquin Valley provides over-wintering habitat to waterfowl on the Pacific Flyway, a 10,000 mile migratory pathway from Alaska to South America (Grassland 2008). Within the Grassland Ecological Area is the Grassland Resource Conservation District (Grassland RCD) near Los Banos, CA.

Figure 2-1: A flock of Canada geese taking flight near Buttonwillow Lake in the Los Banos Wildlife Management Area.

The Grassland RCD is composed of approximately 75,000 acres of private hunting clubs, private owned land, and state and federal refuges. As many as 30% of California's Central Valley wintering ducks use this area, and it is ranked by the U.S. Fish and Wildlife Service as the most important wetland complex in the San Joaquin Valley. Wetlands of the Grasslands RCD are a component of the Western Hemisphere

Shorebird Reserve Network and are now internationally recognized for its importance to shorebirds (Grassland 2008).

2.4 Bird Species and Forage

Migrating waterfowl within the Grassland Ecological Area include Canada geese (Figure 2-1), cinnamon teal, mallard, and northern pintail. Besides these migrating waterfowl the wetlands also host year-around populations of songbirds, egrets, and raptors, in addition to mammals and many other animals. Invertebrates are important food for ducks, shorebirds, songbirds, and others. Invertebrate populations, in turn, depend in large part on the production and type of algae available for their diets. Increased phytoplankton concentrations can lead to increased densities of zooplankton which are, in turn, eaten by bird forage organisms such as fish and predatory midge larvae (*Chaoborus*) (Horne and Goldman, 1994). Midge larvae (*Chironomus*), which feed directly on phytoplankton however, are likely to be the most abundant invertebrate bird forage to be affected by any changes in phytoplankton concentrations.

2.5 Wetland Management

Wetlands are intensively managed to produce crops of moist-soil food plants and invertebrates that have high value to wildlife, particularly waterfowl. Best management practices (BMPs) have been developed to achieve these goals. These BMPs can include grading, discing, mowing, grazing, burning, herbicide application, dry season irrigations, and the timing of wetland flood-up and drawdown. The fall flood-up occurs during the months of September and October, and the spring drawdown occurs during the months of February, March, and April. By timing flood-up and drawdown in the San Joaquin Valley, managers mimic the wet/dry seasonal cycle that these wetlands experienced historically. This seasonal cycle improves wetland habitat and can be adapted to promote desired species (Frederickson and Taylor, 1982).

Research has been undertaken to understand the role of wetland vegetation, water manipulation, irrigation and drainage on waterfowl habitat and use. Altering wetland drainage schedules can affect the rate of drawdown of wetland ponds and hence both the forage value and availability of forage for migrating and over-wintering waterfowl. Wetland salinity management also affects the protein yield of most soil plant seeds and the diversity of vegetation that can be grown in wetlands (Mushet et al., 1992).

Wetland drawdown is typically timed to make seed and invertebrate resources available during peak waterbird migrations and to correspond with optimal germination conditions (primarily soil moisture and temperature) for naturally occurring moist-soil plants (Smith et al., 1995). However, spring drainage that is timed for optimal habitat conditions occurs at a sensitive time for agriculture in the South Delta in that these drainage releases occur during the time crops are being irrigated for the first time and are germinating – potentially affecting crop yields (Quinn and Hanna, 2002; Quinn and Hanna, 2003; Quinn, 2009). As seen in Figure 2-2, the VAMP discharges can more than double the SJR seasonal flows during the period April 15 – May 15, creating considerable assimilative capacity for salts.

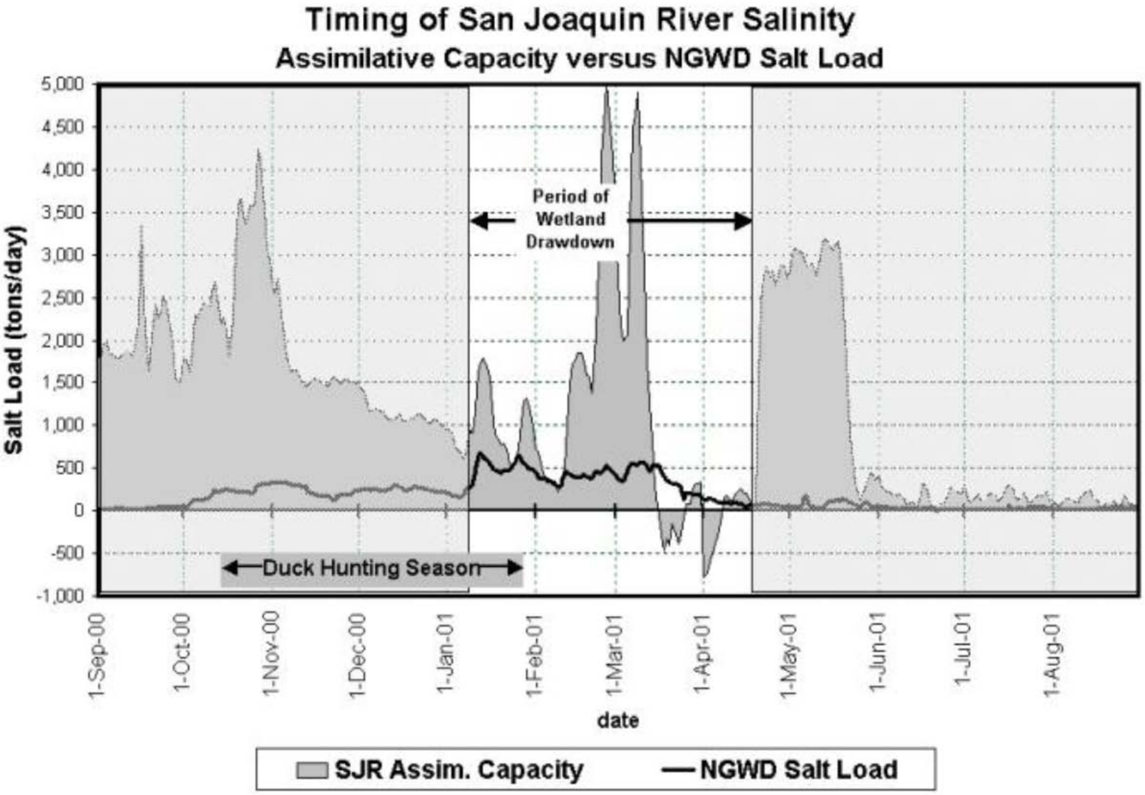

Figure 2-2: Timing of wetland drawdown to coincide with periods of San Joaquin River assimilative capacity. Note the excess assimilative capacity during April 15-May 15 due to the Vernalis Adaptive Management Program (VAMP) which makes arrangements with east and west-side water districts to sustain a minimum flow in the SJR to aid anadromous fish migration (Quinn and Hanna, 2006).

2.6 Potential Impacts

Phytoplankton loads from the Grasslands Basin wetlands account for a significant component of the organic matter entering the SJR. Algae exhibit a growth spurt in response to the increase in light and temperature during the transition from winter to spring. Delaying the start of the wetland drawdown from March until after mid- April or later will most likely increase the gross growth of phytoplankton and the discharge of suspended solids to the SJR. The net algal loading to the SJR will depend on the extent of algae losses due to invertebrate grazing, sedimentation, and other factors. Prolonging the flooded period into May also gives attached and metaphyton algae more time to grow. This can lead to greater areas of the wetlands being covered with floating algae mats or scums (e.g., *Cladophora, Oscillatoria, Anabaena*) and mats of benthic algae that float to the pond surface.

The expected increase in phytoplankton productivity is approximately proportional to the increase in insolation. In the San Joaquin Valley, daily insolation typically increases about 40% from late March to early May (~250 W/m^2 up to ~350 W/m^2) and air temperature increases by 5-7^oC. Under similar light increases, green algae phytoplankton productivity has increased 40%-60% in eutrophic ponds (Oswald, 1996). The production of periphyton can increase even more, rising from 8 to 18 $g/m^2/d$ (volatile solids) from March to May in shallow raceways flowing with nutrient-rich treated wastewater (Craggs, et al. 1994).

In shallow prairie lakes, phytoplankton gross productivity is about 10 $g/m^2/d$ during the summer months (Hickman and Jenkerson 1978). If the depth were 0.5 m and no losses occurred, the resulting suspended solids concentration would increase by 20 mg/L in one day. Epiphytic algae biomass in wetlands ranges widely due to various light and nutrient conditions. Rates as low as 5 g/m^2 of wetland and as high as 65 g/m^2 have been measured (Hooper and Robinson 1976, Hooper-Reid and Robinson 1978a). Measuring net algae productivity (accounting for algal biomass losses) under various conditions is one of the objectives of the proposed study.

Algae growth during delayed drawdown can be limited by nutrients instead of by light intensity and duration. However, nutrient limitations seem unlikely given the mass of decaying vegetation and bird waste present in these wetlands. Water quality analyses of influent and effluent to the wetlands chosen for this study are used to determine if nutrients or light limit algae growth during the delayed drawdown period. Delayed wetland drawdown may produce higher concentrations of phytoplankton in wetland discharge as well as a greater biomass of attached-algae retained within the wetlands. Greater phytoplankton concentrations in wetland discharge could be a detriment to SJR water quality if these algae are transported downstream to the San Joaquin River Deep Water Ship Channel in Stockton. The deep and wide configuration of the Ship Channel causes algae to settle and exert a biochemical oxygen demand as it decomposes. Although greater algae biomass production could be an impact of delayed wetland drawdown most episodes of low dissolved oxygen in the Ship Channel occur in the fall months at the end of the irrigation season when SJR flows are at their lowest and river algae loading is near its peak.

Algae are also undesirable in the intakes of potable water treatment facilities due to their organic carbon content. Conversely, soluble nutrients such as nitrogen and phosphorus assimilated by the algal biomass contained in the wetlands and could improve the wetland discharge quality if these nutrients remained contained within the wetland. Algae biomass typically contains 8%-10% nitrogen and 1%-2% phosphorus (Oswald, 1996) - hence an increase in phytoplankton concentration of 20 mg/L could decrease soluble nitrogen by about 2 mg/L and soluble phosphorus by about 0.2 mg/L. If all algae were retained in seasonally managed wetlands, soil organic matter and nutrient content would increase over time, which could enhance the establishment and growth of wetland vegetation – especially in areas of low natural fertility. Increased algae primary productivity could have a cascading positive effect on invertebrate populations including those invertebrates important to waterfowl as forage.

CHAPTER 3: MATERIALS AND METHODS

3.1 Site Description

Three study sites were chosen within the Grasslands Ecological Area each with different characteristics to obtain representative data for a range of wetland management conditions in the area. Images of the wetlands were captured using Google Earth. The images were then edited so that the traditionally drained wetlands (drained during mid-March) are highlighted in blue while the modified drainage wetlands (drained during mid-April) are highlighted in red.

3.1.1 Ducky Strike

The Ducky Strike Duck Club wetlands are located on private land within the Grasslands Ecological Area (Figure 3-1). The wetlands are notably shallower than the other studied wetland pairs. The shallower wetlands increase the relative impact of evapotranspiration on effluent water quality. Influent to these wetlands is typically higher in salinity compared to the other studied wetlands on account of the fact that inflow to both wetlands is routed through a duck club located south of Ducky Strike South (DSS). Water supply to Ducky Strike North (DSN) is conveyed along a temporary channel formed within Ducky Strike South (DSS) by constructing an earthern berm approximately 30 feet wide along the east side of the wetland. The Ducky Strike South wetland inlet and outlet are co-located at a drop structure that was installed at the northern end of the berm.

Figure 3-1: Ducky Strike North and South wetland ponds during the dry season.

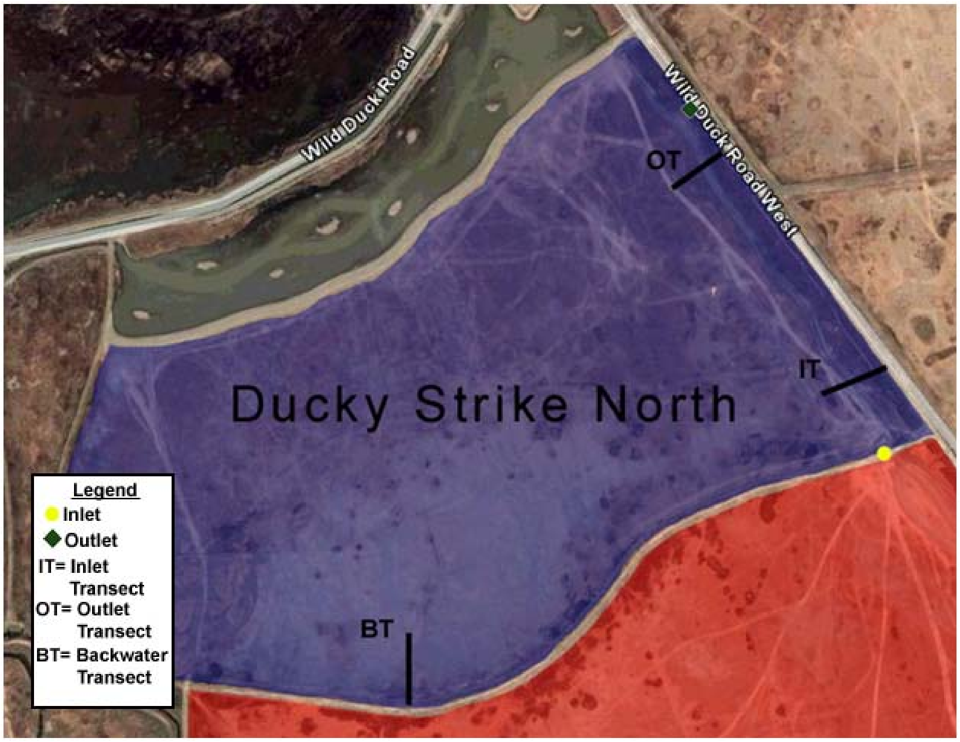

Figure 3-2: Ducky Strike North pond - showing inlet, outlet, and transect locations.

Figure 3-3: Ducky Strike North pond – drainage occurs over the outlet weir in the foreground.

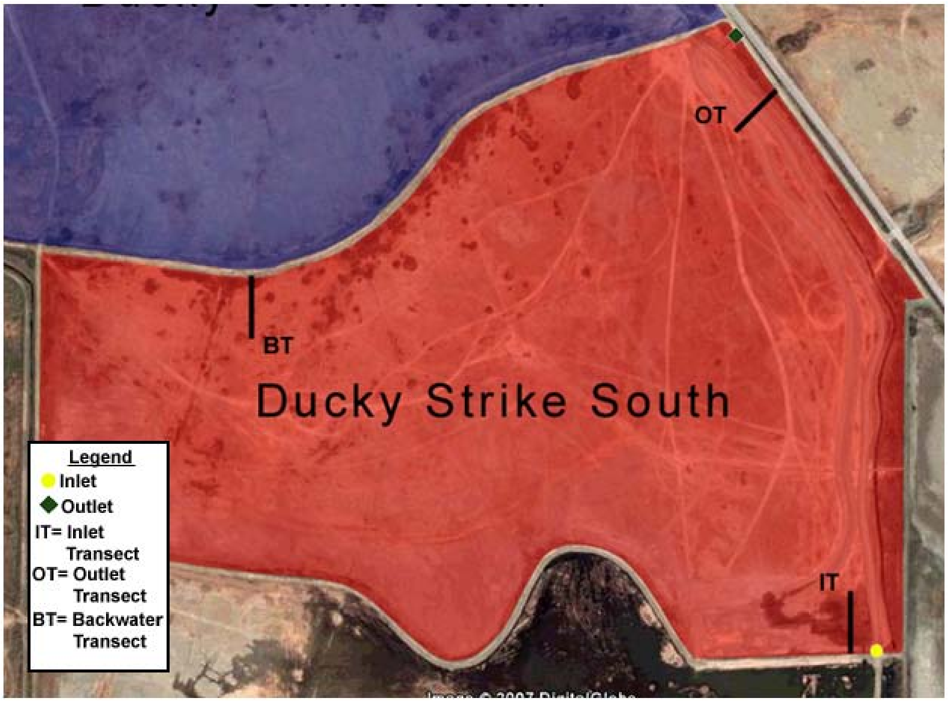

Figure 3-4: Ducky Strike South pond – showing inlet, outlet, and transect locations.

Figure 3-5: Ducky Strike South outlet weir. Student researchers Kyle Poole and Laleh Rastegarzadeh are shown collecting grab samples.

3.1.2 Los Banos Wildlife Area

The two paired wetlands in the Los Banos Wildlife Management Area 33 (LBWA 33 and LBWA 31B) (Figure 3-6) are deeper than the other studied wetland pairs and both have a larger volume. Influent water supply to these wetland ponds is the same as to the Mud Slough wetlands which are located to the south of the Los Banos Wildlife Management Area.

Figure 3-6: Los Banos Wildlife Management Area ponds 31B and 33B.

Figure 3-7: Los Banos Wildlife Management Area pond 31B - showing inlet, outlet, and transect locations.

Figure 3-8: Los Banos Wildlife Management Area pond 31B outlet weir.

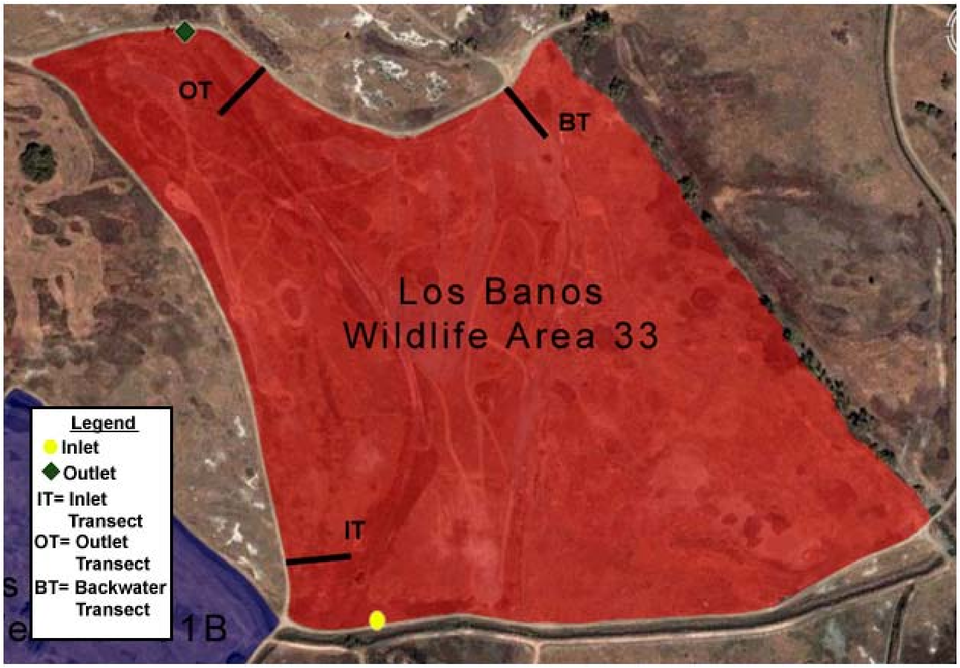

Figure 3-9: Los Banos Wildlife Management Area pond 33 - showing inlet, outlet, and transect locations.

Figure 3-10: Los Banos Wildlife Management Area pond 33 outlet weir.

3.1.3 Mud Slough

The Mud Slough 3B and Mud Slough 4b wetland ponds are located in the Mud Slough Wildlife Management Area. These wetlands have very similar geometry and share the same water supply as the Los Banos wetlands.

Figure 3-11: Mud Slough Wildlife Management Area ponds 31B and 33B.

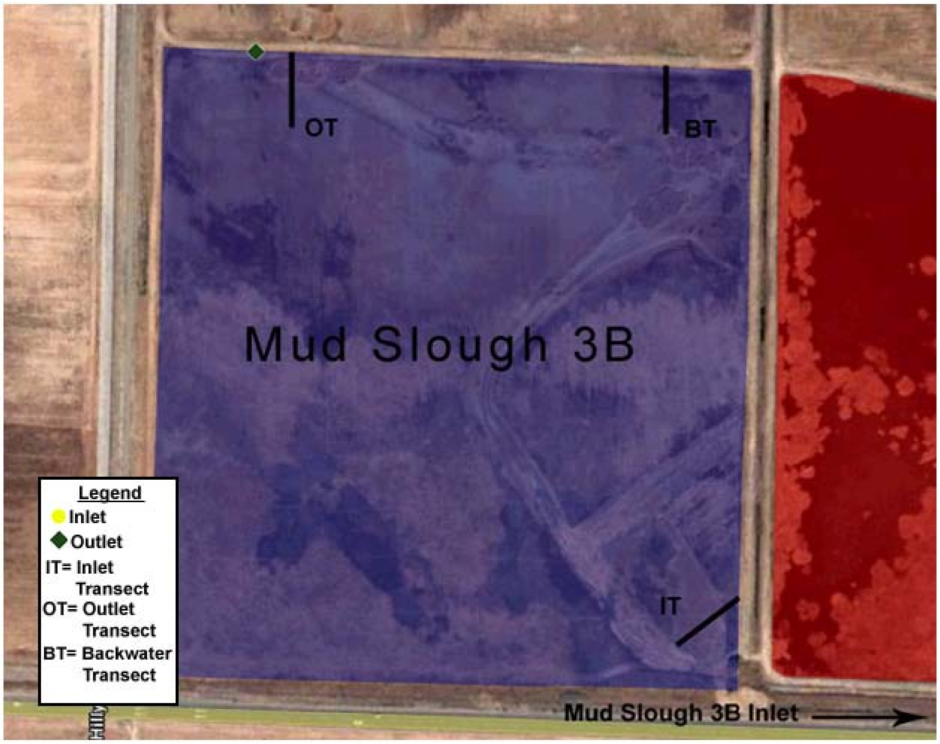

Figure 3-12: Mud Slough Wildlife Management Area pond 3B - showing inlet, outlet and transect locations.

Figure 3-13: Mud Slough Wildlife Management Area pond 3B – location of backwater transect.

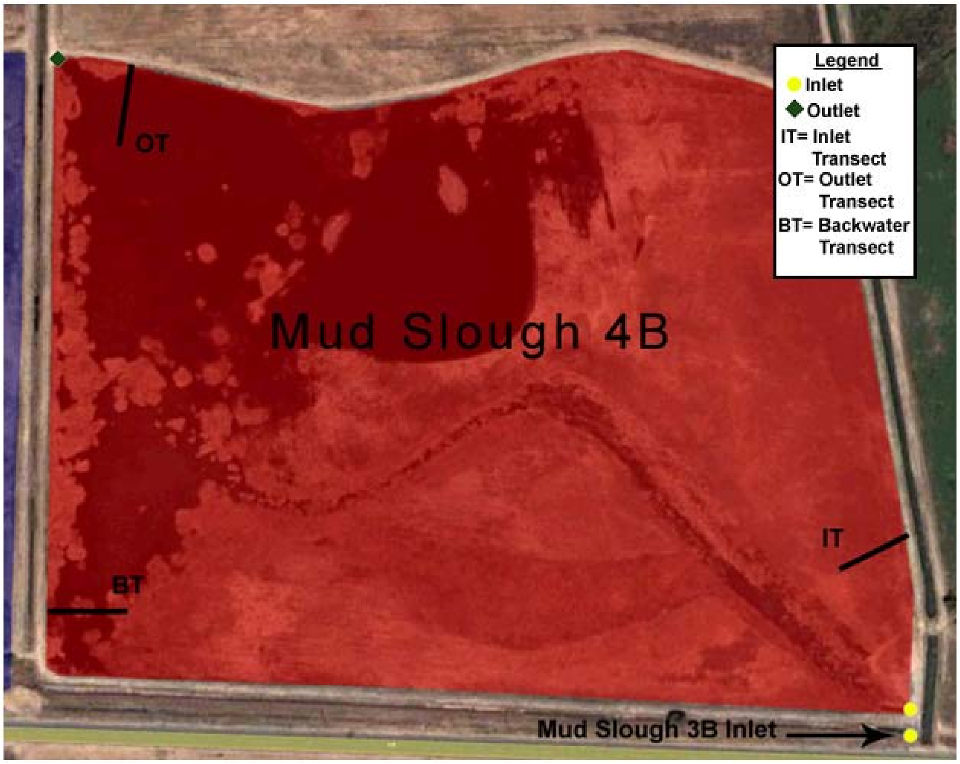

Figure 3-14: Mud Slough Wildlife Management Area pond 4B - showing inlet, outlet, and transect locations.

Figure 3-15: Mud Slough Wildlife Management Area pond 4B outlet weir.

Figure 3-16: Buttonwillow Lake monitoring site which accounts for a significant portion of the drainage discharge from the Los Banos Wildlife Management Area into the San Joaquin River

3.1.4 Drainage Sites

The Buttonwillow Lake and Los Banos 38 wetland drainage sites were added during the 2008 season to characterize drainage water quality from the entire Los Banos Wildlife Management Area wetland complex. These sites were chosen because they drain approximately 50% of the wetland ponds within the Los Banos Wildlife Management Area.

Figure 3-17: Los Banos Wildlife Management Area pond 38 drainage site showing deployment of an auto-sampler.

3.2 Sampling Methods: 2007 Season

The following section describes the methods used to collect samples from the wetland study sites during the 2007 season. Samples were taken from each wetland on three sampling dates: March 2/3, March 17/18, and April 17. Phytoplankton concentrations vary diurnally - hence sampling was conducted as close to 9:00 a.m. as possible. Past freshwater studies have shown that sampling at 9:00 a.m. optimally represents daily average phytoplankton, zooplankton, nutrient, and oxygen demand concentrations (Green et al., 1996). Sampling was conducted over 2 days while the control wetlands were flooded and on the first day when the control wetlands were drained. Planktonic invertebrates were separated and collected from each sample using a 100µm plankton screen. Invertebrates were removed from the screen with water after inverting the screen into a 45 ml polypropylene container with the use of a funnel. Water samples were stored in 0.5 L high density polyethylene containers. All sample containers were triple DI rinsed prior to sampling and rinsed once more with water from the sampling location before collection. Multiple samples were taken at locations with low visible turbidity to ensure adequate sample volume for analysis.

3.2.1 Hydraulic Regime

Drawdown of the treatment wetlands was delayed by approximately one month. During the 2007 season, the traditional wetlands were drained on March 17 (traditionally drained in mid-March), while the wetlands experiencing a delayed drawdown schedule were drained on April 17. The wetlands were flooded at the same time since flood-up timing can alter invertebrate densities (Batzer et al. 1997). During the 2008 season, the traditional wetlands were drained on March 17 while the wetlands under the modified hydrology treatment were drained on April 18.

3.2.2 Inflow and Outflow Sampling

Grab samples for algae and nutrient analysis were taken at each of the wetland inlet and outlet weirs at each sampling date. Continuous flow, depth, conductivity, and temperature readings were also taken at each of the inlet and outlet weirs.

3.2.3 Transect Sampling

Three transects were performed within each wetland to characterize changes in the wetlands along the “flow line” (defined as the line connecting the inlet and outlet weirs) and in the backwater dead zones. To accomplish this, a transect was performed near the inlet (inlet transect-IT); near the outlet, (outlet transect-OT); and in the corner furthest from the flow line (backwater transect-BT). Transects did not completely cross the width of the wetland to minimize disturbances to other ongoing research. Each transect was made at a random distance between 20’-50’ from the inlet/outlet/backwater corner. The transect direction was made perpendicular to the flow line except for the BT, which was made to be perpendicular to the prevailing wind. Three samples were collected along each transect; one within 3’ of the shoreline and two at random distances between 10’-100’. Random numbers were selected from a random number table generated using a Texas Instruments TI-83 Plus graphing calculator. Numbers were thrown out if they were not within the set limits (e.g. less than 10’ or second sample passed the far edge of the wetland). At each sampling location temperature, depth, pH, and habitat type data were recorded. Water and soil samples were collected as described in sections 3.2.3.1 and 3.2.3.2.

3.2.3.1 Water Samples

Water samples were collected using a 6’ pole sampler with a 0.5 L high density polyethylene sampling container. The sample was collected upstream of the transect line. The sampling device was submerged to a depth near the bottom of the wetland with the opening of the container face down. At sampling locations with a depth >15 cm, the sampling device was brought to a depth of 5 cm. For sampling locations with a depth <15 cm, the sampling device was carefully lowered close enough to the soil to collect a representative sample without disturbing sediments. The pole was then rotated and lifted to collect the sample. This method was used to integrate the sample throughout the depth of the sample location. The collected sample was then poured into a 0.5 L high density polyethylene container. Samples were stored on ice during transport to laboratory. Upon arrival to the laboratory, the samples were divided, analyzed, and preserved as described in the section 3.4.

3.2.3.2 Soil Samples

Soil samples were collected along each transect at water sample locations to identify and enumerate benthic organisms living within the top 5 cm of topsoil. Soil samples were taken using a 6” diameter plastic corer with a sharp rim. The cup was pressed through loose detritus and then 5 cm into the soil. A gardening spade was then placed under the corer to aid in bringing the soil to the water surface. The soil sample was stored in a low density polyethylene zip lock bag and placed on ice during transport to the laboratory.

3.3 Sampling Methods: Changes for 2008 Season

Sampling methods were changed for the 2008 season to further reduce disturbances for avian studies as well as to narrow the focus of the project research. To properly characterize the wetlands with transect sampling would have required greater resources and caused added disturbance to cooperative research projects. Hence transect sampling of water constituents was abandoned in place of more frequent outlet sampling. Inlet grab sampling was planned; however no samples were collected because the wetland inflow did not occur on any of the chosen sample dates chosen. Instead, electrical conductivity data were supplied at the key monitoring sites by the SWRCB- sponsored project. This project has operated continuous flow and electrical conductivity stations for three years in the Grasslands Ecological Area. Since no transect sampling took place, benthic sampling was also eliminated from the 2008 season sampling.

Wetland pond outlet sampling was conducted on a bi-monthly basis. Sampling at the drainage sites were increased in frequency to bi-weekly basis for one week after each drawdown in order to observe any spike in water quality constituents due to the drawdown of the wetlands. In place of grab samples, 4 auto-samplers (2x Teledyne ISCO 6712, 1x SIGMA 900 MAX, and 1x SIGMA 1350) were used to sample the 6 wetland pairs and 2 drainage sites over 2 days. Auto-samplers were utilized in order to produce daily averages of water quality constituents as well as phytoplankton and zooplankton densities. Auto-samplers were also used to observe diurnal fluctuations in phytoplankton densities. The auto-samplers were placed near the outlets and took samples every 2 hours for a period of 24 hours (12 samples total), which created a daily composite sample.

For wetlands subjected to delayed drawdown (mid-April drawdown), multiple grab samples were taken from the outlets. This was done to characterize the change in water quality during the drawdown due to scouring of sediment. The wetlands were drained by removing weir boards individually to maximize forage for water birds. After each weir board was removed a grab sample was taken until the wetland was drained.

3.4 Analytical Methods

Upon arrival to the laboratory, water samples were either analyzed immediately or divided and preserved as according to APHA Standard Methods.

3.4.1 Water Quality Analysis

Water quality analysis was performed to characterize the discharge from the wetlands as well as determine limiting factors affecting phytoplankton growth. Table 3-1 summarizes the water quality tests performed and methods used for analysis.

3.4.1.1 Alkalinity

Although unlikely in freshwater wetlands, alkalinity was measured to determine if bicarbonate-C limitation was occurring. Alkalinity was measured within 12 hours of sampling. Alkalinity measurements were taken only when a samples pH was greater than 9.0, which indicates the beginning of bicarbonate-C limitation and reduced number of species (Vymazal, 1995). Alkalinity was determined by the APHA 2320-B. Titration Method.

Table 3-1: Water quality methods of analysis. Cited methods are from APHA 2005.

Parameter	**Method of Analysis**
Alkalinity	APHA 2320-B: Titrimetric method.
Ammonia	Fluorometry (Holmes 1999)
Conductivity	APHA 2510-B
Hydrogen Ion Concentration (pH)	APHA 4500-H^+-B: Potentiometry.
Nitrate (NO_3^-), Nitrite (NO_2^-), Phosphate (PO_4^{3-}), Chloride (Cl^-)	Ion exchange chromatography.
Total Kjeldahl Nitrogen (TKN)*	APHA 4500-N-N_{org}-B and 4500-NH_3-C: Distillation with titrimetric finish.
Total Organic Carbon*	APHA 5310-B: High temperature combustion method
Total Phosphorus, Phosphate (PO_3^{4-}) [2008]	APHA 4500-P-B and 4500-P-E: Persulfate digestion followed by ascorbic acid colorimetry.
Total and Volatile Suspended Solids	APHA 2540-B, 2540-C, 2540-E, 2540-F: Filtration, oven drying, and ashing.
Turbidity	Method 2130-B: Light dispersion.

