

Appendix C3. Water Quality Experiments on Potential Sources of Dissolved Organics and Trihalomethane Precursors for the Delta Wetlands Project

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SUMMARY

This appendix describes four water quality experiments conducted as part of the analysis of impacts of the Delta Wetlands (DW) project on Delta water quality. The Holland Tract flooded wetland and seasonal storage experiments were designed to determine what water quality changes can be expected in the flooded wetland habitat on the DW project islands during October-January and what further changes can be expected during the anticipated water storage period of February-July. The vegetation decay experiment was designed to determine what the expected contribution from decomposition of wetland vegetation would be to levels of dissolved organic carbon (DOC) and associated variables in ponded water in the seasonal wetland. The soil water extraction experiment was designed to determine what relative contributions of DOC and associated variables may be expected from agricultural and wetland soils; it was also used to test the hypothesis that peat soils may leach large quantities of materials to ponded water.

The original DW project concept included wetland vegetation growth in summer, waterfowl habitat flooding in fall, and winter-spring seasonal water storage operations on all four DW project islands. The DW project now being proposed involves two habitat islands and two reservoir islands, as described in Chapter 2, "Delta Wetlands Project and Alternatives". These water quality experiments are interpreted to provide information about likely effects of the DW project as currently conceived.

Analysis of the experimental results focused on DOC concentrations because DOC is recognized as the major precursor of trihalomethanes (THMs) in water disinfected through chlorination for municipal use, and contributions of DOC in discharge from the DW project islands to Delta channels may therefore affect THM levels in Delta exports that are treated by chlorination. The appendix also describes a method to estimate THM concentrations for any combinations of DOC, bromide (Br⁻), and chlorination dose.

The data from the Holland Tract wetland experiments suggest that substantial leaching of peat soil is not likely to occur under flooded wetland conditions and that moderate DOC increases would be associated with vegetation decomposition. Most of the available loading of DOC and other water quality variables would be released to the water in the flooded wetlands during October-January, and very little additional release of materials would occur during the February-July water storage period. The estimated areal loading from flooded wetlands was approximately 21 g/m² per year.

The results of the vegetation decay experiment were used to calculate the areal leaching of DOC from wetland vegetation. Areal loading from vegetation was found to be approximately 7.5 g/m² per year. This result can be used to compare DOC loading from decaying wetland vegetation with loading from other DOC sources in the Delta.

In the soil water extraction experiment, soil water was extracted for analysis from surface and deeper samples of soil from the Holland Tract wetland and adjacent agricultural fields. Analysis of the samples found that availability of DOC was two to three times greater in surface agricultural soils than in the wetland soils or deeper agricultural soils. The peat soils were not found to exhibit substantial leaching of DOC over time.

Although these experiments indicate that concentrations of DOC are greater in agricultural soils than in wetland soils, these differences are only important if the DOC concentrations are leached and transported to Delta channels. These experiments did not quantify the volumes of water affected by leaching, agricultural drainage, or runoff because such water volume data are not available; therefore, the experiments can only be used to provide a relative index of the potential for these soils to contribute to DOC concentrations in drainage or ponded water.

INTRODUCTION

Delta waters serve many beneficial uses, each of which has water quality concerns associated with it. Levels of disinfection byproducts (DBP) are of particular concern in water that has been exported from the Delta and treated for municipal use. The most common DBP is THM compounds, which are produced in the primary disinfection of water by chlorination. THMs are considered a human health risk by the U.S. Environmental Protection Agency (EPA) and are subject to federal drinking water standards. Among the constituents of raw water from the Delta are DOC and Br⁻, both of which might be increased in Delta water under some conditions as a result of DW project operations. DOC is the major precursor of THMs in treated drinking water.

The proposed DW project entails potential year-round storage of water on two Delta islands, Bacon Island and Webb Tract, and creation and management of wetlands for wildlife habitat on two other islands, Bouldin Island and Holland Tract. Under the proposed project, the water diverted by DW onto the reservoir islands would be stored for later sale as export or outflow during periods of demand. Water may also be diverted to the reservoir islands for creation of wetland habitat in fall during nonstorage periods; diversion would probably begin after September 1, after an appropriate dry period to allow for growth of wetland plants of value to wintering waterfowl as forage and cover. DW diversions onto the habitat islands would most likely begin in September, and water would be circulated throughout winter. Water used on the habitat islands would be discharged on a schedule related to wetland and wildlife values, with drawdown typically occurring by May. Water discharged into Delta channels under DW project operations would mix with Delta inflows and would be available for Delta outflow or Delta exports.

In comparison with existing agricultural management practices on the DW project islands, these storage and wetland management activities may substantially reduce the amount of annual biomass residue production and the rate of peat soil oxidation on the islands. Because vegetation decomposition and soil oxidation are the main sources of DOC on the DW project islands, DW project operations could affect concentrations of DOC dis-

charged into Delta channels from the islands and could therefore affect concentrations of THMs in treated water produced from Delta exports.

Jones & Stokes Associates (JSA) conducted the four water quality experiments described below as part of its analysis of impacts of the DW project on Delta water quality. The analysis was performed to support preparation of the environmental impact report/environmental impact statement (EIR/EIS) for the DW project. The four experiments and the question each was designed to answer are as follows:

1. Holland Tract flooded wetland experiment (1989-1990): What water quality changes can be expected in flooded wetland habitat on DW project islands during October-January?
2. Holland Tract seasonal storage experiment (1990): What further water quality changes can be expected during the proposed water storage period of February-July?
3. Vegetation decay experiment (1992): What is the expected contribution from decomposition of wetland vegetation to levels of DOC and associated variables in ponded water in the seasonal wetland?
4. Soil water extraction experiment (1992): What are the expected relative contributions of DOC and associated water quality variables from soils in active agricultural fields and in the demonstration wetland on Holland Tract?

Holland Tract Flooded Wetland and Seasonal Storage Experiments, 1989-1990

The first and second experiments were conducted in the Holland Tract demonstration wetland between October 1989 and July 1990. These experiments were designed to determine the changes in water quality likely to occur when seasonal wetlands are flooded to shallow depths to provide waterfowl habitat and when water is stored to greater depths on the proposed DW project

islands. Although many water quality variables were measured in these experiments, DOC is now known to be the major precursor of THMs. Therefore, DOC and associated variables, such as THM formation potential (THMFP), ultraviolet absorption (UVA), and organic nutrients, are emphasized in discussions of these experiments in this appendix.

The demonstration wetland on Holland Tract was originally constructed to show that plants used by waterfowl could be grown on DW project islands during the late summer-fall period after August 1. The initial DW project design would have involved seasonal storage and seasonal wetland habitat management on each DW island. The current DW project design includes two habitat islands and two reservoir islands. These experiments were conducted with the objective of identifying and quantifying the likely sources of DOC, and the results remain relevant to assessment of water quality impacts of the proposed DW project.

Results of the 1989-1990 Holland Tract experiments were originally presented in the draft EIR/EIS on the DW project (JSA 1990). This appendix summarizes those results.

Vegetation Decay and Soil Water Extraction Experiments, 1992

The vegetation decay and soil water extraction experiments, initially suggested in October 1991, were conducted to verify previous estimates of organic loadings from the DW project demonstration wetland on Holland Tract. Critical water-year conditions in 1992 prevented repetition of the demonstration wetland flooding experiment. JSA initiated the vegetation decay experiment on February 12, 1992, and obtained the last set of biweekly samples on April 29, 1992. JSA obtained soil samples for the soil water extraction experiment on February 27, 1992, and the 1-month soil water extraction was completed in April 1992.

JSA designed the 1992 experiments with suggestions from staff members of the California Department of Water Resources (DWR), Division of Local Assistance (Rick Woodard, Bruce Agee, consultant Marvin Jung), the Metropolitan Water District (MWD) of Southern California (Stuart Krasner, research chemist), the U.S. Geological Survey (USGS) (Steve Deverel), the California State Water Resources Control Board, and DW (consultant Jim Yost). JSA distributed a memorandum describing the experimental protocol for review on January 27, 1992, and MWD (February 4, 1992) and

DWR (February 21, 1992) provided written comments. Several meetings with interested agency staff members were held during this period. The vegetation experiment was designed to determine the contribution of wetland vegetation to DOC concentrations in ponded water (on habitat reservoir islands). The soil experiment was designed to evaluate the relative contribution of wetland and agricultural peat soils to DOC leaching.

JSA distributed a draft report on the experimental results for review on May 28, 1992, and held a meeting to discuss the results on June 3, 1992. DWR and MWD provided written comments on the draft report. The final report on the experiments and analyses of the results (JSA 1993) incorporated the suggestions and comments of the reviewers and included copies of memoranda and comment letters submitted by the technical reviewers. This appendix summarizes these results.

OVERVIEW OF SOIL ORGANIC CARBON SOURCES

DOC measurements were important in the experiments performed to determine possible effects of DW project operation on Delta water quality because DOC is the major precursor of THMs and other types of DBP in treated drinking water. This section provides an overview of sources of organic carbon in Delta soils and the possible mechanisms through which organic material is dissolved and transported from Delta soils to Delta channels. This discussion provides a framework for interpreting the results of the experiments presented below.

Organic material in both peat and mineral Delta soils originates from the decay of vegetation. The peat soils that characterize the Delta lowlands originated from the accumulation of partially decomposed residue of wetland marsh plants. The organic material in mineral soils that characterize the Delta uplands is partially decomposed residue of agricultural crops or natural vegetation. The difference between peat and mineral soils is the amount of organic material present, not the fundamental nature of the organic material. Mineral soils generally have an organic content of 1-20%, whereas peat soils have an organic content of 25-95% (Buckman and Brady 1960).

Carbon Cycle

Figure C3-1 shows the general carbon cycle for agricultural soils in the Delta. During net primary pro-

duction of organic material, atmospheric CO₂, and necessary nutrients and minerals are incorporated from the soil into growing plant tissue. Plant respiration in shoots and roots consumes oxygen and releases CO₂. Net primary production can be measured by the accumulation of plant biomass. Dry plant tissue has a carbon content of approximately 40%; therefore, biomass and carbon units can be interchanged quite easily (e.g., 1 gram per square meter [g/m²] of biomass contains 0.4 g/m² of carbon). This carbon content percentage was used in several of the experimental calculations described in the following sections.

All decomposition processes in soils can be described as enzymic digestion of plant residues and soil organic matter (Buckman and Brady 1960). Microbial decomposition processes in the warm, aerated topsoil differ greatly from those in deeper, saturated anaerobic soil. Fresh plant residues at the surface or in deeper soil are decomposed and digested by soil organisms of all kinds to produce decay products at the soil surface or in the soil column.

The complex chemical nature of plant tissues gives rise to a wide variety of decomposition products. Some plant tissue is easily decomposed and produces relatively simple end products, such as carbon dioxide (CO₂) and nutrients (e.g., nitrogen, phosphorus, and potassium). Most of the CO₂ is lost to the atmosphere, but some becomes dissolved in the soil water and reacts to form carbonates and bicarbonates. Other plant tissue is more difficult to decompose (refractory), and its decomposition results in intermediate products, such as lignins and humus material. These intermediate decomposition products remain in the soil or become dissolved in the soil water as compounds collectively measured as DOC. Soil microbes (bacteria, fungi, and actinomycetes) consume the available nutrients and minerals, and create additional compounds and end products, such as methane and nitrogen gas.

The general carbon cycle shown in Figure C3-1 becomes useful for impact assessment if the factors influencing each major term can be identified and quantified. Each of the DW water quality experiments was generally aimed at quantifying these terms. The following sections present general discussions of the possible contributions of plant decomposition and soil oxidation on the DW project islands to concentrations of DOC in Delta waters.

Plant Decomposition

The amount of net primary productivity of organic material in Delta soils can be characterized by corn crop measurements made for the Delta corn salt-tolerance studies (Hoffman et al. 1983), corn crop measurements made for the 1990 DW project EIR/EIS, and measurements of seasonal wetland plants in the Holland Tract demonstration wetland.

Measurements indicated that corn grown on Terminous Tract in the Delta had a root biomass of about 250 g/m², grain biomass averaging about 1,250 g/m², and shoot growth biomass averaging about 2,500-3,000 g/m² (Hoffman et al. 1983). Aboveground corn crop residue on Bouldin Island was calculated from measurements of stalks and stalk density estimates to be about 1,750 g/m² (Table C3-1). Corn grain had been harvested and removed from the fields on Bouldin Island. Adding the Terminous Tract corn root biomass to the aboveground residue on Bouldin Island produces an estimated 2,000 g/m² of annual biomass residue added to Delta soil from a corn crop.

The plant biomass from seasonal wetlands was measured in the Holland Tract demonstration wetland for 1989 and 1991. The 1989 measurements are summarized in Table C3-1. The average aboveground biomass was 500 g/m². The wetland roots probably contribute a relatively small additional biomass, certainly less than the corn root biomass of 250 g/m². The maximum possible seasonal wetland biomass is therefore approximately 750 g/m².

Most plant residue from corn or wetland plants is decomposed rapidly (within several months) to yield atmospheric CO₂ and soluble nutrients. The longer lasting (more slowly decomposing) portion of the biomass can be roughly approximated by the lignin content of the vegetation because lignin is the most refractory portion of plant tissue (Buckman and Brady 1960). Corn plants had a lignin content of about 7% and wetland plants had a lignin content of about 6% (Table C3-1). The mass of lignin added to the soil from plant residue can be estimated from the total biomass to be about 140 g/m² (2,000 g/m² × 0.07) for corn and about 45 g/m² (750 × 0.06) for wetland plants. These measurements do not indicate the amount of lignin material that may become dissolved in the soil water, but they provide a comparison between the possible amounts of DOC from the two sources.

If fresh plant residue were the only major source of organic material that might become dissolved in the soil water and if the yield of DOC from lignin were always the same, these lignin measurements could indicate that the relative DOC contribution from corn plants would be approximately three times the contribution of DOC from wetland plants. The yield of DOC from organic material may vary, however, if conditions in the soil that control decomposition are different. Furthermore, oxidation and decomposition of the peat soil itself may create a significant source of DOC. An accurate assessment of DOC formation potential must attempt to quantify these factors.

Peat Soil Decomposition

One of the distinctive characteristics of the Delta peat soils is that they have been slowly subsiding at estimated maximum rates of 2-3 inches per year as a result of oxidation and wind erosion of the powdery "muck" soils (SCS 1989). Drying, shrinking, and periodic burning of the peat soils may also play a role in subsidence of the Delta agricultural islands. Several studies have demonstrated that microbial oxidation is probably the major contributor to peat soil subsidence. Thus, the observed subsidence of Delta peat soils may provide evidence that oxidation of these soils is an ongoing process; this oxidation could be contributing DOC to agricultural drainage and runoff that mix with Delta channel waters. Direct evidence of peat soil oxidation would consist of a greater measured loss of CO₂ from the soil surface than could be accounted for by the decomposition of fresh vegetation residue (Broadbent 1960, DWR 1980, Newmarch 1981).

Indirect evidence that the major contributor to peat soil subsidence is microbial oxidation is suggested by studies showing that copper toxicity inhibits the soil microbial activity and reduces subsidence (Mather et al. 1979). Because copper is sometimes required as a fertilizer, the possibility that copper may also control subsidence is of interest for Delta agricultural management.

Other indirect evidence that microbial oxidation is the major contributor to peat soil subsidence is suggested by correlations between the depth to water table and oxidation rate in experiments at the Florida Everglades. Saturated conditions reduce the rate of oxidation of peat soils. The Everglades research results suggest that 50%-75% of the subsidence (average of 1.25 inches/year) has been caused by biochemical oxidation. Seasonal or global correlations with temperature also offer indirect

evidence that microbial processes control subsidence rates (Stephens and Stewart 1976).

Research has demonstrated that flooding peat soils creates anaerobic conditions that reduce the overall rate of microbial activity and shift the microbial processes to facultative and anaerobic metabolism. Denitrification of nitrate to nitrogen gases (N₂ and N₂O) increases dramatically under flooded conditions (Tate 1979, Terry & Tate 1980). A combination of biochemical indicators may provide the clearest picture of peat soil decomposition processes.

Studies by USGS may verify that microbial oxidation is the predominant process contributing to peat subsidence on Delta islands and that physical processes, such as drying, wind erosion, and fire, are of less importance (Deverel et al. in press).

Dissolved Organic Carbon in Soil Water and Agricultural Drainage

The most direct method for determining the magnitude of DOC contributions from Delta soils is measuring DOC and associated nutrients in soil water and agricultural drainage water. For the mass of contributed DOC to be calculated, however, the volume of soil water leaching or draining must be estimated. The experiments described in the following sections determined relative contributions of DOC and associated water quality variables from agricultural and wetland vegetation and soils; the results cannot be used to determine the magnitude of contributions from the DW project island soils to Delta waters because volumes of soil water leaching and drainage are not known. Standard irrigation practice in the peat soils of the Delta includes "spud ditching" to subirrigate and drain fields. This could increase the contribution of DOC relative to the contribution from wetlands and reservoir operations.

The DWR Municipal Water Quality Investigations (MWQI) program has sampled Delta agricultural drainage for several years (DWR 1989, 1990). Agricultural drainage volumes have not yet been measured directly, so the absolute magnitude of DOC sources produced by the various drains cannot be calculated. The relative magnitude of measured DOC concentrations can be used to indicate those drains that are probably the major sources of DOC in the Delta if it is assumed that the drainage volumes per acre are similar for each Delta drain (Table C2-1 in Appendix C2, "Analysis of Delta Agricultural Drainage Water Quality Data", suggests that they

are not uniform). Information on the drainage acreages might allow the drainage volumes to be estimated.

THMFP is measured in the MWQI samples as an index of THM concentrations that could be produced by maximum chlorination of Delta water. Several types of laboratory tests have been developed to measure THMFP in water samples.

The DWR MWQI assay for THMs is performed by spiking a water sample with an initial 120-mg/l concentration of chlorine (Cl_2), holding the sample for 7 days (168 hours) at 25°C, then measuring the THM species with standard EPA analytical laboratory procedures (gas chromatograph purge and trap, EPA method 502.2). This method was recently revised to also control the pH of the sample. The 120 mg/l chlorine dose may not be great enough to produce the maximum THMFP concentration in samples with high DOC concentrations (greater than 30 mg/l). The gas chromatograph method determines concentrations of the four types of THM molecules separately. Each THM molecule resembles methane (CH_4), except that three of the four hydrogen atoms are replaced with a halogen (chlorine or bromine). The four types of THM molecules are chloroform (CHCl_3), dichlorobromomethane (CHCl_2Br), dibromochloromethane (CHClBr_2), and bromoform (CHBr_3). Each type of THM molecule has a different molecular weight because of the difference between the atomic weight of chlorine (35.45) and bromine (79.90). Chloroform has a molecular weight of 119.36, whereas bromoform has a molecular weight of 252.71.

Total THM concentration (by weight) is the basis for current EPA drinking water standards. The greater weight of total THMs resulting from increased bromine incorporation, however, complicates comparison of THM precursors from two water samples with different bromide (Br^-) concentrations. One method to normalize THM concentrations is to measure only the carbon weight of each THM molecule, because each molecule has one carbon atom. The carbon-fraction concentrations of the four THM molecule concentrations are added together to calculate the carbon content of the THM concentration (C-THM), called the "total formation potential carbon" (TFPC) in the DWR MWQI program. Dividing the C-THM concentration by the DOC concentration in a water sample gives the fraction of DOC molecules that were converted to THM molecules during the THMFP assay. This C-THM/DOC ratio is called the THM yield.

HOLLAND TRACT WETLAND EXPERIMENTS

The first two water quality experiments were conducted at the demonstration wetland on Holland Tract. The Holland Tract demonstration wetland has an approximately 62-acre surface area with a total storage capacity of about 164 acre-feet (af) and a mean depth of 2.65 feet (0.8 m) (Figure C3-2). Construction of the pond levees and water control structure began on December 1, 1987, and was completed by January 22, 1988. The low dikes of the demonstration wetland were constructed from material scraped from an agricultural field that consisted of a mosaic of sand and peat soils. The water supply for the demonstration wetland was Old River.

Flooded Wetland Experiment

The first water quality experiment was conducted between October 1989 and January 1990. The objective of this study was to evaluate the contribution of wetland vegetation decomposition and soil leaching to concentrations of THM precursors in flooded wetland water. DOC and associated variables are of primary concern in interpretation of these results because DOC has been determined to be the major precursor of THM. Measurements of organic carbon were not filtered in this experiment and are given as concentrations of total organic carbon (TOC). However, the organic carbon is assumed to be predominantly dissolved; therefore, TOC is assumed to be equivalent to DOC.

Methods

Approximately 25 acres of the demonstration wetland's 62 acres were flooded beginning on October 19, 1989, to an average depth of about 0.5 m (1.5 feet) (see Figure C3-2). No additional siphoning of water into the wetland was required after initial flooding to maintain wetland water depths. Evapotranspiration and rainfall (with runoff from the unflooded portion of the wetlands) were balanced during the sampling period so that the water depth remained nearly constant. A composite sample (several samples mixed together) of the water siphoned from Old River to flood the wetland was used to characterize the initial water quality.

Composite water samples were collected from the flooded wetland approximately every week from November 3, 1989, to January 15, 1990. Samples were collected in a pre-rinsed plastic sampling jug slowly lowered from the water surface down to the wetland bottom. Subsamples were collected at random throughout the pond and composited to form one water sample on each date. A total of 10 composite samples were collected. Samples were labeled and transferred to ice chests for delivery to the contract laboratory.

Results

Measurements of the composite sample used to characterize initial water quality showed electrical conductivity (EC) of 677 microsiemens per centimeter ($\mu\text{S}/\text{cm}$), 556 milligrams per liter (mg/l) total dissolved solids (TDS), 177 mg/l chloride (Cl^-) ($\text{Cl}^-/\text{EC} = 0.26$), 0.55 mg/l bromide (Br^-) ($\text{Br}^-/\text{Cl}^- = 0.0031$), 18 mg/l calcium (Ca^{2+}), 18 mg/l magnesium (Mg^{2+}), 97 mg/l sodium (Na^+), 30 mg/l sulfate (SO_4^{2-}), 4.3 mg/l TOC, and THMFP of 404 micrograms per liter ($\mu\text{g}/\text{l}$) (Table C3-2). Color was not measured but was assumed to be 20 units based on MWQI Rock Slough measurements made on October 2, 1989. These channel water values are assumed to be representative of the initial concentrations of water quality variables in the flooded wetlands, which were flooded on October 19, 1989.

Changes in wetland water quality would have resulted mainly from peat soil leaching and decomposition of the wetland vegetation biomass and associated surface detritus. Rainfall on the entire pond area may have produced runoff and carried organics into the flooded area. Peat soil leaching would be expected to yield salt, minerals, nutrients, and organics. Vegetation residues would also be expected to produce dissolved organics with associated minerals and nutrients.

Several of the dissolved inorganic variables showed no net change over the duration of the experiment. EC and concentrations of TDS, sodium, chloride, and bromide showed no net increase (Figure C3-3). The data suggest that substantial leaching of the peat soil did not occur because these inorganic variables typically increase during soil leaching in agricultural operations.

In contrast, calcium, magnesium, sulfate, color, TOC, and THMFP increased in the demonstration wetland water during the 2-month sampling period (Figures C3-4, C3-5, and C3-6). TOC levels increased from 4.3 mg/l to 38.6 mg/l, as shown in Figure C3-5. THMFP concentrations increased dramatically; the THMFP concentration carbon component (C-THM) increased from

33 $\mu\text{g}/\text{l}$ to a maximum of 420 $\mu\text{g}/\text{l}$ (Figure C3-6). These materials originated either from vegetation decay in the flooded wetland basin or as runoff from the surrounding area within the wetlands that were not flooded. The observed increases may be higher than would be expected if a greater proportion of the wetland basin had been flooded. Increases of approximately 250 color units, 34 mg/l TOC, 50 mg/l sulfate, 20 mg/l calcium, 10 mg/l magnesium, and 300 $\mu\text{g}/\text{l}$ C-THM were observed (Table C3-2).

Based on an estimated increase in TOC of 34 mg/l during the flooded wetland condition and an average pond depth of 0.5 meter, the estimated TOC loading is estimated to be about 17 g/m^2 ($34 \text{ g}/\text{m}^3 \cdot 0.5\text{m} = 17 \text{ g}/\text{m}^2$). If the 34-mg/l increase in TOC was contributed from the entire 62-acre wetland area, the estimated TOC loading would be about 7 g/m^2 ($17 \text{ g}/\text{m}^2 \times 25/62$).

Conclusions based on this experiment are presented following the description of the seasonal storage experiment, under "Conclusions of the Holland Tract Wetland Experiments".

Seasonal Storage Experiment

The second experiment was conducted during April-July 1990. The objective of this experiment was to evaluate changes in water quality during the water storage period. The initial concentrations provided an estimate of flooded wetland load from the entire pond because the wetland water was not drained between the two experiments. This experiment tested the magnitude of potential leaching of the peat soils during extended water storage periods.

Methods

The entire demonstration wetland on Holland Tract was filled to a mean depth of approximately 0.8 m (2.5 feet) during the week of April 16, 1990, to simulate proposed DW storage operations. Composite water samples were collected from the pond's surface water and separately from the bottom on six dates between April 23, 1990, and July 25, 1990 (3-month period), according to procedures described previously for the flooded wetland experiment. The surface and bottom composite samples provided replicate measurements because stratification was not indicated.

Results

Flooded wetland water remaining from winter was mixed with Delta channel water to fill the wetland to capacity, resulting in initial pool concentrations of about 940 $\mu\text{S}/\text{m}$ EC, 600 mg/l TDS, 80 mg/l alkalinity, 150 mg/l sodium, 230 mg/l chloride ($\text{Cl}^-/\text{EC} = 0.24$), 1 mg/l bromide ($\text{Br}^-/\text{Cl}^- = 0.0044$), 30 mg/l calcium, 25 mg/l magnesium, 43 mg/l sulfate, 250 color units, 30 mg/l TOC, and 150 $\mu\text{g}/\text{l}$ C-THM (Table C3-3). MWQI measurements from Rock Slough on April 25 were generally less than the initial pool concentrations (Table C3-3).

