Staten Island Wildlife-Friendly Farming Demonstration-Water Quality Monitoring (CALFED grant # ERP-02-P08) - Final Report

Prepared by: Carol L. DiGiorgio
Department of Water Resources
Municipal Water Quality Investigations Unit
P.O. Box 942836
Sacramento, CA 95814
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1.0 Executive Summary

As part of a CALFED competitive grant process, Ducks Unlimited was awarded a grant to: 1) develop an efficient and cost effective water management infrastructure on Staten Island to maintain and improve sustainable agriculture and wildlife-friendly practices and 2) determine the effect of winter flooding strategies on target bird species by determining the effect of winter flooding on the quantity and quality of organic carbon and nutrients seasonally discharged from seasonally flooded agricultural fields into the Delta channels. As a participant on the grant, the Department of Water Resources (DWR) was responsible for water quality monitoring.

Little actual data exists for organic carbon and nutrient loads discharged from actively farmed Delta peat islands. Often models and extrapolations have been used to quantify Delta island inputs. This CALFED study is one of the few to quantify these parameters. Additionally, Staten Island is composed of several different soil types with more mineralized soils occurring in the northern part of the island and more organic (peat) soils occurring in the southern part. This provided an opportunity to study the effects of water management practices on agricultural lands of different soil types found in the Delta. The water quality monitoring goals in this study were to:

> a) Determine carbon and nutrient loads discharged from an actively farmed Delta peat island and,
> b) Study the effect of 2 different soil types on the water quality in fields flooded for waterfowl use.

Principal findings of this study were:

<u>Flow</u>

- Up to 3 discharge periods occur on the island—pre-irrigation discharge, irrigation discharge, and winter discharge.

- Pre-irrigation and irrigation discharges occur yearly, regardless of year type. Depending on the year type winter discharges may co-occur with pre-irrigation discharges, be non-existent, or occur throughout the rainy season.
- Winter discharge outside of the pre-irrigation discharge season is primarily connected to rainfall, river stage and flooding concerns.
- The greatest volume of water discharged off the island occurred in the summer irrigation season, not the winter rainy season.

Water Quality

- Water quality on the island is controlled by its source water, pumping activity and biological and geochemical mechanisms.
- Simplistically water quality patterns reflect whether the source water is river water or groundwater. Layered on this are residence times and biological activity.
- Water quality between the 2 pump stations is generally similar during the summer irrigation season and statistically different during the pre-irrigation/winter discharge season.
- During the summer irrigation season, river water influenced water quality. In the pre-irrigation/winter discharge season, groundwater and the location of the pump stations combined with pumping dynamics determined water quality.
- Concentrations of electrical conductivity, turbidity, Total Organic Carbon (TOC), total Kjeldahl nitrogen (TKN), total phosphate, and orthophosphate were lower during the summer irrigation season than in the fall and winter. Depending on the analyte, concentrations detected in the pre-irrigation/winter periods could increase tenfold compared to summer values.
- There were no statistical differences between TOC grab samples and TOC autosample samples.
- Statistical differences in TOC concentrations between the 2 pumping plants highlighted the need to sample all discharge points on an island.
- Statistical differences in pre-irrigation/winter TOC concentrations between the 2 pump stations were due to pump location, soil characteristics, and residence time of the groundwater on the island.

- In the winter, pumping and rainfall mobilized nitrate and ammonia. Increases in winter phosphate concentrations were potentially due to the release of phosphate bound to sediments under anoxic conditions.
- Although the impacts of overwintering waterfowl were not examined directly, water quality dynamics could be explained by cropping patterns and the seasonal use of water dictated by agricultural needs. Waterfowl would be expected to impact water quality, but using TKN as a surrogate for waterfowl fecal input, island dynamics appeared to overwhelm any water quality signal provided from waterfowl.

Loading

- For TOC, nitrate, ammonia, and TKN, the greatest loads discharged off the island occurred in the pre-irrigation/winter discharge season.
- For orthophosphate, the greatest loads discharged off the island occurred in the summer irrigation season.
- For total phosphate, loading was similar between the summer and pre-irrigation/winter season with the greatest monthly load discharged in July 2006.
- Of the nitrogen species monitored, organic nitrogen was the primary form of nitrogen discharged off the island (55%) followed by nitrate (37%) and ammonia (8%)
- Annual TOC flux rates were similar to Twitchell Island's but greater than flux rates for Colusa Basin Drain (CBD), Harding Slough, or urban discharge from the Natomas East Main Drainage Canal.
- Annual Staten Island nitrate flux rates were approximately half of those for Twitchell Island, but 7X and 2X greater than CBD, Mud Slough or Delta island agricultural drainage, respectively.
- Annual ammonia flux rates were identical to Twitchell Island.
- No flux rates were available for comparisons to Staten Island's TKN, total phosphate and orthophosphate annualized flux rates.

Fields Flooded for Waterfowl Use

- With the exception of ammonia and TKN, there were no significant differences in water quality between the 2 fields chosen for comparison.
- Lack of statistical differences between the fields were probably due to the contiguous spread of water across all field soil types and, in the case of OC, the similar OC content of the soils in the 2 fields chosen for comparison.
- With the exception of phosphate, statistical differences were always detected between the fields and the pumping plant.
- Statistical differences between the fields and the pumping plant were due to the source water differences between the fields and the pumping plant.

Water Quality Before and After New Pumping Plant Installation

- There were no significant differences between total phosphate, orthophosphate, or ammonia concentrations before or after pump installation.
- Statistical differences were detected for TOC, nitrate and TKN, however these differences could potentially be explained by factors other than the installation of the New PP.
- In the case of TOC, precipitation patterns could potentially explain significant differences in TOC concentrations before and after pump installation.
- In the case of nitrate and TKN, bacterial respiration and primary productivity could potentially explain significant differences in nitrogen species before and after pump installation.

2.0 Introduction

Staten Island is approximately a 9200 acre island located in northern San Joaquin County, between the North and South Forks of the Mokelumne River (Figure 1). As part of a CALFED competitive grant process, Ducks Unlimited was awarded a grant to: 1) develop an efficient and cost effective water management infrastructure on Staten Island to maintain and improve sustainable agriculture and wildlife-friendly practices, and 2) determine the effect of winter flooding strategies on target bird species by determining the effect of winter flooding on the quantity and quality of organic carbon and nutrients discharged from seasonally flooded agricultural fields into the Delta channels. As a participant on the grant, the Department of Water Resources (DWR) was responsible for water quality monitoring.

The grant proposal was originally submitted in 2000, however due to numerous contracting delays, water quality monitoring on the island could not begin until the fall of 2004. During this period, one of the grant's objectives—construction of berms to improve water management on the island was completed by Duck's Unlimited. Therefore, one of the original water quality objectives--monitoring water quality before and after berm construction--was no longer feasible. Through discussions with The Nature Conservancy and Duck's Unlimited, the before and after affects of berm construction on water quality was revised to examine the water quality in fields of 2 different soil types. Staten Island is composed of several different soil types with more mineralized soils occurring in the northern part of the island and more organic (peat) soils occurring in the southern part. This provided an opportunity to study the effects of water management practices on agricultural lands of different soil types found in the Delta.

Few studies have examined the loads of carbon or nutrients discharged off of an actively farmed Delta peat island. Monitoring water quality on Staten Island provided a unique opportunity to examine the effects of agricultural management practices on water quality and on the quantity of organic carbon and nutrients discharged from the island. The Department's Delta Simulation Model (DSM2) classifies Staten Island as an island with high carbon concentrations (Jung, 2000). Templin and Cherry (1997) examined discharge directly from Twitchell Island and indirectly from Delta islands regionally. Using their Twitchell Island discharge data, DWR estimated the discharge of dissolved organic carbon loads from Twitchell Island (DWR, 1996). Recently another study also examined organic carbon discharges from Twitchell Island (Deverel cited in Brown and Caldwell, 2005). Similarly with respect to nutrients, one study quantified nutrient discharges from Twitchell Island (Deverel cited in Brown and Caldwell, 2005).

The water quality monitoring goals in this study were to:

a) Determine carbon and nutrient loads discharged from an actively farmed Delta peat island and,

b) Study the effect of 2 different soil types on the water quality in fields flooded for waterfowl use.

3.0 Materials and Methods

Flow Measurements: The Old Pumping Plant (Old PP) is located at the southernmost end of the island which is the natural lowpoint of the island (Figure 2). There are 4 pumps at the pump station, three100 horsepower pumps and one 200 horsepower pump. During the summer of 2005, DWR staff installed a 1010 MN Controlotron transit-time flow meter with high precision transducers. Per manufacturer's instructions, transducers were attached on each pump's discharge pipe approximately 50-75 feet downstream from the flowmeter. Manufacturer representatives visited the site and confirmed that the flowmeter was working properly. As part of the grant funded study, a second pumping plant was installed on the eastern side of the island (Figure 2). Construction of the new pumping plant (New PP) was finished by December 2005. Like the Old PP, there are 4 pumps at the New PP; three are 100 horsepower electric pumps while the fourth is a 200 horsepower diesel powered pump. Transducers and a flowmeter were installed by February 2006 in the same manner as at the Old PP. Proper flowmeter readings at the New PP were confirmed by factory representatives. For all pipes, flow was recorded every 15 minutes. Flow data was downloaded weekly and average daily flows for each pipe and station were calculated.

Water Chemistry: Grab samples were collected weekly from October 2005 through March 2007, for the Old PP and the North Fork of the Mokelumne River, and from December 2005 through March 2007, for the New PP, for organic carbon (OC), nitrate, ammonia, total Kjeldahl nitrogen (TKN), total phosphate (TP), dissolved orthophosphate, UVA-254, trihalomethanes, and several anion and cation species. All analytes that required filtering were filtered in the field using either an absolute 0.45 µm Geotech versapore cartridge filter or an absolute 0.45 µm, nitrocellulose Millipore filter. Five micron pre-filters were used if waters were especially turbid (absolute 5µm versapore Geotech cartridge filter or a nominal 5 µm nitrocellulose Whatman filter). Filters were flushed with 2 liters of DI water prior to filtering sample waters. Filter and equipment blanks were collected each sampling day and analyzed for OC and nutrient cross contamination from the filters. Analytes were either filtered or preserved based on the methods listed in Table 1. At the time of sample collection, samples were also analyzed in the field for electrical conductivity (EC), dissolved oxygen (DO), temperature, turbidity, and pH. Duplicate QA samples were collected and analyzed monthly. Samples were kept on ice following collection and brought to the Department's Bryte Laboratory within 4-8 hours of collection. Sample containers, volumes collected, holding times, and preservatives used (if required) for all grab samples are documented in the Bryte Chemical Laboratory's QA Manual (Appendix A) (DWR 2002). This manual is designed to meet the U.S. Environmental Protection Agency policy guidelines as outlined in the EPA's Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans (U.S. EPA, 1980), and also to meet the California Department of Health Services, Environmental Laboratory Accreditation Program. This manual is available online at: http://www.water.ca.gov/qa/publicat/Bryte.pdf. Bryte Laboratory is certified by the State of California, Department of Health Services, Environmental Laboratory Accreditation Program for all analyses. Table 1 lists the methods used for analyses.

Table 1. Analytical Methods Used.

Sample Parameter	Matrix	Analytical Method Reference
Ammonia Nitrogen (dissolved)	Water	EPA 350.1
Dissolved Oxygen	Water	Per YSI instruments
Electrical Conductivity	Water	SM 2510-B
Kjeldahl Nitrogen	Water	EPA 351.2
Nitrate, Nitrite	Water	SM 4500-F DWR modified
Organic carbon (TOC, DOC)-combustion	Water	EPA 415.1 (T) EPA 415.1 (D)
Organic carbon (TOC, DOC)-oxidation	Water	EPA 415.1 (T) EPA 415.1 (D)
Orthophosphate (dissolved)	Water	SM 4500-P F
pH	Water	EPA 150.1
Phosphorous (total)	Water	EPA 365.4
Total Dissolved Solids	Water	EPA 160.1
Total Trihalomethane Formation Potential	Water	EPA 510 DWR modified
Turbidity	Water	EPA 180.1
UVA 254	Water	SM 5910B

EPA = US Environmental Protection Agency
SM = Standard Methods, APHA, 1995.

Grab samples were collected using either a clean, stainless steel bucket, lowered into the water from a cable, or from the bank using a telescoping pole and a stainless steel collection vessel. All sampling apparatus were rinsed at least two times with sample water prior to actual sample collection. To avoid oil contamination from the pumps, grab samples at the pumping plants were collected approximately 100-200 feet upstream of the inlet ports near the center point of the drain. River samples were collected from the bank. In all cases, unless the water was too shallow, samples were collected approximately a half meter below the surface.

Refrigerated ISCO autosamplers were installed at both pumping plants approximately 100-200 feet upstream of the pump station. Autosampler samples were collected once a week from the Old and New Pumping Plant whenever that week's flowmeter data indicated that the pumps had been running or it was anticipated that the pumps would run within the next 24 hours. Autosampler samples were collected from the Old PP beginning in October 2005, while autosampler samples were collected from the New PP beginning in February 2006. The autosampler's inlet line was run through a PVC pipe held near the surface by a float so that samples were always collected near the center point of the drainage canal approximately 0.5 meters below the surface. Autosampler samples and grab samples were collected at the same location. Teflon™ lined Tygon tubing attached to a stainless steel strainer was used for the inlet line tubing. Tubing was backflushed with deionized water following each 24 hour sampling event and the autosampler was programmed to flush the line with ambient water prior to every aliquot collection. Tubing, strainer and ISCO silicon peristaltic pump tubing were replaced quarterly. Autosampler samples were collected in 1 liter polypropylene containers. Previous experiments determined that no detectable organic carbon leached from these containers into the sample water (unpublished data, this study). With the exception of one month (2/6/06 to 3/6/06), autosampler samples were kept refrigerated at 4º C ± 2º C throughout the 24 hour sampling period. During the one month time period, the drainage canal supplying the Old PP flooded beyond its banks and electrical power was not available. During this period, blue ice was used to keep autosampler samples cold.

Autosamplers were triggered manually and were programmed to collect a sample every hour for 24 hours. Each hourly sample consisted of three-300 mL subsamples collected every 20 minutes. Within 2 to 4 hours of the 24 hour collection period, flow readings from the flowmeter were downloaded to a laptop. Flow weighted volumes were calculated from the downloaded data and hourly autosample samples were manually composited to form one flow-weighted composite sample. Once composited, samples were handled in the same manner as grab samples. Blank water was placed in each autosampler and analyzed for OC to determine if contamination had occurred from splashing between sample bottles.

Loads were calculated from the average daily flows and the results from weekly sample collections. To calculate loads between weekly measurements, analyte concentrations were interpolated and multiplied by the actual flow measurement.

Comparison between soil types: In the fall of 2004, DWR staff collected weekly grab samples from 2 flooded agricultural fields (fields 41 and 81) that National Resources Conservation Service soil maps indicated were of different soil types (USDA, 1992)

(Figure 2). Sampling began at the end of October 2004, when the fields were fully flooded for waterfowl use, and ended at the beginning of February 2005, when most of the water on the fields had drained. Grab samples were collected concurrently from the Mokelumne River and the Old PP. Grab samples were analyzed using the same methods described above. Three grab samples were collected along a transect line at the lowest part of the field. The points were chosen at random at the beginning of the sampling season. Fields were chosen with similar summer cropping histories and flooding schedules. Although samples were initially to be collected from only fields 41 and 81, flooding for waterfowl resulted in a nearly continuous sheet of water across all fields and soil types. Organic carbon content of the soils was determined by randomly choosing 2 points in each field. Using a soil auger, soil was collected at 2 depths-0-12" and 12-24". Samples were composited and analyzed for OC (Nelson, and L.E. Sommers, 1996.).

4.0 Results and Discussion

4.1 Report Structure

One of the main purposes of this study was to quantify OC and nutrient loads discharged in drainage water from an actively farmed Delta peat island. Load is a calculation of mass and is the product of the volume of water discharged per unit time and the concentration of the analyte of interest in the discharge. While loads are calculated from flow and concentration, examining each component separately provides insights into the underlying processes behind the loads derived from them. Therefore this report examined flow discharge patterns and the concentration patterns of a number of water quality analytes. A second objective of this study was to examine surface water quality when fields were flooded for waterfowl and Sandhill Crane use following fall harvest. These results are presented following the loading analysis.

4.2 Discharge Dynamics-Pumping

Until December 2005, there was one main pump station on Staten Island. The Old PP is located at the southernmost end of the island which is the natural lowpoint of the island. Even without pumping, water in the drains naturally moves to the southern end of the island. Depending on water management goals, any combination of the four pumps can be operating at the pump station. Pumps can be controlled manually, by timers, or by a series of sensors set to trigger or end pumping based on water height in the forebay of the drain. Average daily flows from the Old PP are shown in Figure 3.

In December 2005 a new pumping plant located on the eastern side of the island became operational. The New PP was installed to improve water management options on the island. Operation of the pumps is controlled with the same range of methods as at the Old PP. Average daily flows from the New PP are shown in Figure 4.

Over the course of a year, there were up to three periods of discharge off the island. These discharges were associated with the summer irrigation season, the pre-irrigation season, and depending on the amount of rainfall, the winter rainy season (Figure 5). During this study, corn was the predominant crop grown on the island. With corn, summer irrigation and pre-irrigation discharges occur each year, regardless of the type of water year (WY). Depending on precipitation, winter rainy season discharge may coincide with pre-irrigation discharge, be non-existent, or occur throughout the winter rainy season.

Summer irrigation and pre-irrigation discharges are determined by agricultural requirements. During the summer irrigation season, water is siphoned from the Mokelumne River for summer crop irrigation. Simultaneously groundwater levels are kept below the root zone by drainage pumping to prevent soil saturation and root death. During the summer growing season, these two requirements result in nearly continuous pumping and discharge off the island. In the summer of 2006 summer irrigation discharge occurred from approximately June through the end of August, with pumping beginning and ending earlier at the New PP than at the Old PP because of planting patterns.

Despite the classification of 2006 as a wet year, the greatest volume of water discharged off the island during this WY occurred in the summer growing season, not the winter rainy season (Figure 6). This annual discharge pattern, dictated by crop requirements, is typical for Staten Island (Brent Tadman, pers. comm.). These results differed from discharge patterns reported for Twitchell Island in 1994/95 by Templin and Cherry (1997), where the greatest volumes discharged during a critical WY from Twitchell occurred during the winter (Figure 7). Discharge differences between the 2 islands occurred despite underreporting of flow at the Old PP during the irrigation season. At the end of the 2006 irrigation season it was discovered that one of the transducers at the Old PP had not been reporting flow, therefore both average flow and total volume pumped between June and August would have been greater if the contributions from this pump had been recorded. However, winter discharge volumes were also underreported due to the loss of power for a week at the Old PP during the heavy winter rains occurring at the end of December 2005 and the beginning of January 2006. However, even assuming that all pumps had been running during this period, the loss of data only resulted in a 5% increase in the volume discharged between January and April 2006. Over the course of the study, the greatest volume of water discharged form the island occurred in February 2007, however the study ended before 2007 summer and winter discharges could be compared.

Pre-irrigation discharge occurs every spring regardless of whether it is a wet or dry winter. In early to mid spring, topsoil needs to be dry enough to cultivate with heavy farm equipment but also have sufficient moisture to support plant growth following germination. Salts, leached over the fallow winter season, must also be removed prior to planting.

The amount and timing of winter precipitation determines whether pre-irrigation and winter rainy season discharges overlap. During a wet spring, pumping may occur over a long period of time in an attempt to dry out the soils and lower the groundwater level. This is what occurred in the winter and spring of 2006. Faced with numerous spring rains, elevated river levels, and soil too wet to plant, pumping occurred over an extended period of time, ending with planting beginning in late April. In a dry winter, little or no discharge is associated with rainfall. This is what occurred in the winter and spring of 2007. The winter and spring of 2007 had relatively little rainfall and water that had been applied the previous fall for waterfowl had drained off as groundwater. Beginning in January 2007, water was actively siphoned onto the island to wet the topsoil. Removal of pre-irrigation water began in February 2007 as pumps were run continuously to remove salts and lower the groundwater table for planting that began in March. Discharge in the spring of 2007 was relatively brief compared to the spring of 2006, and had little to do with rainfall. Both the Old and New PPs were in full operation in February 2007 which resulted in a much greater volume discharged from the island than the previous spring when only the Old PP had been used.

