Chapter 3: WATER QUALITY FIELD INVESTIGATIONS

3.1 Introduction

Disinfection byproducts (DBPs) such as trihalomethanes are an issue of concern for the California water system and the In-Delta Storage Program. Maximum contaminant levels and operational criteria are set by regulatory agencies (e.g., D1643 and WQMP) to protect public health and research is being conducted better understand and manage DBP precursors like total and dissolved organic carbon (TOC and DOC) at their source. Field investigation during the feasibility stage of the study focused on better understanding the reservoir biological processes concepts and variations in organic carbon due to peat soils and biological productivity. The field investigations included the following specific tasks to estimate the organic carbon loading from peat soils and biological productivity.

- Reviewed the literature on organic carbon loading in the Delta for information that may be applicable to In-Delta storage.
- Evaluated likely Organic Carbon (OC) concentrations and loads expected in storage water using mesocosms or physical models of the proposed reservoir islands. The experiments were extended to simulation of water circulation in reservoirs to resolve the water quality issues.
- Integrated results from field studies with mathematical models (CALSIM II, DSM2, and DYRESM) to resolve water quality issues and develop desired operations for overall system benefits.

This section is organized to present general information on the development of a conceptual model and the experimental physical model (mesocosms) in the rest of this introductory Section 3.1. Section 3.2 describes the materials and methods used in the mesocosm experiment and Section 3.3 presents and discusses the results. How the data from the experiment were used in the mathematical models is described in Section 3.4. Section 3.5 lists references.

3.1.1 Development of Conceptual Model

DOC and particulate organic carbon (POC) in surface water can come from external or internal sources. For reservoir construction in wetlands, soil could be a dominant source of OC loading, at least initially. In order to adequately predict and mitigate both short-term and long-term impacts associated with flooding peat soils, it is important to understand not just the likely quantity of OC loading but also the quality or sources of that loading. A simplified conceptual model showing the sources of major biological and physical factors in the reservoir DOC is shown in Figure 3.1.

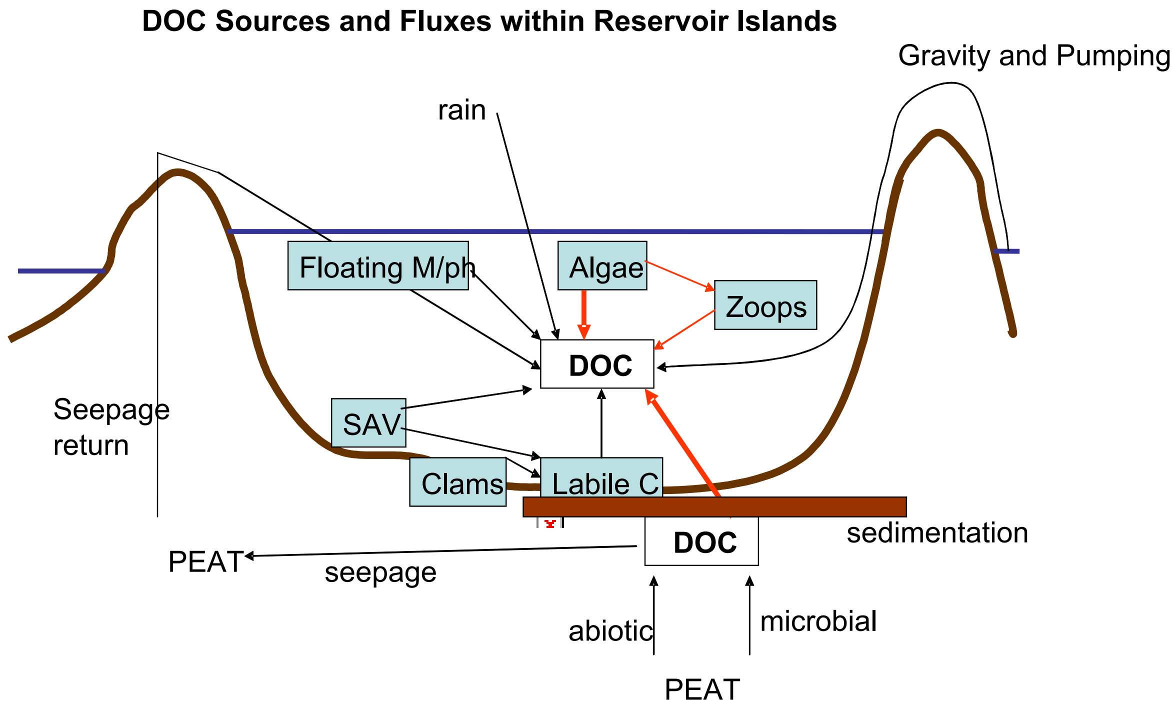

Figure 3.1: Conceptual Model Showing the DOC Sources in Project Island

3.1.2 Development of Physical Models (Mesocosms)

Mesocosms or physical models of the proposed reservoir islands were created to study the ecological processes driving OC loading. This mesocosm study was designed to meet specific needs and timelines of the program. The focus of the study was to reduce uncertainty surrounding estimates of likely rates for the process of OC loading in the proposed reservoir islands. The mesocosms were put together using naturally occurring water and biota. The objective of the experimental design was to include as many complex and interacting ecological factors that drive carbon dynamics in the Delta as possible. Study results in terms of net OC loading rates (such as interacting processes like abiotic leaching, microbial degradation, photooxidation and macrophyte growth and death decomposition) were considered together. Nevertheless, the use of water depth as a treatment variable with the mechanism of light attenuation driving submersed macrophyte growth in a replicated, controlled mesocosm experiment provided a start for fleshing out qualitative and quantitative differences in OC sources.

3.2 Materials and Methods

Mesocosm studies were conducted from March through December 2002 at the Municipal Water Quality Investigations Field Support Unit in Bryte, California (Plate 3.1). Four 3300 L (shallow) and four 6100 L (deep) mesocosms were put together using fiberglass tanks (1.5 m diameter and 1.8 or 3.4 m height respectively). The eight tanks (mesocosms) were filled with 820 L (0.5 m depth) of peat soil, classified as Rindge series muck (Plate 3.2), collected from Bacon Island, California, the site for one of the proposed reservoirs, on March 5, 2002. Before adding the soil to the tanks, living plant material was removed and the soil was well mixed using a front end loader and backhoe (Plate 3. 3). The Division of Natural Resources Analytical Laboratory at the University of California, Davis analyzed the soil for the following analytical groups: salinity, fertility, extractable micronutrients and exchangeable cations. Information on the lab and their analytical methods is available at (http://danranlab.ucdavis.edu/). In addition to these analyses, the % carbon (C), % hydrogen (H) and % nitrogen (N) content of the soil was determined using a Perkin-Elmer model 2400 CHN analyzer with acetanilide used as a standard. Soil fresh weight (fw) % moisture, % ash and % organic matter (OM) as well as dry weight (dw) % ash and % OM and loose soil bulk density were also determined before the soil was added to the tanks (Table 1). The soil was compacted somewhat once inside of the tanks by walking on it as it was applied, leveled and adjusted to the 0.5 m depth.

Plate 3.1: Fiberglass Mesocosms

Plate 3.2: Peat Soil (Rindge Muck) Sample

Plate 3.3: Backhoe and Dump Trucks at Bacon Island

3.2.1 Simulated Hydrology

On March 12, 2002 the tanks were filled with Sacramento River water collected at West Sacramento using a 11,355 L water truck. Once filled, the depth of water over the peat soil was approximately 1.4 m in the shallow mesocosms and 2.9 m in the deep mesocosms. An additional 6,100 L tank was filled with river water only (no soil) and served as a control mesocosm. The water was baffled during filling to reduce soil disturbance. Nevertheless, some mixing of the soil with the overlying water occurred for a few days after the tanks were filled as gas bubbles escaped from the soil and entrained soil particles in the water column. Secchi disk visibility was less than 0.3 m in the days following filling. Two weeks after filling most of the suspended soil particles settled out and Secchi disk visibility increased to one meter (data not shown). Turbidity measurements of water in the mesocosms are presented in Figure 3.2.

Table 3.1: Physical and Chemical Properties of the Peat Soil

Table 1. Physical and chemical conditions of the peat soil used in the experiment.

Analyte	Result	Unit	Reporting Limit
SP[a]	126	%	1
EC	2.98	mmhos/cm	0.01
pH	4.3	pH units	0.1
Ca (SP)	17.5	meq/L	0.1
Mg (SP)	12.1	meq/L	0.1
Na (SP)	5.8	meq/L	0.1
Cl (SP)	3	meq/L	0.1
HCO_3 (SP)	0.6	meq/L	0.1
CO_3 (SP)	<0.1	meq/L	0.1
SO_4-S (SP)	356	ppm	1
NH_4-N	37.5	ppm	0.1
NO_3-N	156	ppm	1
P-Olsen	73	ppm	0.1
Fe (DTPA[b])	688	ppm	1
Mn (DTPA[b])	10.4	ppm	0.1
Cu (DTPA[b])	0.6	ppm	0.1
Zn (DTPA[b])	1.6	ppm	0.1
X[c]-K	1	meq/100g	0.1
X[c]-Na	1.4	meq/100g	0.1
X[c]-Ca	19.6	meq/100g	0.1
X[c]-Mg	6.8	meq/100g	0.1
Soil Density[d]	0.743	Kg/L	1
Soil Moisture	40	%	NA
Organic Matter (dw)[e]	45	%	NA
Ash (dw)[e]	55	%	NA
Carbon[f]	26	%	NA
Nitrogen[f]	1.4	%	NA

[a] The saturation percentage (SP) method involves saturating the soil with water and subsequent extraction under partial vacuum of the liquid phase for the determination of dissolved salts. Soil moisture at the point of complete saturation is the maximum amount of water held when all the soil pore space is occupied by water and when no free water has collected on the surface of the paste.

[b] The DTPA (diethylenetriaminepentaacetic acid) micronutrient extraction method is a non-equilibrium extraction for estimating the potential soil availability of Zn, Cu, Mn and Fe.

[c] Equilibrium extraction of soil for plant available exchangeable potassium, sodium, calcium and magnesium using 1 Normal ammonium acetate (pH 7.0) and subsequent determination by atomic absorption/emission spectrometry

[d] The mass (743g) of 1L of fresh (not oven dried) non-compacted soil divided by 1KG

[e] By combustion of oven dried (70 C) soil in muffle furnace

[f] By CHN analyzer

The mesocosms were filled and drained according to typical modeled reservoir operations. Based on modeled operations, January is the most typical month in which sufficient water is available in the Delta to fill the reservoirs. Filling the tanks in early March was less representative of typical operations than a January fill but the unavoidable result of logistics constraints. The theoretical reservoirs are usually emptied in June and July to a minimum depth of 0.3 meters. The minimum depth is maintained by topping-off diversions. Filling and draining of the reservoirs usually takes two to four weeks depending on the pumping plant design (number of pumps and capacity). Because of logistics constraints and the late start, the tanks were filled in one day on March 12, 2002. The mesocosms were emptied by the same volume each day from July 29 through August 7 until a minimum depth of 0.3 m was reached, to better simulate how the reservoirs will be drained. As the mesocosms were drained, water pressure on the peat soil at the bottom was reduced and gas bubbles again escaped from the soil, mostly in the deep mesocosms. Note the dramatic increase in turbidity in the deep mesocosms after draining to a depth of 0.3 m (Figure 3.2). It was not clear if the gas was from air trapped in the soil when the tanks were initially filled or if the gas was from microbial activity or other sources. The mesocosms were maintained at a Depth of 0.3 m through the end of December except for the addition of rain water which increased the drained depth from 0.3 m to about 0.5 m in the last few weeks of the study. Rain did not have an obvious effect on the mesocosms during must of the study especially when the mesocosms were full and precipitation was only a small fraction (on the order of 1%) of tank volume. Rainfall data for Bryte, CA in are shown in Figure 3.3. River water was added at least monthly to make up for evaporation loss. The tanks were refilled in January 2003 and a second year of this study is currently underway. Similar reservoir operations with winter filling and summer draining were used in the second year's study but a small circulation flow (approximately 15% of reservoir water volume exchanged per month) was simulated in the mesocosms.