The initial mixed concentrations may provide more accurate estimates of the areal load of TOC from the flooded wetland because the entire demonstration wetland area was inundated after being filled to the full water storage capacity. With a pond depth of 0.8 m and an increase in TOC concentration of 26 mg/l (from the channel concentration of 4 mg/l to 30-mg/l initial pool concentration), the TOC load was estimated at 21 g/m^2 ($26 \text{ mg/l} \cdot 0.8\text{m} = 20.8 \text{ g}/\text{m}^2$). The C-THM load was estimated to be 0.1 g/m^2 , based on a depth of 0.8 m and a 120 mg/l increase (from the channel concentration of 30 $\mu\text{g}/\text{l}$ to the 150- $\mu\text{g}/\text{l}$ initial pool concentration).

Additional siphoning of channel water was required to maintain the water storage depth, but Delta water quality improved during the storage period of mid-April through July, and as a result, EC values and concentrations of sodium, chloride, and bromide remained nearly constant (Figure C3-7). The constant levels of inorganic variables suggest that soil leaching with associated release of salts did not occur during the storage period.

Measurements also indicated that color and concentrations of calcium, magnesium, and TOC remained fairly constant during the storage period, suggesting that relatively little additional organic material was released from vegetation decay or peat soil leaching processes during the storage period (Figures C3-8 and C3-9). Sulfate concentrations declined by 50%. THMFP values also remained relatively constant, with a moderate increase in the C-THM component from about 150 $\mu\text{g}/\text{l}$ to about 200 $\mu\text{g}/\text{l}$ (Figure C3-10).

Conclusions of the Holland Tract Wetland Experiments

The seasonal water storage experiment results generally suggest that little additional increase in organic concentrations occurred in the water storage pool. There-

fore, the overall TOC loading from the combined flooded wetland and water storage periods was estimated to be about 21 g/m^2 and the corresponding C-THM load about 0.1 g/m^2 , most of which occurred during the vegetation decay period. These experiments indicate that the majority of loading was from vegetation decay; peat soil leaching was apparently a minor source of loading.

Measurements obtained from water temporarily stored on Tyler Island (cornfields) for the DWR emergency water bank in April and May 1991 provide another example of possible DOC loading for comparison. These measurements indicate that DOC concentrations in water stored for about 1 month increased by 50-60 mg/l. The estimated mean depth of the stored water was about 0.6 m (734 $\text{af}/370$ acres). Thus, estimated DOC loading was approximately 30-36 g/m^2 . This loading is assumed to have originated from rapid vegetation decay and dissolving of surface organic residues, rather than prolonged leaching from peat, because the water was stored for only one month.

These experiments directly answered questions 1 and 2 (What water quality changes can be expected in flooded wetland habitat on DW project islands during October-January? What further water quality changes can be expected during the proposed water storage period of February-July?). The results of these experiments indicate that most of the available loading of DOC and other water quality variables from vegetation and surface soil residues will be released to water in the flooded wetlands during the initial flooding period. Very little, if any, additional release of materials will occur during the water storage period. This suggests that the surface vegetation and soil oxidation residues are the predominant source of DOC; peat soil leaching during water storage periods is a smaller potential source of DOC.

1992 WATER QUALITY EXPERIMENTS

Vegetation Decay Experiment

The 1992 vegetation decay experiment was designed to quantify the possible contribution of decaying wetland vegetation to dissolved organics and associated variables (especially UVA and THMFP) in ponded water in seasonal wetlands. This experiment was intended to verify the results from the 1990 experiments that indicated vegetation to be a major source of DOC.

Methods

Vegetation biomass samples (1-square-foot clippings) were collected on November 22, 1991, from the demonstration wetland on Holland Tract. The vegetation was dominated by smartweed, watergrass, and swamp timothy, similar to the vegetation cover of previous years. Biomass from 38 samples averaged about 435 g/m², and lignin content averaged 9.5% (determined by JL Analytical Services, Modesto, CA). Based on an assumed maximum carbon content in lignin of 50%, the carbon source from lignin was estimated to be about 20 g/m².

In comparison, plant material collected in 1989 at the demonstration wetland averaged 500 g/m² dry weight of biomass with 6% lignin content, for an estimated lignin carbon source of 15 g/m². The total corn shoot and grain biomass measured from Terminous Island was 4,000-4,500 g/m², and the shoot biomass was approximately 2,500-3,000 g/m² (Hoffman et al. 1983).

For the vegetation decay experiment, JSA filled five barrels with water obtained from Rock Slough on January 23, 1992. The barrels were situated outdoors at the JSA office in Sacramento. Approximately 1 gallon of pond water from the Holland Tract demonstration wetland was added to biologically inoculate each barrel with microorganisms.

Dried and pulverized wetland vegetation (as returned from JL Analytical Services) from the Holland Tract demonstration wetland was added to four of the five barrels on February 12, 1992. The fifth barrel (control barrel), with no vegetation biomass, served as a control for the experimental treatments. Each barrel had a bottom area of 2 square feet, a mean depth of 2 feet (0.6 m), and a volume of 4 cubic feet (30 gallons).

Two replicate barrels (barrels #1 and #2; 1X barrels) received approximately the biomass density measured in the wetland (500 g/m²) and therefore simulated concentrations that would result from decay of vegetation in an average water depth of 0.6 m. The other two replicate barrels (barrels #3 and #4; 2X barrels) received twice the measured biomass density (1,000 g/m²) and therefore simulated a pond of shallower depth (0.3 m), as illustrated in Figure C3-11. In comparison, the flooded demonstration wetland on Holland Tract in 1989 had an estimated mean depth of 0.5 m. Temporary water storage on Tyler Island in 1991 (part of the DWR emergency water bank) had a mean depth of 0.6 m. Concentrations in the 2X barrels (two times the areal load) were expected to be twice those in the 1X barrels (one times the areal load). Both sets of concentrations

should yield the same areal loading estimates, as described below.

DWR commented in its June 23, 1992 letter that natural vegetation would not be pulverized and might therefore decay more slowly; because of this, the experiment could measure only the load (i.e., mass) of organic material dissolved in barrel water, not the rate of loading (i.e., mass per unit time). In this comment letter, DWR also expressed concern that water quality was not measured in all five barrels before vegetation was added, to demonstrate that they had the same initial water quality as the control barrel, which was sampled.

The vegetation decay experiment was designed to determine final differences in concentrations of dissolved organics between treatment barrels and the control barrel. Initial water quality was assumed to be the same in all barrels because all barrel water originated from the same source. Changes in water quality between sampling dates were only noted because they provided a means for determining when the concentrations of organic materials from the added biomass had stabilized. Therefore, it was concluded that measurements of initial water quality in all barrels were unnecessary.

Water samples were collected at 2-week intervals from the barrels on February 27, March 10, March 31, April 14, and April 29, 1992. Primary samples were analyzed by Anlab Analytical Laboratory (Anlab) in Sacramento. Duplicate samples from the barrels were sent to Stuart Krasner at MWD for analyses of several parameters of direct interest to MWD. Duplicate analyses allowed comparison of those variables analyzed by both laboratories.

This report uses only the THMFP values measured by MWD. The THMFP values determined by Cal-Enseco Laboratory, under a subcontract to Anlab, were unreliable and were rejected. THMFP values estimated by the MWD method, which used a reactivity-based chlorine (Cl⁺) dose ($3 \times \text{DOC} + 8 \times \text{NH}_3$), must be adjusted (i.e., increased) to expected values for the standard 120 mg/l chlorine dose used by DWR, as described below under "Relationship between Dissolved Organic Carbon, Bromide, Chlorination, and Trihalomethane".

A large group of chemical parameters was measured in each sample. According to the study protocol, the vegetation decay experiment was to be terminated after 10 weeks if the organic loading calculated from sampled water concentrations had stabilized. Measurements of the two key organic variables (DOC and 254-nm UVA) had

stabilized and the experiment was terminated following the April 29, 1992 sampling.

In its comment letter on the draft report, DWR expressed concern that water quality concentrations had not stabilized because the ratio of UVA to DOC was still increasing. However, concentrations of DOC and UVA had remained approximately the same since the first samples were collected on February 27, 1992, 2 weeks after the vegetation was added. DOC and UVA values were both slightly higher in the fifth set of samples collected on April 29, 1992. Some portion of this increase was caused, however, by evaporation and a decreasing water volume in the barrels, as shown by the increased chloride and bromide measurements (see discussion of results below).

Results

Results of the chemical analyses by Anlab and MWD are shown in Table C3-4 through C3-6. Table C3-4 contains the results for the control barrel, Table C3-5 provides the results for the 1X barrels, and Table C3-6 shows the results for the 2X barrels.

In their comment letters on the draft report, MWD and DWR noted the high variability in many of the Anlab measurements. Although Anlab followed and reported standard quality assurance/quality control procedures, variability was substantial. The fact that these were outdoor experiments is not sufficient to explain the variations. MWD suggested that relatively simple anion-cation and EC checks might have alerted Anlab to measurement problems; Anlab did not use anion-cation balance as a quality assurance/ quality control measure.

Comparison of variables presented in Tables C3-4 through C3-6 can be used to determine the most likely interpretation of the measurements. In the case of parameters not showing excessive variability (20% of mean), differences observed between the treatment and control barrel samples can provide evidence of effects of vegetation decay. Some variables cannot be used to differentiate effects because the variability between measurements was too great. Similar results for related parameters increase confidence in the bulk of the data and support reliable conclusions.

Salts. Because all barrels were filled with the same water in January, salt concentrations in each barrel were expected to be similar and to remain relatively constant throughout the experiment. Sampling decreased the remaining water volumes but would not change salt concentrations in the barrels. Evaporation and rainfall could,

however, change the salt concentrations in the remaining water.

Figures C3-12 and C3-13 show the chloride and bromide concentrations measured on the five sample dates in samples from the five barrels by Anlab and MWD. Ignoring the Anlab data from March 10, 1992, chloride varied from approximately 130 mg/l to 200 mg/l during the experiment, with the variation on each sample date usually less than 20 mg/l. Agreement between the Anlab and MWD data was best on the last sample date, with an average value of 180 mg/l (range of 170-190 mg/l). In the MWD data, chloride values increased by approximately 20% from 150 mg/l on February 27 to 180 mg/l on April 29, 1992, showing a moderate effect of evaporation.

Bromide concentrations ranged from 0.4 to 0.75 mg/l (Figure C3-13). Average bromide concentrations appear to have increased from about 0.60 to 0.70 mg/l because of evaporative effects (using MWD data). The average ratio of bromide to chloride (MWD data) was approximately 0.0030, slightly lower than the ratio for ocean water of 0.0035.

Other anions and cations were measured by Anlab only; measurements are shown in Tables C3-4, C3-5, and C3-6. Sodium values were quite similar for all five barrels on each sample date, ranging from about 80 mg/l to 110 mg/l during the course of the experiment. Sulfate values were more variable between barrels, with final concentrations between 30 mg/l and 40 mg/l. Sulfate concentrations may have actually decreased during the experiment. MWD commented that a sulfate decrease might have been the result of anaerobic processes that reduce sulfate and release hydrogen sulfide gas to the atmosphere.

Calcium and magnesium measurements were relatively uniform between sample dates. Calcium varied between 20 mg/l and 30 mg/l, and magnesium varied between 20 mg/l and 25 mg/l. The control concentrations of these cations, about 20 mg/l, were large compared with the possible increases resulting from vegetation decay. The final set of analyses indicated that calcium concentrations were 30 mg/l in the 2X barrels, compared with 20 mg/l in the control barrel. Magnesium concentrations were 25 mg/l in the 2X barrels, compared with 18 mg/l in the control barrel.

In its comment letter on the draft report, MWD suggested that calcium and magnesium concentrations might have been influenced by precipitation and dissolution processes caused by changing pH values. Because vegetation is known to contain moderate concentrations

of calcium (0.2-3.5%) and magnesium (0.1-1.0%), simple release from vegetative decay is also a possible explanation. The increased potassium concentrations discussed in the next section appear to confirm that the vegetation decay and release mechanism was the likely source of the calcium and magnesium increases.

Figure C3-14 shows the measurements of EC in the five barrels. These measurements suggest that vegetation may have released enough salts or nutrients to slightly increase EC values relative to the control barrel EC. On April 29, 1992, conductivity ranged from 800 $\mu\text{S}/\text{cm}$ in the control barrel to 1,000 $\mu\text{S}/\text{cm}$ in the 2X barrels.

Nutrients. Potassium concentrations showed the most dramatic increase as a result of vegetation decay because the potassium concentration of 5 mg/l in the control barrel was low relative to the measured increases from vegetation decay (Figure C3-15). By the final sampling date of April 29, 1992, potassium concentrations had increased to 17 mg/l in the 1X barrels (representing a 12-mg/l increase) and had increased to 27 mg/l in the 2X barrels (a 22-mg/l increase). Potassium may be a useful indicator for determining vegetation effects on water quality in the Delta because vegetation has a high potassium content (between 0.5% and 5.0%).

Substantial increases in organic nitrogen and total phosphorus were also observed. By the final sampling date, concentrations of organic nitrogen had increased by 20 mg/l in all barrels with vegetation added, and phosphorus concentrations had increased by almost 2 mg/l, representing a typical nitrogen-to-phosphorus ratio of 10:1 for vegetation. These high-nutrient concentrations could contribute to algal productivity and subsequent food chain processes.

An elemental analysis of the wetland vegetation was not obtained but elemental content may be calculated to confirm the apparent nutrient release concentrations. The content of potassium, calcium, and manganese in the wetland vegetation can be indirectly estimated in the following way. Because the 2X barrels had a biomass loading of 1,000 g/m^2 and a mean depth of 0.6 m, the concentration of total biomass, if completely dissolved, would be $1,000/0.6 = 1,667 \text{ g}/\text{m}^3$, which is equal to 1,667 mg/l. Therefore, 16.67 mg/l of any substance in the 2X barrels would represent 1% of the total biomass; similarly, 8.3 mg/l of any substance in the 1X barrels would represent 1% of the total biomass.

The final magnesium difference between the 2X barrels and the control barrel was about 8 mg/l, representing 0.5% of the total biomass. The final calcium difference was about 12 mg/l, representing 0.7% of

the biomass. The potassium difference was 22 mg/l (Figure C3-15), representing 1.25% of the biomass. The nitrogen difference was about 25 mg/l, representing 1.5% of the biomass. The phosphorus difference was approximately 2 mg/l, representing 0.12% of the biomass. Each of these values is comparable with vegetation composition percentages for these elements cited in agricultural textbooks (see Table C3-7). These differences between the 2X barrel and control barrel mineral and nutrient concentrations therefore confirm that the observed water quality changes were the result of vegetation biomass decomposition. The 1X barrels showed similar changes.

Organics. Observed DOC concentrations were comparable in the two barrels at each biomass loading level (Figure C3-16), and most of the increase in concentration occurred within the first month. DOC concentration in Rock Slough water (control) was approximately 5 mg/l; the DOC concentration in the 1X barrels increased to about 15 mg/l by February 27, 1992, and remained at that level until April 29, 1992. DOC concentration in the 2X barrels increased to about 30 mg/l (according to the MWD data).

Based on the estimation of biomass content presented in the previous section, it might be expected that carbon, assumed to compose about 40% of the total biomass, would produce an increased DOC concentration in the 2X barrels of approximately $40 \times 16.67 \text{ mg}/\text{l} = 667 \text{ mg}/\text{l}$. However, not all carbon is converted to DOC: only about 25 mg/l (4%) of the possible increase in carbon was measured in the 2X barrels because some of the carbon remained in the vegetation detritus and most of the carbon was released as CO_2 during the decay processes. About 3% of the possible increase in DOC was observed in the 1X barrels (9 mg/l of DOC compared with 333 mg/l of biomass - C).

DOC analyses by MWD were generally quite similar to Anlab values, except for the 2X barrels (Figure C3-16). On the first sampling date, the MWD DOC measurements showed more than twice the increase in DOC for the 2X barrels than the Anlab measurements showed. In DOC procedures at both laboratories, samples are diluted so that a DOC concentration of less than 10 mg/l is measured, and measurements are then multiplied by the dilution factor to estimate the concentration in the sample. The scatter between the laboratories in data on the DOC concentrations from the 2X barrels is quite unfortunate because these are important measurements from the vegetation decay experiment. Fortunately, other measurements, described below, can be used to confirm the general results of the experiment.

Ultraviolet Absorption and Color. UVA appears to be an excellent measurement of organic content because it is known to exhibit a linear increase with DOC. The Anlab and MWD measurements of UVA were quite similar in the vegetation decay experiment. UVA in the control barrel remained at approximately 0.1 cm⁻¹ throughout the experiment (Figure C3-17). UVA values for the 1X barrels were about 0.4 cm⁻¹ on February 27, 1992, and increased slightly to 0.45 cm⁻¹ by April 29, 1992. Much of this increase may be the result of evaporation, as indicated by similar increases in chloride and bromide (Figures C3-12 and C3-13). UVA values for the 2X barrels were about 0.6 cm⁻¹ on February 27, 1992, and increased to more than 0.8 cm⁻¹ in the last sample collected on April 29, 1992.

The ratio between UVA (cm⁻¹) and DOC (mg/l) was relatively constant at values of 0.02 to 0.03 in most samples (Figure C3-18). The low UVA/DOC ratio of 0.015 calculated by MWD for the 2X barrels on the first three sampling dates indicates that reported DOC values were higher than DOC values expected based on the corresponding measured UVA values. Data from the last measurement date for samples from all barrels (including the control) suggested that the average UVA/DOC ratio for organics from vegetation decay is between 0.025 and 0.030. Amy et al. (1990) found a UVA/DOC ratio of 0.025 for river samples and 0.045 for drainage samples. The ratio based on MWQI data from the Banks and Tracy Pumping Plants ranges from 0.025 to 0.035 (see Figure C1-9 in Appendix C1, "Analysis of Delta Inflow and Export Water Quality Data").

Color measurements were increased by vegetation decay, but the scatter in the data reported by Anlab makes these values less precise than the values from the UVA or DOC analyses. The control barrel had a color value of approximately 10 units. An increase of nearly 100 color units was associated with vegetation decay in the 1X barrels, and an increase of about 200 color units was observed in the 2X barrels.

Carbon Content of Trihalomethane. The carbon content of THM (C-THM) is equal to the molar concentration times 12. C-THM concentrations measured by MWD were quite consistent between the replicate barrels and among sample dates (Figure C3-19).

In its comment letter on the draft report, MWD stated that the chlorine dose used for the 2X barrels in the THMFP test was generally close to the 120 mg/l used in the standard DWR test procedure for THMFP. Samples from the control and 1X barrels were dosed, however, with considerably less than the 120 mg/l of chlorine used by DWR. An adjustment can be made to obtain estimates

of the THMFP values that would be produced using the standard DWR test, as described below under "Relationship between Dissolved Organic Carbon, Bromide, Chlorination, and Trihalomethanes". However, the relative values from these MWD measurements of THMFP provide the basis for making an approximate comparison of the effects of vegetative decay on THMFP.

On April 29, 1992, the control C-THM concentration was approximately 50 µg/l, the 1X barrels had C-THM concentrations of about 150 µg/l, and the 2X barrels had C-THM concentrations of 300 µg/l. The C-THM concentration in the 2X barrels was approximately twice that of the 1X barrels (Figure C3-19). The data indicate that the increase in C-THM concentrations occurred within 2 weeks of initial loading of biomass into the barrels as determined from the control barrel concentrations. C-THM concentrations (and other measures of organic content) were judged by JSA to have stabilized sufficiently after 10 weeks for the experiments to be terminated as planned.

Figure C3-20 shows that the ratio of C-THM (µg/l) to DOC (mg/l) was very uniform, with a value of approximately 10 µg/mg (range of 8-12 µg/mg) indicating that approximately 1% of the DOC had become THM molecules during the MWD test for THMFP.

Bromine Incorporation. Incorporation of bromine in THM molecules (Br-THM) from inorganic bromine can be estimated from the ratio of Br-THM to bromide ion (Figure C3-21). The ratio was approximately 40-50% in most samples.

Each THM molecule has three halogen sites. The bromine incorporation value is the average number of halogen sites occupied by bromine; the value (n) varies from 0 to 3. The value can be estimated as:

$$n = \frac{\text{Br-THM}/80}{3 \cdot \text{C-THM}/12}$$

$$= \text{Br-THM}/(\text{C-THM} \cdot 20)$$

where 80 and 12 represent the molar weights of bromine and carbon, respectively, and 3 represents the number of halogen sites.

The bromine incorporation value was about 0.27 for the control barrel, about 0.08 for the 1X barrels, and about 0.04 for the 2X barrels. Because the bromide concentration remained constant at about 0.4 mg/l in all barrels, it can be concluded that the bromine incorporation decreased as the total THMFP concentration increased.

Recent work by MWD and DWR (1992) suggests that bromine incorporation in THM molecules increases as a function of the ratio of chlorine dose to DOC (approximately 3.0 in the MWD measurements), and the ratio of bromide to DOC (0.015 to 0.030 in these experiments). DWR and MWD commented that the incorporation of bromine into THM molecules in actual drinking water will be higher than these experimental measurements, and therefore these bromine incorporation factors should not be used directly in the water quality assessment for the DW project (see Appendix C5, "Modeling Trihalomethane Production at a Typical Water Treatment Plant Using Delta Export Water", for further discussion). The estimation of bromine incorporation is described in the method for adjusting MWD and DWR measurements of THMFP under "Relationship between Dissolved Organic Carbon, Bromide, Chlorination, and Trihalomethanes", below.

Conclusions

Differences in final DOC concentrations between the two wetland vegetation treatments and the control observed in this experiment can be used to estimate the mass loading per surface area, as illustrated in Figure C3-11. For each treatment, the concentration difference from the control (in mg/l) times the mean depth (in m) is the equivalent loading per unit area (g/m^2). Areal loading estimates (g/m^2) can be converted to pounds/acre units by multiplying by 8.92. Using this approach, observed DOC loading from decaying wetland vegetation can be described relative to other DOC sources in the Delta.

This experiment directly answered question 3 (What is the expected contribution from decomposition of wetland vegetation to levels of DOC and associated variables?) and provided estimates of the contribution of vegetation to the areal loading of DOC and other water quality variables. DOC concentrations increased by approximately 9 mg/l in the 1X barrels and approximately 25 mg/l in the 2X barrels (Figure C3-16). Based on these concentration increases, areal DOC loading was calculated to be approximately 5.4 g/m^2 in the 1X barrels (i.e., 9 mg/l X 0.6 m = 5.4 g/m^2), and 40% higher, at 7.5 g/m^2 , in the 2X barrels (i.e., 25 mg/l X 0.3 m = 7.5 g/m^2). The 2X barrels might provide the more accurate estimate because the change in concentration was greater and, therefore, analytical measurement errors would likely be a smaller percentage of the measured value. Comparing these results with those of the flooded wetlands experiments indicates that about 25% of the observed DOC loading of approximately 25 g/m^2 -year may have been contributed from decay of fresh wetland vegetation.

Soil Water Extraction Experiment

The soil water extraction experiment was designed to quantify and compare potential concentrations of DOC and associated variables in soil samples collected from agricultural field and wetland locations in the Delta. This experiment does not quantify the actual release of these variables into Delta channels because the water movement through or from the soil water is not evaluated and the possible conversion or uptake of DOC within the soil column is not quantified. As a secondary objective, the chemical composition of the peat soil samples provided a general characterization of peat soil on Holland Tract.

Methods

Soil samples were collected on February 27, 1992, with a scoop from the soil surface and from the bottom of holes 2 feet (0.6 m) deep at two arbitrarily selected locations in the Holland Tract demonstration wetland and at two arbitrarily selected locations in an adjacent field that had been farmed during 1991. Thus, a total of eight soil samples were collected, two from each of the four locations. Each of the soil samples was then split into three 1-kilogram (kg) portions for saturated soil water extraction, as described below. Thus, a total of 24 samples were analyzed.

The standard agricultural soil "saturated paste" technique was used to extract soil water from the samples. In this technique, just enough water is added to saturate the soil sample. This technique is used to extract concentrations of soil water salts and nutrients to which crop roots would be exposed. The saturated extract concentrations of constituents should approximate soil water concentrations for saturated soil conditions. This technique was used in experiments on salt tolerance of Delta corn (Hoffman et al. 1983).

In the standard extraction technique, the soil paste is allowed to stand for 2 hours before the soil water sample is vacuum extracted for chemical analyses. For this experiment, saturated soil samples were also held for 7 days and 30 days to determine whether the extracted water concentrations would change with a longer saturation period. This was to test the hypothesis that peat soils may leach large quantities of materials, as a tea bag does.

Wet soil samples of approximately 1 kg were saturated with the addition of deionized water. The extracted water (250-500 milliliters [ml]) was diluted to obtain approximately 1.5 liters needed for chemical

analyses. The required dilution factors were recorded. The primary chemical analyses were made by Anlab. Subsamples from these diluted extract volumes were sent to Stuart Krasner at MWD. The MWD-measured DOC, UVA, and THMFP data from these subsamples are presented and described here. Tables C3-8 (wetland soils) and C3-9 (agricultural soils) show all chemical analyses of the eight soil samples for the three holding times.

In its comment letter on the draft report, DWR commented that the initial soil moisture content is an important variable for determining the original quantity of soil material. Anlab determined initial soil moisture in the samples by drying a subsample of the soil. The solids content (percentage) and the volatile solids fraction (percentage) of the dry soil material were both measured for each sample. The moisture content can be calculated by subtracting the solids percentage from 100%. The initial water weight (in grams) is another expression of the moisture content in the initial weight of wet soil (grams). These soil moisture values are listed in Tables C3-8 and C3-9.