Winter discharges occur when there are extended periods of rainfall or there is the threat of flooding. If long-range weather forecasts predict rainfall over an extended period of time, pumps may be turned on to prevent excess groundwater from collecting on the island. As with other islands, the farm manager of Staten Island uses data from the California Data Exchange Center (CDEC) to determine when rivers influencing Staten Island will reach flood stage. Using this information, the manager may choose to pump to prevent the island from flooding due to increased groundwater seepage from elevated river stage. Preventing groundwater from flooding the island is important for several reasons; 1) if a levee breach did occur, pumping would have to eliminate not only water inundating the island from the breach but also the excess groundwater already flooding the island and 2) even without a levee breach, allowing groundwater to flood the island could result in wave action against the unprotected landward side of the levee resulting in levee erosion inside the island and potentially levee failure. Figures 8a and b show pumping as it relates to rainfall and river stage at Benson's Ferry, immediately upstream of Staten Island.

In the 2006 WY pumping generally occurred when river stage was approaching or above the 12 foot monitoring stage. The stage data shows this occurred over an extended period in the 2006 WY. Since river stages are related to rainfall, pumping also occurred throughout the rainy period, however between January and April 2006, 64% of the days with rainfall had rainfall levels of ≤ to 0.25 inches, therefore river stage was an important component in the decision to pump. In contrast, figures 8a and 8b show that when winter discharge did occur in the 2007 WY, it was not related to river stage and only loosely tied to rainfall. With both the new and old PPs in operation, pumping rates in February 2007 were well above those of the previous wet winter, however river stages were below 12 feet and most rainfall levels were below 0.25", therefore the discharge period was relatively brief and only associated with agricultural needs.

4.3 Island Water Quality Dynamics

The island's water quality is controlled by the island's source water (groundwater or siphoned river water), pumping activity and residence time of water in the drains, and biological or geochemical activity. The island's source water is determined by the growing season and the water management strategies used for crop production, crop fallowing, and waterfowl habitat. Given these varying requirements, the factors that control the island's water quality breaks down, in simplified form, into 2 seasons, the irrigation season and the non-irrigation season. During the irrigation season, drainage water quality reflects many of the characteristics of riverine water siphoned onto the island for irrigation. During the non-irrigation season, drainage water quality reflects groundwater seepage and to a lesser extent, depending on the intensity, surface water inputs from rainfall and intentional shallow flooding of the fields for waterfowl habitat. Affecting both of these seasons is the residence time of the water (i.e. whether island water is actively moving on the island via the pumps) and the effects of biological activity in the drainage ditches themselves.

Over the course of this study, the water quality differences between the 2 respective pumping plant drains underscored the need to sample all drains on a multi-drain island.

As Table 2 shows, the water quality of the 2 drains was generally similar during the summer irrigation season. With the exception of turbidity, most significant differences between the 2 sites occurred during the non-irrigation season.

Table 2. Average Values and Statistical Differences by Season between the Old and New Pumping Plants.

	Old PP	New PP
EC-summer	337	249
EC-winter	845	577
Turbidity-summer	16.7	26.8
Turbidity-winter	29.0	46.2
DO-summer	5.4	5.8
DO-winter	3.6	3.8
TOC(ox)-summer	11.3	7.6
TOC(ox)-winter	35.8	16.0
DOC(ox)-summer	10.6	7.1
DOC(ox)-winter	30.7	13.8
Ammonia-summer	0.10	0.09
Ammonia-winter	0.47	0.37
TKN-summer	1.41	1.02
TKN-winter	4.40	2.47
Nitrogen as N-summer	0.22	0.20
Nitrogen as N-winter	0.59	0.17
Orthophosphate-summer	0.02	0.03
Orthophosphate-winter	0.03	0.02
Total Phosphate-summer	0.13	0.16
Total Phosphate-winter	0.51	0.38

Units: EC: µSiemens/cm, Turbidity: NTU, All other analytes: mg/L

Shaded area: significantly different at $p < 0.05$, Wilcoxon signed rank test or signed rank test for datasets containing data < detection limit

Summer: June 06-August 06, Winter: September 06-March 07

These results show the importance of source water. In the summer, river water is actively siphoned onto the island for crop irrigation. With the pumps operating continuously, this large, steady influx of freshwater dominates the drain's water quality and the water quality characteristics of both drains closely match those of the source river waters. Continuous pumping reduces the residence time of water in the drainage channels. Since surface water residence times are much reduced, the effects of soil type and pump location do not play a large role in determining water quality. Thus during active irrigation, water quality is similar at the Old and New PP. However, once the constant influx of surface water ceases, other factors such as residence times, biochemical processes in the drainage channels, and pumping regimes influence water quality, producing differences between the 2 pump stations. The dynamics of several water quality constituents are examined below.

4.4 Physical Field Parameters - EC, DO, pH, temperature, turbidity

The transition in the island's water quality from one dominated by surface water to one dominated by groundwater was clearly seen in the electrical conductivity (EC) record. The temporal changes in EC are shown in Figure 9. The effect of siphoned river water inflow onto the island occurred soon after the irrigation season began. At the Old PP, EC fell rapidly from a high of 1513 µS/cm to levels near those in the Mokelumne River. EC rose immediately at both PPs as soon as siphoned water inflows ceased. Following the end of the irrigation season there were 2 distinct increases in EC. The first occurred between September 2006 and January 2007. The second began in February 2007. These patterns illustrated that although water quality could be divided into irrigation and non-irrigation seasons, pumping dynamics also had an effect on water quality during the non-irrigation season. As shown in Figure 10, the first rise in EC, following the summer irrigation season, corresponded to a period when little or no pumping occurred, suggesting that the first rise in EC reflected relatively slower groundwater flow towards the southernmost end of the island. The second rise in EC corresponded to the beginning of active pumping to lower the groundwater table for planting and illustrated the effect active pumping had on groundwater movement on the island. Both influences resulted in statistically higher ECs at the Old PP.

Temperature followed the expected rise and fall with the seasons. However in the fall of 2006, there was a noticeable dissolved oxygen (DO) drop at both the Old and New PP (Figure 11). An influx of anoxic groundwater could explain part of the drop in DO, however at the Old PP, EC levels were higher in the fall of 2005 with no comparable drop in DO. These results suggest that biological respiration was also responsible for the observed fall in DO.

The greatest fluctuation in turbidity was observed at the New PP (Figure 12). The differences between the Old and New PP were due to the lack of vegetation on the slopes of the New PP combined with the current water management strategy which often resulted in lower water levels at the drain to the New PP compared to that at the Old PP.

4.5 Organic Carbon Dynamics

For this study, total organic carbon (TOC) and dissolved organic carbon (DOC) were measured from composite autosampler samples and grab samples using combustion and oxidation analytical methods. From a drinking water perspective, TOC- not DOC- is regulated by the EPA, therefore this report primarily focused on TOC results. There are several approved techniques for measuring TOC and DOC. Since a) the temporal and spatial patterns were similar for the two techniques (Figure 13), b) the majority of California State Water Contractor facilities use the oxidation method to quantify organic carbon, and, c) the oxidation method appears to accurately reflect the fraction of organic carbon responsible for disinfection byproduct production (DWR, 2003), only oxidation results were presented in this report, unless otherwise stated.

There were no statistically significant differences between organic carbon concentrations from grab samples collected once a week or flow-weighted composite samples collected by an autosampler over a 24 hour time period. Depending on the site and analyte, the p values comparing the 2 collection methods ranged between 0.31 and 0.97 (Wilcoxon signed rank test). These results suggested that unlike rapidly changing creeks or streams, organic carbon water chemistry on Staten Island did not change quickly enough over a short period of time to warrant the time, expense, or difficulty of collecting autosample samples. Since more data was available from grab samples, only grab sample results were presented in this report.

Discharge of irrigation water at the New PP began several weeks earlier than at the Old PP, however by the end of June 2006, both plants were discharging summer irrigation water. Total organic carbon concentrations between the 2 plants were similar and remained low until the end of the summer growing season (Figure 14). Outside of the summer irrigation season, there was a marked statistical difference between organic carbon concentrations measured at the 2 plants (Table 2). These differences underscored the need to sample all discharge sites from the island and illustrated the importance of island geography, groundwater dynamics and the effect pumping had on the movement of organic carbon. In the winter months prior to or following the summer irrigation season, organic carbon concentrations at the Old PP were as high as 64.8 mg/L, and although the concentrations gradually decreased, they remained at or above 20 mg/L until their fall at the start of the irrigation season. In contrast, organic carbon concentrations at the New PP fell rapidly during the winter months, and remained at or below 9 mg/L from late spring until the end of the summer irrigation season.

Both pumping and island geography could have been responsible for the winter differences observed between the 2 pumping plants. With the exception of early trial pumping in Dec and January of the 2006 WY, pumping did not occur at the New PP until the beginning of the summer irrigation season while pumping occurred at the Old PP until May. Both passive gravity flow and active pumping would have directed groundwater away from the New PP and towards the Old PP at the lowest point on the island. At the Old PP, concentrations potentially remained higher because increased travel time from the top of the island to its base at the Old PP increased the contact time of groundwater with peat soils. Soils at the southernmost end of the island also have a higher organic carbon content than the soils immediately surrounding the New PP (DWR, 1995).

To examine if a first flush or dilution effect occurred over time, samples were collected immediately prior to a pump startup and then at timed increments thereafter. To begin lowering the water table for planting, pumps at both pumping plants were started on 2/5/07. As shown in Figure 15, there was little change in TOC concentrations over a 24 hour time period. This result suggested that a large pool of high concentration organic carbon water existed in the drains, such that after 24 hours of pumping, the backlog of water with high concentrations of carbon was still present. Concentrations at the Old PP remained elevated for approximately one month after pumping started. After a month of continuous pumping, organic carbon concentrations at the Old PP fell as the pooled water on the island gradually cleared through the system and groundwater with less contact time with the island's peat soils was pulled to the pumps. By the end of March 2007, organic carbon concentrations were similar to those detected in April 2005. The pattern of initially high concentrations of organic carbon followed by a slow fall to levels around 20 mg/L suggested that there is a natural minimum background level of organic carbon present on the island. A similar drop-off in organic carbon concentrations over the same time period was observed at the New PP, however the water level was so shallow in the drain, the diluting effects of rainfall could not be ruled out.

4.6 Nitrogen and Phosphorus Dynamics

Water management, season, and biological and geochemical factors drove nitrogen and phosphorus dynamics on the island. Changes in nitrate (NO_3) and ammonia (NH_3) over time are shown in Figures 16 and 17. Temporal patterns for both species were similar for the 2 pumping plants. With respect to nitrate, concentrations were fairly constant throughout the summer irrigation season suggesting that nitrogen was not limiting aquatic primary production. However, by the beginning of September 2006, when summer irrigation had ceased, nitrogen levels fell at both pumping plants and were generally not detected until the end of January. The decline in nitrate, following the summer irrigation season, coincided with an increase in ammonia concentrations suggesting that the turnover from oxic surface water conditions to anoxic groundwater conditions reduced nitrate to N_2 or ammonia. During the summer irrigation season, ammonia levels were also low suggesting that under oxic conditions ammonia was driven to nitrate and taken up by crops and primary producers.

In addition to geochemical factors, biological activity in the drains following the summer irrigation season could have also quickly depleted nitrogen no longer replenished by a steady influx of surface water. While not measured directly, a visual examination of the filters used to prepare samples for chemical analyses suggested that primary productivity was still high in the drains for a number of weeks following the cessation of summer irrigation. As mentioned previously, the DO sags following the 2006 summer irrigation season were greater than those observed in the fall of 2005 when EC levels indicated that anoxic groundwater was already dominating the drain. Since the 2006 fall temperatures remained elevated longer than temperatures in the fall of 2005, primary productivity could have played an important role in the water chemistry observed in the drains. This may have been especially true at the New PP where fish mortality was observed several weeks after the cessation of summer irrigation water. Since the waters were shallower and water temperatures were warmer, bacterial respiration under anoxic conditions could have contributed to the DO sag and converted particulate organic nitrogen from algal blooms into ammonia. Low DO levels, not ammonia toxicity, were responsible for fish mortality as ammonia levels were below toxicity levels for fish.

In the 2006 WY the majority of the rainfall occurred between January and April. Both nitrate and ammonia concentrations rose in the drains as the constituents were mobilized from the soils into the drain water and the pumping plant pulled groundwater through the island. With little rainfall in the 2007 WY, nitrate and ammonia concentrations increased at both pumping plants when pumping began in February.

TKN concentrations, total phosphorus and dissolved orthophosphate concentrations are shown in Figures 18, 19 and 20. At the Old PP, with the exception of orthophosphate, concentrations of TKN and total phosphate decreased during the summer irrigation season and increased during the non-irrigation season. Unlike the Old PP, TKN concentrations at the New PP did not remain elevated throughout either WY's winter season. Total phosphorus patterns between the 2 pumping plants were similar and never fell below the detection limit, suggesting that the system was not phosphorus limited. Unlike nitrate and ammonia, phosphorus is not labile; therefore increases in winter concentrations may have been due to its release from particles under anoxic conditions. Unlike many other constituents, orthophosphate showed relatively little variability with the season.

Using TKN concentrations as a fingerprint of waterfowl nutrient inputs suggests that the TKN concentrations already present on the island overwhelmed any nutrient inputs provided by overwintering waterfowl. At both the old and New PPs TKN concentrations remained low throughout the summer irrigation season and immediately increased from approximately 1 mg/L to between 3 and 7 mg/L. At the old PP, TKN concentrations generally remained within these ranges regardless of whether there was water on the fields for waterfowl. The gradual decline in TKN at the old PP suggests that TKN sources were slowly flushed from the system.

5.0 Loading

Loading is a calculation of mass and is a function of both concentration and flow. As discussed above, both flow and concentration were regulated by a number of factors. These factors controlled the loads discharged off the island. The following discussion examines organic carbon and nutrient loads. Table 3, referred to in the following paragraphs, summarizes the percent load discharged off the island for each of the analytes by season.

Table 3. Percent Load Discharged by Season

	Pre-irrigation/Rainy	Irrigation	Non-irrigated crop growth	Ponded
Ammonia	71	17	2	10
Nitrate as N	93	6	0.2	0.3
Organic Carbon	63	21	5	11
Orthophosphate	26	65	1	8
Total Kjeldahl Nitrogen	63	27	0.5	10
Total Phosphorus	42	37	1	20

Definitions:

Pre-irrigation/Rainy-- Jan-April (06)

Irrigation--Jun-Aug (06)

Non-irrigated crop growth--May (06)

Ponded--Oct-Dec (05)

5.1 Organic Carbon

The greatest TOC loads discharged off the island in the 2006 and 2007 WYs occurred in the winter (Figure 21a). In the 2006 WY the greatest discharge load occurred in March (52,871 kg/month). In the summer, loads were approximately half of those recorded in the winter, but the lowest value was recorded in May as the fields were prepared for planting (3,254 kg/month). Since the greatest volume of water pumped off the island occurred in the summer, differences between winter and summer loads were a function of concentration, not pumping. The New PP was not operating during the 2005-2006 winter, however during the summer irrigation season, both the Old and New PPs contributed similar loads of carbon (Figure 21b). Unlike the 2006 WY, the 2007 WY was classified as critical for the San Joaquin region, however because both pumping plants were operational, total island carbon discharge nearly doubled over the previous winter (Jan-Apr 06 = 139,575 kg; Jan-Mar 07=209,070 kg). In the 2007 WY, the greatest loading occurred in February when pre-irrigation water was discharged off the island. The differences in TOC discharge between the 2 pumping plants was due to the higher TOC concentrations pooled at the lower end of the island as well as the longer period of discharge at the Old PP. Since pre-irrigation discharge is a necessary part of the cropping cycle, pre-irrigation discharge should comprise a greater amount of river outflow during dry or critical winters. In the 2006 WY, approximately 63% of TOC was discharged during the winter while approximately 21% was discharged in the summer (Table 3).

With respect to other agricultural drainages in the Sacramento or San Joaquin basins, annualized carbon discharges from Staten Island were similar to those calculated for Twitchell Island. Staten Island flux rates were greater than rice drainage from Colusa Basin Drain or agricultural drainage to the San Joaquin River from Harding drain, however it was approximately half of the carbon input from Sacramento Slough and was an order of magnitude less than a tidal marsh (Table 4).

Table 4. Comparison of Annual Organic Carbon Loading Rates

	g/m2/yr	
	TOC	DOC
Staten Island[1]	8.46	7.87
Twitchell Island[2]	12.88	10.64
Colusa Basin Drain (Sac Rvr ag drainage)[3]	3.84	2.94
Colusa Basin Drain (Sac Rvr ag drainage)[5]	0.907	
Sacramento Slough[3]	17.45	11.24
NEMDC-Steelhead Creek (urban drainage)[4]	3.69	
Harding drain (San Joaquin ag drainage)[5]	2.36	
Tidal Marsh (Sac.-SJ Delta)[6]	150	

[1]2006 WY; this study
[2]Brown and Caldwell, 2005.
[3]1995-1998 WY, from: Saleh and others, 2003.
[4]Long term avg, worked record, 2001-2005 WYs from Zanoli and Sickman, in prep;
[5]Tetra Tech, April 14, 2006. (calculation of wet year loads).
[6]Jassby and Cloern, 2000

5.2 Nitrate

Like organic carbon, the greatest nitrogen loads discharged off the island occurred during the winter (Figure 22a). Unlike organic carbon there were dramatic changes in nitrogen loading within the winter season, with loads varying by an order of magnitude between January 2006 (15,896 kg/month) and February 2006 (1,592 kg/month). The discharge pattern between the 2 months reflected both the differences in pumping rates between January and February, as well as the differences in concentrations between January and the remaining winter months. Beginning in February 2006, nitrogen loads increased monthly until the summer irrigation season when nitrate loads fell dramatically. Like organic carbon, the lower nitrate loads during the summer irrigation season were most likely a result of lower nitrogen concentrations, not decreased pumping. From June through August, less than 2,000 kg of nitrate was discharged off the island (Figure 22b). During the summer, both the Old and New PPs contributed similar loads of nitrogen. The 2 pumping plants also contributed similar loads in the 07 winter. This pattern was related to the timing of discharge and concentrations at the 2 pumping plants. In the winter of the 2007 WY, over 90% of the nitrogen loads were discharged from pre-irrigation discharge. From January through March 2007, 7,290 kg of nitrate was discharged off the island. This was slightly less than half of what was discharged the previous January through April (25,817 kg) and suggested that with a drier winter there was less mobilization of nitrate. In the 2006 WY, approximately 93 % of the nitrogen was discharged during the winter while approximately 6 % was discharged in the summer (Table 3).

With respect to other agricultural drainages in the Sacramento or San Joaquin basin, annualized total nitrogen discharge from Staten Island was approximately half that of Twitchell Island, but was approximately 7 times greater than the nitrogen load in rice drainage from Colusa Basin drain and approximately twice that of nitrogen discharge from Mud Slough or the collective agricultural discharge from the Delta (Table 5). Note that estimates for Delta island export rates were based on the best information available, however, there are limitations to this number. DWR's Delta Island Consumptive Use (DICU) estimate of flows from Delta drainage was used and a mean monthly nitrate concentration value for all island drains was used for nitrogen concentrations. Both of these sources have limitations. The DICU model was calibrated from a 1960 detailed flow study with Twitchell Island, while nitrogen data from islands around the Delta is extremely limited. As shown in Figure 23, there were large differences between the DOC discharge predictions for Staten Island using the DICU model compared to actual measured discharges from this study. Therefore, nutrient extrapolations for Delta agriculture should be viewed cautiously.

Table 5. Comparison of Annual Nitrogen Loading Rate

	g/m²/yr				
	NO_3	$NO_3 + NO_2$	NH_3	TKN	Total N_2
Staten Island[1]	0.81	-	0.11	0.83	1.75
Twitchell Island[2]	-	3.91	0.11	-	4.02
Colusa Basin Drain (Sac Rvr ag drainage)[3]	-	-	-	-	0.25
Mud Slough (San Joaquin ag drainage)[3]	-	-	-	-	0.74
Delta Islands[4]	-	-	-	-	0.86

[1]2006 WY; this study

[2]Brown and Caldwell, 2005.

[3]TetraTech, Sept. 20, 2006. (calculation of wet year loads).

[4]TetraTech, Sept. 20, 2006.