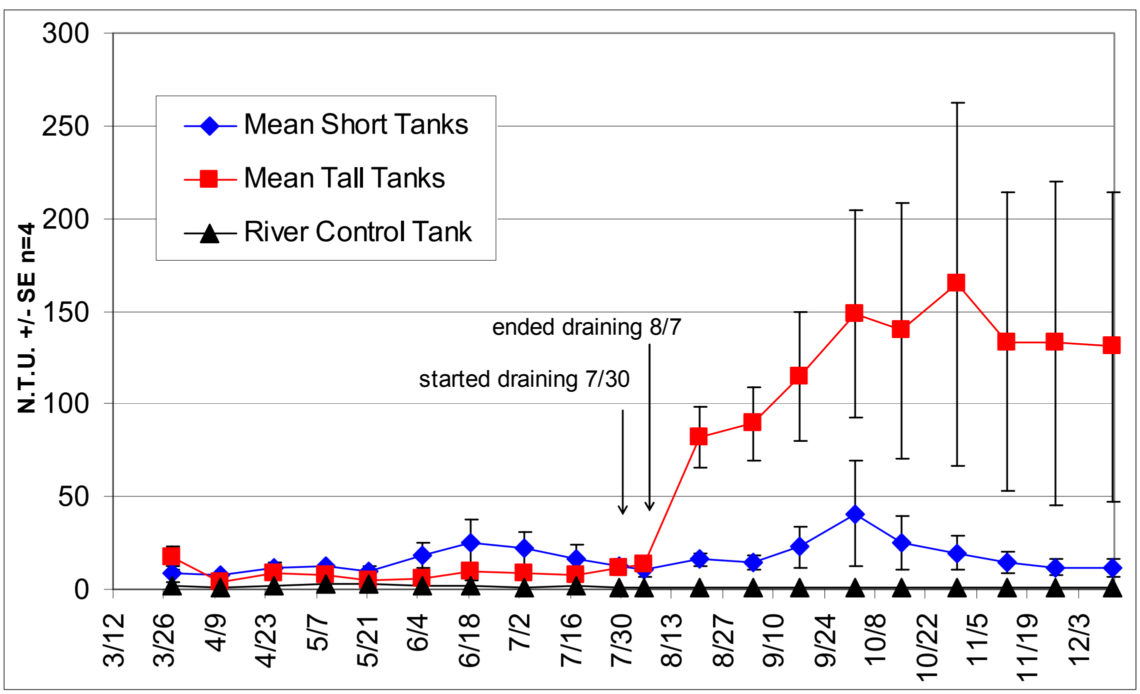

Figure 3.2: Mean Turbidity in Mesocosms in 2002

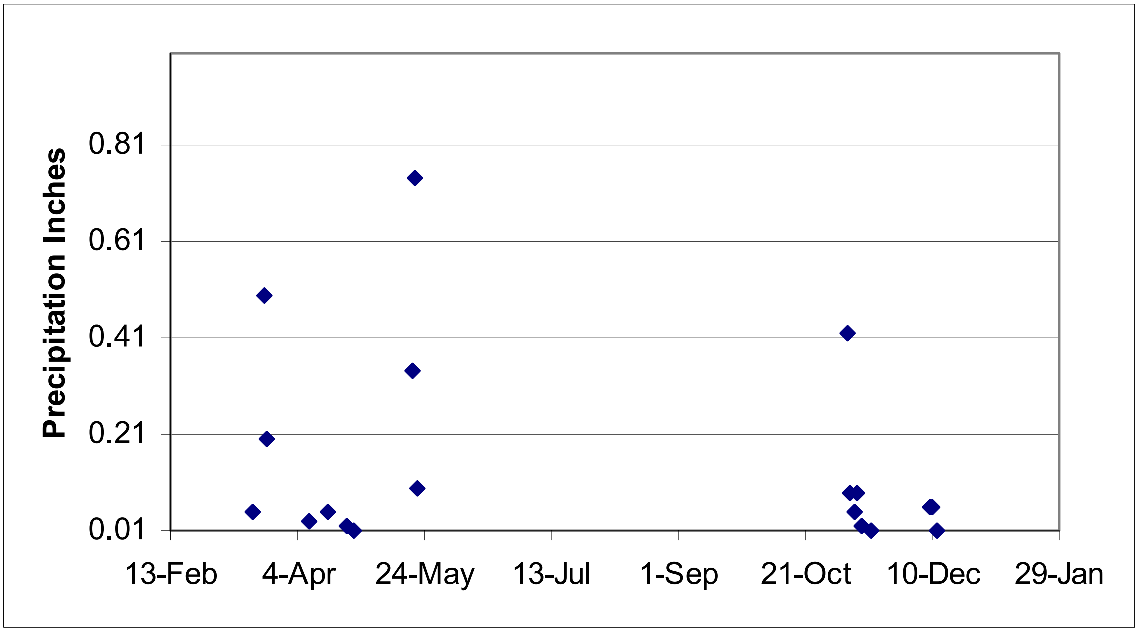

Figure 3.3: Daily Precipitation Totals for Bryte Station for 2003-2003

3.2.2 Soil Disturbance

Disturbance or manipulation of the soil used to fill the mesocosms was not considered a problem in this study. The objective of the study was to physically model conditions in the proposed reservoir islands after flooding. Of the proposed reservoir islands' land areas, 85% to 90% is in production agriculture and subject to the disturbance of annual tilling. Tilling turns over approximately the top 30 cm of soil, the same surface layer of soil collected for this study. Note the vast area of tilled peat soil in the agricultural fields of Bacon Island shown in Plate 3.3. Peat soil on the reservoir islands will also be disturbed during construction of the integrated facilities, levee modification and excavation for borrow material (sand) located under the peat soil. This disturbed peat soil will form the soil/water interface when the islands are flooded. Gas bubbles will also escape from the reservoir soils when the islands are first flooded. In addition, the reservoirs will be filled through pumping facilities at a rate of 1500 cfs. This flowing water together with wind waves will cause some erosion and mixing of soil and water during filling. Nevertheless, the same soil and mesocosms were used in the second year's study. Other than the simulated reservoir diversions and discharges and the resulting release of interstitial gas bubbles, which will also occur in the real reservoir islands, disturbance did not occur in this subsequent year's study.

3.2.3 Biota

Soil from Bacon Island (one of the proposed reservoir islands) together with naturally occurring biota in the Sacramento River water as well as macrophytes, invertebrates and fish collected from the Delta were used in this study to create physical models (mesocosms) of the reservoir islands. Soil from one of the proposed reservoirs was used and provided inoculation of the mesocosms with appropriate seeds, eggs and organisms.

The Sacramento River will be the source of most of the water diverted to the reservoir islands. Untreated water from this river was added to the tanks within an hour of collection in order minimize plankton mortality. The most common zooplankton that developed in the mesocosms were (in order of abundance): cyclopoid nauplii, *Acanthocyclops vernalis*, *Bosmina*, *Daphnia* and rotifers. Common phytoplankton included: *Ankistrodesmus, Synedra, Cryptomonas, Melosira, Chlorella, Chlamydomonas* and unidentified flagellates.

Egeria densa is probably the most abundant submersed macrophyte in the Delta although good diversity and abundance data do not exist for submersed or other aquatic plants in the Delta (Jassby and Cloern 2000). After observing the onset of active growth of *Egeria* in the Delta, fragments were collected from Franks Tract and added to the mesocosms that same day, April 17, 2002. Ten fragments (total 80 g f.w.) were added to each mesocosm. Naturally occurring invertebrates, epiphytic algae, eggs or other organisms on the *Egeria* fragments were not removed and the fragments were transported in coolers filled with Delta water to minimize mortality. Light levels in the mesocosms were approximately 550 and 150 μmol m^{-2} s^{-1} at depths of 0.3 and 1.0 m respectively in the mesocosms. In the deep mesocosms, light levels were less than 50 μmol m^{-2} s^{-1} at depths over two meters and were probably too low to support *Egeria* growth. In May 2003 however, an *Egeria* stem was observed growing up to the surface in one of the deep mesocosms. Light levels may have been higher, high enough to support growth of any surviving *Egeria*, when the mesocosms were in a drained (0.3 m depth) condition from August 2002 to January 2003.

On May 1, eleven adult Threespine stickleback were added to each mesocosm. These fish were selected because they are naturally occurring in the Delta and they satisfied mosquito concerns of the County vector control district. *Gambusia* populations unexpectedly appeared in the mesocosms and it is not clear if these recruits got in with the Threespine stickleback, the river water, *Egeria* fragments or otherwise. Minnow traps were used to remove the fish from the mesocosms before draining. Trapping was stopped when fish were no longer caught. More *Gambusia* than threespine sticklebacks were caught in the traps. Some adult threespine sticklebacks died before trapping and were removed when found. Trapping did not completely remove all of the fish because additional threespine stickleback juveniles were caught in 2003.

3.2.4 Temperature and Dissolved Oxygen

Maximum and minimum water temperatures in the mesocosms were recorded every two weeks and ranged from 8 to 34 C during the study. Temperature changes between day and night were enough to keep the mesocosms from permanently stratifying. Diurnal stratification did develop in the mesocosms, especially on hot summer afternoons, but cool nights resulted in homogeneous temperatures and DO concentrations early in the morning. To simulate wave action and mixing on the surface of the reservoirs and to ensure dissolved oxygen (DO) concentrations remain high enough for fish, small aquarium air stones (4 cm-length x 1.3 cm width) were placed five cm under the water surface on the same day that the fish were added. On September 4, 2002 a kink in the air line to one of the short tanks was observed. Without aeration, DO concentrations dropped to 4.6 mg/L. After the kink was removed, DO concentrations returned to nearly saturated concentrations. Otherwise, the lowest DO concentration observed in the mesocosms was 5.7 mg/L and occurred before the aeration stones were installed. With aeration, DO concentrations remained close to or above saturation. The size and placement of the air stones were such that approximately the top 20 cm of water were mixed but mixed gently enough so not to disturb the sediment/water interface which was about 140 and 290 cm below the surface in the shallow and deep mesocosms, respectively. Low turbidity measurements through April and May show that the sediment was not stirred when the airstones were installed on May1, 2002 (Figure 3.2). As mentioned, the jump in turbidity following draining was probably due to the loss of head pressure and the observed gas bubbles escaping from the peat soil. Diurnal temperature stratification was less obvious after installation of the air stones but was still observed on hot afternoons.

3.2.5 Water Sampling

Water samples were taken from a depth of 0.3 m from each mesocosm every two weeks using a Van Dorn sampler. Samples were analyzed using standard methods by the Department of Water Resources Bryte Analytical Laboratory (http://wq.water.ca.gov/bryte/) for the following water quality parameters: Total Organic Carbon by combustion (TOC), Dissolved Organic Carbon by combustion (DOC), UV Absorbance at 254nm (UV254), Turbidity, pH, Total Mercury, Total Kjeldahl Nitrogen (TKN), Dissolved Ammonia, Dissolved Nitrite and Nitrate, Total phosphorus and Ortho-phosphate. In addition to these water quality measures, the following field data were collected at the time of sampling: Temperature, Dissolved Oxygen (DO) and Secchi Depth. Sub-samples of juvenile fish trapped in 2002 were analyzed for whole fish total mercury concentrations by the California Department of Fish and Game Water Pollution Control Laboratory in Rancho Cordova, California. These analyzed fish hatched in the mesocosms, were observed as fry and were later trapped and analyzed at a juvenile length of approximately two to three cm.

3.2.6 Salinity

Salinity in the mesocosms was not monitored in 2002. However, at the end of the study, specific conductance (SC) was 194 uS/cm in the deep mesocosms and 243 uS/cm in the shallow mesocosms. Specific conductance in the Sacramento River at West Sacramento ranges from 124 to 241 uS/cm, and is 161 uS/cm on average (DWR 2003). During the study period, March through December 2002, evaporation less precipitation was approximately 50 cm in the mesocosms. The water lost to evaporation was replaced with Sacramento River water collected from the same West Sacramento location. In the deep mesocosms which contain approximately 290 cm of water, this 50 cm of water loss is about 18% of the volume. Specific conductance of the water used to fill the mesocosms in early 2003 was about 170 uS/cm. Assuming a starting SC of 170 uS/cm, an 18% increase in SC would have resulted in an increase of SC from about 170 to 201 uS/cm, consistent with the measured SC at the end of the study which ranged from 180 to 204 uS/cm in the four mesocosms. Similarly in the shallow mesocosms which contain slightly less than half the water volume as the deep mesocosms, a 36% increase in SC would have resulted in an increase of SC from about 170 to 231 uS/cm, consistent with the measured SC at the end of the study which ranged from 234 to 257 uS/cm in the four mesocosms. Other factors that could have affected salinity include the potential release of salt from the soil and the fact that precipitation fell in the mesocosms not just when they were full but also when they were drained to a depth of one foot which would increase dilution of salts. Nevertheless, increases in salinity were consistent with what would be expected from evaporation and dramatic changes in salinity were not apparent.

3.3 Results and Discussion

Using mesocosms or physical models of the proposed reservoir islands allowed for a better understanding of some ecological processes that will influence project operations and be influenced by operations. Phytoplankton biomass at the time of reservoir release was lower than expected considering that nutrient rich agricultural peat soils were flooded. Further understanding of the mechanisms likely to control phytoplankton dynamics and the development of predictive models for the proposed reservoirs will require additional small, medium and large scale studies. Nutrient concentrations in the mesocosms are presented in Figures 3.4 through 3.8. Chlorophyll *a* and pheophytin *a* concentrations are presented in Figures 3.9 and 3.10, respectively. Zooplankton developed visible clusters in the clear-brown water of the mesocosms and may have controlled algal populations, but again many additional studies are needed, on many scales, to flesh out all the complex and interacting ecological processes controlling the processes of phytoplankton dynamics and their effects on the process of OC loading. Another factor, among many, that may be in part responsible for lower than expected phytoplankton contributions to OC concentrations could be a negative interaction between DOC and phytoplankton (Carpenter et al. 1998). Plate 3.4 shows a sample of the clear-brown, DOC rich, water in the mesocosms.