*Not available during 2007 sampling season

3.4.1.2 Nutrients

Nutrient testing was performed to determine the mass of soluble nutrients being discharged from the wetlands, and to determine if nutrient concentrations in the wetlands were limiting phytoplankton growth. Nitrate (NO_3^-), nitrite (NO_2^-) and phosphate PO_3^{4-} were analyzed using ion exchange chromatography. PO_3^{4-} was changed to 4500-P-E: ascorbic acid colorimetry during the 2008 season to reduce the detection limit and increase accuracy. A detailed ion chromatography method is described in Appendix B: Ion Chromatography. Ammonia concentrations were determined using a flouremetry (Holmes 1999).

Nitrogen testing was performed to monitor the amount of NO_3^- , NO_2^-, NH_3, and TKN present in the wetlands' discharge. Nitrogen testing also was used to calculate the amount of nitrogen present in the phytoplankton. This was calculated by subtracting the NH_3 present in a sample from the TKN. This concentration was then divided by the volatile suspended solids concentration to find the percentage of nitrogen in the sample.

Phosphorus testing was performed to determine the amount of soluble phosphate (PO_3^{4-}) and total phosphorus present in the wetlands' discharge. Phosphorus testing was also used to calculate the amount of phosphorus present in the phytoplankton. This was calculated by subtracting the PO_3^{4-} present in a sample from the Total Phosphorus (TP). This concentration was then divided by the volatile suspended solids concentration to find the percentage of phosphorus in the sample.

3.4.1.3 Suspended Solids

Volatile suspended solids (VSS) measurements were used to quantify the mass of phytoplankton present in a sample and to determine the amount of biodegradable organic matter being discharged to the SJR.

3.4.1.4 Total Organic Carbon

Total organic carbon (TOC) was analyzed to determine the amount of organic carbon being discharged from the wetlands. Filtered (0.2µm) and unfiltered (screened through 100µm mesh for zooplankton analysis) samples were analyzed using a Shimadzu TOC-5000A analyzer, which utilizes the high-combustion NDIR detection method as described in APHA 5310-B. Unfiltered samples were homogenized by sonication using a Branson Sonifier 250 for 60 seconds. 10 ml Samples were acidified and sparged with Ultra-Zero grade compressed air for 10 minutes before injection. The mean of three injections was collected once the covariance of the results was less than 5%.

3.4.1.5 Turbidity

Turbidity was used to determine if insolation was limiting growth in deep (>30cm) sample locations. Turbidity was also used to create correlations with other water quality constituents in order to create possible real-time monitoring tools. Turbidity was analyzed using a Hach 2100P Portable Turbidimeter.

3.4.2 Wetland Biota Analysis

Analysis of wetland biota was conducted to observe changes in benthic invertebrate, phytoplankton, and planktonic invertebrate densities.

3.4.2.1 Phytoplankton

Phytoplankton samples were preserved with Lugol’s solution upon arrival to the laboratory. Phytoplankton concentrations were below the level necessary for statistical enumeration through direct counting. However, predominant algae species were identified using a trinocular Olympus CX 41 optical microscope with phase contrast and an Infinity 2 digital camera.

3.4.2.2 Zooplankton

Zooplankton were enumerated through direct microscopic counting. Samples were poured into a divided Petri dish and counted under an optical dissecting microscope. Invertebrates were identified to the order level using. During the 2007 season, several random samples were saved for VSS analysis. The VSS data was used as an average biomass per invertebrate. This allowed the conversion of numerical concentration data to mass concentration data so that invertebrate data could be compared directly with phytoplankton data. During the 2008 season, identification was abandoned due to the elimination of transect sampling since the samples were no longer representative of the wetland as a whole. Zooplankton biomass was recorded by conducting VSS analysis on both screened (100μm) and unscreened samples. The difference was recorded as the mass of zooplankton in the discharge. Any debris noticed in the unscreened samples was carefully removed in order to minimize disturbances from detritus. Figure 3-18 shows screened and unscreened samples after oven drying.

Figure 3-18: VSS samples after oven drying. The seven samples on the left are screened samples for phytoplankton quantification while the right seven are unscreened for zooplankton analysis. The sample in the upper left corner is an analytical blank.

3.4.2.3 Benthic Invertebrates

Benthic invertebrates were enumerated through screening of the soil samples taken. The samples were initially screened through a 5mm mesh, where debris was washed and removed. Then the samples were screened though a 500µm mesh. Invertebrates were separated and then identified to the family level.

CHAPTER 4: RESULTS AND DISCUSSION

Experimental results are presented as water quality and biota line charts for wetlands divided into two categories - modified (delayed drawdown) or traditional (drainage). Trend lines were removed for data sets with less than five data points. For the 2007 season, experimental data points represent the mean of all the samples collected within the wetland. For the 2008 season, the experimental data was collected at the drainage outlets. The graphs presented use the following abbreviations:

- Ducky Strike North: DN
- Ducky Strike South: DS
- Los Banos Wildlife Area 31b: L1
- Los Banos Wildlife Area 33: L3
- Mud Slough 3b: M3
- Mud Slough 4b: M4
- Los Banos Wildlife Area 38: L8
- Button Willow Lake: BW

4.1 Weather Data

Data collected from the CIMIS website are presented in the following graphs. In Figure 4-1 the 2007 season appears warmer (p=0.06) than the 2008 season and may have contributed to greater growth of algae biomass in the ponds. However total solar insolation, the total amount of incident light, did not show the same differences and was remarkably similar between both seasons.

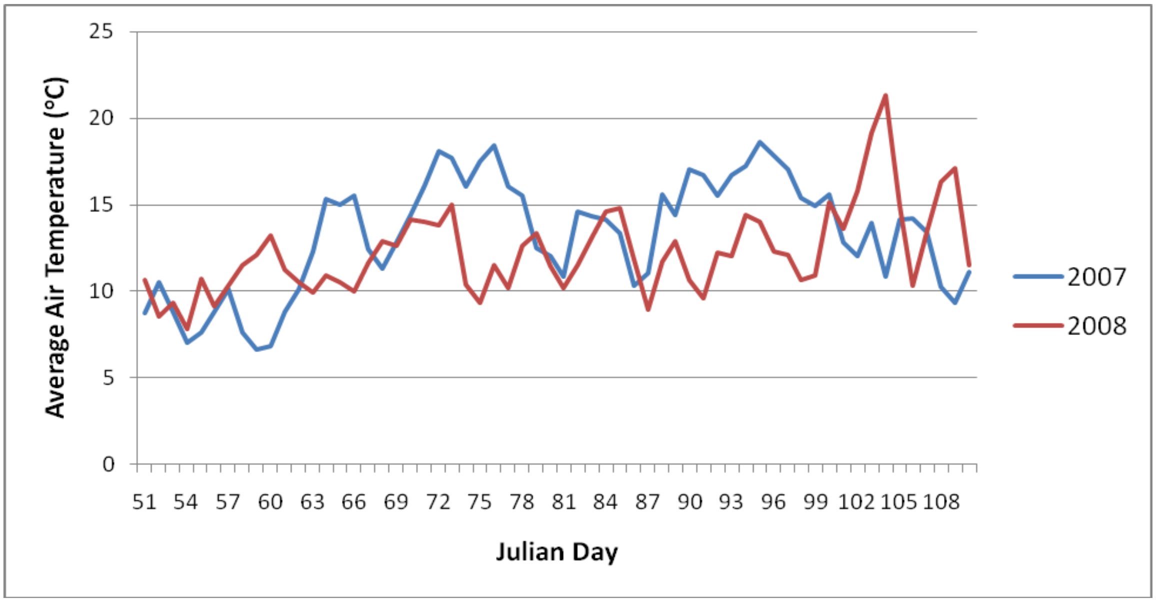

Figure 4-1: Average air temperatures during both sampling seasons.

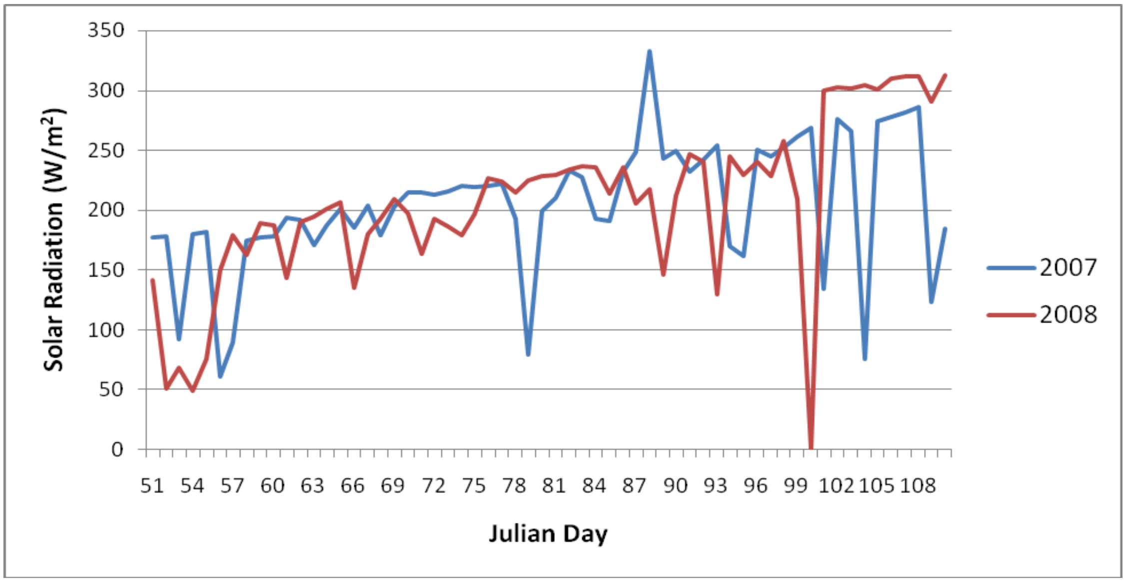

Figure 4-2: Daily solar radiation for both sampling seasons.

4.2 Aquatic Biota

The following sections contain the aquatic biota results. Phytoplankton, zooplankton and benthic invertebrates were analyzed in each of the ponds and these results compared across years.

4.2.1 Phytoplankton

VSS concentrations (after screening with a 100-µm mesh) were used to represent phytoplankton concentrations in the ponds. The concentrations of phytoplankton were too low for enumeration. However, observations showed that the phytoplankton were predominantly diatoms. Figure 4-3, Figure 4-4, and Figure 4-5 are micrographs of some of the phytoplankton species observed in the ponds.

4.2.1.1 Traditionally Drained Wetlands

For the traditionally drained wetlands, phytoplankton concentration increased in all wetlands during the 2007 season (). However, during the 2008 season, phytoplankton concentration decreased slightly in two of three wetlands investigated (Figure 4-7). Increases in phytoplankton concentration during the 2007 season could be due to either (a) a warmer growing season or (b) sampling events made after drawdown had started (for the 03/17/07 event). The standard error in the data (collected during the last sampling event) increased dramatically for both 2007 and 2008 flooded seasons, suggesting that phytoplankton growth conditions may have been different between experimental wetland ponds.

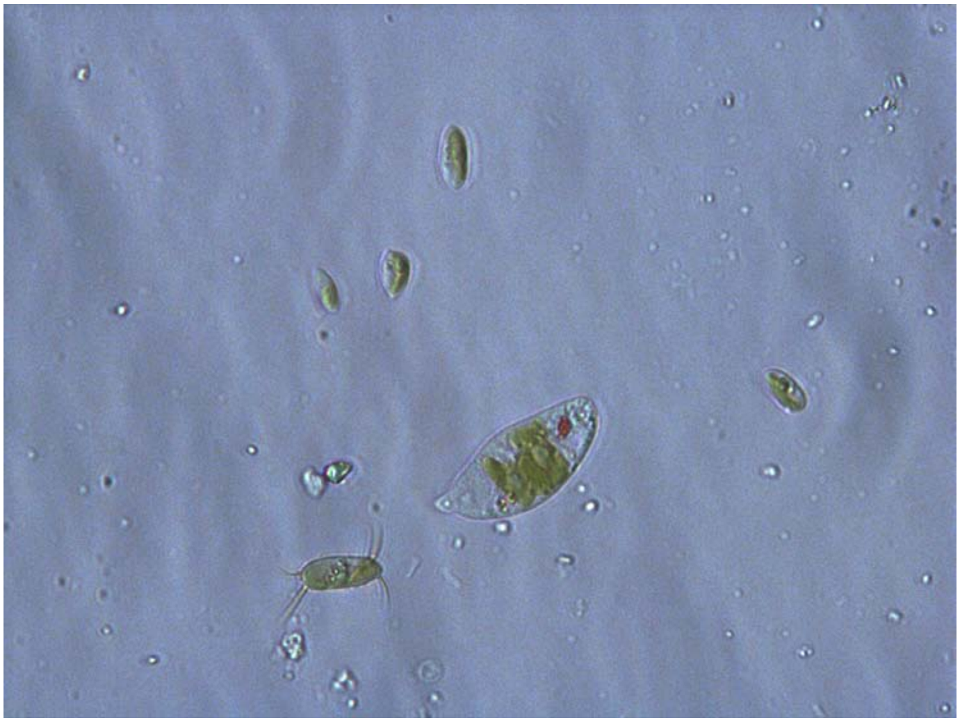

Figure 4-3: A cluster of phytoplankton in a sample taken from Mud Slough 3B during the 2007 flooded season (1000x). Phytoplankton genera *Euglena*, *Chlorella,* and *Chodatella* appear to be present.

Figure 4-4: Diatoms in a sample taken from Ducky Strike North during the 2007 flooded season (1000x). *Navicula gracilis* is on on the left and a *Diatoma* species on the right.

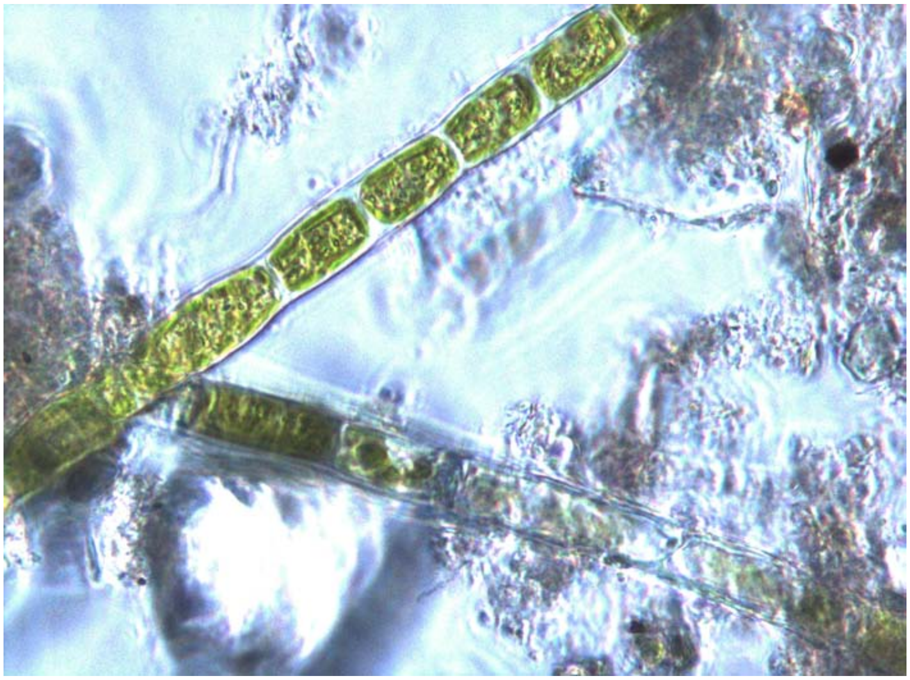

Figure 4-5: Decaying filamentous algae, *Zygnema stellinum*, mixed in with detritus in a Los Banos 33 sample taken during the 2007 flooded season (1000x).

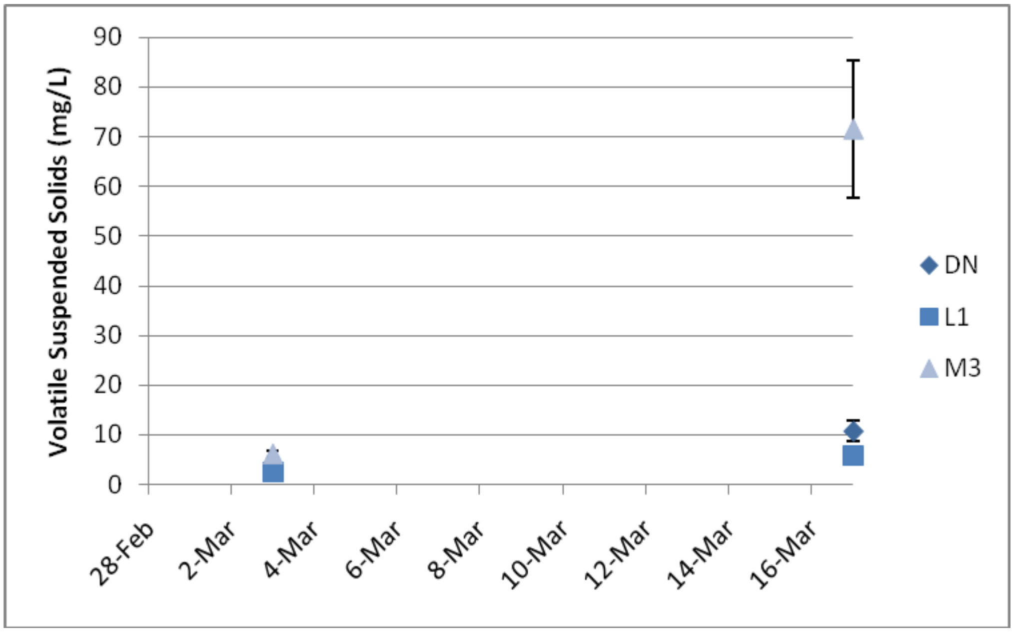

Figure 4-6: Phytoplankton concentration in traditionally drained wetlands during the 2007 flooded season. Error bars represent the standard error of the mean.

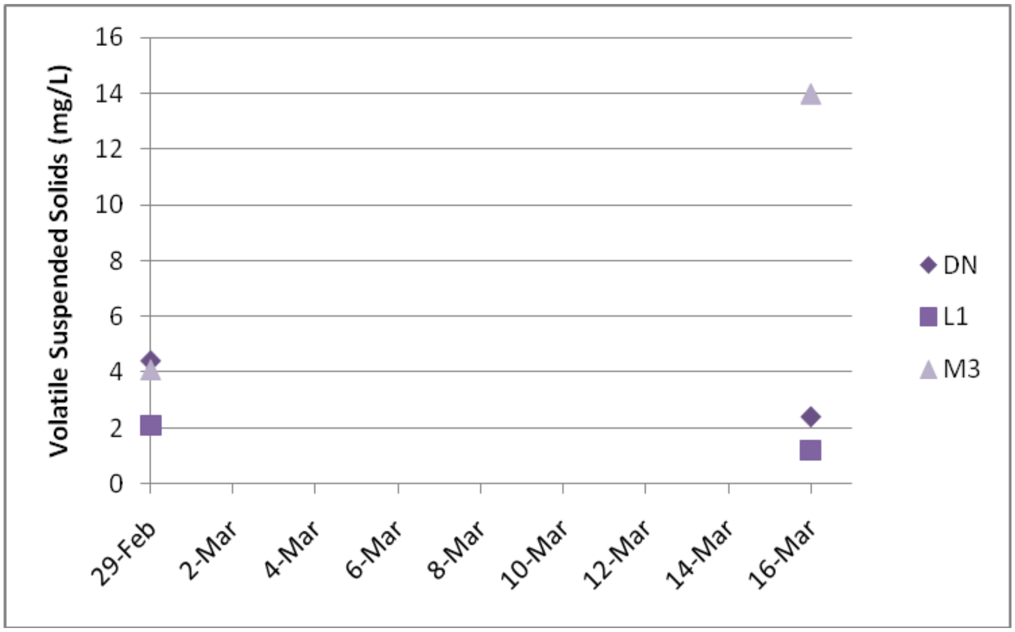

Figure 4-7: Phytoplankton concentration in traditionally drained wetlands during the 2008 flooded season.

4.2.1.2 Wetlands subjected to Delayed Drawdown

Phytoplankton growth in the wetlands subjected to delayed drawdown varied between sampling locations. Phytoplankton concentration increased in two of three wetlands during the 2007 flooded season (Figure 4-8). This increase is most likely due to sampling once drainage had begun. Phytoplankton concentration decreased in Los Banos 33b, which has the largest storage volume of the studied wetlands. The large volume delays the effect of drawdown scour (Figure 4-9) and significant increases in phytoplankton numbers do not occur until the final sampling event. During the 2007 season, phytoplankton concentration increased initially and then stabilized at less than 10 mg/L (Figure 4-9). After drawdown began (4/18/08), phytoplankton concentration increased substantially in all three wetlands. This increase is likely due to scouring of periphyton caused by increased flow.

4.2.1.3 Drainage Sites

For the drainage sites during 2008, there was an observed trend of increasing phytoplankton concentration throughout the season (Figure 4-10). After the drawdown dates (03/17/08 and 04/18/08), there appeared to be an increase in phytoplankton concentration at the Los Banos 38 drainage site. However, at the Buttonwillow lake drainage site, there was a decrease in phytoplankton concentration. This decrease may be due to other management practices that may dilute the drainage discharge from each of the studied wetlands.

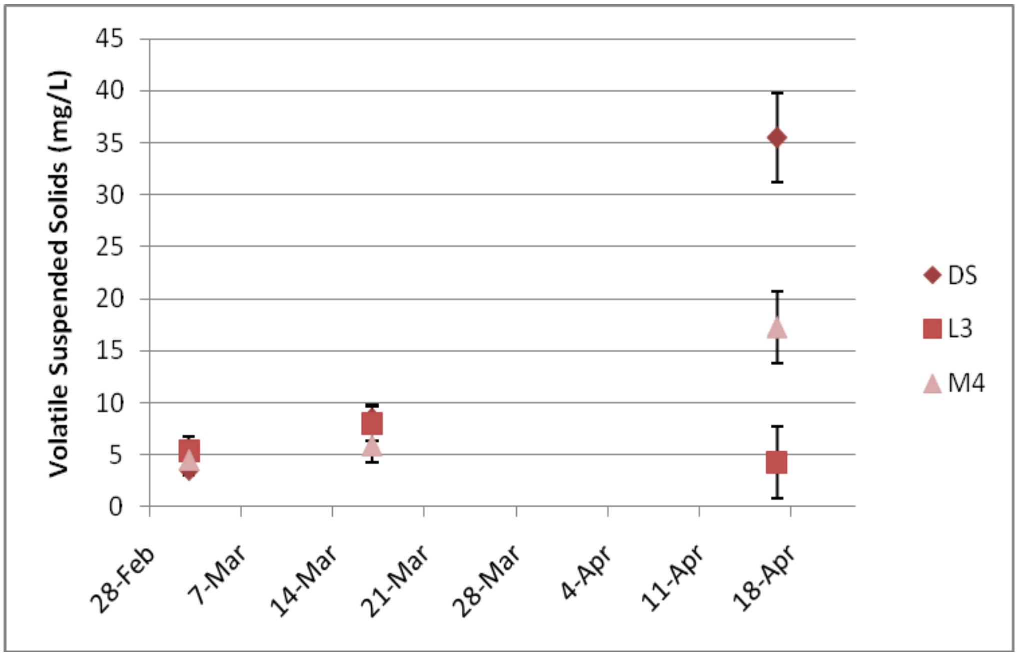

Figure 4-8: Phytoplankton concentration in wetlands subjected to modified drainage for 2008. Error bars represent the standard error of the mean.

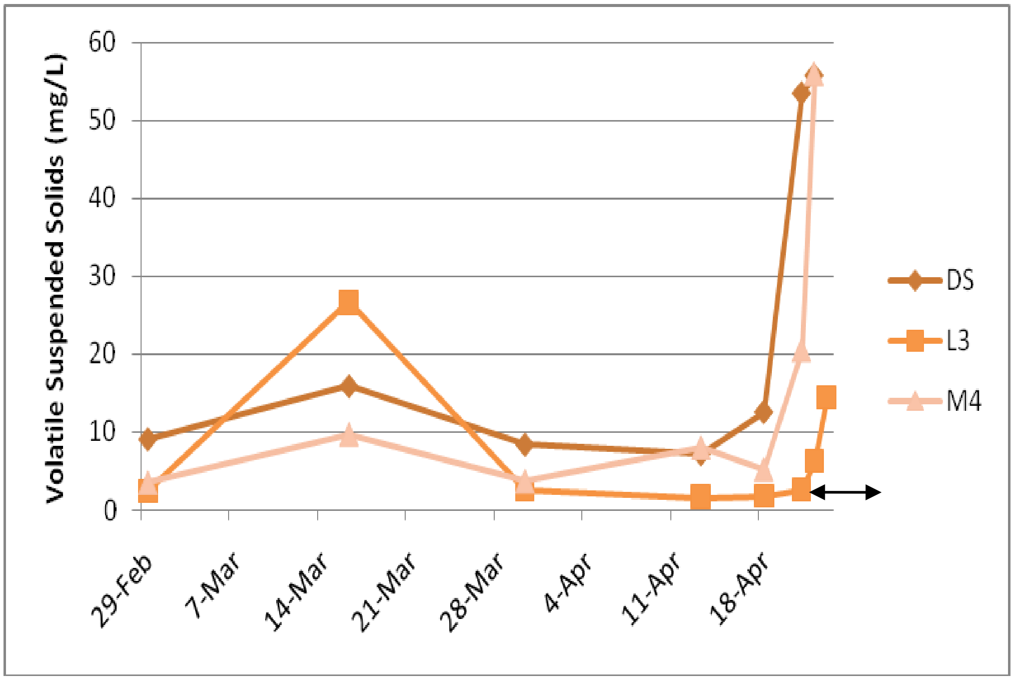

Figure 4-9: Phytoplankton concentration in modified drainage wetlands for 2008. The drawdown period is indicated by the line with arrows.

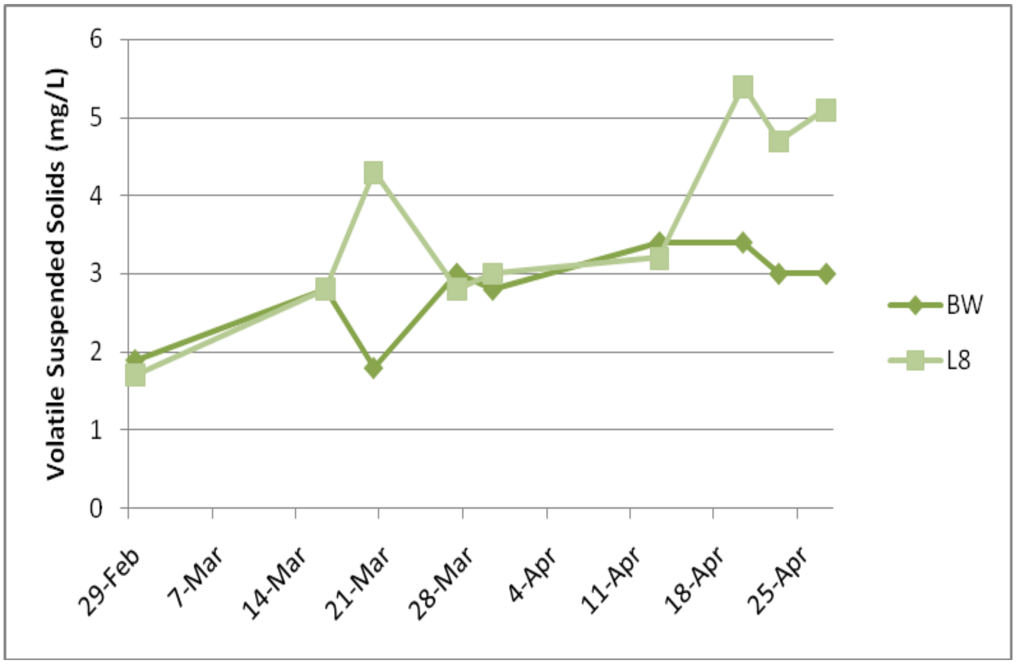

Figure 4-10: Phytoplankton concentrations at drainage sites for 2008.

Figure 4-11: A mat of filamentous algae found early in the season near the Buttonwillow drainage site.

Figure 4-12: Remains of filamentous algae bloom seen in Figure 4-11 later in the season.

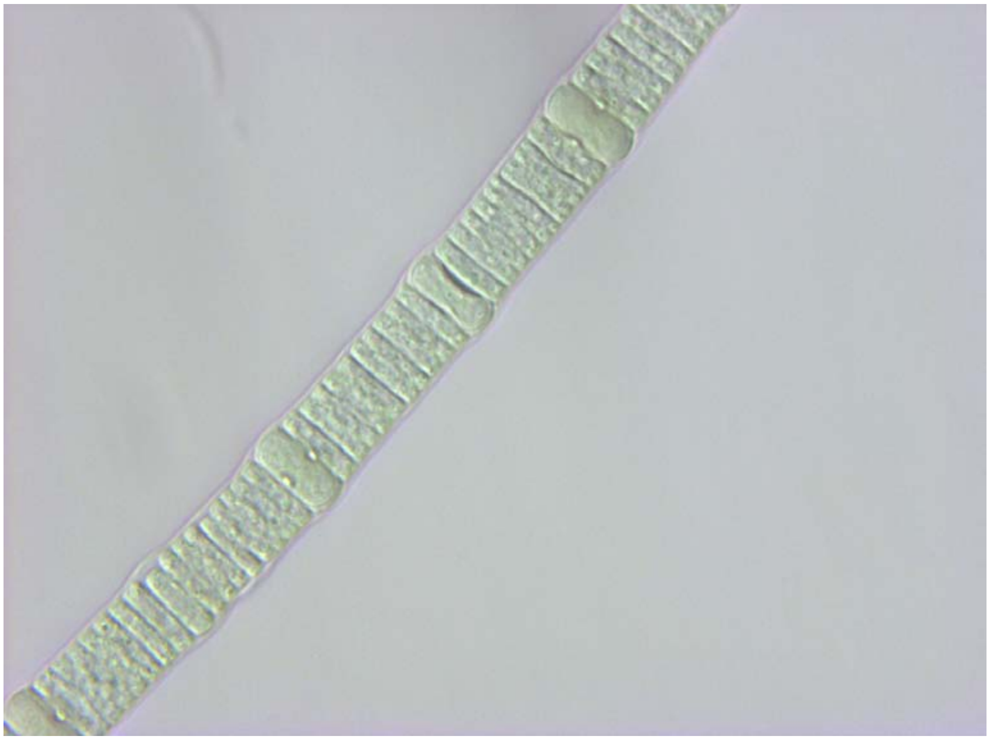

Figure 4-13: Micrograph of filamentous algae (*Nodularia*) found near the Los Banos 38 drainage site.

A filamentous algae bloom was observed during the February 29, 2008 sampling event as shown in Figure 4-11. During the March 30, 2008 sampling session the algae mat had receded as seen in Figure 4-12. The primary algal species was identified as *Nodularia* (Figure 4-13). This type of growth was expected in the studied wetlands, but was only observed in wetlands that were not a part of this study. This observation is provided for the possible benefit of future studies.

4.2.2 Zooplankton

Zooplankton concentration was calculated by counting zooplankton and then using an average weight per specimen to convert to a weight basis during the 2007 season. This allowed identification of zooplankton species. During the 2008 season, concentration was calculated by taking the difference between screened (100 µm) and unscreened volatile suspended solids values. This allowed more direct analysis.

4.2.2.1 Traditional Wetlands

For the traditionally managed wetlands during the 2007 flooded season, zooplankton concentration increased in two of three wetlands while it decreased in the third (

Figure 4-14). During the 2008 season, all three wetlands showed decreases in zooplankton concentration (Figure 4-15).