5.3 Ammonia

As with other analytes, the greatest ammonia loads in the 2006 WY occurred in the winter, as opposed to the summer irrigation season (Figure 24a). However, ammonia loads in the winter of 2006 did not fluctuate as greatly as nitrate loads. In the 2006 WY, the greatest load occurred in March (969 kg/month), not January as it did for nitrate. The relatively low, but consistent ammonia concentrations in the summer resulted in fairly constant loading values throughout the summer irrigation season with loads ranging from 160 to 237 kg/month between June and August. During the summer irrigation season, the New and Old PPs generally contributed similar amounts to the total ammonia load pumped off the island, however the following winter, the majority of the ammonia discharged originated from the Old PP (Figure 24b). This was different from the nitrate pattern. The explanation for these differences was likely due to concentration differences between the 2 analytes. In February, nitrate concentrations at the New PP were very high, in contrast nitrate concentrations at the Old PP were less than half those at the New PP. Therefore, while pumping occurred over a longer period at the Old PP, the initial high concentrations of nitrate at the New PP resulted in nearly equal loads pumped off the island from the 2 pumping plants. In contrast, ammonia concentrations at the Old PP remained elevated for the entire time pumping occurred. Since pumping continued at the Old PP after pumping had ended at the New PP, ammonia loads discharged from the Old

PP were greater than those observed at the New PP. In the 2006 WY, approximately 70% of the ammonia was discharged during the winter, while approximately 17% was discharged in the summer (Table 3).

5.4 Total Kjeldahl Nitrogen (TKN)

Like most other analytes, the greatest TKN loads in the 2006 WY occurred outside the summer irrigation season (5,420 kg/month-April 2006) (Figure 25a). During the summer, TKN loads were approximately half those recorded the previous winter with both pumping plants discharging similar amounts (Figure 25b). The following winter, during pre-irrigation discharge, a similar amount of TKN was discharged in February 2007 as the entire 2006 winter discharge season (17,657-Feb. 07 kg vs.16,887 Jan. 06-April 06). For reasons similar to ammonia loading, the Old PP contributed twice the load of TKN to the river as the New PP. In the 2006 WY, approximately 63% of the load occurred during the winter while about a third of the discharge occurred during the summer irrigation season (Table 3).

In total, 93,616 kg of nitrogen were discharged off the island between October 2005 and March 2007. Of this, 51,282 kg or 55% of the total nitrogen load came from TKN, 34,946 kg or 37% came from nitrate, and 7,388 or 8% came from ammonia.

5.5 Total Phosphorus

Because phosphate concentrations were less variable compared to other analytes, total phosphorus loads were tied closely to pumping and remained fairly constant, regardless of season. During the 2006 WY the highest load exported off the island occurred during the summer irrigation season (July 06, 410 kg) (Figure 26a), however exports of phosphorus in the 2006 winter and summer irrigation season were similar (42 vs. 37% for winter and summer, respectively, Table 3). Unlike other analytes, total phosphorus loads exported from the New PP during the summer irrigation season were approximately double those of the Old PP (Figure 26b). Turbidity differences between the Old and New

PP during this time period were minimal, therefore phosphorus bound to particles could not explain the difference between the 2 pumping plants. Since phosphate loads were so closely tied to pumping rates, the greatest loads exported off the island occurred during the pre-irrigation season discharge of February 2007.

With respect to other agricultural drainages in the Sacramento or San Joaquin basin, annualized phosphate discharge from Staten Island was 2-4X greater than rice drainage from Colusa Basin drain or agricultural drainage to the San Joaquin River from Mud Slough (Table 6). The same caveat associated with total Delta nitrogen flux rates should be applied to the phosphate flux rate calculated from agricultural drainage from the Delta.

Table 6. Comparison of Annual Phosphate Loading Rate

	$g/m^2/yr$		
	Phosphate	orthophosphate	Total Phosphate
Staten Island[1]	0.08	0.01	0.09
Colusa Basin Drain (Sac Rvr ag drainage)[2]	-	-	0.05
Mud Slough (San Joaquin ag drainage)[2]	-	-	0.02
Delta Islands[3]	-	-	0.03

[1]2006 WY; this study
[2]TetraTech, Sept. 20, 2006.
(calculation of wet year loads).
[3]TetraTech, Sept. 20, 2006.

5.6 Orthophosphate

Like total phosphorus, the greatest orthophosphate loads during the 2006 WY were discharged during the summer irrigation season with the highest load (98 kg) occurring in July 2006 (Figure 27a). Unlike total phosphorus, monthly loads varied throughout the year with summer loads approximately double those calculated for the preceding winter months (26 vs. 65 % for winter and summer, respectively, Table 3). Like total phosphorus, the New PP was the major contributor to loads discharged off the island (Figure 27b).

6.0 Water Quality in Fields Flooded for Waterfowl Use

Initially, sampling protocol called for collection of 3 replicate samples from the levee side of the field (intake side), and 3 replicate samples on the road side of the field (discharge side), with 2 points near the middle edge of the field, however, from the beginning of the sampling season, it became apparent that this approach would not be feasible. In field 81, the levee side either did not have water, or enough contiguous water over the field, to be considered representative of water quality coming onto the field. With few exceptions there was no water in the middle sampling sites. Field 41 initially had water on both the levee, middle, and road sides, however water on the levee side shrank steadily to the point where it was no longer contiguous over the field. Therefore, given the questionability of whether levee side water was truly representative of levee side water quality, and the time and number of personnel required to sample and process samples, it was decided to only sample from the discharge side of a field.

Replicate samples were initially collected at 3 points along the low side of the fields. With respect to physical parameters, there were no statistical differences between the replicates, therefore, beginning 11/23/04, samples were collected from one discharge site near the lowest point on the field. Samples were collected at this point until there was no more water interconnecting the furrows and staff began sampling subsurface drainage leaching into the field drain.

Table 7 summarizes the statistical differences for selected parameters between fields 41 and 81 and for the fields vs. the Old PP and the Mokelumne River. A Mann-Whitney test was used to test differences between the fields while a Kruskal-Wallis test, followed by a Dunn's multiple comparison tests was used to compare differences across more than 2 sites. With the exception of ammonia and TKN, there were no significant differences between the 2 fields and any of the analytes measured. Similarly, with the exception of the phosphorus nutrients, statistical differences were always detected between the fields and the pumping plant.

Table 7. Statistical Comparisons between Fields 41, 81, the Old Pumping Plant and the Mokelumne River

	EC	Turbidity	TOC ox	DOC ox	NO3	NH3	TKN	PO4	Ortho Phosphate
Between Fields	No	No	No	No	Yes	No	No	No	Yes
Fields vs. PP	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Fields and PP vs. Mok River	Yes	Yes	Yes	Yes	Yes	Field 41 No Field 81 Yes	Yes	Yes	Yes

Yes: statistically different at $p < 0.05$ or less, either Mann-Whitney, Kruskal-Wallis or Dunn Multiple comparison test.

No: no statistical differences

One explanation for the lack of statistical differences between fields 41 and 81 was the continuous spread of water across numerous fields and the similar organic carbon contents of the soils. Although fields are physically separated in the summer by feeder drains branching off the levee's toe drain, when the fields were flooded for waterfowl, water overtopped the feeder drains and formed a nearly continuous sheet of water across the flooded portion of the island. Additionally, fields 41 and 81 were sampled because soil survey maps indicated that the soil types of the 2 fields were different, with the more peaty soil occurring on field 81 (USDA, 1992). However, an analysis of organic carbon content of soil samples indicated that both fields had similar organic carbon contents. The organic carbon content of field 41 was 10.4% and 8.2% for field 81. For these reasons any water quality differences between the fields may have been obscured.

Of all the nitrogen analytes, TKN was detected the most frequently, with only one case (the Mokelumne River) where TKN was never detected. Conversely, for dissolved nitrate, non-detects were common in island samples, but were always detected in the Mokelumne River. Total phosphorus was always detected in a sample. Orthophosphates were always detected in the river, but orthophosphates were occasionally not detected in the fields or at the pumping plant.

The temporal patterns of several of the water quality constituents of interest are presented below.

6.1 Physical Field Parameters-EC, DO, pH, and turbidity

Until the end of the sampling period, ECs in both fields remained fairly flat or increased only slightly (Figure 28). The sharp increase in ECs at the end of the sampling period reflected collection of subsurface drainage water. The EC at the Old pumping plant was generally twice as high as values measured on the fields. Unlike field samples which collected only surface water, the pumping plant received field surface water and groundwater. The pumping plant ECs ranged from 593 to 1305 µSiemens/cm. In contrast, the EC in the Mokelumne River was dictated by forces outside the island. EC in the Mokelumne River fell steadily with time reflecting the freshwater runoff influence from winter storms and reservoir releases.

Statistically, the EC between fields 41 and 81 were not significantly different (Mann-Whitney, $p = 0.8185$), however, the ECs from both fields were significantly different from those measured at the pumping plant (Dunn's test, $p < 0.000$). These differences reflected the differences between field surface water ECs and the groundwater collected at the pumps. The EC from all island sites were significantly different from the Mokelumne River (Dunn's test, $p < 0.000$).

DO patterns in the fields and the pumping plant were similar. DO levels generally ranged between 2 and 4 mg/L at the beginning of the sampling period and increased over time to near 7 or 8 mg/L (Figure 29). Near the end of the sampling period, DO levels began to fall. Several factors in the fields probably controlled this dynamic. At the start of the sampling period, warmer water temperatures resulted in decreased solubility of oxygen in the water and potentially increased bacterial respiration in the nutrient rich waters as corn stalks decomposed. At the pumping plant, bacterial respiration or the influx of anoxic groundwater could have lowered DO. As temperatures fell, DO levels tended to rise in both the fields and at the pumping plant due to increased solubility of oxygen in cold water and decreased bacterial respiration. In the fields, the drop in DO, near the end of the sampling period, corresponded to increasing water temperatures and the effects of sampling anoxic drain water.

DO levels in field 41 tended to be lower than in field 81, with 50% of the samples registering at or below 2.4 mg/L. Dissolved oxygen levels in the fields were not significantly different from those measured at the pumping plant (Dunn's test $p > 0.05$). Collectively, DO levels in both fields and the pumping plant were statistically lower than those measured in the river (Dunn's test, $p < 0.000$).

Temporally, pH patterns in the fields and the pumping plant were similar. At the beginning of sampling, pH values at the 3 island sites were less than 7 (Figure 30). Over the next 2 months, pH values gradually increased to as high as 7.5. By mid-January, as temperatures began to increase, pH values gradually decreased. In contrast, during the same period, pH in the river, showed relatively little change or declined slightly. Gradual increases or decreases in pH over time also co-occurred with the gradual decreases or increases in temperature, suggesting that bacterial respiration as well as acidic groundwater influenced pH measurements. Like other physical parameters, river pH was not driven by the physical dynamics present on the island.

The pH levels between fields 41 and 81 were not significantly different from each other (Mann-Whitney, $p = 0.2185$), or the pumping plant (Dunn's test, $p > 0.05$). pH levels from all sampled points on the island were significantly lower than the Mokelumne River (Dunn's test, $p = 0.000$).

In general, turbidities in the fields and the pumping plant were higher than in the river, with the highest turbidities observed in the fields. Turbidity levels at the pumping plant and fields 41 and 81 increased during the first few months of sampling, but by early January, turbidity levels began to decline (Figure 31). Decreasing turbidity in flooded fields over time has been observed consistently over the years (Jim Shanks, pers. communication). The high turbidity levels at the beginning of the sampling season reflected the large amount of crop debris and sediment re-suspended in the shallow water column of the newly flooded fields. Turbidity levels decreased as crops decomposed and heavier particles settled out of the water column. Changes in turbidity in the shallow water of the fields due to rainfall or waterfowl and Sandhill Crane disturbance were either transitory or highly localized in nature. For example, turbidity levels in the fields began to fall in early January, however, rainfall occurring at this time did not translate to increased turbidity in the fields. In contrast, turbidity levels in the Mokelumne River steadily increased and continued to increase throughout January when island turbidity levels were falling. Near the end of the sampling season, turbidity levels were again rising on the island while they were falling in the river. The rise in turbidity over time in the Mokelumne River reflected increasing stormwater runoff from rainfall events.

Turbidity levels between fields 41 and 81 were not significantly different (Mann-Whitney, $p = 0.9022$), nor were they significantly different from turbidities measured at the pumping plant (Dunn's test, $p > 0.05$). In contrast, the turbidity at all island sampling sites was significantly higher than the Mokelumne River (Dunn's test, $p = 0.0003$).

6.2 Organic Carbon

The highest TOC and DOC values at the pumping plant and field 41 were detected at the beginning of the sampling season, with levels declining over time. This pattern reflected the initial leaching of organic carbon into water first applied onto the fields. This pattern was reversed in the Mokelumne River, where organic carbon levels rose as the season progressed due to increased organic carbon loads from the flushing effects of rainfall. Field 81 did not follow the same dramatic decline in organic carbon observed at field 41 or the pumping plant.

Average TOC concentrations in the water over the fields were as high as 135.9 mg/L (Figure 32) while average DOC concentrations were as high as 120.2 mg/L (Figure 33). The minimal dilution effect of a small volume of water spread over an entire field, as well as the initial leaching effects of the water on the entire field was probably responsible for these extremely high organic carbon values. By the end of the sampling season, with the effects of both dilutions from rainfall, onsite pumping of riverwater, and the settling of sediment from the water column TOC values had fallen to between 12 and 30 mg/L and DOC values had fallen to similar levels. Due to larger water volumes, concentrations were never as high at the pumping plant. Over the course of the sampling season, TOC carbon concentrations ranged from 31 to 69 mg/L. Total organic carbon concentrations in the Mokelumne River never exceeded 12 mg/L.

Like most other analytes, there were no significant differences between the fields for TOC or DOC (Table 7), however field organic carbon values were always statistically different from the pumping plant and the Mokelumne River.

6.3 Dissolved Nitrate

Nitrate was undetected in over 67% of the samples collected from fields 41 and 81. In cases where it was detected, values remained low and never showed a strong increase over time. In contrast, at the pumping plant, non-detects occurred in about 35% of the samples with non-detects occurring in the fall and early winter, followed by a marked increase in levels in the beginning of January (Figure 34). Nitrate is a highly soluble form of nitrogen and depending on the soil can move into the groundwater. The sudden high levels of nitrates at the pumping plant potentially reflected the time it took for nitrates to leach through the soil into the main irrigation ditches to the pumping plant. A greater number of non-detects in the surface field waters was potentially due to the previous movement of soluble nitrate into the groundwater during the irrigation season. Nitrate is regulated in drinking water. The Maximum Contaminant Limit (MCL) for finished drinking water nitrate is 45 mg/L as nitrate. In the case of the Mokelumne River both analytes were always detected in all samples collected with the highest levels occurring in January potentially reflecting runoff from the numerous storm events.

Nitrate was one of the few analytes that were significantly different between the 2 fields (Table 7). However, with so many non-detects, it is difficult to determine how meaningful these statistical differences truly are. Concentrations of both analytes in the fields were significantly different from both the pumping plant and the Mokelumne River.

6.4 Dissolved Ammonia

Ammonia concentrations in the fields and the pumping plant increased in the beginning of December and again in mid-January (Figure 35). The rise in December may have reflected the conversion of nitrogen to ammonia under anoxic conditions while the rise in January may have been due to increased pumping. Like all other parameters, dissolved ammonia in the river did not follow island patterns. Until mid December, dissolved ammonia levels were fairly constant and mostly higher than those observed on the island. By mid-December, riverine dissolved ammonia levels began to fall and remained low throughout the rest of the sampling period. Lowered levels of ammonia corresponded to increased flows in the river.

Like most other analytes, there were no significant differences in dissolved ammonia levels between field 41 and 81 (Table 7). Ammonia levels in the fields were significantly lower from the concentrations measured at the pumping plant (Dunn's, $p = 0.000$).

6.5 Total Kjeldahl Nitrogen (TKN)

In December, TKN concentrations on the fields were as high as 11 mg/L, with levels falling and/or leveling off in the following months (Figure 36). Although levels were lower, the pumping plant increased from 2 mg/L at the beginning of sampling to 4 mg/L through the beginning of December. Initial increases in TKN could have been related to the release of organic nitrogen from the soils upon initial floodup. Concentrations also initially rose at the pumping plant, but TKN concentrations were lower due to the greater volume of water at the pumping plant. By early December, TKN concentrations had fallen in both fields. Potentially the pool of readily leachable soil organic carbon and nitrogen were expended resulting in declining TKN levels. Waterfowl use of the fields may have also been declining as water levels fell in the fields, however the contributions of organic nitrogen from waterfowl to the system were not observed at the pumping plant. From early December until the end of the sampling period, TKN concentrations at the pumping plant remained fairly flat despite increases or decreases in the 2 fields.

Comparisons between TKN and dissolved ammonia levels suggested that the majority of the nitrogen in the TKN measurements were from organic nitrogen and not dissolved ammonia. Figures 34 and 35 also illustrate the mineralization of TKN to dissolved ammonia; as TKN decreased, dissolved ammonia increased. In contrast to the fields, organic nitrogen levels in the Mokelumne River were much lower, reflecting the lack of the high organic sources of nitrogen available on the island.

Statistically there was no difference in the measured concentrations of TKN between the 2 fields. When compared to both the pumping plant and the Mokelumne River, field TKN concentrations were higher.

6.6 Total Phosphorus

Total phosphorus was detected in all samples submitted for analysis. Phosphorus levels in field 41 started out higher than in field 81, but gradually fell to similar levels (Figure 37). With the exception of one sample in January, total phosphorus levels in field 81 remained fairly consistent throughout the sampling season. Although turbidities in field 41 were not statistically higher than in field 81, the highest turbidities were recorded in field 41. Higher particulate levels may have accounted for higher total phosphorus measurements in field 41 than in field 81. Both turbidity and total phosphorus began decreasing in field 41 in mid-December, further suggesting that turbidity levels may have played a part in the differences in total phosphorus levels seen between the 2 fields. Like field 41, total phosphorus measurements at the pumping plant started out higher in the fall and gradually fell throughout the sampling season. The Mokelumne river's total phosphorus patterns were opposite from those of the fields or the pumping plant. In the river, total phosphorus levels started out low at the beginning of the sampling season and gradually increased as the season progressed. The river's pattern reflects the input of total phosphorus into the system from the increased sediment loads carried into the river from stormwater runoff. Total phosphorus levels in the river, even with the effects of stormwater runoff, were always considerably lower than the fields or the pumping plant.

Like all other parameters, there were no significant differences in total phosphorus concentrations between fields 41 and 81. Total phosphorus levels in the 2 fields were also not significantly different from samples analyzed from the pumping plant, however the total phosphorus concentrations detected on the island were significantly different from the levels detected in the Mokelumne River.

6.7 Dissolved Orthophosphate

Like total phosphorus, dissolved orthophosphates were elevated in the 2 fields at the beginning of the season and gradually fell throughout the sampling season (Figure 38). This pattern probably reflected the release of orthophosphate from the fields as they were first flooded and then fell as equilibrium was established between actively bound phosphorus in the soil and the water column. Interestingly, the pumping plant did not show the same pattern as the fields. Concentrations detected at the pumping plant remained at the low level that dissolved orthophosphate rapidly reached in the flooded fields. As with other parameters, dissolved orthophosphate in the Mokelumne River followed a different pattern than on the island. Dissolved orthophosphate levels in the river tended to be higher than on the island and showed a gradual increase with increased stormwater runoff beginning in January. Dissolved orthophosphate was not detected in up to 10% of the island samples. Dissolved orthophosphate was always detected in the river.

Unlike most other parameters, concentrations of dissolved orthophosphate levels were significantly different between the 2 fields (Table 7). However, when all samples were compared together, sample variability obscured differences between the 2 fields. No significant difference was found between the fields and the pumping plant. Dissolved orthophosphate concentrations detected on the island were significantly different from levels detected in the Mokelumne River.

7.0 Water Quality Before and After New Pumping Plant Installation

Water quality was compared before and after installation of the New PP. Samples collected prior to the New PP's installation (10/04-2/05, 05 WY) were compared to samples collected immediately after pump installation (10/05-2/06, 06 WY), and one year after pump installation (10/06-2/07, 07 WY). There were no significant differences between total phosphate and orthophosphate concentrations before or after pump installation (Kruskal-Wallis, Dunn's Multiple Comparison test, $p > 0.05$). Ammonia concentrations were also not statistically different (Kruskal-Wallis, Dunn's Multiple Comparison test, $p > 0.05$).

When statistical differences were observed between analytes, it was unclear whether the installation of the New PP was responsible for these differences. Statistical differences were detected for TOC, nitrate and TKN, however these differences could potentially be explained by factors other than the installation of the New PP. In the case of TOC, median concentrations were significantly different between samples collected the year prior to pump installation and the year of installation (Figure 39), however lower TOC concentrations in the 06 WY could have resulted from the dilution of TOC from the 14.64 inches of rain that fell between October and February. In contrast, the 05 WY, like the 06 WY, was also classified as a wet year, however, nearly an inch less of rain (13.88") fell during the sample collection period.