The extracted percentage of the total water and the carbon content of the soil were calculated for comparing and normalizing concentrations. The total water in the saturated soil sample is the original water content plus the added deionized water required to saturate the sample. The extracted fraction of the total soil water is the actual volume obtained following vacuum extraction. The carbon content of the soil was estimated from the initial (dry) weight of organic matter (volatile solids) in the soil, assuming a carbon content of 40% (average carbon content of organic materials). The percentages of solids, volatile solids, and extracted water volumes were quite consistent between the three holding-time treatments for each soil sample.

Results

The results of the soil analyses and the soil water extract concentrations for the three holding times are compared for groups of related parameters. Because separate soil subsamples were used for the three holding-time treatments, some variability in the soil properties and extracted water concentrations was expected. The mass of DOC or other chemical constituent in the saturated soil water volume can be calculated by multiplying the concentration observed in the extracted volume by the total estimated soil water volume (extract volume/percent water extracted/100).

Soil Properties. The wet weight and the dried weight for each soil extract sample were used to estimate the initial water weight (and volume) of each sample. The solids content varied from about 30% to 60%, which is typical of peat soils (Buckman & Brady 1960).

The initial volume of soil water was calculated from the weight of initial water (assuming 1 ml/g). The volume of water added to saturate the soil sample was recorded, and the total volume of water in the saturated sample was calculated. The extracted volume was recorded, and the portion of the total soil water volume represented by the extracted volume was calculated. The extracted portion of the total saturated soil water volume varied from about 25% to 50%. The remainder is retained in the soil under the vacuum conditions used for extraction.

The organic content of the soil samples was estimated from the volatile solids fraction and varied from 20% to 60% (Figure C3-22), which is typical of peat soils (Buckman & Brady 1960). The estimated mass of organic carbon in the soil samples was calculated, based on the assumption that 40% of the organic content of the soil was carbon, and ranged between 30 g and 90 g. This soil organic carbon content value was used to determine the fraction of soil organic carbon measured in the extracted water DOC.

Organics. DOC concentrations in the extracted water did not consistently increase with longer holding times (Figure C3-23). Some concentrations differed a great deal between the three holding-time treatments, but this variability between replicate soil samples was expected because they were separate subsamples. The highest DOC concentrations and the greatest differences between soil samples were observed in the two surface agricultural soil samples. Although other samples had DOC concentrations between 30 mg/l and 90 mg/l, the agricultural surface samples had DOC values between 110 mg/l and 240 mg/l. These soil water concentrations represent the highest possible DOC concentrations in drainage water from these soil samples because drainage processes would normally provide some dilution of these soil water concentrations.

Ultraviolet Absorption. The UVA values for the extracted water samples showed a similar pattern (Figure C3-24), with no consistent increases related to holding time. The UVA values were generally similar ($1-2 \text{ cm}^{-1}$) for all the bottom samples and the surface wetland soils. The UVA values were much higher ($4-12 \text{ cm}^{-1}$) for the surface agriculture soils. These represent the highest possible UVA values in drainage or leaching

water from these soil samples because drainage processes would provide some dilution of these values.

Figures C3-23 and C3-24 indicate that the Anlab and MWD measurements for both DOC and UVA from the soil extract samples were quite similar, increasing confidence in the general results of this experiment.

The ratios of UVA to DOC were similar for all wetland and bottom agricultural samples, with values generally of 0.025-0.040 (Figure C3-25), similar to the ratios from barrel sample measurements from the vegetation decay experiment (Figure C3-18). The surface agricultural samples gave UVA/DOC values greater than 0.04. Amy et al. (1990) reported that the UVA/DOC ratio for river inflow water was about 0.025 and for several Delta agricultural drainage samples averaged 0.045.

DWR's comment letter suggested that the ratio of UVA to DOC may indicate the reactivity of the DOC material to form THM. UVA, rather than the more general DOC measurement, has been used in other studies to indicate the presence of reactive THM precursors (suspected to be fulvic and humic acids). If the ratio between UVA and DOC is slightly different for each source of DOC, possible source variation in the yield of THM from DOC can be estimated by using this UVA measure. Therefore, UVA may provide a much simpler measurement and perhaps a more direct index of THM precursors.

Delta peat soils appear to have somewhat higher UVA/DOC ratios (0.025-0.060 in Figure C3-25) than decaying vegetation samples (0.025-0.030 in Figure C3-18). In comparison, DWR MWQI data for 1990-1991 showed that samples of Delta export water had UVA/DOC ratios of 0.025-0.035, whereas the Sacramento River has lower UVA/DOC ratios of 0.020-0.025. MWQI data for 1990-1991 from agricultural drains on the DW project islands (Bouldin and Bacon Islands and Webb and Holland Tracts) had average UVA/DOC ratios of 0.035-0.050. UVA values may therefore differ slightly between water from wetlands (fresh vegetation) and from agricultural (soil and organic residue) drainage, with agricultural drainage contributing higher UVA values for the same DOC concentration.

Ratio of Dissolved Organic Carbon to Soil Organic Carbon. DOC measurements in the extracted water can be compared with the estimated soil sample organic carbon content (actual carbon content measurements were not included in study design) to provide an index of the fraction of the organic carbon in the soil that is dissolved as DOC. If the total DOC mass (mg) in the

saturated soil water volume is compared with the TOC content of the soil sample (g), the relative magnitude of the potential source of DOC from these soil samples can be indexed and comparatively assessed. Measurement of the soil-sample carbon content should be made in future tests of this sort.

Soil sample carbon content was estimated from the measured volatile solids fraction, based on an assumed carbon content of 40%. For example, the first column of Table C3-8 indicates that the 2-hour holding time sample from the surface of wetlands site 1 had an initial weight of 1,200 g, a solids content of 58%, and a volatile solids content of 28%. The soil sample is calculated to have a carbon content of 78 g ($1,200\text{g} \cdot .58 \cdot .28 \cdot .40 = 78\text{g}$). The corresponding ratio of DOC to soil organic carbon was 0.39 mg/g ($30\text{mg}/78\text{g} = .39\text{ mg/g}$).

In this experiment, the bottom samples from all four locations had similar ratios of DOC to soil organic carbon of 0.4-0.8 milligrams per gram (mg/g), suggesting that only 0.04% to 0.08% of the soil organic carbon is dissolved in the soil water (Figure C3-26). The surface wetland samples also had similar ratios of DOC to soil organic carbon of 0.4-0.8 mg/g. In contrast, the surface agricultural soil samples had ratios of DOC to soil organic carbon of 1.0-2.2 mg/g. The magnitude of these ratios suggests that only a very small fraction of the soil organic carbon is readily dissolved in the saturated soil water, even with a holding time of 30 days. The ratios of DOC to carbon in surface agricultural soil samples of 1-2 mg/g suggest that only 0.1% to 0.2% of the organic carbon in the soil samples is dissolved in the soil water. The availability of DOC is considerably greater (two to three times) in the surface agricultural soils than in the wetland soils or deeper agricultural soils.

Carbon Content of Trihalomethane. Figure C3-27 shows the C-THM values measured by MWD. By calculating the C-THM/DOC ratio, the yield of C-THM from DOC can be determined. As shown in Figure C3-28, the C-THM/DOC ratio was between 4.5 $\mu\text{g}/\text{mg}$ and 9 $\mu\text{g}/\text{mg}$, suggesting that about 0.5-1.0% of the DOC becomes THM molecules during the THMFP assay performed by MWD. These ratios for the soil extract samples are similar to those obtained by MWD for the vegetation decay experiment samples (7-12 $\mu\text{g}/\text{mg}$, or 0.7-1.2%), as shown in Figure C3-20.

Recent work by DWR and MWD indicates that the yield of C-THM from DOC depends on the strength of the chlorine dose relative to the DOC concentration (DWR 1992). This relationship is described below, under "Relationship between Dissolved Organic Carbon, Bromide, Chlorination, and Trihalomethanes". The

MWD technique, however, uses a constant chlorine-to-DOC ratio of about 3. The similar C-THM/DOC ratios from the vegetation and soil experiments suggest that the reactivity of DOC to form THM molecules during chlorination is generally similar for both vegetation decay and soil extract sources of DOC.

MWD commented on the draft report that the similar relative yield of C-THM from DOC for both agricultural and wetlands soils emphasized the need to quantify the mass balance of DOC from Delta soils under alternative land management practices. The greater concentrations of DOC in agricultural soils are only significant if the DOC concentrations are leached and transported to the Delta drains by agricultural water management. These soil water measurements suggest that the maximum possible DOC concentrations in drainage water from agricultural surface soils are considerably higher than concentrations from wetland or subsurface soils. Because it is likely that the movement of water through the agricultural soils during irrigation and salt leaching is greater than the movement through wetland soils, the mass of DOC from agricultural soils is likely to be higher than from wetlands. However, these DOC mass measurements were not made in this experiment.

Salts. Extract concentrations of salts were somewhat variable among the soil samples and the holding-time treatments, as shown for the general variables of TDS and EC in Figure C3-29. The agricultural-2 samples had extremely high salt concentrations. Calcium and magnesium showed a similar pattern, with variations not related to the extract holding time. Individual anions and cations generally show constant ratios in each soil sample, independent of the saturated holding time. Salt concentrations did not show consistent increases with saturation holding time, perhaps because soluble salts are readily available and dissolve quickly.

pH. DWR recommended that reduction-oxidation (redox) potential be measured for each soil sample to demonstrate the general chemical conditions for each sample. Alternatively, the pH of a soil water extract provides an indication of the general chemical conditions of the soils. Table C3-9 indicates that extracts from all agricultural soil samples had pH values between 5.6 and 6.6. The surface wetland soil extracts had pH values between 5.0 and 5.6, and the bottom (2-foot-deep) wetland soil extracts had the lowest pH values, between 4.5 and 5.1 (Table C3-8). These pH values generally confirm the hypothesis that agricultural soils would be more oxidized (with higher pH) than wetland soils and may therefore contribute more DOC than wetland soils would contribute to Delta waters.

Conclusions

The soil sample extracts provide a relative index of the potential for soil drainage or leaching to contribute to UVA, DOC, minerals, and nutrients in drainage or ponded water. This experiment generally confirmed the hypothesis that surface agricultural soils constitute the greatest potential source of DOC and that wetlands soils are less of a potential source than agricultural soils. This provides an answer for question 4 (What are the relative contributions of DOC and associated water quality variables from agricultural and wetland soils?): agricultural surface soil has approximately twice the DOC yield index as wetland soils (Figure C3-26).

Salts, UVA, and DOC (humic material) appear to be rapidly dissolved from the soil matrix into the saturated water. The potential contribution of these materials from different soils can be determined from the soil water extraction procedure demonstrated with this experiment, but the actual movement of these materials from soils into drainage or leaching water depends on water movement and other factors that were not addressed by these experiments.

The ratio of DOC to soil organic carbon provides an appropriate index for comparing the potential DOC contribution from soils, but the actual amount of DOC released from the soils cannot be determined unless it is known what volume of soil water is removed during agricultural practices or is leached into a flooded wetland or storage water volume. It does appear, however, that wetland soils would yield lower DOC loading than agricultural soils if a similar volume of soil water were extracted during agricultural practices and wetland flooding.

Similar experiments might be performed to characterize the potential for release of DOC from other Delta soils. It appears that the basic 2-hour holding time is sufficient to obtain representative extract water concentrations for salts and organics. The similarity between the 2-hour measurements and 7-day and 30-day measurements suggests that the DOC contribution from peat soils does not increase with holding time. These soil extract water concentrations characterize the potential sources of organics from the soil matrix but cannot be directly used to estimate the loading to agricultural drainage water or to flooded wetlands or storage water.

RELATIONSHIP BETWEEN DISSOLVED ORGANIC CARBON, BROMIDE, CHLORINATION, AND TRIHALOMETHANE

One of the major purposes of measuring the contributions to Delta waters of DOC from Delta agricultural and wetland islands is to calculate the increase in DOC at the Delta export locations and estimate the anticipated THM concentrations in treated drinking water resulting from these increases. Increased bromide concentrations during periods of seawater intrusion or from San Joaquin River sources may also affect the anticipated THM concentrations in treated drinking water. Two basic methods can be used to estimate the THM concentrations in treated drinking water:

- Predict THM based on levels of basic water quality variables and the expected chlorination dose and time in the water treatment plant, using a regression equation developed from previous THM tests. This is the method used in the EPA water treatment plant (WTP) THM model (Appendix C5, "Modeling Trihalomethane Production at a Typical Water Treatment Plant Using Delta Export Water").
- Estimate the THMFP from a chemical assay procedure to identify the relative potential to form THM (but not the actual THM concentration). This is the method used by DWR in its THMFP assay for Delta channel water and drainage water and the method used by MWD in its simulated distribution system (SDS) assay.

Following the analysis of available DWR and MWD data and the experimental results described in this appendix, a generalized method for estimating THM concentrations for any combination of DOC, bromide, and chlorination dose has been developed that is sufficiently accurate for impact assessment purposes. This generalized method provides a conceptual framework for understanding the yield of C-THM from DOC and the incorporation of bromine into the THM molecules. This method is applicable for the full range of possible chlorination doses, and therefore can be used to predict THMFP assay, SDS assay, or actual treatment plant THM data. Figure C3-30 illustrates the method for estimating THM concentrations from DOC, bromide, and chlorination (Cl⁺) dose.

Yield of C-THM from Dissolved Organic Carbon

The first step in the generalized method is to describe the expected yield of C-THM from the DOC concentration. The DWR MWQI data for Delta water indicates that the yield of C-THM is approximately 1-2% of the DOC concentration. However, it is recognized that this THM yield is a function of chlorine dose and is therefore much lower in the SDS assay or actual treated water than in the THMFP assay.

The THMFP assay used by DWR MWQI to estimate the THMFP of Delta water and agricultural drainage uses a relatively strong initial chlorine dose (120 mg/l Cl⁺) with an incubation time of 7 days at 25°C (DWR 1992). The ratio of chlorine to DOC would be 40:1 for low DOC concentrations (3 mg/l) and would decrease to 4:1 for high DOC concentrations (30 mg/l). The SDS assay, used by MWD to estimate actual distribution system THM concentrations, uses a variable chlorination dose ($3 \times \text{DOC} + 8 \times \text{NH}_3$) to oxidize the ammonia and provide a chlorine-to-DOC ratio of about 3:1 at 25°C (Symons et al. 1993). Actual chlorine doses at typical water treatment plants may be characterized by a chlorine-to-DOC ratio of less than 1 (Appendix C5, "Modeling of Trihalomethane Production at a Typical Water Treatment Plant Using Delta Export Water").

Results from several special THMFP and SDS assays with variable chlorine doses performed by MWD and DWR (DWR 1992) suggest that the yield of C-THM would increase rapidly at low chlorine-to-DOC ratios and level off at relatively high chlorine-to-DOC ratios. A half-saturation curve was tested as a reasonable way to describe this tendency for the C-THM yield to saturate at high chlorine doses. The yield of C-THM as a percentage of DOC was estimated as a function of the chlorine-to-DOC ratio that was used as the chlorine saturation variable.

The maximum yield of C-THM was estimated as 2%, based on the maximum yield observed in the MWQI Delta channel data, having chlorine saturation values (120/DOC) of greater than about 20 (see Figure C1-8 in Appendix C1, "Analysis of Delta Inflow and Export Water Quality Data"). The half-saturation value for chlorine saturation could not be estimated from the MWQI Delta channel data, because few of these samples had low chlorine saturation values. The MWQI agricultural drainage samples, however, had much lower chlor-

ine saturation values (1-20) because the DOC concentrations were much higher in these samples. The chlorine saturation value that gives a C-THM yield of 1% DOC is the half-saturation coefficient. This coefficient was estimated as a chlorine-to-DOC ratio of approximately 5. The yield of C-THM is therefore estimated as:

$$\text{C-THM/DOC (\%)} = 2 \cdot \text{Cl}^+/\text{DOC}/(5+\text{Cl}^+/\text{DOC})$$

This relationship was then tested with the MWD SDS data, which represented relatively low chlorine saturation values (1-3). All three data sets generally followed (with considerable scatter) this estimated half-saturation curve for C-THM yield. (Figures 3C-31 [channels], 3C-33 [drains], and 3C-35 [SDS]).

Bromine Incorporation

The second step in the general method to estimate THM concentrations is to calculate the bromine incorporation (n), with a value between 0 and 3, as a function of the bromine saturation, defined as the molar ratio of bromine to THM halogen sites ($3 \cdot \text{THM}$). Another half-saturation relationship between the bromine incorporation and the bromine saturation variable was tested as a reasonable way to describe this bromine saturation. The bromine saturation value is calculated as:

$$\begin{aligned} \text{Br saturation} &= \frac{\text{Br}/79.9}{3 \cdot \text{C-THM}/12} \\ &= \text{Br}/(\text{C-THM} \cdot 20) \end{aligned}$$

The maximum possible bromine incorporation value is 3, so the half-saturation coefficient was estimated as the bromine saturation value that gave a bromine incorporation (n) of 1.5. This half-saturation coefficient was approximately 2. The half-saturation curve for bromine incorporation (n) is:

$$n = 3 \cdot \text{Br saturation} / (2 + \text{Br saturation})$$

The bromine concentration was estimated for some samples without bromine measurements as 0.0035 · chloride, using the ocean ratio of bromide to chloride. All MWQI and MWD data generally follow (with some scatter) this bromine incorporation curve (Figures 3C-32 [channels], 3C-34 [drains] and 3C-36 [SDS]).

Trihalomethane Concentration

The third step in the general method to estimate THM concentration is to calculate the final THM concentration from the C-THM and bromine incorporation (n) estimates. With no bromine incorporation (n=0), the THM molar weight is 119 g/mole. With complete bromine incorporation (n=3), the THM molar weight is 252.5 g/mole, for an incremental molar weight of 44.5g for each integer of bromine incorporation (n). The THM concentration is therefore:

$$\text{THM } (\mu\text{g/l}) = \text{C-THM}/12 \cdot (119 + n \cdot 44.5)$$

Trihalomethane Species

A simple probability calculation can be used to estimate the concentration of individual THM molecules (Hutton and Chung 1994). Because the probability that any one halogen site is occupied by bromine is n/3, the probability that a site is occupied by chlorine is 1-n/3. The distribution (fraction) of THM species can then be estimated as:

$$\begin{aligned} \text{CHCl}_3 &= (1-n/3)^3 &= 1 - n + 1/3 n^2 - 1/27 n^3 \\ \text{CHBrCl}_2 &= 3 (1-n/3)^2 (n/3) &= n - 2/3 n^2 + 1/9 n^3 \\ \text{CHBr}_2\text{Cl} &= 3 (1-n/3) (n/3)^2 &= 1/3 n^2 - 1/9 n^3 \\ \text{CHBr}_3 &= (n/3)^3 &= 1/27 n^3 \end{aligned}$$

Figures C3-31 and C3-32 show the DWR MWQI Delta channel measurements of C-THM yield and bromine incorporation (n). These data have relatively high chlorine-to-DOC ratios and provide an estimate of the maximum yield of C-THM from DOC of about 2%. There is certainly a great deal of scatter about the proposed chlorine saturation curve, caused by possible variations in the assay conditions or deviations from the general saturation curve.

The bromine incorporation curve for the DWR MWQI Delta channel measurements follows the proposed bromine saturation curve through the entire range of bromine saturation, including some high bromide concentration samples from Mallard Island.

Figures C3-33 and C3-34 show the DWR MWQI Delta agricultural drainage measurements of C-THM yield and bromine incorporation (n). These data have lower chlorine-to-DOC ratios and provide an estimate of the half-saturation coefficient for chlorine saturation of about 5. The C-THM yield appears to be limited at lower chlorine-to-DOC ratios, confirming the general saturation curve description. There is certainly a great deal of scatter about the proposed chlorine saturation curve, caused by possible variations in the assay conditions or deviations from the general saturation curve.

The bromine incorporation curve for the DWR MWQI Delta agricultural drainage measurements follows the proposed bromine saturation curve in the lower range of bromine saturation, caused by much higher C-THM formation with relatively little bromide concentration in the samples.

Figures C3-35 and C3-36 show the MWD SDS assay results for C-THM yield and bromine incorporation (n) from Delta water. These data have much lower chlorine-to-DOC ratios and are more representative of actual water treatment plant conditions. The C-THM yield appears to be definitely limited at these low chlorine-to-DOC ratios, confirming the general chlorine saturation curve description and the half-saturation coefficient for chlorine saturation of approximately 5. There is some remaining scatter about the proposed chlorine saturation curve, caused by variations in the assay conditions (incubation time and temperature) or deviations from the general saturation curve.

The bromine incorporation curve for the MDW SDS assay results for Delta water, including some bromine spike experiments, follows the proposed bromine saturation curve throughout the range of bromine saturation, caused by much lower C-THM formation compared with the available bromide concentration in the samples.

These three independent data sets of THM assay measurements provide some confirmation of the general conceptual framework for estimating THM concentrations from the DOC, bromide, and chlorination conditions. This method can be used for assessment of the potential effects of DW project discharges on Delta channel DOC concentrations and the expected change in THM concentrations in treated drinking water exported from the Delta. It therefore can be used for mitigation monitoring of DW discharges to prevent significant adverse impacts on treated drinking water THM concentrations.

SUMMARY OF RESULTS

The water quality experiments described in this appendix demonstrate that concentrations of organic THM precursors are consistently related to concentrations of other nutrients and minerals in the Delta. Vegetation and soils in the Delta each have characteristic chemical compositions that produce distinctive residual chemical compounds during decay and oxidation.

Many of the observed relationships among these organic variables are similar to those described by the DWR MWQI data from Delta channels and agricultural drains (see Appendix C1, "Analysis of Delta Inflow and Export Water Quality Data", and Appendix C2, "Analysis of Delta Agricultural Drainage Water Quality Data"). DOC is the major variable of concern as a measurement of organic THM precursors produced from vegetation and peat soils. DOC exhibits consistent relationships with UVA and C-THM. The consistent relationships among these variables provide a solid basis for developing impact assessment models and for specifying mitigation monitoring requirements for DW operations.

The vegetation decay experiment in 1992 demonstrated that little (approximately 3-4%) of the organic carbon produced by decaying vegetation remains in the water as DOC; most is lost as CO₂ during aerobic decomposition. Most of the minerals (calcium, magnesium, and potassium) and nutrients (nitrogen and phosphorus), however, remain dissolved in the water in concentrations that reflect the original plant composition.

DOC concentrations produced by decaying vegetation may be most closely related to the lignin content of the vegetation. The observed DOC load produced by wetland vegetation was estimated to be between 5 g/m² and 7.5 g/m². The expected DOC load from corn crop residues left in agricultural fields is estimated to be approximately four times as much, based on a much larger biomass, with approximately the same lignin content. Contributions of DOC from corn crop residues in the Delta have not been measured directly.

The 1992 soil water extraction experiment demonstrated that little (less than 0.2%) of the organic carbon in Delta peat soils was dissolved in the soil water. The ratio of DOC to soil carbon was greater (two times), however, in surface samples from the agricultural field than in the deeper samples from the agricultural field or in samples from the demonstration wetland. This experiment indicated that the availability of DOC in soil water is greater in surface peat soils under agricultural conditions than in wetland soils.

The 1989-1990 flooded wetland and seasonal water storage experiments in the Holland Tract demonstration wetland indicated a DOC load in the wetland of approximately 25 g/m². Apparently, almost all this DOC load originated from the vegetation and surface residues on the wetland soil; the DOC load did not increase substantially during the 3-month water storage period from peat soil leaching. The vegetation experiment DOC estimate of 5-7.5 g/m² indicated that decay of fresh wetland vegetation may account for only 25% of the estimated DOC load from the wetland. Therefore, the remainder must have originated from surface peat soil oxidation or vegetation residues from previous growing seasons.

A direct estimate of DOC load from agricultural drainage on Holland Tract or any other Delta island is not available because the MWQI does not yet have access to drainage volumes to combine with the DOC concentration measurements. For the EIR/EIS impact assessment, the probable DOC load conditions for the DW project and for no-project agricultural drainage from the DW islands must be estimated.

Because direct measurements are not available, the most reasonable procedure for assessing the potential effects of DW project operation on DOC is to combine available measurements in a conceptual model of Delta island agricultural water and salt management. Such a model can then be used to estimate drainage quality for the Delta agricultural islands and DW project islands. Such a conceptual model of Delta agricultural water management, salt balance, and organic carbon cycle is presented in Appendix C4, "DeltaDWQ: Delta Drainage Water Quality Model". Potential effects of Delta export water quality (especially bromide and DOC concentrations) on THM concentrations in treated drinking water are presented in Appendix C5, "Modeling of Trihalomethane Production at a Typical Water Treatment Plant Using Delta Export Water".