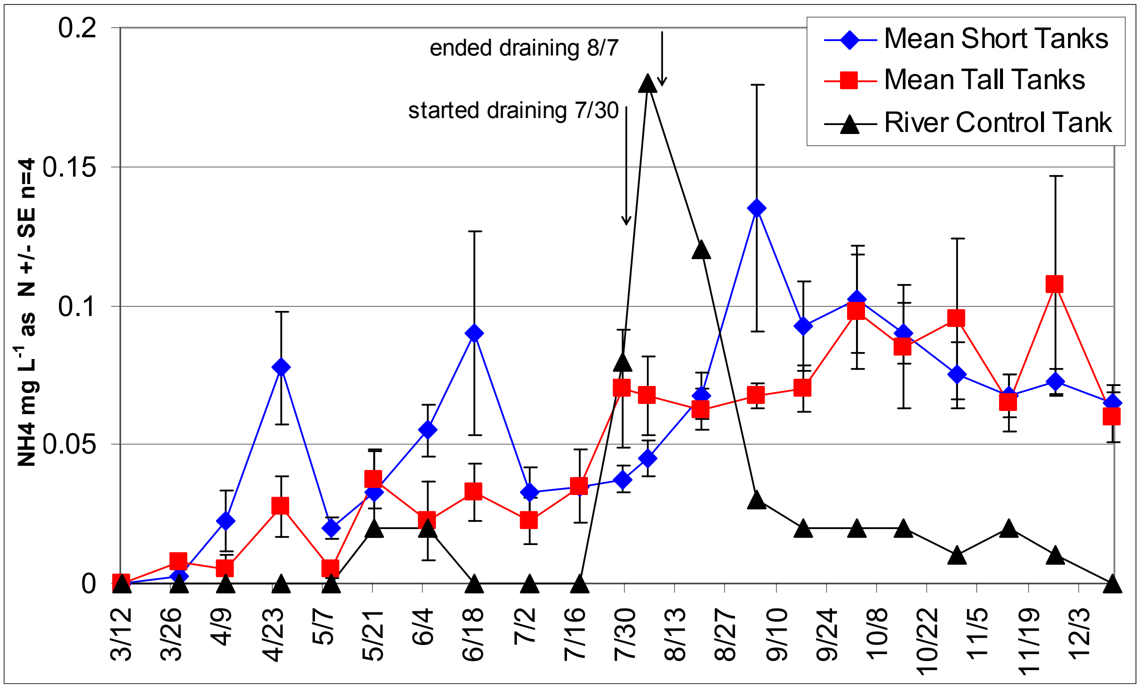

Figure 3.4: Mean Dissolved Ammonia in Mesocosms

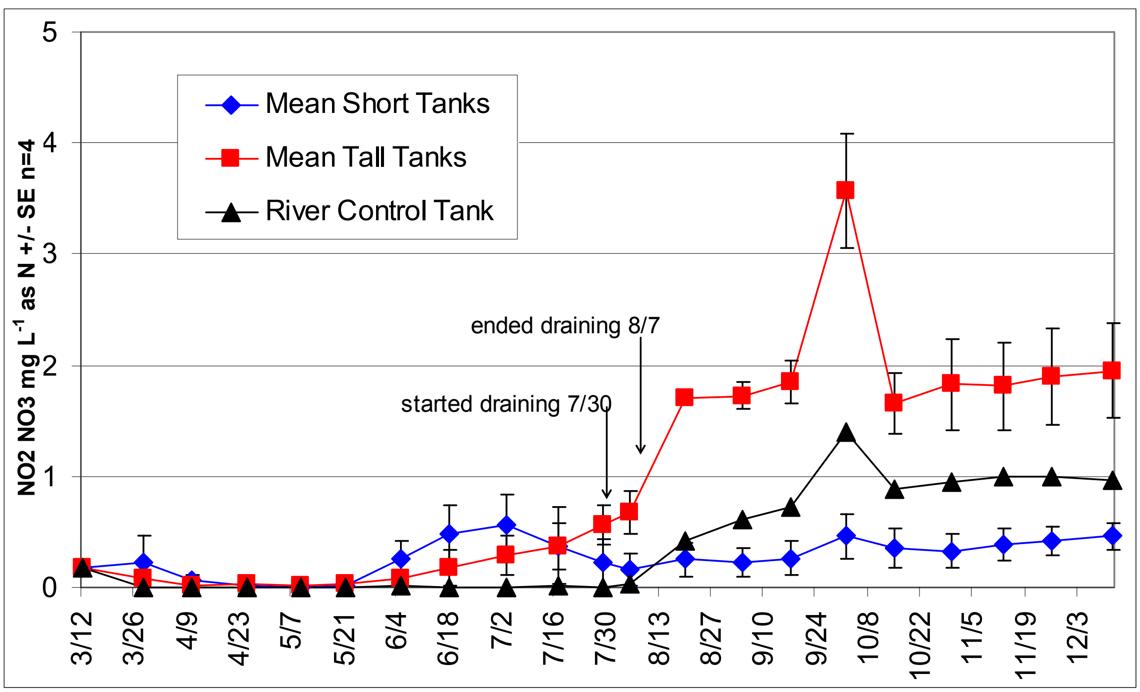

Figure 3.5: Mean Dissolved Nitrite and Nitrate in Mesocosms

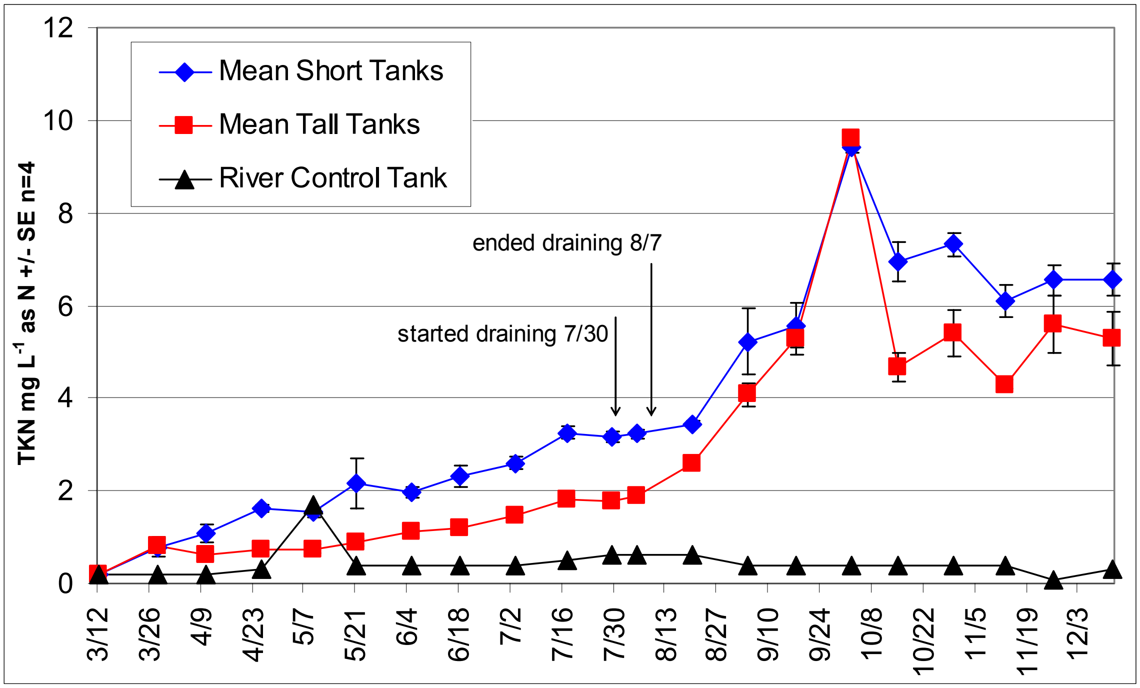

Figure 3.6: Mean TKN in Mesocosms

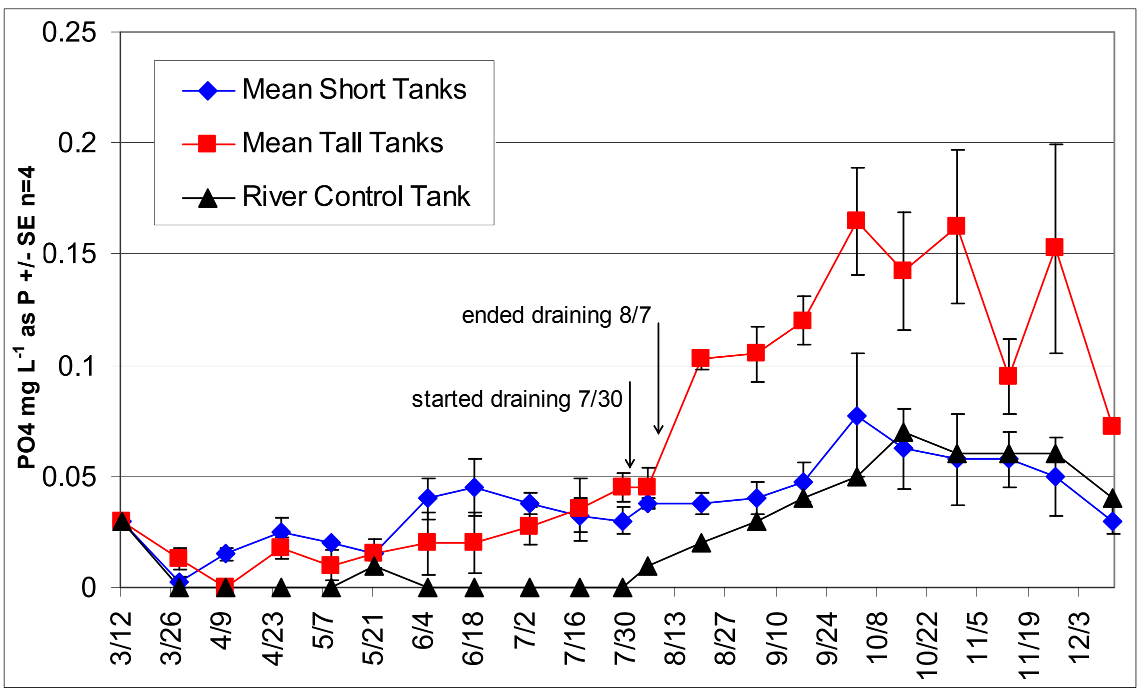

Figure 3.7: Mean Dissolved Orthophosphate in Mesocosms

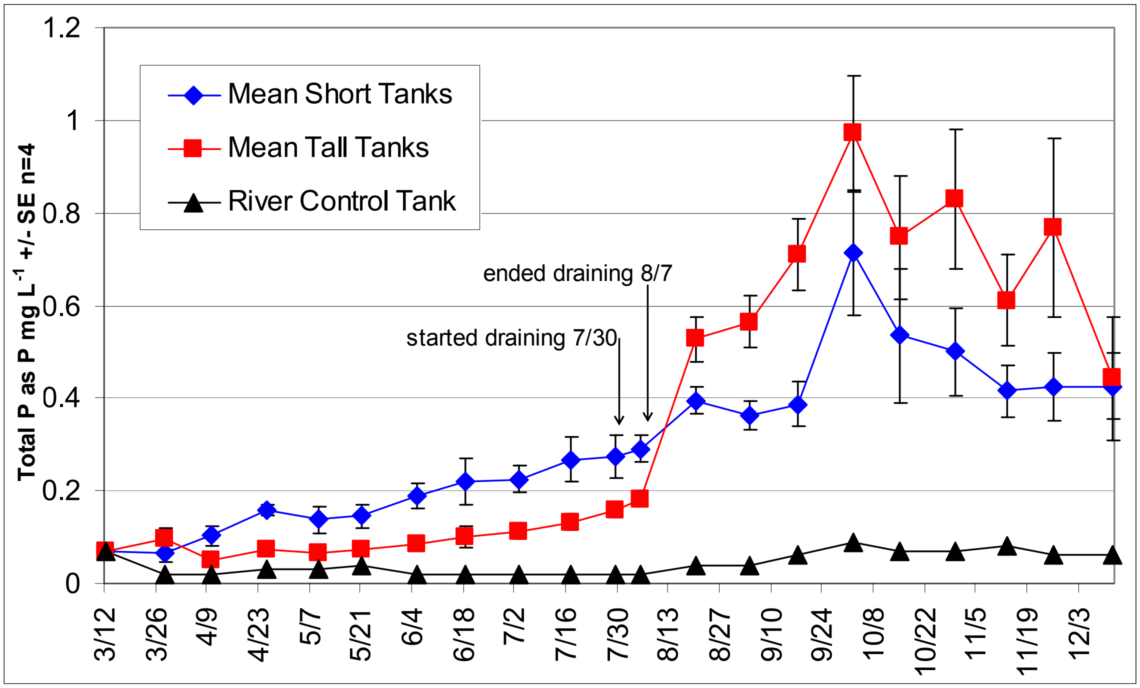

Figure 3.8: Mean Total Phosphorus in Mesocosms

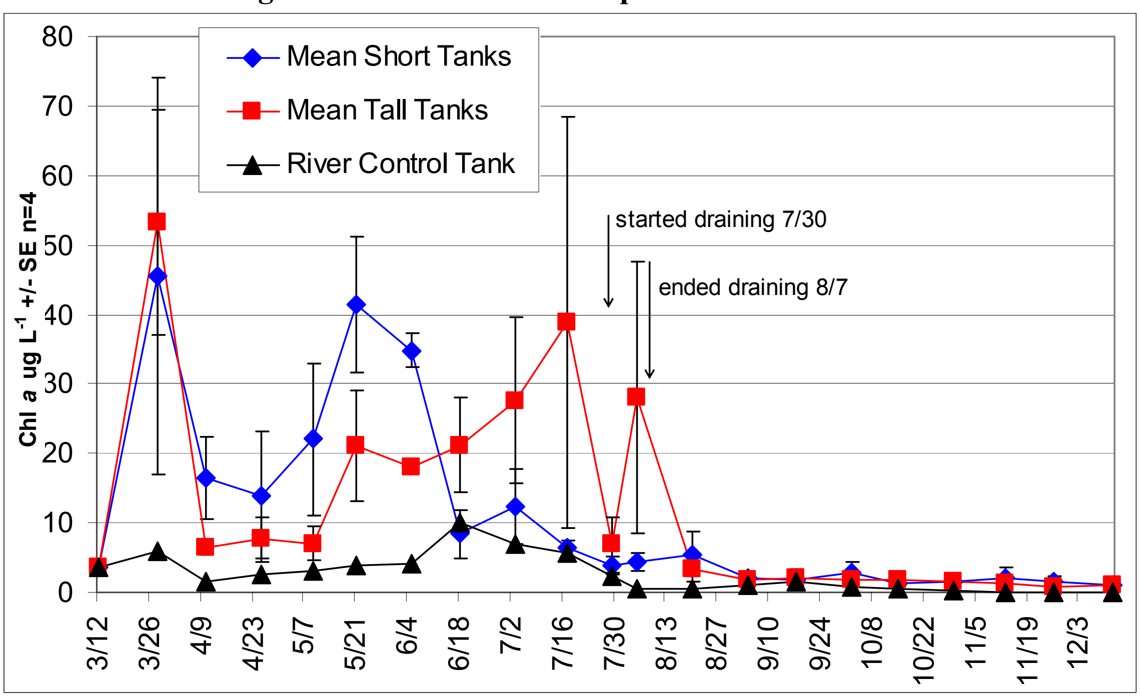

Figure 3.9: Mean Chlorophyll a Concentrations in Mesocosms

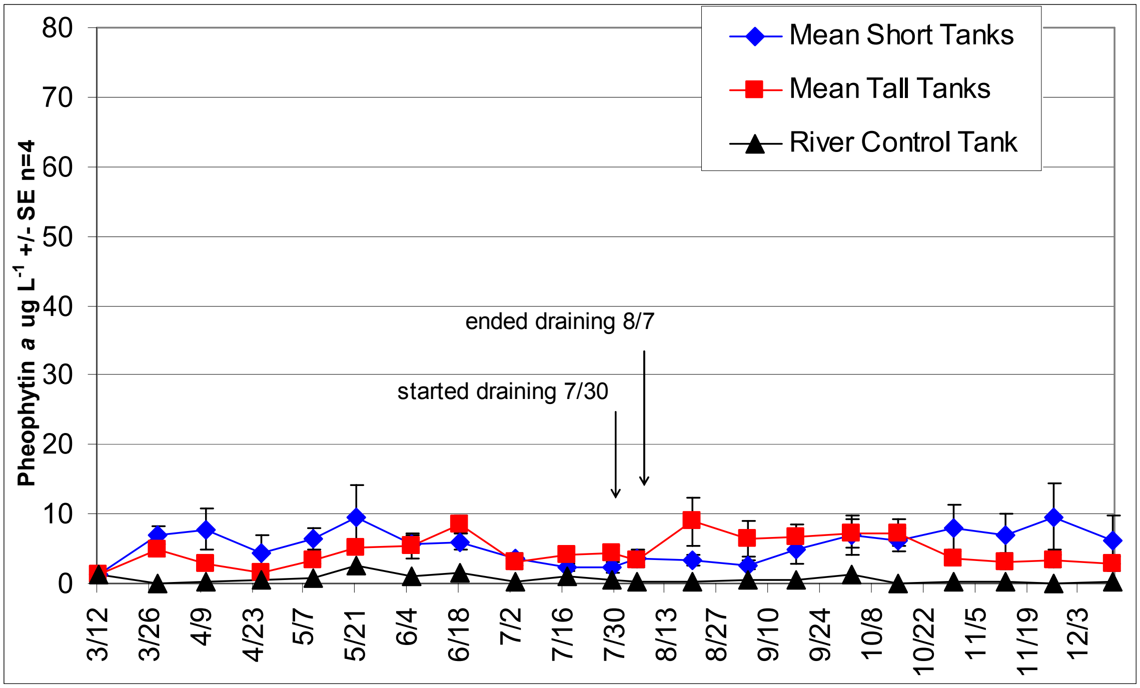

Figure 3.10: Mean Pheophytin a Concentrations in Mesocosms

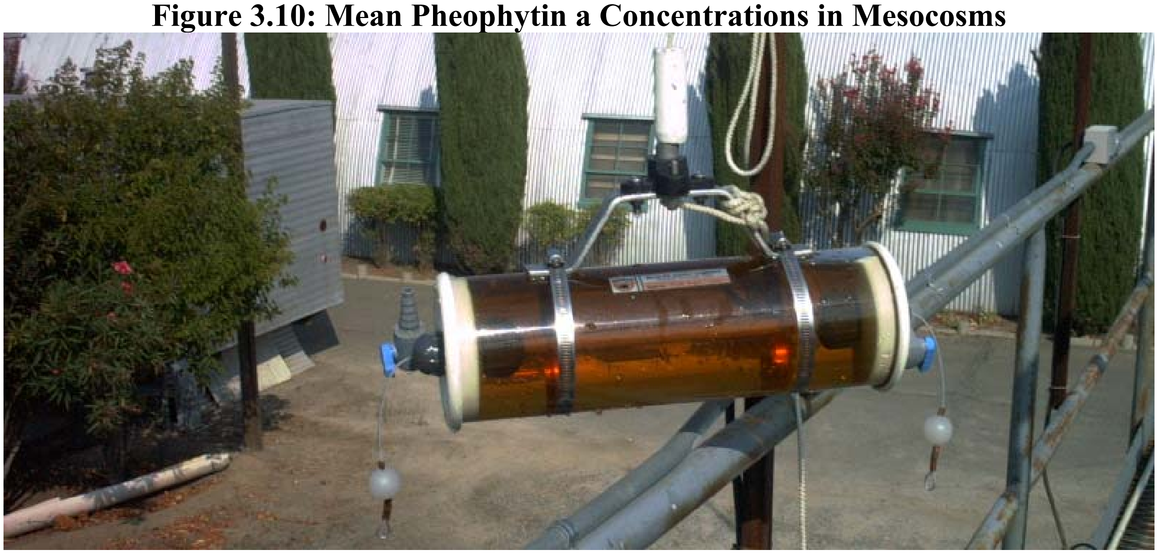

Plate 3.4: Sample of Mesocosm Water in the Van Dorn Sampler

3.3.1 Egeria densa

While Egeria appears to have increased OC loading rates, especially after the mesocosms were drained, differences between loading rates in the deep versus shallow mesocosms (Figures 3.14 trough 3.17) were not dramatic like the observed differences were between submersed macrophyte biomass. After draining, there was zero biomass observed in the deep mesocosms while dense beds of plants filled the shallow mesocosms (Plates 3.5 and 3.6). The plants were not destructively sampled for quantitative biomass measurements but there was so much *Egeria* that grew in the shallow mesocosms that terrestrial grass plant was able to get a root-hold and grow out of one of the shallow mesocosms (Plate 3.5). Similar loading rates between shallow and deep mesocosms despite dramatic differences in *Egeria* biomass (Figures 3.14 trough 3.17) suggest that peat soil is the overwhelming source of OC loading.