The processes behind the statistical differences for nitrate and TKN were more complex than TOC and suggested that biological factors accounted for the differences before and after pump installation. For both analytes, there were no statistically significant differences between the year prior to installation and the year the New PP was installed (Kruskal-Wallis, Dunn's Multiple Comparison test, $p > 0.05$). However, for both analytes, median concentrations were significantly different between the 05 and 07 WY ($p = 0.0055$) (Figures 40 and 41), and TKN concentrations were also significantly different between the 06 WY and the 07 WY. As discussed previously, biological conditions in the fall of 06 appeared to result in high algal blooms followed by a potential bacterial bloom. The statistically significant high concentrations of TKN in the 07 WY coupled with the lowest median concentrations of nitrate suggested that nitrate was taken up biologically and transformed into organic nitrogen resulting in the statistical differences observed between the 05 and 07 WYs.

8.0 Conclusions

Understanding Delta agricultural drainage volumes and contributions is important to developing accurate fingerprinting models for in-Delta agricultural drainage contributions to drinking water quality at the Banks Pumping Plant. As part of CALFED's decision to develop a statewide drinking water policy, conceptual models were produced by TetraTech for organic carbon and nutrient loads for tributary and in-Delta sources (TetraTech, 2006). Because most estimates of in-Delta agricultural drainage values are based on DICU models rather than data, their conceptual model reports identified the uncertainty of in-Delta agricultural drainage data as a high priority item. This report addresses that need by providing measurements of flow and concentrations of constituents from an actively farmed Delta island. Data from this report illustrates the potential departures between actual and modeled drainage discharges. Measured DOC winter and spring loads were as much as 137 times greater than those predicted by the DICU model. During the summer irrigation season, the DICU model over-predicted measured July 2006 DOC loads but under-predicted measured loads in June and August 2006.

In-Delta agriculture discharges are controlled by agricultural requirements and the need for levee protection, however, while not directly comparable, discharge pattern differences between Twitchell Island and this study suggest that discharge patterns may vary between Delta islands. These differences may be a function of the type of crops grown on the island, or whether the island is under the control of a single entity (like Staten Island), or multiple leasees. From a modeling perspective, this suggests that further drainage volume studies are required to better understand the variations of in-Delta agriculture discharge patterns and those impacts on water quality.

Source water is one of the most important factors controlling water quality on Staten Island. As illustrated by the statistical differences between the Old and New PP, geographic location, pumping activity and residence time play an important role in the quality of water discharged off the island. This underscores the need to sample all discharge points from a Delta island and avoid extrapolation from one site to the whole island or to an entire region of the Delta.

From a modeling perspective, this study illustrates that the timing of winter discharge is controlled by different factors. In the 2006 WY, flooding concerns as well as pre-irrigation discharge needs, resulted in a prolonged discharge period. In the 2007 WY, winter discharges were associated primarily with pre-irrigation discharges and occurred over a relatively short time period. Although timing will vary from year to year, these results suggest that flexibility should be incorporated into Delta discharge models to encompass different year type discharge patterns and volumes.

Although the impacts of overwintering waterfowl were not examined directly, water quality dynamics could be explained by cropping patterns and the seasonal use of water dictated by agricultural needs. Waterfowl would be expected to impact water quality, but using TKN as a surrogate for waterfowl fecal input, island dynamics appeared to overwhelm any water quality signal provided from waterfowl.

9.0 Acknowledgements

This study would not have been possible without the help and support of a number of people. The author wishes to thank Brent Tadman, Sally Shanks and the late Jim Shanks for their generosity and cooperation. Their participation was key to understanding how a Delta island is farmed and managed. The author also thanks the MWQI Field Unit;

David Gonzalez, Steve San Julian, and Arin Conner for their help in sampling and installation of the flowmeters. The author would also like to thank Otome Lindsey for her editorial help and the reviewers who read and commented on earlier drafts of this paper. The author thanks CALFED, Greg Green of Duck's Unlimited, and Keith Whitener and Jennifer Buck of The Nature Conservancy for their support of this project.

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Figure 1. Location of Staten Island

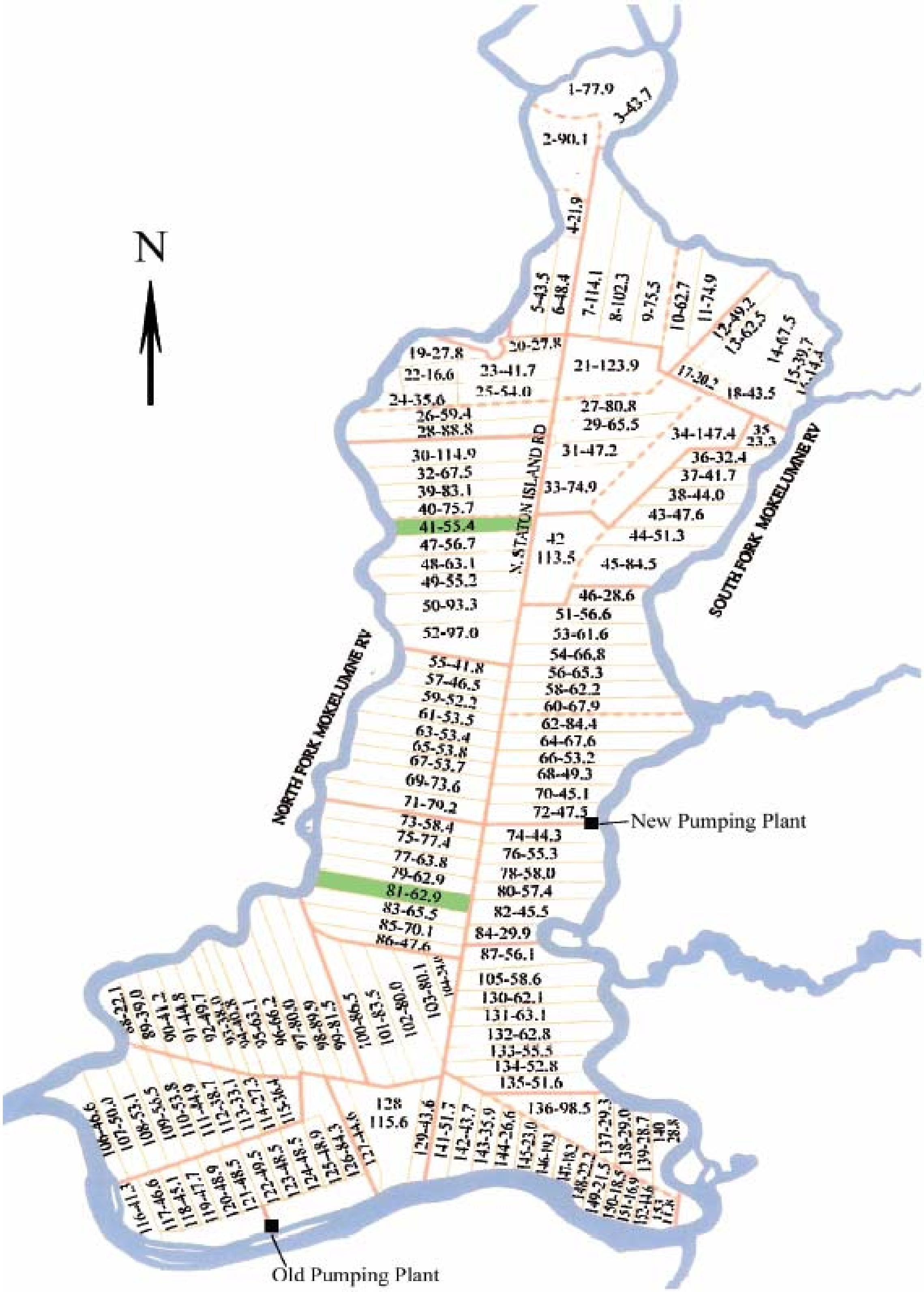


Figure 2. Location of pumping plants and fields 41 and 81.