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Table C3-1. Demonstration Wetland Biomass Composition Compared with Bouldin Island Corn Biomass Composition

Sample	Dry Weight (gram)	Cellulose (percent)	Hemi- cellulose (percent)	Lignin (percent)	Biomass (ton/acre)	Biomass (kg/sq. m)	Lignin (kg/sq. m)
Holland Tract Demonstration Wetlands Vegetation Samples^a							
October 1989							
1	107	35.4	27.7	4.6	1.71	0.38	0.02
2	153	36.2	28.2	4.0	2.45	0.55	0.02
3	130	33.6	24.3	5.7	2.08	0.47	0.03
4	184	32.9	27.4	5.5	2.94	0.66	0.04
5	191	28.5	35.5	4.0	3.06	0.68	0.03
6	260	25.6	30.4	6.6	4.16	0.93	0.06
7	123	22.9	34.4	3.8	1.97	0.44	0.02
8	197	37.9	22.8	5.8	3.15	0.71	0.04
Average	168.1	31.6	28.8	5.0	2.69	0.60	0.03
November 1989							
1	82	35.4	27.0	4.2	1.31	0.29	0.01
2	129	35.4	26.0	4.2	2.06	0.46	0.02
3	108	35.8	21.1	7.4	1.73	0.39	0.03
4	116	38.3	25.6	4.7	1.86	0.42	0.02
5	204	32.2	28.2	5.7	3.26	0.73	0.04
6	126	34.7	20.7	10.9	2.02	0.45	0.05
7	112	37.7	25.2	6.6	1.79	0.40	0.03
8	222	40.8	23.2	5.5	3.55	0.80	0.04
Average	137.4	36.3	24.6	6.2	2.20	0.49	0.03
January 1990							
1	83	36.7	26.6	5.1	1.33	0.30	0.02
2	71	39.7	26.9	3.8	1.14	0.25	0.01
3	114	36.5	21.9	8.3	1.82	0.41	0.03
4	103	41.6	27.7	4.9	1.65	0.37	0.02
5	168	30.1	30.1	7.8	2.69	0.60	0.05
6	71	33.3	25.0	6.3	1.14	0.25	0.02
7	143	37.6	23.9	6.8	2.29	0.51	0.03
8	148	40.7	24.5	6.8	2.37	0.53	0.04
Average	112.6	37.0	25.8	6.2	1.80	0.40	0.03
Grand Average	139.4	35.0	26.4	5.8	2.23	0.50	0.03
Bouldin Island Corn Stalks^b							
November 1989							
1	201	42.2	29.9	7.2	6.6	1.5	0.11
2	213	40.7	27.9	7.1	7.0	1.6	0.11
3	280	36.8	28.8	7.4	9.2	2.1	0.15
Average	231	39.9	28.9	7.2	7.6	1.7	0.12

^a Each sample was composite of three 1-ft² clip plots of aboveground biomass. Species composition varied and was dominated by watergrass and smartweed. Samples 1-4 were flooded vegetation; samples 5-8 were dry vegetation.

^b Each sample was one stalk with roots but without the ear. Corn is planted at a density of 30,000 stalks per acre.

Table C3-2. Water Quality of the Holland Tract Demonstration Wetland during the Flooded Wetland Period of October 1989--January 1990

Variables	Units	Rock Slough	Composite	Sampling Dates										
		at Old River	Inflow	Nov 3	Nov 10	Nov 17 ^a	Nov 17 ^a	Nov 30	Dec 8	Dec 15	Dec 22	Dec 29	Jan 5	Jan 15
		Oct 2	Oct 19											
Water depth gage	inches		NA	NA	23.25	22.25		23.75	23.75	23.25	23.00	23.00	23.25	24.75
Field temperature	°C		21.0	NA	14.0	11.0		10.5	9.5	9.5	5.3	6.3	7.8	11.5
TOC ^b	mg/l	3.5	4.3	14.3	16.9	20.4	20.4	30.7	32.0	32.1	35.6	38.6	37.5	38.4
Color	units	20	NA	100	200	200	150	240	350	350	300	310	325	250
pH	units		7.8	6.6	8.2	6.8	6.9	6.8	6.9	6.8	7.0	7.0	7.0	7.1
EC	µS/cm	520	677	826	809	831	840	816	891	737	725	746	715	680
TDS	mg/l		556	590	501	511	485	578	557	570	471	415	456	434
Chloride	mg/l	97	177	188	169	202	197	187	178	191	172	158	159	175
Sulfate	mg/l		30	65	66	80	78	105	88	99	97	92	90	83
Nitrate-N	mg/l		0.31	<.05	<.05	<.05	<.05	<0.5	<0.5	<.05	<.05	<.05	<.05	<.05
Bromide	mg/l		0.55	0.61	0.64	0.68	0.67	0.58	0.56	0.62	0.65	0.60	0.54	0.57
Alkalinity	mg/l		67	58	60	66	66	66	72	68	73	77	72	81
Calcium	mg/l		18	27	29	29	33	36	38	36	40	40	40	38
Magnesium	mg/l		18	22	23	22	24	27	27	26	28	28	27	26
Sodium	mg/l	62	97	106	108	110	114	111	113	104	108	104	101	102
Chloroform	µg/l	250	130	1,500	1,300	1,800	1,800	3,500	2,900	2,800	3,300	2,300	2,800	2,600
Bromodichloroform	µg/l	83	120	320	240	250	230	400	470	350	320	250	390	320
Dibromochloromethane	µg/l	82	130	42	33	25	24	50	47	32	42	19	30	37
Bromoform	µg/l	9	24	ND	ND	ND	ND	4	ND	ND	ND	ND	ND	ND
THMFP	µg/l	424	404	1,862	1,573	2,075	2,054	3,954	3,417	3,182	3,662	2,569	3,220	2,957
C-THM	µg/l	40	33	193	164	220	218	420	359	338	391	274	341	314
Cl-THM	µg/l	272	189	1,480	1,266	1,714	1,705	3,296	2,791	2,648	3,082	2,158	2,665	2,458
Br-THM	µg/l	112	182	189	143	142	131	238	266	196	189	137	214	185

Notes:

NA = Not analyzed.

ND = Not detected.

^a Replicate samples.^b Organic carbon measured in this experiment is assumed to be dissolved; therefore, TOC is equivalent to DOC.

Table C3-3. Water Quality of the Holland Tract Demonstration Wetland during the Seasonal Water Storage Period of April-July 1990

Variables	Units	Rock Slough at Old River	Surface Samples						Bottom Samples					
		April 25	April 23	May 7	May 18	June 4	June 25	July 25	April 23	May 7	May 18	June 4	June 25	July 25
Water depth gage ^a	inches		53	58	57	56	52	56						
Field temperature	°C		19.5	22	21	21.8	23.5	26	19.3	22	21	21.5	23	23.5
Field dissolved oxygen	mg/l		6	5.5	5.8	6.8	6.8	8.8	5.5	4.3	5.8	6.4	6.2	6.6
Secchi depth	feet		2.9-3.1	1.9-2.8	3.1-3.4	3.0-3.5	3.0-4.0	3.2	2.9-3.1	1.9-2.8	3.1-3.4	3.0-3.5	3.0-4.0	3.2
TOC ^b	mg/l	3	30	32	32	33	31	31	29	32	31	32	31	31
Color	units	20	250	200	250	200	200	200	250	250	250	200	225	200
pH	units		7.5	7.7	7.6	7.8	7.6	7.7	7.6	7.7	7.7	7.7	7.6	7.8
Organic nitrogen	mg/l		1	1.5	1.5	1.1	1.5	1.3	1.9	1.5	1.4	1.3	1.2	1.5
Ammonia-N	mg/l		0.58	0.59	0.41	0.53	<.1	0.14	0.58	0.62	0.44	0.5	0.35	0.13
Total phosphorus	mg/l		0.18	<.05	<.05	<.05	<.05	0.07	0.2	<.05	<.05	<.05	<.05	0.15
Ortho phosphorus	mg/l		0.1	<.05	<.05	<.05	<.05	<.05	0.11	<.05	<.05	<.05	<.05	<.05
EC	μS/cm	864	938	940	988	964	955	807	937	938	984	965	965	803
TDS	mg/l	466	605	607	622	637	590	485	584	636	617	582	575	538
Chloride	mg/l	195	229	260	243	238	235	211	226	268	242	242	238	202
Sulfate	mg/l	39	43	43	40	38	33	23	43	43	40	39	34	23
Nitrate-N	mg/l	1.2	0.12	0.19	0.19	0.16	<.05	<.05	0.12	0.2	0.18	0.16	<.05	<.05
Bromide	mg/l	0.66	0.97	1	0.9	0.92	0.96	0.98	0.98	1	0.89	0.93	1	0.99
Alkalinity	mg/l	65	82	92	92	93	102	104	83	91	93	93	104	104
Calcium	mg/l	18	30	33	32	32	31	28	30	33	31	33	31	28
Magnesium	mg/l	20	25	26	27	25	25	23	25	26	26	25	25	23
Sodium	mg/l	120	147	158	159	152	153	137	147	158	156	153	153	136
Chloroform	μg/l	140	1,100	1,600	1,000	1,700	1,600	1,600	1,100	730	1,100	1,700	1,600	1,400
Bromodichloroform	μg/l	130	390	460	310	500	440	490	380	310	410	500	440	430
Dibromochloromethane	μg/l	130	69	93	100	69	100	95	48	62	97	100	100	79
Bromoform	μg/l	39	3	5	7	3	4	ND	3	6	5	3	3	ND
THMFP	μg/l	439	1,562	2,158	1,417	2,272	2,144	2,185	1,531	1,108	1,612	2,303	2,143	1,909
C-THM	μg/l	36	156	219	141	231	217	221	154	109	160	233	217	193
Cl-THM	μg/l	203	1,158	1,638	1,040	1,740	1,630	1,651	1,151	794	1,172	1,745	1,630	1,444
Br-THM	μg/l	201	247	302	236	301	296	313	226	205	280	325	295	272

Notes:

ND = Not detected.

^a Some siphoning of Old River water was used to maintain pond depth during the experiment.^b Organic carbon measured in this experiment is assumed to be dissolved; therefore, TOC is equivalent to DOC.

Table C3-4. Evaporation Effects: Water Quality Variables in the Control Samples for the Vegetation Decay Experiment

Barrel 5 Variables	Units	Sample Dates									
		1/23/92	2/27/92	3/10/92	3/10/92	3/31/92	3/31/92	4/14/92	4/14/92	4/29/92	4/29/92
Laboratory		AAL	MWD			AAL	MWD	AAL	MWD	AAL	MWD
DOC	mg/l	8.2	4.74			4.3	4.27	7.2	4.33	5.8	4.86
Color	units	30				15		10		10	
UVA @ 254nm	1/cm	0.164	0.129			0.129	0.113	0.12	0.112	0.132	0.124
UVA/DOC		0.0200	0.0272				0.0265	0.0167	0.0259	0.0228	0.0255
pH	units	7.3				8.5		7.4		7.6	
Organic nitrogen	mg/l	<0.5				2		<1.6		<1.7	
Ammonia-N	mg/l	0.26	<0.03			<0.05	<0.03	<.05	<0.03	<.05	<0.03
Total phosphorus	mg/l	0.13				0.03		0.09		0.08	
Ortho phosphorus	mg/l	0.11				<0.02		<.02		<.02	
EC	μS/cm	747				668		664		796	
TDS	mg/l							460		420	
Chloride	mg/l	160	136			130	141	180	144	170	170
Sulfate	mg/l	40				33		35		39	
Nitrate-N	mg/l	0.84				<0.02		0.02		0.03	
Bromide	mg/l		0.42			0.37	0.41	0.3	0.4	0.5	0.48
Bicarbonate	mg/l							76		83	
Anions	meq/l	5.4				4.4		7.0		7.0	
Calcium	mg/l	39				17		17		19	
Magnesium	mg/l	20				16		16		18	
Potassium	mg/l	6.1				5.3		5.6		5.6	
Sodium	mg/l	96				85		82		100	
Cations	meq/l	7.9				6.0		5.9		6.9	
Anions/Cations		0.68				0.72		1.20		1.00	
Sum of Ions	mg/l	367				291		419		442	
EC/Sum of Ions		2.0				2.3		1.6		1.8	
EC/TDS								1.4		1.9	
Bromide/Chloride		<0.0031	0.0031			0.0028	0.0029	0.0017	0.0028	0.0029	0.0028
Bromodichloromethane	μg/l		160				153		178		180
Bromoform	μg/l		26				32		37		37
Chloroform	μg/l		160				150		179		180
Dibromochloromethane	μg/l		138				141		173		165
THMFP	μg/l		484				476		567		562
Chlorine dose	mg/l		14.2				12.9		13		15.1
Chlorine residual	mg/l		3.75				6.25		4.25		5
pH of THMFP test	units		8.2				8.3		8.26		8.2
C-THM	μg/l		40				39		46		46
Cl-THM	μg/l		235				223		265		266
Br-THM	μg/l		209				214		256		250
Br-THM/Br ⁻	μg/mg		0.50				0.52		0.64		0.52
Bromine-Incorporation (n)			0.26				0.28		0.28		0.27
C-THM/DOC	μg/mg		8.4				9.1		10.7		9.5
C-THM/UVA			310				343		412		371

Table C3-5. Natural Loading Effects: Water Quality Variables in the Single-Dose (1X) Samples for the Vegetation Decay Experiment

Barrel 1 Variables	Units	Sample Dates									
		2/27/92	2/27/92	3/10/92	3/10/92	3/31/92	3/31/92	4/14/92	4/14/92	4/29/92	4/29/92
Laboratory		AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD
DOC	mg/l	15	16.94	16	12.44	13	13.59	14	13.23	18	15.4
Color	units	60		100		150		100		100	
UVA @ 254nm	1/cm	0.362	0.397	0.354	0.373	0.382	0.389	0.388	0.399	0.469	0.456
UVA/DOC		0.0241	0.0234	0.0221	0.0300	0.0294	0.0286	0.0277	0.0302	0.0261	0.0296
pH	units	6.7		6.7		6.8		6.6		6.8	
Organic nitrogen	mg/l	2.6				7.6		18		20	
Ammonia-N	mg/l	< 0.5	0.07	< 0.5	0.03	< 0.05	0.05	0.05	<.03	<.05	<.03
Total phosphorus	mg/l	1.1		1.6		1		1.7		1.9	
Ortho phosphorus	mg/l	0.74		0.39		0.23		0.07		0.04	
EC	µS/cm	732		748		773		773		913	
TDS	mg/l							460		510	
Chloride	mg/l	180	152	61	152	160	154	190	157	180	188
Sulfate	mg/l	44		16		32		38		36	
Nitrate-N	mg/l	<.02		<.02		<0.02		0.05		<.02	
Bromide	mg/l	0.39	0.49	0.31	0.47	0.4	0.4	0.4	0.46	0.5	0.52
Bicarbonate	mg/l							120		150	
Anions	meq/l	6.0		2.1		5.2		8.1		8.3	
Calcium	mg/l	19		20		23		24		28	
Magnesium	mg/l	19		18		20		20		24	
Potassium	mg/l	14		15		15		15		18	
Sodium	mg/l	79		88		86		90		110	
Cations	meq/l	6.3		6.7		6.9		7.2		8.6	
Anions/Cations		0.95		0.31		0.75		1.13		0.96	
Sum of Ions	mg/l	361		220		342		506		555	
EC/Sum of Ions		2.0		3.4		2.3		1.5		1.6	
EC/TDS								1.7		1.8	
Bromide/Chloride		0.0022	0.0032	0.0051	0.0031	0.0025	0.0026	0.0021	0.0029	0.0028	0.0028
Bromodichloromethane	µg/l		280		280		280		317		380
Bromoform	µg/l		1		1.5		1.5		1.6		2
Chloroform	µg/l		1,040		860		840		1,069		1,080
Dibromochloromethane	µg/l		55		73		71		76		84
THMFP	µg/l		1,376		1,214		1,193		1,463		1,546
Chlorine dose	mg/l		51.4		37.5		41		39.7		46.2
Chlorine residual	mg/l		6		2.95		4.25		3.4		5.5
pH of THMFP Test	units		8.2		8.23		8.24		8.23		8.16
C-THM	µg/l		140		121		119		148		154
Cl-THM	µg/l		1,055		898		880		1,101		1,139
Br-THM	µg/l		181		195		193		215		253
Br-THM/Br ⁻	µg/mg		0.37		0.41		0.48		0.47		0.49
Bromine-Incorporation (n)			0.064		0.080		0.081		0.073		0.082
C-THM/DOC	µg/mg		8.3		9.8		8.8		11.2		10.0
C-THM/UVA			353		326		306		370		338

Table C3-5. Continued

Barrel 2 Variables	Units	Sample Dates									
		2/27/92	2/27/92	3/10/92	3/10/92	3/31/92	3/31/92	4/14/92	4/14/92	4/29/92	4/29/92
Laboratory		AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD
DOC	mg/l	13	13.06	13	12.39	11	12.29	13	11.94	17	13.7
Color	units	70		100		100		100		100	
UVA @ 254nm	1/cm	0.384	0.39	0.337	0.352	0.365	0.373	0.386	0.387	0.458	0.433
UVA/DOC		0.0295	0.0299	0.0259	0.0284	0.0332	0.0303	0.0297	0.0324	0.0269	0.0316
pH	units	6.8	8.28	6.7		6.7		6.6		6.8	
Organic nitrogen	mg/l	3.4				9.4		16		19	
Ammonia-N	mg/l	ND	0.03		<0.03	0.05	0.04	0.05	<.03	<.05	<.03
Total phosphorus	mg/l	1.1		1.5		1.2		1.6		1.7	
Ortho phosphorus	mg/l	0.66		0.48		0.43		0.2		0.22	
EC	µS/cm	708		723		737		735		859	
TDS	mg/l							420		470	
Chloride	mg/l	180	149	110	143	150	144	190	147	190	175
Sulfate	mg/l	41		23		32		33		34	
Nitrate-N	mg/l	<.02		<.02		<.02		<.02		0.03	
Bromide	mg/l	0.34	0.5	0.35	0.45	0.33	0.41	0.3	0.45	0.4	0.49
Bicarbonate	mg/l							120		140	
Anions	meq/l	5.9		3.6		4.9		8.0		8.4	
Calcium	mg/l	18		20		22		23		25	
Magnesium	mg/l	18		18		19		19		22	
Potassium	mg/l	13		15		14		15		17	
Sodium	mg/l	72		88		82		82		110	
Cations	meq/l	5.9		6.7		6.6		6.7		8.3	
Anions/Cations		1.01		0.53		0.74		1.20		1.01	
Sum of Ions	mg/l	348		278		324		490		547	
EC/Sum of Ions		2.0		2.6		2.3		1.5		1.6	
EC/TDS								1.8		1.8	
Bromide/Chloride		0.0019	0.0034	0.0032	0.0031	0.0022	0.0028	0.0016	0.0031	0.0021	0.0028
Bromodichloromethane	µg/l		300		280		267		309		372
Bromoform	µg/l		1.1		1.5		1.3		1.5		1.8
Chloroform	µg/l		1,080		780		796		1,040		1,056
Dibromochloromethane	µg/l		55		73		63		71		80
THMFP	µg/l		1,436		1,134		1,127		1,421		1,510
Chlorine dose	mg/l		39.4		37.5		37.5		35.8		40.9
Chlorine residual	mg/l		1.8		5.7		4.5		3.4		5.3
pH of THMFP Test	units		8.3		8.21		8.24		8.24		8.15
C-THM	µg/l		146		113		113		143		151
Cl-THM	µg/l		1,100		827		834		1,071		1,113
Br-THM	µg/l		190		195		181		208		246
Br-THM/Br ⁻	µg/mg		0.38		0.43		0.44		0.46		0.50
Bromine-Incorporation (n)			0.065		0.086		0.080		0.072		0.081
C-THM/DOC	µg/mg		11.2		9.1		9.2		12.0		11.0
C-THM/UVA			375		320		302		371		348

Note:

ND = Not detected.

Table C3-6. Double Loading Effects: Water Quality Variables in the Double-Dose (2X) Samples for the Vegetation Decay Experiment

Barrel 3 Variables	Units	Sample Dates									
		2/27/92	2/27/92	3/10/92	3/10/92	3/31/92	3/31/92	4/14/92	4/14/92	4/29/92	4/29/92
Laboratory		AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD
DOC	mg/l	20	39.62	26	36.74	22	34.58	26	29.73	42	34.43
Color	units	150		100		150		100		250	
UVA @ 254nm	1/cm	0.595	0.611	0.613	0.645	0.671	0.625	0.636	0.691	0.944	0.883
UVA/DOC		0.0298	0.0154	0.0236	0.0176	0.0305	0.0181	0.0245	0.0232	0.0225	0.0256
pH	units	6.5		6.5		6.8		6.6		6.7	
Organic nitrogen	mg/l	8.2				14		32		28	
Ammonia-N	mg/l	0.05	0.21	0.1	0.16	0.06	0.4	0.12	0.45	0.14	0.91
Total phosphorus	mg/l	2.2		3		2.1		2.9		3.1	
Ortho phosphorus	mg/l	1.1		0.51		0.86		0.96		1.14	
EC	µS/cm	770		834		866		802		939	
TDS	mg/l							480		580	
Chloride	mg/l	170	145	110	143	140	146	180	150	180	175
Sulfate	mg/l	45		23		32		25		28	
Nitrate-N	mg/l	<.02		<.02		<.02		0.1		0.03	
Bromide	mg/l	0.39	0.43	0.34	0.42	0.37	0.42	0.3	0.43	0.5	0.55
Bicarbonate	mg/l							180		210	
Anions	meq/l	5.7		3.6		4.6		8.5		9.1	
Calcium	mg/l	22		24		27		28		31	
Magnesium	mg/l	22		21		22		22		25	
Potassium	mg/l	23		24		23		23		27	
Sodium	mg/l	88		93		88		84		100	
Cations	meq/l	7.3		7.6		7.6		7.5		8.7	
Anions/Cations		0.78		0.47		0.61		1.14		1.05	
Sum of Ions	mg/l	376		299		337		551		611	
EC/Sum of Ions		2.0		2.8		2.6		1.5		1.5	
EC/TDS								1.7		1.6	
Bromide/Chloride		0.0023	0.0030	0.0031	0.0029	0.0026	0.0029	0.0017	0.0029	0.0028	0.0031
Bromodichloromethane	µg/l		364		350		324		360		364
Bromoform	µg/l		0.55		0.19		0.32		0.33		0.29
Chloroform	µg/l		2,534		2,400		2,228		2,491		2,400
Dibromochloromethane	µg/l		33		35		36		42		39
THMFP	µg/l		2,932		2,785		2,588		2,893		2,803
Chlorine dose	mg/l		120.7		111		107.3		92.8		111
Chlorine residual	mg/l		21.5		19.8		16.3		4		1.75
pH of THMFP Test	units		8.3		8.23		8.26		8.25		8.06
C-THM	µg/l		310		294		273		305		295
Cl-THM	µg/l		2,417		2,292		2,128		2,379		2,299
Br-THM	µg/l		204		199		187		209		209
Br-THM/Br ⁻	µg/mg		0.48		0.47		0.44		0.49		0.38
Bromine-Incorporation (n)			0.033		0.034		0.034		0.034		0.035
C-THM/DOC	µg/mg		7.8		8.0		7.9		10.3		8.6
C-THM/UVA			507		456		437		442		335

Table C3-6. Continued

Barrel 4 Variables	Units	Sample Dates									
		2/27/92	2/27/92	3/10/92	3/10/92	3/31/92	3/31/92	4/14/92	4/14/92	4/29/92	4/29/92
Laboratory		AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD	AAL	MWD
DOC	mg/l	22	38.2	30	36	23	33.02	27	30.5	34	31.16
Color	units	100		150		100		150		200	
UVA @ 254nm	1/cm	0.53	0.544	0.58	0.593	0.54	0.663	0.60	0.66	0.77	0.826
UVA/DOC		0.0242	0.0142	0.0194	0.0165	0.0238	0.0201	0.0223	0.0216	0.0229	0.0265
pH	units	6.4	8.25	6.6		6.8		6.6		6.8	
Organic nitrogen	mg/l	11				7.5		29		23	
Ammonia-N	mg/l	ND	0.07	0.1	0.05	< 0.05	0.2	0.09	0.5	0.09	0.09
Total phosphorus	mg/l	2.2		3.7		1.7		2.1		1.8	
Ortho phosphorus	mg/l	0.9		0.51		0.9		0.54		0.47	
EC	μS/cm	867		840		866		914		984	
TDS	mg/l							530		610	
Chloride	mg/l	200	171	180		140	163	180	160	180	186
Sulfate	mg/l	54		37		32		29		33	
Nitrate-N	mg/l	< 0.02		< 0.02		< 0.02		0.47		0.05	
Bromide	mg/l	0.35	0.49	0.31	0.46	0.46	0.49	0.4	0.46	0.5	0.52
Bicarbonate	mg/l							170		200	
Anions	meq/l	6.8		5.8		4.6		8.5		9.0	
Calcium	mg/l	23		25		27		28		31	
Magnesium	mg/l	25		24		25		25		27	
Potassium	mg/l	27		27		26		26		29	
Sodium	mg/l	91		94		89		88		110	
Cations	meq/l	7.9		8.0		8.0		8.0		9.3	
Anions/Cations		0.86		0.73		0.58		1.06		0.97	
Sum of Ions	mg/l	427		393		344		555		620	
EC/Sum of Ions		2.0		2.1		2.5		1.6		1.6	
EC/TDS								1.7		1.6	
Bromide/Chloride		0.0018	0.0029	0.0017		0.0033	0.0030	0.0022	0.0029	0.0028	0.0028
Bromodichloromethane	μg/l		405		380		331		358		384
Bromoform	μg/l		1		0.25		0.41		0.46		0.34
Chloroform	μg/l		2,300		2,200		1,959		2,311		2,280
Dibromochloromethane	μg/l		45		41		41		42		42
THMFP	μg/l		2,751		2,621		2,331		2,711		2,706
Chlorine dose	mg/l				109		100.9		95.7		94.6
Chlorine residual	mg/l				20.5		13.8		3.7		2.25
pH of THMFP Test	units				8.22		8.25		8.24		8.07
C-THM	μg/l		288		275		244		285		284
Cl-THM	μg/l		2,229		2,128		1,893		2,218		2,201
Br-THM	μg/l		234		218		194		208		221
Br-THM/Br ⁻	μg/mg		0.48		0.47		0.40		0.45		0.42
Bromine-Incorporation (n)			0.041		0.040		0.040		0.036		0.039
C-THM/DOC	μg/mg		7.5		7.6		7.4		9.4		9.1
C-THM/UVA			530		464		369		432		344

Note:
ND = Not detected.