3.3.2 Organic Carbon

Figures 3.11 through 3.13 show the mean TOC, DOC and POC concentrations in the mesocosms during the study. The TOC loading rates presented in Figures 3.14 through 3.17 were calculated by standardizing the rate of TOC concentration increase over time to a one meter water depth by multiplying by the water depth in the mesocosms. This calculation removed the effect of dilution by depth and produced aerial loading rates. DOC loading rates (not shown) calculated the same way were almost identical to those calculated from TOC concentrations. The low concentrations of POC shown in Figure 3.13 were indirect measures, calculated as the difference between TOC and DOC. Nevertheless, chlorophyll *a* and pheophytin *a* concentrations were also low relative to the high OC concentrations in the water and further suggest that the peat soil was the dominant source of OC loading in the mesocosms. Observations from 2003 suggest that *Egeria* biomass is increasing relative to 2002 and results may show that biological productivity has a larger contribution to OC loading in years following initial flooding. DOC has been extracted from water from the both shallow and deep mesocosms for carbon dating and should be another indirect tool for comparing loading from peat vs. primary productivity. Results from the carbon dating are expected soon.

Plate 3.5: Inside one of the Shallow Mesocosms after draining
(Note the dense bed of *Egeria* and the grass growing at the surface of the water (not in the soil) supported by the Egeria)

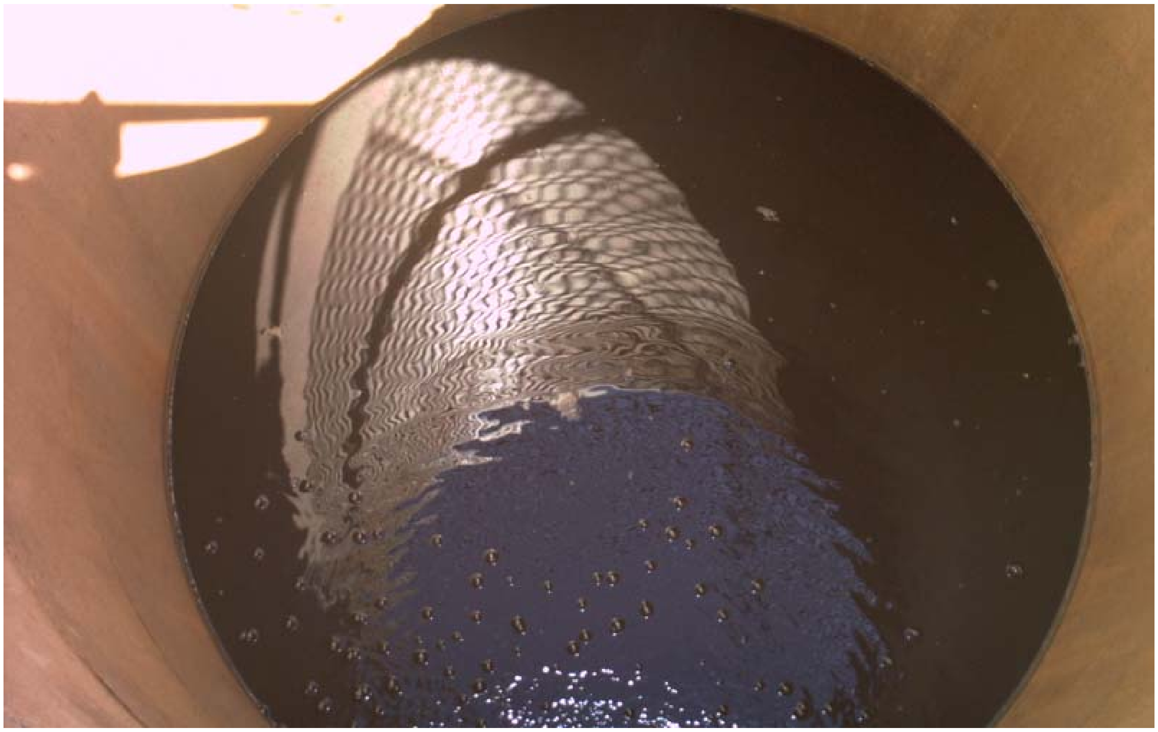

Plate 3.6: Inside of a Deep Mesocosm after Draining to a Depth of 0.3 m

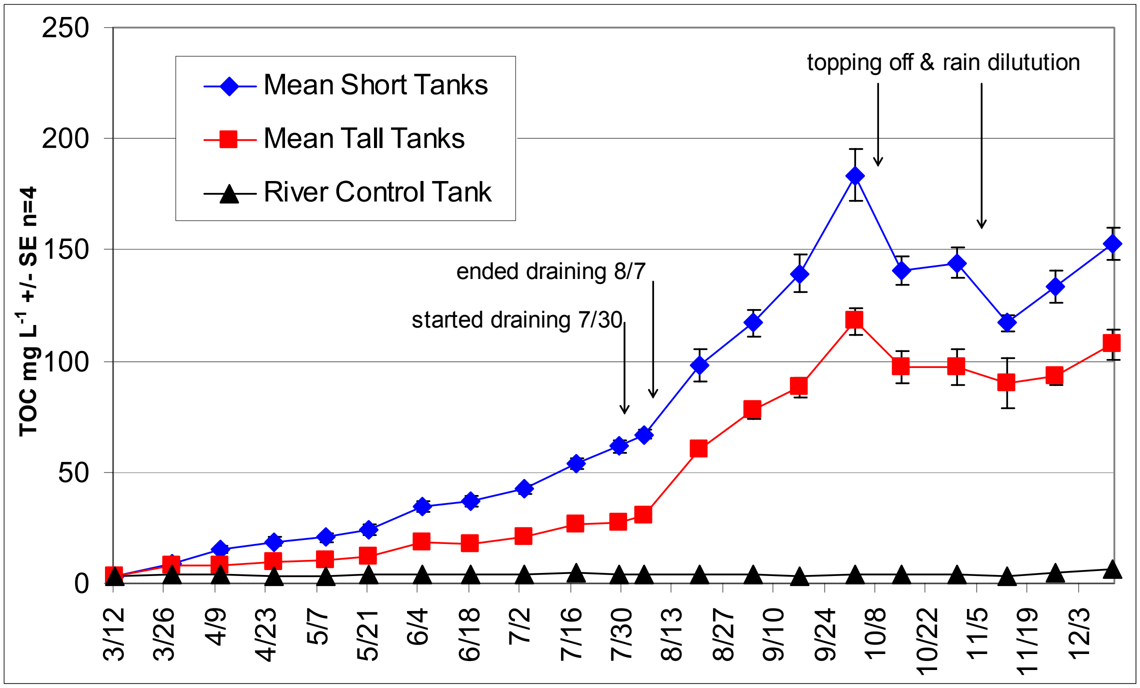

Figure 3.11: Mean TOC Concentrations in the Mesocosms

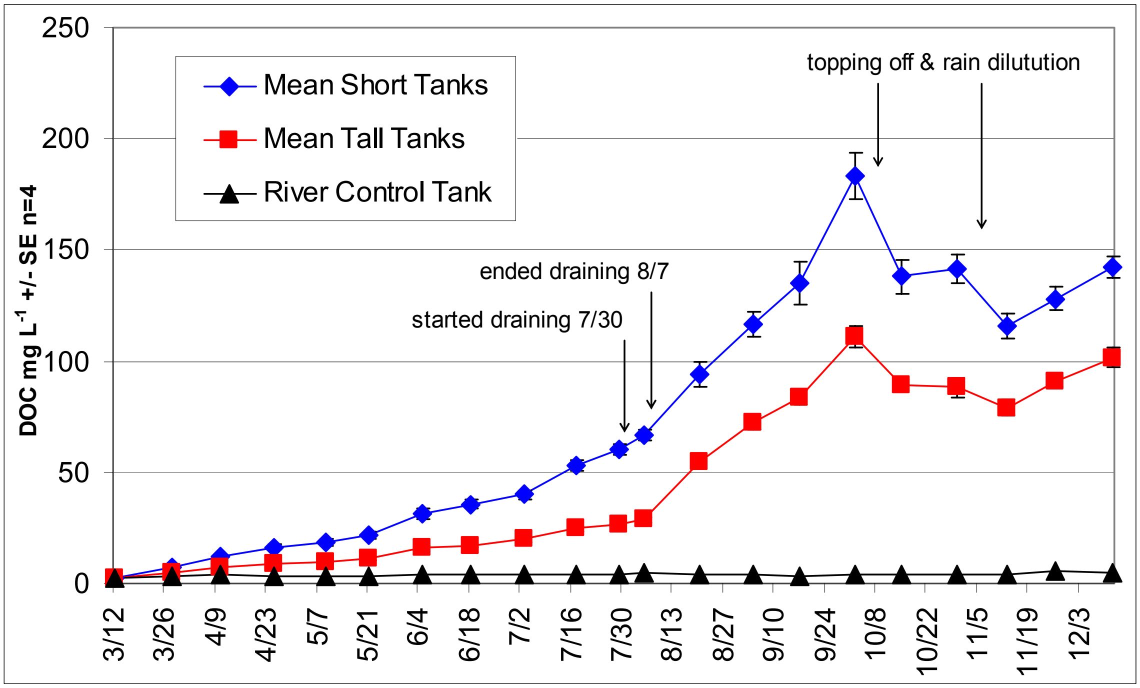

Figure 3.12: Mean DOC Concentrations in Mesocosms

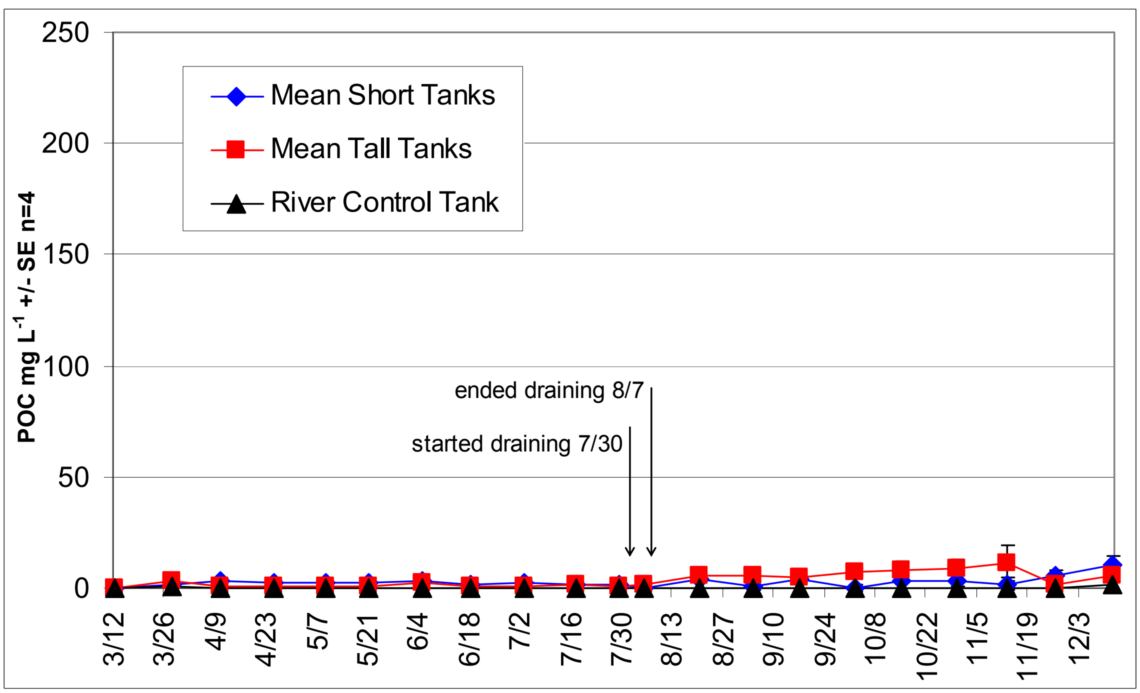

Figure 3.13: Mean POC Concentrations in Mesocosms

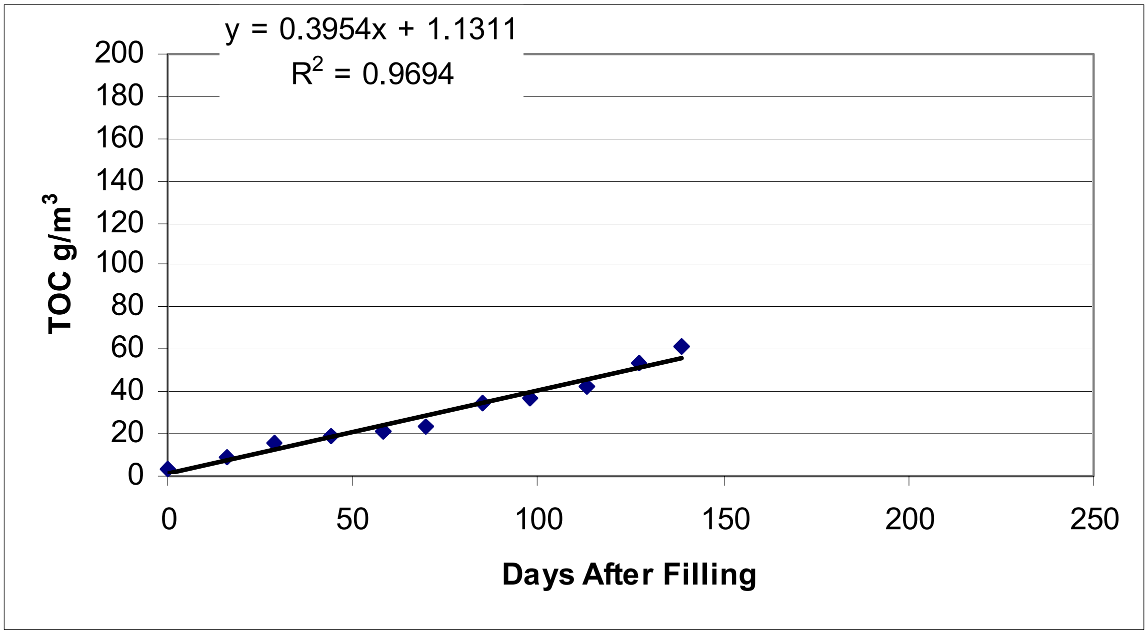

Figure 3.14: Total Organic Carbon in full Shallow, 1.4 m, Mesocosms
(Note: Standardized for 1 meter, m*1.4 = 0.554 gC/m2/d.)