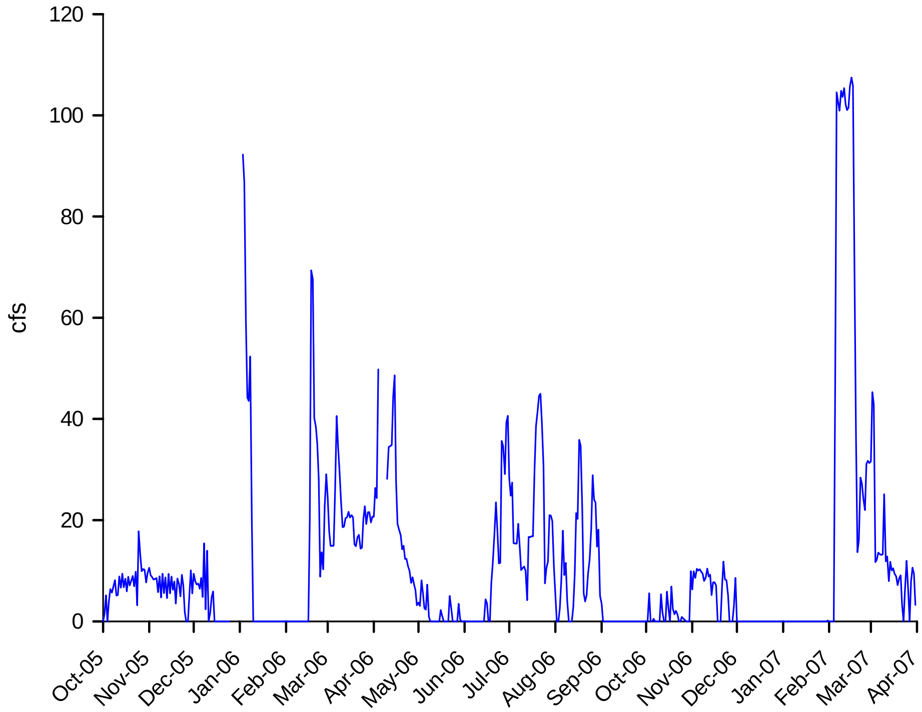


Figure 3. Old pumping plant, average daily flow

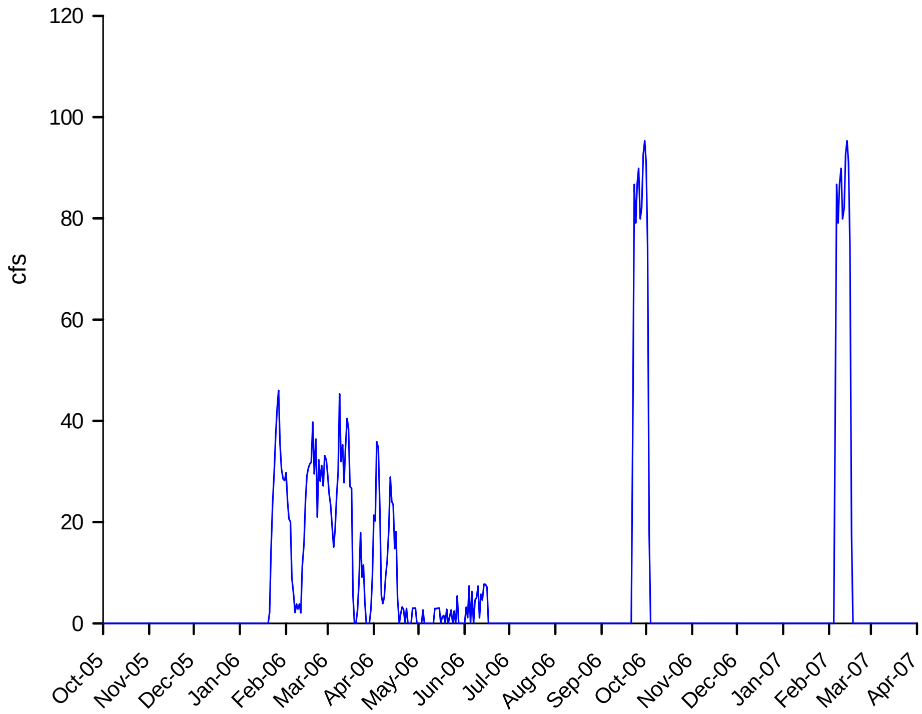


Figure 4. New pumping plant, average daily flow

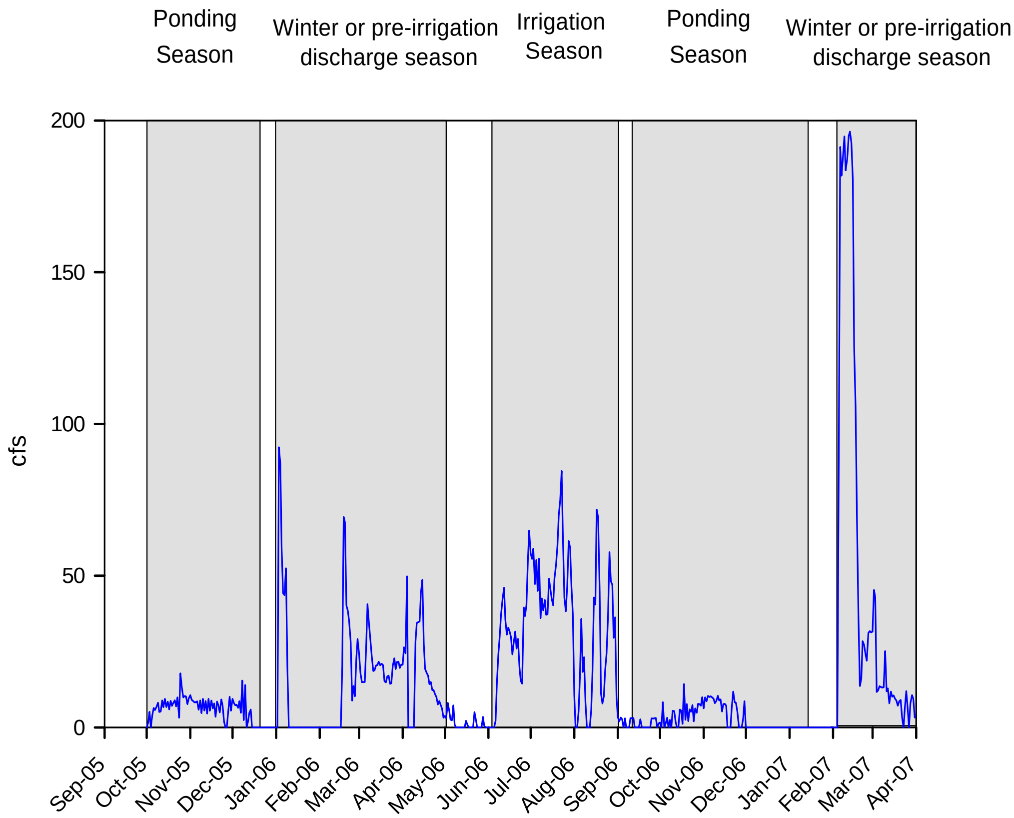


Figure 5. Total daily discharges from Staten Island vs. discharge season

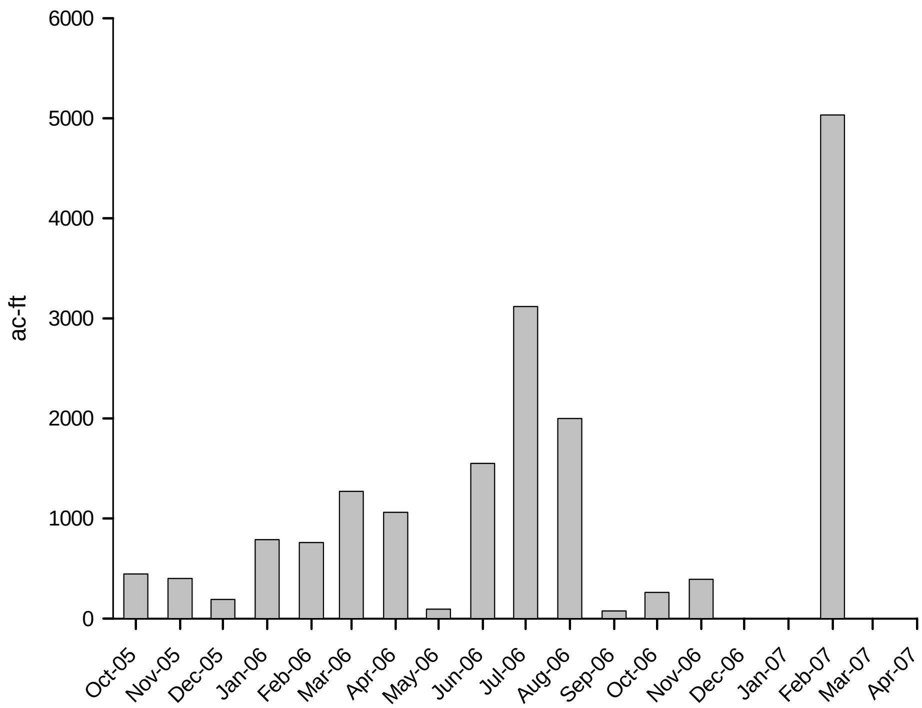


Figure 6. Total volume of water pumped off of Staten Island

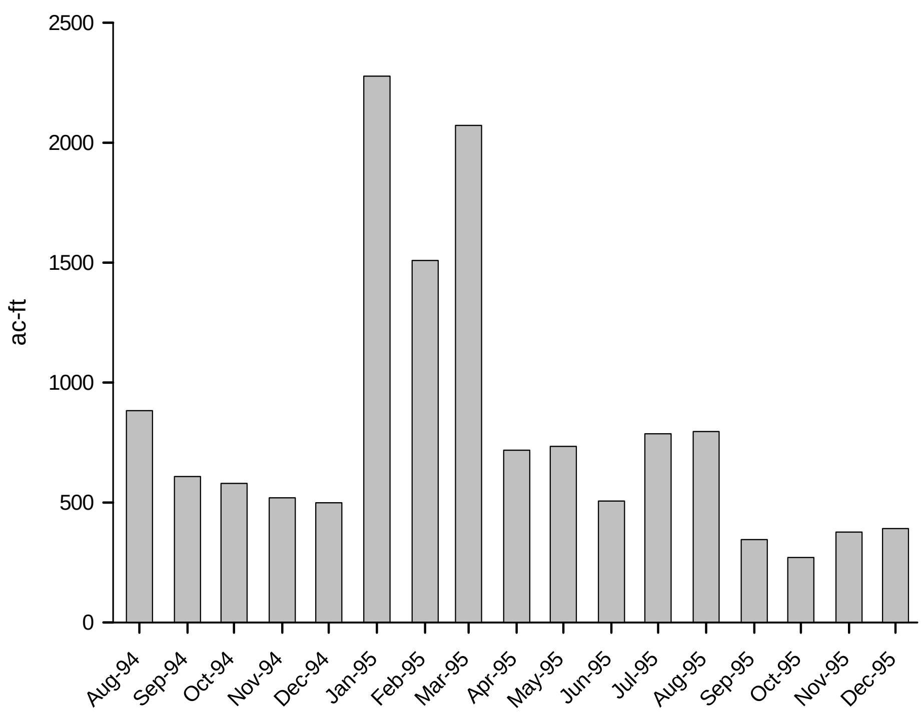


Figure 7. Total volume of water pumped off of Twitchell Island

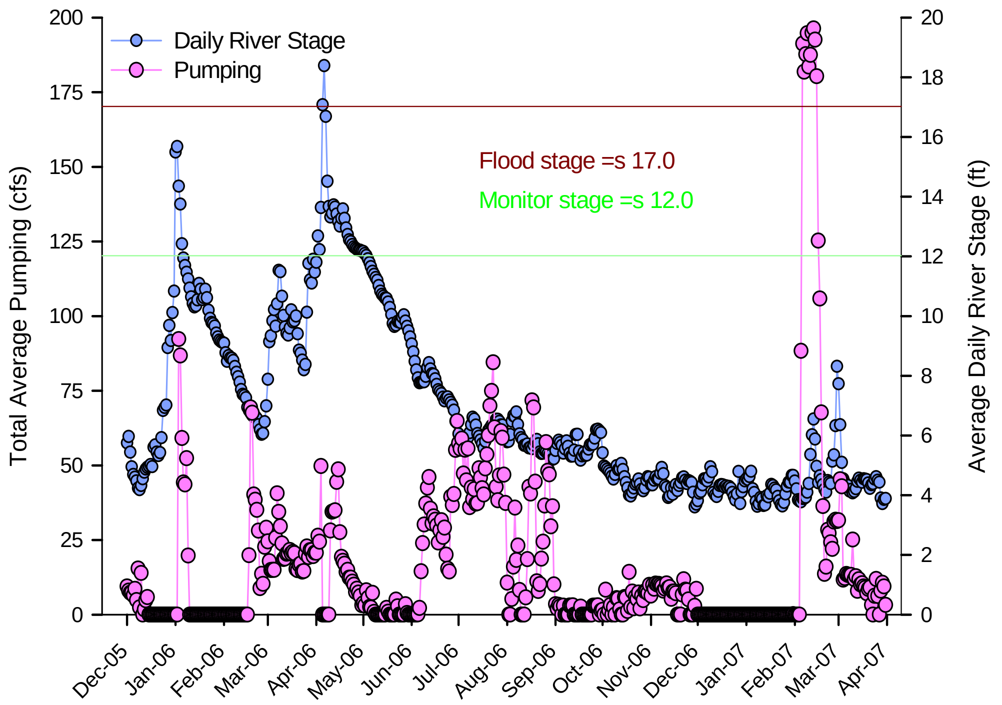


Figure 8 a. Pumping vs. Mokelumne River stage at Benson's Ferry

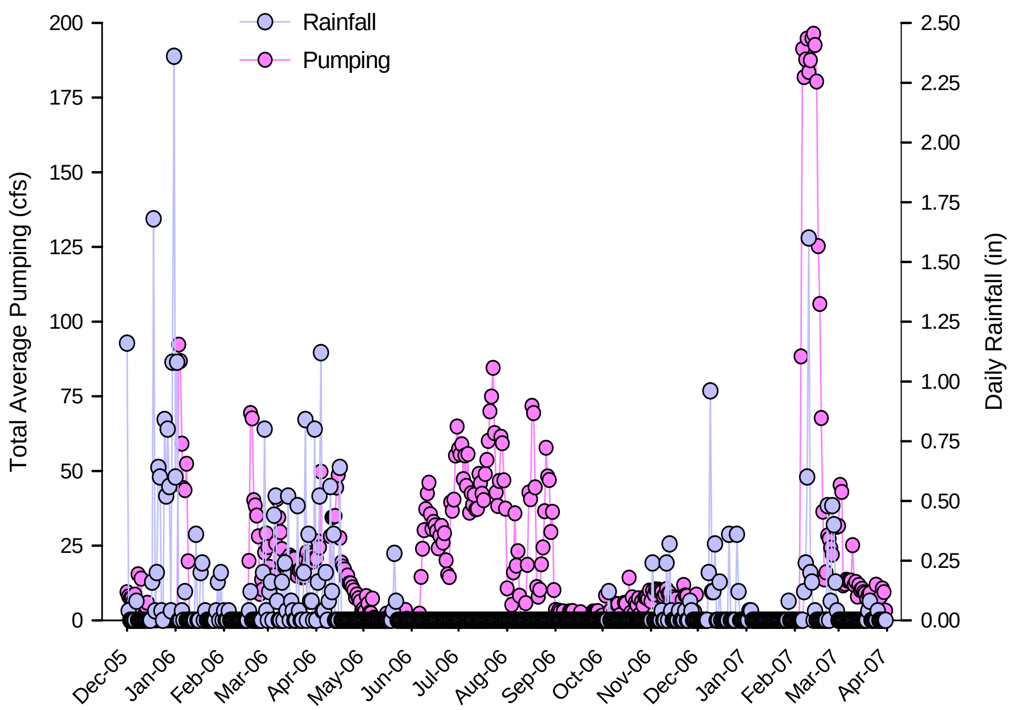


Figure 8 b. Pumping vs daily rainfall

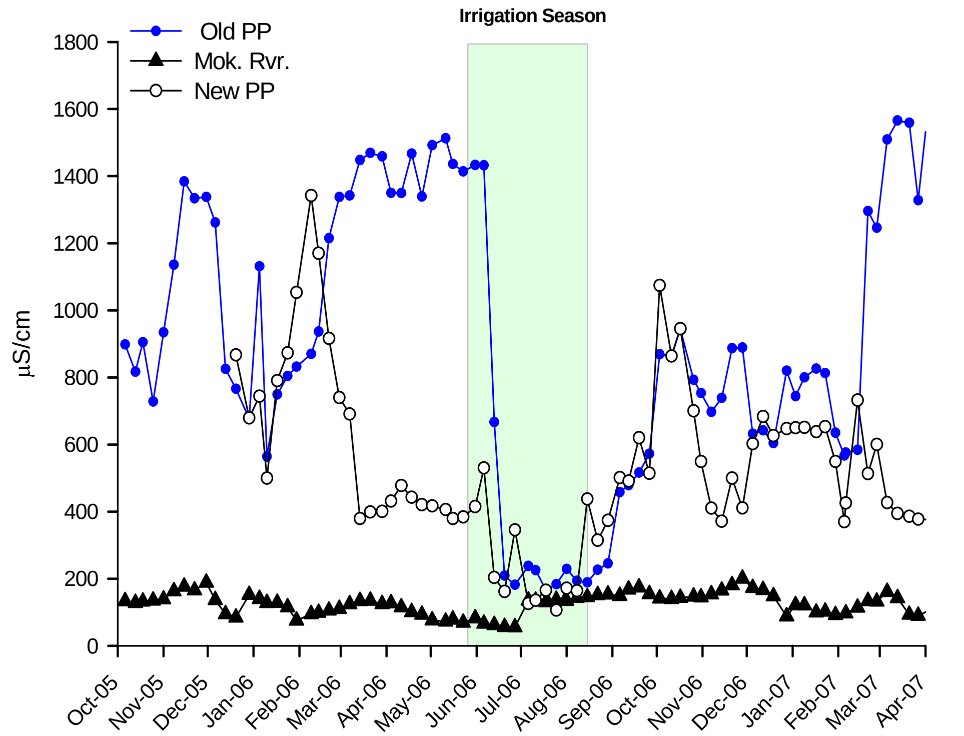


Figure 9. EC comparisons between the old and new pumping plants and the Mokulmne River

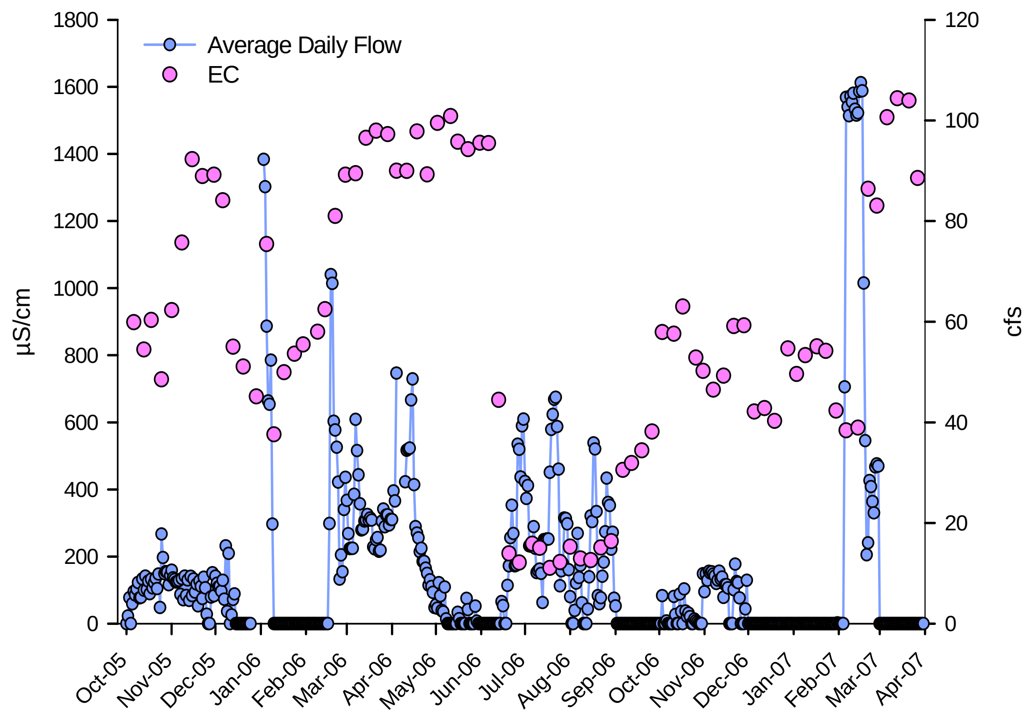


Figure 10. EC vs. pumping at the old pumping plant

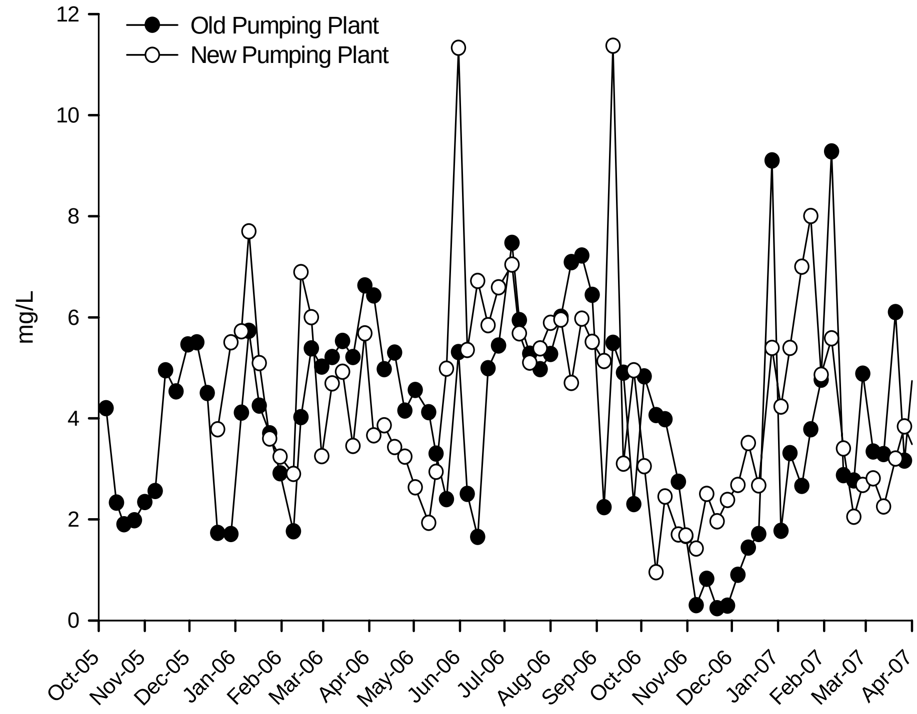


Figure 11. DO comparisons between old and new pumping plants

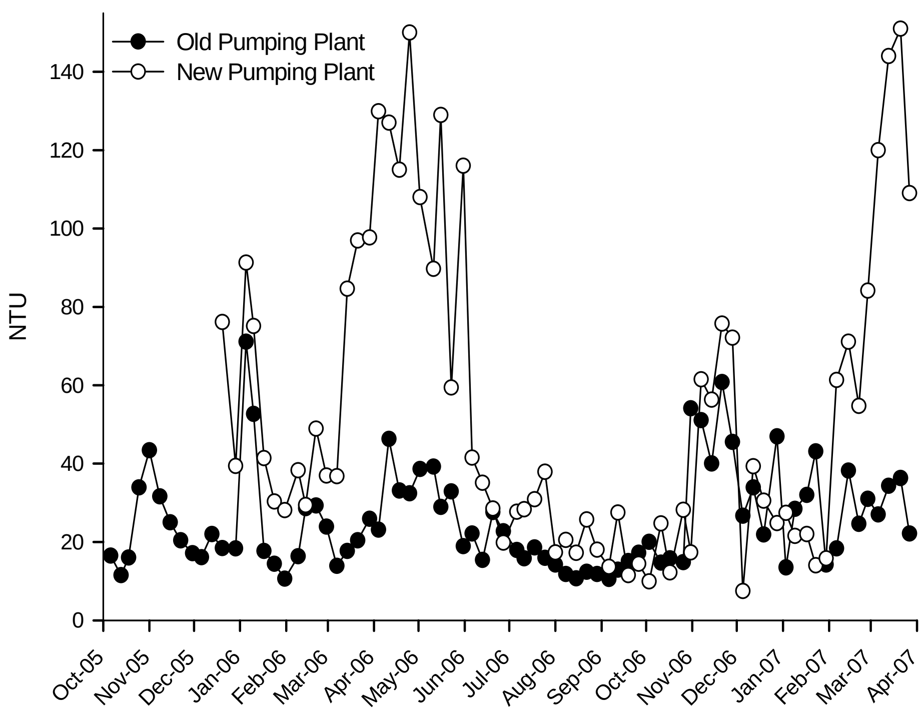


Figure 12. Turbidity comparisons between the old and new pumping plants

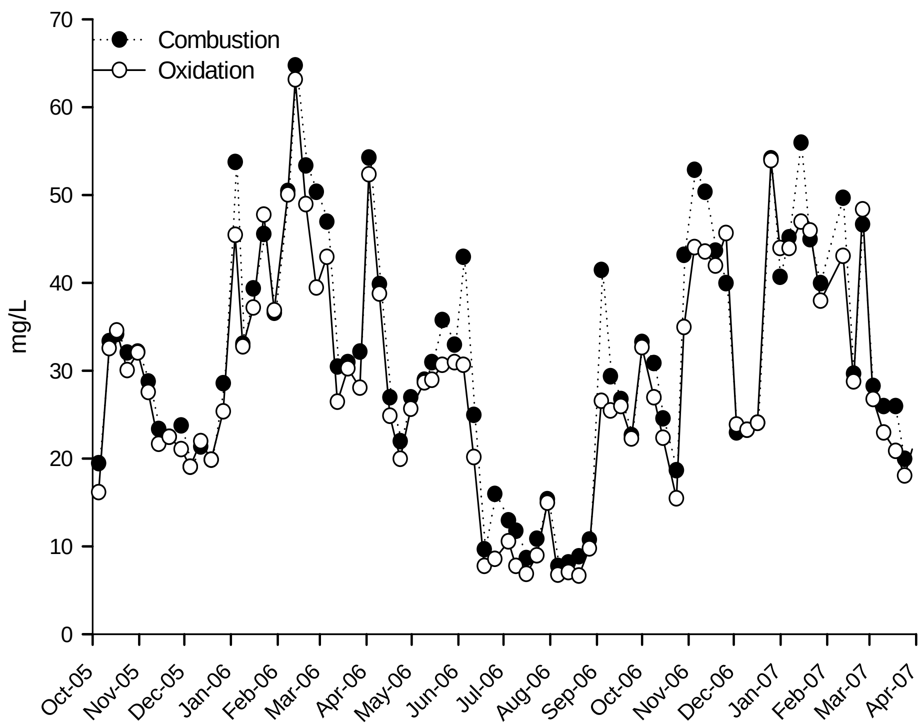


Figure 13. TOC combustion vs. oxidation at the old pumping plant

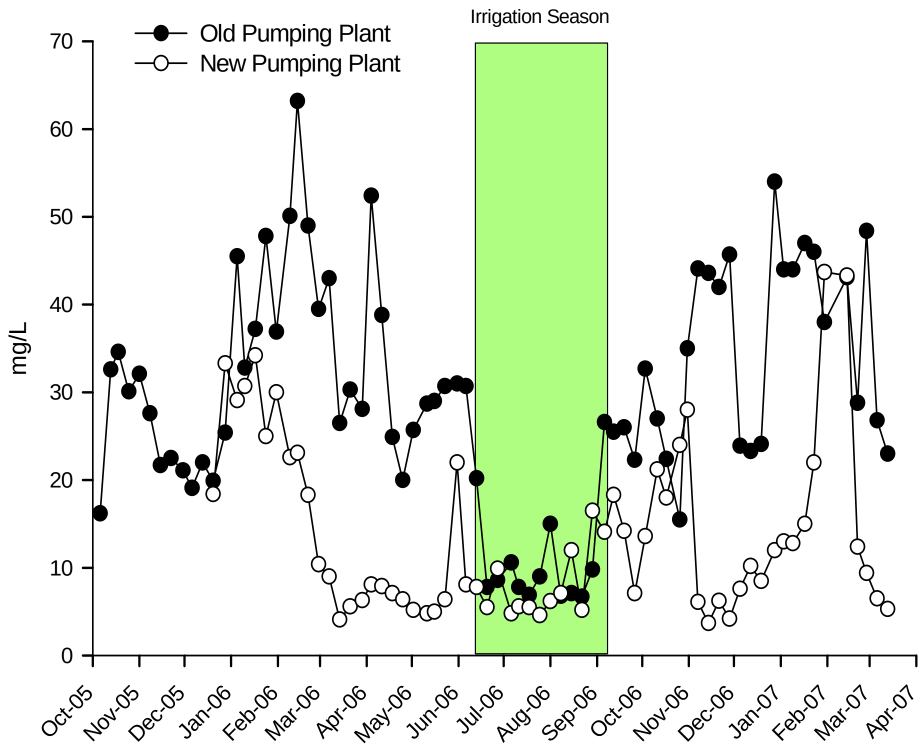


Figure 14. TOC comparisons between the old and new pumping plants

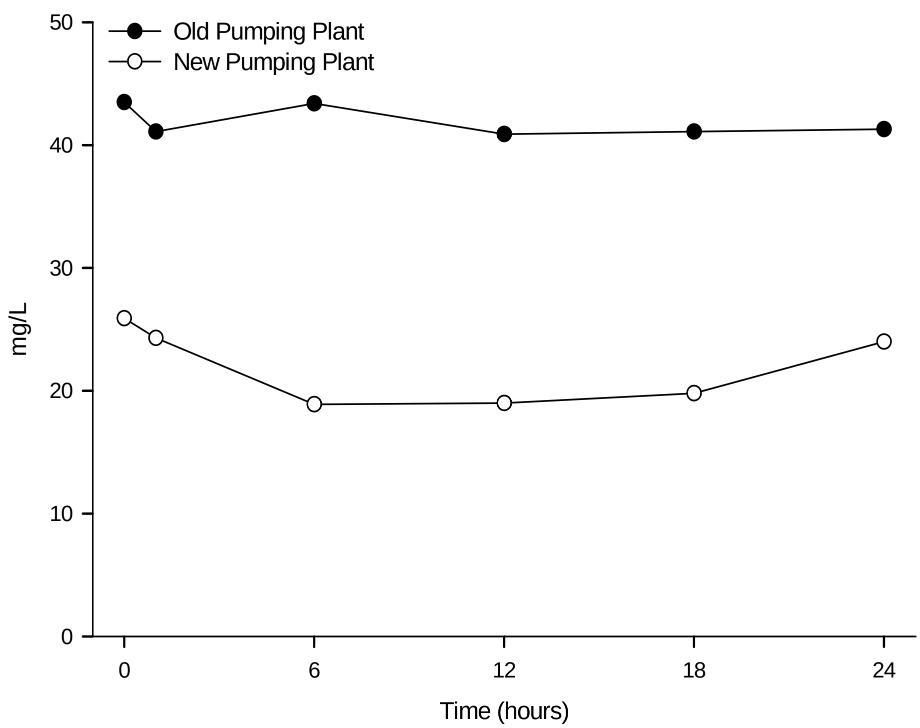


Figure 15. First flush pumping event (2/5/07-2/6/07)

