Review of Delta Wetlands Water Quality: Release and Generation of Dissolved Organic Carbon from Flooded Peatlands

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Summary

The CALFED Record of Decision (ROD) has identified five water storage projects in the upper Sacramento and San Joaquin River watersheds. The proposed In-Delta Storage project involves the conversion of existing islands in the Delta from agricultural land use to water storage reservoirs and wildlife habitat. Webb Tract and Bacon Island are proposed for water storage reservoirs, while Holland Tract and Bouldin Island will be developed for wildlife habitat.

A major environmental concern is that the re-hydration of organic rich peat soils in Delta islands will result in substantial release of dissolved organic carbon (DOC). The exchange of water from these reservoirs for urban use can potentially increase the export of dissolved constituents, especially DOC that form disinfection byproducts such as trihalomethanes, chloroform, and bromodichloromethane. Thus, it is important to quantify the sources and fate of dissolved organic matter (DOM) in these reservoirs, since major nutrients are associated with DOM.

This report presents: (1) a review of the methodology of mesocosm experiments conducted to determine DOC and TOC release from peat soils; (2) analysis of the consistency of the data collected; (3) conclusions that can be drawn from the data about the rate of DOC and TOC release into water column; (4) limitations of the data and its use; and, (5) recommendations on the approach used and additional work required to improve the predictability of DOC and TOC release.

Mesocosm experiments were conducted to determine DOC and TOC flux rates from soil to overlying water column. The first set of experiments was conducted in 1999-2000. Tanks were repacked with peat soil from Bacon Island and new experiments were initiated in 2002 and continued until 2004. During these three years, hydraulic operation modes were different, which made it difficult to compare results of DOC and TOC flux rates.

Data presented in the DWR reports are adequate, but additional analysis of the data is needed. There were some inconsistencies with the analysis of 2003 DOC data. These data were reanalyzed by accounting for the mass DOC removed during water exchange periods. The DOC and TOC loading rates for all years were computed using the data provided by DWR staff.

Conclusions drawn in the reports on DOC and TOC release are generally acceptable. The data analysis primarily produced average DOC and TOC loading rates for the whole study period. No consideration was given for the temporal effects on DOC release. Further analysis of the data showed a positive relationship between ambient air temperature and DOC flux rates.

The DOC accounted for approximately 93 to 98% of TOC in mesocosm water column, while under field conditions (Jones Tract flooding) the DOC accounted for 84% of the TOC. Average DOC flux rate was 0.6 g/m^2 day in 2002, decreased to 0.4 g/m^2 day in

2003, and 0.15 g/m^2 day in 2004. When compared to 2002 data, flux rates decreased by approximately 40% in 2003 and by 70% in 2004. These results suggest that the initial "tea bag" effect sustains for approximately 2 years.

Flooding of Jones Tract agricultural lands resulted in substantial release of DOC and TOC into the water column. During the first 48 days of flooding, DOC and TOC flux rates were 0.48 g/m^2 day. This rate was similar to those observed in 2002 mesocosm experiments.

The data collected in mesocosm experiments was adequate to estimate the DOC flux rates. However, the data collected is not adequate to explain changes and dynamics of DOC fate in these systems. Operation of mescosms should be continued for another 2 years to determine the steady state. Operation mode of the mesocosms should be maintained in a consistent manner. Sampling frequency should be increased to determine the true temporal variability. At the minimum, samples should be analyzed for TOC.

Data on physico-chemical environment of the water column is needed. At the minimum dissolved oxygen, temperature and conductivity of water column should be monitored.

Some effort should be placed to identify sources, chemical nature, and the fate of DOC in the water column (see the last section in the report for additional data needs).

A field study is more appropriate to determine more realistic DOC/TOC loading rates. Mesocosm experiments provided the first approximation of the DOC loading rates, but the rates may be lower under field conditions. Mesocosms functioned more as static systems and lack hydrodynamic events that would occur under field conditions.

Introduction

Peatlands or organic soils (histosols) are naturally productive and contain large amounts of organic carbon (C), nitrogen (N), sulfur (S), and phosphorous (P). These soils are poorly drained and have high water holding capacities. In many areas of the United States, these organic soils were formerly wetlands, which were drained for use in agriculture. Globally, peatland area is estimated to be in the range of 388 to 408 million hectare (ha), and approximately 25 million ha of peatland has been drained and developed for agriculture and forestry (Armentano and Verhoeven, 1988). Peatlands have become a vast global carbon pool, holding approximately 390 gigatons of terrestrial carbon or 28% of the global soil carbon stock (jenkinson et al., 1991). A classic example, is the drainage of more than one million acres of organic soils in South Florida for use in agriculture (sugarcane, vegetables, and other crops). Because these soils have high water holding capacity, they are artificially drained when used for agriculture and the drainage water is often pumped into adjacent wetlands and aquatic systems. Overall loss of peat soil as a result of biological oxidation and subsidence was estimated to range from 1.4 to 2.54 cm/year (Shih et al., 1997), subsidence rates up to 3.4 cm/year were observed in New Zealand peatlands (Schipper and McLeod, 2002). Drainage of these soils produces substantial amounts of dissolved organic and inorganic nutrients, causing serious environmental concern.

Agricultural lands adjacent to ecologically sensitive aquatic systems are now being acquired by state and federal agencies, and in many cases, these areas are converted back to their natural conditions. Many of these lands were once intensively used for agriculture with continuous application of fertilizers and pesticides for a number of years. The first step in the restoration efforts of these lands is the re-establishment of hydrology through flooding in an attempt to convert them into wetlands. Initial flooding of these lands poses potential water quality problem as the dissolved nutrients stored in these soils are rapidly released into the water column. With time after flooding, hydrophytic vegetation becomes estabilished with macrophyte communities such as *Typha, Sagittaria, Polygonum, Panicum, Pontedaria,* and others, and may aid in reducing the dissolved constituents through uptake and breakdown. Similarly, the proposed In-Delta Storage Project (IDSP), which involves conversion of four Delta islands for water storage and wildlife habitat, will need to address the environmental concern.

The CALFED Record of Decision (ROD) identified five water storage projects in the upper Sacramento and San Joaquin River watersheds. The proposed In-Delta Storage project involves the conversion of existing islands in the watershed from agricultural land use to water storage reservoirs and wildlife habitat. Webb Tract and Bacon Island are proposed for water storage reservoirs, while Holland Tract and Bouldin Island will be developed for wildlife habitat (DWR, 2003). Soils of the all project sites are histosols, with organic carbon content greater than 12%. Water will be diverted into reservoirs during winter months when flows are high, while water will be released into Delta channels during summer months when flows are low and demand is high. A major environmental concern is that the re-hydration of organic rich peat soils in Delta islands will result in substantial release of dissolved organic carbon (DOC), dissolved organic and inorganic forms of nitrogen and phosphorus. Thus exchange of water from these reservoirs for urban use can potentially increase the export of dissolved constituents, especially DOC and its role in formation of disinfection byproducts such as trihalomethanes, chloroform, and bromodichloromethane. Thus it is important to quantify the sources and fate of dissolved organic matter (DOM) in these reservoirs, since major nutrients are associated with DOM. This report focuses primarily on DOC and TOC release rates from soil to the overlying water column.

Shallow reservoirs and wetlands are characterized by abundant and diverse sources of organic matter including the inputs of allochthonous sources of organic matter (from adjacent watersheds) and autochthonous sources (planktonic and macrophyte photosynthesis). Organic matter in these systems is present as dissolved organic carbon

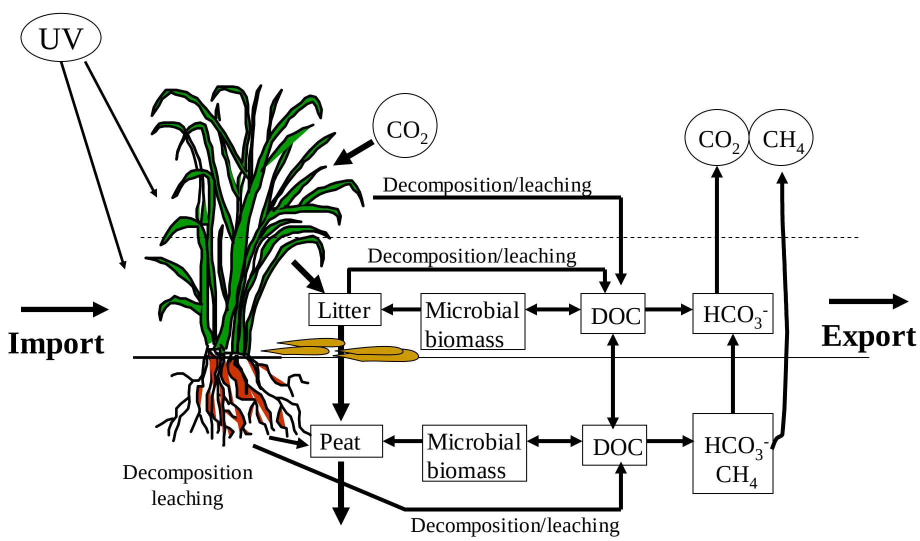


Figure 1. Organic carbon cycling in a flooded peatland. Litter, peat, and microbial biomass are considered as particulate organic carbon (POC).

(DOC) and particulate organic carbon (POC) (Figure 1). Both of these fractions are derived from dead plant tissue produced within the system, native soil organic matter or exported from adjacent ecosystems. The biogeochemical characteristics of allochthonous organic matter loaded to wetlands may vary spatially and temporally, depending on watershed management. For example, organic matter derived from silvicultural operations will have different chemical characteristics than the organic matter exported from watersheds dominated by agriculture. In addition to spatial variations in organic matter sources, temporal variations can occur as result of dynamic nature of aquatic systems.