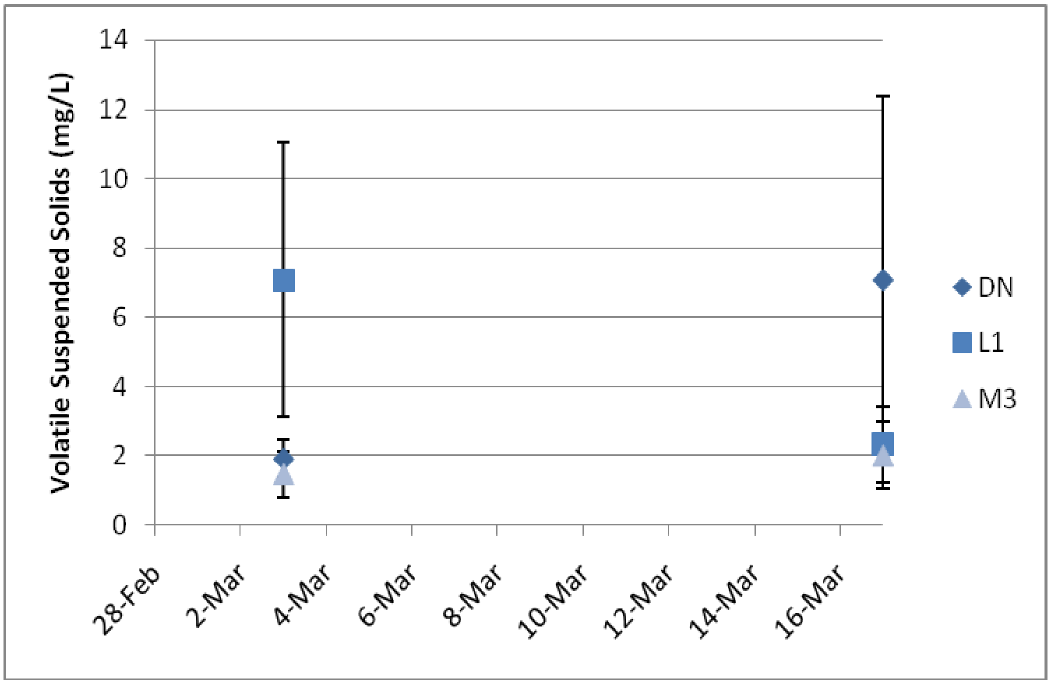

Figure 4-14: Zooplankton concentration in traditional drainage wetlands for 2007.

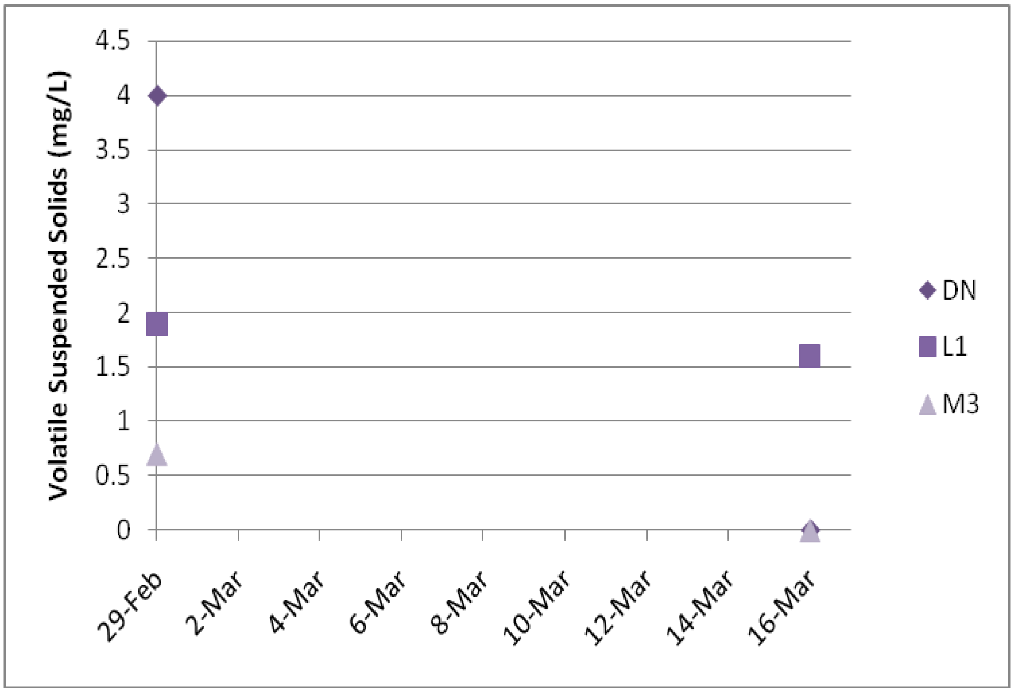

Figure 4-15: Zooplankton concentration in traditional drainage wetlands for 2008.

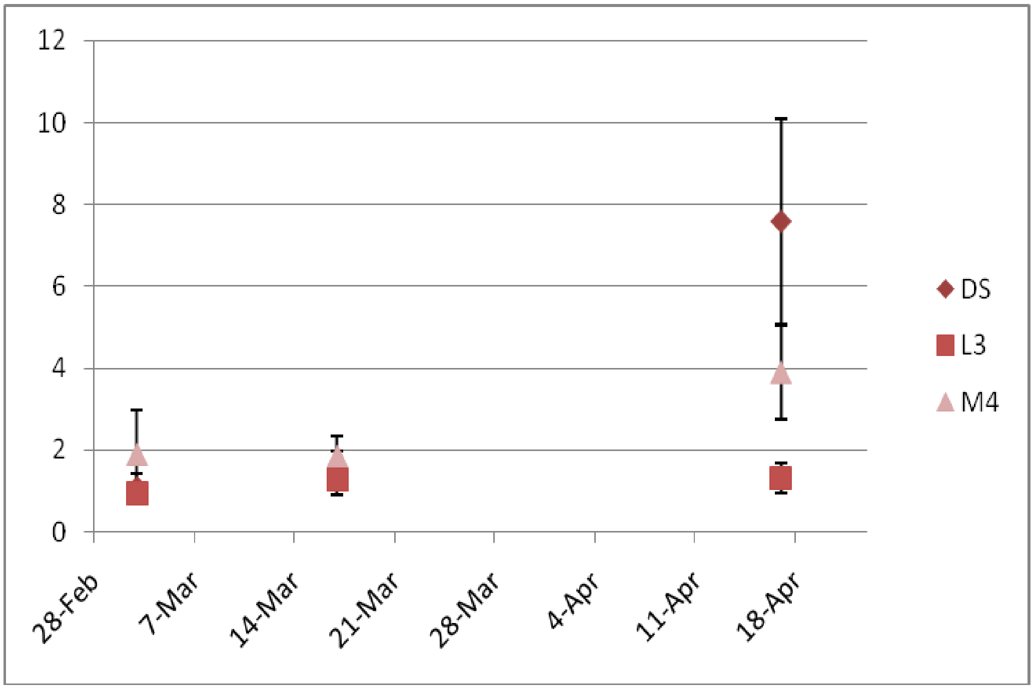

Figure 4-16: Zooplankton concentration in wetlands subjected to modified drainage for 2007.

4.3 Modified Wetlands

For modified wetlands during the 2007 season, increases in zooplankton concentration were seen during the extended flood period (March 17 through April 17) (Figure 4-16). These increases are due to improved conditions for zooplankton growth which likely resulted in concentration during the drawdown period. During the 2008 season, zooplankton concentration fluctuated more widely throughout the season – though it also concentrated during the drawdown period (Figure 4-17).

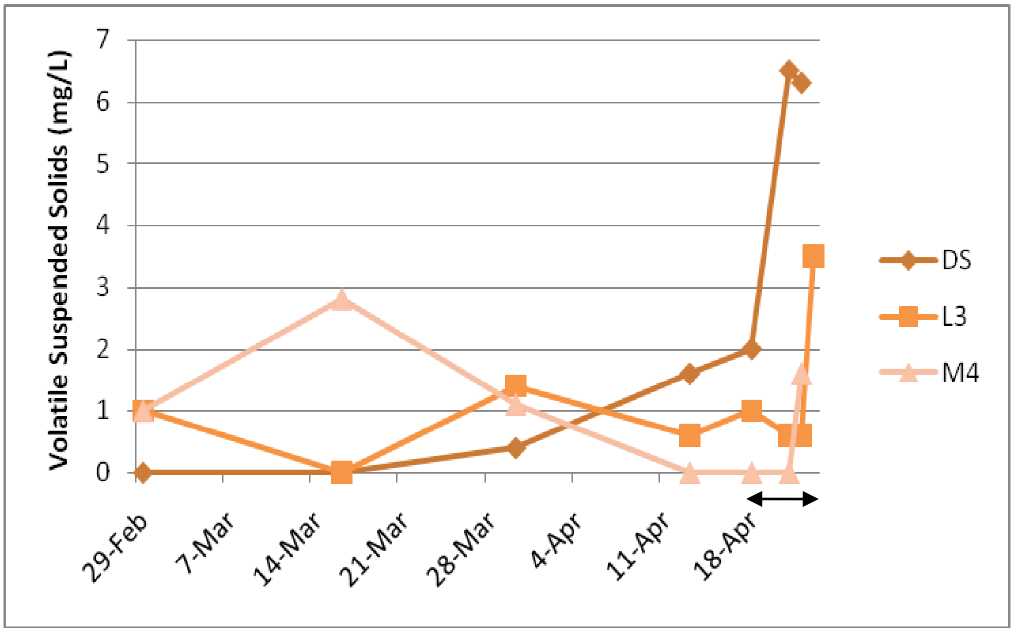

Figure 4-17: Zooplankton concentration in wetlands subjected to modified drainage during the 2008 sampling season. The drawdown period is indicated by the line with arrows.

4.3.1 Aquatic Biota

4.3.1.1 Drainage Sites

At the drainage sites during 2008 - zooplankton concentrations fluctuated greatly throughout the flooded season. This variation could have been due to boom-bust events or changes in the source of influent water supply.

4.3.1.2 Distribution

Zooplankton enumeration and identification data is presented in Table 4-1 which shows the distribution of zooplankton species in the studied wetlands. Zooplankton were predominantly Cladocera. However, at the end of the season the Cladocera population declined while the

Ostracoda population increased. This change may be due to either grazing or a change in environmental conditions. The overall density of zooplankton increased during the extended drawdown period.

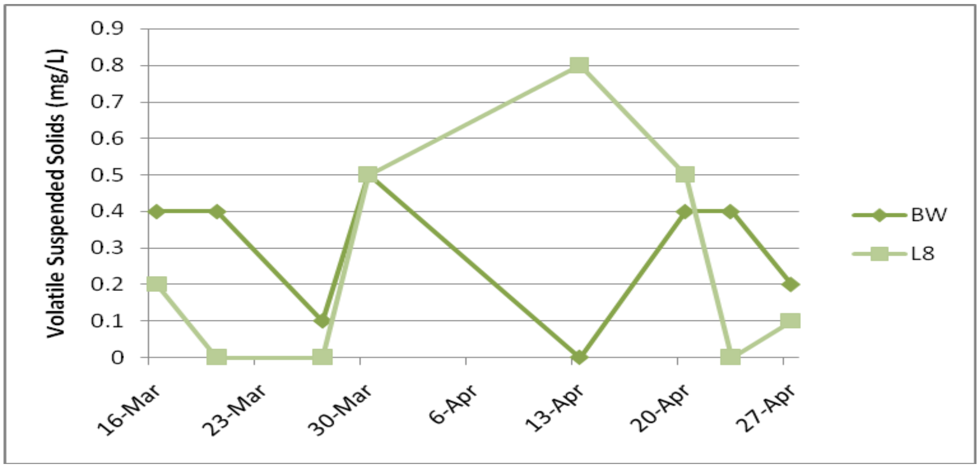

Figure 4-18: Zooplankton concentration at the drainage sites for 2008.

Table 4-1: Zooplankton distribution

Taxa	% of Total Collected		
	March 3, 2007	March 17, 2007	April 17, 2007
# of Samples	N = 62	N = 42	N = 27
# Counted	n = 4150	n = 1981	n = 1874
*Density (#/L)	90	90	130
Cladocera	76.5%	75.3%	56.1%
Ostracoda	14.6%	17.4%	31.9%
Copepoda	6.3%	3.7%	8.8%
Corixidae	1.9%	1.9%	2.6%
Other	0.7%	1.6%	0.5%
TOTAL	100.0%	100.0%	100.0%

*Standard errors ranged from 26-30 #/L

4.3.2 Benthic Invertebrates

Benthic invertebrates were monitored during the 2007 season. In traditionally drained wetlands, Mud Slough 3b was the only wetland in which benthic invertebrate density was observed to decline (Figure 4-19). In the modified drainage wetlands, the invertebrate density increased in all three wetlands initially. During the extended drawdown period, the invertebrate density in Ducky Strike South decreased (Figure 4-20).

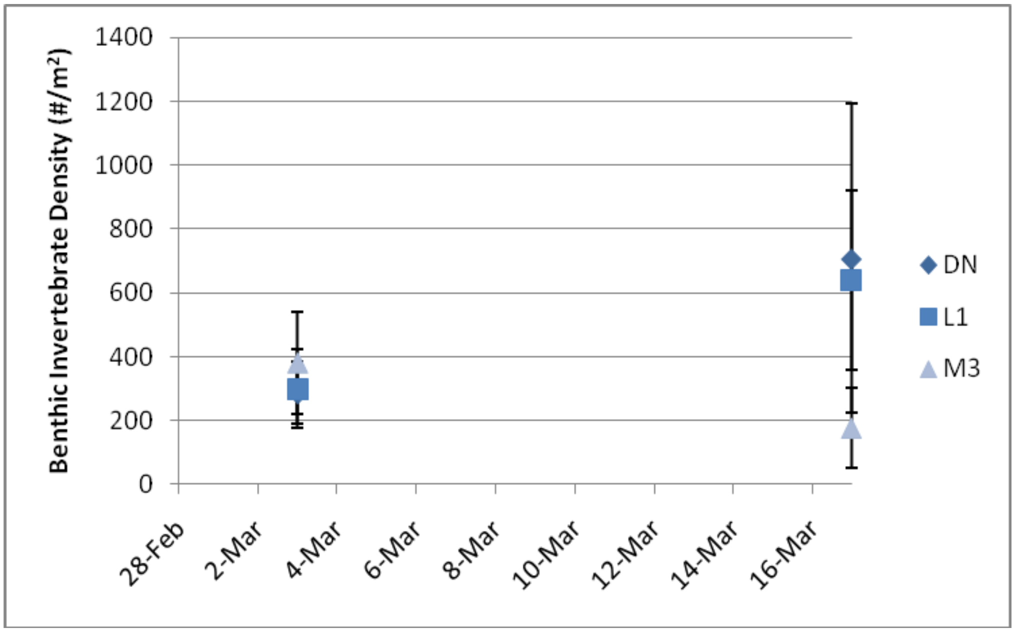

Figure 4-19: Benthic invertebrate density in traditional drainage wetlands for 2007.

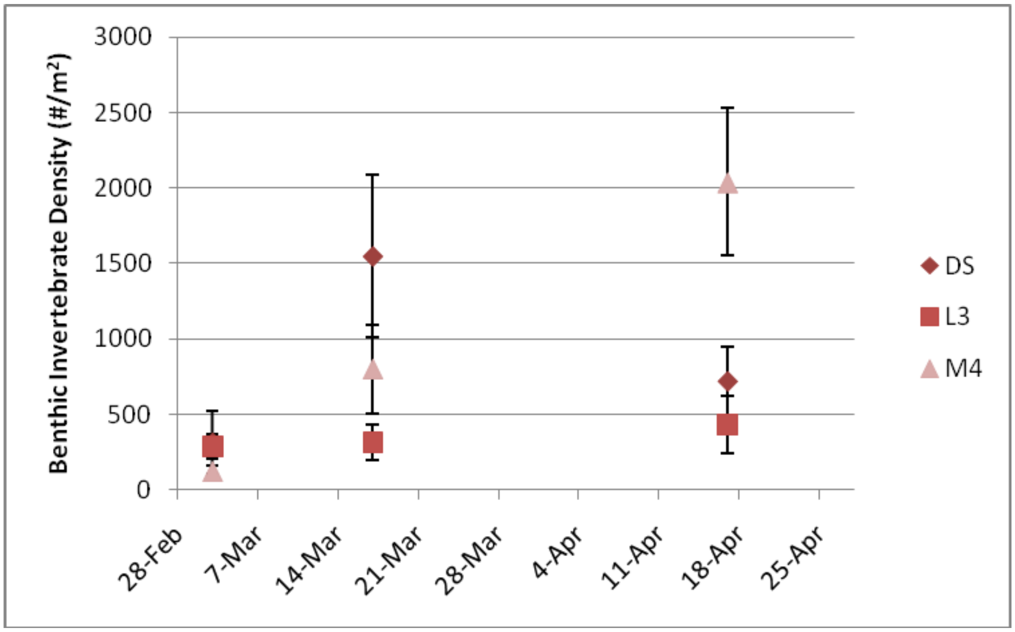

Figure 4-20: Benthic invertebrate density in modified drainage wetlands for 2007.

4.3.2.1 Distribution

Benthic invertebrate enumeration and identification data is presented in Table 4-2. Benthic invertebrates were predominantly Blood Worms (Chironomidae) and Tubifex Worms (Tubificidae). The overall density of benthic invertebrates increased throughout the season.

Table 4-2: Benthic invertebrate distribution

Taxa	% of Total Collected		
	March 3, 2007	March 17, 2007	April 17, 2007
# of Samples	N = 54	N = 36	N = 27
# Counted	n = 124	n = 308	n = 235
*Density (#/m^2)	280	700	1070
Chironomidae	67.7%	56.8%	74.0%
Tubificidae	22.6%	29.5%	20.4%
Hydrophilidae	9.7%	2.9%	2.6%
Other	0.0%	10.7%	3.0%
TOTAL	100.0%	100.0%	100.0%

*Standard errors ranged from 50-200 #/m^2

Table 4-4 summarizes the aquatic biota data in three columns:

1. Traditional

   This column contains average values from all data points taken at the traditional wetland sites (Ducky Strike North, Los Banos 31B, and Mud Slough 4B).
2. Modified: Traditional Period

   This column contains average values from all data points taken at the modified wetland sites (Ducky Strike South, Los Banos 33, and Mud Slough 3B) prior to the drawdown of the traditional wetlands.
3. Modified: Extended Period

   This column contains average values from all data points taken at the modified wetland sites (Ducky Strike South, Los Banos 33, and Mud Slough 4B) after the drawdown of the traditional wetlands, but before drainage of the modified wetlands had begun.

4.3.3 ***Aquatic Biota Summary***

As noted previously, VSS data were used to estimate phytoplankton biomass. During 2007 the average VSS concentration from all the transects and effluent points were similar over the season. No trends in the data were observed except that the VSS concentration increased during the extended drawdown period in 2007. There was a large difference between the mean VSS concentration in the traditional and modified wetlands during the traditional flooded period. This suggests differences in phytoplankton productivity between the wetland pairs.

Table 4-3: Aquatic biota data summary for 2007. Data is expressed as the mean +/- the standard deviation of the mean with the number of samples analyzed in parentheses.

	Traditional	Modified: Traditional Period	Modified: Extended Period
VSS (mg/L)	5.4 +/- 3.4 (43)	5.6 +/- 4.8 (62)	16 +/- 15 (27)
Zooplankton Mass (mg/L)	4.0 +/- 8.3 (39)	1.4 +/- 1.7 (54)	3.7 +/- 4.2 (24)
Benthic Density (#/L)	510 +/- 850 (37)	580 +/- 900 (55)	1000 +/- 1200 (24)

Table 4-4: Aquatic biota data summary for 2008. Data are expressed as the mean +/- the standard deviation of the mean with the number of samples analyzed in parentheses.

	Traditional	Modified: Traditional Period	Modified: Extended Period
VSS (mg/L)	5.9 +/- 4.3 (6)	10 +/- 7.1 (6)	6.5 +/- 3.8 (9)
Zooplankton Mass (mg/L)	1.4 +/- 1.5 (6)	0.81 +/- 1.0 (6)	0.90 +/-0.70 (9)

4.4 Water Quality

The following sections contain water quality sampling data for the study which includes measurements of nitrogen, phosphorus, organic carbon, and salinity concentrations at the study sites.

4.4.1 Nitrogen

Inorganic nitrogen results are presented below. Nitrate, nitrite, ammonia, and total Kjeldahl concentrations were determined from the water quality samples collected.

4.4.1.1 Traditional Wetlands

The concentrations of $NO_3^-$and NO_2^- in samples were low during both 2007 and 2008 (<1 mg/L). The $NO_3^-$and NO_2^- concentrations decreased in all three traditionally drained wetlands during 2007 (Figure 4-21). This corresponded with increases in phytoplankton concentration in all three wetlands (). During 2008 the $NO_3^-$and NO_2^- concentrations increased in two of three wetlands (Figure 4-22). This corresponded to a decrease in phytoplankton concentrations in the same two wetlands (Figure 4-7). $NO_3^-$and NO_2^- concentrations decreased in the Mud Slough 3b wetland, which corresponded with increases in phytoplankton.

Ammonia concentration increased in all three traditionally drained wetlands during 2007 while they decreased in all three wetlands during 2008 (Figure 4-23 and Figure 4-24 respectively). Large increases in ammonia during 2007 were likely due to scour since samples were taken after wetland drawdown had begun.

Total Kjeldahl nitrogen concentration remained constant in the traditionally drained wetlands near 1.5 mg/L (Figure 4-25).

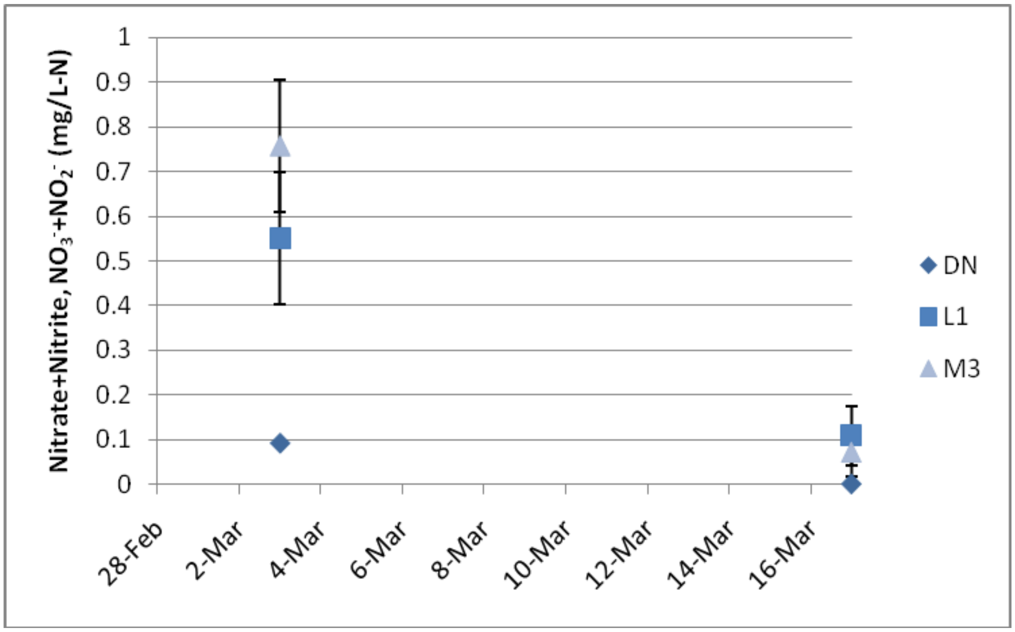

Figure 4-21: Nitrate + Nitrite nitrogen concentrations in traditional drainage wetlands for 2007.

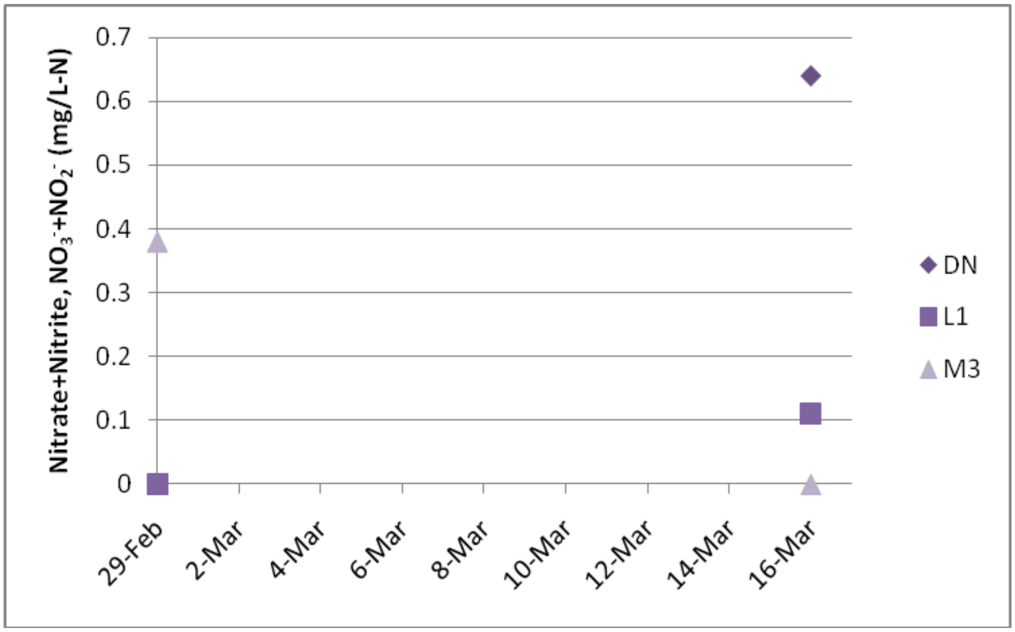

Figure 4-22: Nitrate + Nitrite nitrogen concentrations in traditional drainage wetlands for 2008.

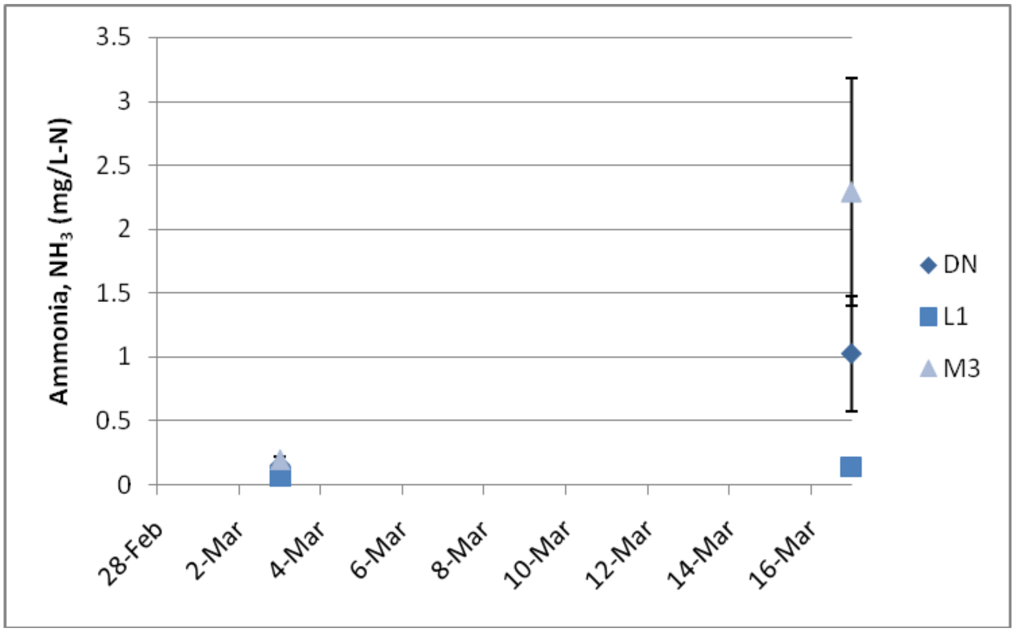

Figure 4-23: Total ammonia nitrogen concentration in traditional drainage wetlands for 2007.

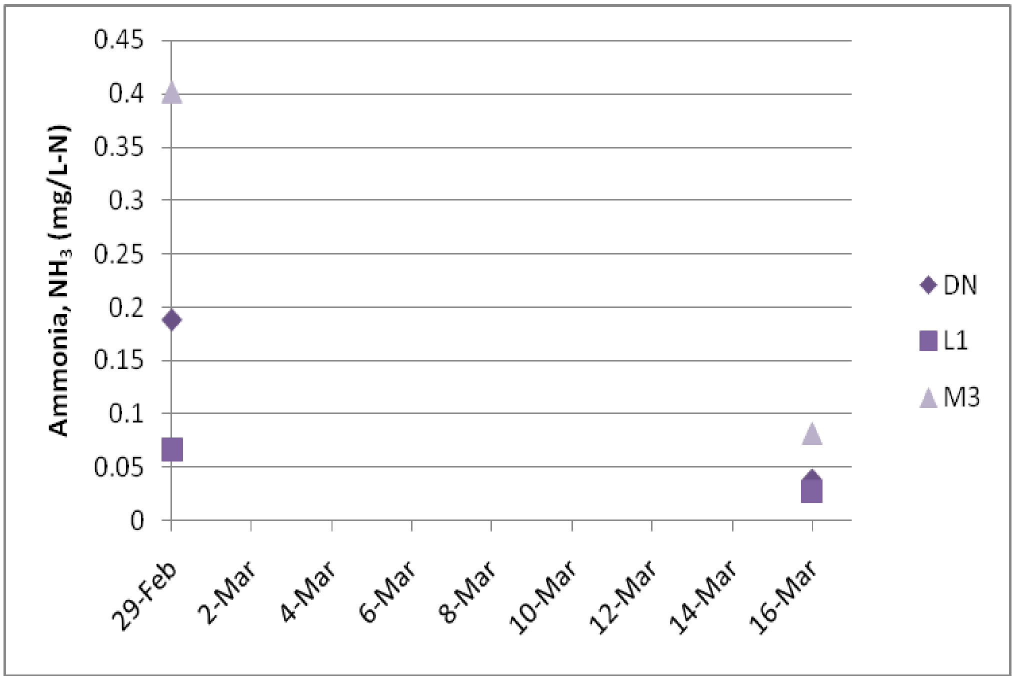

Figure 4-24: Total ammonia nitrogen concentration in traditional drainage wetlands for 2008.

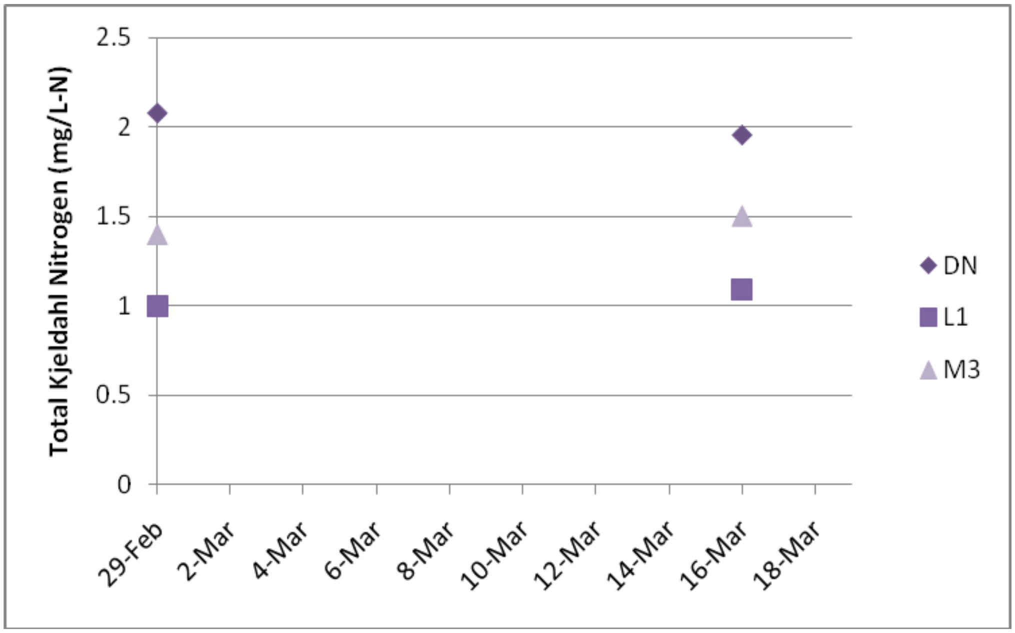

Figure 4-25: Total Kjeldahl Nitrogen concentration in traditional drainage wetlands for 2008.