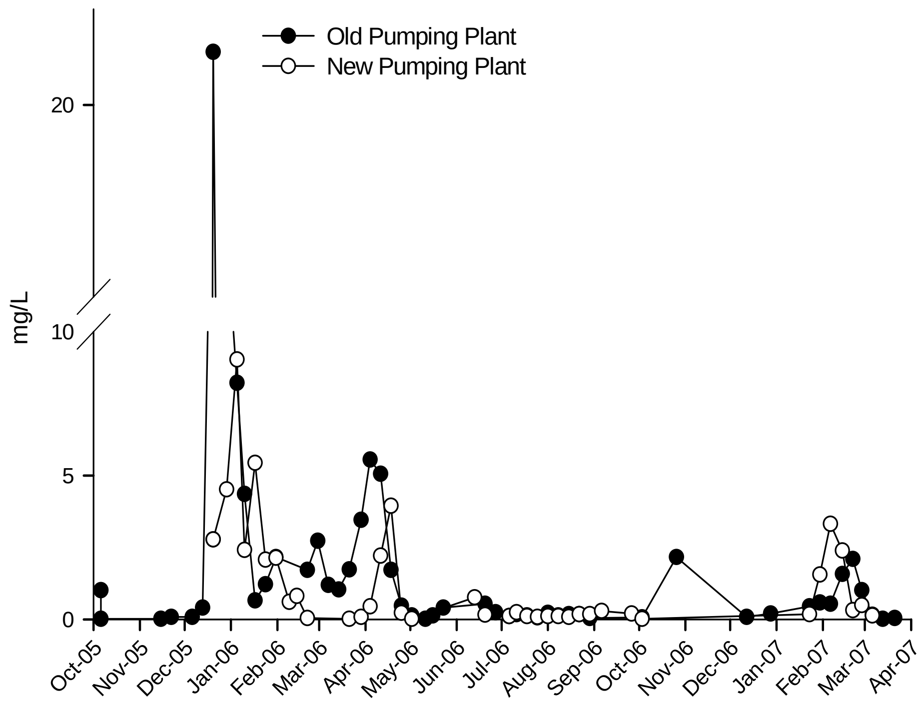


Figure 16. Nitrate as N comparisons between the old and new pumping plants

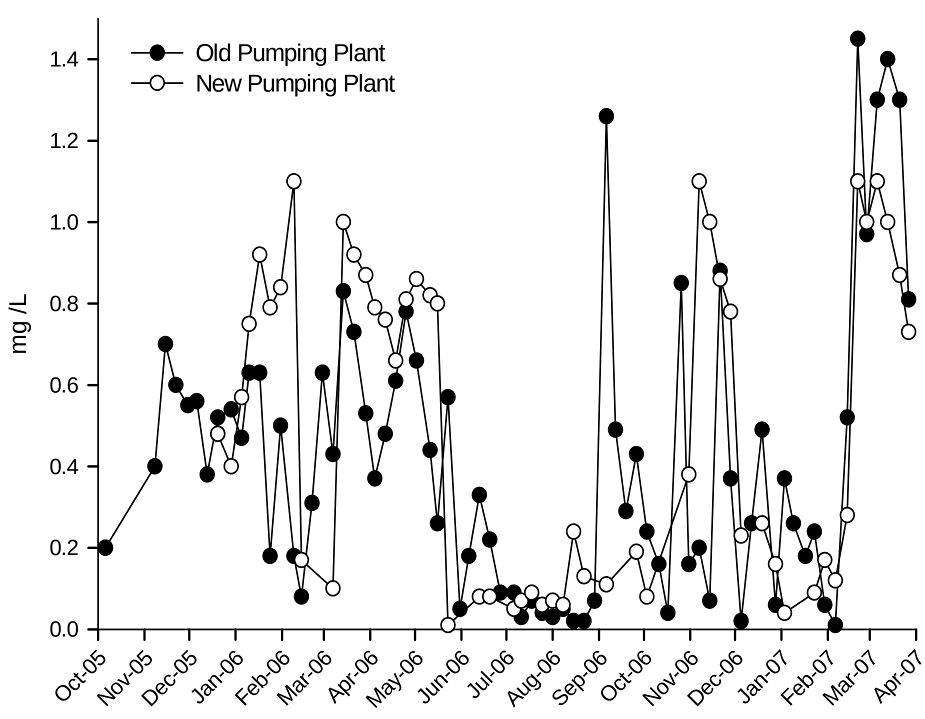


Figure 17. Ammonia comparisons between the old and new pumping plants

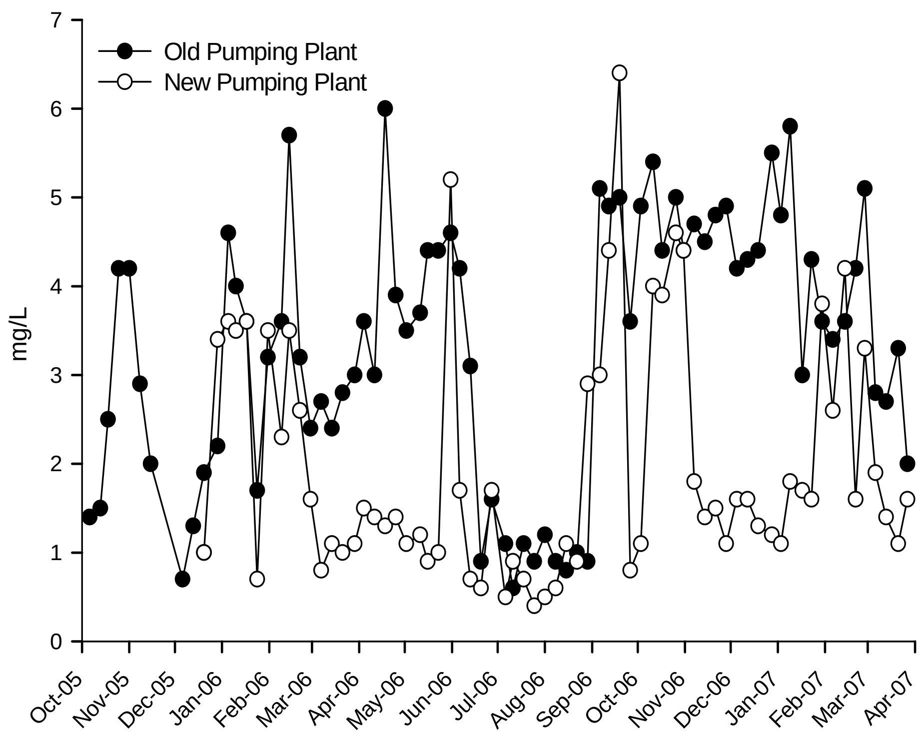


Figure 18. TKN comparisons between the old and new pupmping plants

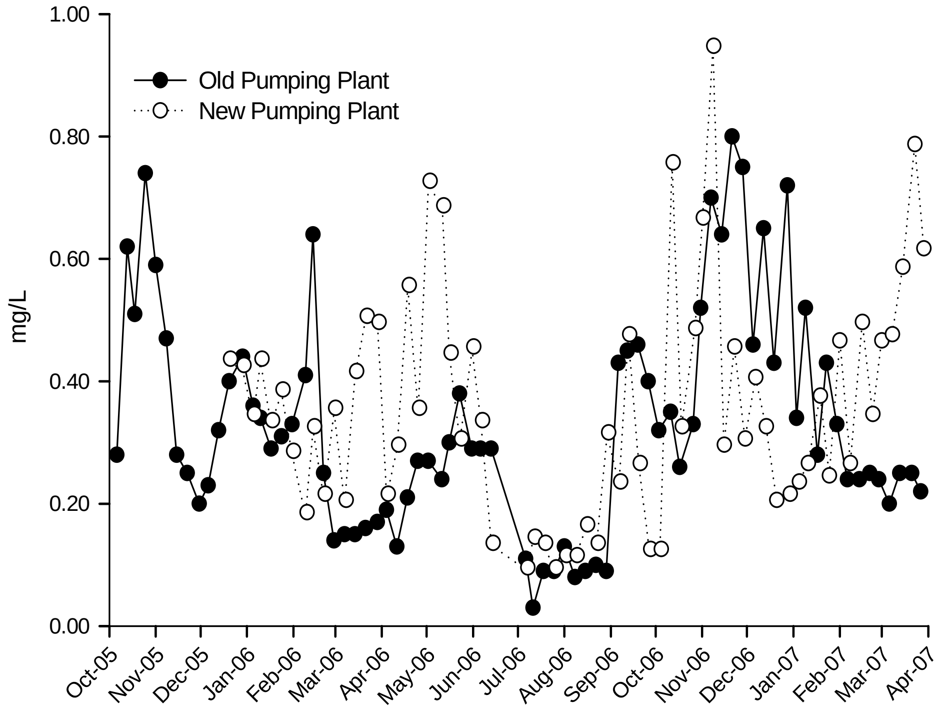


Figure 19. Total phosphate comparisons between the old and new pumping plants

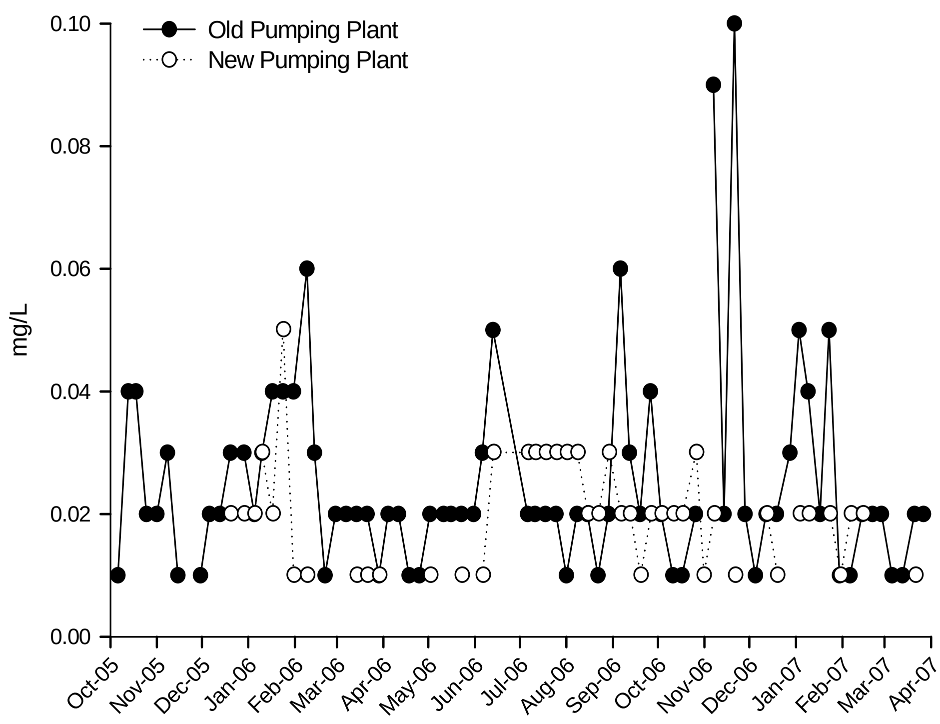


Figure 20. Orthophosphate comparisons between the old and new pumping plants

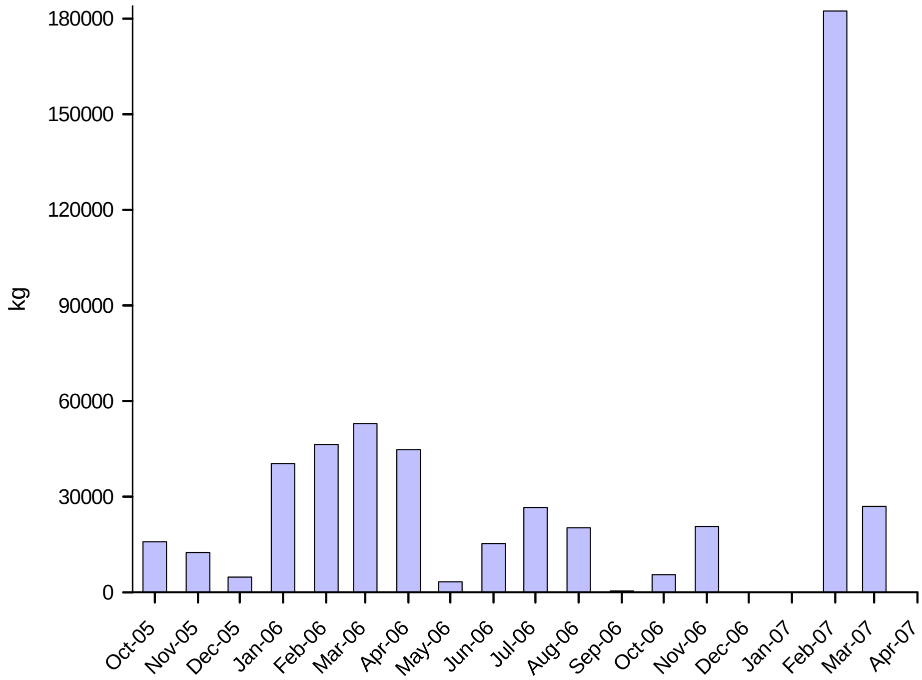


Figure 21 a. Total monthly TOC loads

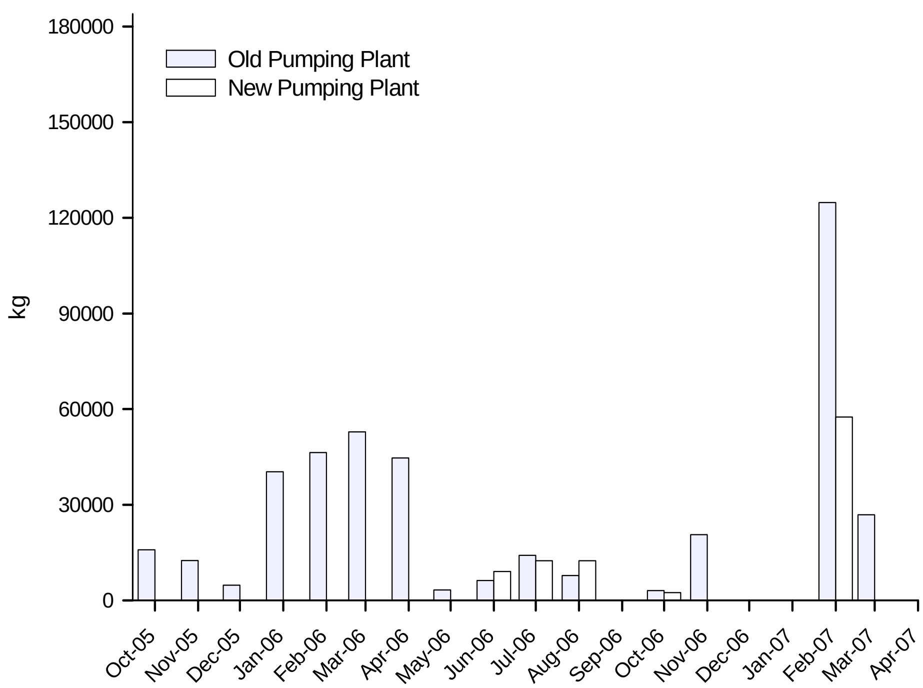


Figure 21 b. Monthly TOC loads by site

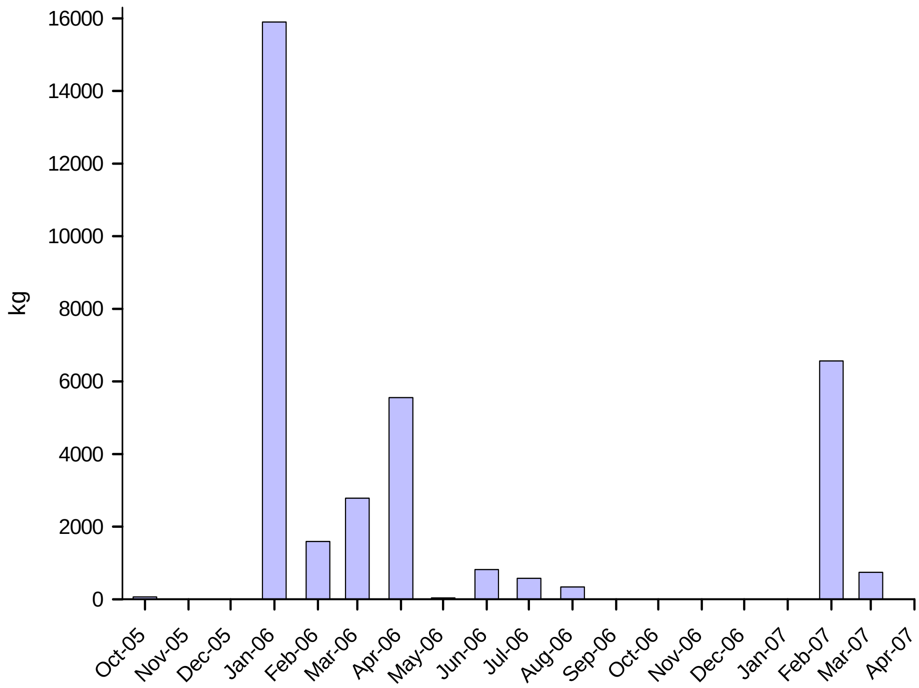


Figure 22 a. Total monthly nitrate loads

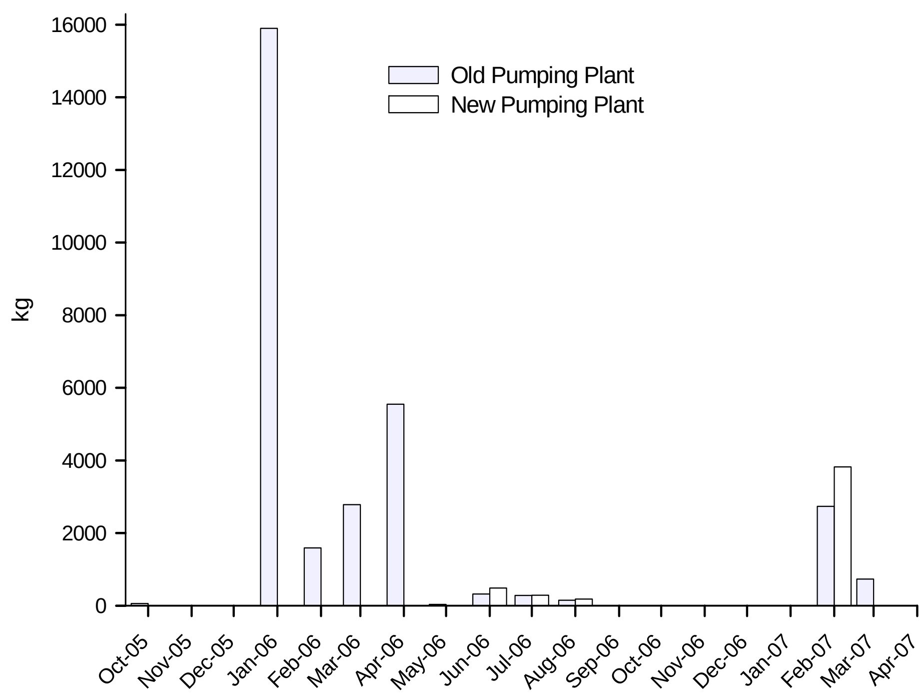


Figure22 b. Monthly nitrate load by site

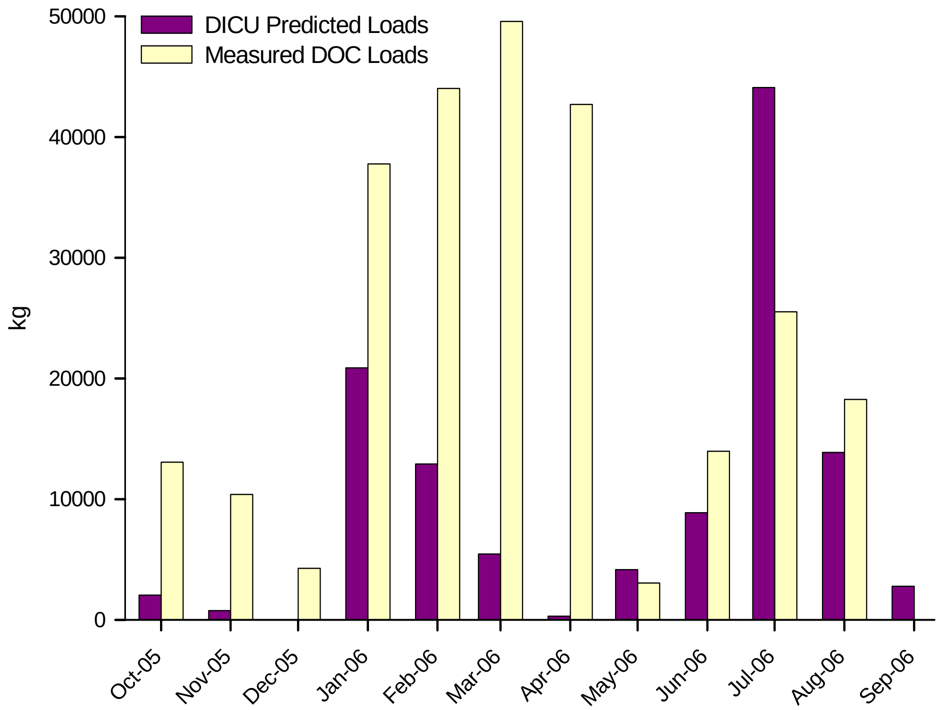


Figure 23. Comparison between predicted DOC loads using DICU and actual DOC loads discharged off of Staten Island