Wet precipitation can be considered as allochthonous source of DOC to reservoirs. The DOC concentrations in precipitation range from 0.6 to 7.6 mg/L. Dissolved organic carbon fluxes from precipitation vary with values in the range of 0.3 to 8.9 g C/m^2 year in North America, 1.9 to 3.9 g C/m^2 year in tropical islands, 1.3 to 4.8 g C/m^2 year in South America, 1.4 to 5.8 g C/m^2 year in Europe, 3.4-3.5 g C/m^2 year in Australia, and 1.1 g C/m^2 year in Africa (Aitkenhead-Peterson et al. 2003). A wide range of DOC fluxes (1-

84 g C/m^2 year) from terrestrial ecosystems (forests, grasslands, peatlands) have been reported (Aitkenhead-Peterson et al. 2003). In a recent study, Freeman et al (2004a, b) observed a 65% increase in the DOC concentration of freshwater draining from upland watersheds in the United Kingdom over the past 12 years. These researchers attribute the increase in DOC to an increase in the activity of phenol oxidase, an enzyme believed to regulate carbon storage in peatlands. They showed increase in temperature had significant effect on the activity of phenol oxidase. A 10° C rise in temperature (in the range of 2° to 20° C) resulted in 36% increase in activity and was also accompanied by an equivalent increase in the amount of DOC released (Freeman et al., 2004a,b).

In water storage reservoirs created on peatlands, autochthonous DOC of algal and macrophyte origin can be an important contributor to the total DOC pool. The relative importance of these two sources (algae and macrophytes) depends on water depth, nutrient status, and physico-chemical environment in the water column. During active growth, both algae and macrophytes release a significant proportion of their primary production as DOC. The DOC produced from these sources consists of low-molecular weight compounds, is biologically labile and readily used as an energy source by microorganisms (Stuart et al., 2003).

The ecological significance of DOC is poorly understood and has not been clearly defined. This is mainly due to lack of a clear understanding of the composition of the DOC and its biodegradability. The DOC may represent a broad spectrum of organic compounds of varying environmental recalcitrance; thus it may not be possible to treat DOC as a homogeneous category. Both DOC and POC involves both labile and non-labile (recalcitrant) organic matter, the latter comprising the major fraction. Turnover of

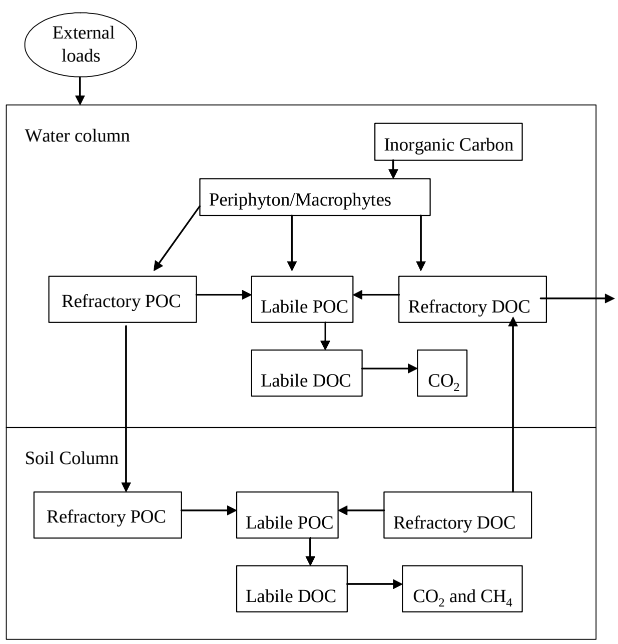


Figure 2. Carbon pools in flooded peatlands

highly labile, energy rich organic substrates may approach a rate of 5-10 times per day; thus actual concentration of the labile organic fraction may be extremely low. Despite the fact that recalcitrant DOC and POC are slow to mineralize, these pools represent a major portion of the organic matter processed by the heterotrophic community due to the relatively massive size of these pools (Figure 2).

The DOC in the mixture of organic material in DOM can be separated into two broad categories: humic and non-humic substances. The non-humic substances contain simple organic compounds such as proteins, carbohydrates, lipids, waxes, and low molecular weight organic acids. These highly labile materials are generally of low molecular weight (<500 Da) and are readily degraded. Humic substances are typically high molecular weight (500 to over 10,000 Da), more recalcitrant and often impart a yellow or blace color to natural waters.

The majority (>95%) of organic matter in aquatic ecosystems is composed of polymeric, high-molecular weight compounds. These high-molecular weight compounds must be broken into simple, low-molecular weight compounds, before microbes can utilize them. The high-molecular weight compounds are too large to pass through microbial cytoplasmic membrane. This means the majority of the POC and DOC may not be readily available (Chrost, 1990). In a natural environment, these polymeric organic substrates undergo stepwise enzymatic depolymerization and hydrolysis. Many heterotrophic bacteria are excellent producers of these hydrolytic enzymes. Enzymatic hydrolysis is often considered as the rate limiting step in overall breakdown of DOC and POC in aquatic environments (Chrost, 1990; Wright and Reddy, 2001).

Photolysis has recently been investigated in wetland environments as one of the controlling mechanisms for degradation DOC. Photodegradation of DOC increases the labile carbon pool, which stimulates microbial activity (De Haan 1993). The UV region of solar radiation (280 to 400 nm) is most active in breaking down DOC (Moran and Zepp 1997). Wetzel et al (1995) described photolysis of littoral detritus as increasing availability of simple carbon substrates for bacterial metabolism. They concluded that though UV can photolysize complex organic matter to more available carbon forms, solar radiation can also limit activity of bacteria and plankton populations. Nevertheless, photolysis provides a continual-decay pathway for recalcitrant organic carbon (humic substances) into bioavailable forms of DOC. Most humics are chromophoric in that they absorb UV radiation and can under go photolytic degradation. Although many reports view that the photochemical degradation of DOC as a mechanism for carbon transfer to the microbial food web, new observations are emerging to explain positive and negative effects on bioavailability. These positive and negative effects have been related to source of DOC. For example, photolysis effects on DOC derived from algae, phytoplankoton, and macrophytes may result in condensation reactions of low molecular weight compounds into refractory macromolecules such as formation of humic substances (Harvey et al. 1983). In contrast, older DOC derived from macrophytes may consist of aromatic compounds which may be subjected to breakdown during photochemical reactions, making this DOC more biologically available (Moran Covert, 2003). Partial photolytic breakdown of humic substances results in generation of fatty acids and other related simple organic compounds that can serve as energy sources for microbes.

However, photolysis of humic substances can result in complete breakdown to CO_2 with the result of some inorganic nutrients.

After enzyme hydrolysis or photolytic breakdown, small molecular weight compounds are taken up and utilized as C and energy sources by heterotrophic microorganisms. A multitude of different microorganisms may be involved in this terminal step of decomposition, which depends largely on availability of electron acceptors. Diverse types of microorganisms couple oxidation of organic C substrates (electron donors) and reduction of electron acceptors to energy (ATP) production required for growth. The most common electron acceptors include O_2, NO_3, Mn^{+4}, Fe^{+3}, SO_4^{2-}, and CO_2, that are gained through both internal and external inputs (Reddy and D'Angelo, 1994). For example, internal inputs include oxidation of chemical species (NH_4, H_2S, Fe^{+2}, and Mn^{+2}) that diffuse from anaerobic to aerobic soil zones. External inputs of electron acceptors include atmospheric O_2, seawater (SO_4), surface water runoff (NO_3), and precipitation. Most wetlands contain several electron acceptors, so there exists competition for electron donors between microbial groups. Aerobic organisms are more efficient in breaking down DOC than anaerobic microbes. Thus, oxygenation of the water column can potentially decrease the DOC concentration.

Several physical, chemical, and biological transformations in soil and water column may result in breakdown of plant detritus and soil organic matter and export dissolved and particulate organic C. However, a large portion of detrital organic matter is burried via accretion, which provides a means for long-term storage of contaminants associated with organic C, such as nutrients (N and P), metals, and toxic organics. Depending on environmental conditions, stored nutrients and other contaminants may be released from the organic matrix through mineralization and then cycled through the ecosystem or exported from the system. As the detritus tissue C and N are cycled through a wetland at various stages of decomposition a portion can be lost as gaseous end products. Fate of DOC in aquatic ecosystems has been extensively studied as reported by Stuart et al. (2003).

A major component of the feasibility study is to assess the water quality impacts of the proposed IDSP, especially with respect to organic carbon concentrations from releases of stored water from the IDSP reservoir islands. This report presents: (1) a review of the methodology of a mesocosm experiment conducted to determine DOC release from peat soils; (2) analyze the consistency of the data collected; (3) conclusions that can be drawn from the data about the rate of DOC release into water column; (4) limitations of the data and its use; and' (5) recommendations on the approach used and additional work required to improve the predictability of DOC release.

Specific tasks to be addressed in this report are:

- Review the information pertaining to the mesocosm experiments (often referred as water quality field investigations) contained in the reports provided by DWR .
- Review data and experimental procedures for consistency and determine if data are expressed in terms that are comparable and if not, determine if data can be

standardized to allow for comparison of like units. If standardization is necessary, standardize the data.

- Review the Jones Tract water quality data and estimate DOC release rates.
- Prepare a draft report that contains findings and recommendations concerning the use of the experiment and include discussion of (1) whether the data contributes to the understanding of annual, seasonal and shorter or longer term loading rates of organic carbon in flooded peat soil Delta environments, (2) the consistency of the data and analytical procedures, and (3) limitations of the data and its use.

The Department of Water Resources (DWR) provided the following information for review:

- Water sample results for all constituents measured, 2002 present
- Department of Water Resources, Draft Water Quality Report, In-Delta Storage State Feasibility Studies – December 2003.
- Department of Water Resources, In-Delta Storage Program State Feasibility Study CALFED Science Panel Review. August 2003.
- Department of Water Resources, In-Delta Storage Program Planning Studies, Water Quality evaluations, May 2002.
- Duval, Robert, Draft Research Paper.
- Duval, Robert, Experiment Data Collection Notes.
- Reddy, K. R., Review of Delta wetlands water quality modeling for release and regeneration of dissolved organic carbon, Final Report, 2002.
- Jones Tract Water Quality data, 2004.