Table C3-7. Comparison of Chemical Composition of Plant Tissue
and Observed Concentrations in the Vegetation Decay
Experiment (in Percentages)

Chemical Element	Corn Shoots	General Plants	2X Barrels (1,000 g/m ²)
K	1.9	0.50-0.60	1.25
Ca	0.4	0.20-3.50	0.70
Mg	0.3	0.10-0.80	0.50
N	2.8	1.00-4.00	1.50
P	0.3	0.10-0.80	0.12
S	0.2	0.05-1.00	

Table C3-8. Holland Tract Demonstration Wetland Soil Sample Results

Variables	Units	Site 1						Site 2					
		Surface Samples			Bottom Samples			Surface Samples			Bottom Samples		
		2-Hour Holding Time	7-Day Holding Time	30-Day Holding Time									
Initial Weight ^a	g	1,200	1,000	1,000	1,000	1,000	755	1,000	1,000	1,000	1,000	1,000	1,000
Solids ^a	%	58	58	59	29	40	29	59	58	58	40	55	48
Percent Volatile ^a	%	28	27	29	58	36	58	21	24	24	18	21	21
Initial Water ^a	g	504	420	410	710	600	536	410	420	420	600	450	520
Deionized Water ^a	ml	500	260	250	100	25	70	250	270	216	10	96	0
Extract Volume ^a	ml	465	274	280	420	340	315	255	300	235	134	235	255
Percent Water Extracted ^a	%	46	40	42	52	54	52	39	43	37	22	43	49
Dilution Factor ^a		3	6	5	4	5	5	6	5	6	8	7	6
Organic Carbon-40% ^a	g	78	63	68	67	58	51	50	56	56	29	46	40
DOC ^a	mg/l	30	43	52	37	40	66	34	40	71	30	31	25
DOC ^b	mg/l	33	46	NA	34	41	NA	NA	38	NA	24	37	NA
Color ^a	units	120	90	150	160	120	180	180	180	210	220	100	90
UVA @254 nm ^a	1/cm	1.19	1.16	1.58	1.49	1.21	1.58	1.48	1.25	1.90	0.84	0.75	0.91
UVA @254 nm ^b	1/cm	1.08	1.27	1.25	1.28	1.26	1.32	1.15	1.23	1.5	0.7	0.74	0.62
UVA/DOC ^a		0.0397	0.0269	0.0304	0.0403	0.0301	0.0239	0.0436	0.0313	0.0268	0.0281	0.0242	0.0364
UVA/DOC ^b		0.0327	0.0276		0.0376	0.0307			0.0324		0.0292	0.0200	
DOC/Soil Organic Carbon ^a	mg/g	0.39	0.47	0.50	0.45	0.43	0.79	0.45	0.50	0.81	0.64	0.37	0.32
pH ^a	units	5	5.4	5.6	4.5	4.7	4.6	5.3	5.3	5.6	4.8	5	5.1
Organic nitrogen ^a	mg/l	2.5	3.5	6.5	3.8	< 0.25	<2.5	4.6	< 0.25	<3.2	4.6	4.4	<5.6
Ammonia-N ^a	mg/l	0.17	<0.3	0.43	0.83	0.28	0.99	0.35	1.6	0.36	0.69	< 0.39	0.44
Total phosphorus ^a	mg/l	<.09	0.12	<.1	<.08	<0.10	<.1	<.12	< 0.10	<.12	<.16	< 0.14	<.12
EC ^a	μS/cm	1,056	1,990	1,770	1,604	1,790	1,550	612	795	990	1,520	1,460	1,510
TDS ^a	mg/l	600	1,100	1,100	840	1,000	880	370	495	580	820	770	750
Chloride ^a	mg/l	80	300	180	210	310	220	25	42	80	160	420	200
Sulfate ^a	mg/l	220	450	400	210	420	210	140	370	340	140	250	210
Nitrate-N ^a	mg/l	16	21	0.85	4.1	11	<.1	11	3	1.8	4.4	6.6	0.8
Bromide ^a	mg/l	<1.8	< 12	<.15	<1.2	4	<.15	<3		<.6	<1.6	< 1.4	<.18
Bicarbonate ^a	mg/l	<7	22	<12	<10	<12	<12	<15	18	<15	24	< 17	<15
Anions ^a	meq/l	7.09	18.53	13.42	10.36	17.71	10.57	3.80	9.23	9.37	7.89	17.15	10.02

Table C3-8. Continued

Variables	Units	Site 1						Site 2					
		Surface Samples			Bottom Samples			Surface Samples			Bottom Samples		
		2-Hour Holding Time	7-Day Holding Time	30-Day Holding Time									
Calcium ^a	mg/l	54	120	130	96	110	80	19	34	52	56	55	72
Magnesium ^a	mg/l	23	41	46	34	36	30	11	16	22	26	24	31
Potassium ^a	mg/l	8.4	9	8.5	10	6.5	6	14	10	6	4	3.8	4.8
Sodium ^a	mg/l	100	130	150	160	130	120	55	80	120	100	120	160
Cations ^a	meq/l	9.18	15.30	17.07	14.85	14.32	11.87	4.62	6.77	9.80	9.42	10.06	13.26
Anions/Cations ^a		0.77	1.21	0.79	0.70	1.24	0.89	0.82	1.36	0.96	0.84	1.70	0.76
Sum of Ions ^a	mg/l	501	1,060	915	724	1,028	666	275	546	622	478	879	679
Sum Ions/TDS ^a		0.84	0.96	0.83	0.86	1.03	0.76	0.74	1.10	1.07	0.58	1.14	0.90
EC/TDS ^a		1.8	1.8	1.6	1.9	1.8	1.8	1.7	1.6	1.7	1.9	1.9	2.0
Bromodichloromethane ^b	µg/l	62	72		122	86		40	90		110	63	
Bromoform ^b	µg/l	<1.2	<2.4			<2.0		NA	NA		NA	NA	
Chloroform ^b	µg/l	2,400	2,688		2,140	2,640		2,090	4,950		1,280	1,449	
Dibromochloromethane ^b	µg/l	4	6		5	4		NA	NA		10	NA	
TTHMFP ^b	µg/l	2,472	2,760		2,260	2,720		2,130	5,040		1,400	1,512	
Chlorine dose ^b	mg/l	99	139		102	122		96	282		73	110	
Chlorine residual ^b	mg/l	47	84		33	80		26	81		25	52	
pH of THMFP test ^b	units	8.2	8		8.3	8.1		8.3	8.3		8.3	8.3	
C-THM ^b	µg/l	269	302		245	298		233	552		150	164	
C-THM/DOC ^b	µg/mg	8	7		7	7		6			6	4	
C-THM/UVA ^b		249	238		192	236		190	368		215	222	

Notes:

All soil samples were collected on 2/27/92. Surface samples were collected by scraping the ground surface with a small trowel; bottom samples were collected from a 2-foot-deep hole.

NA = Not analyzed (some samples were not analyzed by MWD because of insufficient extracted soil water).

^a Analyzed by AAL.

^b Analyzed by MWD.

Table C3-9. Agricultural Soil Sample Results

Variables	Units	Site 1						Site 2					
		Surface Samples			Bottom Samples			Surface Samples			Bottom Samples		
		2-Hour Holding Time	7-Day Holding Time	30-Day Holding Time	2-Hour Holding Time	7-Day Holding Time	30-Day Holding Time	2-Hour Holding Time	7-Day Holding Time	30-Day Holding Time	2-Hour Holding Time	7-Day Holding Time	30-Day Holding Time
Initial Weight ^a	g	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Solids ^a	%	46	45	45	38	34	29	57	55	55	54	58	55
Percent Volatile ^a	%	49	49	46	46	42	40	35	34	36	30	32	34
Initial Water ^a	g	540	550	550	620	660	710	430	450	450	460	420	450
Deionized Water ^a	ml	235	202	160	154	30	26	280	284	274	230	250	210
Extract Volume ^a	ml	300	335	345	315	305	350	295	305	335	280	245	260
Percent Water Extracted ^a	%	39	45	49	41	44	48	42	42	46	41	37	39
Dilution Factor ^a		5	5	4	5	5	4	5	5	5	5	6	6
Organic Carbon-40% ^a	g	90	88	83	70	57	46	80	75	79	65	74	75
DOC ^a	mg/l	190	130	120	60	44	41	130	110	240	65	85	56
DOC ^b	mg/l	178	148	NA	58	43	NA	131	113	NA	82	92	NA
Color ^a	units	2,000	750	600	220	150	180	350	500	2,000	180	210	240
UVA @254 nm ^a	1/cm	11.10	6.05	5.05	2.11	1.36	1.69	4.04	4.54	12.40	2.22	2.38	1.97
UVA @254 nm ^b	1/cm	10.7	5.98	4.48	1.86	1.36	1.44	4.06	4.56	NA	2.05	2.38	NA
UVA/DOC ^a		0.0584	0.0465	0.0421	0.0351	0.0308	0.0412	0.0310	0.0413	0.0517	0.0342	0.0280	0.0352
UVA/DOC ^b		0.0601	0.0404		0.0321	0.0316		0.0310	0.0404		0.0250	0.0259	
DOC/Soil Organic Carbon ^a	mg/g	1.63	1.11	1.03	0.66	0.53	0.65	1.16	1.08	2.19	0.69	0.77	0.49
pH ^a	units	5.8	6	6.2	5.8	6.4	6.3	5.7	6.1	6.6	5.6	5.7	6.2
Organic nitrogen ^a	mg/l	12	6.8	5.7	5.9	3	<2.2	11	6.2	10	6.2	5.5	3
Ammonia-N ^a	mg/l	0.32	< 0.30	0.67	0.46	< 0.28	0.56	1.6	< 0.33	0.76	0.58	< 0.30	<.3
Total phosphorus ^a	mg/l	0.2	< 0.10	0.12	<.1	<0.10	<.08	0.2	<0.10	0.39	<.1	< 0.12	<.12
EC ^a	μS/cm	455	1,440	2,610	3,225	2,700	1,800	9,000	2,710	525	7,200	11,500	4,300
TDS ^a	mg/l	640	1,000	1,900	1,900	1,400	1,100	6,000	1,800	740	6,500	6,600	2,600
Chloride ^a	mg/l	9	52	180	390	290	230	1,100	64	16	870	1,800	570
Sulfate ^a	mg/l	80	380	830	630	890	320	1,900	1,200	75	1,500	3,000	940
Nitrate-N ^a	mg/l	3.1	1.6	<.08	43	32	1.7	100	1.2	0.57	73	120	57
Bromide ^a	mg/l	<1	< 0.15	0.16	<10	< 4.0	0.32	<20	< 1.0	0.28	<20	< 1.0	<3.6
Bicarbonate ^a	mg/l	10	24	49	12	18	29	18	24	130	12	24	44
Anions ^a	meq/l	2.14	9.80	23.17	25.00	27.52	13.65	72.48	27.22	4.16	57.13	115.53	37.28

Table C3-9. Continued

Variables	Units	Site 1						Site 2					
		Surface Samples			Bottom Samples			Surface Samples			Bottom Samples		
		2-Hour Holding Time	7-Day Holding Time	30-Day Holding Time									
Calcium ^a	mg/l	26	90	210	220	160	120	850	160	42	650	840	280
Magnesium ^a	mg/l	9.5	38	92	100	80	60	410	75	16	310	450	160
Potassium ^a	mg/l	1.2	7	12	4.8	1.4	1.2	60	27	10	12	24	40
Sodium ^a	mg/l	48	180	230	190	170	170	650	230	80	650	480	400
Cations ^a	meq/l	4.21	15.67	28.47	27.72	22.09	18.42	106.47	24.94	7.17	86.90	100.98	45.75
Anions/Cations ^a		0.51	0.63	0.81	0.90	1.25	0.74	0.68	1.09	0.58	0.66	1.14	0.81
Sum of Ions ^a	mg/l	172	737	1,530	1,572	1,614	889	5,061	1,745	175	4,059	6,702	2,425
Sum Ions/TDS ^a		0.27	0.74	0.81	0.83	1.15	0.81	0.84	0.97	0.24	0.62	1.02	0.93
EC/TDS ^a		0.7	1.4	1.4	1.7	1.9	1.6	1.5	1.5	0.7	1.1	1.7	1.7
Bromodichloromethane ^b	μg/l	210	190	240	180	140	192	660	174		178	302	120
Bromoform ^b	μg/l	1						<2.0	<2.0				
Chloroform ^b	μg/l	14,260	9,820	8,440	3,180	2,600	4,768	7,680	7,980		3,475	4,320	4,440
Dibromochloromethane ^b	μg/l	4	1	12	12	10		46	11		10	26	ND
TTHMFP ^b	μg/l	14,470	10,010	8,680	3,375	2,750	4,960	8,400	8,160		3,650	4,680	4,560
Chlorine dose ^b	mg/l	537	452	580	172	130	257	400	344		245	279	697
Chlorine residual ^b	mg/l	66	132	236	56	46	31	276	100		98	223	408
pH of THMFP test ^b	units	8.2	8	8.2	8.2	8.2	8.3	8.2	8.2		8.3	8.3	8.3
C-THM ^b	μg/l	1,586	1,095	948	365	298	540	900	892		397	501	498
C-THM/DOC ^b	μg/mg	9	7		6	7		7	8		5	5	
C-THM/UVA ^b		148	183	212	196	219	375	222	196		194	210	

Notes:

All soil samples were collected on 2/27/92. Surface samples were collected by scraping the ground surface with a small trowel; bottom samples were collected from a 2-foot-deep hole.

NA = Not analyzed (some samples were not analyzed by MWD because of insufficient extracted soil water).

ND = Not detected.

^a Analyzed by AAL.

^b Analyzed by MWD.

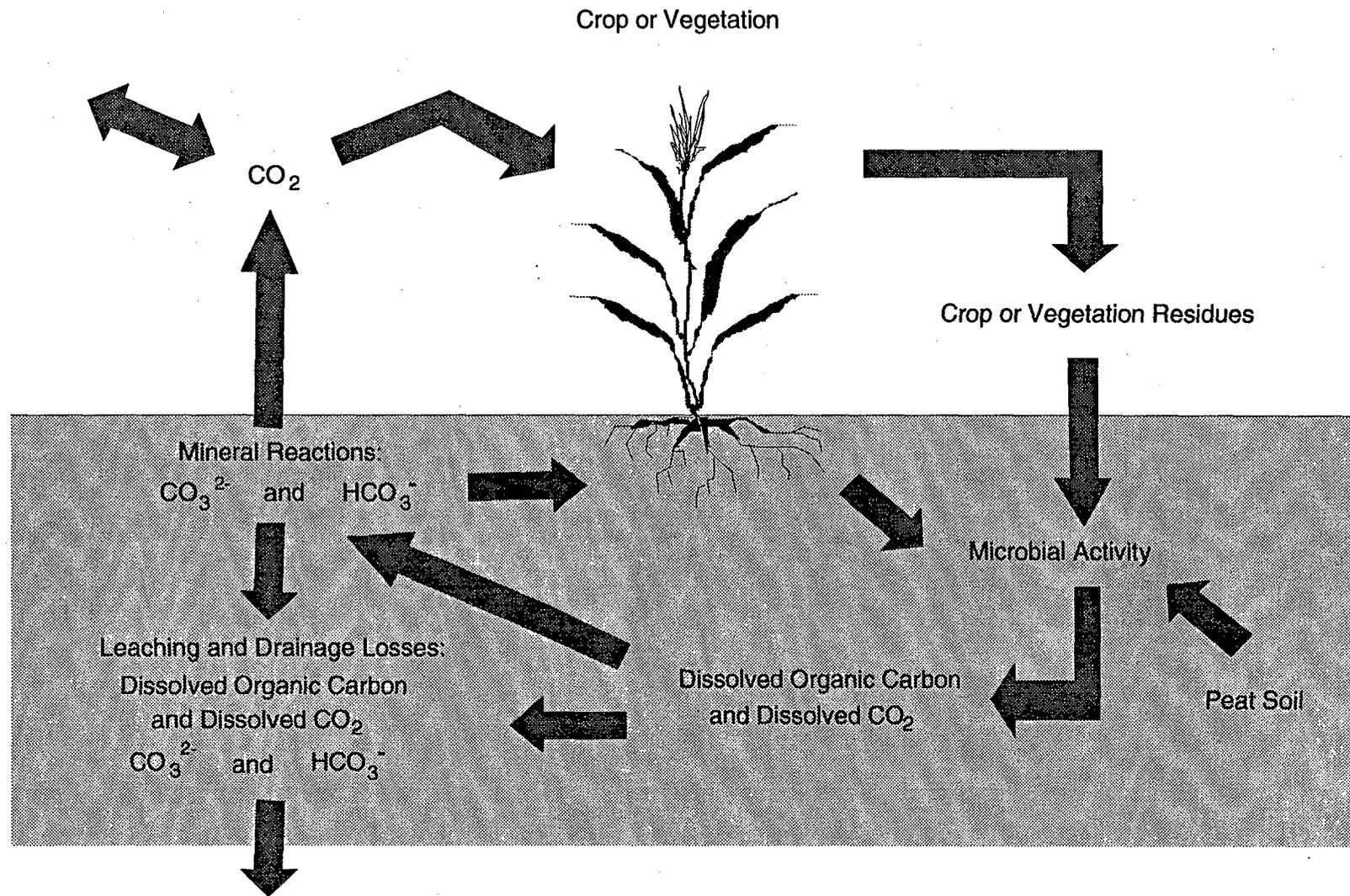


Figure C3-1.
Generalized Carbon Cycle in the Delta

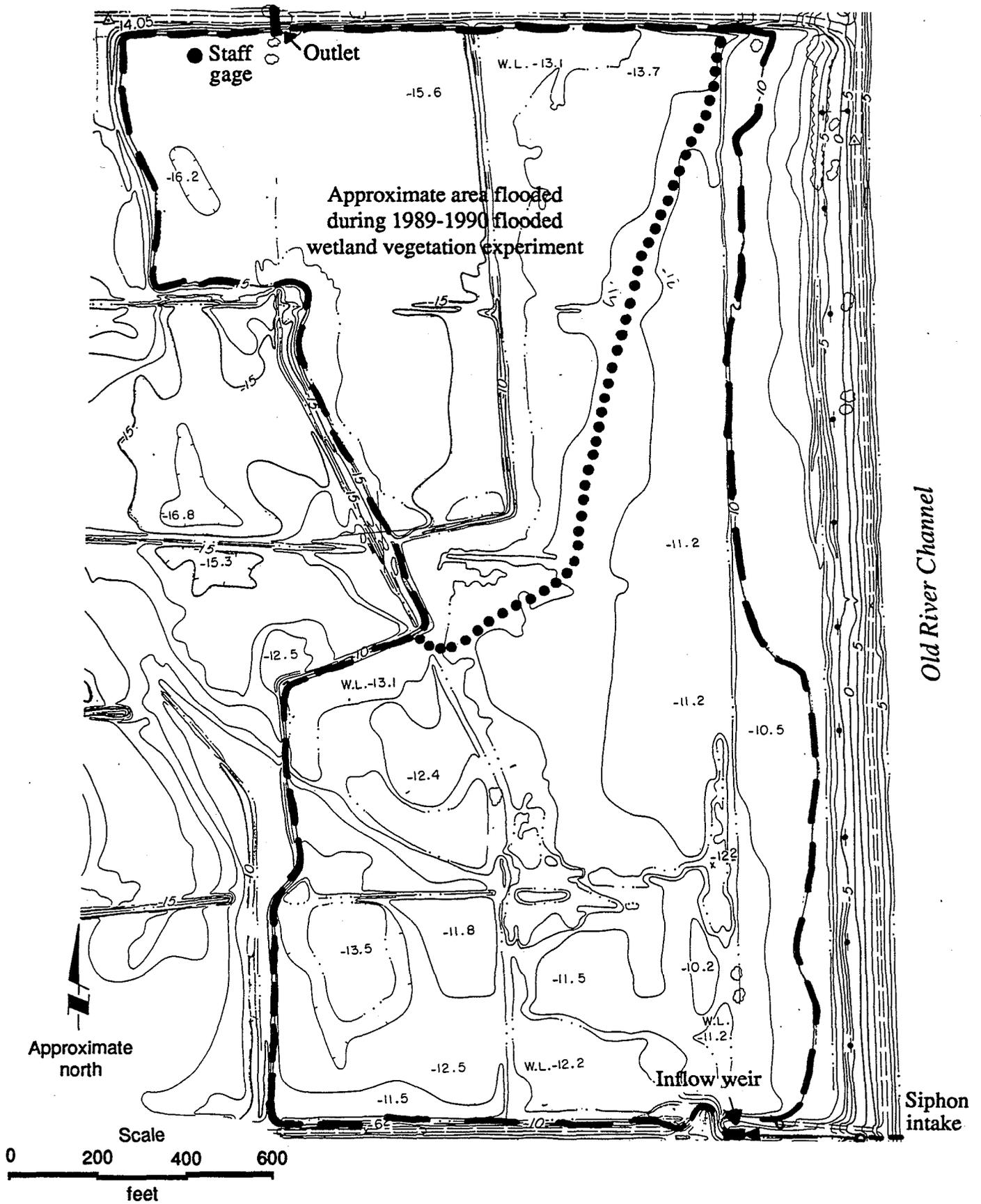


Figure C3-2.
Holland Tract Demonstration Wetland

**DELTA WETLANDS
 PROJECT EIR/EIS**

Prepared by: Jones & Stokes Associates

Figure C3-3.
 Concentration of Minerals during the
 1989-1990 Flooded Wetland Period

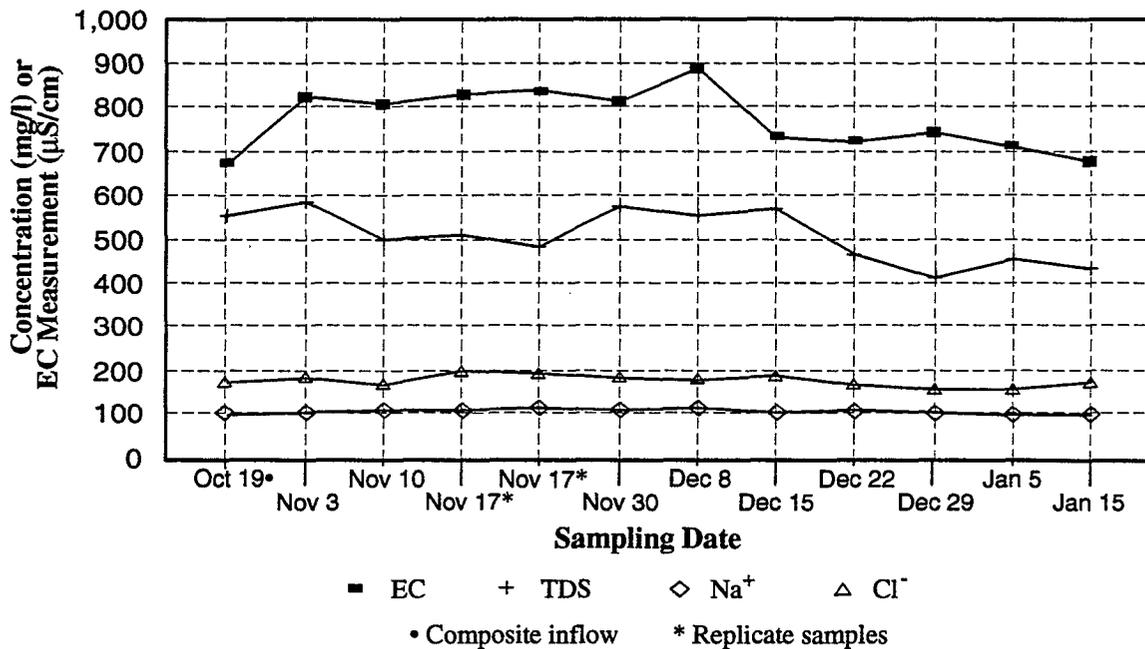
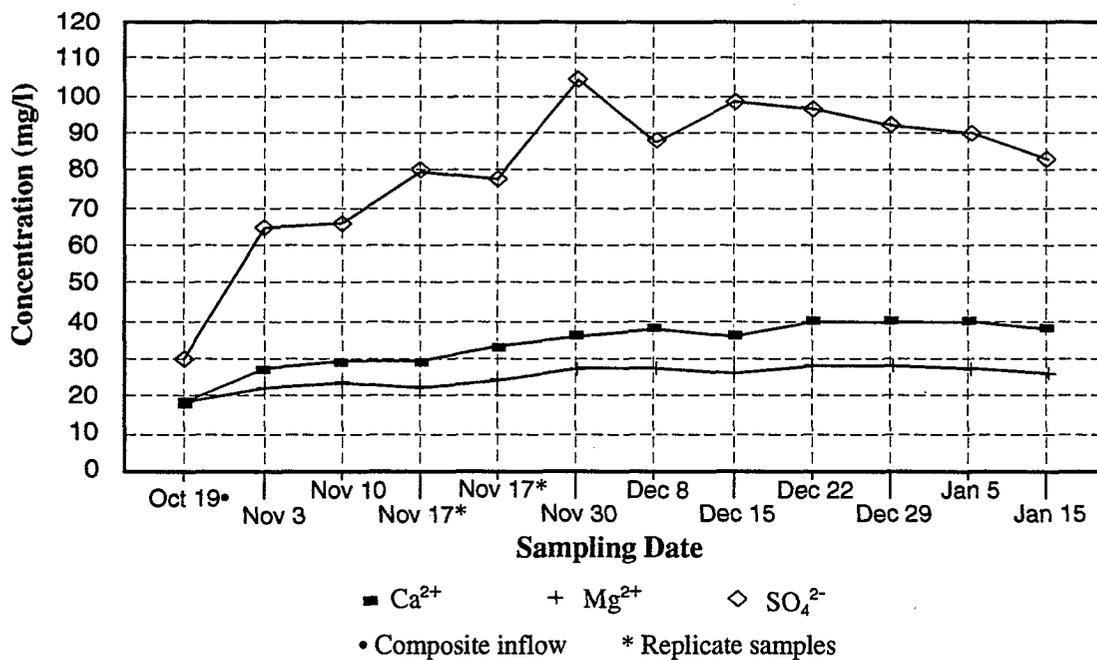


Figure C3-4.
 Concentration of Plant Nutrients during the
 1989-1990 Flooded Wetland Period