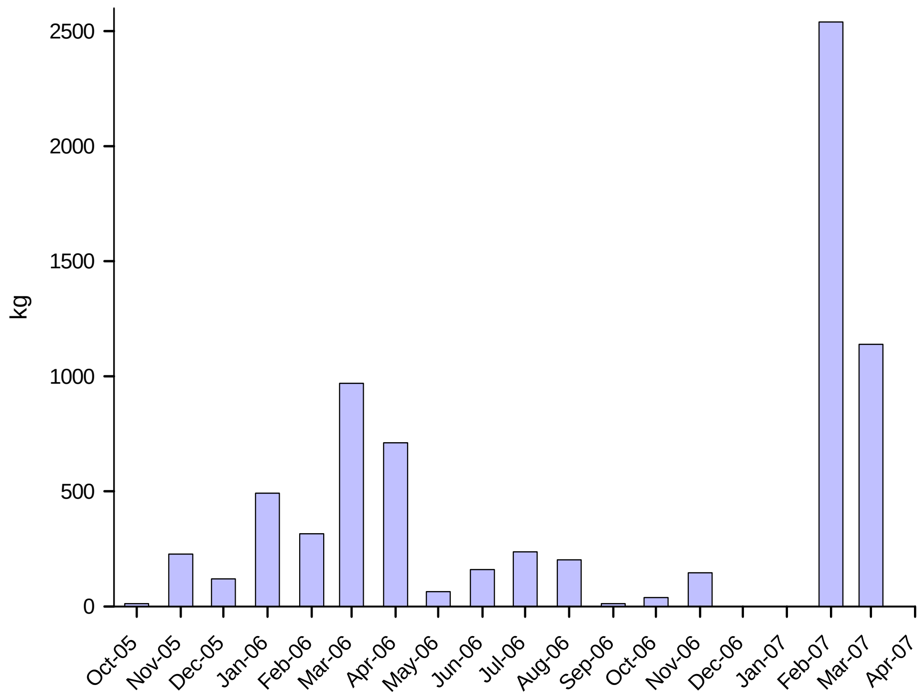


Figure 24 a. Total monthly ammonia loads

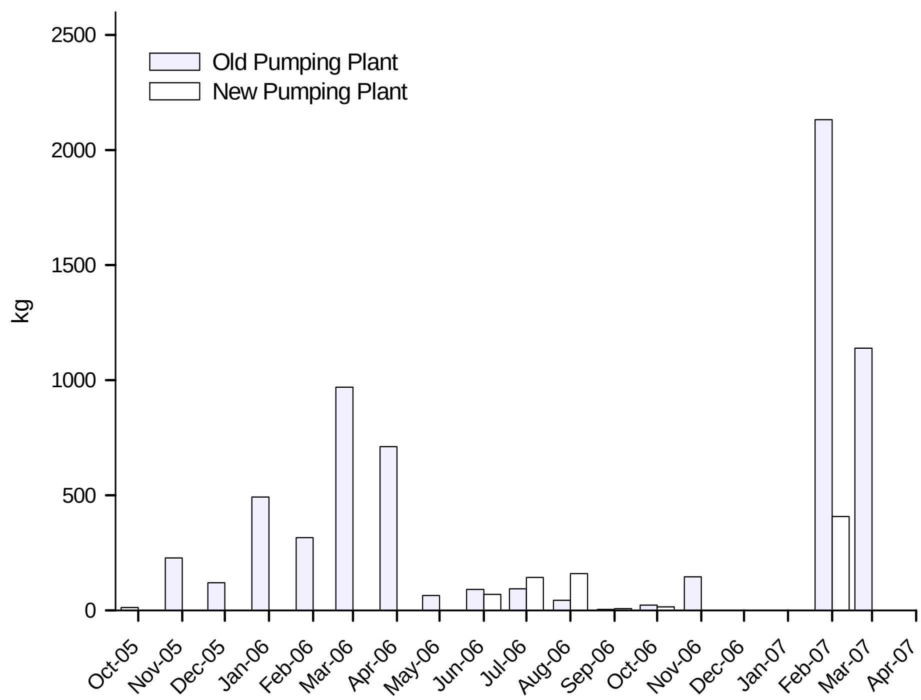


Figure 24 b. Monthly ammonia loads by site

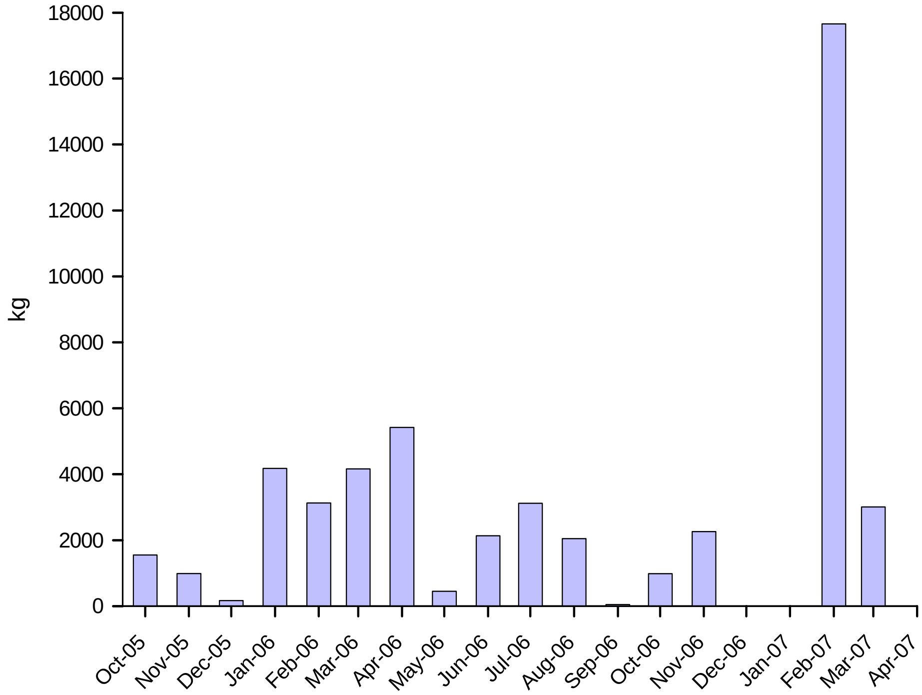


Figure 25 a. Total monthly total Kjeldahl nitrogen loads

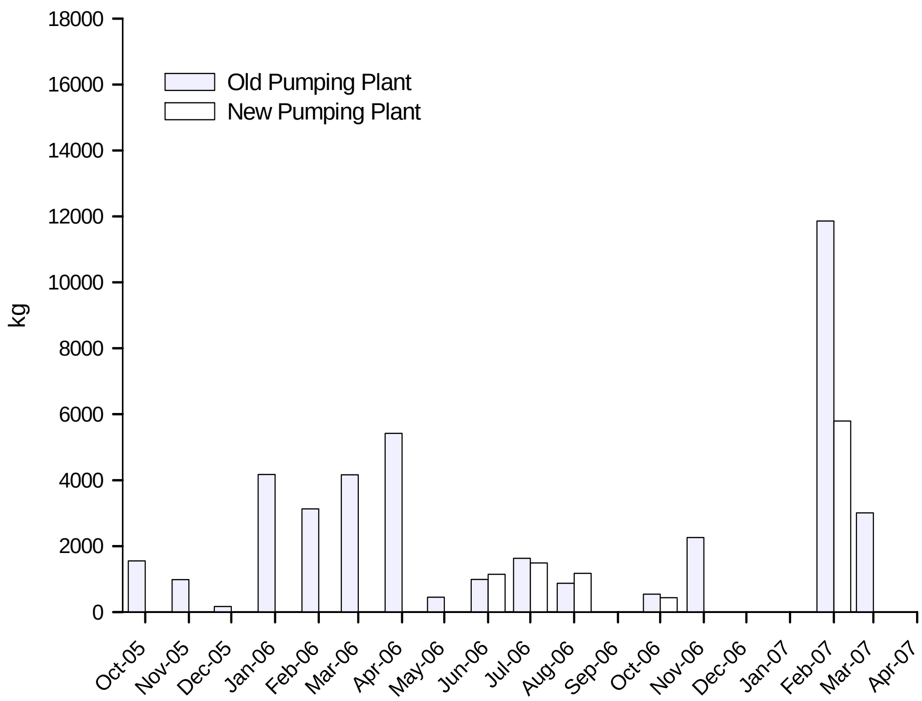


Figure 25 b. Monthly total Kjeldahl nitrogen loads by site

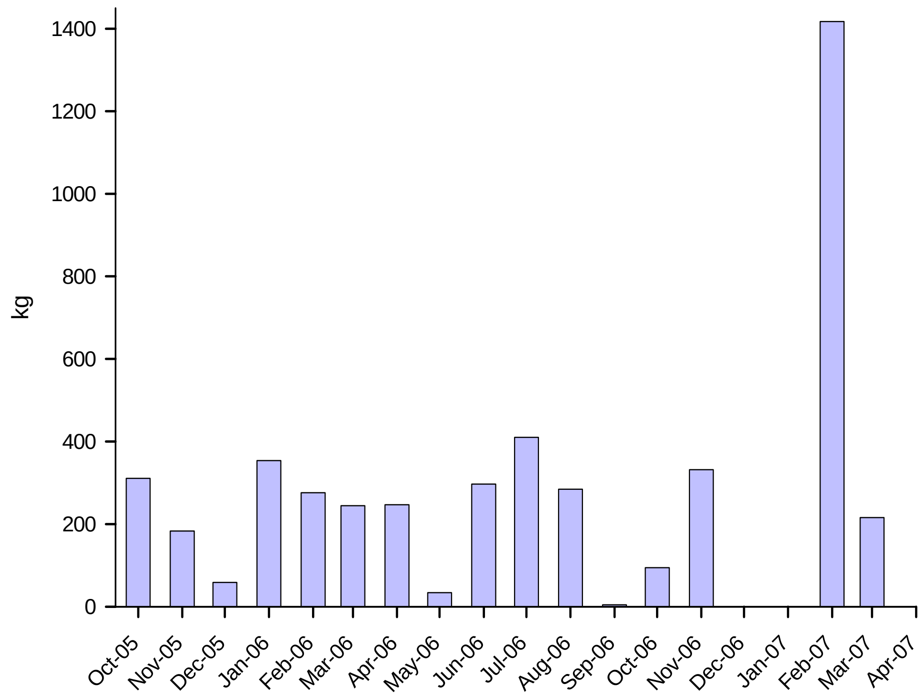


Figure 26 a. Total monthly total phosphate loads

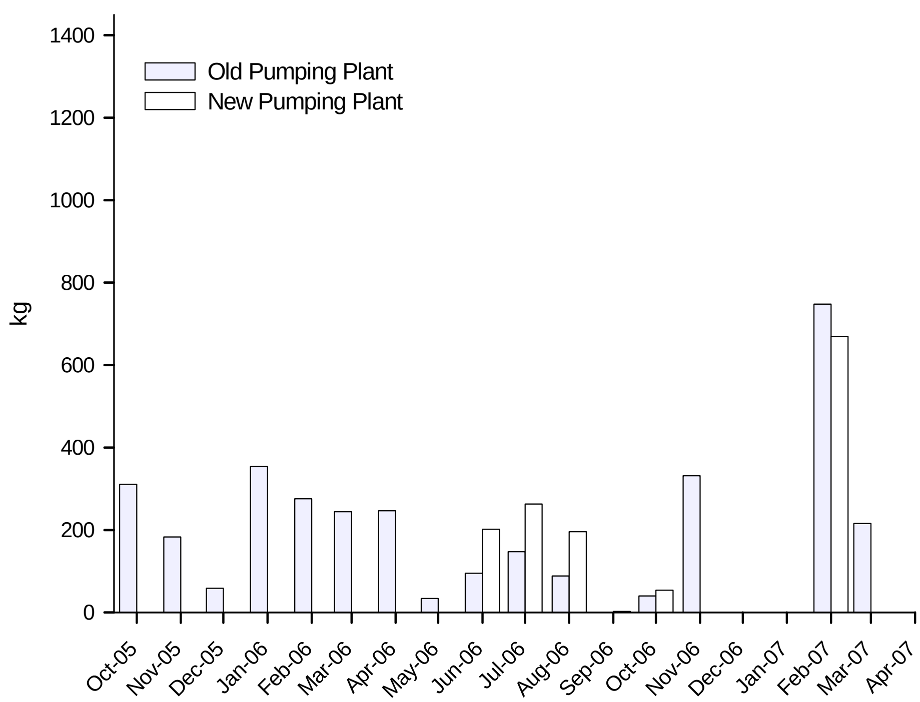


Figure 26 b. Monthly total phosphate loads by site

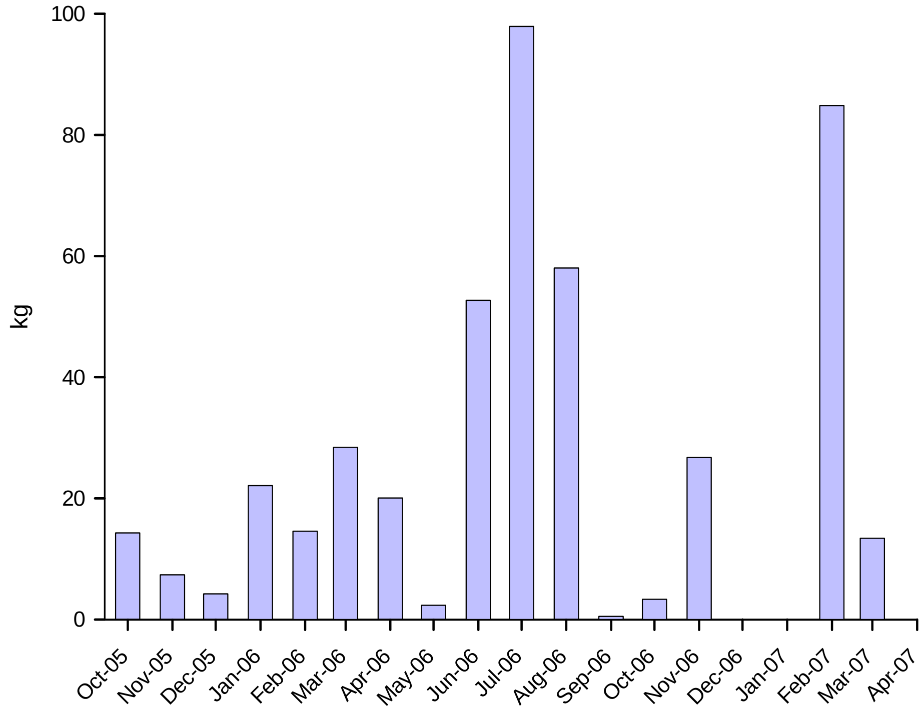


Figure 27 a. Total monthly orthophosphate loads

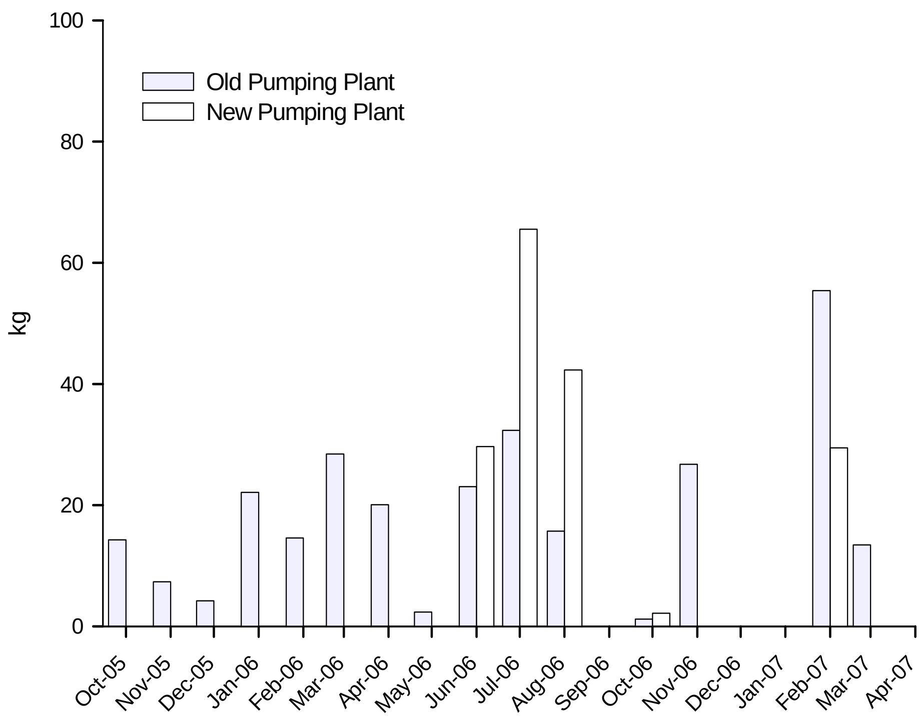


Figure 27 b. Monthly orthophosphate loads by site

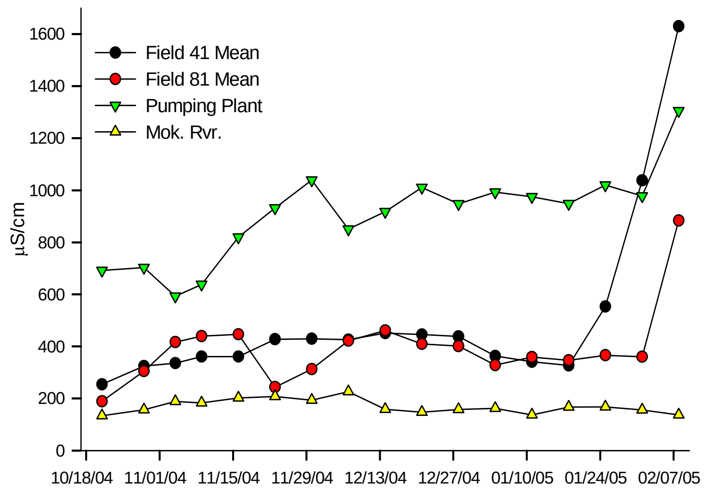


Figure 28. EC changes-fields 41 and 81, pumping plant and Mokelumne River

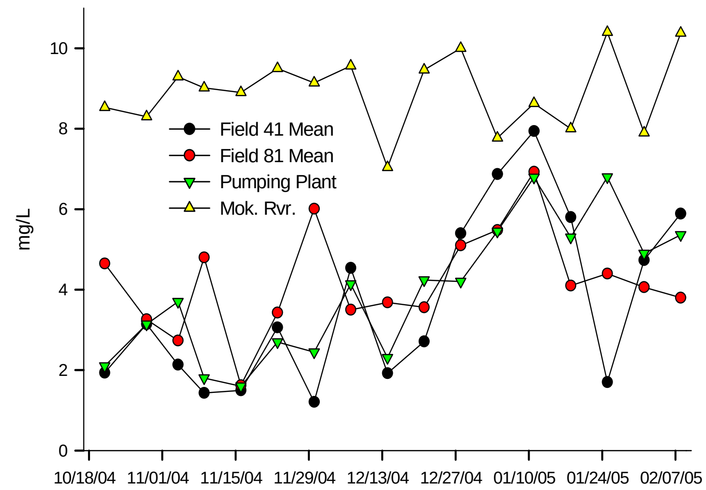


Figure 29. DO changes-fields 41 and 81, pumping plant and Mokelumne River

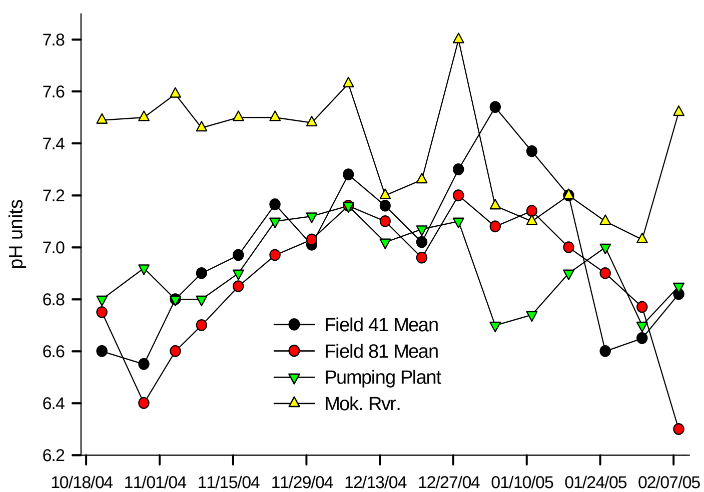


Figure 30. pH changes-fields 41 and 81, pumping plant and Mokelumne River

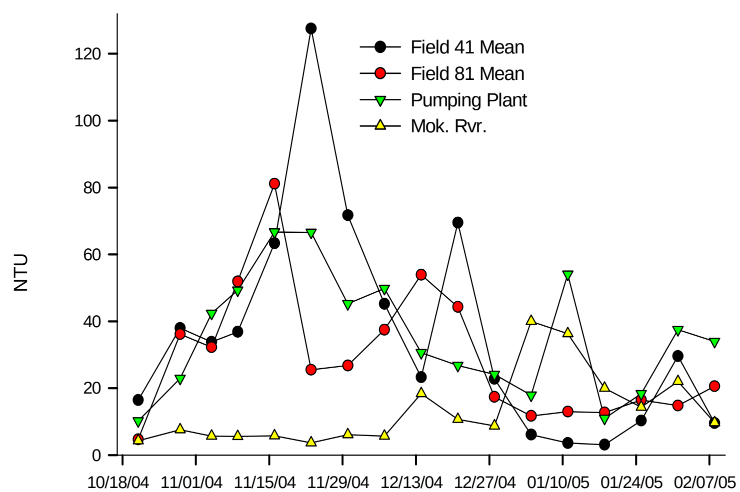


Figure 31. Turbidity changes-fields 41 and 81, pumping plant and Mokelumne River

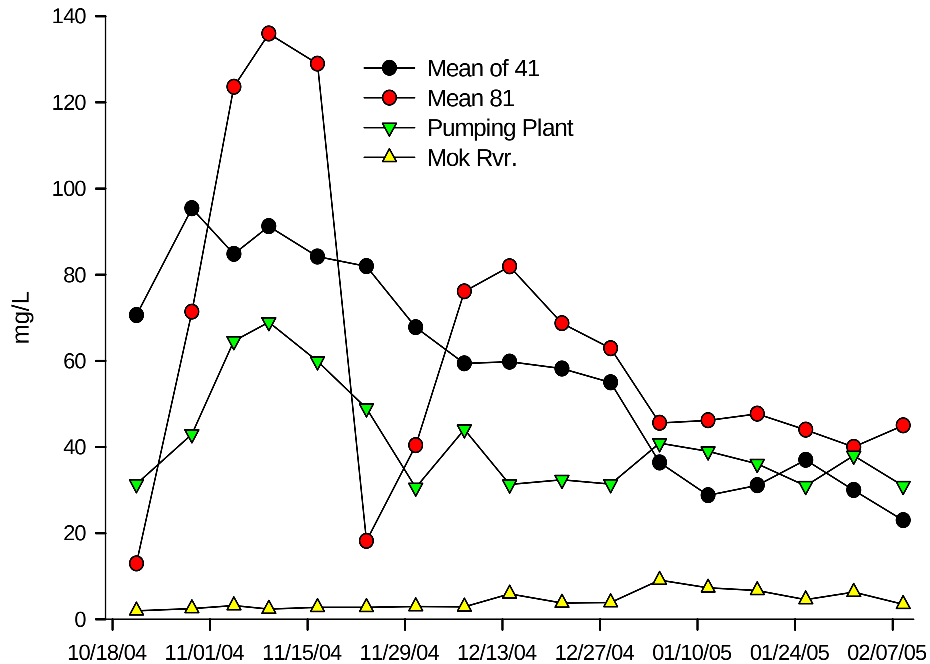


Figure 32. Total organic carbon changes-fields 41 and 81, pumping plant and Mokelumne River