Review the information pertaining to the mesocosm experiments (often referred as water quality field investigations) contained in the reports provided by DWR

2002 Mesocosm Experiments – Methods

Mesocosm studies were initiated in March 2002 at the Municipal Water Quality Investigations Field Support Unit in Bryte, California. Essentially, the mesocosms consist of four 3300 L (shallow) and four 6100 L (deep) fiberglass tanks (1.5 m diameter and 1.8 and 3.4 m height respectively. Peat soil depth in each mesocosm was set at 0.5 m. Soil used in mesocosms was obtained from Bacon Island, California, one of the proposed site for water storage reservoirs. Sacramento River water was used to fill tanks. Once filled, the depth water over the peat soil was approximately 1.4 m in the shallow mesocosms and 2.9 m in deep mesocosms. Tanks were filled in March and drained to 0.3 m depth in July. A control mesocosm (6100 L) with no soil was also included. Water samples were obtained once every two weeks and analyzed for several water quality parameters. Details of the experimental setup and water quality parameters can be found in DWR (2003).

2003 Mesocosm Experiments – Methods

In 2003 experiments, water column was replaced by filling thirds over a three months period starting January 2003. Winter filling and summer draining – typical reservoir operation was used. In addition approximately 15% of reservoir water volume was replaced every month. Water column was monitored for one year.

2004 Mesocosm Experiments – Methods

In 2004 experiments, operation of mesocosms was continued and water column chemistry was monitored for select water quality parameters.

Specific comments on methods used in mesocosm experiments are given below:

- The water quality data collected on mesocosms is adequate to estimate DOC loading rates and methods used followed all necessary QA/QC.
- Experiments conducted during 2002-04 lack consistency in terms of operational mode imposed on mescosms. This made comparison of results made it difficult. The DOC loading rates estimated for each year should be interpreted in this context.
- Water and soil temperature data are not available to determine the relationships between DOC flux rates and temperature.

Mesocosm experiments – Results

The water column DOC data collected during 2002, 2003, and 2004 were used to estimated DOC release from soil to overlying water column.

Data on relationships between DOC and TOC are shown in Figure 3. The slopes of linear

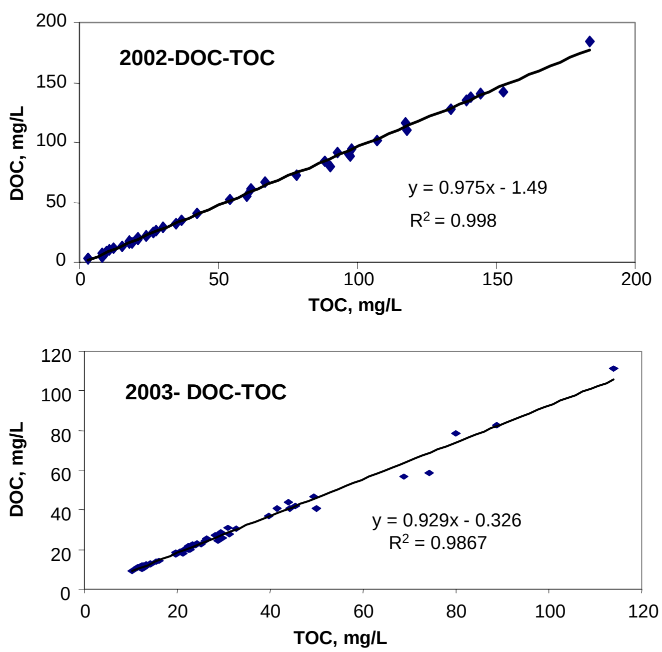


Figure 3. Relationship between dissolved organic carbon (DOC) and total organic carbon (TOC) in the water column during the year 2002 and 2003. Data points represent average values of four mesocosms for shallow and deep water depths.

regressions (ratio of DOC/TOC) are 0.975 and 0.929, respectively, for 2002 and 2003. These ratios suggest that approximately 93 to 98% of the TOC is DOC. If the ratio between DOC/TOC is close to 1 (as shown in Figure 3) the data suggest that the source of DOC is from the underlying peat soil and possibly this DOC is slowly biodegradable. Low DOC/TOC ratio suggests that there is planktonic production of particulate organic carbon (POC) in the water column and rapid consumption of bioavailable DOC.

Under field conditions, it is very unlikely such a relationship exists. Typically under field conditions, POC is generated by plankton and other living biota in the water column. Low levels of POC in the water column suggest that the source of TOC to the water is primarily due to diffusive flux of DOC from underlying peat soils. Mesocosm water column are static systems with very little or no hydrodynamic events, such as wind induced circulation and mixing and resuspension of surface soils during heavy wind events. These systems at best represent potential DOC flux rates from soil to the overlying water column.

In 2002, mesocosms were filled on March 12 and water was stored until July 2002, simulating conditions of proposed reservoir operation. Water column DOC concentrations increased steadily from background levels to approximately 30 and 60 mg C/L at water depths of 2.9 and 1.4 m respectively (Figure 4). Low levels of DOC at

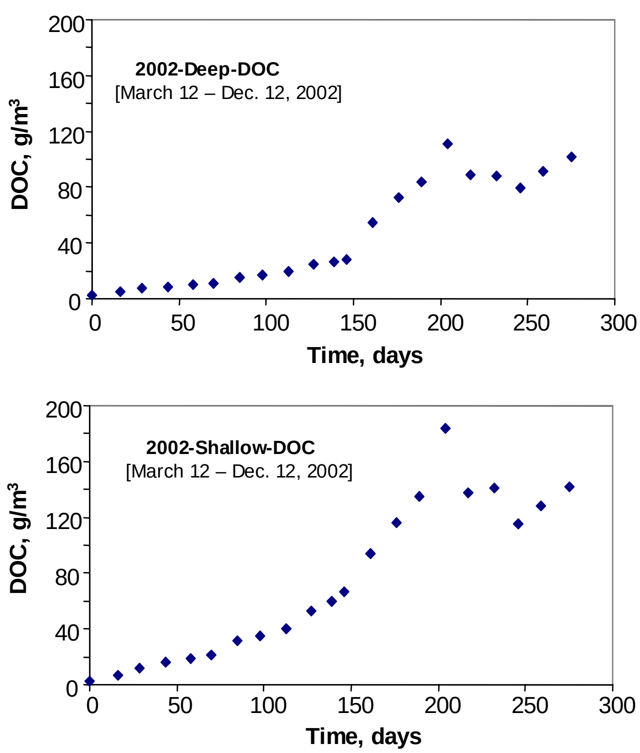


Figure 4. Dissolved organic carbon concentration in the water column of mesocosms during 2002. Deep water depth = 2.9 m; Shallow water depth = 1.4 m. Mesocosms were drained during the last week of July and operated at 0.3 m water depth during the

remainder of the year. Data points represent average values of four mesocosms for shallow and deep water depths.

higher water depth is primarily due to dilution. At the end of July 2002, mesocosms were drained to a water depth of 0.3 m and maintained at that level during the remainder of the year. Concentrations of DOC steadily increased to high levels in the range of 12 to 160 mg C/L. This is expected due to shallow water depth and concentration effects. During November and December, DOC concentrations leveled off as a result of dilution due to rainfall and slower release of DOC from peat soils. High DOC concentrations in the water column suggest that the soil porewater concentrations are substantially high resulting in flux from soil to overlying water column.

Cumulative mass DOC release from soil to overlying water column during 2002 is shown in Figure 5. Mass DOC release per unit area was calculated as follows:

Mass DOC in the water column (g/m^2)
= Water column DOC concentration (g/m^3) x water depth (m)

Mass DOC in the water column showed three distinct release rates. Slow release during the first two months (March and April) was probably due to start-up effects and low

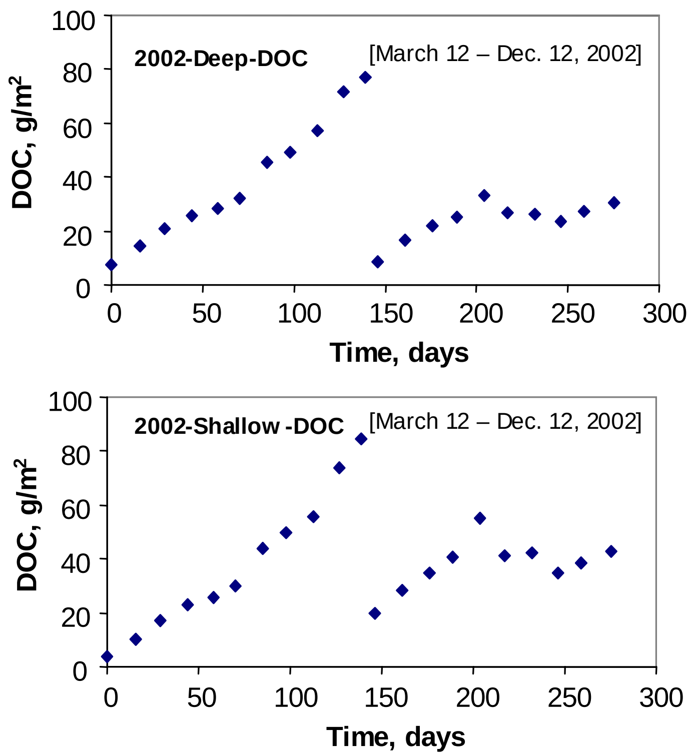


Figure 5. Mass DOC release into the water column of mesocosms during 2002. Deep water depth = 2.9 m; Shallow water depth = 1.4 m. Mesocosms were drained during the last week of July and operated at 0.3 m water depth during the remainder of the year. Data points represent average values of four mesocosms for shallow and deep water depths.

temperatures. During the months of May through July highest rates of DOC release rates were observed. This was followed by decrease in DOC release rates during the months of August and September. Water depth had minimal effect on DOC release rates during 2002.