**DELTA WETLANDS
 PROJECT EIR/EIS**

Prepared by: Jones & Stokes Associates

Figure C3-5
 Concentration of TOC during the
 1989-1990 Flooded Wetland Period

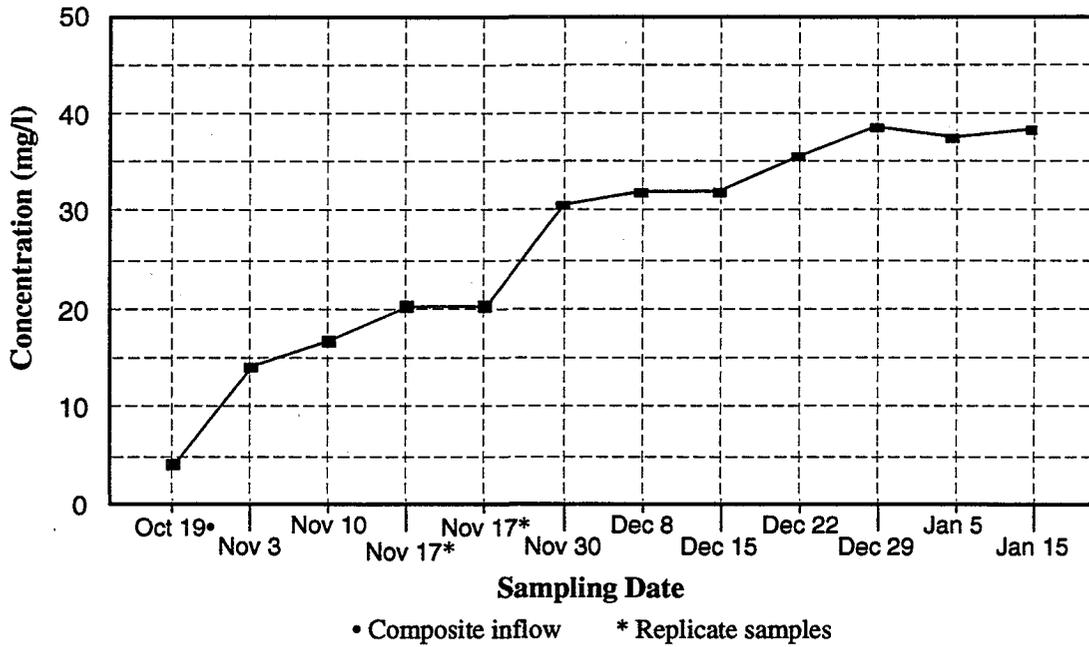


Figure C3-6.
 Concentration of THMFP Components during the
 1989-1990 Flooded Wetland Period

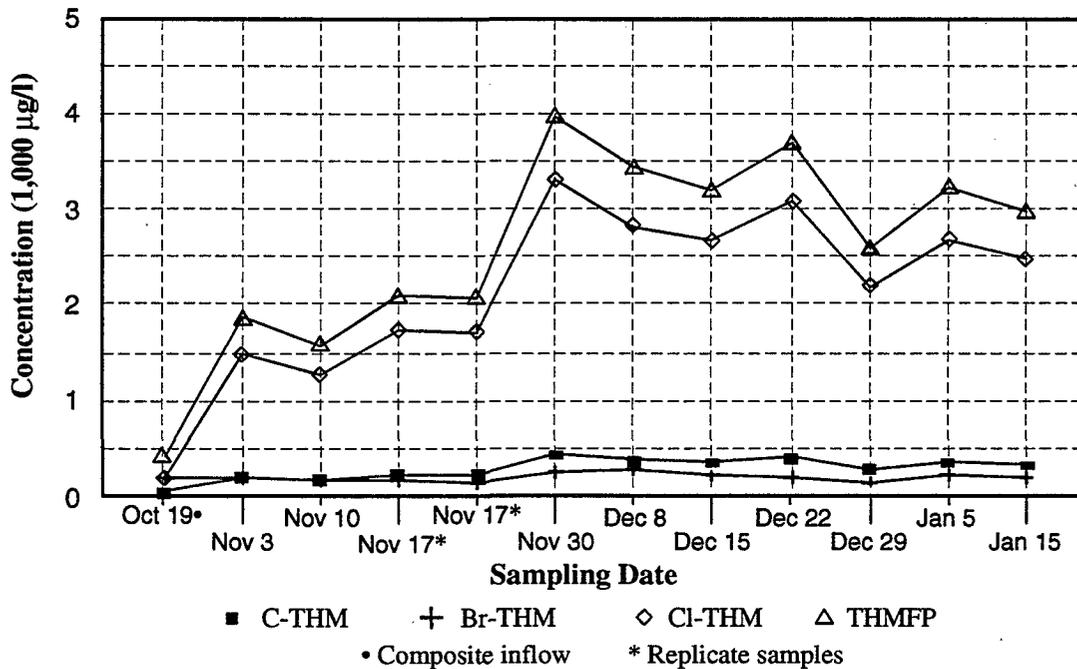


Figure C3-7.
 Concentration of Minerals during
 the 1990 Seasonal Storage Period

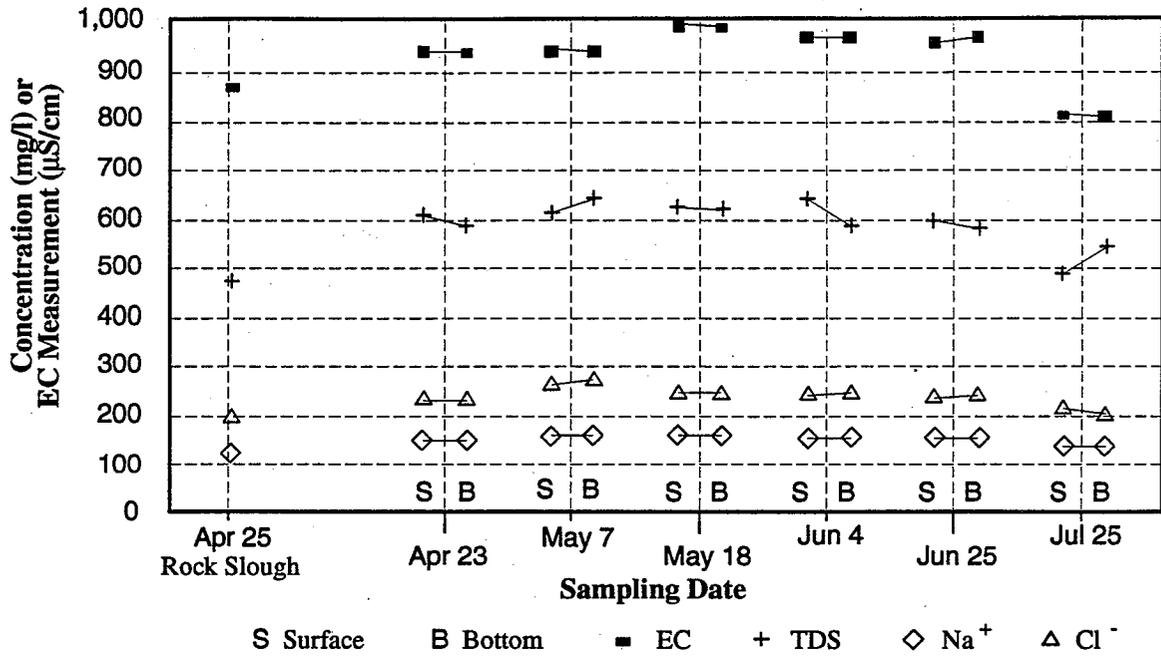


Figure C3-8.
 Concentration of Plant Nutrients during
 the 1990 Seasonal Storage Period

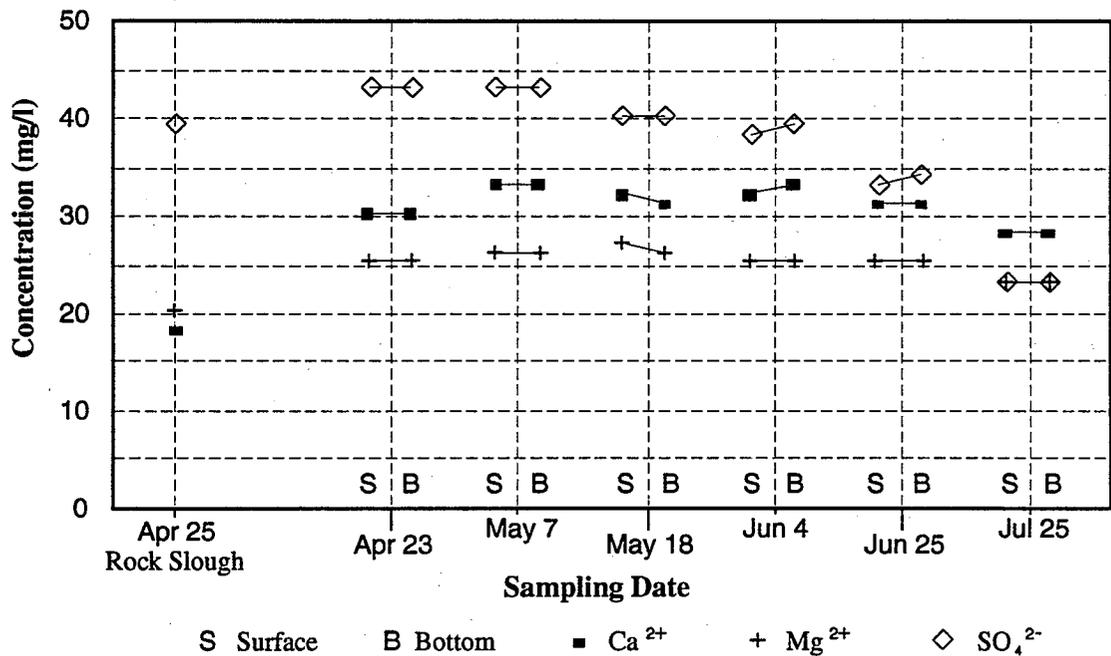


Figure C3-9.
 Concentration of TOC during the
 1990 Seasonal Storage Period

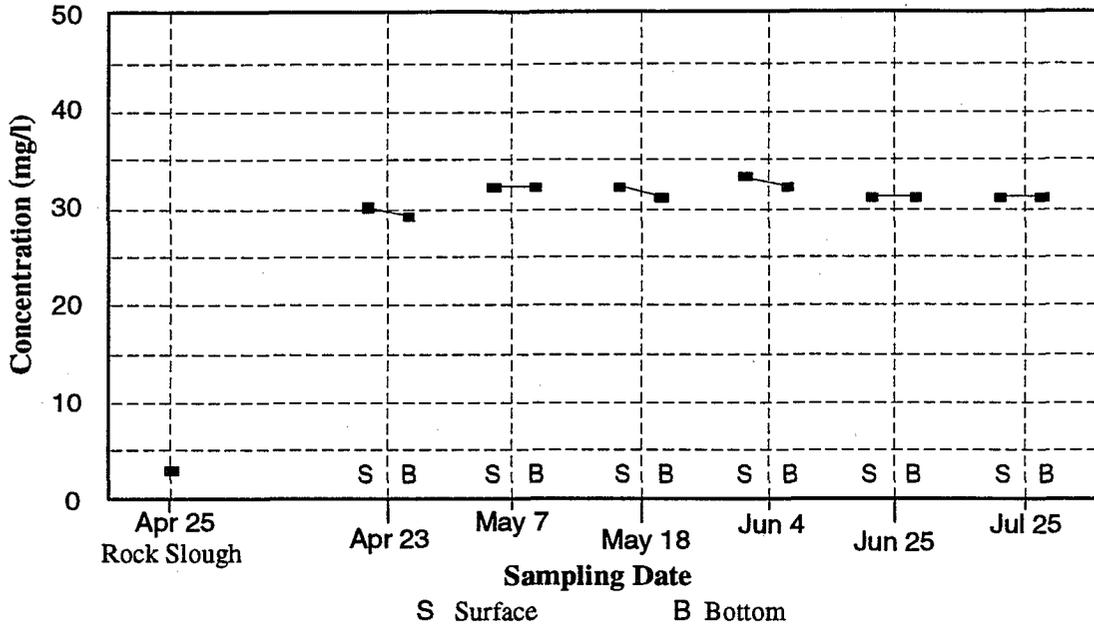
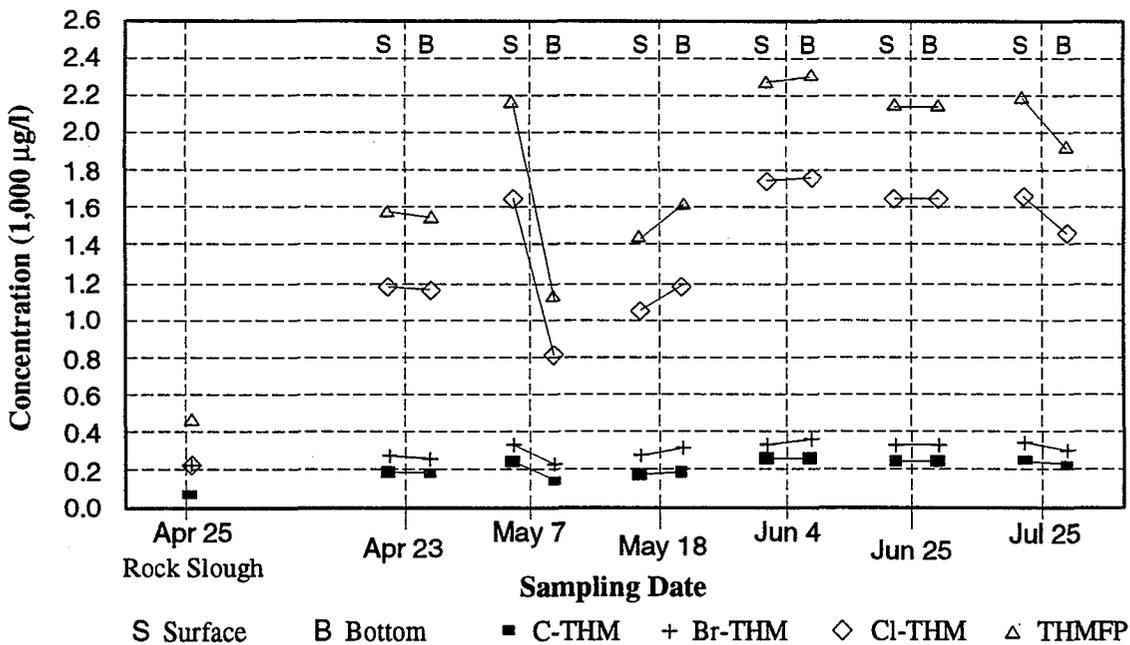


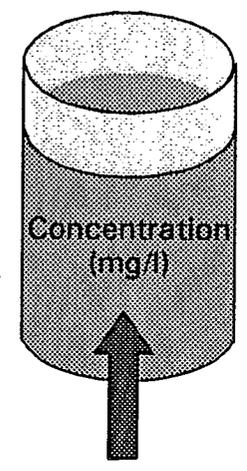
Figure C3-10.
 Concentration of THMFP Components during
 the 1990 Seasonal Storage Period



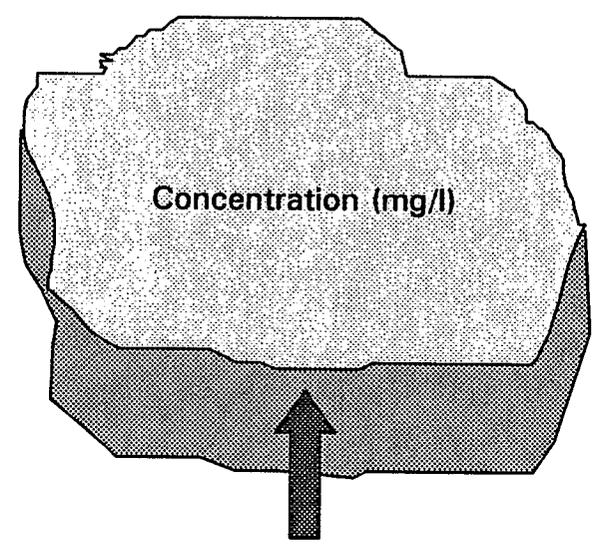
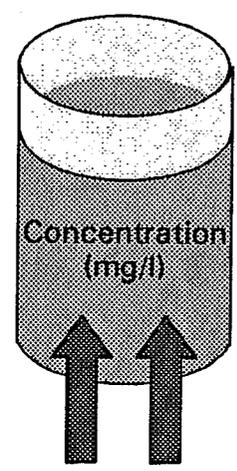
$$\text{Load (g/m}^2\text{)} = \text{Concentration (mg/l)} \times \text{Mean Depth (m)}$$

Vegetation Decay Barrels

Demonstration Wetland



0.6-m Depth



0.3- to 0.5-m Depth

1 x Load (g/m²)

2 x Load (g/m²)

1 x Load (g/m²)

C-061794

Figure C3-11.
Relationship between Load, Depth, and Concentration

Figure C3-12.
 Concentration of Chloride during the 1992
 Wetland Vegetation Decay Experiment

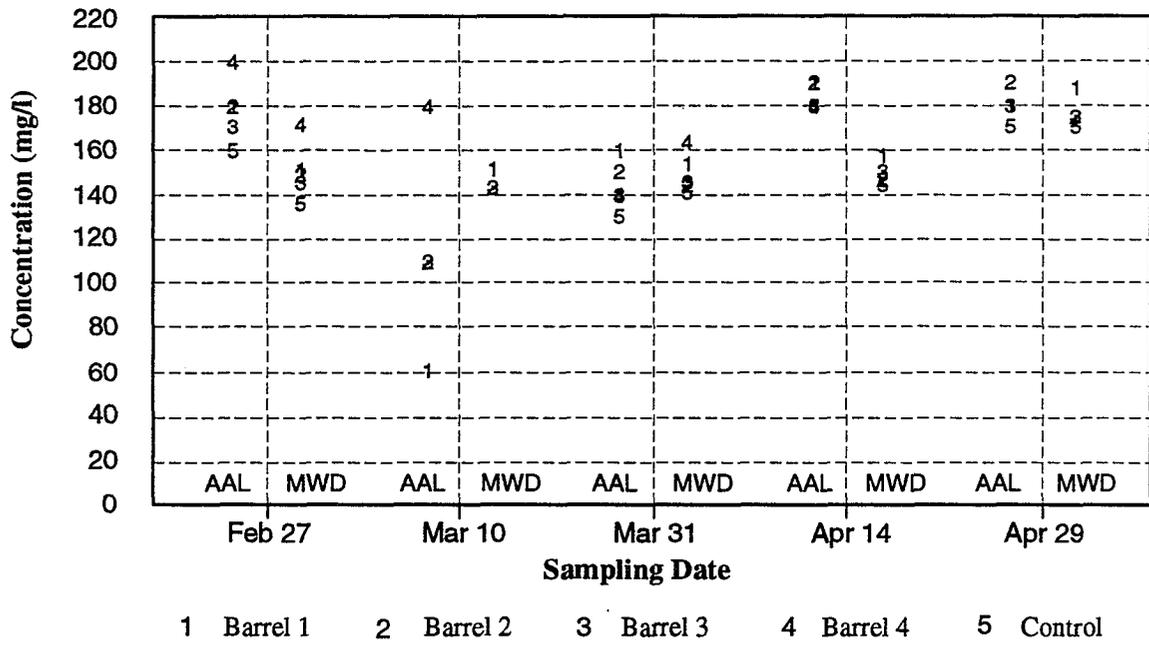


Figure C3-13.
 Concentration of Bromide during the 1992
 Wetland Vegetation Decay Experiment

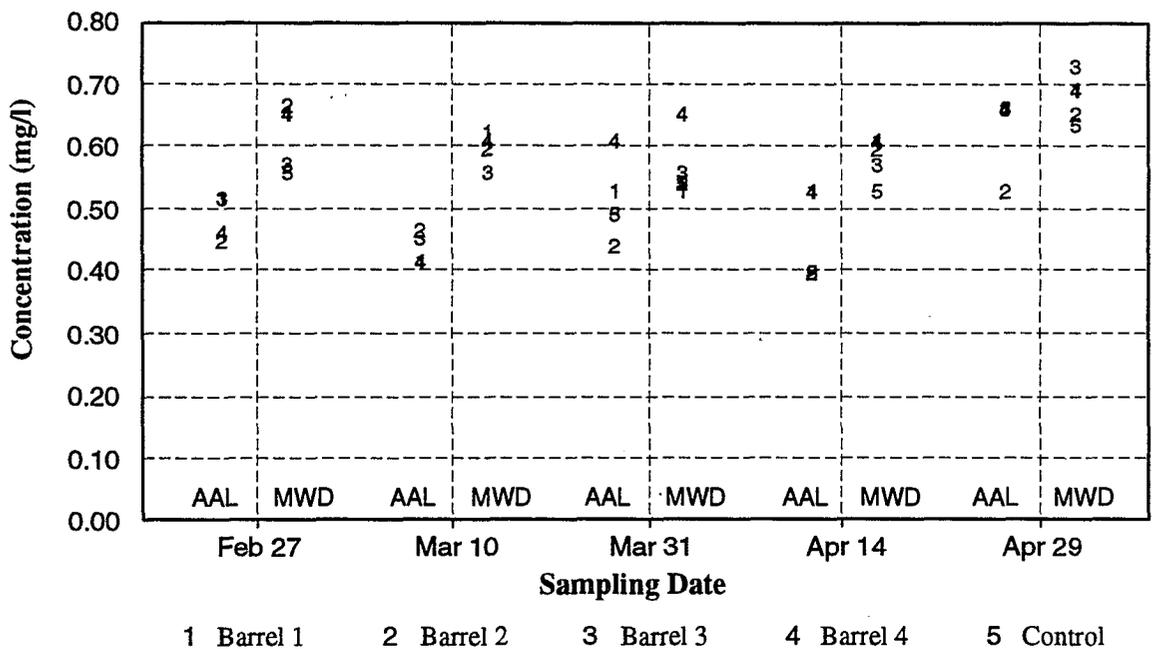


Figure C3-14.
 EC during the 1992
 Wetland Vegetation Decay Experiment

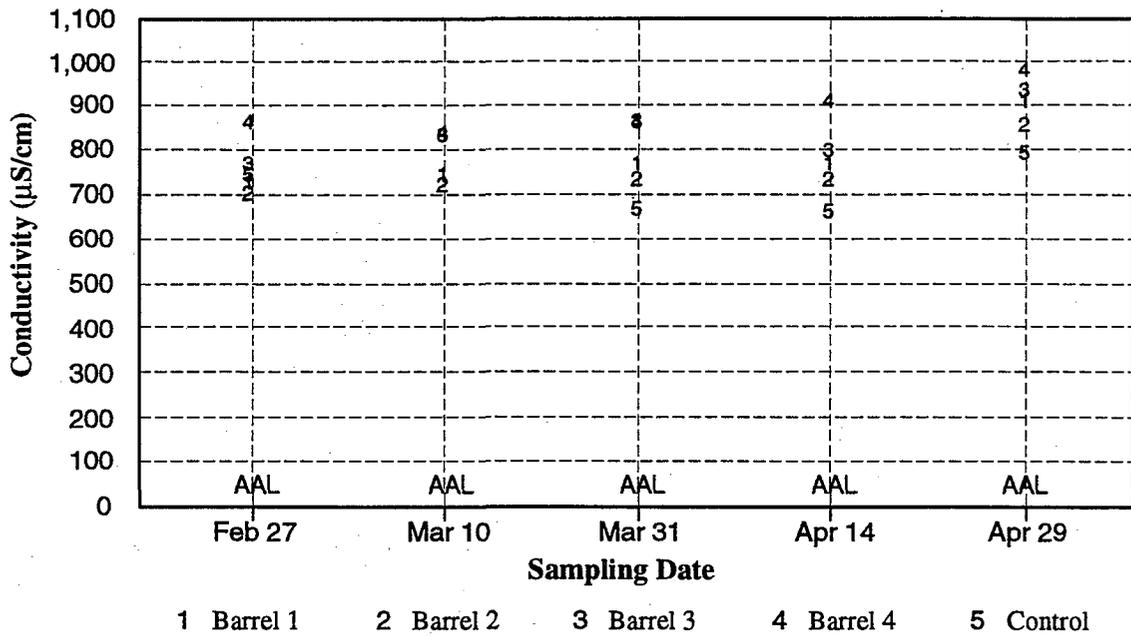


Figure C3-15.
 Concentration of Potassium during the 1992
 Wetland Vegetation Decay Experiment

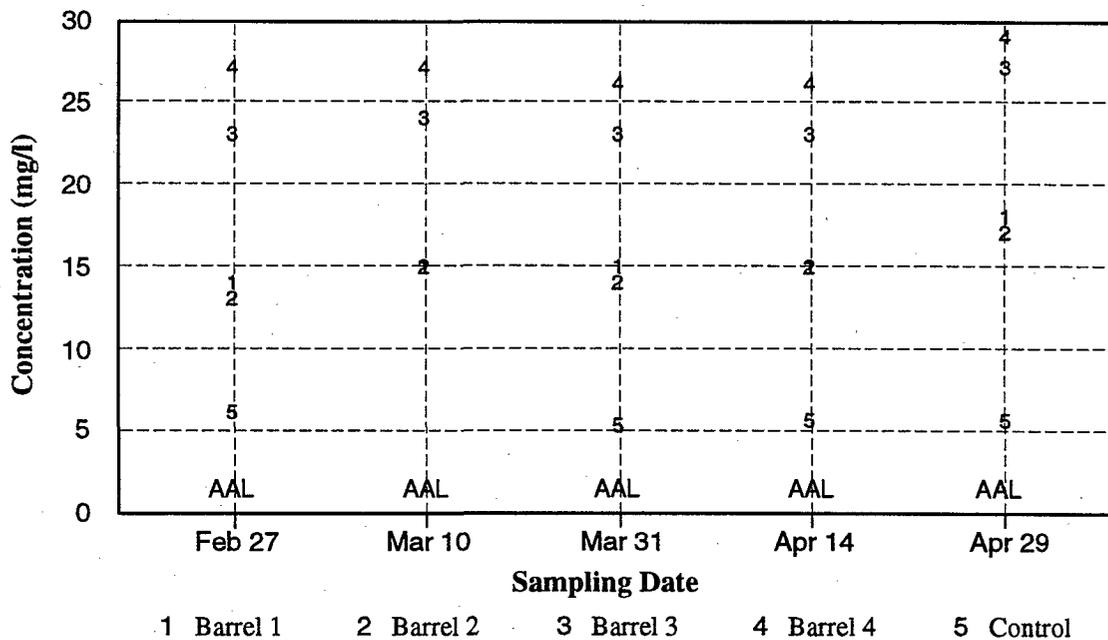


Figure C3-16.
 Concentration of DOC during the 1992
 Wetland Vegetation Decay Experiment