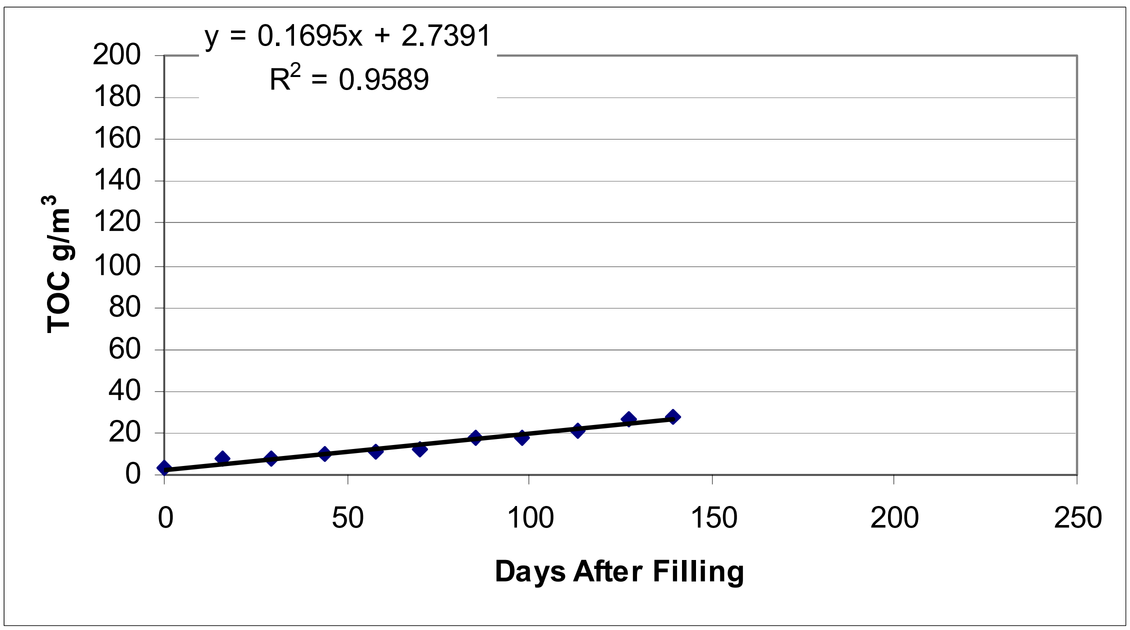

Figure 3.15: Total Organic Carbon in Full Deep, 2.9 m, Mesocosms
(Note: Standardized for 1 meter, m*2.9 = 0.492 gC/m2/d)

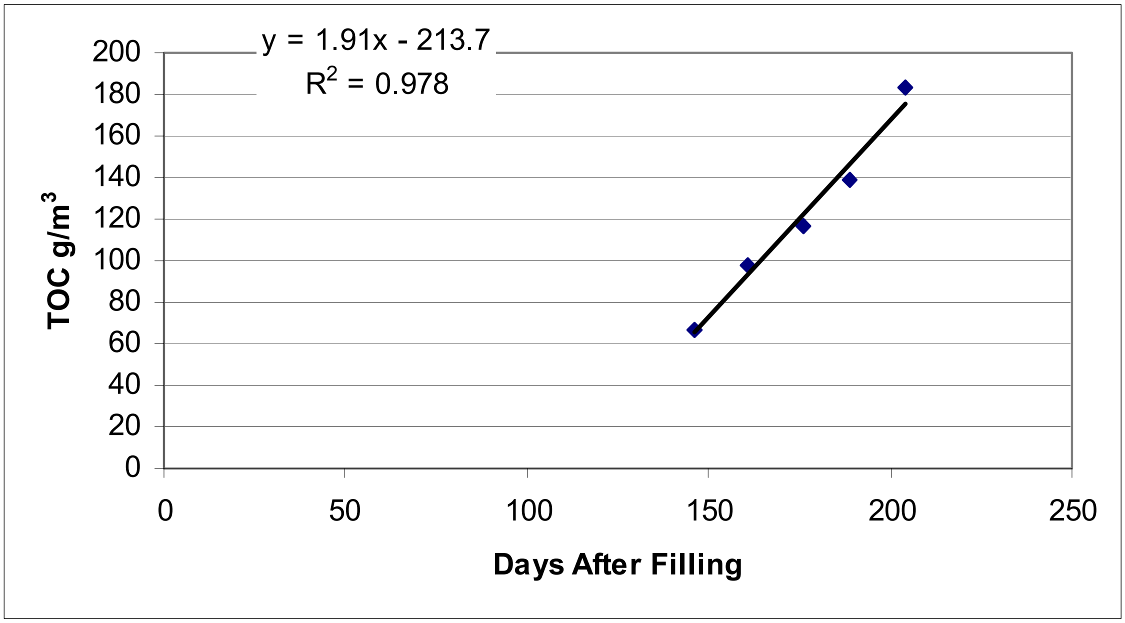

Figure 3.16a: Total Organic Carbon in drained shallow, 0.3 m, Mesocosms
(Note: Standardized for 1 meter, m*0.3 = 0.573 gC/m2/d)

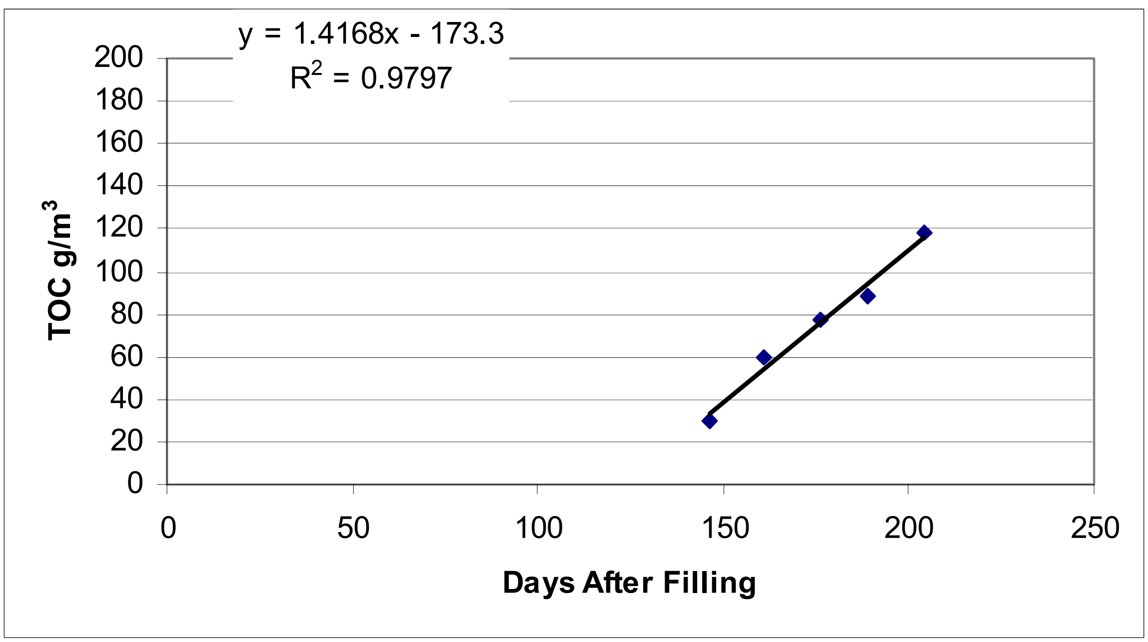

Figure 3.16b: Total Organic Carbon in Drained Deep, 0.3 m, Mesocosms
(Note: Standardized for 1 meter, m*0.3 = 0.425 gC/m2/d)

3.3.3 Precipitation and Evaporation

Rain falling in the mesocosms (Figure 3.3) from November 7th through November 10^{th} had a noticeable dilution effect on water quality in the drained mesocosms (Figures 3.11 and 3.12). A similar amount of rain fell in May but had a minor if noticeable effect on water quality because the mesocosms were full then. The November rain was about 10% of the volume of the drained mesocosms but in May when mesocosms were full this amount of rain was only about 1 % of the volume of the water in the full mesocosms. Similarly, dilution effects from topping off the mesocosms to make up for evaporation losses are obvious when the mesocosms were drained to a depth on 0.3 m but not apparent when the mesocosms were full.

3.3.4 Mercury

Mean total mercury (Hg) concentrations in fish from the mesocosms were 0.03 ug/g (ppm) for threespine stickleback samples and 0.01 ug/g for *Gambusia* samples collected from the mesocosms. The detection limit was 0.01 ug/g. All the fish analyzed were born and reared in the mesocosms and were approximately three months old when collected. Total Hg analyses of mesocosm water never resulted in detection of Hg but the detection limit was 0.2 ug/L. This detection limit is probably an order of magnitude above the concentrations at which methylmercury dynamics operate in the Delta.

3.3.5 Biological Productivity

The treatment variable in this study was water depth. Varying water depth and hence the light available for submersed macrophyte growth facilitated the identification of the effects of submersed macrophytes on the process of organic carbon loading. The mechanism controlling macrophytes and their effects on water quality was light attenuation. Submersed macrophytes were not destructively harvested in this study because it is a multiple year study. Nevertheless qualitative and quantitative descriptions of the *Egeria* productivity are possible. Approximately 100% of the surface area of the shallow mesocosms became covered with *Egeria* by the end of July when the mesocosms were drained to simulate reservoir discharge while 0% or no *Egeria* was observed in the deep mesocosms before or after draining (Plates 3.5 and 3.6, respectively). Published data on the standing biomass of submersed vegetation vary widely because of inconsistencies in excluding or including underground organs, epiphytic algae and inorganic matter. However a reasonable range for estimates of submersed macrophyte biomass for species such as *Ceratophyllum demersum, Potamogeton pectinatus* is about 100 g d.w. m^{-2} to 1000 g d.w. m^{-2} (Sculthorpe 1967). In the spring and early summer of 1996, Anderson et al. 1996 measured *Egeria* in Sandmound Slough and Seven Mile Slough by physically removing *Egeria* from under a quadrant. Their measurements were about, 1800 g d.w. m^{-2} and 2100 g d.w. m^{-2} respectively, and suggest that *Egeria* biomass in the Delta is at the upper end or above Sculthorpe's range. Filamentous algae and periphyton growing intertwined in the plant beds and on the plants can result in higher biomass estimates however. By early August 2002 when the mesocosms were drained, *Egeria* biomass was probably around 200 to 300 g d.w. m^{-2}.

Higher OC loading rates were observed in the mesocosms with *Egeria* but a linear relationship between DOC and TTHMFP (Figure 3.17) suggests that peat soil and not primary productivity was the overwhelming, or effectively the single source, of OC. A linear relationship between DOC and THMFP has been related to a single source of OC because OC from vegetation has two to five times higher THM reactivity than other sources of OC, such as peat, in reservoirs (USGS 2001). Changes in formation potential for TTHM, chloroform and bromodichloromethane are shown in Figures 3.18 and 3.19. However, a problem was identified in the data used to generate Figures 3.17 through 3.20. Samples collected before October 15, 2002 were not properly diluted by the analytical lab before dosing with chlorine and at least some THMFP data are suspect (Agee 2003 personal communication). Without proper dilution, all of the chlorine is used up and the THMF maxes out prematurely. A flat spot in the data from August 20 through October 2, 2002 is obvious in Figures 3.18 and 3.19. These data were not used in the DOC and TTHMFP regression (Figure 3.17). Analyses completed before August 20, 2002 appear to be valid because they were in the 'transition zone' where the method might have worked, but were above the prescribed DOC concentration of 10 mg/L and should be considered invalid. Figure 3.21 shows TTHMFP data only for samples collected October 15, 2002 or later when proper dilutions were made by the lab prior to chlorination. Other researchers have identified a problem with the dose-based method for THMFP analysis because results are highly dependent on sample dilution (Fujii et al. 1997). Mean dilutions used by the analytical lab are presented in Figure 3.22.