During 2003 mesocosm mode of operation was changed by introducing new water circulation. Tanks were filled in thirds over a 3-month period starting in January 2003. After that period approximately 25% of the water was replaced with Sacramento River water once every month until August 2003. Complexity introduced in operation of mesocosms during 2003 experiments makes it difficult to compare results of earlier study conducted in 2002, which were operated as static systems. Exchange of water creates lower DOC concentration in the water column, which results in increased gradient between soil and overlying water column. Concentrations of DOC in the water column were in the range of 15 to 30 mg/L during February to July, 2003. In addition, exchange of water can also maintain higher dissolved oxygen levels in the water, thus increasing the overall biotic degradation of DOC. In the DWR Report, DOC mass release rates were calculated by normalizing DOC concentrations with measured water depth at the time of sampling. No attempt was made to account for mass of DOC removed during exchange periods. In the report provided (DWR, 2003) experimental and sampling

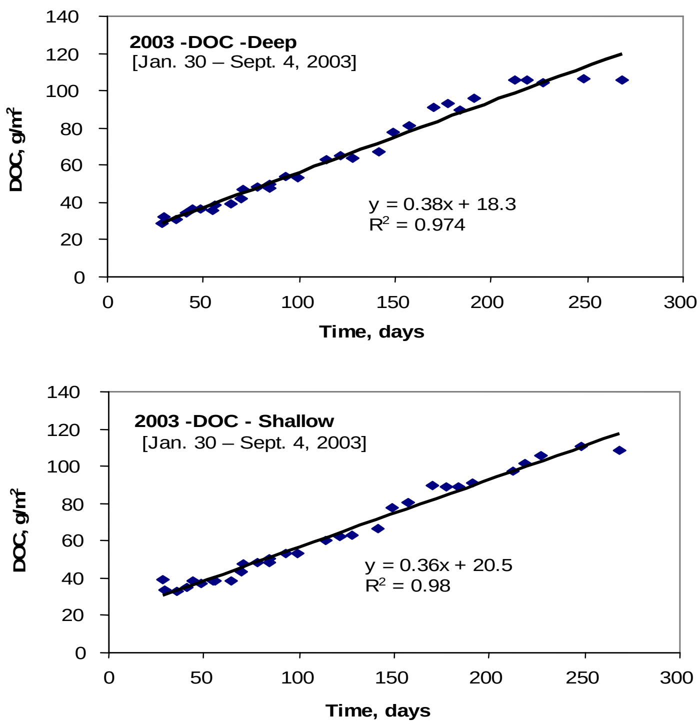


Figure 6. Mass DOC release into the water column of mesocosms during 2003. Deep water depth = 2.9 m; Shallow water depth = 1.4 m. Data points represent average values of four mesocosms for shallow and deep water depths.

protocols were not adequately described. Exchange of water probably added error to estimation of mass release rates. The DOC mass release rates (Figure 6) for each sampling step were calculated by accounting the amount of DOC removed during each water exchange cycle. Cumulative mass DOC release as function of time is presented. The DOC mass release rates in 2003 experiments were influenced by water circulation and seasonal temperature fluctuations. Adequate sampling was not done to determine true seasonal influences. However, bulk measurements as presented in Figure 6 suggest a linear increase in mass DOC release during the sampling period. Steady release in DOC was observed during the study period, with very little or no release during the first two months (January and February), and higher release observed during months May through August, reflecting the influence of temperature on DOC release. Results strongly suggest that DOC release is influenced significantly by seasonal fluctuations in temperature. Water temperature data are not available to develop the relationship between temperature and DOC release. Many biogeochemical processes are influenced by temperature, with reaction rates often doubled for every 10^{o}C degree rise in temperature. Temporal variations in DOC flux rates are further discussed during the later part of this report.

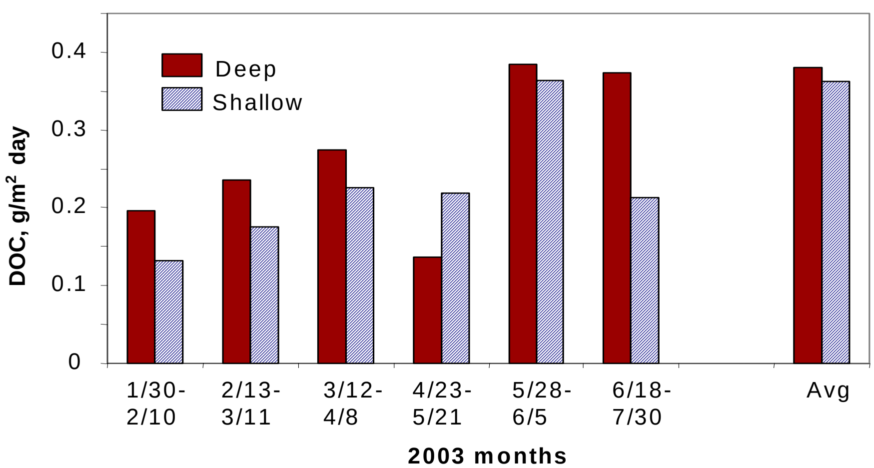


Figure 7. Mass DOC release rates between each water exchange periods during 2003. Deep water depth = 2.9 m; Shallow water depth = 1.4 m. Data points represent average values of four mesocosms for shallow and deep water depths.

The DOC mass release rates between each water exchange period were calculated to determine the influence of water exchange on DOC release (Figure 7). The estimated rates were influenced by errors associated with water exchange including dilution, measuring water depths, and seasonal temperatures. Adequate sample populations were not available between each sampling period, which may have added additional errors in estimating DOC flux rates. In general, shallow water depth tanks released slightly less DOC than the deep water depth mesocosms. However, these differences may not be significant. It is surprising to note that the DOC flux rates determined by the whole data set resulted in 0.37 g C/m^2 day. The rates measured between each water exchange period were lower or equal to the rates obtained for the whole experiment period. These results suggest the flux rates measured between each water exchange period are underestimating the overall DOC flux. Experimental methods are not clear on how accurately water exchange mode of operation was accomplished and how well the water column was mixed during and between sampling periods.

In November 2003 mesocosms operation was changed again, this time by filling tanks to their respective depths of 1.4 and 2.8 m with Sacramento River water, with no water circulation. At the time of this report preparation, water column TOC data from November 2003 to June 2004 was available. During the experimental period, water depth was adjusted for evaporative losses. Earlier studies have shown that the DOC/TOC ratio of the water in mesocosm experiments is in the range 0.94 to 0.98. Thus the mass TOC release will be slightly higher than the DOC release observed in previous experiments. Concentrations of TOC in the water column were in the range of 7 to 12 mg/L at the start of the experiment and increase steadily to 15 to 30 mg/L. The TOC concentrations of the water in tank with no peat soil ranged from 2.5 to 4 mg/L. As described previously, DOC mass release rates were calculated by normalizing DOC

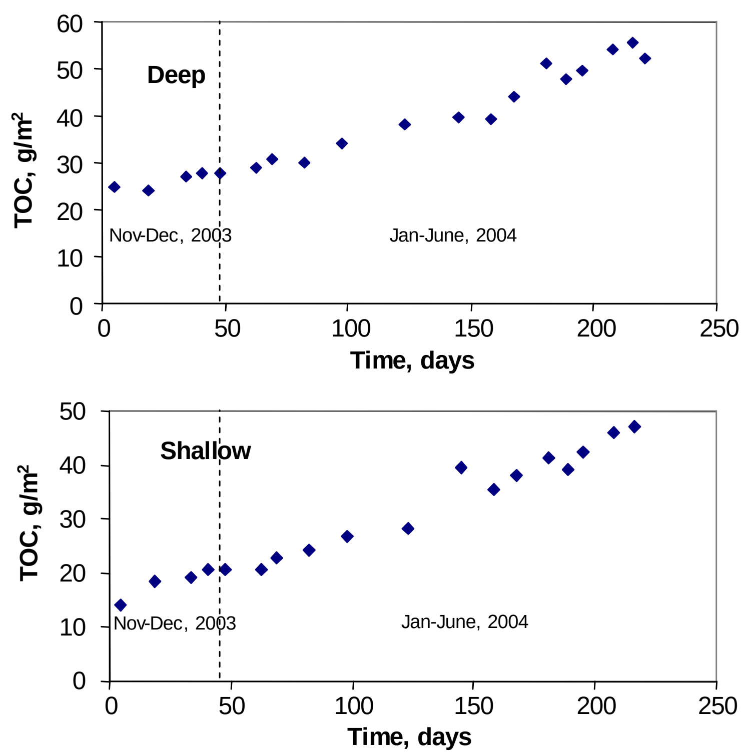


Figure 8. Mass DOC release into the water column of mesocosms during 2003-04. Deep water depth = 2.8 m; Shallow water depth = 1.4 m. Vertical dashed line represents January 1. Data points represent average values of four mesocosms for shallow and deep water depths.

concentrations with measured water depth at the time of sampling. Data on mass DOC release into water column are presented in Figure 8. The TOC release was slower during months of November 2003 to February 2004. Higher rates were observed during the remainder of the study period (March –June, 2004). Mass release rates substantially decreased as compared to 2002 and 2003 experiments. At the end of the study (June 2004) TOC mass release was 50 and 52 g C/m^2 for 1.4 and 2.8 m water depths, respectively.

A summary of DOC and TOC flux rates estimated from mesocosm experiments from 1999 to 2004 are summarized in Table 1. Experimental conditions varied during each experiment. Experiments in 1999 and 2000 used various peat depths, flushing rates, and water depths. Mesocosms were reconstructed with new soil and constant peat depth of 0.5 m, but the experimental conditions varied during each year (2002, 2003, and 2004) study. For comparison purposes, we assumed that the experimental conditions imposed have minimal effect of DOC/TOC release from peat soil into water column. Last 3 years data shows the capacity of flooded peat soil to release DOC/TOC into water column.

Table 1. Dissolved organic carbon (DOC) and total organic carbon (TOC) release rates from flooded organic soils.