4.4.1.2 Modified Wetland Hydrology

Concentrations of NO_3^- and NO_2^- were low during the flooded periods of both 2007 and 2008 (<1mg/L). NO_3^- and NO_2^- concentrations decreased in all three modified drainage wetlands during 2007 (Figure 4-26). This corresponded with and increase in phytoplankton concentration in all but the Los Banos 33b wetland (Figure 4-8). During the 2008 season, NO_3^- and NO_2^- concentrations decreased initially and were reduced to non-detect in all three wetlands during the drawdown period. These results emulate the trend of phytoplankton concentration (Figure 4-9) – both NO_3^- and NO_2^- decreasing during phytoplankton growth and increasing during decay.

Ammonia concentration was also low during both 2007 and 2008 (<0.5 mg/L). Ammonia levels initially increased and then decreased in the modified drainage wetlands during the 2007 flooded season (Figure 4-28). Ammonia concentration decreased throughout the season during 2008 before drainage drawdown was initiated (Figure 4-29). During drawdown, ammonia concentration increased significantly in all wetlands. This was most likely due to the scouring of nutrient rich sediments within the wetlands.

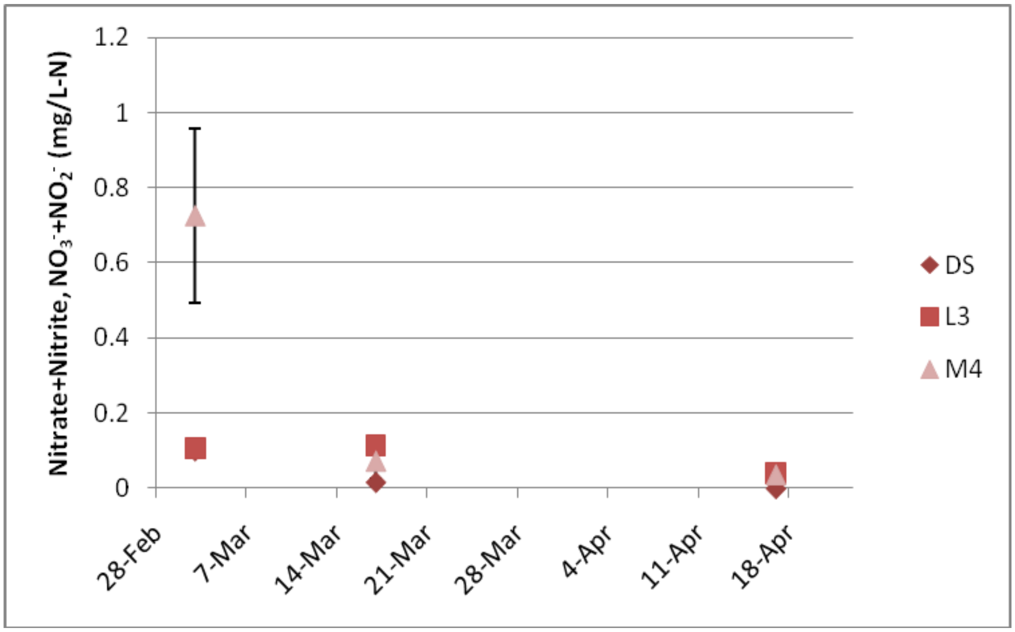

Figure 4-26: Nitrate + Nitrite nitrogen concentrations in modified drainage wetlands for 2007.

Total Kjeldahl nitrogen concentration remained relatively constant in the modified drainage wetlands throughout the 2008 flooded season near 2 mg/L (Figure 4-30). During the drainage period, total Kjeldahl nitrogen concentration increased. This was also likely due to scouring of nutrient rich soils and periphyton from increased flow during drawdown.

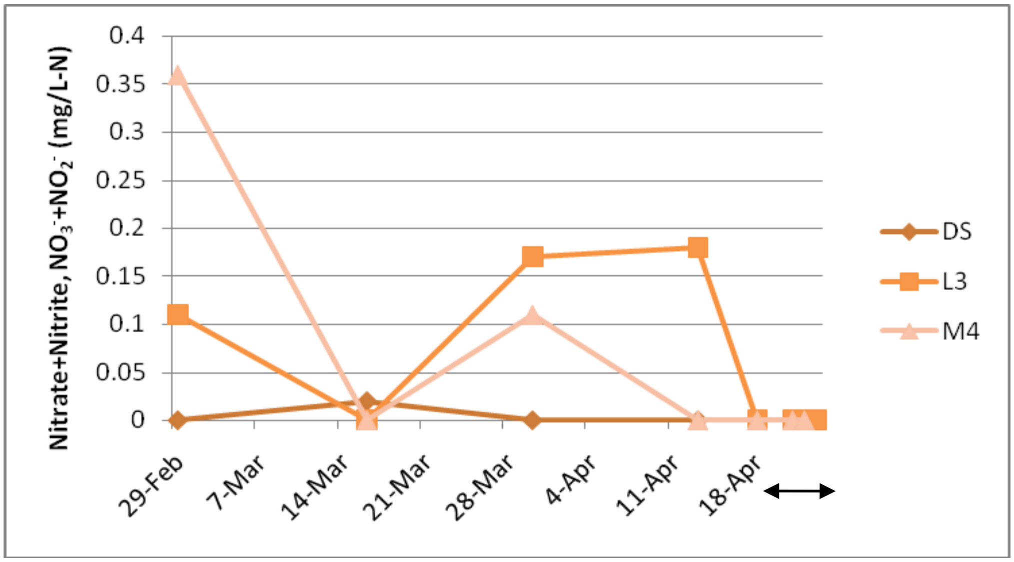

Figure 4-27: Nitrate + Nitrite nitrogen concentrations in modified drainage wetlands for 2008. The drawdown period is indicated by the line with an arrow.

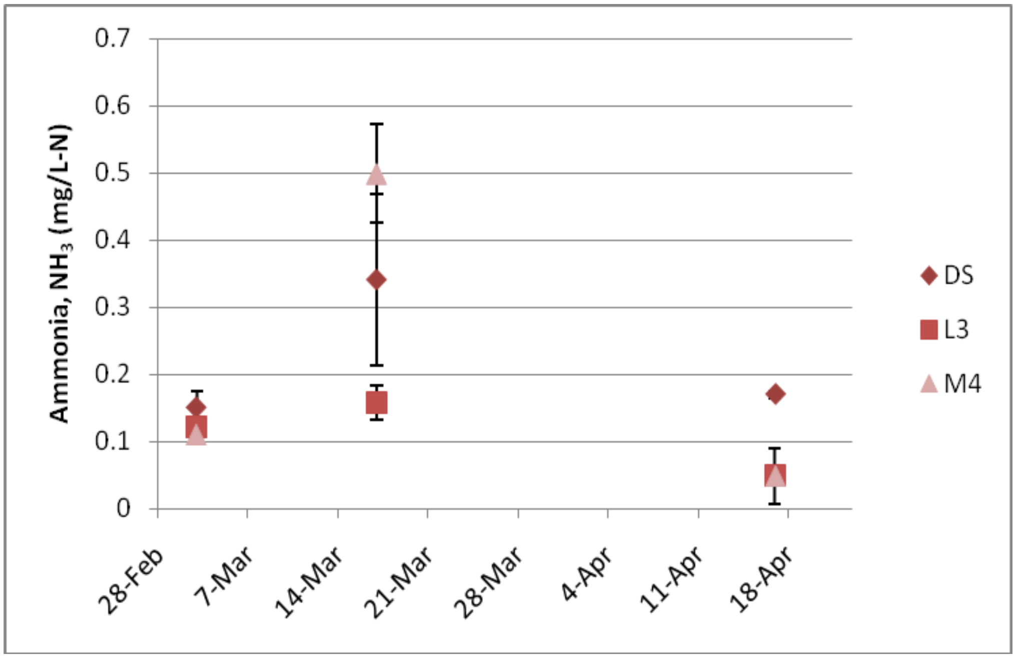

Figure 4-28: Total ammonia nitrogen concentration in modified drainage wetlands for 2007.

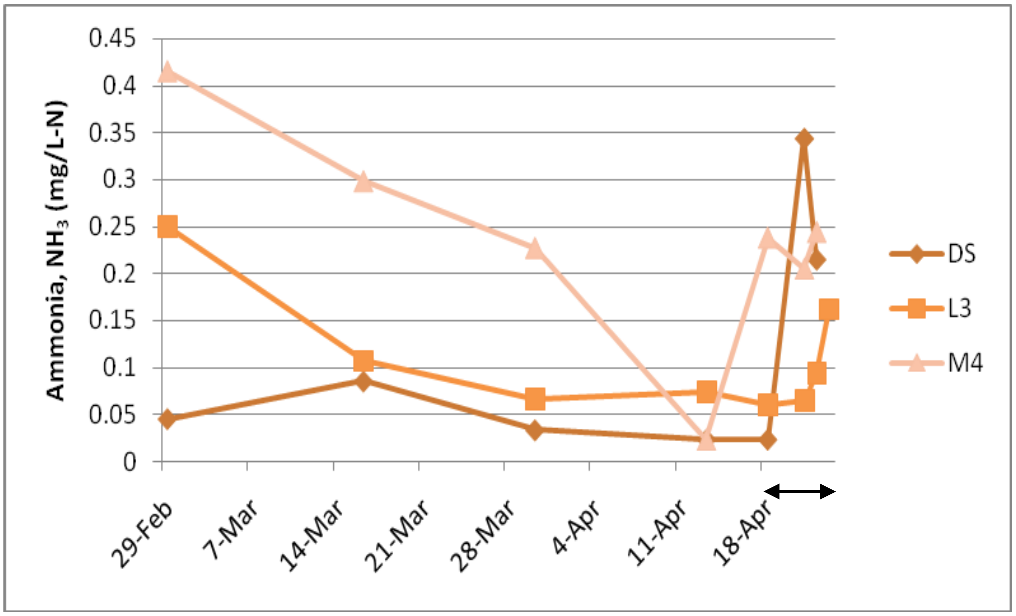

Figure 4-29: Total ammonia nitrogen concentration in modified drainage wetlands for 2008. The drawdown period is indicated with an arrow.

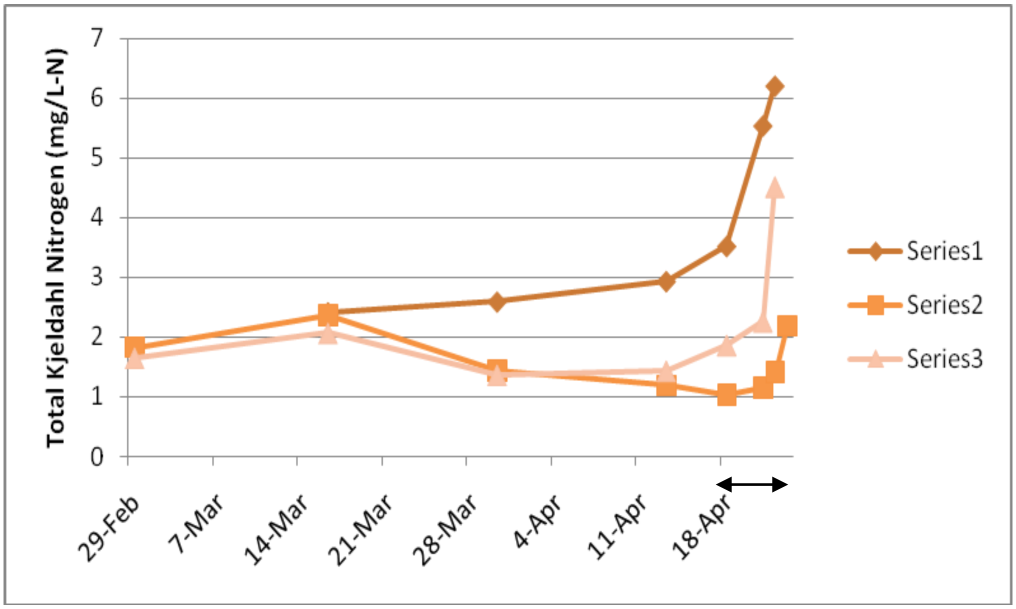

Figure 4-30: Total Kjeldahl nitrogen concentration in modified drainage wetlands for 2007. The drawdown period is indicated by the line with an arrow.

4.4.1.3 Drainage Sites

NO_3^-+NO_2^- levels varied dramatically at all of the drainage sites (Figure 4-31). Ammonia concentration varied slightly between 0.035 and 0.095 mg/L-N (Figure 4-32). Total Kjeldahl nitrogen concentration increased slightly throughout the season but remained below 2 mg/L (Figure 4-33).

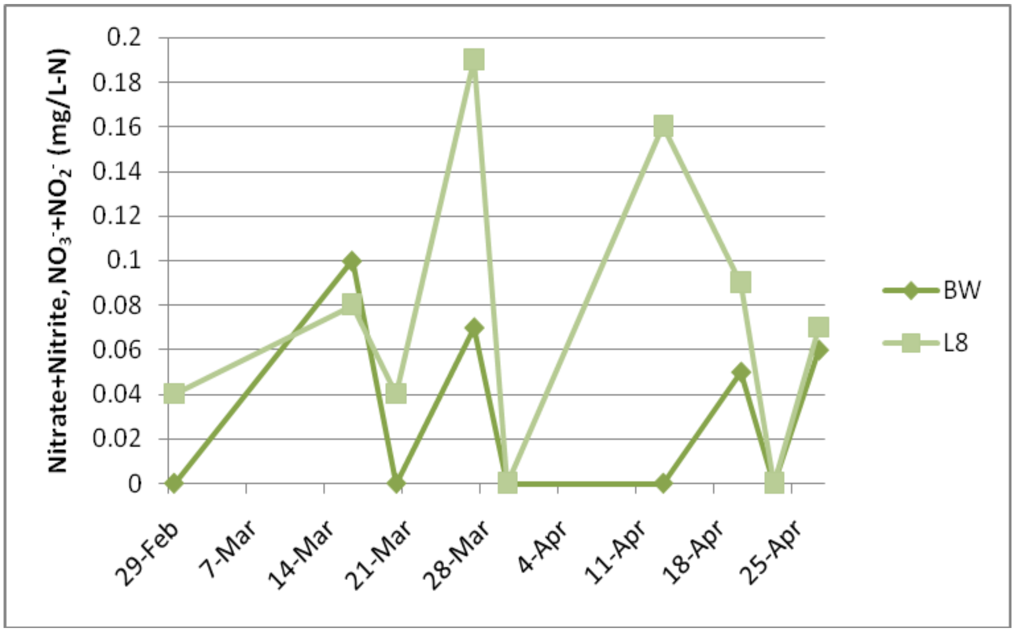

Figure 4-31: Nitrate + Nitrite nitrogen concentrations at the drainage sites for 2008.

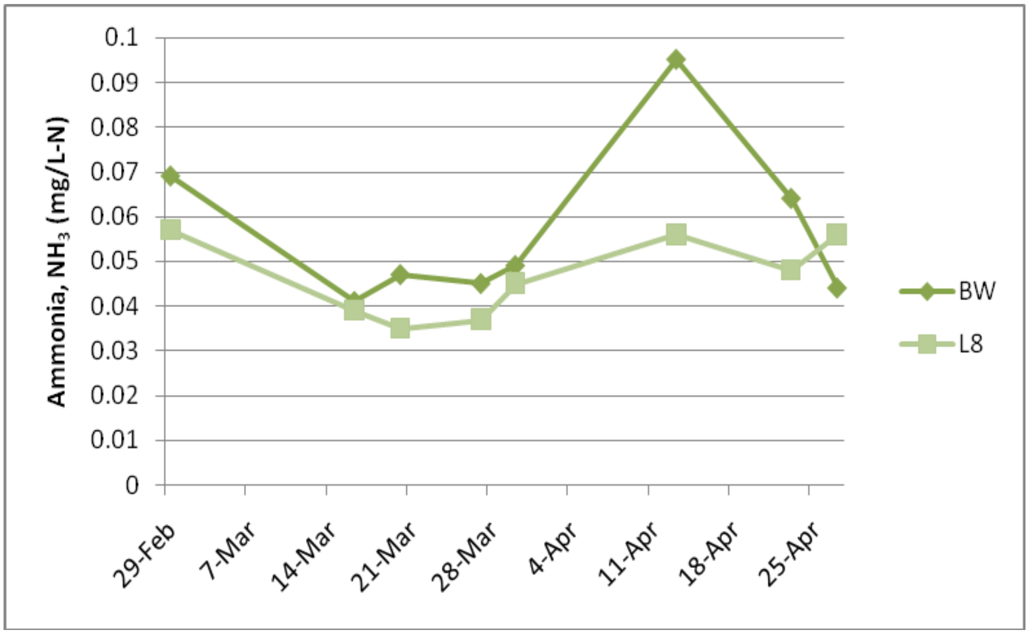

Figure 4-32: Total ammonia nitrogen concentration at the drainage sites for 2008.

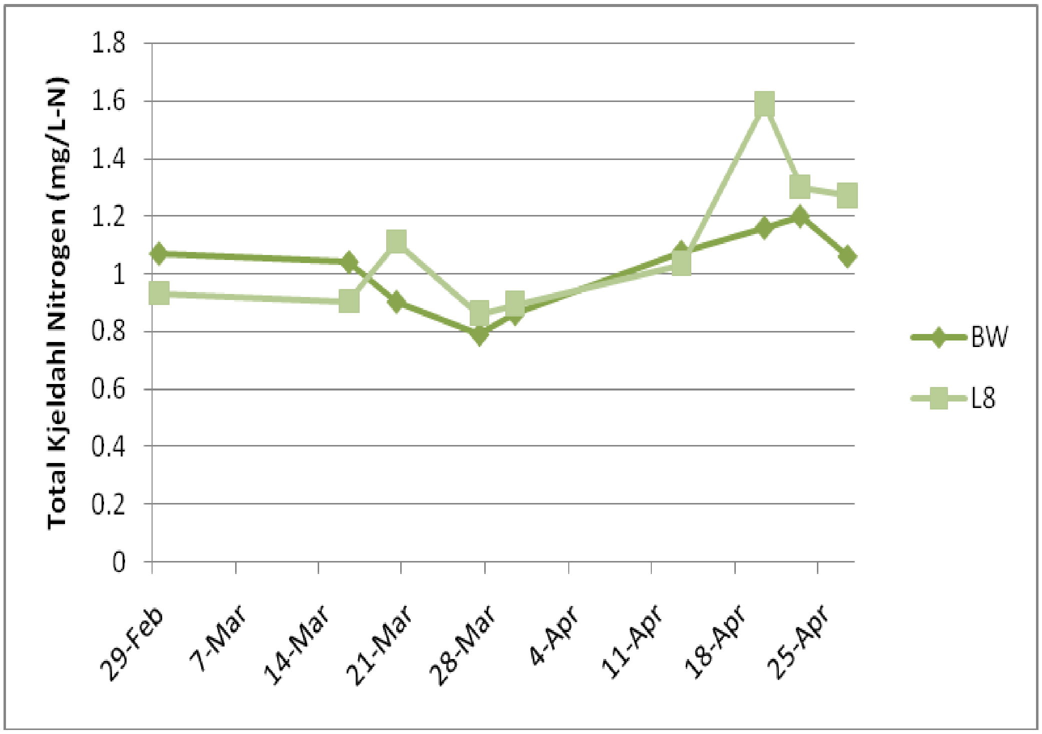

Figure 4-33: Total Kjeldahl nitrogen concentration at the drainage sites for 2008.

4.4.2 Phosphorus

Phosphorus results are presented below. Orthophosphate and total phosphorus concentrations were determined from the field samples.

4.4.2.1 Traditional Wetlands

In traditionally drained wetlands the phosphate concentration in samples taken was consistently below 0.4 mg/L (Figure 4-34 and Figure 4-35). Phosphate concentration increased in two of three wetlands during 2007 (Figure 4-34). Total phosphorus concentration increased in all three wetlands in 2007 (Figure 4-36). During 2008 phosphate concentration increased in all three wetlands but remained below 0.09 mg/L (Figure 4-35). Total phosphorus concentration decreased in two of three wetlands (Figure 4-37) and were below 0.3 mg/L.

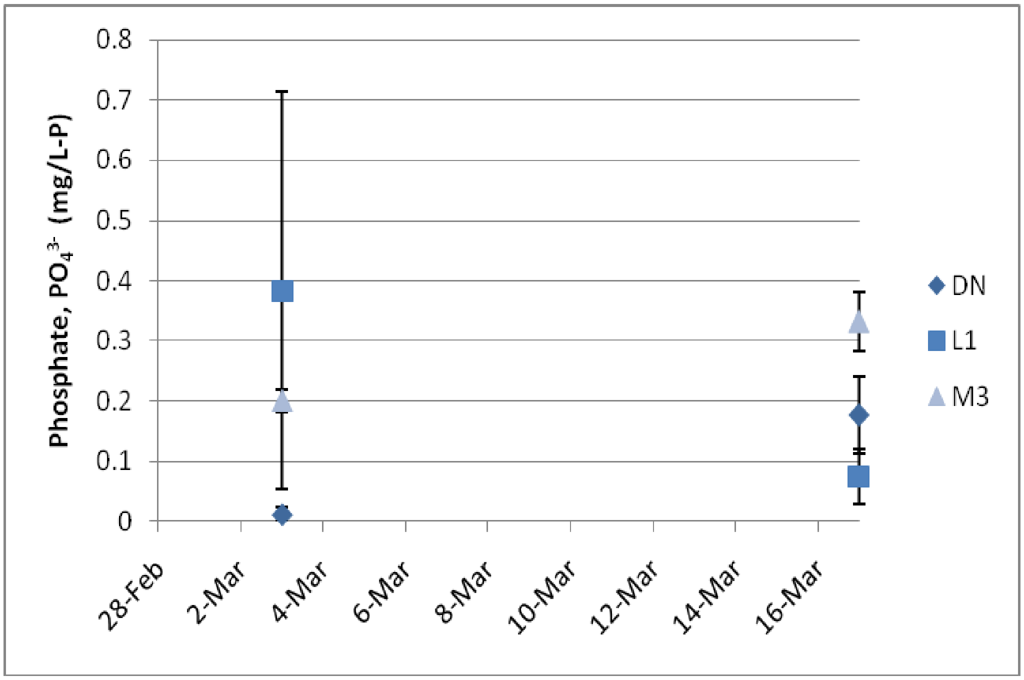

Figure 4-34: Phosphate concentration in traditional drainage wetlands for 2007.

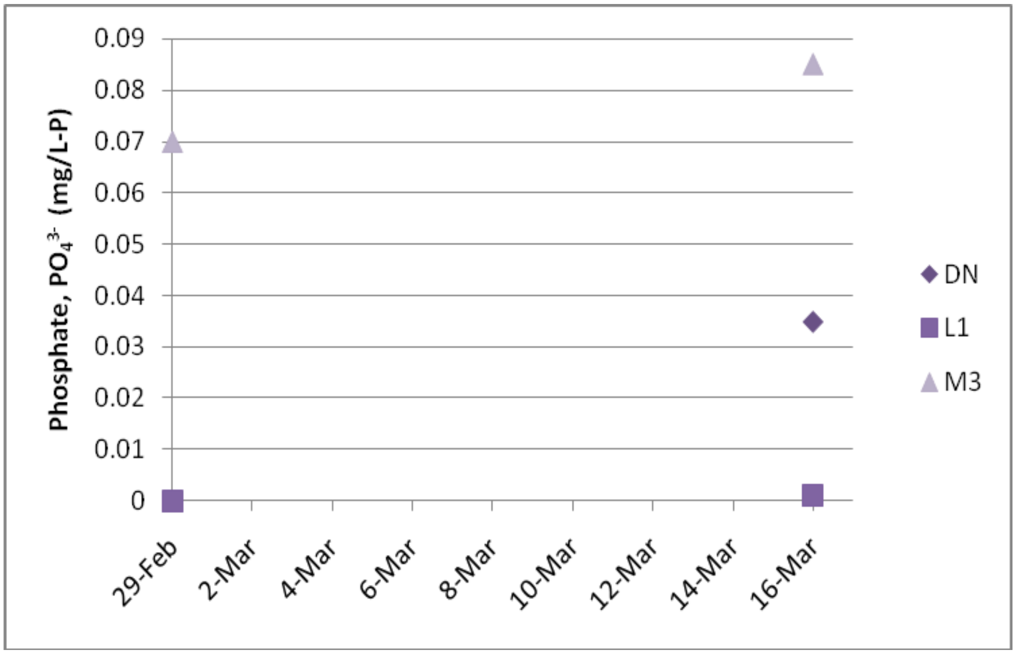

Figure 4-35: Phosphate concentration in traditional drainage wetlands for 2008.

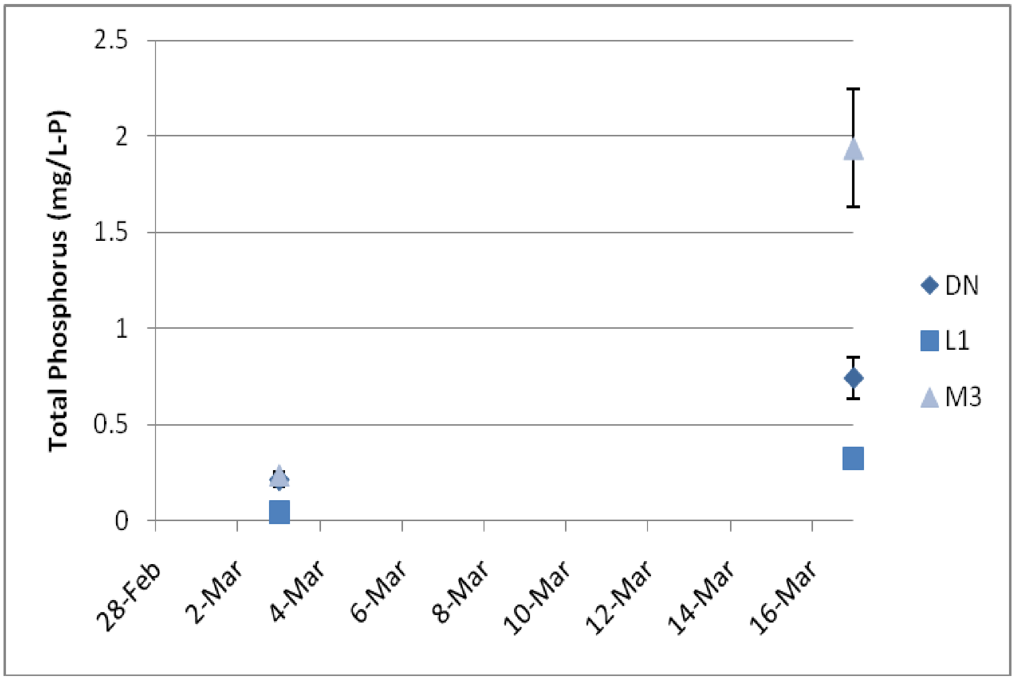

Figure 4-36: Total phosphorus concentration in traditional drainage wetlands for 2007..

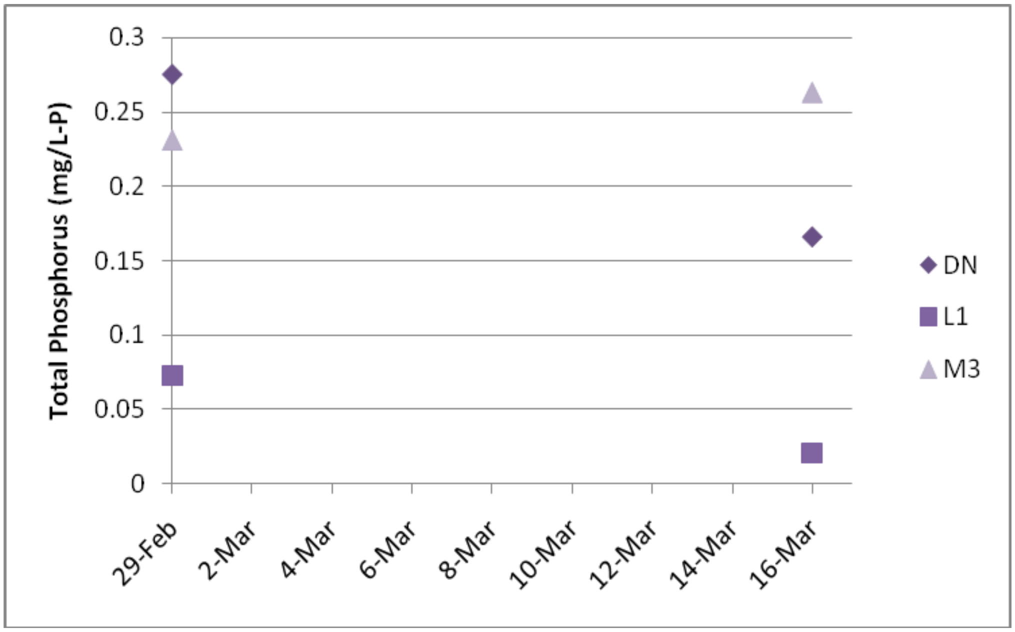

Figure 4-37: Total phosphorus concentration in traditional drainage wetlands for 2008 .

4.4.2.2 Modified Wetland Hydrology

During the 2007 flooded season, phosphate concentration remained below 0.4 mg/L in the modified drainage wetlands. There was an initial increase in phosphate concentration followed by a decrease during the extended flood period (Figure 4-38). Total phosphorus concentration in samples followed the same trend except for Ducky Strike South, which increased in total phosphorus throughout the extended flood period (Figure 4-39). However total phosphorus concentration remained below 1 mg/L.

During 2008, phosphate concentration remained below 0.2 mg/L, but did not follow an upward or downward trend (Figure 4-39). During drainage drawdown, phosphate concentration increased initially then decreased in all two of three wetlands. Phosphate concentration in Ducky Strike South increased throughout the drainage period. Total phosphorus concentration remained below 1 mg/L. Concentration increased during the extended flood period in all three wetlands. During drainage, there was an initial decrease in total phosphorus concentration followed by a large increase. The large increase in concentration of phosphate is likely due to the scouring of nutrient rich sediments and periphyton during drawdown.

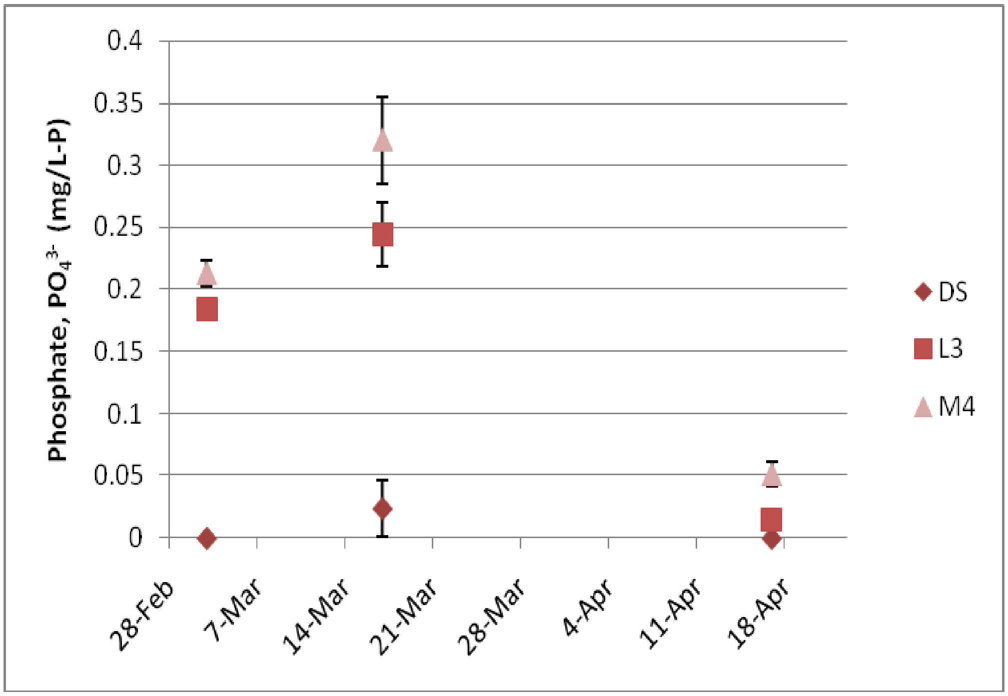

Figure 4-38: Phosphate concentration in modified drainage wetlands for 2007.