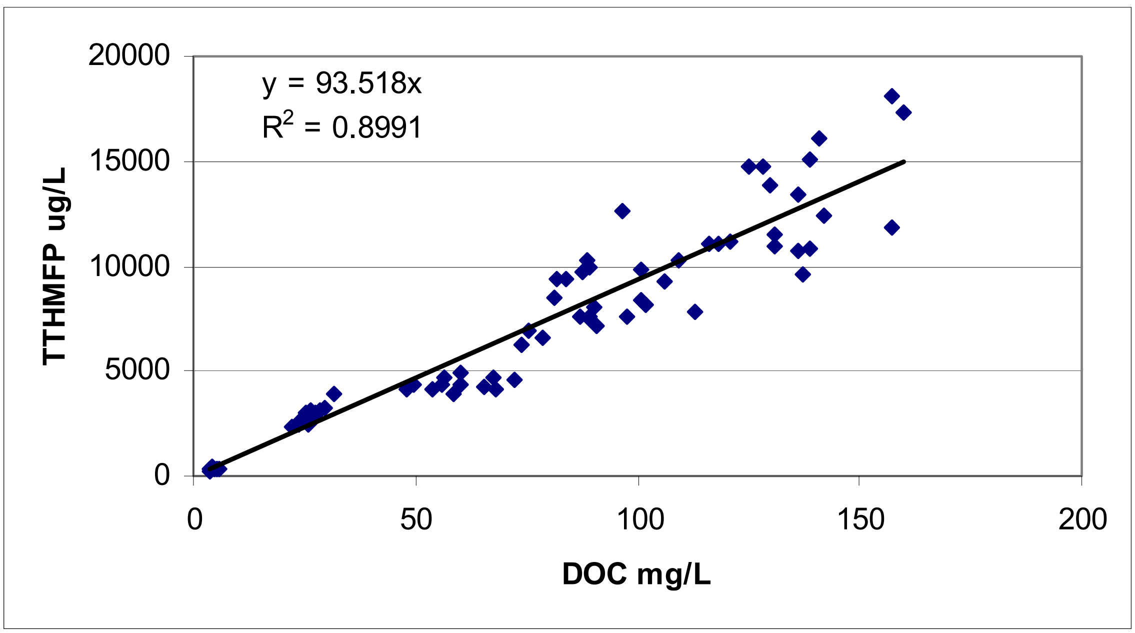

Figure 3.17: Relationship between THMFP and DOC for Mesocosms Water

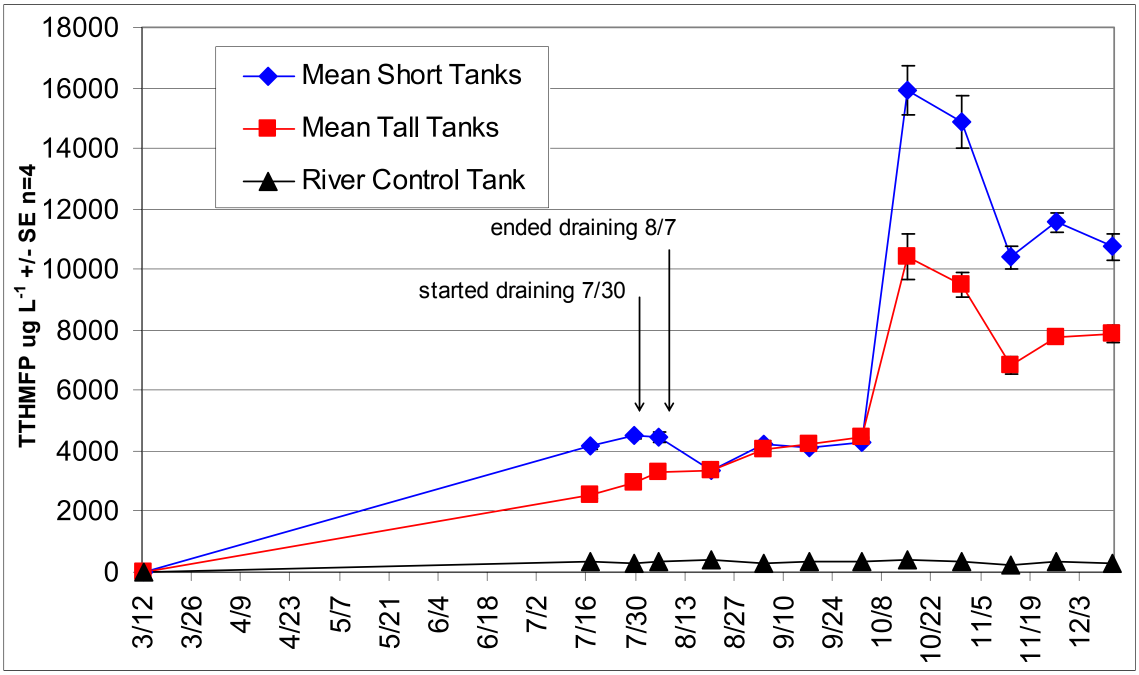

Figure 3.18: TTHMFP for Mesocosm Water

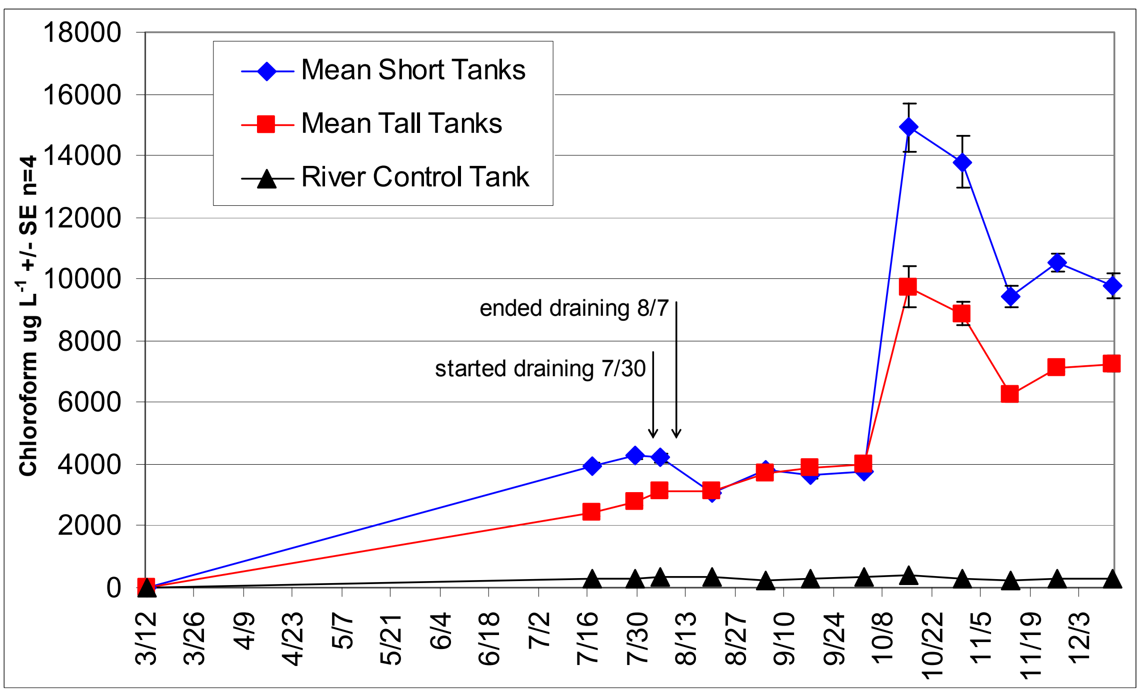

Figure 3.19: Chloroform Formation Potential for Mesocosm Water

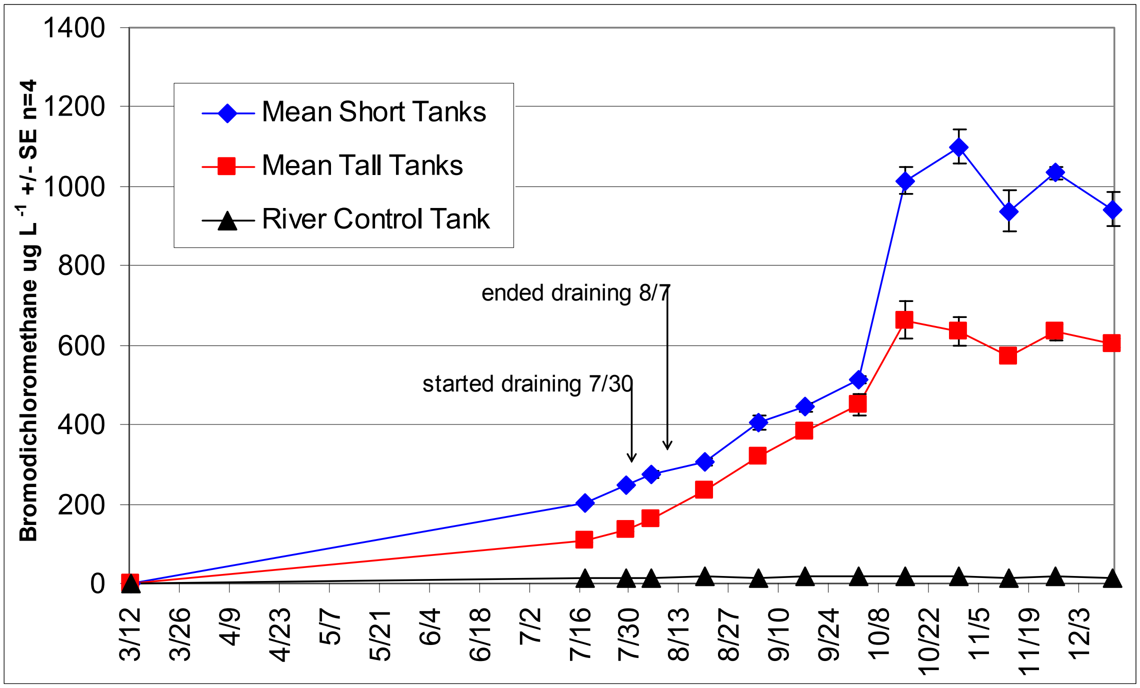

Figure 3.20: Bromodichloromethane Formation Potential for Mesocosm Water

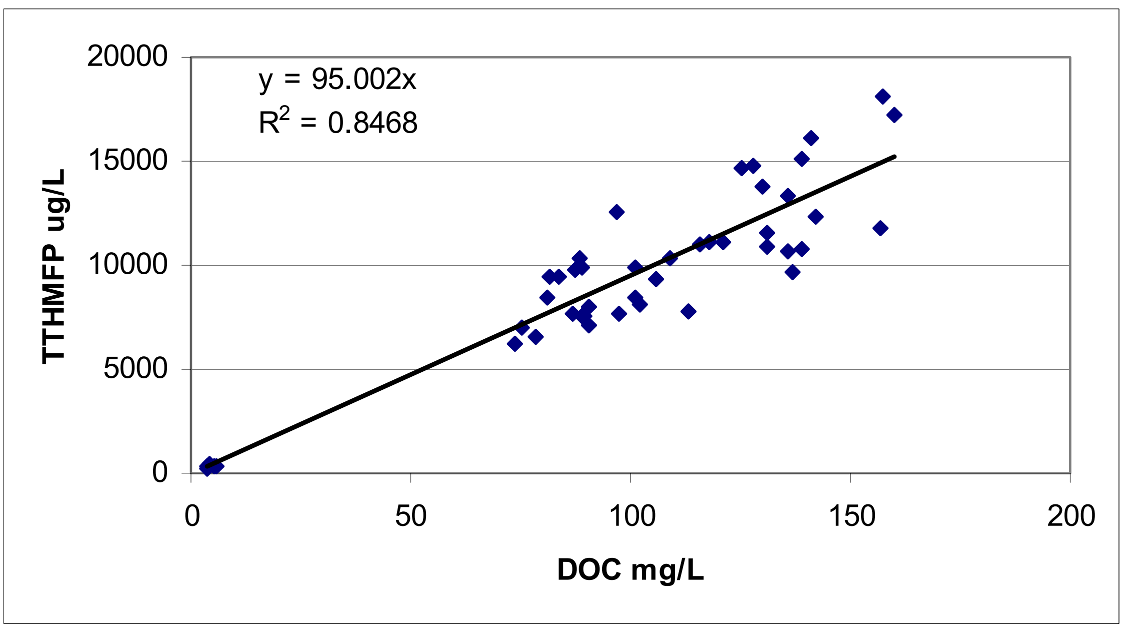

Figure 3.21: Relationship between DOC and TTHMFP
(Note only for samples collected October 15, 2002 or later)

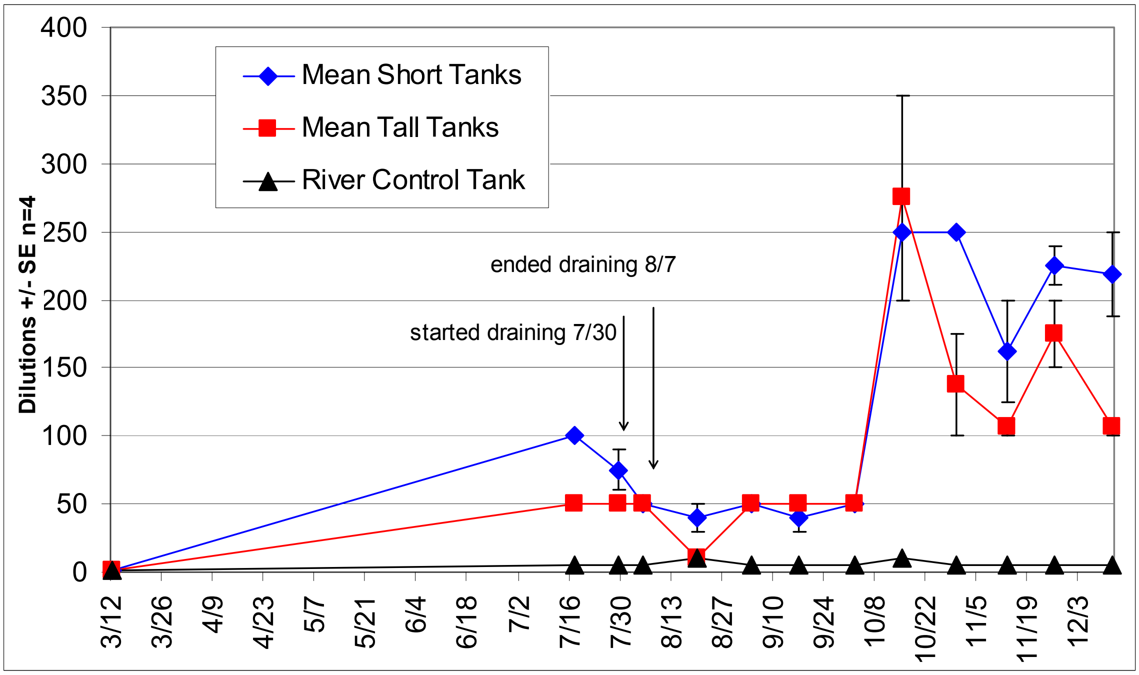

Figure 3:22: Mean Dilutions used in Analyses of THMFP

3.3.6 Trihalomethane Formation Potential

Despite the problem with the THMFP analysis, the linear relationship between DOC and TTHMFP shown in Figures 3.18 and 3.21 is strong (r^2 = 0.899 and 0.847) and suggests that the peat soil was effectively the single source of OC (USGS 1998). There might be indirect mechanisms that can explain why *Egeria* appeared to increase carbon loading but not result in a non-linear increase in THMFP. The *Egeria* could have facilitated higher peat-derived DOC loading by oxidizing the peat soil near the soil-water interface or otherwise increasing microbial activity or degradation of the peat. Labile *Egeria* exudates or decomposing biomass may have been rapidly metabolized by bacteria and not been a mechanism responsible for higher DOC concentrations in the mesocosms with *Egeria*. Similarly, bacteria may have used phytoplankton exudates and prevented phytoplankton from increasing OC loading relative to the peat soil. Kamjunke et al. (1997) found that phytoplankton exudation, not allochthonous DOC can be the main source of DOC used by bacteria in eutrophic waters. This phytoplankton derived DOC may be easily and rapidly consumed by bacteria and therefore not contribute significantly to overall OC loading relative to peat soil.

3.3.7 Phytoplankton

Phytoplankton productivity or biomass might also have been limited by the high concentrations of DOC. Carpenter et al. (1998) showed that increasing DOC concentrations substantially reduce chlorophyll concentrations, primary production and their variability. Bioavaliable POC in the Delta is derived primarily from autochthonous phytoplankton production but this production is a small component of the ecosystems mass balance (Sobczak et al. 2002). Phytoplankton-derived DOC is probably an important source of bioavaliable carbon to bacteria in the Delta but may also be ephemeral and in short supply. Therefore, phytoplankton in the mesocosms, in the proposed reservoir islands and in the Delta may not be a significant source of OC loading relative to peat soil. Nutrient supply is another factor that affects phytoplankton dynamics and OC loading. Additional studies are needed to further identify and quantify the complex and interacting sources of OC.