Experimental conditions	DOC Release Rate [g C/m^2 day]	TOC Release Rate [g C/m^2 day]
DWR mesocosm experiments1999 and 2000		
Water depth = 0.6 m		
Tank 1 [0.46 m peat and no water exchange]	0.274	
Tank 2 [0.46 m peat and weekly water exchange]	0.684	
Tank 3 [0.92 m peat and no water exchange]	0.411	
Tank 4 [0.92 m peat and weekly water exchange]	0.767	
Water depth = 2.1 m		
Tank 5 [0.92 m peat and no water exchange]	0.093	
Tank 6 [0.46 m peat and weekly water exchange]	0.591	
Tank 7 [0.46 m peat and no water exchange]	0.123	
Tank 8 [0.92 m peat and weekly water exchange]	1.055	
DWR mesocosm experiments 2002 (March –December)- All tanks		
2.9 m water column [March-July]	0.492	0.492
0.3 m water column [August-Sept.]	0.403	0.425
1.4 m water column [March-July]	0.554	0.554
0.3 m water column [August –Sept.]	0.574	0.573
DWR mesocosm experiments - 2003 - All tanks		
[January-August] – Shallow	0.362	
[January-August] - Deep	0.380	
DWR mesocosm experiments 2003 - All tanks [no circulation]		
[November-December] - Shallow		0.142
[November – December] - Deep		0.087
DWR mesocosm experiments 2004 - All tanks [no circulation]		
[January-June]- Shallow		0.150

[January – June] - Deep	0.146

For years 2002 through 2004 of the study, seasonal influences on DOC flux rates were estimated and the data are presented in Figure 9a, 10, and 11. Distinct seasonal effect on DOC flux was observed during all three years. Unfortunately, data were not collected consistently during all 3 years to determine true seasonal effect on DOC flux. For example, in 2002 experiments were initiated in March and useful data were collected until the end of September 2002. Data collected in October –December, 2002 were affected by rainfall. Highest DOC flux rates in 2002 were observed during July (Figure 9a). DOC flux rates were higher in mesocosms with 1.4 m water depth as compared to tanks with 2.9 m water

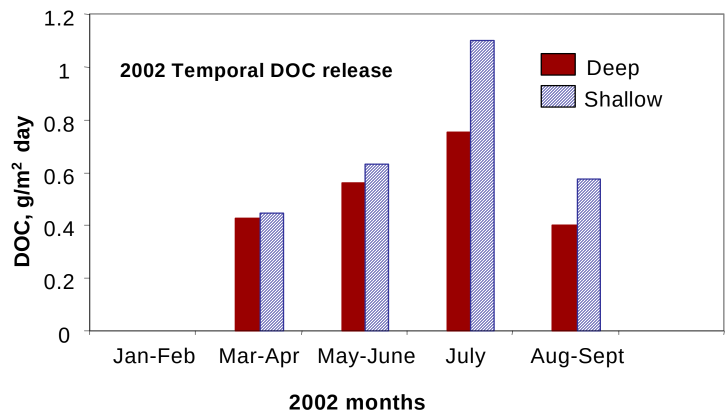


Figure 9a. Seasonal influences on DOC flux from peat soil to overlying water column during 2002. Deep = 2.9 m water depth; Shallow = 1.4 m water depth. Data points represent average values of four mesocosms for shallow and deep water depths.

depths. Maximum and minimum air temperatures at the Bryte site for 2002 are shown in Figure 9b. Highest maximum and minimum temperatures were observed during the month June – July. During these months DOC flux rates were also high. Trends in DOC flux rates reflect in temporal changes in temperature.

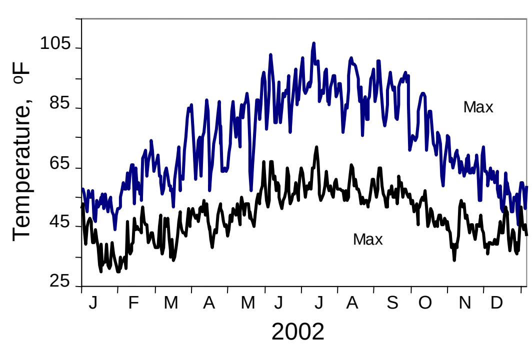


Figure 9b. Maximum and minimum air temperature at the Bryte site.

During the year 2003, water quality data was collected from January 1, 2003 to September 4, 2003. Seasonal rates were calculated based on regressions using the data on bimonthly basis and on a monthly basis. In addition to temporal variability, it should be noted that the rates were also influenced by water exchange periods. The DOC flux rates show, typical season patterns with rates lower during winter and higher during summer months. DOC fluxes steadily increased with no positive flux during January-February, and maximum flux during July and August months. In addition, during the 2003 experiments seasonal DOC fluxes were also influenced by variable water exchange rates.

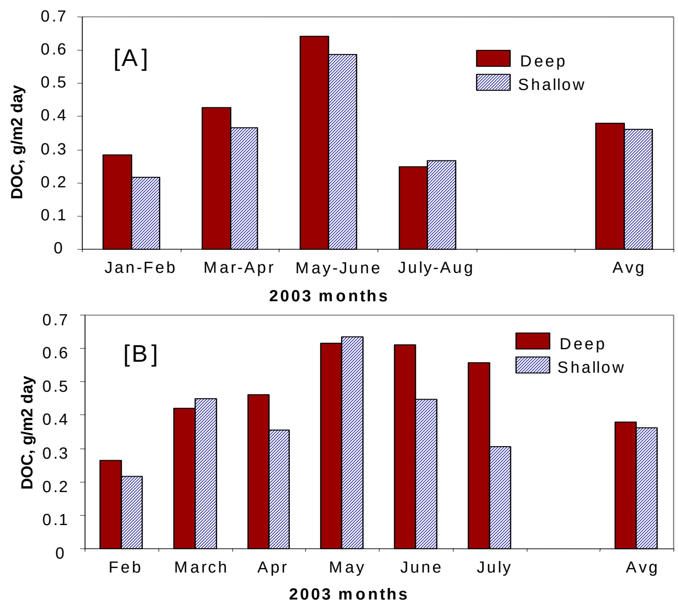


Figure 10. Seasonal influences on DOC flux from peat soil to overlying water column during 2003. Deep = 2.9 m water depth; Shallow = 1.4 m water depth. Data points represent average values of four mesocosms for shallow and deep water depths. [A] Rates calculated on bi-monthly basis. [B] Rates calculated on monthly basis.

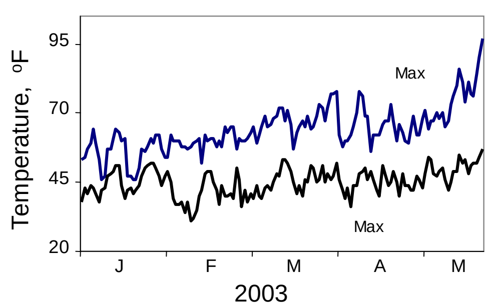


Figure 11. Maximum and minimum air temperature at the Bryte site during the months January to May.

At the time of preparation of this report, temperature data were available for the whole year of 2002 (Figure 9b) and for January-May in 2003 (Figure 11). To determine the relationships between temperature and DOC flux rates, 2002 data were used for some of the months in 2003. Average daily ambient air temperature was calculated as follows:

Average daily air temperature = sum $(T_{max} + T_{min})/2t$

Where: T_{max} is the maximum daily air temperature; T_{min} is the minimum daily air temperature; t is the number of days used in calculation of DOC flux rates (bimonthly). The relationship between DOC flux rates and the average daily air temperature is shown in Figure 12.

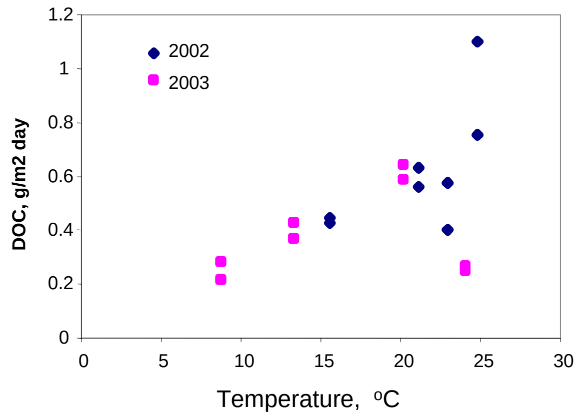


Figure 12. Relationship between ambient average air temperature and the DOC flux rates for the year 2002 and 2003. DOC flux rates estimated on a bimonthly basis.

With the exception of two data points, there exists a positive relationship between ambient average air temperature and DOC flux rates. The flux rates approximately doubled with 10° C rise in temperature, suggestion a Q_{10} value of 2. Sampling frequency was not adequate enough to develop strong relationships. However, Figure 12 shows strong temperature effects. It should be noted that DOC flux rates are also influenced by a number of other factors such as biological activity in the water column, dissolved oxygen in the water column, and the lability of the DOC to breakdown. The influence of these factors was not evaluated in this study.

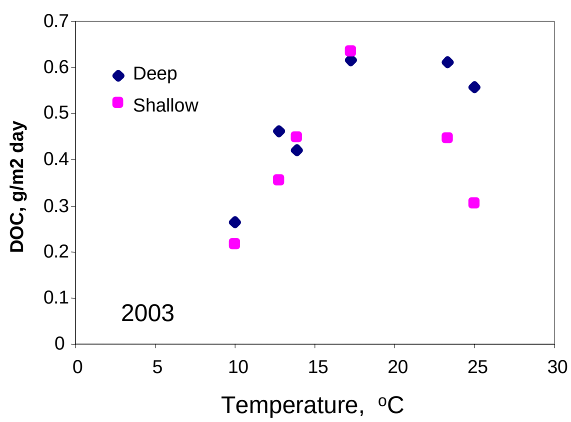


Figure 13. Relationship between ambient average air temperature and DOC flux rates in 2003 experiment. DOC flux rates estimated on a monthly basis.

For the year 2003, the DOC flux rates were estimated once every month and the relationship between rates and the ambient average air temperature is presented in Figure 13. Temperature data for June, July, and August used in this study was derived from the year 2002. Although there is some scatter in the relationships, there is a general trend on the influence of temperature on DOC flux rates.