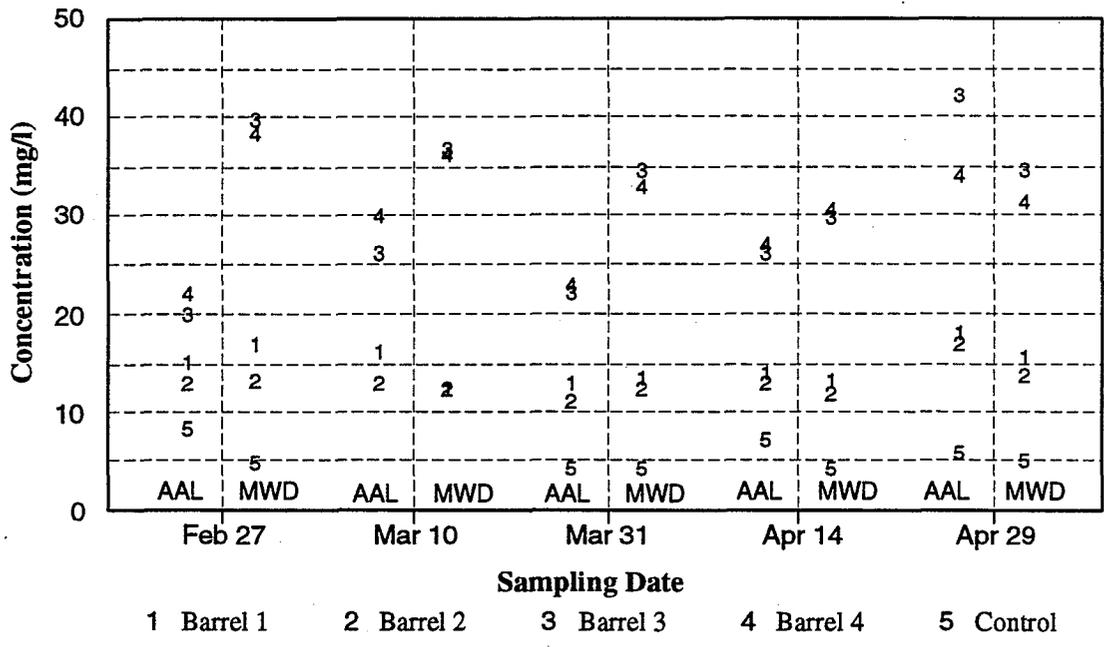


Figure C3-17.
 UVA during the 1992
 Wetland Vegetation Decay Experiment

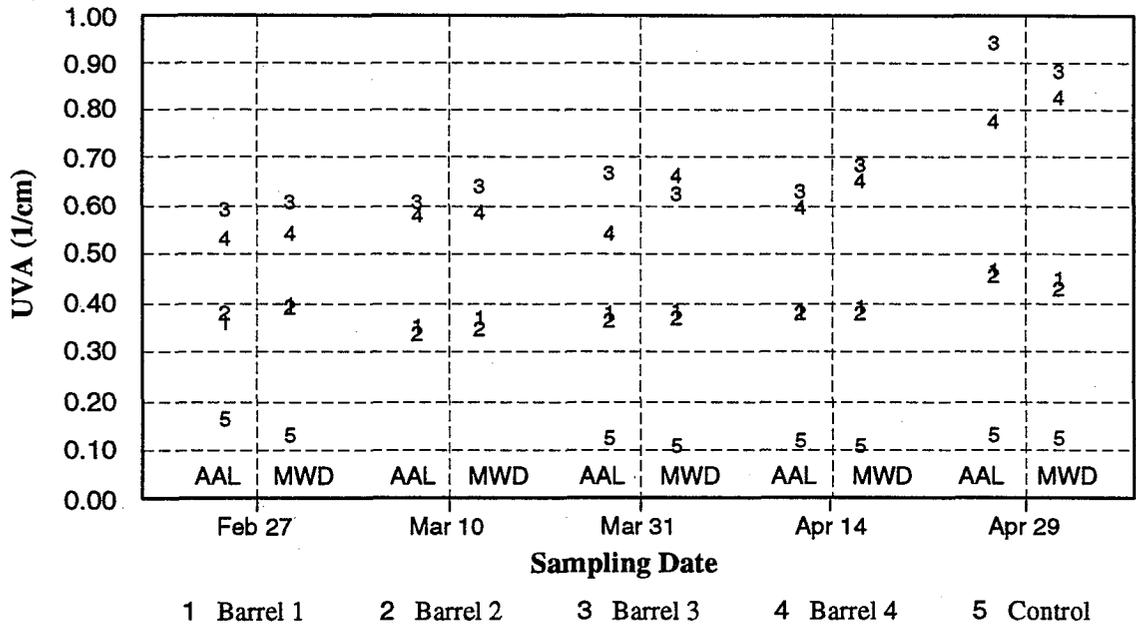


Figure C3-18.
 UVA/DOC Ratio during the 1992 Wetland
 Vegetation Decay Experiment

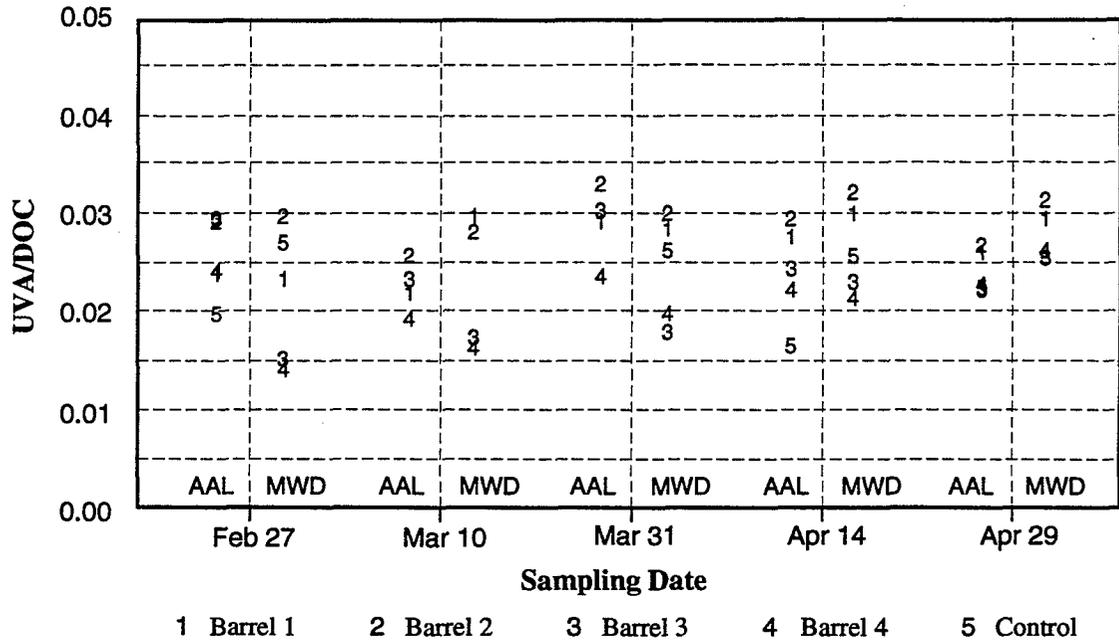


Figure C3-19.
 Concentration of C-THM during the 1992
 Wetland Vegetation Decay Experiment

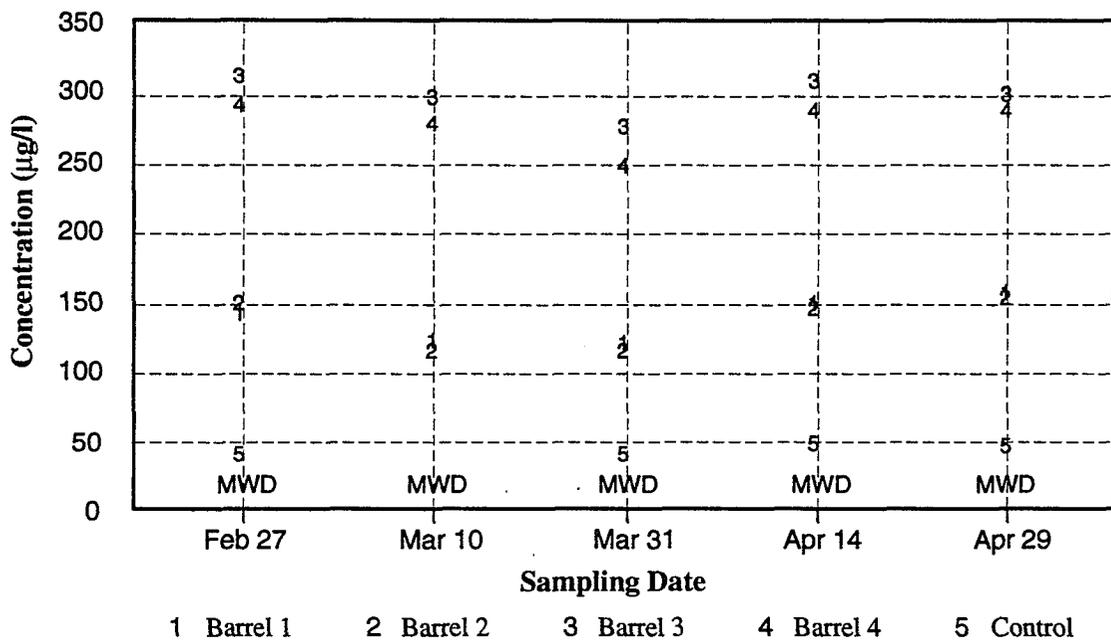


Figure C3-20.
C-THM/DOC Ratio during the 1992
Wetland Vegetation Decay Experiment

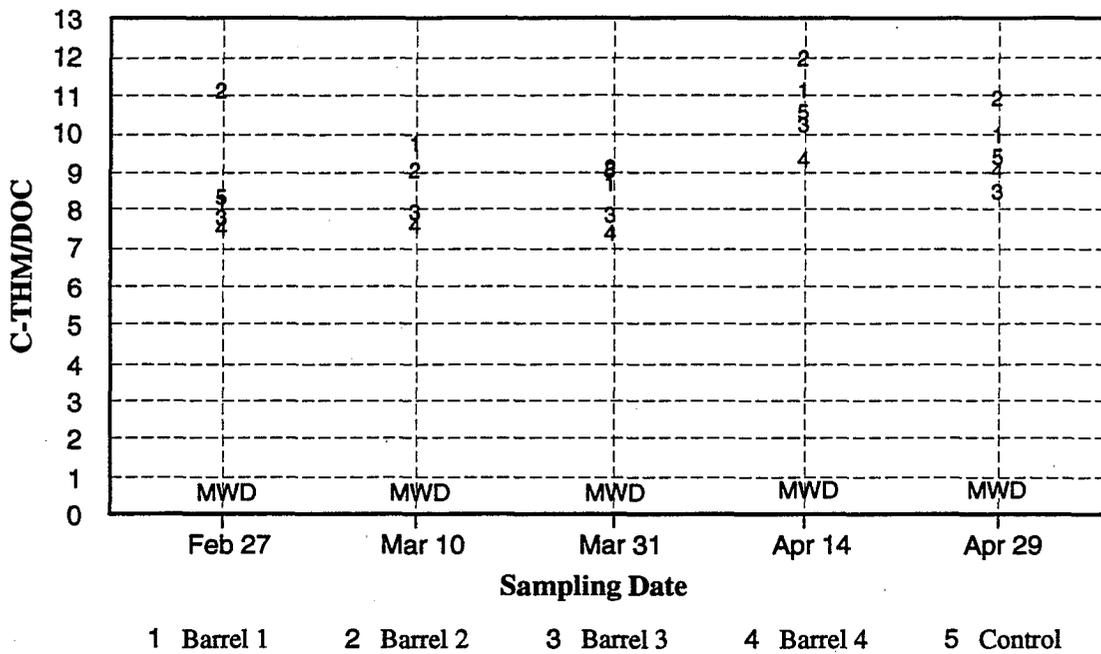


Figure C3-21.
Br-THM/Bromide Ratio during the 1992
Wetland Vegetation Decay Experiment

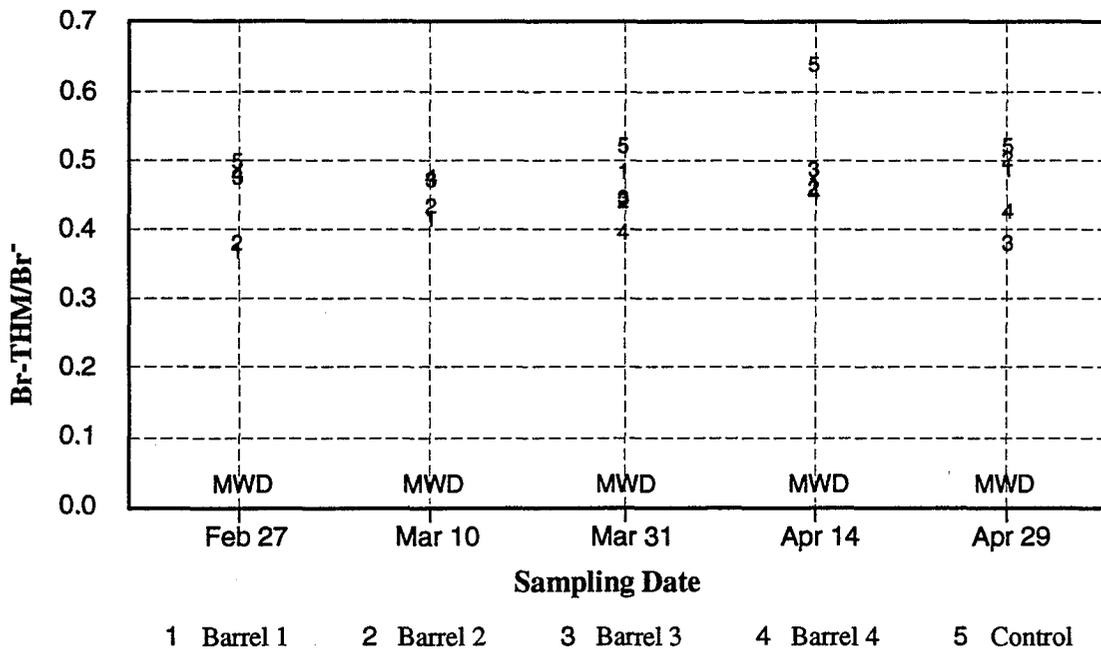


Figure C3-22.
Organic Content of Soil Samples from Holland Tract
during the 1992 Soil Water Extraction Experiment

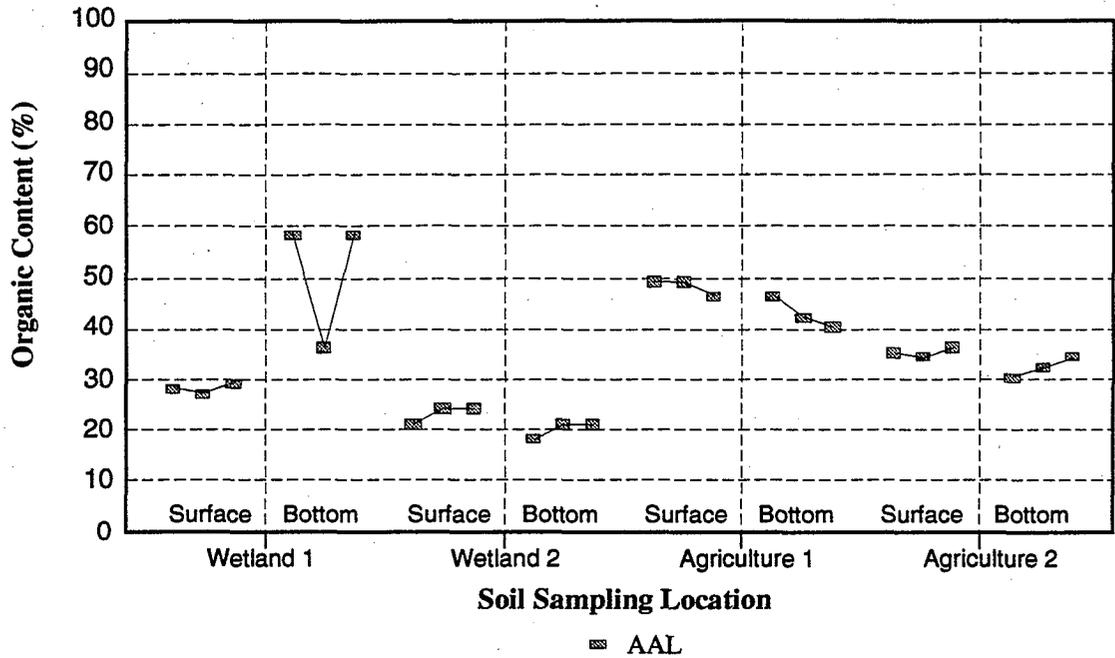


Figure C3-23.
Concentration of DOC during the 1992
Soil Water Extraction Experiment

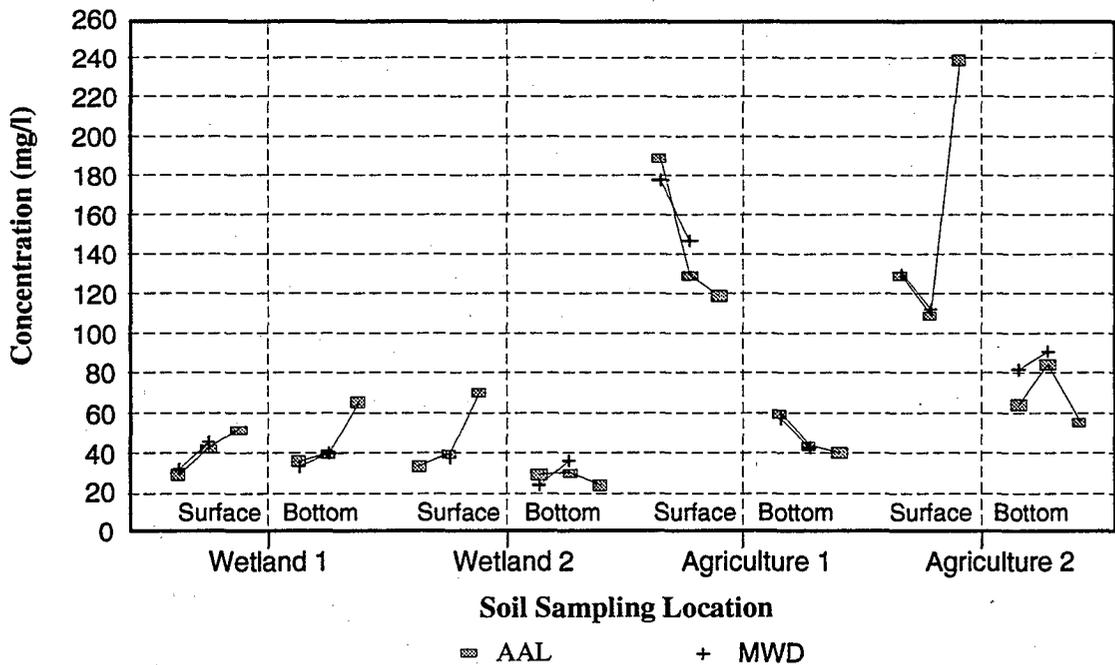


Figure C3-24.
 UVA during the 1992 Soil
 Water Extraction Experiment

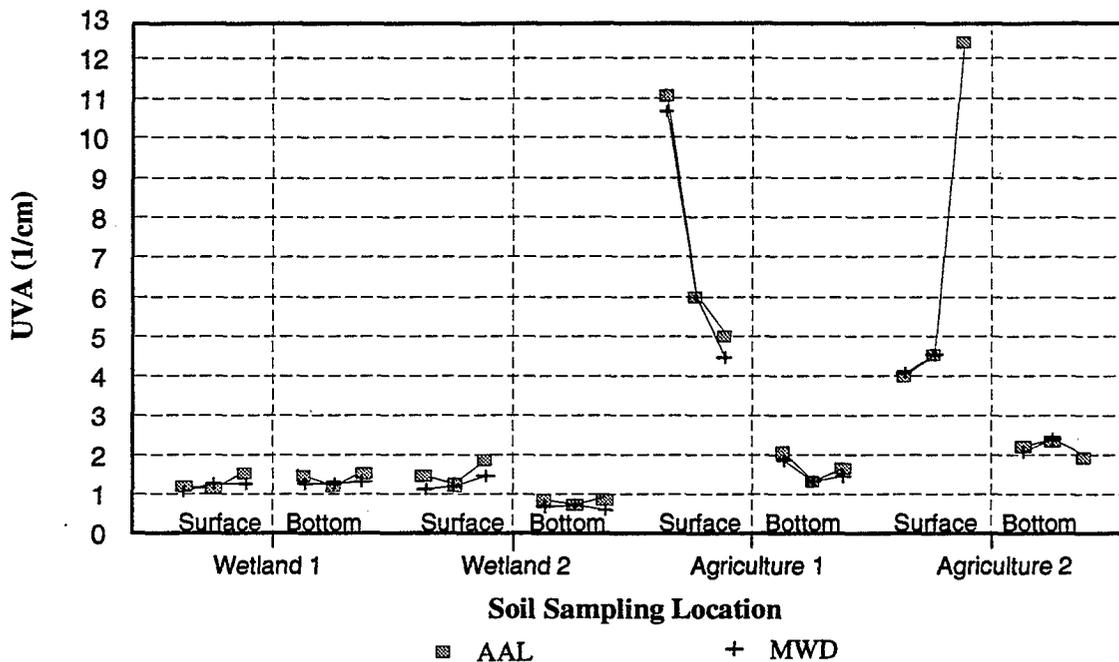


Figure C3-25.
 UVA/DOC Ratio during the 1992
 Soil Water Extraction Experiment

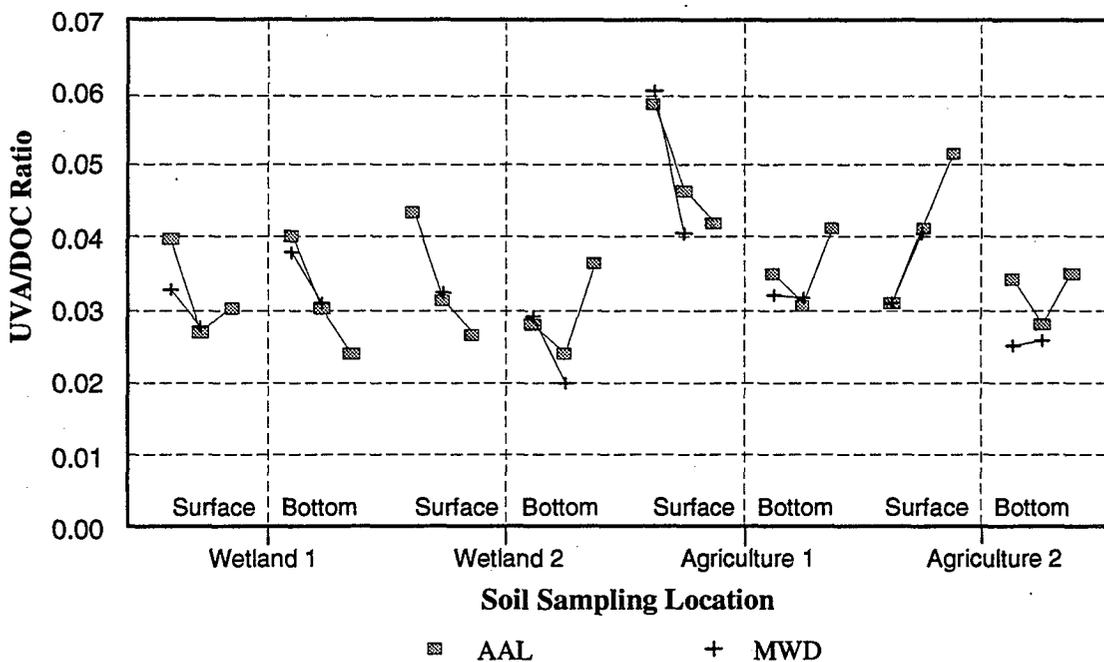


Figure C3-26.
 DOC/Soil Organic Carbon Index of Soil Samples from Holland
 Tract during the 1992 Soil Water Extraction Experiment