3.3.8 Specific Ultraviolet Absorbance

Specific ultraviolet absorbance (SUVA) is calculated by dividing ultraviolet absorbance (UVA) by DOC and provides information about the aromatic structure of DOC in water (USGS 1998). UVA and SUVA results are shown in Figure 3.23 and 3.24, respectively. There was another problem at the analytical lab, this time in the measurement of UVA. During July and early August, samples were not properly diluted before analysis and again resulted in readings that were too low. This problem primarily effected samples from the shallow mesocosms. Only one data point was compromised in the deep mesocosm series. It was possible to interpolate estimates for the bad readings from the relationship between UVA and DOC concentrations (Figure 3.25). The bad data points are shown by the missing UVA and DOC data around 3 abs/cm and mg/L in Figure 3.26. Interpolated estimates were used to create the data points identified by four pointed stars in Figure 3.23. The actual and estimated data were then used to generate the SUVA data shown in Figure 3.24. Mean SUVA values were similar between the deep and shallow mesocosms and remained relatively constant during the study. However, SUVA values were dramatically lower in the river water only mesocosm.

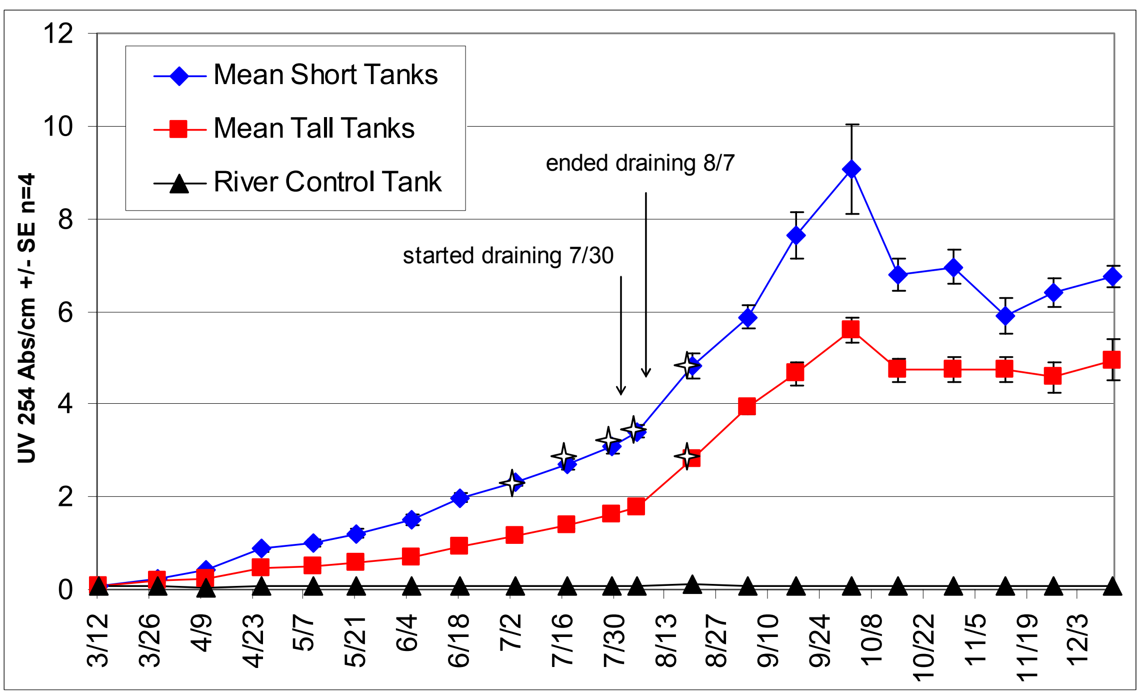

Figure 3.23: UV 254nm Absorbance
(Note estimated data indicated by four-pointed stars)

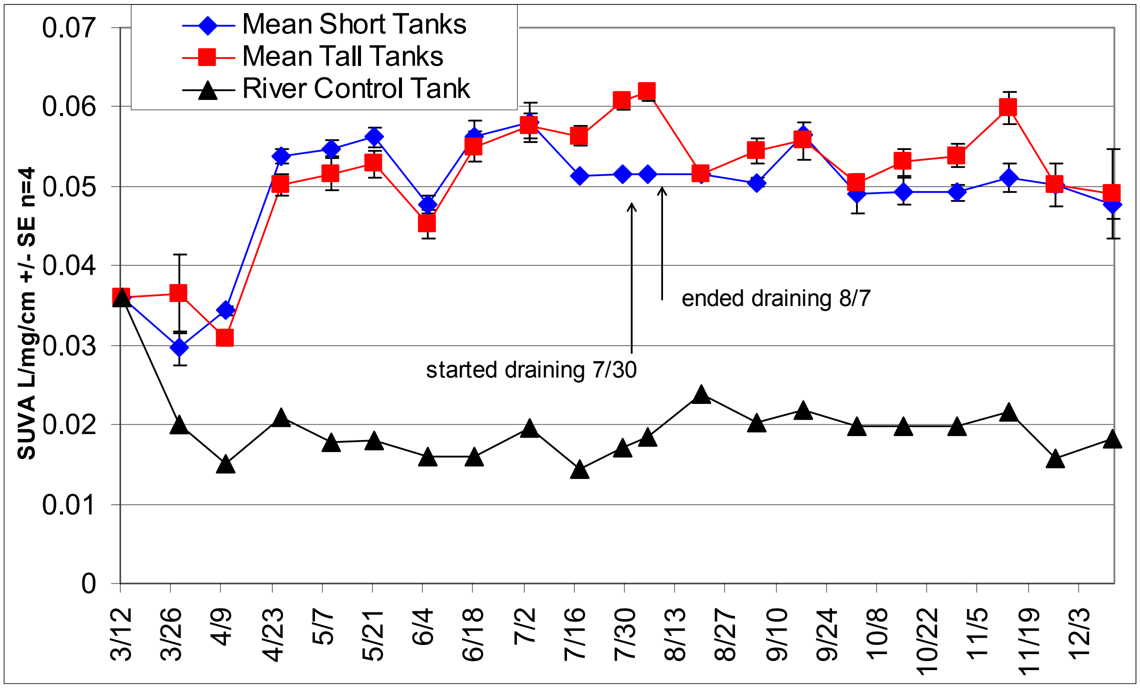

Figure 3.24: Mean Specific UV Absorbance (UVA/DOC)

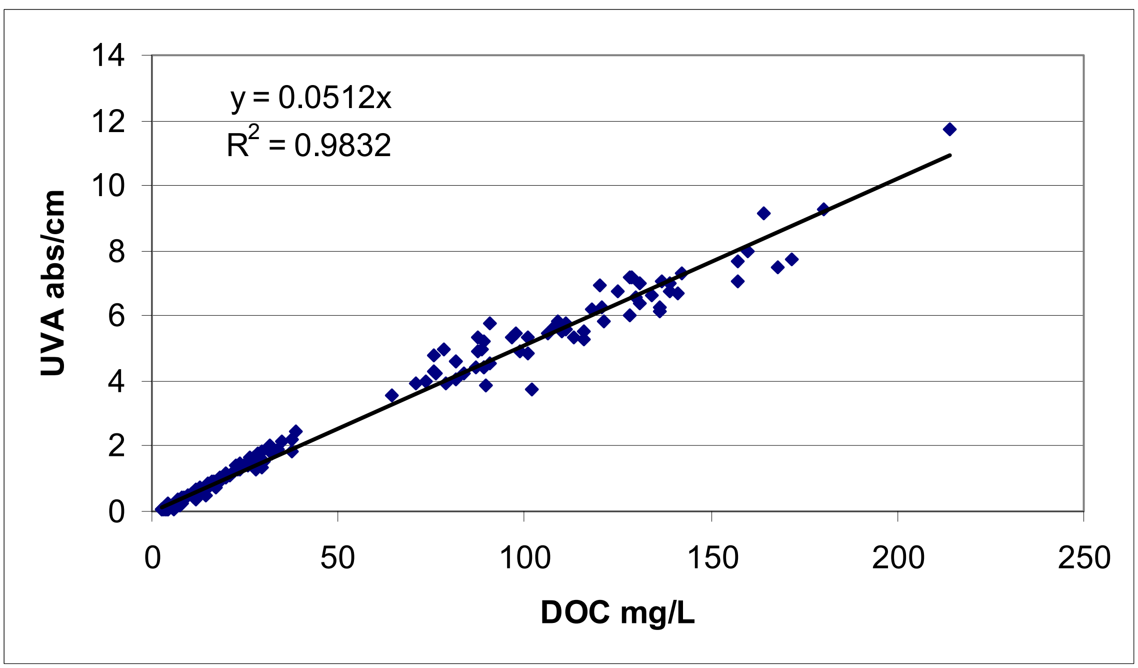

Figure 3.25: Relationship between UVA and DOC for Mesocosm Water

The relationship between UVA and TTHMFP is also linear (Figure 3.26). If the TTHMFP data that were identified as potentially invalid, those data for before October 15, 2002, are removed from Figure 3.27 the relationship stays mostly the same but the r^2

value declines slightly from 0.884 to 0.82 but the linear relationship does not change (Figure 3.27). The strong linear relationships between THMFP and DOC and UVA together with the lack of a linear relationship between SUVA and STTHMFP (Figure 3.29) provide both quantitative and qualitative information about the processes of OC loading that will be important to the in-Delta storage. These relationships suggest that not only was DOC overwhelmingly from a single source, the peat soil, but also that non-aromatic forms of DOC were probably the dominant THM precursors in the water (USGS 1998).

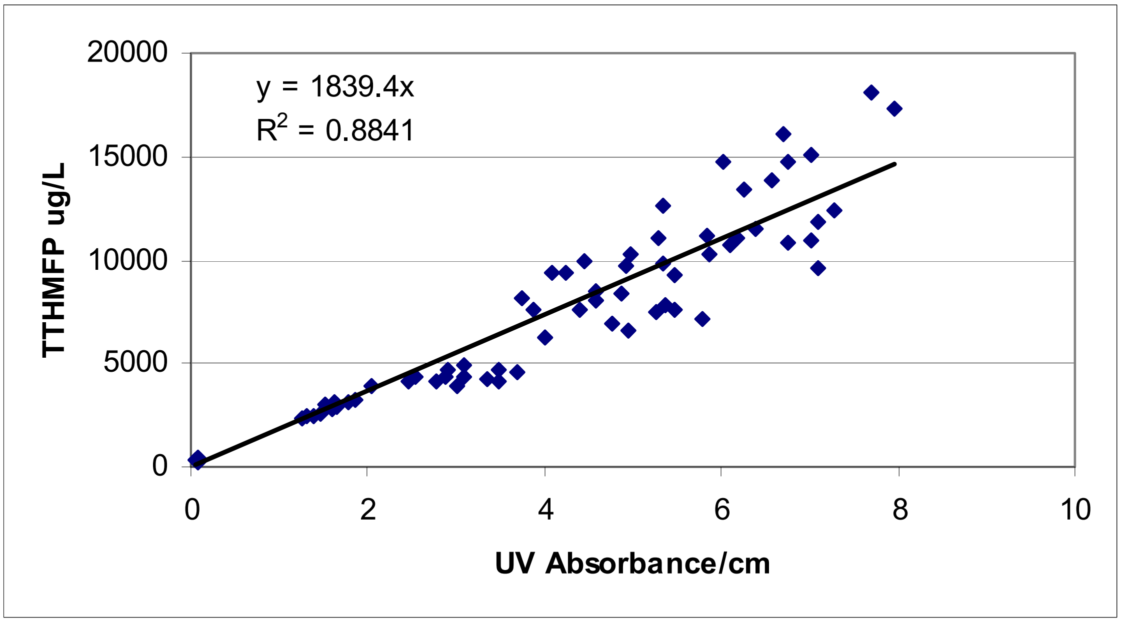

Figure 3.26: Relationship between UV Absorbance and THMFP

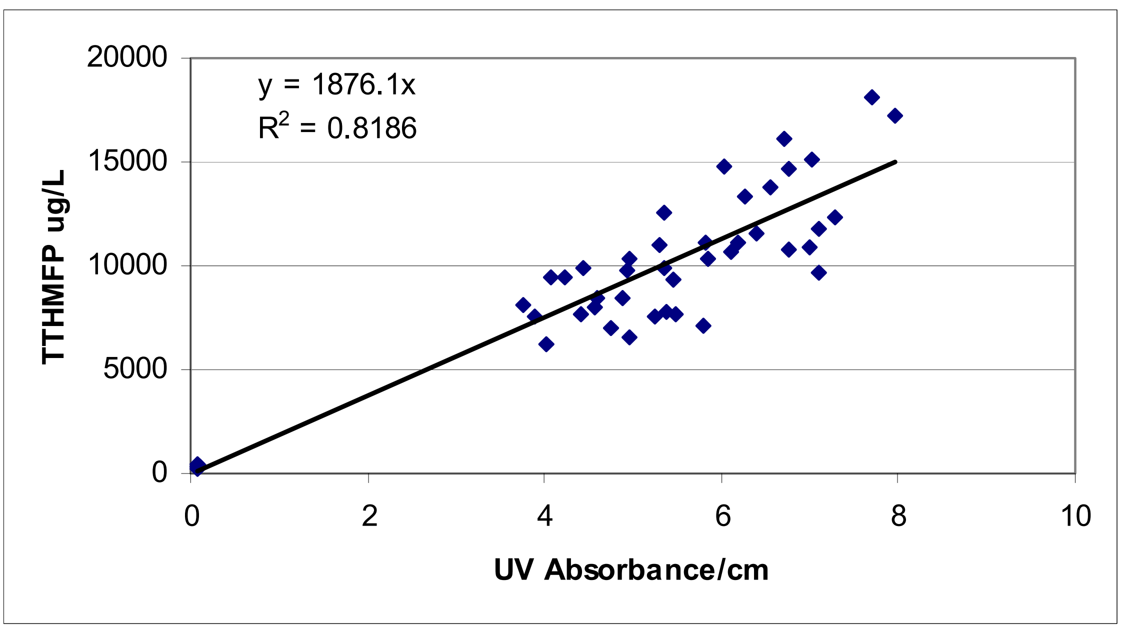

Figure 3.27: Relationship between UV Absorbance and THMFP
(Note: using only data from October 15, 2002 or later)

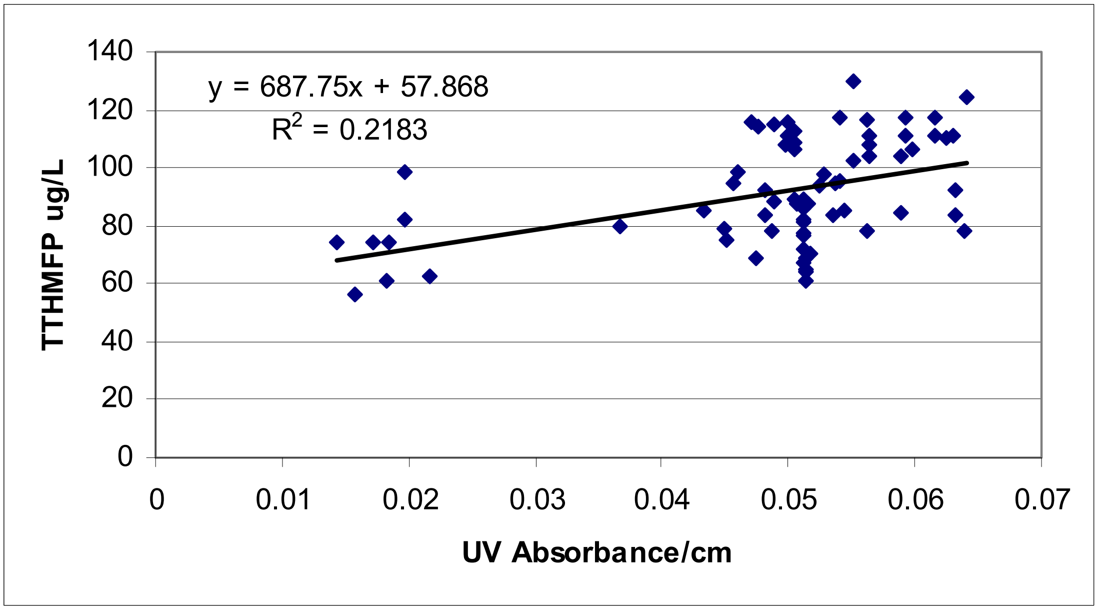

Figure 3.28: Relationship between SUVA and STTHMFP

In the 2003 study, the new circulation operation for the reservoir islands was simulated in the operation of the mesocosms. Figure 3.29 shows DOC concentrations in the mesocosm water (preliminary data). Declines in DOC are due to dilution from filling and circulation. The tanks were filled in thirds over a three month period starting in January 2003. For example if there was 2.1 m head space at the beginning of the study in late January, 0.7 m or 1/3 of the storage capacity was added. Then at the end of February the second third (0.7 m) was added and at the end of March the final third was added and the mesocosms were then full. The percent (%) of water circulated or exchanged in the mesocosms is shown by the arrows in Figure 3.29. For example, if there was one meter of water in a mesocosm and 0.25 meters of water was drained and replaced with Sacramento River water this was a 25% circulation. Figure 3.29 shows relatively flat organic carbon concentrations during the March through July storage period because the exchange or circulation rate was approximately in balance with OC loading rates.