In November 2003 tanks were filled to respective water depths and water column was monitored for TOC until June 2004. Again, only partial data are available to truly evaluate seasonal effects on TOC/DOC flux rates. Data in Figure 14 shows seasonal TOC flux rates during November 2003 to June 2004. Data collected in 2002 and 2003 showed that the ratio of DOC/TOC is in the range of 0.95 to 0.98. Thus, the TOC flux represents the DOC flux and comparisons can be made with previous years. Although TOC flux rates are substantially lower than previous years, similar seasonal effects were observed as compared to previous years. Highest flux rates were observed during the May-June months. Similar to other years, additional environmental data are needed to evaluate the role of temperature on flux rates.

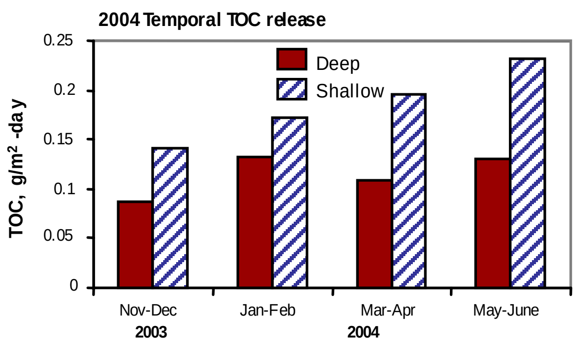


Figure 14. Seasonal influences on DOC flux from peat soil to overlying water column during 2003-2004. Deep = 2.9 m water depth; Shallow = 1.4 m water depth. Data points represent average values of four mesocosms for shallow and deep water depths.

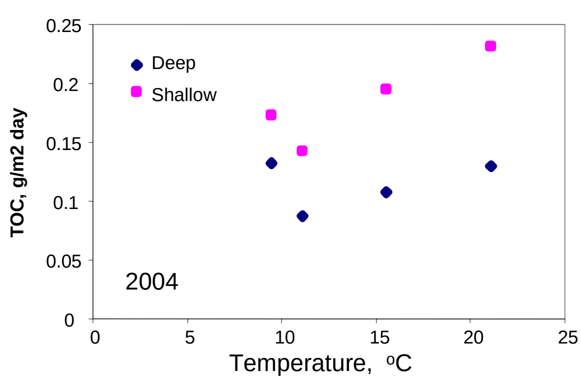


Figure 15. Relationship between TOC flux rates measured during 2004 (bimonthly) and average daily ambient temperature in the year 2002. Temperature data for 2004 are not available at the time of this report preparation.

Although there is considerable scatter in these relationships, there is general trend between ambient daily air temperature and TOC flux rates. The flux rates did not double for every 10° C rise in temperature, suggesting that the TOC released into the water column is less labile that previous years.

A wide range of DOC flux rates (0.093 to 1.055 g/m^2 day) were observed in experiments conducted in 1999 and 2000 experiments. The average DOC flux rate in these experiments was 0.5 g/m^2 day. Experiments in 2002 involved repacking tanks with new soil. Average DOC flux measured during the year 2002 was 0.51 g/m^2 day. Average DOC flux during the subsequent experimental periods decreased to 0.4 and 0.15 g/m^2 day, respectively for 2003 and 2004. For comparison, we have calculated DOC fluxes for May-June period during each experimental period (Figure 16). Temperatures during this period are optimal for maximum biological activity and production of DOC.

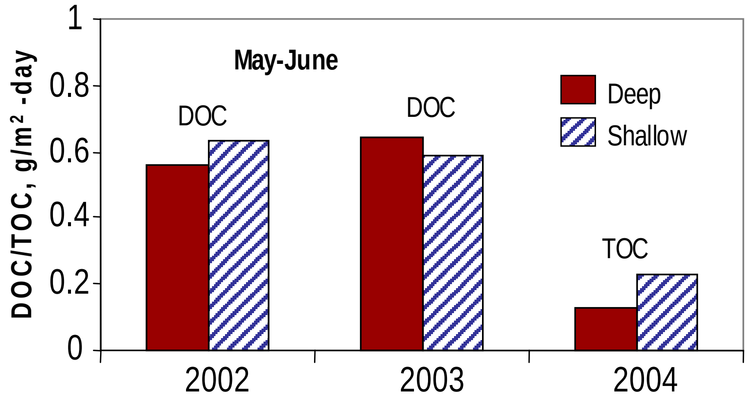
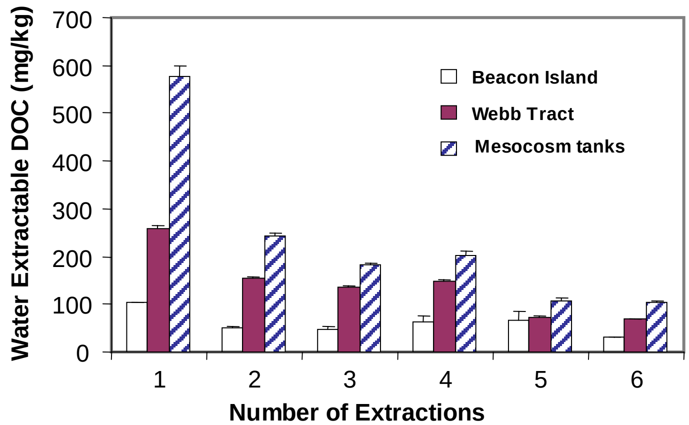


Figure 16. Dissolved organic carbon (DOC) and total organic carbon (TOC) release rates from flooded organic soils during May-June of each yearly experimental period. Data points represent average values of four mesocosms for shallow and deep water depths. In 2004, water samples were not analyzed for DOC

When compared 2002 DOC flux, May-June flux rates decreased by 18% in 2003 and by 72% in 2004 (Figure 16). In 2004 only TOC concentrations were measured. We assume that DOC represents approximately 95% of TOC, accordingly flux rates should be adjusted. Slow rates of DOC flux in 2004 suggests the initial 'tea bag' effect decreased and the system may be approaching steady state DOC flux from peat soil. With the limited data, it is difficult to estimate the time required to reach steady state DOC flux from soil to overlying water column.

Dissolve Organic Carbon Production

A simple laboratory study was conducted to determine the DOC leaching potential of three soils collected from the region. The study used two soils collected from Bacon Island and Web Tract, and a third soil also from Beacon Island that was used in the mescosm experimental tanks and flooded for a 3 year period. Soils were subjected for repeated sequential extractions for a total of 6 times during a 2-day period. Results are



presented in Figure 17.

Figure 17. Water extractable DOC from selected soils in the region.

Soils obtained from the field conditions had lower water contents representing drained conditions. The DOC release from two field soils was lower than the soil maintained under flooded conditions for a 3- year period. Under aerobic or drained conditions DOC breakdown is much faster and the decomposition is carried over all the way to CO_2 production. Under anaerobic conditions, decomposition of organic matter is slower and also incomplete, resulting in accumulation of labile DOC in soil. Similar results were observed in Florida's peatlands as shown in Figure 18. These results suggest that approximately 1.6 times more DOC is produced under flooded conditions than under drained conditions.

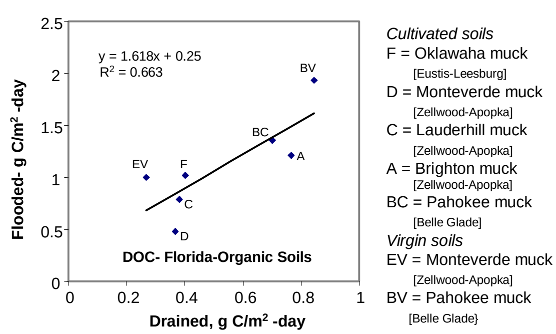


Figure 18. DOC release rates under flooded and drained conditions of several Florida's peatlands (Reddy, 1982).

Jones Tract Flooding and Water Quality Monitoring

On June 3, 2004, breach occurred on the levee of Middle River, resulting in flooding of Upper and Lower Jones Tracts (Figure 19). Approximately, 140,000 acre-feet of water

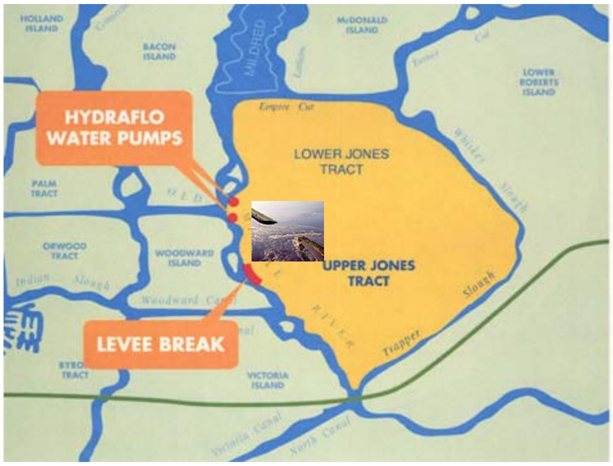


Figure 19. Map showing levee break in the Middle River west of Jones Tract.

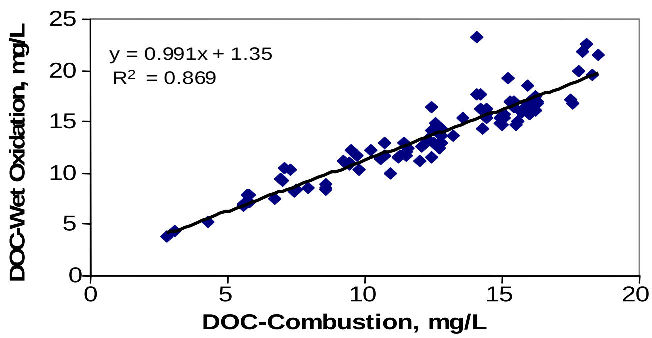
flooded 12,165 acre farm land. Levee was restored and the pumpout operations began onJuly 12, 2004. At the time of flooding average depth of the water covering the rich Delta farmland was estimated at 3.5 m. To determine the effects of flooding, the Department of Water Resources (DWR) established a number of water quality monitoring stations as shown in Figure 20 and Table 2.

Figure 20. A map of Jones Tract showing water quality monitoring stations.

Table 2. Water quality sampling locations in Jones Tract.