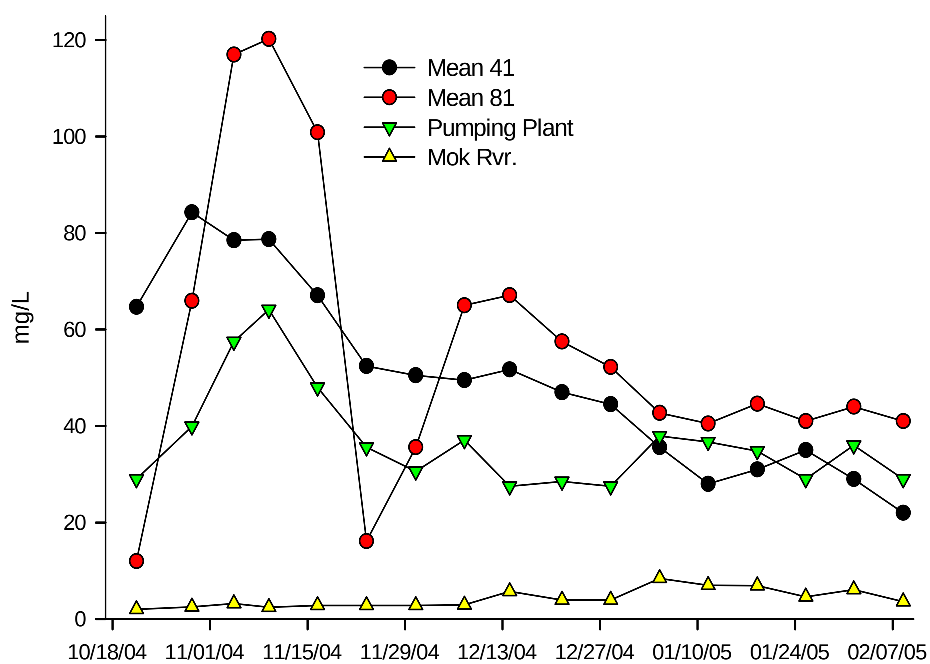


Figure 33. Dissolved organic carbon changes-fields 41 and 81, pumping plant and Mokelumne River

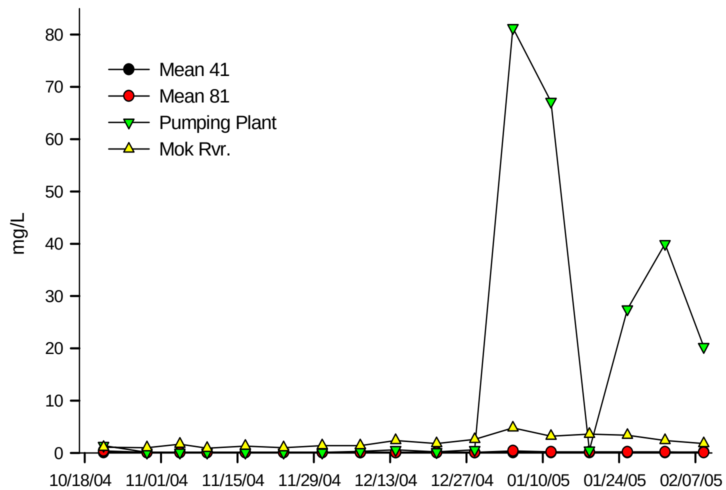


Figure 34. Nitrate (as NO_3) changes-fields 41 and 81, pumping plant and Mokelumne River

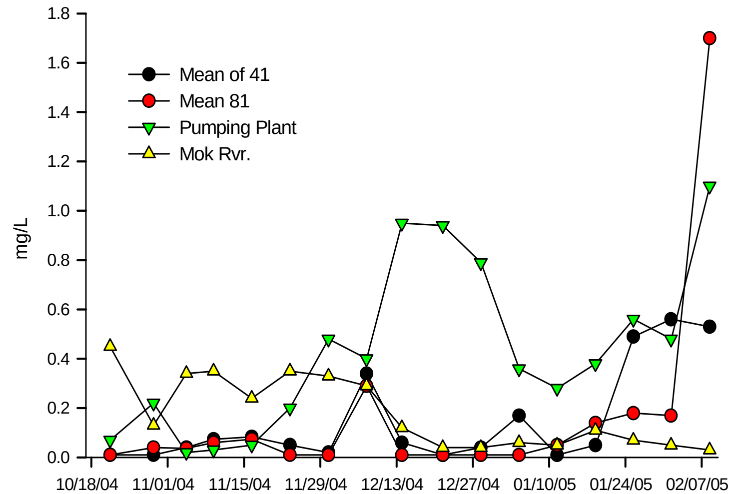


Figure 35. Ammonia changes-fields 41 and 81, pumping plant and Mokelumne River

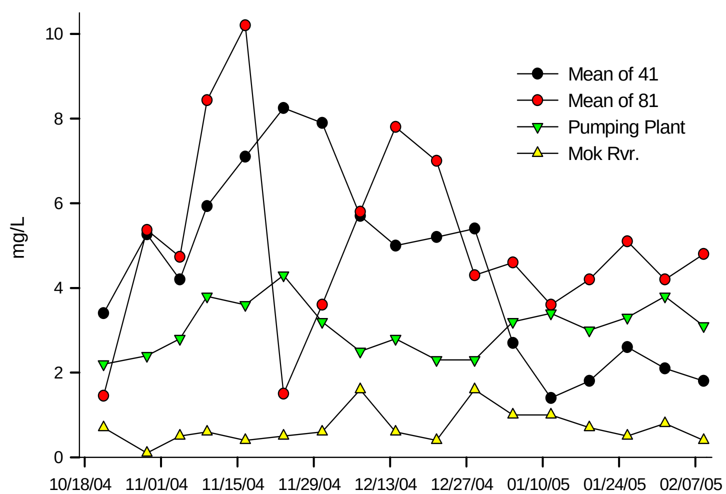


Figure 36. Total Kjeldahl nitrogen changes-fields 41 and 81, pumping plant and Mokelumne River

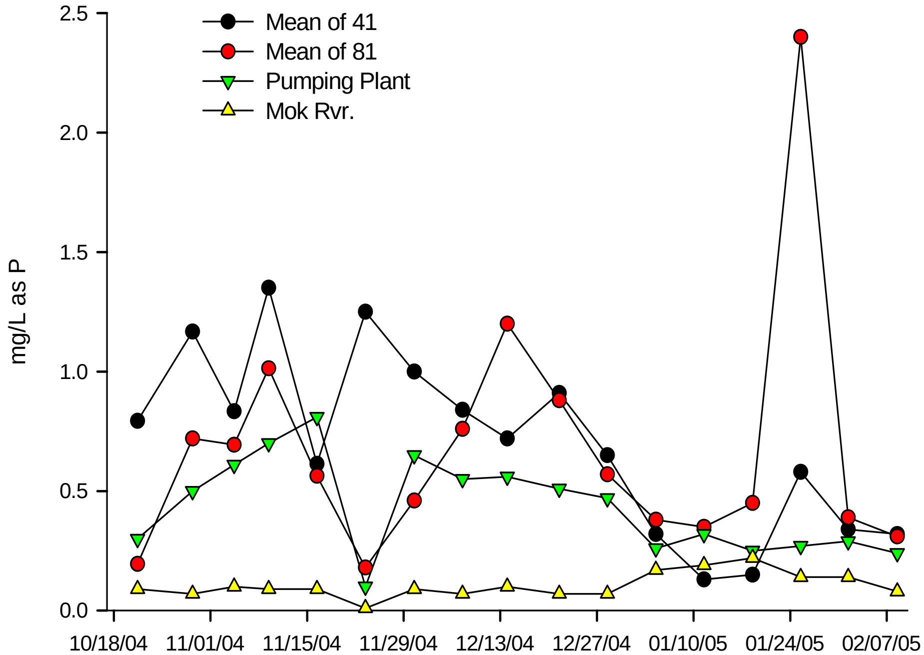


Figure 37. Total phosphate changes-fields 41 and 81, pumping plant and Mokelumne River

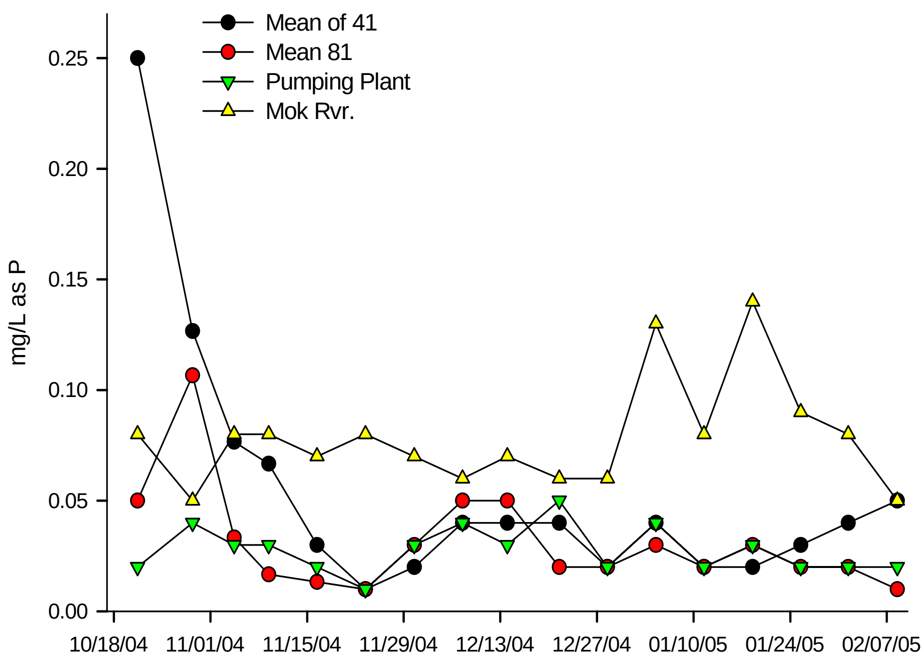
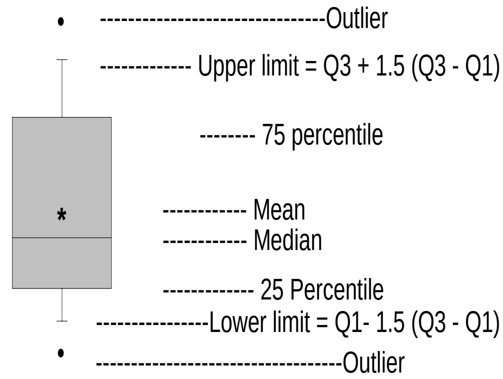


Figure 38. Orthophosphate changes-fields 41 and 81, pumping plant and Mokelumne River



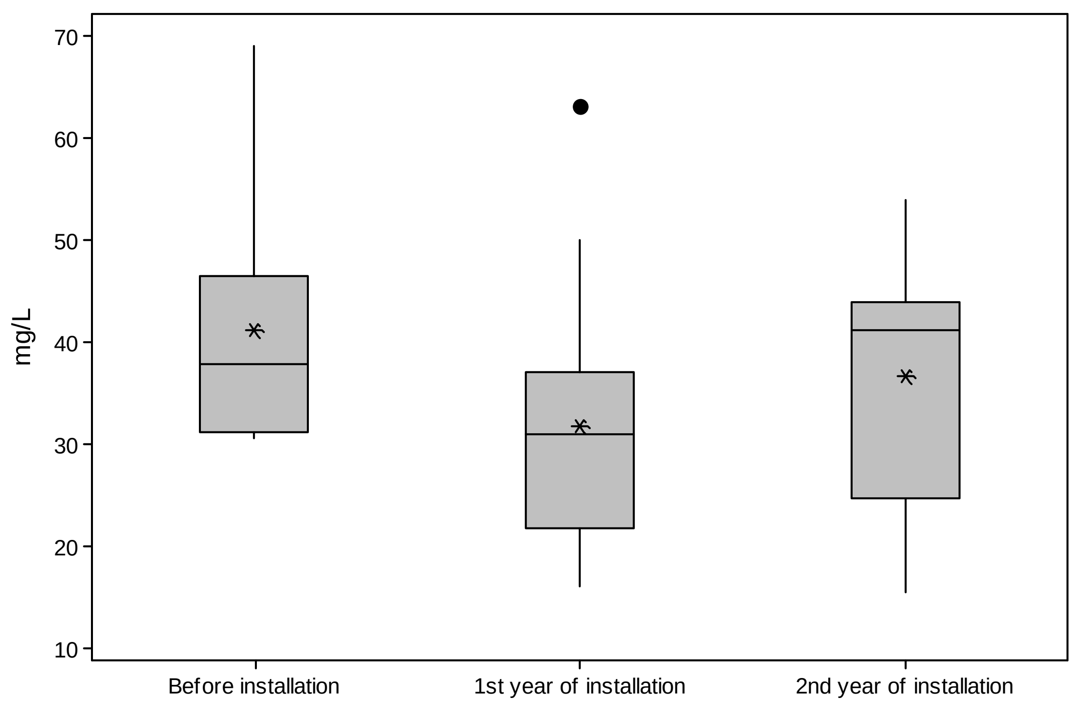


Figure 39. TOC comparisons at the Old Pumping Plant before and after installation of the New Pumping Plant (Before:10/21/04-2/8/05), (1st year: 10//05-2/14/06), (2nd: 10//06-2/14/07)

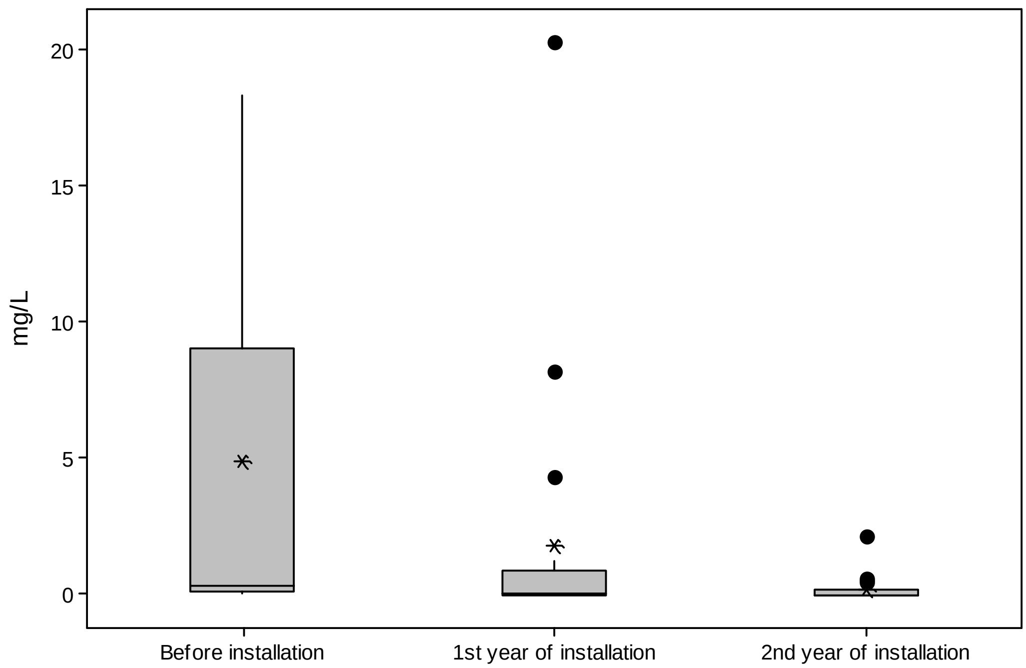


Figure 40. Nitrate as N comparisons at the Old Pumping Plant before and after installation of the New Pumping Plant (Before:10/21/04-2/8/05), (1st year: 10//05-2/14/06), (2nd: 10//06-2/14/07).

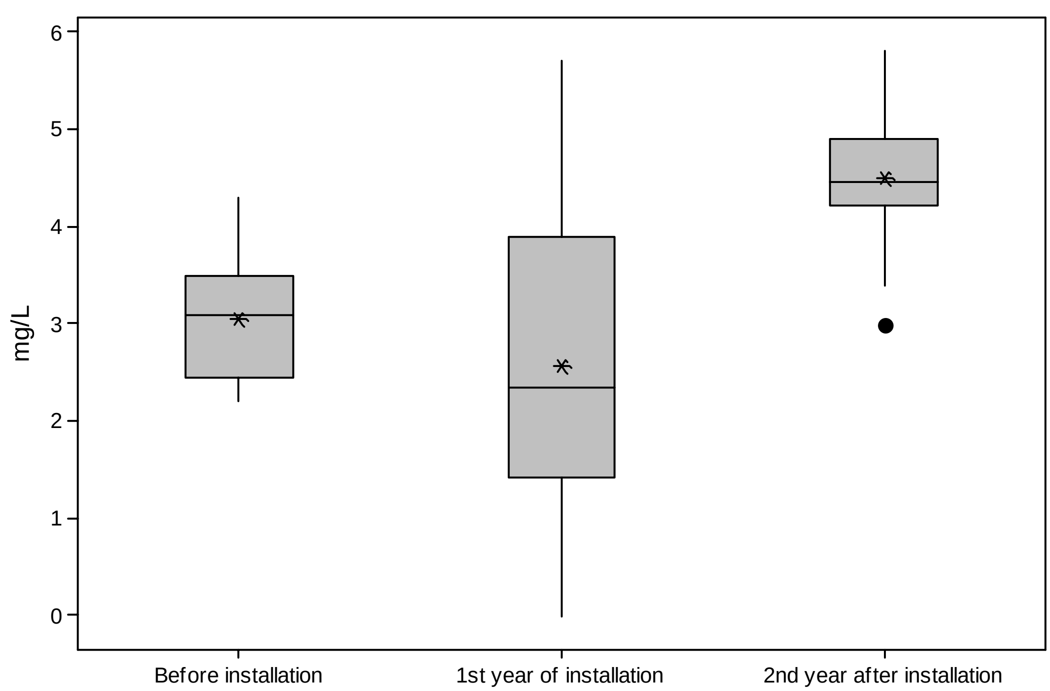


Figure 41. TKN comparisons at the Old Pumping Plant before and after installation of the New Pumping Plant (Before:10/21/04-2/8/05), (1st year: 10//05-2/14/06), (2nd: 10//06-2/14/07)