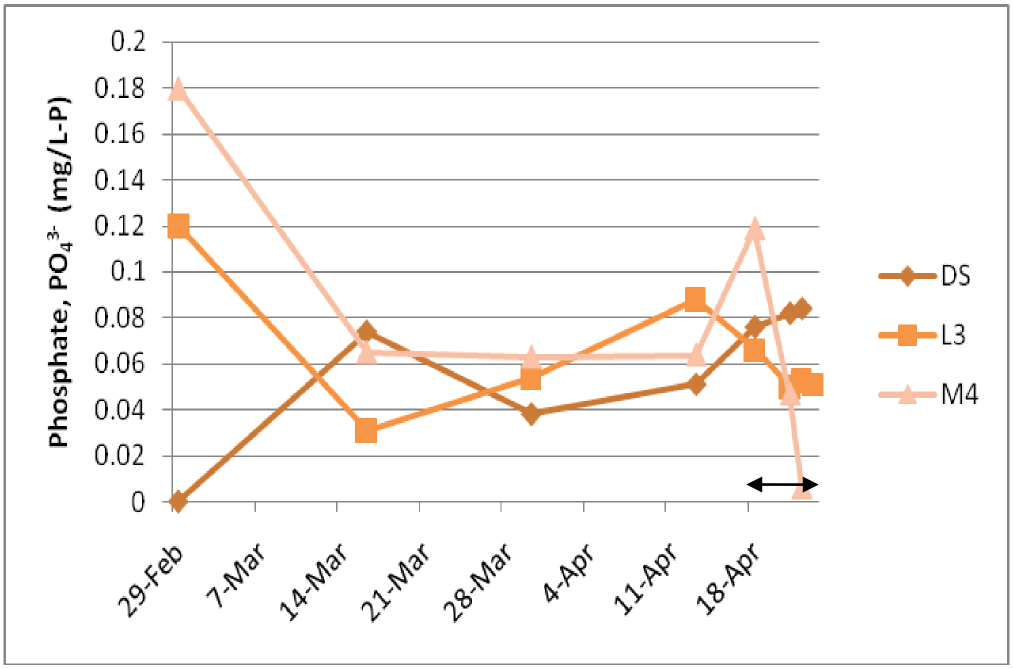

Figure 4-39: Phosphate concentration in modified drainage wetlands for 2008. The drawdown period is indicated by the line with the arrow.

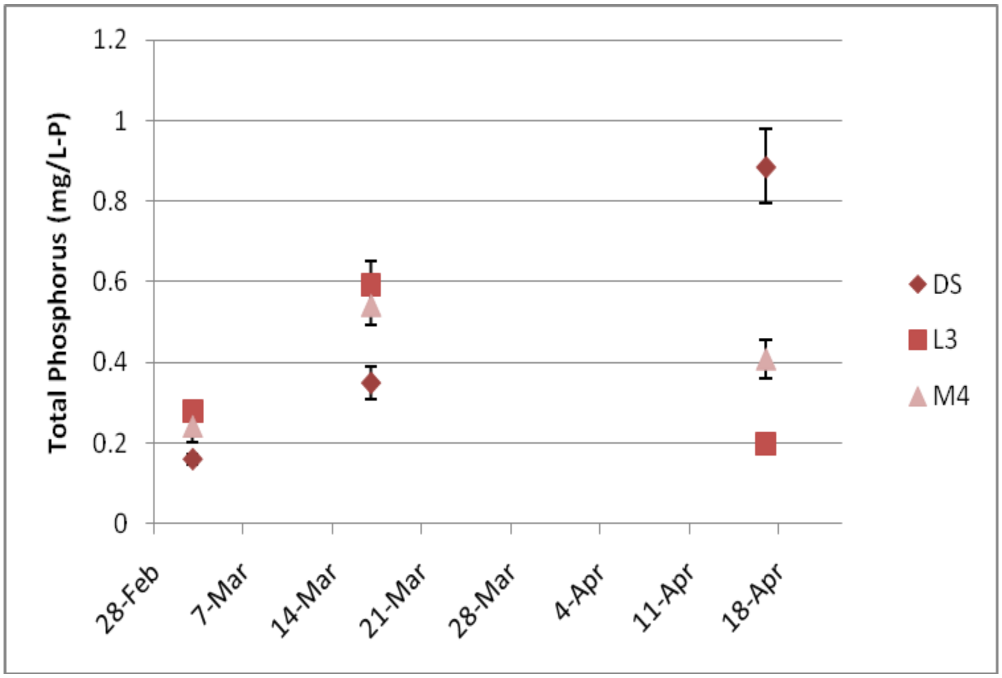

Figure 4-40: Total phosphorus concentration in modified drainage wetlands for 2007.

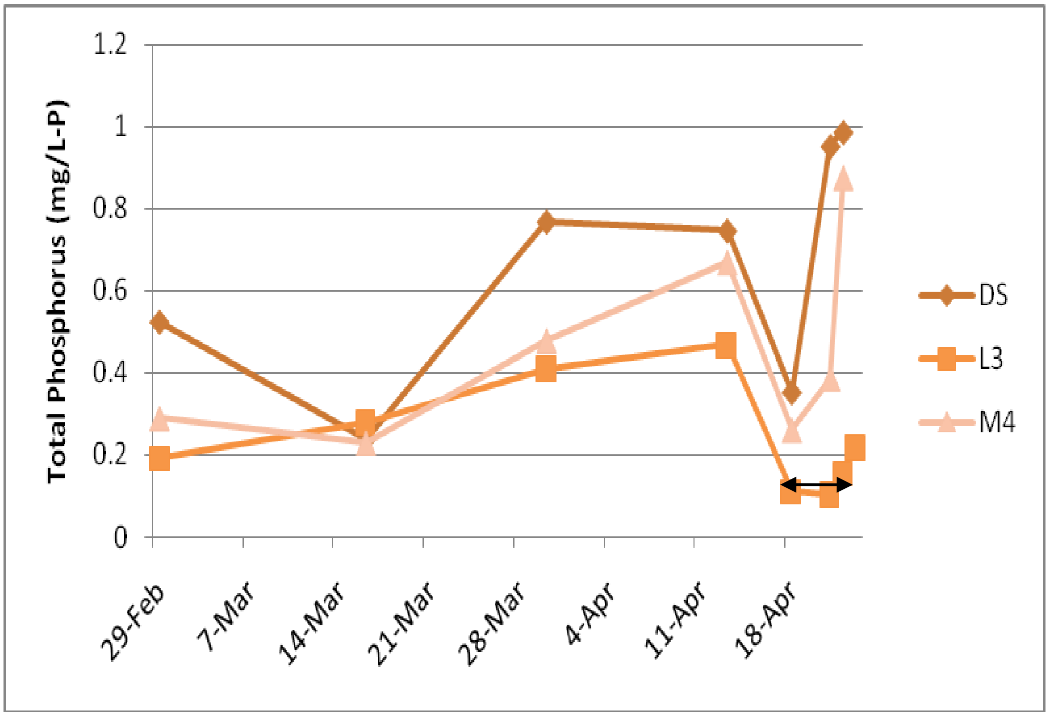

Figure 4-41: Total phosphorus concentration in modified drainage wetlands for 2008. The drawdown period is indicated by the arrow.

4.4.2.3 Drainage Sites

Phosphate concentration at the drainage sites remained below 0.25 mg/L at the drainage sites during the 2008 flooded season (Figure 4-42). There was a slight increase in phosphate concentration at both sites throughout the season. Total phosphorus concentration remained below 1 mg/L (Figure 4-43). No change in phosphate or total phosphorus concentrations was observed in the samples drawn during drawdown for the studied wetlands.

4.4.3 Organic Carbon

Total and dissolved organic carbon was measured during the 2008 sampling season. Organic carbon concentration remained constant throughout the flooded period. During drawdown, both dissolved and total organic carbon concentrations increased substantially as seen in Figure 4-46 and Figure 4-47. At all sites, the majority of the total organic carbon consisted of dissolved organic carbon. Using all 2008 data points, dissolved organic carbon contributed 80 +/- 13% (mean +/- standard deviation) of the total organic carbon than the other traditional wetlands.

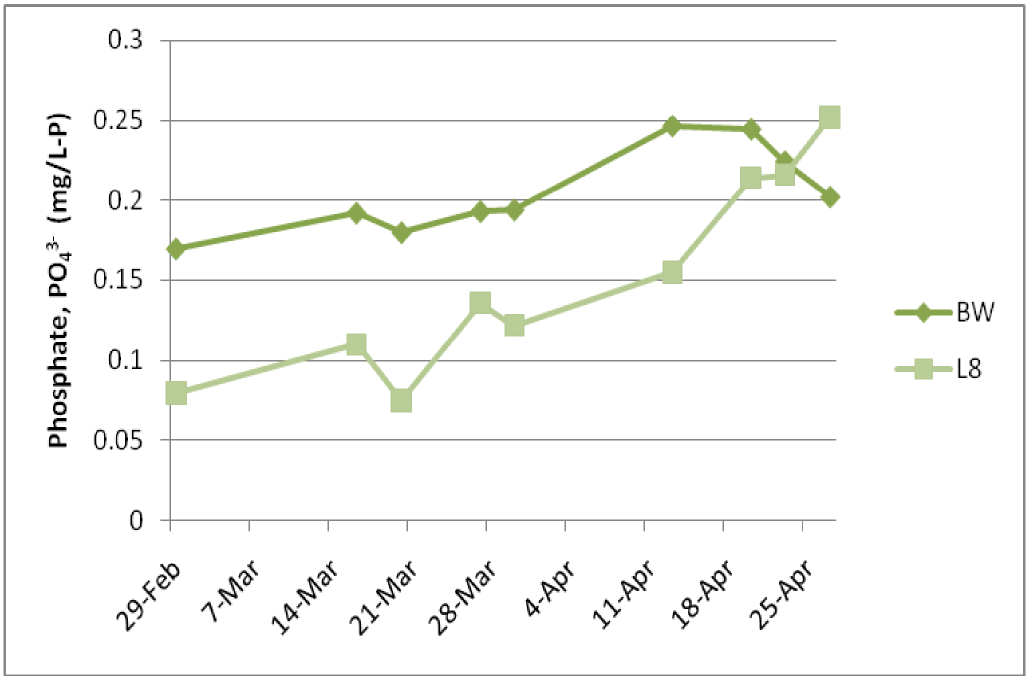

Figure 4-42: Phosphate concentration at drainage sites for 2008.

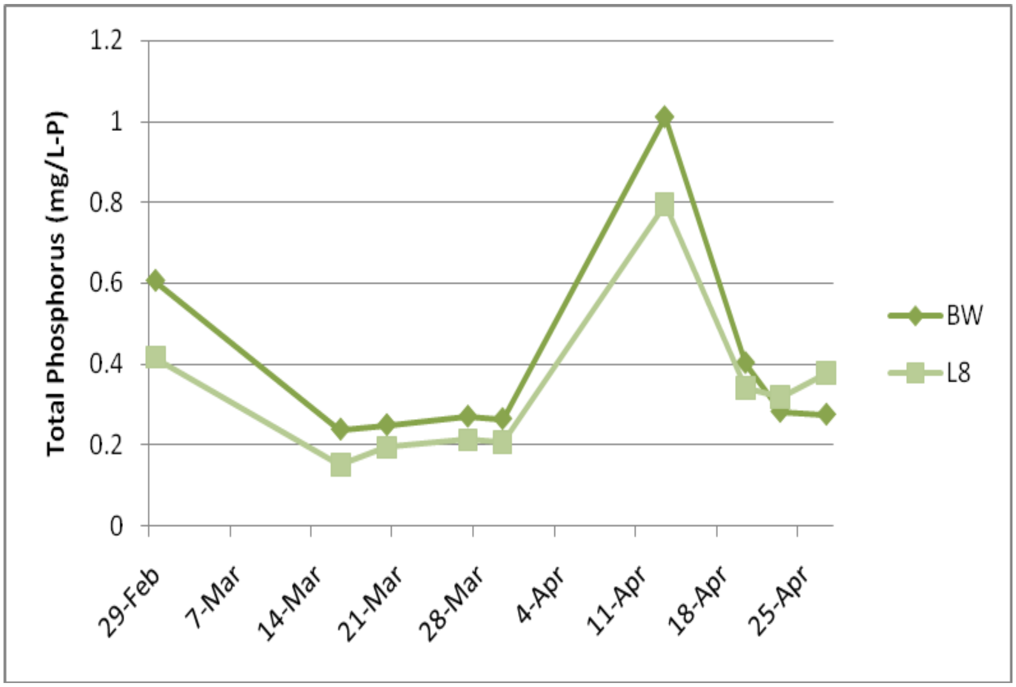

Figure 4-43: Total phosphorus concentration at drainage sites for 2008.

4.4.3.1 Traditional Wetlands

Dissolved and total organic carbon remained constant for all traditional wetlands throughout the season (Figure 4-44 and Figure 4-45). Ducky Strike North had consistently more dissolved and total organic carbon.

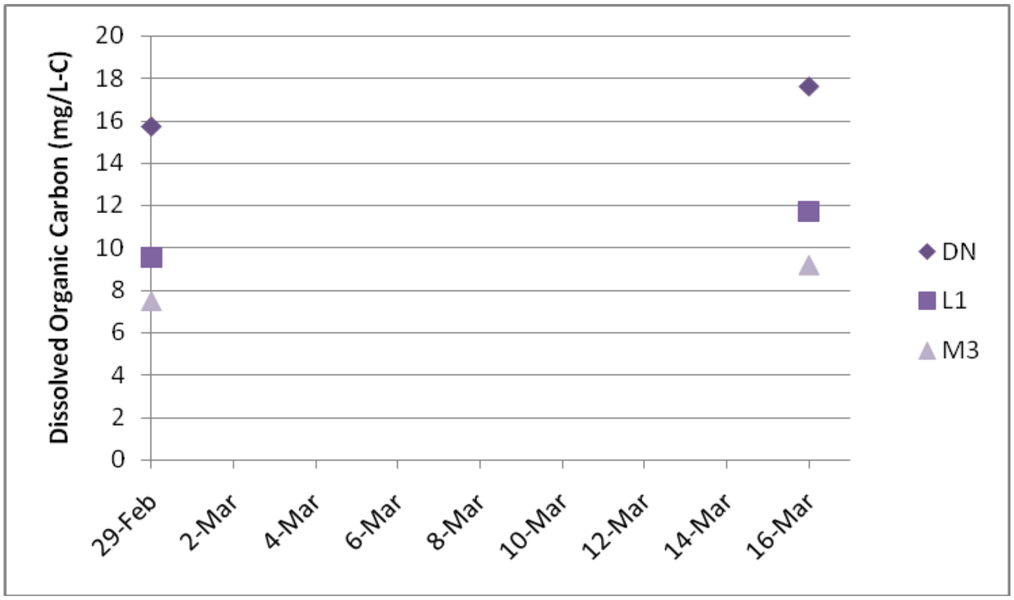

Figure 4-44: Dissolved organic carbon concentrations in traditional drainage wetlands for 2008.

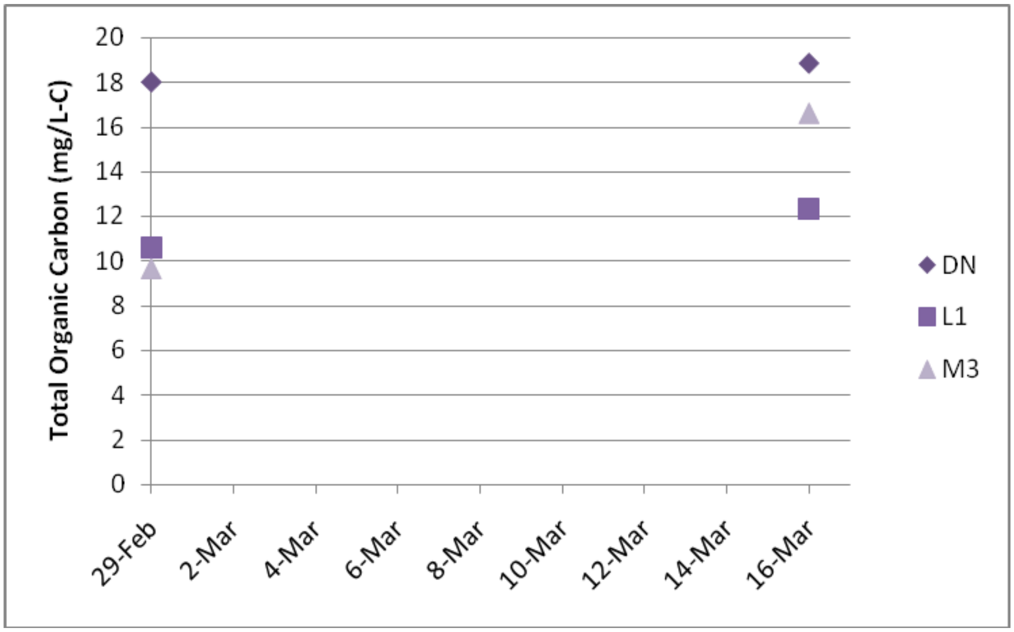

Figure 4-45: Total organic carbon concentrations in traditional drainage wetlands for 2008. Particulate organic carbon load was estimated at 52% of VSS.

4.4.3.2 Modified Wetlands

Dissolved and total organic carbon concentrations remained constant throughout the season in Los Banos 33 and Mud Slough 4b, while a general increase was observed throughout the season in Ducky Strike South (Figure 4-46 and Figure 4-47). Organic carbon concentration increased substantially in all three wetlands during the drawdown period probably due to scouring of nutrient rich sediments and periphyton. Total organic carbon concentration was as high as 65.7 mg/L-C in Ducky Strike South.

4.4.3.3 Drainage Sites

Total and dissolved organic carbon concentrations in samples taken at the wetland drainage sites remained between 10 – 18 mg/L-C (Figure 4-48 and Figure 4-49). Twin spikes in concentration were noticed at both sites approximately one week after wetland drawdown at the project sites. The spikes were likely due to scouring of nutrient rich sediments and periphyton. At the drainage sites, dissolved organic carbon contributed 88 +/- 3% (mean +/- standard deviation) of the total organic carbon content.

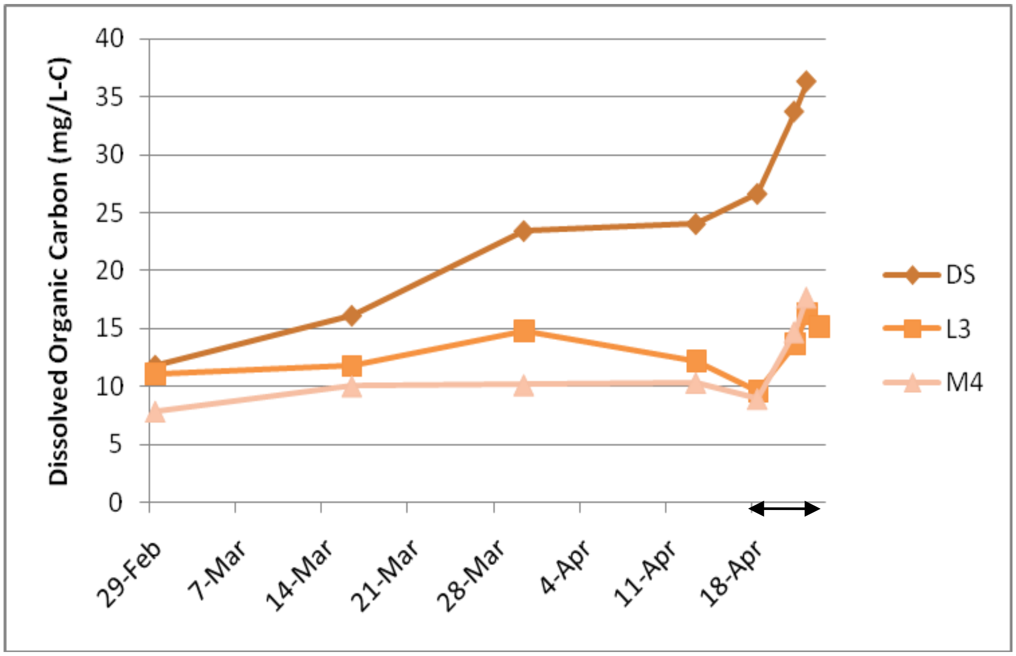

Figure 4-46: Dissolved organic carbon concentration in modified drainage wetlands for 2008. The drawdown period is indicated with an arrow.

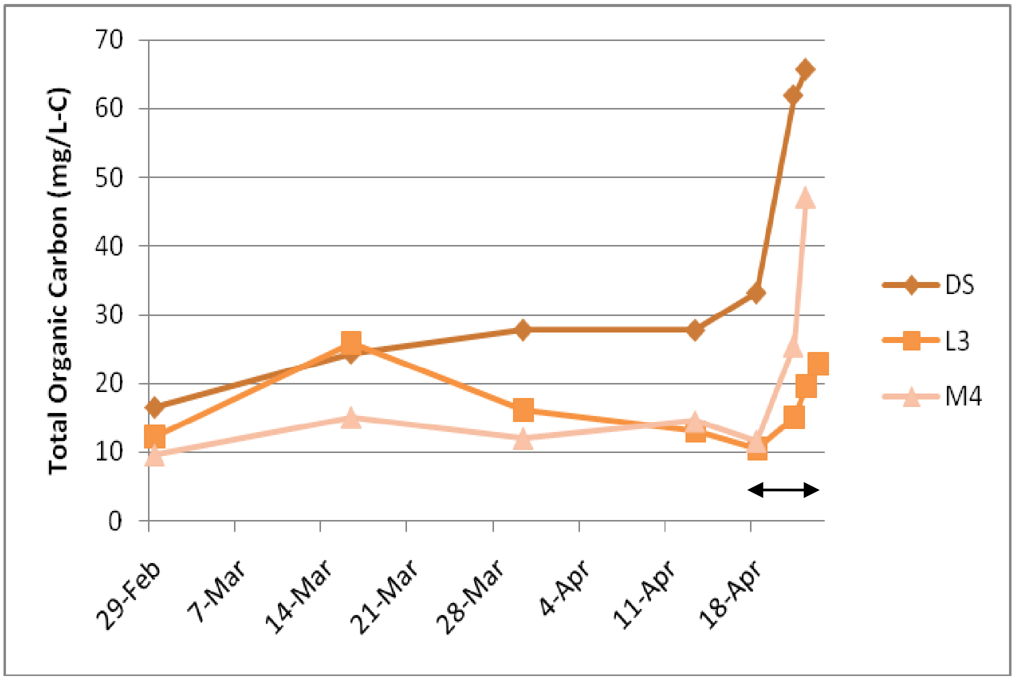

Figure 4-47: Total organic carbon concentration in modified drainage wetlands for 2008. Particulate organic carbon was estimated at 52% of VSS. The drawdown period is indicated with an arrow.

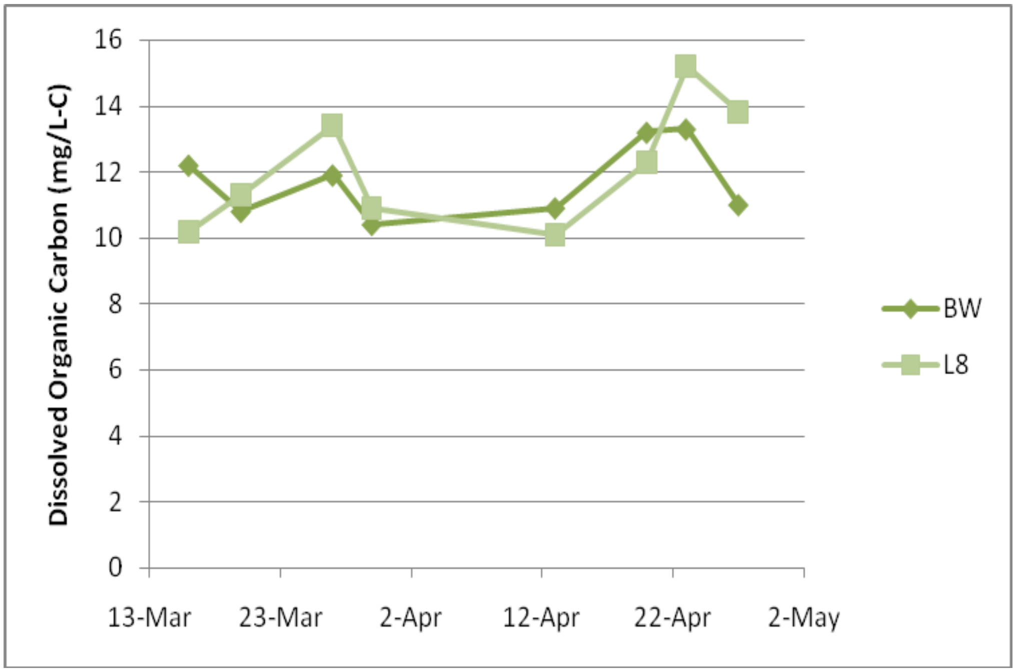

Figure 4-48: Dissolved organic carbon concentration at drainage sites for 2008.

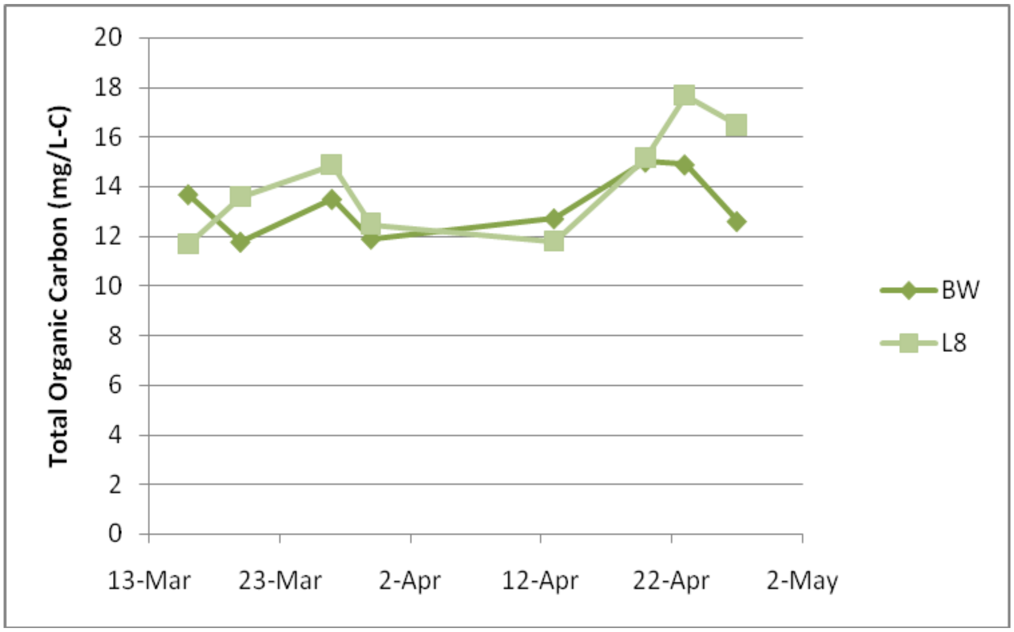

Figure 4-49: Total organic carbon concentration at drainage sites for 2008. Particulate organic carbon loading was estimated to be approximately 52% of VSS.

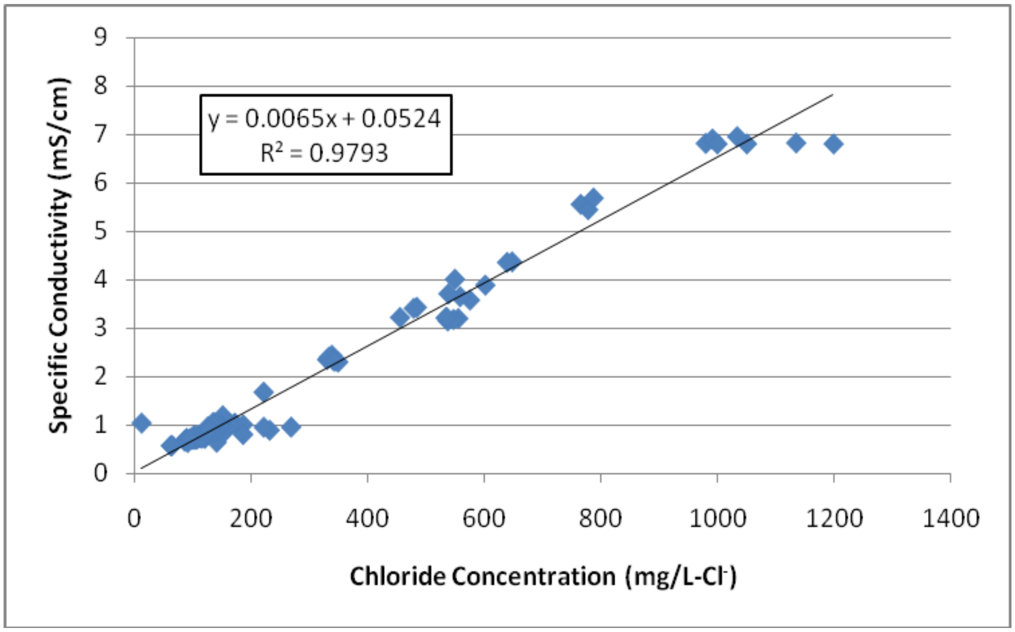

Figure 4-50: Correlation between specific conductivity and chloride concentrations. Data is for 2007.

4.4.4 Salinity

Salinity was measured by conductivity and chloride concentration. A strong correlation was found between chloride concentration and conductivity during the 2007 flooded season (Figure

4-50). Since not all samples were tested for conductivity, this correlation was used to convert chloride concentrations to conductivity measurements.

4.4.4.1 Traditional Wetlands

Specific conductivity readings increased slightly in two of three traditional drainage wetlands during the 2007 sampling season (Figure 4-51). In the Los Banos 31b wetland, specific conductivity values slightly decreased. This may be due to the introduction of freshwater during

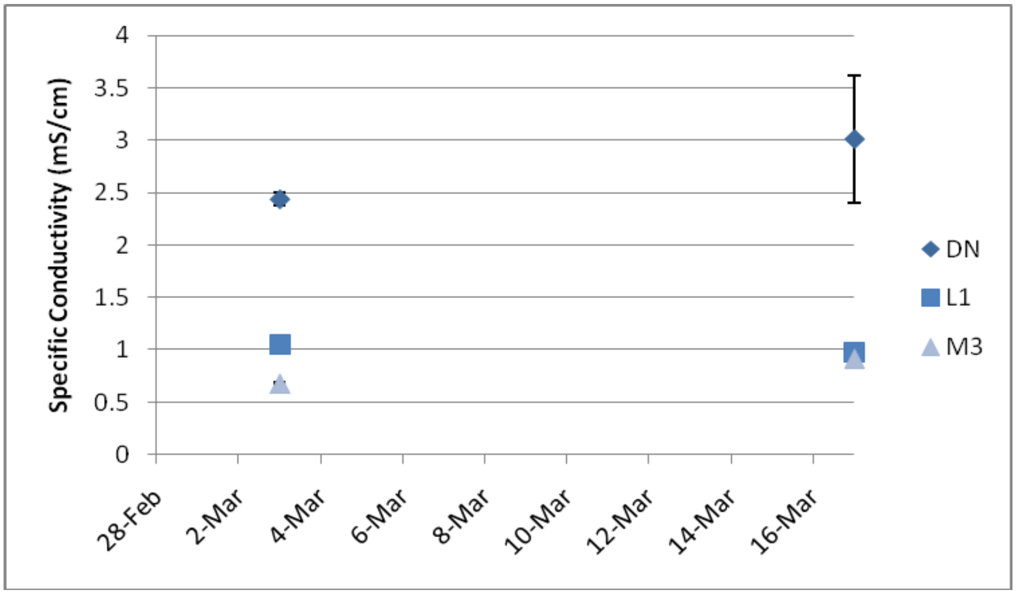

Figure 4-51: Specific conductivity results from traditional drainage wetlands for 2007.