SITES (see map at left for approximate locations)	**N coordinate**	**W coordinate**	**Sampling depth**
Lower Jones near the Intake (LJI)	N37°56.485'	W121°31.646'	1 meter below surface
LJ Mid island top of water column (LJMT)	N37°56.785'	W121°30.722'	1 meter below surface
LJ Mid island bottom water column (LJMB)	N37°56.785'	W121°30.722'	1/2 meter off bottom
LJ Discharge (LJD)			from sample port on discharge pipe
Upper Jones near Intake (UJI)	N37°56.223'	W121°31.592'	1 meter below surface
UJ Mid island top (UJMT)	N37°55.553'	W121°30.897'	1 meter below surface
UJ Mid island bottom (UJMB)	N37°55.553'	W121°30.897'	1/2 meter off bottom
UJ Discharge (UJD)			from sample port on discharge pipe
Middle River (MR)	N37°55.146'	W121°30.903'	sampled from shore with pole and can about 0.3 m below surface
Upper Jones Breach (UJB)	N37°55.252'	W121°30.975'	sampled from shore with pole and can about 0.3 m below surface
Lower Jones East Shore (LJES)	N37°57.170'	W121°27.166'	sampled from shore with pole and can about 0.3 m below surface
LJES Duplicate (LJESD)	N37°57.170'	W121°27.166'	sampled from shore with pole and can about 0.3 m below surface

Soils in the Jones Tract are Histosols with peat depths of up to 3 m. Although flooding of 12,000 acre farmland is an environmental disaster, it does provide an opportunity to



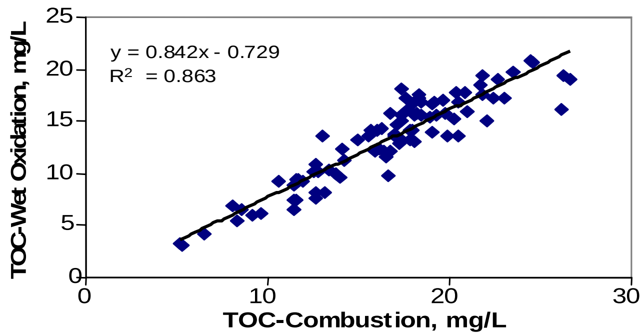


Figure 21. Relationship between TOC/DOC determined by wet oxidation and combustion methods.

determine the effect of flooding on TOC and DOC release potential of peat soils. In this report we present a preliminary analysis of water column DOC and TOC data and determine the flux rates from soil to overlying water column.

Water samples obtained were analyzed for DOC and TOC using both wet oxidation method and total combustion method. A comparison of both methods is presented in Figure 21. Both methods showed similar recoveries with respect to DOC analysis. However, TOC analysis by wet oxidation method accounted for 84% of the TOC determined by combustion method. These results suggest that wet oxidation provides incomplete oxidation of organic carbon resulting in lower recoveries. For all other data analysis, we will use DOC and TOC determined by combustion method.

Data on relationship between TOC and DOC of water samples are shown in Figure 22. Approximately 84% of the TOC was present as DOC and the remaining as POC. The source of POC in was probably due to resuspension of fine soil particles from the underlying peat soils and plankton in the water column.

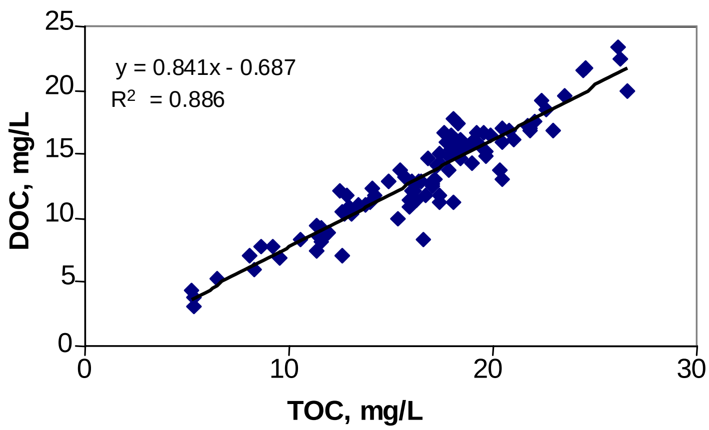


Figure 22. Relationship between TOC and DOC of water samples collected from flooded Jones Tract.

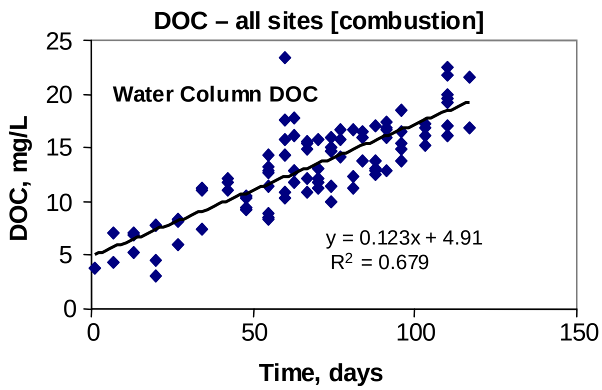


Figure 23. Influence of flooding on dissolved organic carbon concentration of the water column.

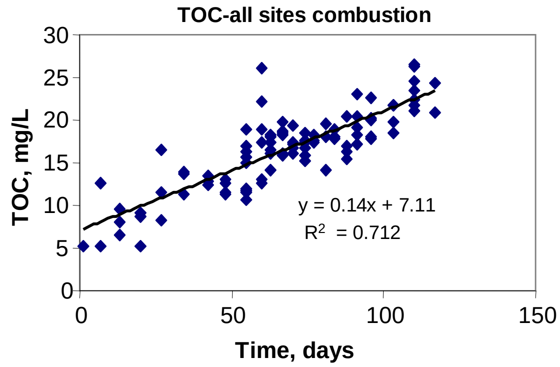
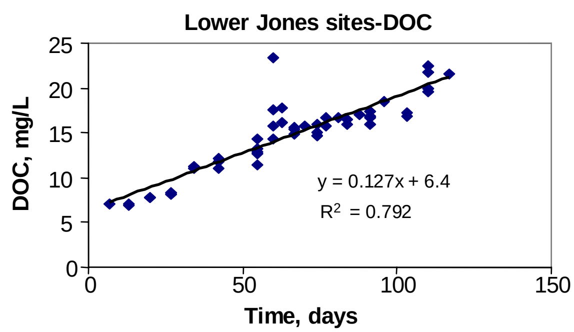


Figure 24. Influence of flooding on TOC release (samples from all sites) from peat soil to the overlying water column.

For all sampling sites, DOC concentrations in the water column increased steadily from 5 mg/L to approximately 20 mg/L, in about four months (Figure 23), while TOC concentrations increased from 6 mg/L to approximately 25 mg/L (Figure 24). Similar trends in DOC and TOC increase were observed for both Lower and Upper Jones Tracts, suggesting very little difference in characteristics soil organic matter in both regions (Figure 25 and 26).



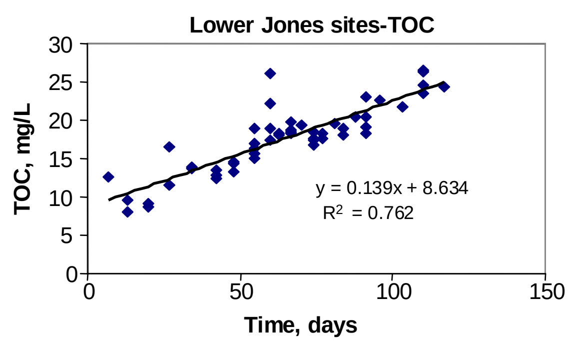
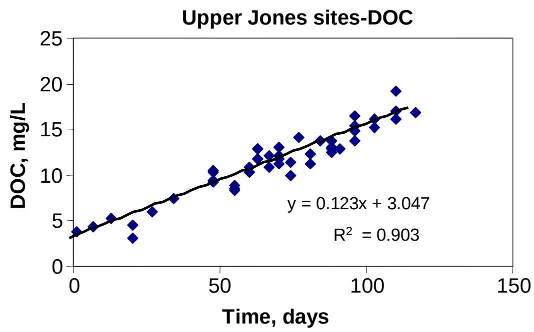


Figure 25. Influence of flooding on DOC and TOC release in Lower Jones Tract



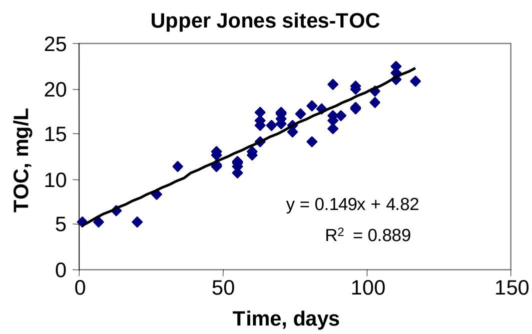


Figure 26. Influence of flooding on DOC and TOC concentrations of water in Upper Jones Tract

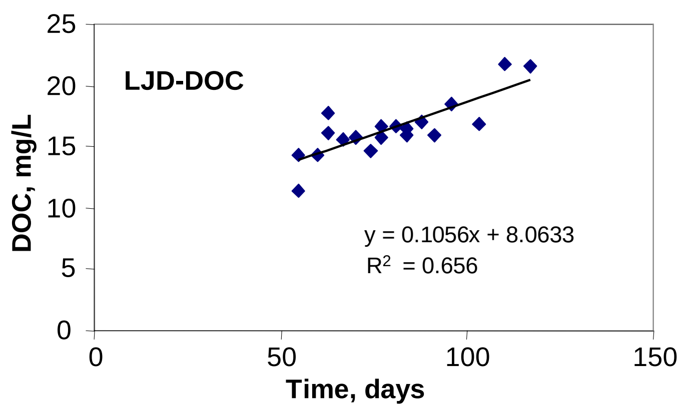


Figure 27. Dissolved organic carbon concentration of the water samples collected from the discharge point in Lower Jones Tract.