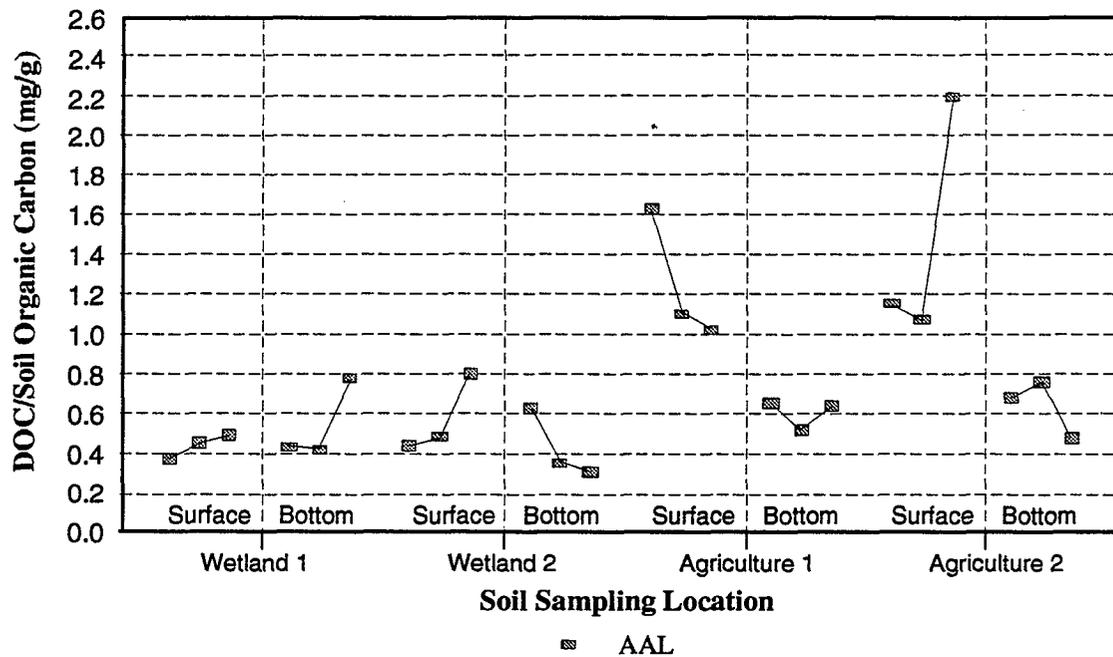


Figure C3-27.
 C-THM Concentration during the 1992
 Soil Water Extraction Experiment

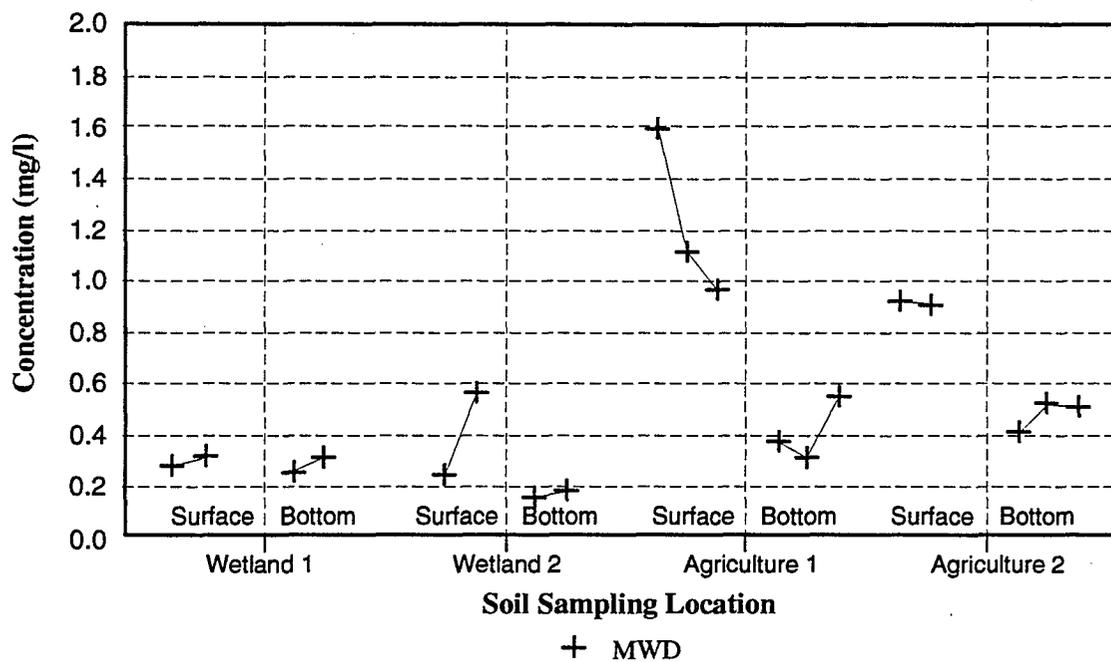


Figure C3-28.

C-THM/DOC Ratio of Soil Samples from Holland Tract during the 1992 Soil Water Extraction Experiment

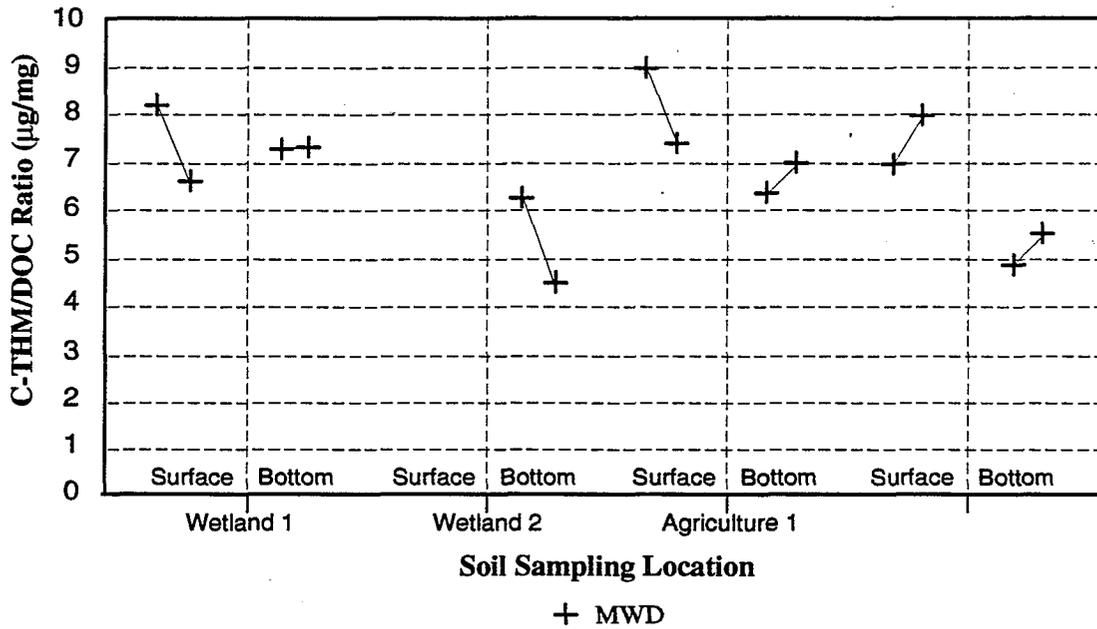
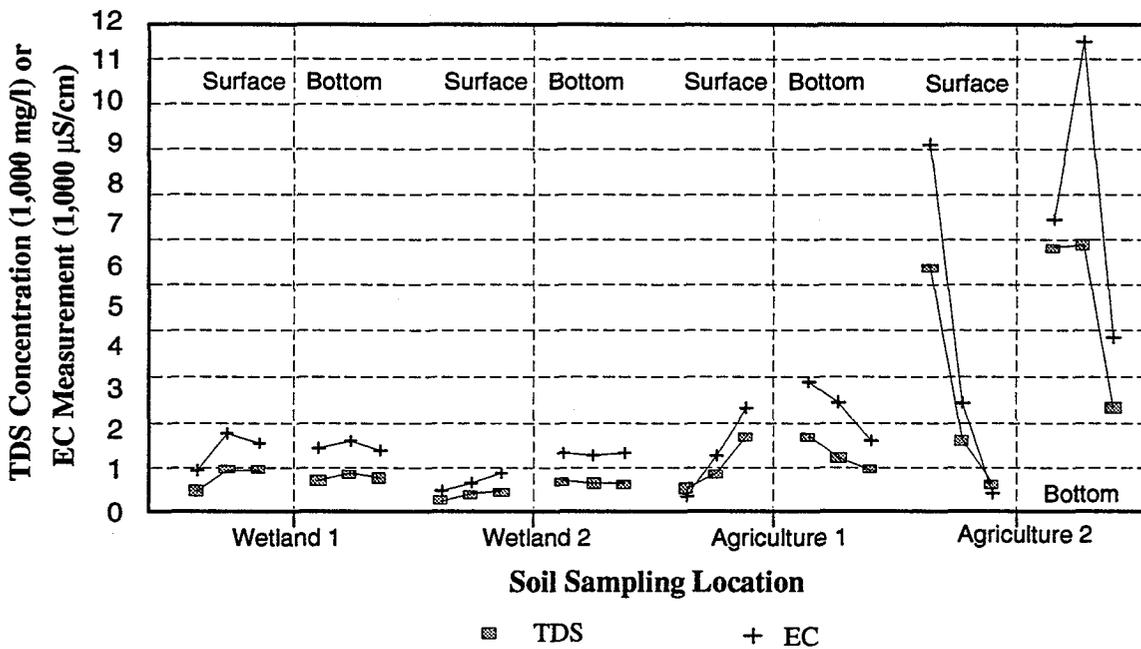


Figure C3-29.

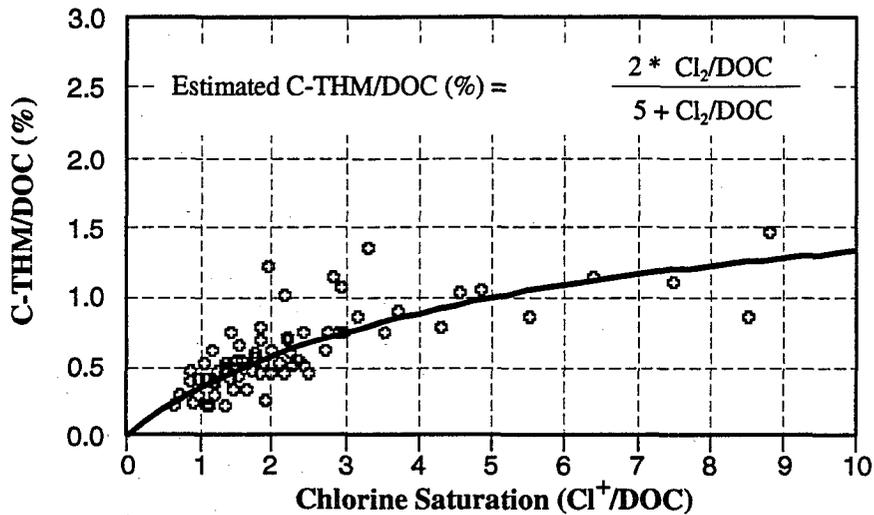
TDS Concentration and EC during the 1992 Soil Water Extraction Experiment



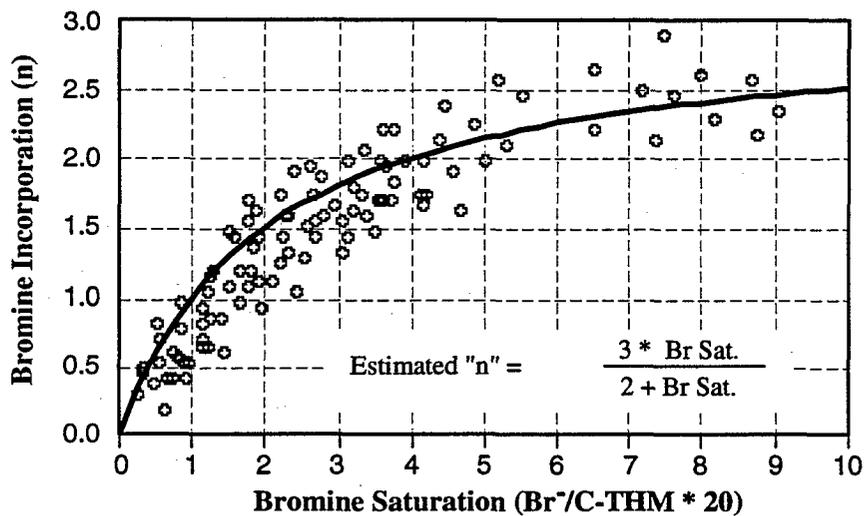
**DELTA WETLANDS
PROJECT EIR/EIS**

Prepared by: Jones & Stokes Associates

Step 1: From measured DOC and chlorine dose, estimate the THM yield (the fraction of DOC that will become C-THM):



Step 2: From calculated bromide (chloride * 0.0035) and estimated C-THM, estimate bromine saturation and bromine incorporation (n):



Step 3: Estimate the THM molar weight and the distribution of THM species as a function of "n":

$$THM \text{ (Molar Weight)} = 119 + 44.5 * n$$

$$\begin{aligned} CHCl_3 &= \left(1 - \frac{1}{3}n\right)^3 &= 1 - n + \frac{1}{3}n^2 - \frac{1}{27}n^3 \\ CHCl_2Br &= 3 * \left(1 - \frac{1}{3}n\right)^2 * \frac{1}{3}n &= n - \frac{2}{3}n^2 + \frac{1}{9}n^3 \\ CHClBr_2 &= 3 * \left(1 - \frac{1}{3}n\right) * \left(\frac{1}{3}n\right)^2 &= \frac{1}{3}n^2 - \frac{1}{9}n^3 \\ CHBr_3 &= \left(\frac{1}{3}n\right)^3 &= \frac{1}{27}n^3 \end{aligned}$$

Figure C3-30.
General THM Prediction Model

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Figure C3-31.
 C-THM Yield from DOC in DWR MWQI Delta
 Channel Measurements for 1982-1991

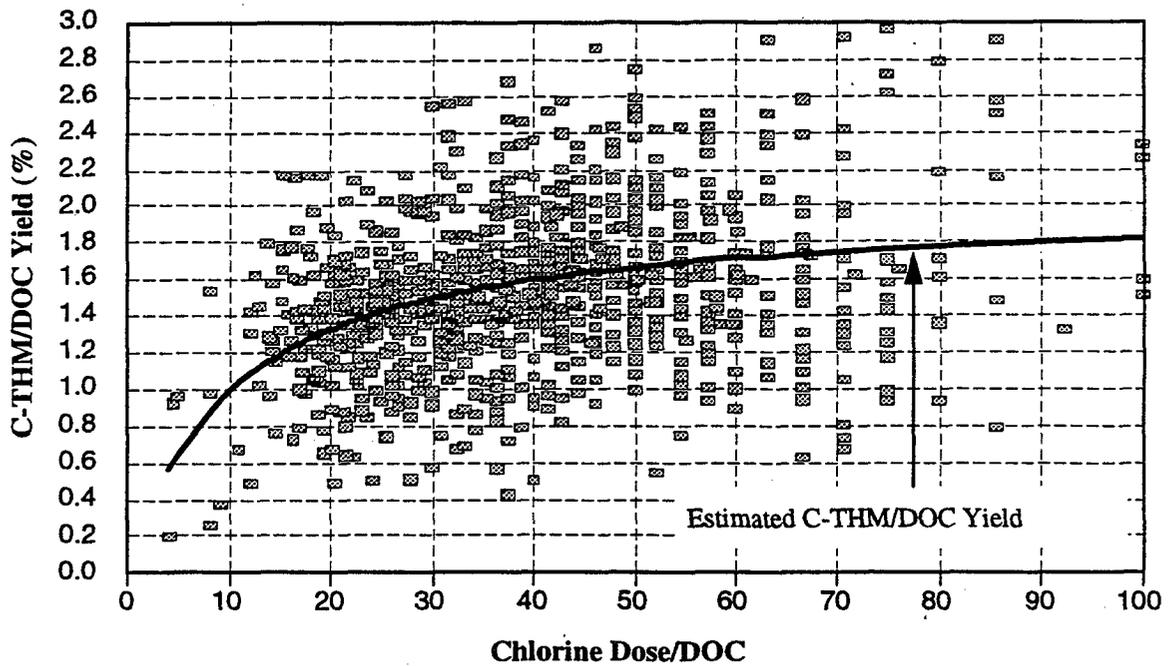


Figure C3-32.
 Bromine Saturation of THM in DWR MWQI
 Delta Channel Measurements for 1982-1991

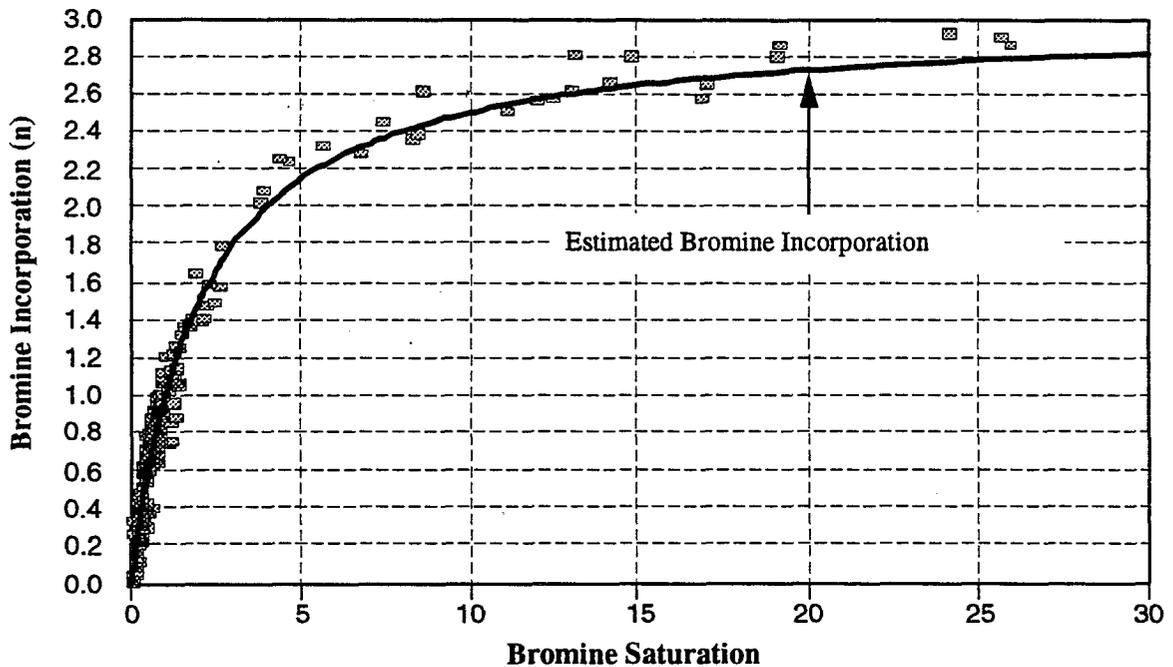


Figure C3-33.

C-THM Yield from DOC in DWR MWQI Delta Agricultural Drainage Measurements for 1985-1991

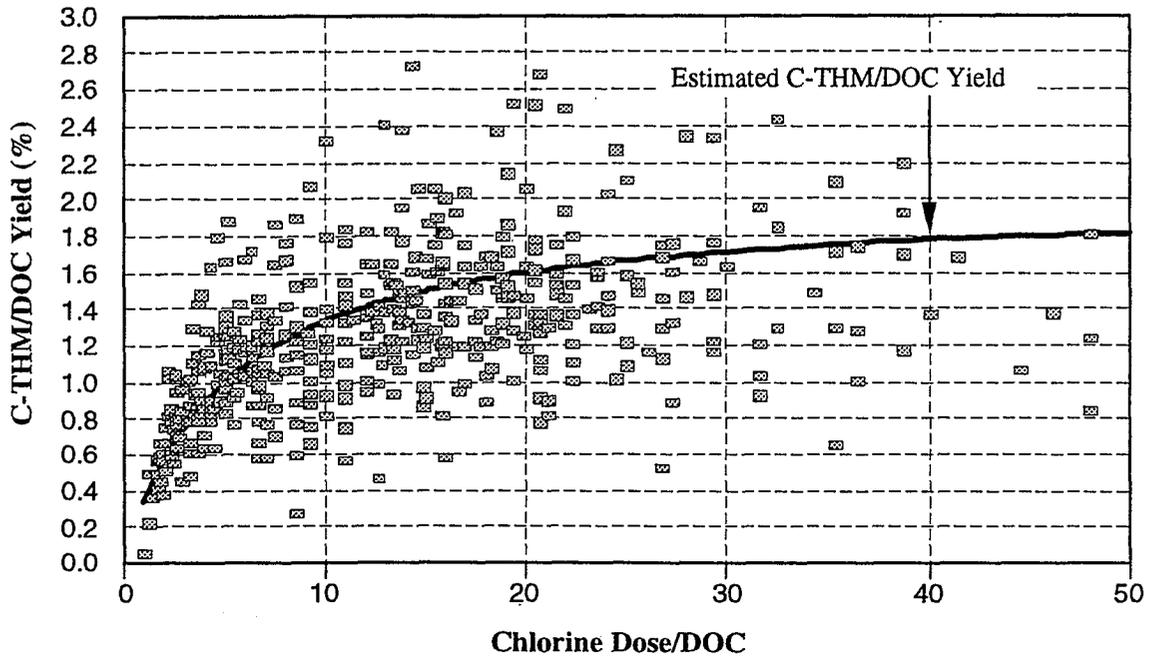


Figure C3-34.

Bromine Saturation of THM in DWR MWQI Delta Agricultural Drainage Measurements for 1985-1991

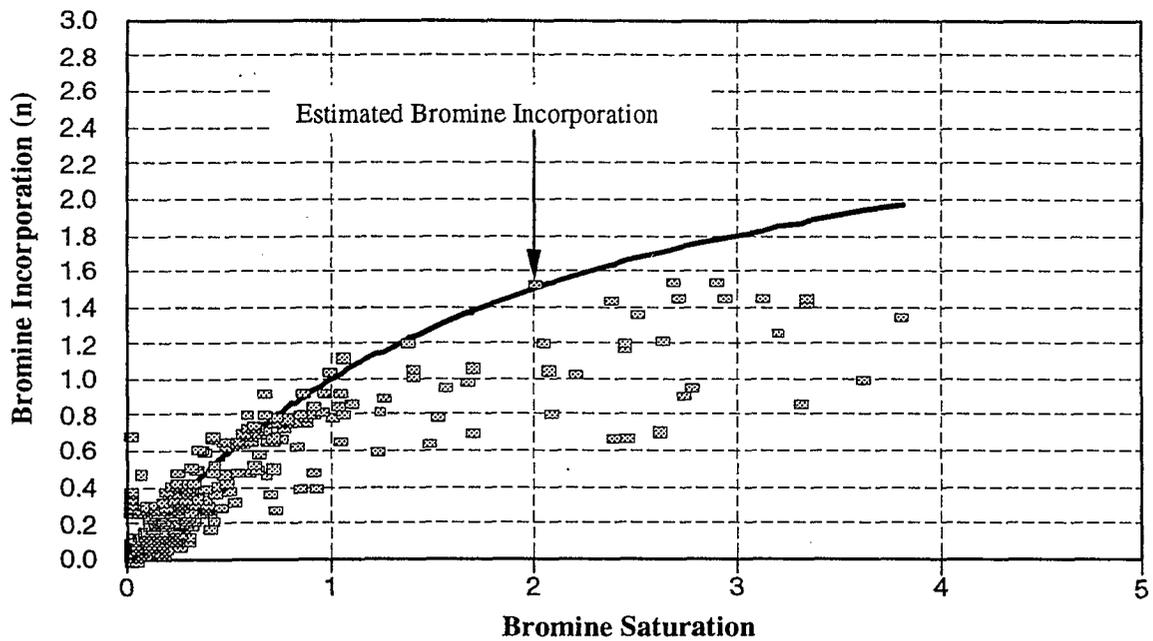


Figure C3-35.
C-THM Yield from DOC in MWD
SDS Assays of THM for 1991-1993

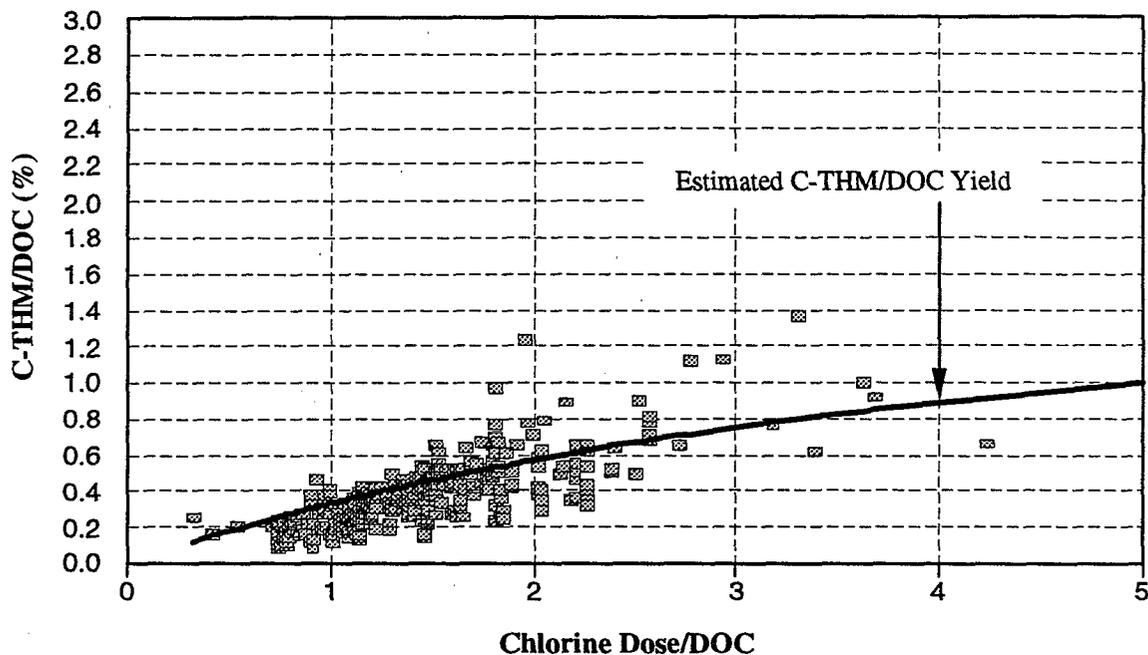


Figure C3-36.
Bromine Saturation of THM in MWD
SDS Assays of THM for 1991-1993