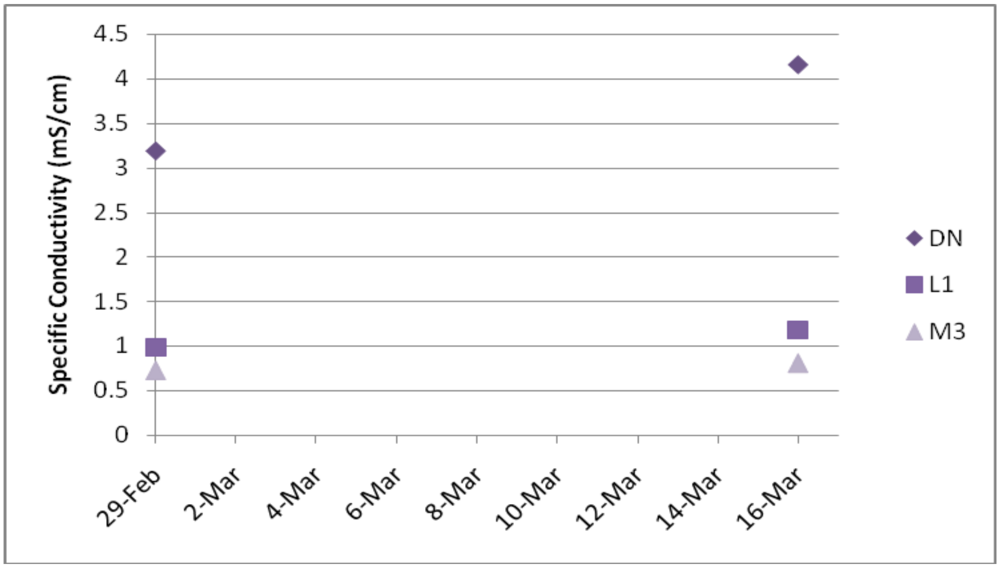

Figure 4-52: Specific conductivity results from traditional drainage wetlands for 2008.

the season. The Los Banos wetlands are also deeper than the other wetlands and are less prone to evapotranspiration. During the 2008 season, specific conductivity readings increased in all three traditional drainage wetlands. The largest increases were noticed in the Ducky Strike North, which are shallower than the other wetlands and are more susceptible to the effects of evapotranspiration.

4.4.4.2 Modified Wetland Hydrology

Specific conductivity increased slightly in two of three modified drainage wetlands during 2007 (Figure 4-53). In the Los Banos 33 wetland, specific conductivity decreased slightly. This may be due to the introduction of freshwater or rainfall during the flooded season. The Los Banos WMA wetlands are also deeper than the other wetlands and lose less evapotranspiration as a fraction of the flooded area. Specific conductivity increased in all three wetlands during the 2008 flooded season (Figure 4-54). The greatest increase was observed in Ducky Strike South, which is shallow and where evapotranspiration is likely to have a greater impact on water quality. During the 2008 drawdown , specific conductivity increased substantially reaching almost 9 mS/cm in the Ducky Strike South.

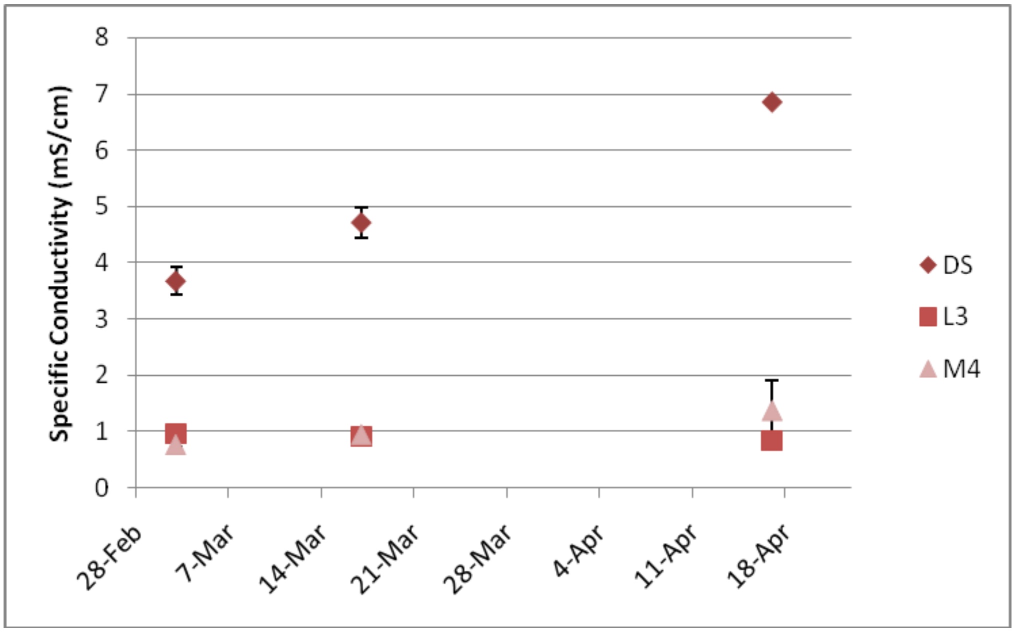

Figure 4-53: Specific conductivity readings from modified drainage wetlands for 2007.

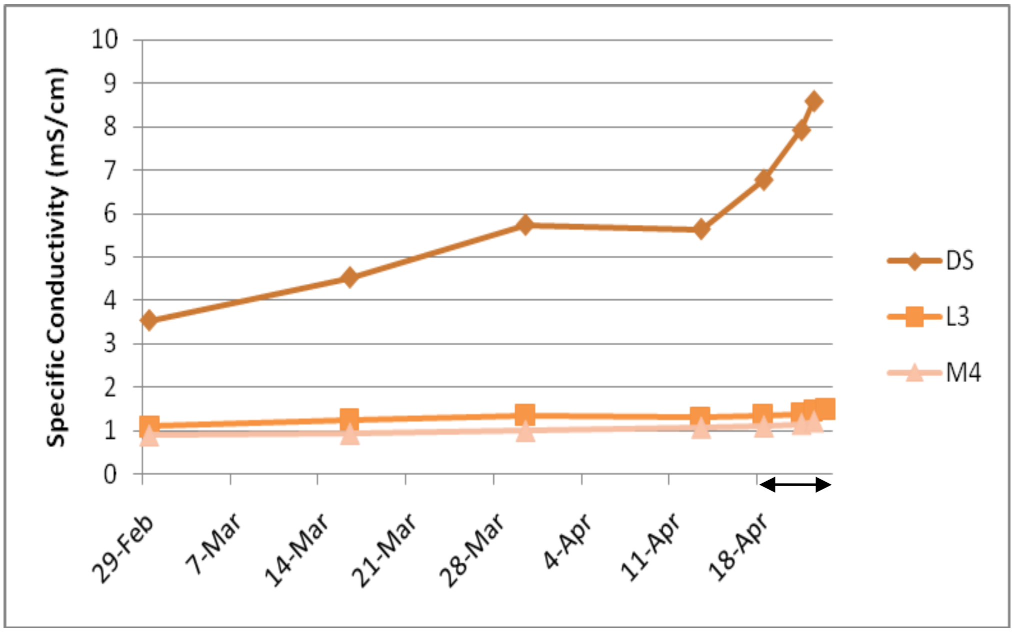

Figure 4-54: Specific conductivity readings from modified drainage wetlands for 2008. The drawdown period is indicated by the line with arrows.

4.4.4.3 Drainage Sites

At the drainage sites, specific conductivity values remained fairly constant (Figure 4-55). There was a slight increase in specific conductivity, but these values remained below 2 mS/cm. There was no observed change in specific conductivity during the drawdown of the studied wetlands.

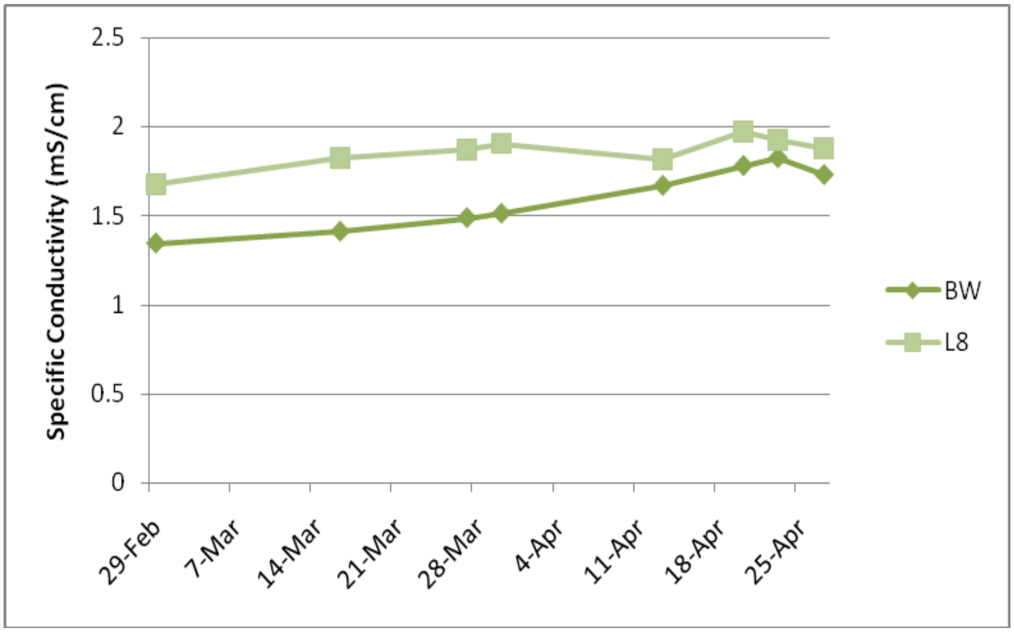

Figure 4-55: Specific conductivity readings from drainage sites for 2008.

4.4.5 Turbidity-Volatile Suspended Solids Correlation

A strong correlation was found between volatile suspended solids and turbidity throughout the study. This correlation could be used as a real-time management tool to monitor how much degradable organic matter is being discharged from the wetlands. The slopes for the correlations between wetland sites vary from 0.110 to 0.204 (Figure 4-56, Figure 4-57, Figure 4-58, and Figure 4-59). This variation may be due to different conditions between wetlands. An overall correlation is given in Figure 4-60.

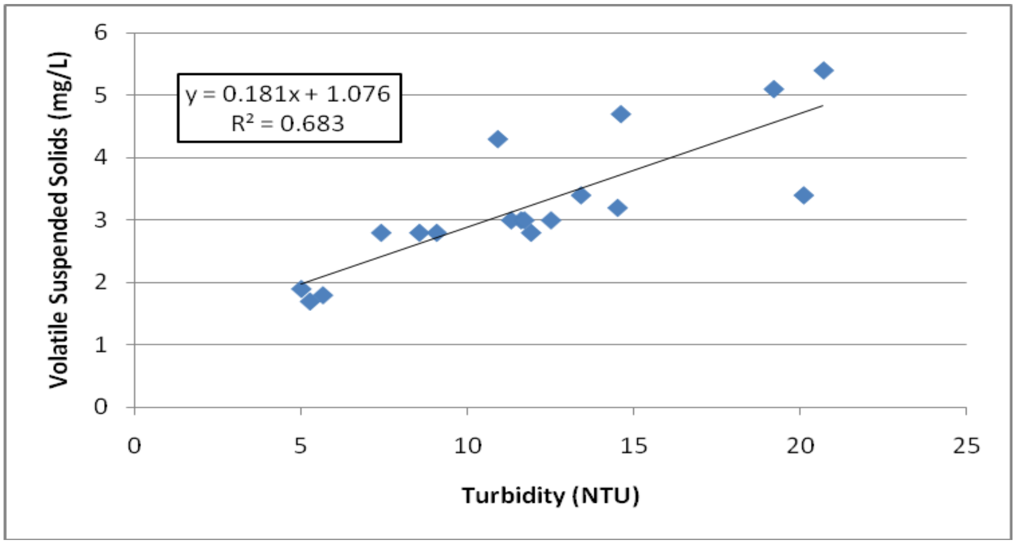

Figure 4-56: Correlation between volatile suspended solids and turbidity using drainage data for 2008.

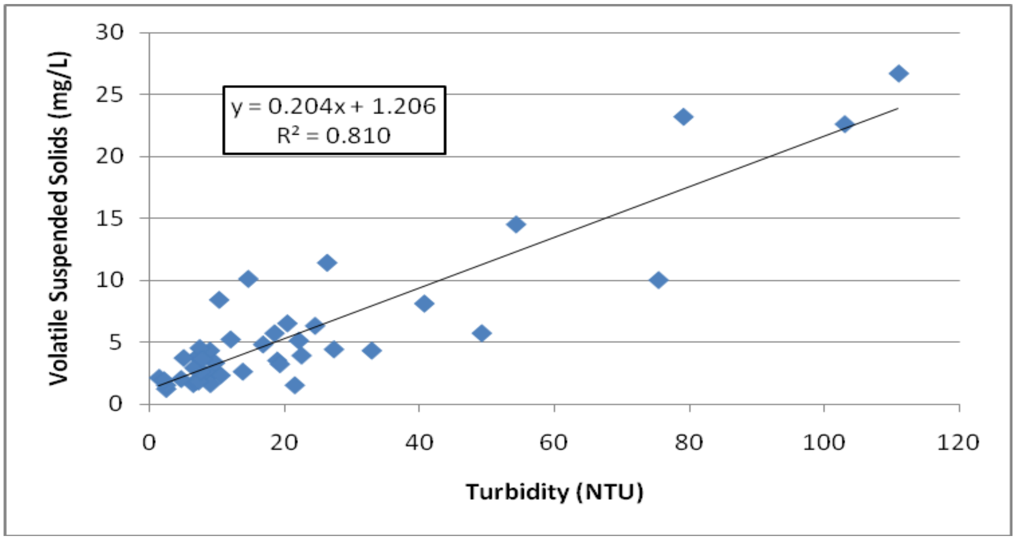

Figure 4-57: Correlation between volatile suspended solids and turbidity using Los Banos data from both sampling seasons.

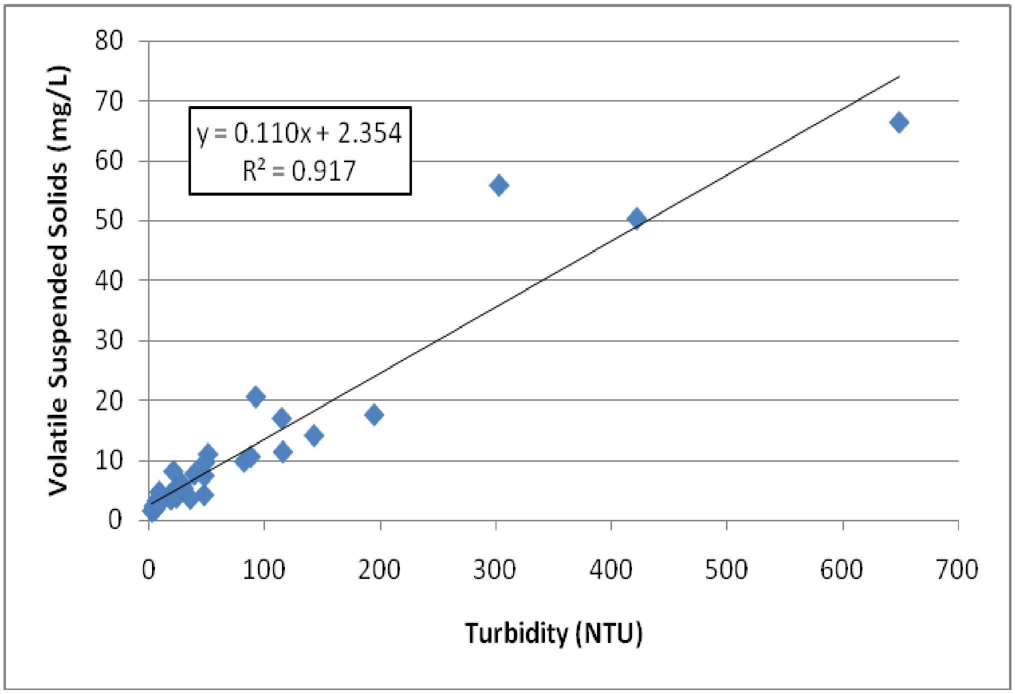

Figure 4-58: Correlation between volatile suspended solids and turbidity using Mud Slough data from both sampling seasons.

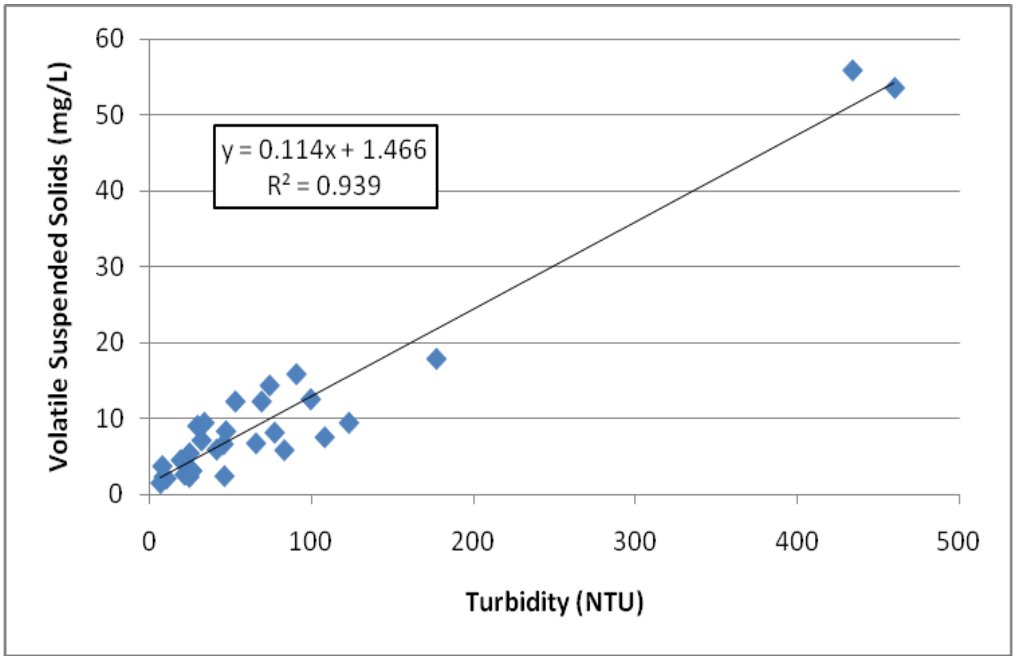

Figure 4-59: Correlation between volatile suspended solids and turbidity using Ducky Strike data from both sampling seasons.

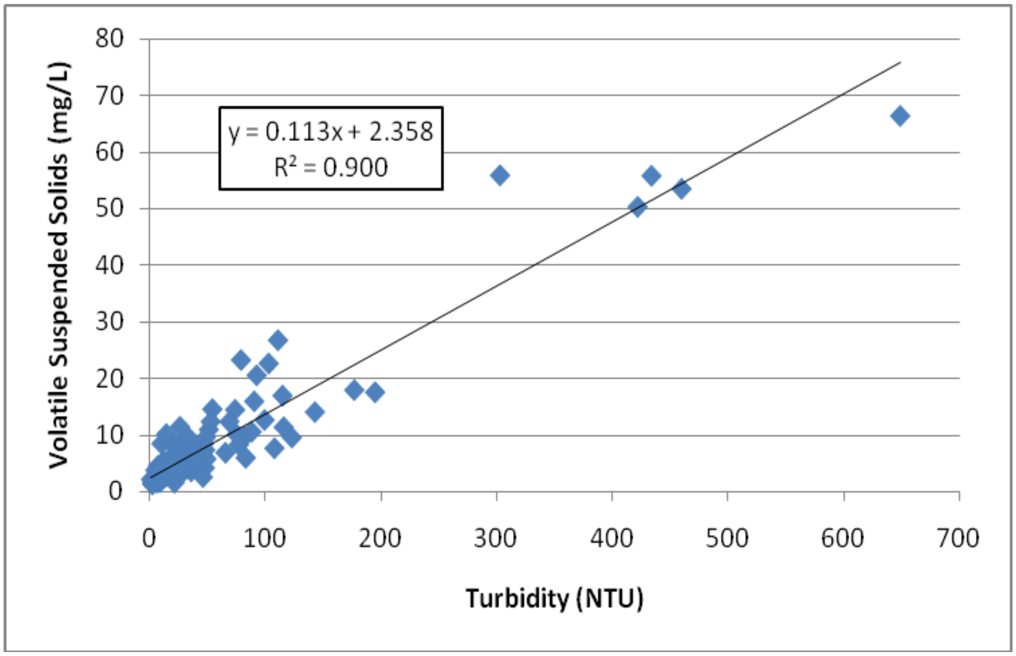

Figure 4-60: Correlation between volatile suspended solids and turbidity using all data from both sampling seasons.

4.4.6 Water Quality Summary

As in the previous summary Table 4-6 summarizes the water quality data in three columns:

1. Traditional

   This column contains average values from all data points taken at the traditional wetland sites (Ducky Strike North, Los Banos 31B, and Mud Slough 4B).

2. Modified: Traditional Period

   This column contains average values from all data points taken at the modified wetland hydrology sites (Ducky Strike South, Los Banos 33, and Mud Slough 3B) prior to the drawdown of the traditional wetlands.

3. Modified Hydrology: Extended Period

   This column contains average values from all data points taken at the modified wetland hydrology sites (Ducky Strike South, Los Banos 33, and Mud Slough 4B) after the drawdown of the traditional wetlands, but before drainage of the modified hydrology wetlands had begun.

Specific conductivity values increased during the extended period in modified hydrology wetlands during both sampling seasons, likely due to evapotranspiration. Soluble nutrient concentrations decreased during the delayed drawdown period in 2007 but not during 2008. Organic carbon concentrations increased only slightly during the delayed drawdown period.

Table 4-5: Water quality data summary for 2007. Data is expressed as the mean +/- the standard deviation of the mean with the number of samples analyzed in parentheses.

	Traditional	Modified Hydrology: Traditional Period	Modified Hydrology: Extended Period
NO_3^-+NO_2^- (mg/L-N)	0.35 +/- 0.44 (42)	0.20 +/- 0.40 (62)	0.027 +/- 0.038 (27)
NH_3 (mg/L-N)	0.23 +/- 0.43 (43)	0.22 +/- 0.21 (60)	0.11 +/- 0.091 (26)
PO_4^{3-} (mg/L-P)	0.18 +/- 0.51 (42)	0.16 +/- 0.13 (62)	0.031 +/- 0.054 (27)
Specific Conductivity (mS/cm)	1.4 +/- 1.0 (42)	1.9 +/- 1.5 (63)	2.5 +/- 2.7 (27)

Table 4-6: Water quality data summary for 2008. Data is expressed as the mean +/- the standard deviation of the mean with the number of samples analyzed in parentheses.

	Traditional	Modified Hydrology: Traditional Period	Modified Hydrology: Extended Period
NO_3^-+NO_2^- (mg/L-N)	0.19 +/- 0.26 (6)	0.08 +/- 0.14 (6)	0.05 +/- 0.07 (9)
NH_3 (mg/L-N)	0.13+/- 0.14 (6)	0.20+/- 0.14 (6)	0.09 +/- 0.08 (9)
PO_4^{3-} (mg/L-P)	0.03 +/- 0.03 (6)	0.08 +/- 0.06 (6)	0.07 +/- 0.02 (9)
DOC (mg/L-C)	11 +/- 1.6 (6)	11 +/- 1.1 (6)	15 +/- 2.3 (9)
TOC (mg/L-C)	14 +/- 1.6 (6)	17 +/- 2.6 (6)	18 +/- 2.8 (9)
Specific Conductivity (mS/cm)	1.8 +/- 0.59 (6)	2.0 +/- 0.64 (6)	2.8 +/- 0.81 (9)

4.5 Seasonal Loading

Mass loads for volatile suspended solids, organic carbon, and salinity were calculated throughout the sampling season. Both drainage sites and one wetland site (Mud Slough 4b) for the 2008 season, had a complete flow data set through the drawdown period. Since the majority of the constituent loading occurs during drawdown, loading from other studied wetlands was not calculated. Loading was calculated for both drainage sites using flow data measured as described in Section 3. Table 4-7 summarizes the seasonal loading of volatile suspended solids (VSS), total dissolved solids (TDS), total organic carbon (TOC), and dissolved organic carbon (DOC) for 2008.

Table 4-7: Seasonal loading during the 2008 sampling season.

Site	VSS Seasonal Load (lbs)	TDS Seasonal Load (tons)	TOC Seasonal Load (lb)	DOC Seasonal Load (lb)
Mud Slough 4b	770	26	1200	760
Button Willow	1500	293	7300	6500
Los Banos 38	2500	524	10,000	9200

4.5.1 Volatile Suspended Solids

Volatile suspended solids loading for the Mud Slough 4b wetland, Los Banos 38, and Buttonwillow drainage sites are shown below. Figure 4-61 and Figure 4-63 show the changing volatile suspended solids load throughout the season. When Figure 4-61 is compared to the flow values in Figure 4-62, it appears that the Buttonwillow loading follows the same trend as the flow, as expected. However, the Los Banos 38 loading has two noticeable spikes that do not follow the flow trend. These spikes correspond to the drainage from the project wetlands, the first spike coming after drainage of the traditional wetland (March 17, 2008) the other coming after the drainage of the modified hydrology wetland (April 18, 2008). Loading for Mud Slough 4b is shown in Figure 4-63. It can be seen that 79% of the total volatile suspended solids load occured during drainage. Increases in load can be ascribed to increased flow and scouring of periphyton.

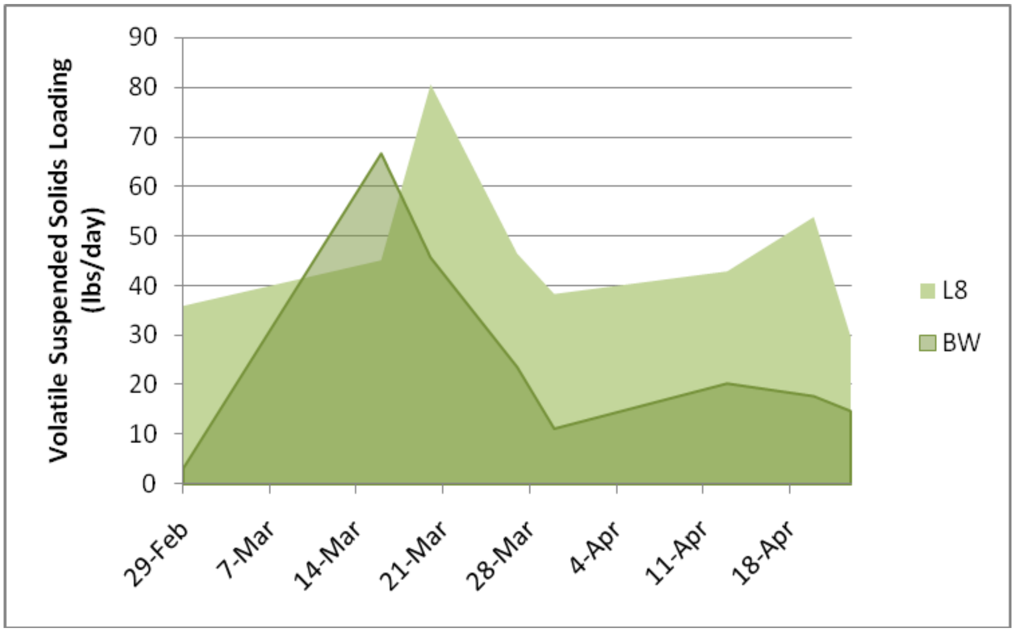

Figure 4-61: Volatile suspended solids loading from drainage sites during 2008. The area under the curve represents the seasonal volatile suspended solids load.

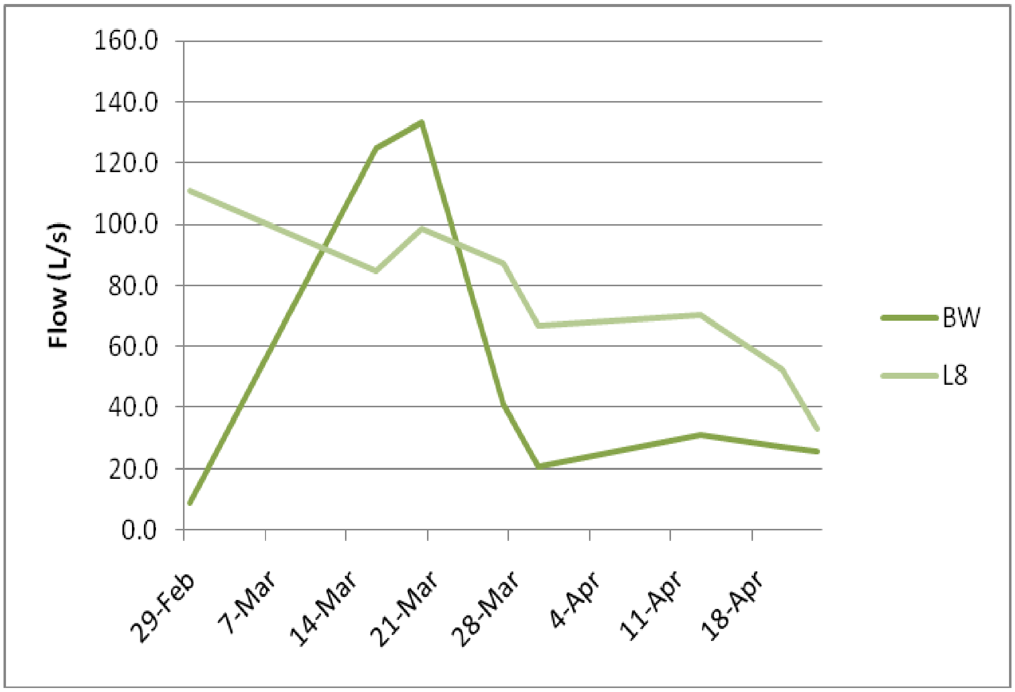

Figure 4-62: Flow from drainage sites during 2008

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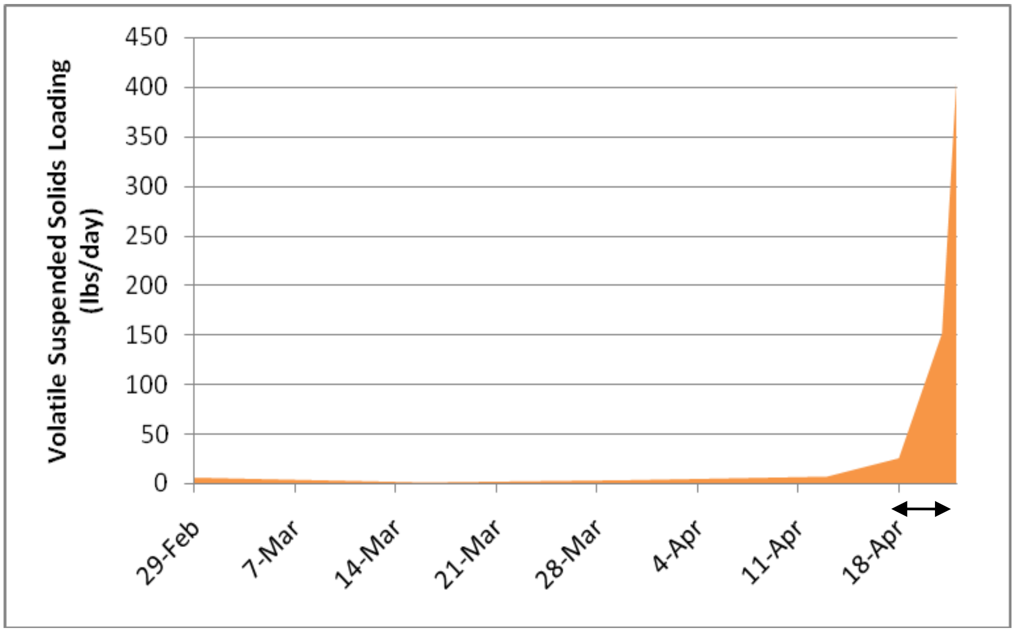

Figure 4-63: Volatile suspended solids loading from Mud Slough 4b during 2008. The area under the curve represents the seasonal load. The drawdown period is indicated with the arrow.

4.5.2 Organic Carbon

Dissolved and total organic carbon loading for the drainage sites are shown in Figure 4-64 and Figure 4-65 respectively. Loading followed the same trend as flow data shown in Figure 4-62. No noticeable spikes were observed during the days following drainage of the studied wetlands.