While the circulation operation in 2003 was different than 2002 mesocosm hydrology, preliminary results from the 2003 study suggest that organic carbon loading rates are consistent with 2002 rates. Also, little POC was observed in 2003 as in 2002 i.e., the TOC:DOC ratio appears to be close to one in both years (TOC and other water quality data have not yet been fully tabulated and analyzed). Figure 3.30 shows the DOC concentrations during the March through July storage period as in Figure 3.29 but standardized to a one meter water depth to account for dilution effects from refilling and circulation operations. These preliminary data are consistent with the OC loading algorithm used in DSM2**.** The OC loading algorithm as implemented in DSM2 assumed a zero rate for OC loading in the winter months. The preliminary 2003 data shown in Figure 3.31 for the winter months of January and February are also consistent with this assumption. After the tanks were drained to a depth of 0.3 meters water was no longer circulated, i.e. the mesocosm hydrology was the same as in 2002 after draining. Therefore, the 2003 January-February data do not need to be standardized for comparison with 2002 data. Figure 3.32 shows DOC concentrations as measured (not transformed) for the non-storage or drained period. Again, preliminary 2003 results are consistent with the OC growth rate developed from the 2002 study. Additional 2003 data like trihalomethane formation potential and UV absorbance have not yet been analyzed for the 2003 data.

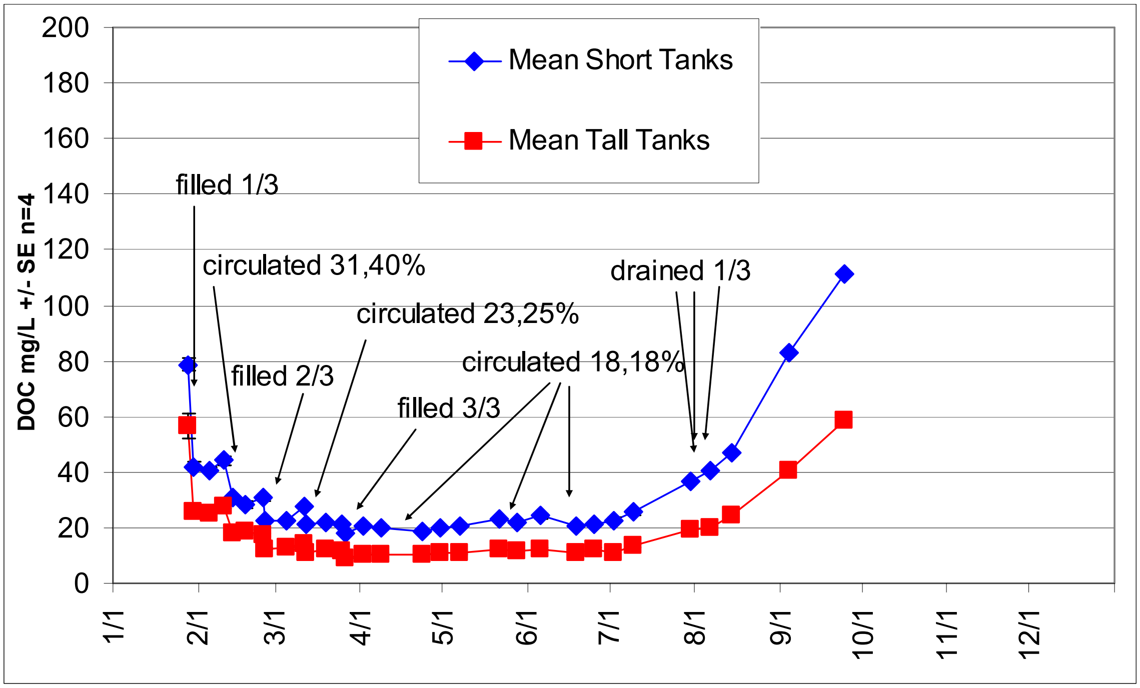

Figure 3.29: Mean 2003 DOC concentrations in mesocosms.

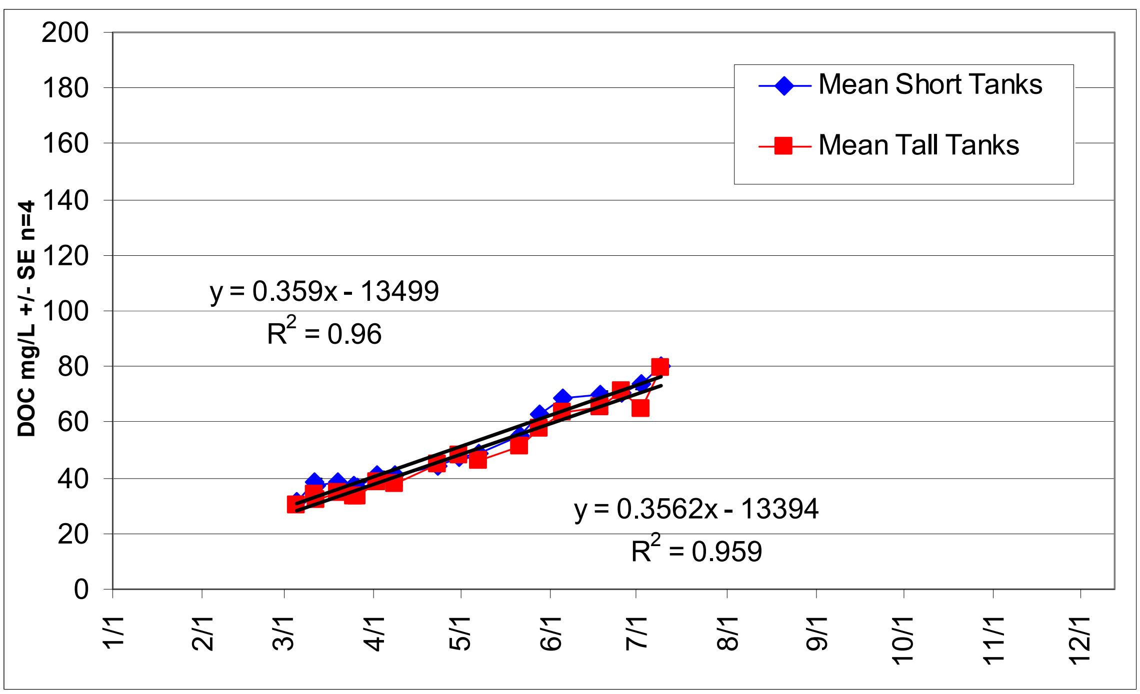

Figure 3.30: 2003 March-July storage period DOC concentrations in mesocosms (Means standardized to a one-meter water depth).

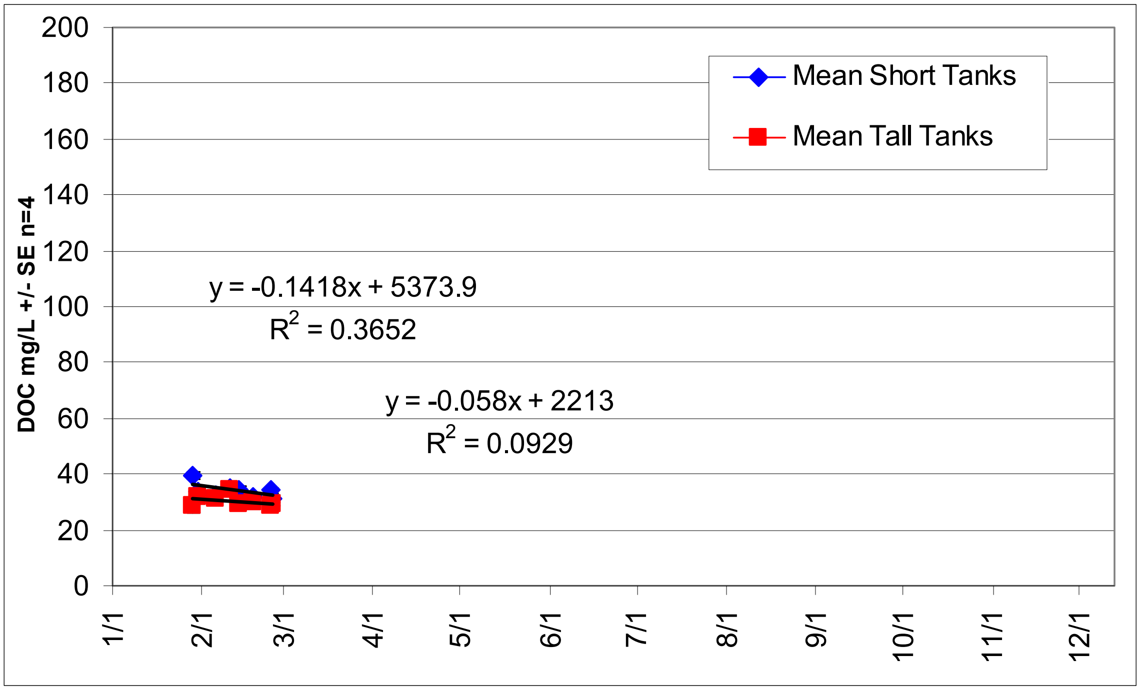

Figure 3.31: 2003 winter DOC concentrations in mesocosms
(Means standardized to a one meter water depth).

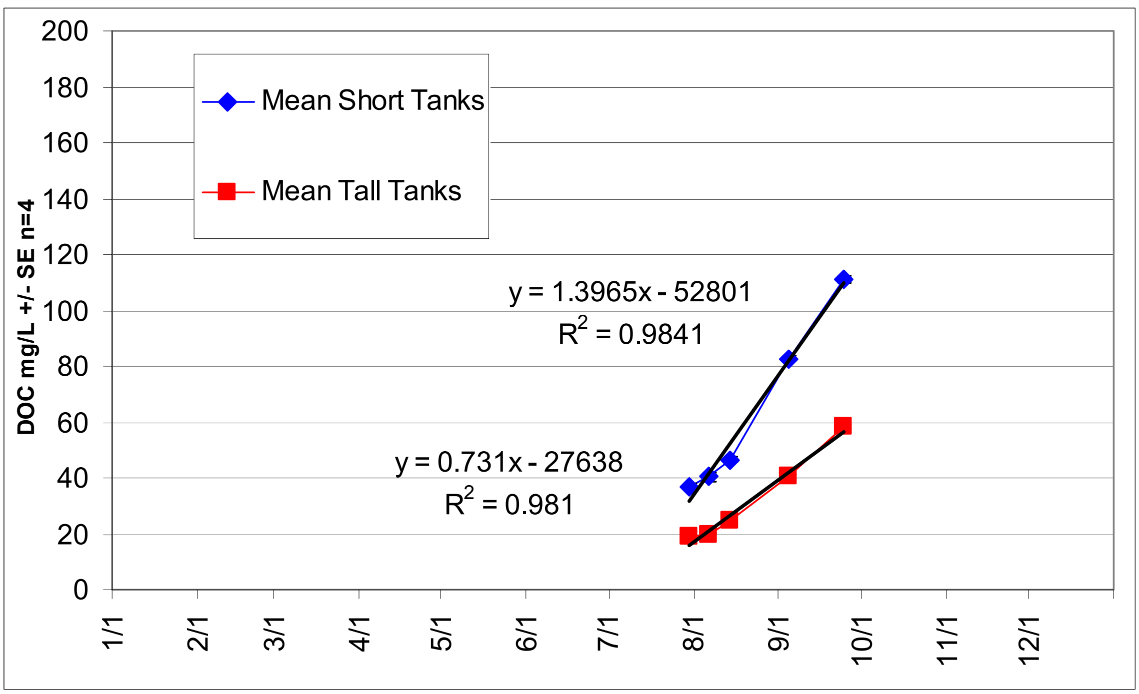

Figure 3.32: 2003 drained period DOC concentrations in mesocosms.
(These means are DOC concentrations as measured i.e. not standardized because no circulation flows during this period. In order to standardize slopes as in Figures 3.11 through 3.16 m*0.3 = 0.42 and 0.22 gC/m^2/d respectively.)

Predicting organic carbon loading in the proposed in-Delta reservoir islands has been a challenge for over a decade. The first estimates were a part of a 1990 Delta Wetlands Inc. draft EIR (DW 1990), mostly qualitative and based on comparisons to Delta island agricultural drainage. Estimates in this and subsequent EIRs were also limited in that algal and vascular aquatic plant productivity (bioproductivity) was not adequately considered. In recent years, DWR has conducted studies in order to reduce uncertainty and make a recommendation on the project. Much still needs to be done in order to develop process-level, mechanistic models of the reservoirs especially ones that can be used to accurately predict water quality in the reservoirs and at downstream drinking water intakes. Nevertheless, this mesocosm study is the latest step in an ongoing and integrative process to reduce uncertainty.

3.4 Use of OC Field Data in Modeling

Comparison of the mean 2002 and 2003 OC concentrations in the mesocosms shown in Figures 3.11 through 3.16 and Figures 3.29 through 3.32 (respectively) indicates similar OC values in both years. The annual average areal loading rate is on the order of 100gC/m^2/yr. The OC growth rates shown in Table 3.2 were used in the DSM2 model runs. These rates vary over the course of the year and are consistent with this annual average areal loading rate of about 100 gC/m^2/yr.

Table 3.2: Project Island Organic Carbon Growth Rates (gC/m2/day)

Island	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Bacon Island	0.59	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.35	0.35	0.59	0.59
Webb Tract	0.59	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.35	0.35	0.59	0.59

3.5 References

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