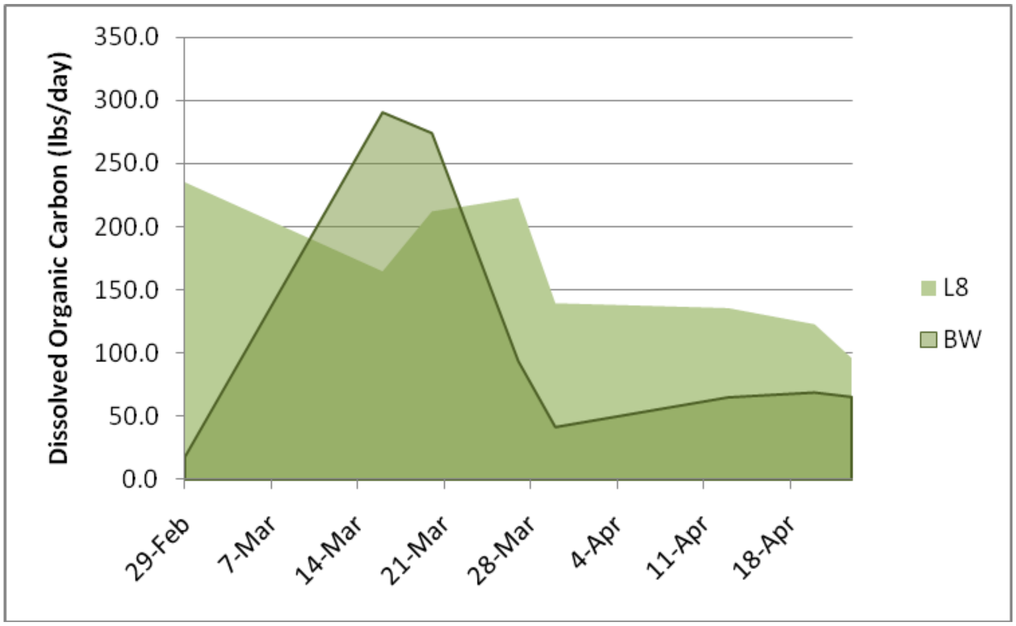

Figure 4-64: Dissolved organic carbon loading from drainage sites during 2008. The area under the curve represents the seasonal load.

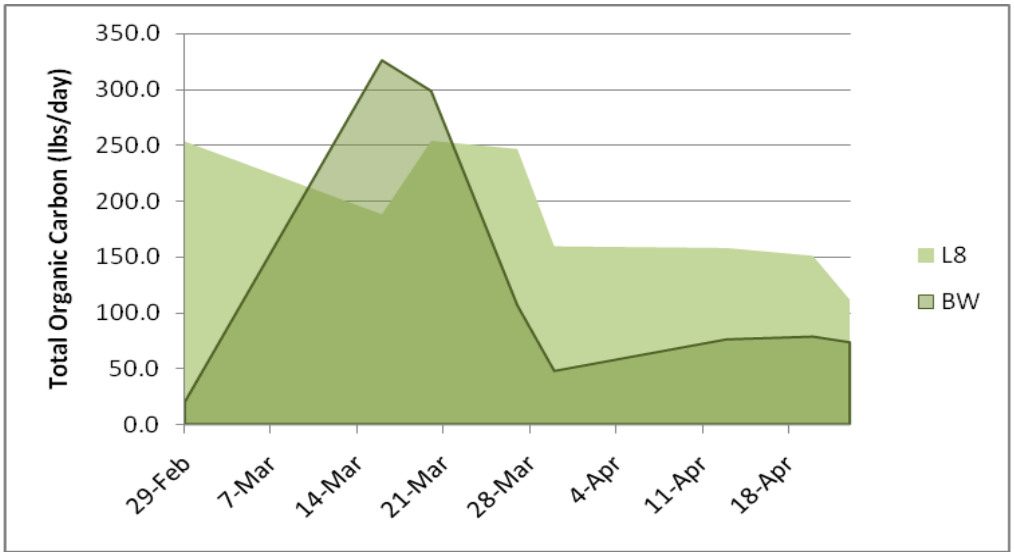

Figure 4-65: Total organic carbon loading from drainage sites during 2008. Particulate organic carbon load was estimated at 52% of VSS. The area under the curve represents the seasonal load.

Dissolved and total organic loading for Mud Slough 4b are shown in Figure 4-66 and Figure 4-67. The majority of the seasonal load occurred during drainage. The loading during drainage was calculated to be 45% and 54% of the seasonal load for dissolved organic carbon and total organic carbon respectively. This increase in loading is due to both increased flow and the scouring of periphyton and nutrient rich sediments.

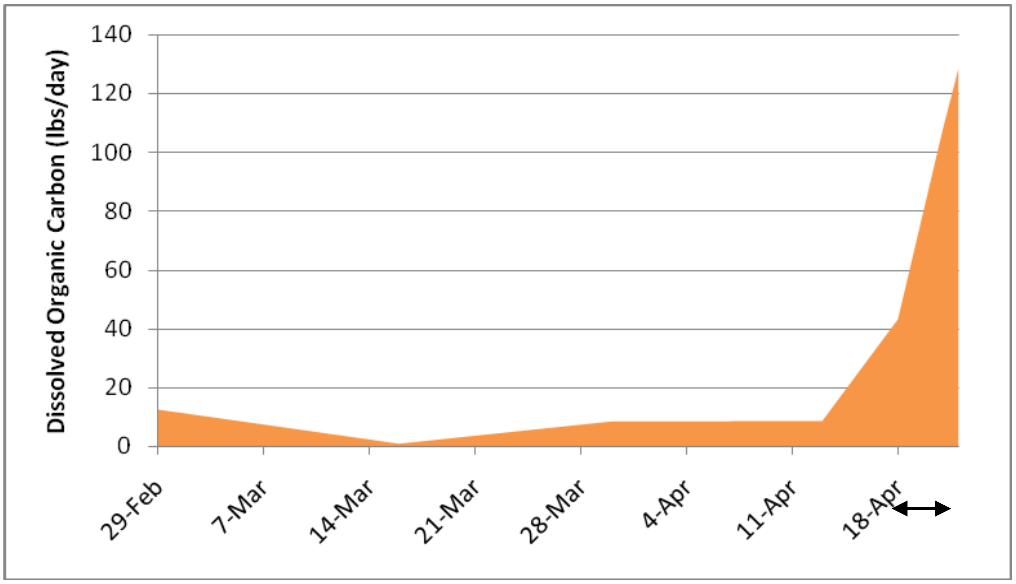

Figure 4-66: Dissolved organic loading from Mud Slough 4b during 2008. The area under the curve represents the seasonal load. The drawdown period is indicated with an arrow.

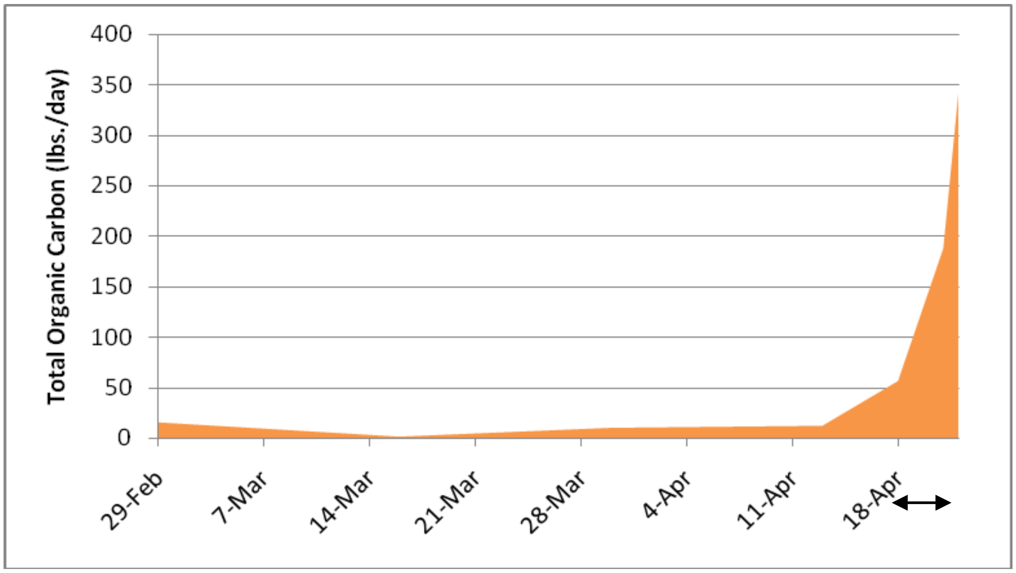

Figure 4-67: Total organic carbon loading from Mud Slough 4b during the 2008 season. The area under the curve represents the seasonal load. Particulate organic carbon was estimated at 52% of VSS. The drawdown period is indicated by the line with arrows.

4.6 Salinity

Salinity loading results are given below. Specific conductivity was converted to total dissolved solids (TDS) using a conversion factor. The California regional Water Quality Control Board found that specific conductivity to total dissolved solids ratios ranged from 0.61 to 0.69 in the Grasslands Ecological Area (Grober, 1998) The ratio for Salt Slough was found to be 0.68. This ration was used to convert specific conductivity to total dissolved solids. Total seasonal loads of dissolved solids are shown in Table 4-7.

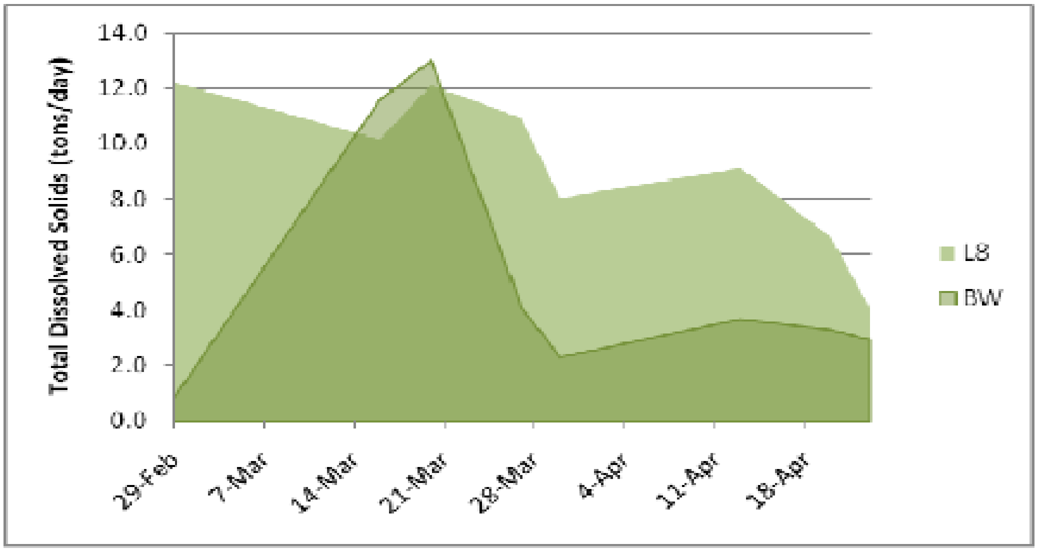

Figure 4-68: Total dissolved solids loading from drainage sites during 2008. The area under the curve represents the seasonal load.

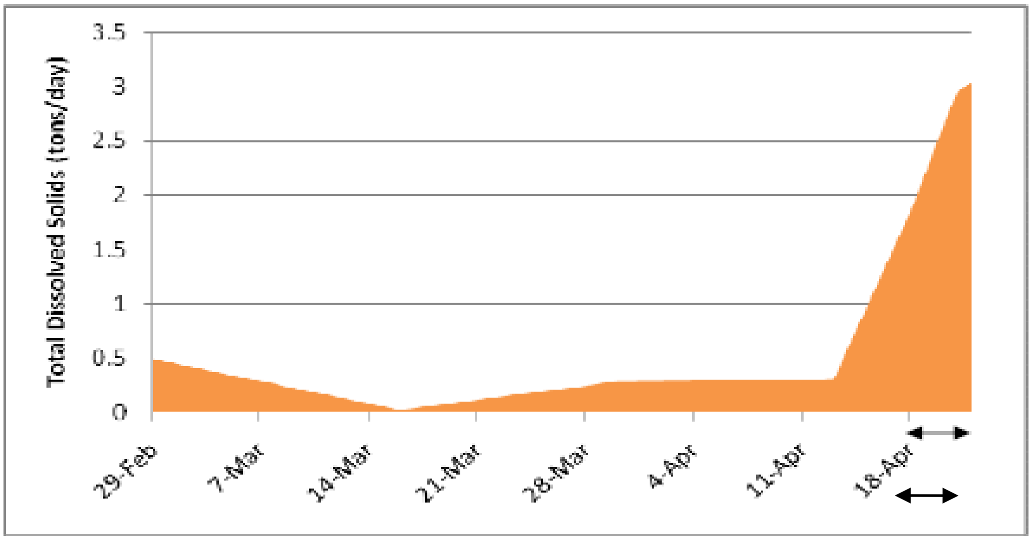

Figure 4-69: Total dissolved solids loading from Mud Slough 4b during 2008 . The area under the curve represents the seasonal load. The drawdown period is indicated with an arrow.

Loading at the drainage sites (Figure 4-68) followed the same trend as flow data in Figure 4-62. There were no observed spikes resulting from project wetland drainage. Loading from Mud Slough 4b is shown in Figure 4-69. Most of the dissolved solids load was produced during the wetland drawdown period (39%).

CHAPTER 5: CONCLUSIONS

This study has provided an initial screening of a broad range of information on the effects of delayed drawdown on water quality and aquatic biota. The study has provided a snapshot limited in spatial and temporal detail of conditions in the wetlands that were part of the study. The study does not pretend to represent average conditions across the wetland landscape. The study was limited in the frequency and duration of sampling - considerably more data will need to be gathered to adequately test the initial hypotheses. If possible, future sample collection programs should be done when intensive avian survey programs are not also being conducted (as occurred during this study). The need to prevent bird disturbance before and during avian survey data collection limited wetland access for water sampling. This study gathered a significant amount of data regarding wetland water quality, densities of benthic and nektonic microinvertebrates, concentrations of phytoplankton, and the present species of phytoplankton and aquatic invertebrates and helped to refine the methods of data collection. The data collected in this study will be more useful when considered in conjunction with data from the concurrent hydrological and water quality studies of the same wetlands.

Due to the lack of adequate replication, statistical hypothesis testing was not conducted as part of this study. However, observational conclusions have been made based on the data collected and the initial scientific hypotheses formulated .

1. **Salt concentration in seasonal drawdown is expected to be <u>similar</u> for the modified drainage wetlands than for traditionally drained wetland discharges, expect during the extended drawdown period.**

   Although total dissolved solids concentration was not significantly different for either the Mud Slough and Los Banos wetlands when traditional and modified drainage treatments were compared - a clear trend of increasing salinity after the traditional drawdown period was observed in Ducky Strike. It is reasonable to expect that total dissolved solids would concentrate in a wetland throughout the delayed drawdown period – the Ducky Strike wetland contained the highest initial and ending dissolved solids concentrations.

2. **Concentrations of oxygen-demanding substances (e.g., plankton) will <u>be the same</u> in the delayed wetland discharges as in the traditionally drained wetland discharges.**

Using volatile suspended solids (VSS) as a proxy for organic carbon, VSS concentration remained fairly constant in most wetlands during the flooded period. Significant increases were observed only during drawdown periods for both traditional and modified drainage wetlands. At the drainage sites, a slight positive trend was evident over the course of the 2008 season. No difference in the concentration of oxygen-demanding substances could be discerned between the discharges of the traditional and modified drainage wetlands.

3. **Nutrient concentrations and discharged mass <u>will be less</u> in the traditionally drained wetland discharges than in the delayed wetland discharges.**

   Soluble nitrogen and phosphorus forms (NO_3^-+NO_2^-, $NH_{3,}$ PO_4^{3-}) were consistently below 1 mg/L-N/P. Most of the soluble nutrient data was highly variable. However, total nitrogen and total phosphorus concentrations remained fairly constant throughout the two seasons except for substantial increases during drawdown. Logically, these total nutrient trends followed a similar trend to phytoplankton concentrations. No difference in the nutrient concentration could be discerned between the discharges of the traditional and modified drainage wetlands.

4. **Zooplankton densities <u>will increase</u> in the treatment wetlands during the extended flooded period.**

   Zooplankton data were highly variable, which is consistent with the boom-bust nature of these organisms. The only noticeable trend was a minor increase in density during the delayed drawdown period in 2007 and a significant increase in density during drawdown of modified wetlands in 2008.

Zooplankton were identified to the order level and were found to be predominantly Cladocera. Benthic invertebrates were identified to the family level and were predominantly Chironomidae. Due to low concentrations, enumeration of algal populations was not performed. However, the observed species were predominantly diatoms, with some chlorophytes present.

Loading from the drainage sites was estimated for volatile suspended solids, total organic carbon, dissolved organic carbon, and total dissolved solids. The seasonal load of volatile suspended solids draining through the Buttonwillow site was estimated to be 1,500 lbs while it was estimated to be 2,500 lbs from the Los Banos 38 site. The seasonal load of total organic carbon draining through the Buttonwillow site was estimated to be 7300 lbs, while it was estimated to be 10,000 lbs through the Los Banos 38 site. A large percentage of the total organic carbon load came from dissolved organic carbon with seasonal loads of 6500 lbs and 9200 lbs from Buttonwillow and Los Banos 38, respectively. The seasonal load of total dissolved solids draining through the Buttonwillow site was estimated to be 293 tons, while it was estimated to be 524 tons from the Los Banos 38 site.

Mud Slough 4B was the only wetland with a complete flow data set during the 2008 sampling season. Its seasonal load was estimated to be 770 lbs volatile suspended solids, 1200 lbs total organic carbon, 760 lbs dissolved organic carbon, and 26 tons for total dissolved solids. The majority of the load for these constituents came during drawdown (79% for VSS, 54% for TOC, 45% for DOC, and 39% for TDS). This pulse was likely due to increased flow and the scouring of sediments.

Turbidity strongly correlated with volatile suspended solids concentrations. This correlation was seen in all wetland pairs, as well as the drainage sites. However, the slope varied between sites. With further data collection, a correlation could be made for different wetland types. This correlation could be used to monitor the mass of volatile suspended solids being discharged.

The data collected during this study provides a snapshot of conditions in wetlands within the Grassland Ecological Area for 2007 and 2008 flooded seasons. It would be dangerous to infer that these conditions are representative for other years or other sites within the Grasslands Ecological Area given the year to year variations in influent water supply quality from the Delta Mendota Canal and the high spatially variable soils and surface hydrology of the Basin. No two years are ever completely alike. In the study - analysis of the collected data showed insufficient statistical power to make any meaningful commentary on the earlier proposed hypotheses. However, this information does provide a starting point for further in-depth analysis of effects of delayed drawdown on water quality and aquatic biota in seasonal wetlands. The sampling methods developed and tested as part of this study may have application in future studies.

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APPENDIX A: RAW DATA

2007 Raw Data

Label	Date	Depth (cm)	Water Temp (°C)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	Zooplankton Density (#/L)
L3I	3-Mar	.	.	.	.	.	.
L3I1	3-Mar	17	13.5	.	10.9	4.6	26
L3I2	3-Mar	14	17	.	26.5	7.1	80
L3I3	3-Mar	18	15	.	10.4	2.5	25
L3O	3-Mar	.	.	.	17.8	4.7	87
L3O1	3-Mar	29	14.6	18.9	15.2	3.5	16
L3O2	3-Mar	50	14.8	40.7	41.4	8.1	9.5
L3O3	3-Mar	70	14.6	19.3	14.9	3.2	36.7
L3B1	3-Mar	26	11.5	32.9	27.9	4.3	16.7
L3B2	3-Mar	22	12.5	49.2	43.0	5.7	11.5
L3B3	3-Mar	28	12.5	75.4	85.7	10	13.5
L1I	3-Mar	91	15	.	.	.	0.5
L1I1	3-Mar	30	17	4.66	5.3	2	35
L1I2	3-Mar	40	16.2	8.99	9.4	1.6	82
L1I3	3-Mar	45	15.8	8.94	15.6	4.3	23
L1O	3-Mar	79	12.1	.	2.5	1.4	32
L1O1	3-Mar	45	14.6	21.5	3.2	1.5	150
L1O2	3-Mar	35	15.5	2.43	3.0	1.5	119
L1O3	3-Mar	30	16.5	2.13	2.8	1.9	285
L1B1	3-Mar	31	13	7.07	10.3	3.8	1588
L1B2	3-Mar	45	13	12	21.5	5.2	90
L1B3	3-Mar	25	.	.	7.0	2.4	289
M3I	3-Mar	.	.	.	55.8	7.1	.

Label	Date	Depth (cm)	Water Temp (°C)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	Zooplankton Density (#/L)
M3I1	3-Mar	8	.	51.3	63.6	10.9	230
M3I2	3-Mar	17	.	28.6	34.1	5.9	80
M3I3	3-Mar	17	.	.	31.2	4.7	14
M3O	3-Mar	58	13.3	22.2	26.7	4.9	7.5
M3O1	3-Mar	10	17.2	48.7	60.1	9.5	18
M3O2	3-Mar	35	15.3	25.4	23.3	5.1	0
M3O3	3-Mar	55	15.5	48.1	38.2	7.3	7
M3B1	3-Mar	20	16.7	20.1	16.0	3.6	8
M3B2	3-Mar	35	15.3	18.6	14.5	4.2	123
M3B3	3-Mar	30	15.3	19.1	15.2	3.4	22
M4I	3-Mar	.	.	.	55.8	7.1	.
M4I1	3-Mar	16	.	.	19.4	3.8	41
M4I2	3-Mar	27	.	115	92.4	16.9	20
M4I3	3-Mar	25	.	39.5	48.5	7.6	22
M4O	3-Mar	64	16.6	.	3.2	1.5	2
M4O1	3-Mar	44	15.4	5.37	7.4	1.6	18
M4O2	3-Mar	44	17.2	2.72	2.9	1.4	73
M4O3	3-Mar	38	16.6	9.05	13.3	4.6	60
M4B1	3-Mar	25	.	6.94	10.0	2.6	400
M4B2	3-Mar	28	.	.	4.2	1.1	11.6
M4B3	3-Mar	26	.	.	5.1	1.1	5.2
DSI	3-Mar	88	.	21.5	24.5	2.7	15.5
DSI1	3-Mar	5	.	24.4	25.9	2.4	45
DSI2	3-Mar	20	.	26.2	26.6	3.2	41
DSI3	3-Mar	.	.	46.1	36.1	2.5	.
DSO	3-Mar	85	.	.	15.4	2	6
DSO1	3-Mar	10	.	.	15.5	4.9	101
DSO2	3-Mar	5	.	.	15.7	5.4	42

Label	Date	Depth (cm)	Water Temp (°C)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	Zooplankton Density (#/L)
DSO3	3-Mar	20	.	.	19.7	2.9	10
DSB1	3-Mar	5	23.4	.	20.5	4.9	.
DSB2	3-Mar	5	.	.	23.0	4	.
DSB3	3-Mar	15	.	.	30.9	3.5	.
DNI =DSO	3-Mar	.	.	.	15.4	.	.
DNI1	3-Mar	20	17.7	.	9.4	2.2	31.3
DNI2	3-Mar	32	18.1	10.3	9.7	2.2	61.3
DNI3	3-Mar	8	19.7	.	26.7	4.4	50.7
DNO	3-Mar	.	19.5	.	11.3	2.2	9.6
DNO1	3-Mar	17	17.5	.	11.2	3.4	224
DNO2	3-Mar	42	19.2	6.64	4.5	1.6	24
DNO3	3-Mar	26	19.7	.	9.4	2.7	76
DNB1	3-Mar	12	21.6	24.6	23.6	5.5	26
DNB2	3-Mar	7	20.7	45.5	50.6	6.7	108
DNB3	3-Mar	7	20.7	41.3	37.5	6	52
L3I	17-Mar	.	.	.	.	.	.
L3I1	17-Mar	.	26	10.3	19.1	8.4	64
L3I2	17-Mar	16	26.3	7.23	7.4	1.8	.
L3I3	17-Mar	18	25.2	7.56	10.0	2.6	.
L3O	17-Mar	.	23.6	10.5	8.8	2.3	18
L3O1	17-Mar	30	24.7	9.68	10.4	3.3	12
L3O2	17-Mar	60	23.8	79.1	133.2	23.2	72
L3O3	17-Mar	48	24.6	.	.	.	114
L3B1	17-Mar	20	26.2	22.5	20.1	3.9	15
L3B2	17-Mar	30	26	103	172.3	22.6	26
L3B3	17-Mar	39	25.2	27.3	26.2	4.4	30
L1I	17-Mar	.	.	.	.	.	.
L1I1	17-Mar	15	25.7	16.8	21.7	4.8	4

Label	Date	Depth (cm)	Water Temp (^{o}C)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	Zooplankton Density (#/L)
L1I2	17-Mar	15	24.4	22.1	22.6	5.1	.
L1I3	17-Mar	23	26.3	20.4	28.8	6.5	.
L1O	17-Mar	59	27.4	6.63	6.4	2.9	.
L1O1	17-Mar	24	26.7	5.04	7.5	3.7	.
L1O2	17-Mar	15	28.6	7.41	11.1	4.5	16
L1O3	17-Mar	14	29.2	18.5	22.2	5.7	8
L1B1	17-Mar	19	28.3	26.3	50.5	11.4	202
L1B2	17-Mar	20	27.8	7.77	10.0	3.6	196
L1B3	17-Mar	6	29.3	14.6	31.4	10.1	58
M3I	17-Mar	.	.	.	.	.	.
M3I1	17-Mar	.	.	.	.	.	.
M3I2	17-Mar	.	.	.	.	.	.
M3I3	17-Mar	.	.	.	.	.	.
M3O	17-Mar	17	19	.	713.2	97.6	.
M3O1	17-Mar	11	22	422	296.4	50.3	36
M3O2	17-Mar	.	.	.	.	.	.
M3O3	17-Mar	.	.	.	.	.	.
M3B1	17-Mar	9	23.8	649	358.8	66.4	104
M3B2	17-Mar	.	.	.	.	.	.
M3B3	17-Mar	.	.	.	.	.	.
M4I	17-Mar	.	.	.	.	.	.
M4I1	17-Mar	.	14.9	88.2	99.8	10.5	182
M4I2	17-Mar	14	15.4	116	102.0	11.3	18
M4I3	17-Mar	20	15	195	181.7	17.5	92
M4O	17-Mar	58	17.2	4.39	6.3	2.2	22
M4O1	17-Mar	27	16.3	6.68	8.8	3.1	10
M4O2	17-Mar	39	16.8	8.12	10.9	3.2	26
M4O3	17-Mar	31	18.2	5.39	6.0	2	50

Label	Date	Depth (cm)	Water Temp (^{o}C)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	Zooplankton Density (#/L)
M4B1	17-Mar	16	16.7	9.84	15.3	4	88
M4B2	17-Mar	20	18.7	6.91	9.1	2.7	37
M4B3	17-Mar	17	18.3	8.58	10.3	2.5	112
DSI	17-Mar	.	.	203	.	.	.
DSI1	17-Mar	13	25.8	74	197.9	14.4	98
DSI2	17-Mar	24	24.2	65.6	66.7	6.8	.
DSI3	17-Mar	23	23.9	.	78.1	8.6	34.7
DSO	17-Mar	.	24.8	123	113.7	9.5	.
DSO1	17-Mar	22	24.7	108	96.8	7.6	96
DSO2	17-Mar	.	.	.	.	.	.
DSO3	17-Mar	.	.	.	.	.	.
DSB1	17-Mar	7	28.1	7.7	15.3	3.8	12
DSB2	17-Mar	3	28.7	52.9	98.4	12.3	28
DSB3	17-Mar	13	25.3	19.2	26.3	4.6	54
DNI	17-Mar	.	.	.	.	.	.
DNI1	17-Mar	26	24	177	152.5	17.9	98
DNI2	17-Mar	.	.	.	.	.	.
DNI3	17-Mar	.	.	.	.	.	.
DNO	17-Mar	.	.	77.1	62.5	8.2	54
DNO1	17-Mar	.	.	69	71.3	12.3	33
DNO2	17-Mar	.	.	33.7	47.3	9.5	978
DNO3	17-Mar	.	.	.	.	.	.
DNB1	17-Mar	5	26.7	83.1	75.7	5.9	62
DNB2	17-Mar	.	.	.	.	.	.
DNB3	17-Mar	.	.	.	.	.	.
L3I	17-Apr	.	.	.	.	.	.
L3I1	17-Apr	7	21.5	.	4.9	2	33
L3I2	17-Apr	7	20.9	.	8.3	3.7	100

Label	Date	Depth (cm)	Water Temp (°C)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	Zooplankton Density (#/L)
L3I3	17-Apr	10	22.1	.	12.7	3	10
L3O	17-Apr	87	17.7	.	9.4	2.8	8.7
L3O1	17-Apr	18	18	.	23.9	6.5	116
L3O2	17-Apr	57	17.7	.	9.7	2.6	5
L3O3	17-Apr	66	18	.	66.0	12.8	60
L3B1	17-Apr	17	18.3	.	13.8	2.9	62
L3B2	17-Apr	33	17.6	.	14.5	3.3	8.0
L3B3	17-Apr	21	17.6	.	13.1	2.7	52.0
M4I	17-Apr	.	.	.	.	.	.
M4I1	17-Apr	9	23.3	.	174.4	28.2	378.0
M4I2	17-Apr	13	22.2	.	265.6	26.2	110.0
M4I3	17-Apr	15	22.2	.	287.9	30.3	128.0
M4O	17-Apr	49	20.3	.	88.4	18.6	7.3
M4O1	17-Apr	20	20.4	.	36.1	7.1	96.0
M4O2	17-Apr	28	21.6	.	44.0	10	96.0
M4O3	17-Apr	29	21.4	.	121.5	24.6	.
M4B1	17-Apr	8	21.9	.	10.0	3.1	66.0
M4B2	17-Apr	10	24.3	.	28.8	6.4	196.0
M4B3	17-Apr	11	23.9	.	20.4	4.3	.
DSI	17-Apr	.	.	.	.	.	.
DSI1	17-Apr	6	19.9	.	467.6	47.9	36.0
DSI2	17-Apr	14	19.3	.	481.8	36.4	312.0
DSI3	17-Apr	14	19.3	.	421.5	32.3	260.0
DSO	17-Apr	52	18.7	.	378.7	36.2	.
DSO1	17-Apr	5	16.1	.	142.5	19.8	138.0
DSO2	17-Apr	3	.	.	179.4	25	176.0
DSO3	17-Apr	5	.	.	487.8	51.2	650.0
DSB1	17-Apr	.	.	.	.	.	.

Label	Date	Depth (cm)	Water Temp (^{o}C)	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)	Zooplankton Density (#/L)
DSB2	17-Apr	.	.	.	.	.	.
DSB3	17-Apr	.	.	.	.	.	.

Label	Date	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	Nitrate+Nitrite (mg/L-N)	Ammonia (mg/L-N)	Benthic Density (#/m^{2})
L3I	3-Mar	.	.	.	.	.
L3I1	3-Mar	0.293	0.174	0.0748	0.076	367.1
L3I2	3-Mar	0.267	0.171	0.0731	0.173	0.0
L3I3	3-Mar	0.235	0.170	0.0781	0.049	0.0
L3O	3-Mar	0.287	0.188	0.1249	0.118	.
L3O1	3-Mar	0.287	0.201	0.1216	0.170	611.9
L3O2	3-Mar	0.329	0.206	0.1182	0.158	611.9
L3O3	3-Mar	0.274	0.220	0.1099	0.072	367.1
L3B1	3-Mar	0.254	0.183	0.1236	0.118	367.1
L3B2	3-Mar	0.280	0.156	0.1216	0.155	244.8
L3B3	3-Mar	0.293	0.174	0.1166	.	0.0
L1I	3-Mar	.	.	.	.	.
L1I1	3-Mar	.	0.000	0.9170	0.050	979.0
L1I2	3-Mar	.	0.000	0.6914	0.070	856.7
L1I3	3-Mar	.	0.000	0.5026	0.080	122.4
L1O	3-Mar	0.047	0.513	0.1550	0.040	.
L1O1	3-Mar	.	0.000	0.2218	0.050	122.4
L1O2	3-Mar	.	0.000	0.3897	0.060	244.8
L1O3	3-Mar	.	0.000	0.5276	0.060	0.0
L1B1	3-Mar	.	0.000	0.2820	0.100	367.1
L1B2	3-Mar	.	0.000	0.1366	0.060	0.0
L1B3	3-Mar	.	3.323	1.6805	0.070	0.0

Label	Date	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	Nitrate+Nitrite (mg/L-N)	Ammonia (mg/L-N)	Benthic Density (#/m^2)
M3I	3-Mar	0.185	.	.	0.118	.
M3I1	3-Mar	0.271	0.132	1.3312	0.079	367.1
M3I2	3-Mar	0.189	0.145	1.3446	0.071	0.0
M3I3	3-Mar	0.195	0.138	1.5919	0.072	1468.6
M3O	3-Mar	0.211	0.194	0.4340	0.265	.
M3O1	3-Mar	0.309	0.176	0.5787	0.218	244.8
M3O2	3-Mar	0.268	0.237	0.4118	0.256	122.4
M3O3	3-Mar	0.280	0.188	0.5410	0.228	244.8
M3B1	3-Mar	0.242	0.255	0.3882	0.275	0.0
M3B2	3-Mar	0.246	0.237	0.3682	0.287	122.4
M3B3	3-Mar	0.233	0.297	0.5987	0.247	856.7
M4I	3-Mar	0.185	0.213	1.9465	0.118	.
M4I1	3-Mar	0.156	0.146	0.9150	0.087	0.0
M4I2	3-Mar	0.631	0.176	1.7953	0.095	244.8
M4I3	3-Mar	0.238	0.213	1.8798	0.103	122.4
M4O	3-Mar	0.188	0.192	0.0724	0.069	.
M4O1	3-Mar	0.200	0.231	0.1147	0.079	0.0
M4O2	3-Mar	0.188	0.219	0.0970	0.067	244.8
M4O3	3-Mar	0.225	0.273	0.0903	0.082	0.0
M4B1	3-Mar	0.222	0.231	0.3726	0.142	0.0
M4B2	3-Mar	0.207	0.231	0.3482	0.181	244.8
M4B3	3-Mar	0.216	0.225	0.3437	0.190	244.8
DSI	3-Mar	0.120	0.000	0.1072	0.336	.
DSI1	3-Mar	0.142	0.000	0.0838	0.161	0.0
DSI2	3-Mar	0.135	0.000	0.0896	0.156	0.0
DSI3	3-Mar	0.185	0.000	0.1267	0.115	0.0
DSO	3-Mar	0.095	0.000	0.0974	.	.
DSO1	3-Mar	0.148	0.000	0.0929	0.074	244.8

Label	Date	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	Nitrate+Nitrite (mg/L-N)	Ammonia (mg/L-N)	Benthic Density (#/m^2)
DSO2	3-Mar	0.160	0.000	0.0974	0.101	244.8
DSO3	3-Mar	0.110	0.000	0.0996	0.231	122.4
DSB1	3-Mar	0.226	0.000	0.1033	0.114	0.0
DSB2	3-Mar	0.229	0.000	0.1130	0.101	1958.1
DSB3	3-Mar	0.201	0.000	0.0955	0.114	244.8
DNI =DSO	3-Mar	.	.	.	.	.
DNI1	3-Mar	0.157	0.000	0.0955	0.114	367.1
DNI2	3-Mar	0.137	0.000	0.0966	0.161	734.3
DNI3	3-Mar	0.199	0.000	0.0895	0.193	734.3
DNO	3-Mar	0.137	0.000	0.0850	0.136	.
DNO1	3-Mar	0.239	0.000	0.0867	0.137	0.0
DNO2	3-Mar	0.114	0.000	0.0935	0.170	367.1
DNO3	3-Mar	0.131	0.000	0.1030	0.090	0.0
DNB1	3-Mar	0.500	0.123	0.0974	0.131	122.4
DNB2	3-Mar	0.297	0.000	0.0818	0.209	244.8
DNB3	3-Mar	0.239	0.000	0.0916	0.161	0.0
L3I	17-Mar	.	.	.	.	.
L3I1	17-Mar	0.550	0.257	0.0818	0.060	0.0
L3I2	17-Mar	0.334	0.107	0.0946	0.092	0.0
L3I3	17-Mar	0.307	0.187	0.1403	0.102	0.0
L3O	17-Mar	0.688	0.310	0.1251	0.248	.
L3O1	17-Mar	0.681	0.390	0.1266	0.237	856.7
L3O2	17-Mar	0.849	0.253	0.1477	0.252	367.1
L3O3	17-Mar	.	0.168	0.1726	.	489.5
L3B1	17-Mar	0.586	0.293	0.0672	0.118	122.4
L3B2	17-Mar	0.776	0.284	0.0562	0.197	122.4
L3B3	17-Mar	0.560	0.200	0.1317	0.115	856.7
L1I	17-Mar	.	.	.	.	.

Label	Date	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	Nitrate+Nitrite (mg/L-N)	Ammonia (mg/L-N)	Benthic Density (#/m^2)
L1I1	17-Mar	0.590	0.474	0.6576	0.062	489.5
L1I2	17-Mar	0.371	0.081	0.2317	0.064	1835.7
L1I3	17-Mar	0.329	0.032	0.1111	0.082	2325.2
L1O	17-Mar	0.265	0.000	0.0000	0.172	.
L1O1	17-Mar	0.400	0.028	0.0000	0.311	0.0
L1O2	17-Mar	0.236	0.067	0.0000	0.140	122.4
L1O3	17-Mar	0.423	0.059	0.0452	0.080	489.5
L1B1	17-Mar	0.304	0.000	0.0379	0.235	244.8
L1B2	17-Mar	0.194	0.000	0.0000	0.137	244.8
L1B3	17-Mar	0.178	0.000	0.0000	0.087	0.0
M3I	17-Mar	.	.	.	.	.
M3I1	17-Mar	.	.	.	.	0.0
M3I2	17-Mar	.	.	.	.	0.0
M3I3	17-Mar	.	.	.	.	0.0
M3O	17-Mar	2.412	0.277	0.1766	0.509	.
M3O1	17-Mar	1.360	0.287	0.0376	3.176	489.5
M3O2	17-Mar	.	.	.	.	0.0
M3O3	17-Mar	.	.	.	.	0.0
M3B1	17-Mar	2.044	0.432	0.0000	3.191	1101.4
M3B2	17-Mar	.	.	.	.	0.0
M3B3	17-Mar	.	.	.	.	0.0
M4I	17-Mar	.	.	.	.	.
M4I1	17-Mar	0.523	0.255	0.0633	0.181	856.7
M4I2	17-Mar	0.466	0.223	0.1858	0.262	2570.0
M4I3	17-Mar	0.493	0.148	0.4884	0.232	1713.3
M4O	17-Mar	0.390	0.261	0.0000	0.554	.
M4O1	17-Mar	0.420	0.330	0.0000	0.298	0.0
M4O2	17-Mar	0.435	0.309	0.0000	0.611	244.8

Label	Date	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	Nitrate+Nitrite (mg/L-N)	Ammonia (mg/L-N)	Benthic Density (#/m^2)
M4O3	17-Mar	0.409	0.287	0.0000	0.626	0.0
M4B1	17-Mar	0.769	0.480	0.0000	0.775	0.0
M4B2	17-Mar	0.747	0.475	0.0000	0.735	979.0
M4B3	17-Mar	0.761	0.438	0.0000	0.722	856.7
DSI	17-Mar	.	.	.	.	.
DSI1	17-Mar	0.495	0.000	0.0000	0.225	3426.6
DSI2	17-Mar	0.271	0.159	0.0000	0.124	1101.4
DSI3	17-Mar	0.268	0.000	0.0000	0.125	2814.7
DSO	17-Mar	0.459	0.000	0.0640	0.922	.
DSO1	17-Mar	0.457	0.011	0.0508	0.921	4160.9
DSO2	17-Mar	.	.	.	.	0.0
DSO3	17-Mar	.	.	.	.	0.0
DSB1	17-Mar	0.271	.	.	0.115	0.0
DSB2	17-Mar	0.380	0.000	0.0000	0.125	1958.1
DSB3	17-Mar	0.191	0.000	0.0000	0.165	489.5
DNI	17-Mar	.	.	.	.	.
DNI1	17-Mar	1.051	0.295	0.0000	1.610	1223.8
DNI2	17-Mar	.	.	.	.	0.0
DNI3	17-Mar	.	.	.	.	0.0
DNO	17-Mar	0.810	0.028	0.0000	2.480	.
DNO1	17-Mar	0.839	0.350	0.0000	0.700	4405.7
DNO2	17-Mar	0.617	0.163	0.0000	0.160	734.3
DNO3	17-Mar	.	.	.	.	0.0
DNB1	17-Mar	0.395	0.053	0.0000	0.170	0.0
DNB2	17-Mar	.	.	.	.	0.0
DNB3	17-Mar	.	.	.	.	0.0
L3I	17-Apr	.	.	.	.	.
L3I1	17-Apr	0.180	0.044	0.0739	0.037	856.7

Label	Date	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	Nitrate+Nitrite (mg/L-N)	Ammonia (mg/L-N)	Benthic Density (#/m^2)
L3I2	17-Apr	0.184	0.052	0.0655	0.032	122.4
L3I3	17-Apr	0.205	0.029	0.0722	0.037	489.5
L3O	17-Apr	0.199	0.000	0.0000	0.059	.
L3O1	17-Apr	0.196	0.017	0.0739	0.059	0.0
L3O2	17-Apr	0.205	0.000	0.0000	0.052	611.9
L3O3	17-Apr	0.258	0.000	0.0000	0.063	1713.3
L3B1	17-Apr	0.193	0.000	0.0806	0.046	0.0
L3B2	17-Apr	0.193	0.000	0.0000	0.050	0.0
L3B3	17-Apr	0.162	0.000	0.0438	0.047	122.4
M4I	17-Apr	.	.	.	.	.
M4I1	17-Apr	0.672	0.087	0.0448	0.152	367.1
M4I2	17-Apr	0.471	0.021	0.1173	0.325	122.4
M4I3	17-Apr	0.606	0.114	0.0786	0.395	3549.0
M4O	17-Apr	0.322	0.037	0.0000	0.049	.
M4O1	17-Apr	0.326	0.056	0.0000	0.193	3181.9
M4O2	17-Apr	0.303	0.017	0.0000	0.104	2937.1
M4O3	17-Apr	0.357	0.040	0.0000	0.054	1835.7
M4B1	17-Apr	.	0.257	0.0000	.	2080.5
M4B2	17-Apr	0.319	0.044	0.0923	0.079	3916.2
M4B3	17-Apr	0.303	0.048	0.0000	0.067	367.1
DSI	17-Apr	.	.	.	.	.
DSI1	17-Apr	0.941	0.000	0.0000	0.181	611.9
DSI2	17-Apr	0.979	0.000	0.0000	0.154	856.7
DSI3	17-Apr	1.162	0.000	0.0000	0.160	122.4
DSO	17-Apr	0.914	0.000	0.0000	0.177	.
DSO1	17-Apr	0.521	0.000	0.0000	0.161	244.8
DSO2	17-Apr	0.586	0.000	0.0000	0.163	1468.6
DSO3	17-Apr	1.103	0.000	0.0000	0.195	0.0

Label	Date	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	Nitrate+Nitrite (mg/L-N)	Ammonia (mg/L-N)	Benthic Density (#/m^2)
DSB1	17-Apr	.	.	.	.	1468.6
DSB2	17-Apr	.	.	.	.	1713.3
DSB3	17-Apr	.	.	.	.	0.0

Label	Date	Solar Radiation (Ly/day)	Chloride Concentration (mg/L-Cl^-)	Specific Conductivity (mS/cm)
L3I	3-Mar	401	.	.
L3I1	3-Mar	401	220	1.674
L3I2	3-Mar	401	149	1.11
L3I3	3-Mar	401	145	1.042
L3O	3-Mar	401	115	.
L3O1	3-Mar	401	114	.
L3O2	3-Mar	401	115	0.811
L3O3	3-Mar	401	115	.
L3B1	3-Mar	401	116	.
L3B2	3-Mar	401	117	0.829
L3B3	3-Mar	401	117	0.825
L1I	3-Mar	401	.	.
L1I1	3-Mar	401	163	1.01
L1I2	3-Mar	401	152	.
L1I3	3-Mar	401	165	.
L1O	3-Mar	401	10	1.036
L1O1	3-Mar	401	170	1.032
L1O2	3-Mar	401	171	.
L1O3	3-Mar	401	170	.
L1B1	3-Mar	401	170	1.02

L1B2	3-Mar	401	184	1
L1B3	3-Mar	401	162	0.997
M3I	3-Mar	397	.	.
M3I1	3-Mar	397	99	0.718
M3I2	3-Mar	397	100	0.719
M3I3	3-Mar	397	100	0.779
M3O	3-Mar	397	89	0.634
M3O1	3-Mar	397	86	.
M3O2	3-Mar	397	84	0.679
M3O3	3-Mar	397	84	0.661
M3B1	3-Mar	397	87	.
M3B2	3-Mar	397	95	.
M3B3	3-Mar	397	95	0.701
M4I	3-Mar	397	119	0.741
M4I1	3-Mar	397	133	1.05
M4I2	3-Mar	397	118	.
M4I3	3-Mar	397	118	0.721
M4O	3-Mar	397	102	0.7
M4O1	3-Mar	397	96	0.727
M4O2	3-Mar	397	98	0.696
M4O3	3-Mar	397	105	0.707
M4B1	3-Mar	397	105	.
M4B2	3-Mar	397	108	0.734
M4B3	3-Mar	397	110	0.734
DSI	3-Mar	397	535	3.15
DSI1	3-Mar	397	552	.
DSI2	3-Mar	397	558	.
DSI3	3-Mar	397	921	.
DSO	3-Mar	397	554	3.2
DSO1	3-Mar	397	532	3.21
DSO2	3-Mar	397	545	3.18

DSO3	3-Mar	397	534	3.22
DSB1	3-Mar	397	600	3.89
DSB2	3-Mar	397	574	3.58
DSB3	3-Mar	397	557	3.65
DNI =DSO	3-Mar	397	.	.
DNI1	3-Mar	397	328	2.35
DNI2	3-Mar	397	337	2.44
DNI3	3-Mar	397	344	2.32
DNO	3-Mar	397	347	2.3
DNO1	3-Mar	397	331	2.4
DNO2	3-Mar	397	341	.
DNO3	3-Mar	397	340	2.32
DNB1	3-Mar	397	437	.
DNB2	3-Mar	397	383	.
DNB3	3-Mar	397	401	.
L3I	17-Mar	454	.	.
L3I1	17-Mar	454	149	1.188
L3I2	17-Mar	454	105	0.77
L3I3	17-Mar	454	102	.
L3O	17-Mar	454	142	0.944
L3O1	17-Mar	454	142	.
L3O2	17-Mar	454	144	0.9
L3O3	17-Mar	454	103	.
L3B1	17-Mar	454	148	0.951
L3B2	17-Mar	454	147	.
L3B3	17-Mar	454	150	0.832
L1I	17-Mar	454	.	.
L1I1	17-Mar	454	139	0.637
L1I2	17-Mar	454	113	0.725
L1I3	17-Mar	454	230	0.888
L1O	17-Mar	454	215	.

L1O1	17-Mar	454	184	0.799
L1O2	17-Mar	454	155	0.908
L1O3	17-Mar	454	162	.
L1B1	17-Mar	454	206	.
L1B2	17-Mar	454	220	0.95
L1B3	17-Mar	454	267	0.952
M3I	17-Mar	458	.	.
M3I1	17-Mar	458	.	.
M3I2	17-Mar	458	.	.
M3I3	17-Mar	458	.	.
M3O	17-Mar	458	136	.
M3O1	17-Mar	458	139	0.913
M3O2	17-Mar	458	.	.
M3O3	17-Mar	458	.	.
M3B1	17-Mar	458	143	0.891
M3B2	17-Mar	458	.	.
M3B3	17-Mar	458	.	.
M4I	17-Mar	458	.	.
M4I1	17-Mar	458	155	.
M4I2	17-Mar	458	140	.
M4I3	17-Mar	458	136	.
M4O	17-Mar	458	132	0.915
M4O1	17-Mar	458	131	0.873
M4O2	17-Mar	458	135	0.873
M4O3	17-Mar	458	134	0.876
M4B1	17-Mar	458	146	0.974
M4B2	17-Mar	458	146	0.963
M4B3	17-Mar	458	144	0.976
DSI	17-Mar	458	.	.
DSI1	17-Mar	458	764	5.56
DSI2	17-Mar	458	776	5.45

DSI3	17-Mar	458	786	5.69
DSO	17-Mar	458	548	4.01
DSO1	17-Mar	458	559	.
DSO2	17-Mar	458	.	.
DSO3	17-Mar	458	.	.
DSB1	17-Mar	458	.	4.59
DSB2	17-Mar	458	646	4.37
DSB3	17-Mar	458	637	4.36
DNI	17-Mar	458	.	.
DNI1	17-Mar	458	454	3.22
DNI2	17-Mar	458	.	.
DNI3	17-Mar	458	.	.
DNO	17-Mar	458	482	3.43
DNO1	17-Mar	458	477	3.41
DNO2	17-Mar	458	537	3.71
DNO3	17-Mar	458	.	.
DNB1	17-Mar	458	644	.
DNB2	17-Mar	458	.	.
DNB3	17-Mar	458	.	.
L3I	17-Apr	583	.	.
L3I1	17-Apr	583	60	0.569
L3I2	17-Apr	583	61	0.565
L3I3	17-Apr	583	62	0.572
L3O	17-Apr	583	125	0.918
L3O1	17-Apr	583	119	0.887
L3O2	17-Apr	583	124	0.961
L3O3	17-Apr	583	132	.
L3B1	17-Apr	583	136	0.942
L3B2	17-Apr	583	135	1.033
L3B3	17-Apr	583	135	0.987
M4I	17-Apr	583	.	.

M4I1	17-Apr	583	88	0.684
M4I2	17-Apr	583	87	0.719
M4I3	17-Apr	583	88	0.685
M4O	17-Apr	583	93	0.713
M4O1	17-Apr	583	127	0.909
M4O2	17-Apr	583	126	0.892
M4O3	17-Apr	583	95	.
M4B1	17-Apr	583	958	.
M4B2	17-Apr	583	169	.
M4B3	17-Apr	583	159	.
DSI	17-Apr	583	.	.
DSI1	17-Apr	583	978	6.82
DSI2	17-Apr	583	1198	6.81
DSI3	17-Apr	583	990	6.91
DSO	17-Apr	583	998	6.81
DSO1	17-Apr	583	1133	6.83
DSO2	17-Apr	583	1049	6.81
DSO3	17-Apr	583	1032	6.96
DSB1	17-Apr	583	.	.
DSB2	17-Apr	583	.	.
DSB3	17-Apr	583	.	.

2008 Raw Data

Label	Date	TSS (mg/L)	VSS (mg/L)	Unscreened VSS (mg/L)	Turbidity (NTU)	Solar Radiation (W/m^2)
BW	29-Feb	10.8	1.9	0	4.99	188
L8	29-Feb	5.8	1.7	0	5.25	188
L1	29-Feb	4.0	2.1	1.9	1.41	188
L3	29-Feb	8.7	2.4	1	8.38	188
M3	29-Feb	37.5	4.1	0.7	47.8	188
M4	29-Feb	27.2	3.5	1	36	188
DN	29-Feb	17.6	4.4	4	20.9	188
DS	29-Feb	30.3	9.1	0	29.4	188
BW	16-Mar	11.0	2.8	0.4	8.54	227
L8	16-Mar	8.6	2.8	0.2	7.39	227
L1	16-Mar	1.4	1.2	1.6	2.45	227
L3	16-Mar	122.2	26.7	0	111	227
M3	16-Mar	112.0	14	0	143	227
M4	16-Mar	72.0	9.7	2.8	82.4	227
DN	16-Mar	9.4	2.4	0	8.59	227
DS	16-Mar	97.0	15.9	0	90.5	227
BW	20-Mar	5.8	1.8	0.4	5.64	229
L8	20-Mar	13.3	4.3	0	10.9	229
BW	27-Mar	17.0	3	0.1	11.6	206
L8	27-Mar	9.6	2.8	0	9.06	206
BW	30-Mar	16.2	2.8	0.5	11.9	212
L8	30-Mar	11.0	3	0.5	11.3	212
L3	30-Mar	12.4	2.6	1.4	13.8	212
M4	30-Mar	22.6	3.7	1.1	23.9	212
DS	30-Mar	46.0	8.4	0.4	47	212
BW	13-Apr	16.8	3.4	0	13.4	305

Label	Date	TSS (mg/L)	VSS (mg/L)	Unscreened VSS (mg/L)	Turbidity (NTU)	Solar Radiation (W/m^{2})
L8	13-Apr	15.2	3.2	0.8	14.5	305
L3	13-Apr	4.6	1.6	0.6	6.45	305
M4	13-Apr	36.0	8	0	21.3	305
DS	13-Apr	21.2	7.2	1.6	32	305
L3	18-Apr	6.0	1.8	1	6.82	291
M4	18-Apr	25.5	5.2	0	30.3	291
DS	18-Apr	93.3	12.6	2	99.4	291
BW	20-Apr	15.2	3.4	0.4	20.1	317
L8	20-Apr	20.6	5.4	0.5	20.7	317
L3	21-Apr	9.6	2.6	0.6	9.45	312
M4	21-Apr	88.5	20.5	0	92.6	312
DS	21-Apr	407.0	53.5	6.5	460	312
L3	22-Apr	27.1	6.3	0.6	24.5	190
M4	22-Apr	250.0	55.9	1.6	303	190
DS	22-Apr	393.0	55.8	6.3	434	190
BW	23-Apr	17.4	3	0.4	11.7	239
L8	23-Apr	16.7	4.7	0	14.6	239
L3	23-Apr	57.3	14.5	3.5	54.3	239
BW	27-Apr	15.4	3	0.2	12.5	315
L8	27-Apr	21.6	5.1	0.1	19.2	315

Label	Date	Ave. Wind Spd (MPH)	Ave Daily Temp (^{o}F)	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	TKN (mg/L-N)
BW	29-Feb	4.5	55.8	0.606	0.170	1.1
L8	29-Feb	4.5	55.8	0.417	0.080	0.9
L1	29-Feb	4.5	55.8	0.073	.	1.0

Label	Date	Ave. Wind Spd (MPH)	Ave Daily Temp (°F)	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	TKN (mg/L-N)
L3	29-Feb	4.5	55.8	0.192	0.120	1.8
M3	29-Feb	4.5	55.8	0.231	0.070	1.4
M4	29-Feb	4.5	55.8	0.288	0.180	1.7
DN	29-Feb	4.5	55.8	0.275	.	2.1
DS	29-Feb	4.5	55.8	0.525	.	.
BW	16-Mar	19.2	52.6	0.238	0.192	1.0
L8	16-Mar	19.2	52.6	0.151	0.110	0.9
L1	16-Mar	19.2	52.6	0.021	0.001	1.1
L3	16-Mar	19.2	52.6	0.279	0.031	2.4
M3	16-Mar	19.2	52.6	0.263	0.085	1.5
M4	16-Mar	19.2	52.6	0.228	0.065	2.1
DN	16-Mar	19.2	52.6	0.166	0.035	2.0
DS	16-Mar	19.2	52.6	0.239	0.074	2.4
BW	20-Mar	6.0	52.5	0.249	0.180	0.9
L8	20-Mar	6.0	52.5	0.195	0.075	1.1
BW	27-Mar	8.6	47.9	0.270	0.193	0.8
L8	27-Mar	8.6	47.9	0.213	0.136	0.9
BW	30-Mar	10.5	51.1	0.264	0.194	0.9
L8	30-Mar	10.5	51.1	0.208	0.122	0.9
L3	30-Mar	10.5	51.1	0.410	0.054	1.4
M4	30-Mar	10.5	51.1	0.478	0.063	1.4
DS	30-Mar	10.5	51.1	0.769	0.038	2.6
BW	13-Apr	4.3	70.3	1.011	0.246	1.1
L8	13-Apr	4.3	70.3	0.795	0.155	1.0
L3	13-Apr	4.3	70.3	0.469	0.088	1.2
M4	13-Apr	4.3	70.3	0.669	0.064	1.4
DS	13-Apr	4.3	70.3	0.747	0.051	2.9
L3	18-Apr	8.1	62.8	0.111	0.066	1.0

Label	Date	Ave. Wind Spd (MPH)	Ave Daily Temp (°F)	Total Phosphorus (mg/L-P)	Phosphate (mg/L-P)	TKN (mg/L-N)
M4	18-Apr	8.1	62.8	0.259	0.119	1.9
DS	18-Apr	8.1	62.8	0.354	0.076	3.5
BW	20-Apr	6.8	47.5	0.403	0.244	1.2
L8	20-Apr	6.8	47.5	0.342	0.214	1.6
L3	21-Apr	5.0	49.5	0.103	0.050	1.2
M4	21-Apr	5.0	49.5	0.385	0.047	2.3
DS	21-Apr	5.0	49.5	0.953	0.082	5.5
L3	22-Apr	5.9	52.2	0.156	0.053	1.4
M4	22-Apr	5.9	52.2	0.876	0.006	4.5
DS	22-Apr	5.9	52.2	0.987	0.084	6.2
BW	23-Apr	7.8	55.3	0.282	0.224	1.2
L8	23-Apr	7.8	55.3	0.319	0.216	1.3
L3	23-Apr	7.8	55.3	0.219	0.051	2.2
BW	27-Apr	4.1	71.1	0.275	0.202	1.1
L8	27-Apr	4.1	71.1	0.378	0.252	1.3

Label	Date	Ammonia (mg/L-N)	Nitrate+Nitrite (mg/L-N)	TOC (mg/L-C)	DOC (mg/L-C)
BW	29-Feb	0.069	0.000		.
L8	29-Feb	0.057	0.040	.	.
L1	29-Feb	0.067	0.000	10.5	9.5
L3	29-Feb	0.25	0.110	12.0	11.1
M3	29-Feb	0.401	0.380	10.2	7.5
M4	29-Feb	0.415	0.360	8.6	7.8
DN	29-Feb	0.188	0.000	18.2	15.7
DS	29-Feb	0.045	0.000	13.7	11.8

Label	Date	Ammonia (mg/L-N)	Nitrate+Nitrite (mg/L-N)	TOC (mg/L-C)	DOC (mg/L-C)
BW	16-Mar	0.041	0.100	11.8	12.2
L8	16-Mar	0.039	0.080	13.1	10.2
L1	16-Mar	0.028	0.110	13.8	11.7
L3	16-Mar	0.107	0.000	19.7	11.8
M3	16-Mar	0.082	0.000	11.6	9.2
M4	16-Mar	0.298	0.000	13.4	10.0
DN	16-Mar	0.038	0.640	20.1	17.6
DS	16-Mar	0.085	0.020	21.5	16.1
BW	20-Mar	0.047	0.000	10.6	10.8
L8	20-Mar	0.035	0.040	12.1	11.3
BW	27-Mar	0.045	0.070	10.3	11.9
L8	27-Mar	0.037	0.190	11.2	13.4
BW	30-Mar	0.049	0.000	10.9	10.4
L8	30-Mar	0.045	0.000	11.0	10.9
L3	30-Mar	0.066	0.170	14.8	14.8
M4	30-Mar	0.227	0.110	9.9	10.1
DS	30-Mar	0.033	0.000	22.4	23.4
BW	13-Apr	0.095	0.000	.	10.9
L8	13-Apr	0.056	0.160	.	10.1
L3	13-Apr	0.074	0.180	.	12.2
M4	13-Apr	0.023	0.000	.	10.3
DS	13-Apr	0.023	0.000	.	24.0
L3	18-Apr	0.06	0.000	.	9.6
M4	18-Apr	0.238	0.000	.	8.9
DS	18-Apr	0.023	0.000	.	26.6
BW	20-Apr	.	0.050	.	13.2
L8	20-Apr	.	0.090	.	12.3
L3	21-Apr	0.065	0.000	.	13.7
M4	21-Apr	0.205	0.000	.	14.7

Label	Date	Ammonia (mg/L-N)	Nitrate+Nitrite (mg/L-N)	TOC (mg/L-C)	DOC (mg/L-C)
DS	21-Apr	0.344	0.000	.	33.7
L3	22-Apr	0.094	0.000	.	16.3
M4	22-Apr	0.244	0.000	.	17.7
DS	22-Apr	0.215	0.000	.	36.3
BW	23-Apr	0.064	0.000	.	13.3
L8	23-Apr	0.048	0.000	.	15.2
L3	23-Apr	0.162	0.000	.	15.2
BW	27-Apr	0.044	0.060	.	11.0
L8	27-Apr	0.056	0.070	.	13.8

Label	Date	Weir Flow (L/s)	Specific Conductivity (mS/cm)	Total Organic Carbon (mg/L-C)	Dissolved Organic Carbon (mg/L-C)
BW	29-Feb	9.1	1.34	11.5	10.5
L8	29-Feb	111.2	1.68	12.0	11.1
L1	29-Feb	0.0	0.99	10.6	9.5
L3	29-Feb	4.4	1.09	12.4	11.1
M3	29-Feb	3.8	0.73	9.7	7.5
M4	29-Feb	8.4	0.89	9.6	7.8
DN	29-Feb	2.1	3.19	18.0	15.7
DS	29-Feb	0.0	3.53	16.6	11.8
BW	16-Mar	125.1	1.41	13.7	12.2
L8	16-Mar	84.8	1.83	11.7	10.2
L1	16-Mar	0.0	1.18	12.3	11.7
L3	16-Mar	0.1	1.25	25.9	11.8
M3	16-Mar	6.9	0.81	16.6	9.2
M4	16-Mar	0.4	0.93	15.1	10.0

Label	Date	Weir Flow (L/s)	Specific Conductivity (mS/cm)	Total Organic Carbon (mg/L-C)	Dissolved Organic Carbon (mg/L-C)
DN	16-Mar	0.8	4.16	18.9	17.6
DS	16-Mar	0.0	4.52	24.5	16.1
BW	20-Mar	133.4	.	11.8	10.8
L8	20-Mar	98.5	.	13.6	11.3
BW	27-Mar	41.4	1.49	13.5	11.9
L8	27-Mar	87.3	1.87	14.9	13.4
BW	30-Mar	21.0	1.51	11.9	10.4
L8	30-Mar	67.2	1.91	12.5	10.9
L3	30-Mar	0.3	1.35	16.2	14.8
M4	30-Mar	4.4	1.00	12.1	10.1
DS	30-Mar	0.0	5.74	27.8	23.4
BW	13-Apr	31.4	1.67	12.7	10.9
L8	13-Apr	70.5	1.82	11.8	10.1
L3	13-Apr	4.4	1.30	13.0	12.2
M4	13-Apr	4.4	1.07	14.5	10.3
DS	13-Apr	3.8	5.64	27.8	24.0
L3	18-Apr	.	1.35	10.6	9.6
M4	18-Apr	.	1.11	11.6	8.9
DS	18-Apr	.	6.78	33.3	26.6
BW	20-Apr	27.4	1.78	15.0	13.2
L8	20-Apr	52.4	1.98	15.2	12.3
L3	21-Apr	.	1.39	15.1	13.7
M4	21-Apr	.	1.16	25.5	14.7
DS	21-Apr	.	7.93	61.9	33.7
L3	22-Apr	.	1.46	19.6	16.3
M4	22-Apr	.	1.22	47.2	17.7
DS	22-Apr	.	8.60	65.8	36.3
BW	23-Apr	25.8	1.83	14.9	13.3

Label	Date	Weir Flow (L/s)	Specific Conductivity (mS/cm)	Total Organic Carbon (mg/L-C)	Dissolved Organic Carbon (mg/L-C)
L8	23-Apr	33.2	1.93	17.7	15.2
L3	23-Apr	.	1.49	22.9	15.2
BW	27-Apr	.	1.73	12.6	11.0
L8	27-Apr	.	1.88	16.5	13.8

APPENDIX B: ION CHROMATOGRAPHY

Nitrite, Nitrate, and Phosphorus where analyzed using ion chromatography. A Dionex DX 120 Ion Chromatograph was used with a setup including;

- AG9-HC IonPac® Guard Column
- AS9-HC 4mm IonPac® IC column
- DS4-1 Detection Stabilizer.
- AS40 Automated Sampler.

Sodium bicarbonate with a concentration of 9mM was used as eluent. The eluent was prepared by degassing Grade 1 DI water with Ultra High Purity helium for 30 minutes and diluting concentrated 0.5M sodium carbonate to create 9mM eluent for the various volumes needed. Ultra High Purity Helium was supplied to the IC at a pressure of 40 psi. Internal pressure of the IC was maintained between 2300 and 2500 psi. Flow of eluent was set to 1.10 ml/min. The eluent was allowed to flow for at least 1 hour prior to running any samples through the column. The total run time for each sample was 30 minutes. The actual Chromel Program only recording peaks for 13 minutes allowing ions up to phosphate to be analyzed.

Standards were prepared using Dionex 7 Anion standard solution. Three separate dilutions were made to create a 3-point calibration curve. Samples were filtered through 0.22µm Millipore Express PLUS® Membrane filters with the assistance of a HDPE plunger. Samples were placed into 5ml Dionex poly vials and caped with Dionex 20µm filter caps. A spike of 7-anion solution was added to one sample for each series for quality assurance. At the start of each run a DI rinse was used prior to running any samples through. After any standards where run a DI blank was analyzed to confirm that had been no contamination and to show any background noise from the machine. If more than 15 samples were run in one sitting, a second 3-point calibration curve was used.