Water samples from two discharge stations (LJD and UJD) were obtained 55 days (July 29, 2004) after flooding occurred. At this point DOC and TOC concentrations increased from 5 mg/L to approximately 15 mg/L. Slightly lower DOC and TOC levels were observed in water samples collected from two discharge sites in Lower a (LJD) (Figures

27 and 28) and Upper (UJD) Jones Tract (Figure 29), as compared to interior sites. This may be due to possible dilution during pumping events.

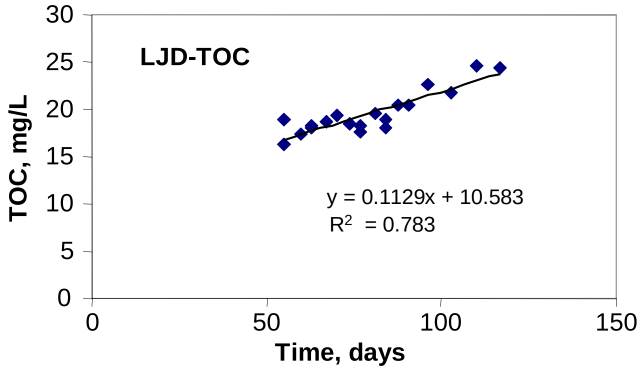


Figure 28. Total organic carbon concentration of the water samples collected from the discharge point in Lower Jones Tract.

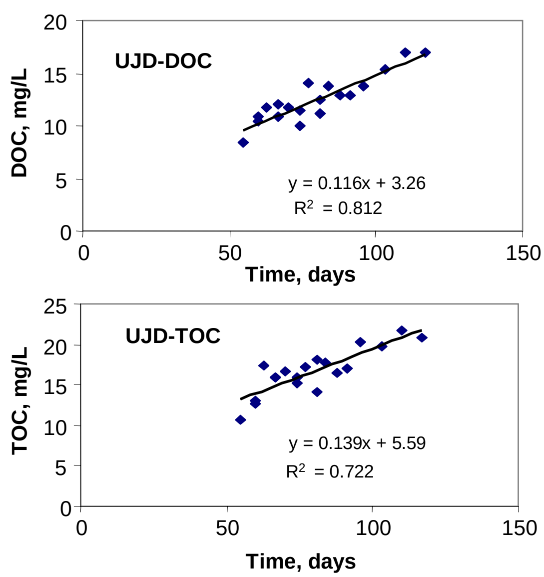


Figure 29. Dissolved and total organic carbon concentrations of the water samples collected from the discharge point in Upper Jones Tract.

At all sampling sites, flooding increased DOC and TOC concentrations of the water column by approximately five times in four months. Mesocosm studies have shown that when drained soils are flooded, initially substantial amounts of DOC and TOC released. Average estimated water depth in the Jones Tract during the sampling period was estimated to be 2.61 m. Slopes of regression equations presented in Figures 22-29 were multiplied to estimate flux rates expressed as g/m^2 day. Results are presented Table 3.

Table 3. Dissolved organic carbon (DOC) and total organic carbon (TOC) release rates from flooded peat soils in the Jones Tract.

Experimental conditions	DOC Release Rate [g C/m^2 day]	TOC Release Rate [g C/m^2 day]
Jones Tracts WQ monitoring		
June 2004-September 2004		
Average water depth = 2.61 m		
All sites	0.321	0.365
Lower Jones sites	0.331	0.363
Upper Jones sites	0.321	0.389
LJD	0.276	0.295
UJD	0.302	0.362

Both DOC and TOC flux rates presented in Table 3 are approximately in the same range as those observed in mesocosm experiments (Table 1). Accurate water depth estimates are key in determining the reliability of estimated DOC and TOC flux rates. The flux rates reported in Table 3 assume a constant water depth and DOC and TOC

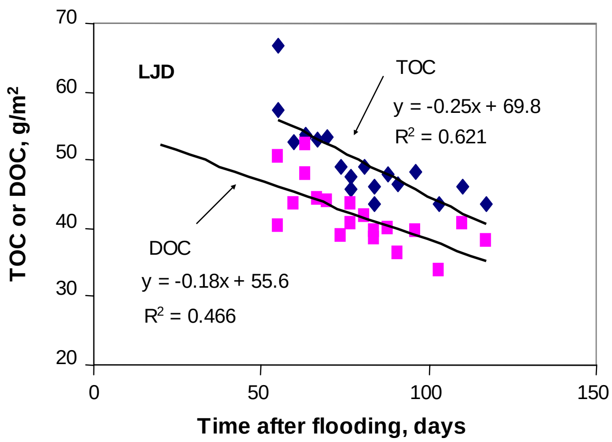


Figure 30. Mass TOC and DOC release as estimated based on calculated water depths in the Lower Jones Tract.

concentration increase occurred at this depth. Water depth was estimated based on acre-feet present at the time flooding and normalized to area of the Jones Tract. It is estimated that at the time pumping started (July 12, 2004, day 38 after flooding), there was approximately 140,000 acre-feet of water present in an area of 12,165 acres. This resulted in approximate water depth of 3.6 m. As water was pumped out of the Jones Tract, water depth steadily decreased. At the last sampling period (September 28, 2004, day 117 after flooding), the amount of water present in Jones Tract was 71,000 acre-feet, which resulted in a calculated water depth of 1.8 m. Based on estimated water depths, we have calculated mass of DOC and TOC released into the water column. One example of these results for LJD site is presented in Figure 30.

At LJD site, mass DOC and TOC release, 55 days after flooding (July 28, 2004) was highest and decreased during next two months of pumping events, even though concentrations increased during that time (Figure 31). It was expected that mass TOC and DOC will increase with time, as observed in the mesocosm experiments. Increase in TOC and DOC concentrations in the water column were not high enough to compensate for the decrease in water depth during pumping events.

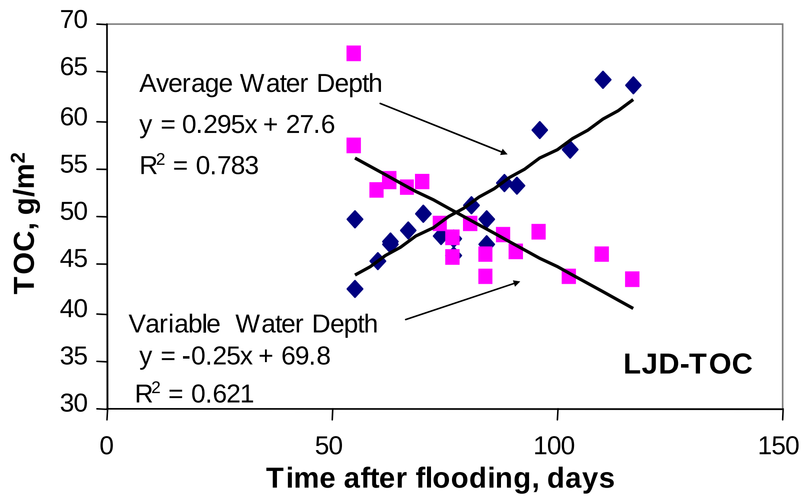


Figure 31. Mass DOC and TOC release from Day 55 to Day 117 after flooding of Jones Tract. Water depth this period was estimated to be 3.51 m.

Similar trends were observed for all sampling sites (Figure 32). An inverse relationship was observed between mass TOC release estimated using average water depth and variable water depth. Estimates based on variable water depth were probably more representative of dynamic changes occurring under field conditions. This raises a key concern on the reliability of estimated water depths for the whole area. Alternatively, the data on DOC and TOC concentrations were not adequate to truly represent the dynamic changes in the water column. Thus caution should be exercised on the use of Jones Tract DOC and TOC loading rates presented in Table 3.

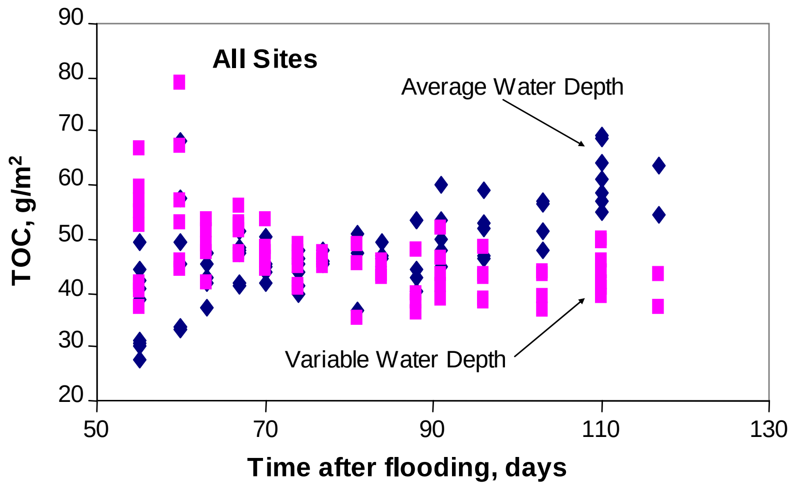


Figure 32. Mass DOC and TOC release from flooded Jones Tract (all sampling sites), as estimated (1) using average water depth (2.61 m), and (2) using variable water depth during the pumping period

Jones Tract was flooded on June 3, 2004 and water pumping was started July 12, 2004 (Day 38 after flooding). Estimated water depth during the initial flooding period (until July 28) was approximately 3.51 m. For this initial period of flooding, mass DOC and TOC release were calculated using 3.51 m water depth and data for all site are presented in Figure 33 and Table 4. During this period, mass DOC and TOC increased by 2 to 3 times, indicating initial flushing of labile organic carbon from soil to overlying water column. Similar flux rates were observed for both DOC and TOC and these values are approximately in the same range as those observed in 2002 and 2003 mesocosm experiments.

Table 4. Dissolved organic carbon (DOC) and total organic carbon (TOC) release rates from flooded peat soils in the Jones Tract during the first 50 days after flooding

Experimental conditions	DOC Release Rate [g C/m^2 day]	TOC Release Rate [g C/m^2 day]
Jones Tracts WQ monitoring		
June 3, 2004-July 28, 2004		
Water depth = 3.51 m		
All sites	0.482	0.482

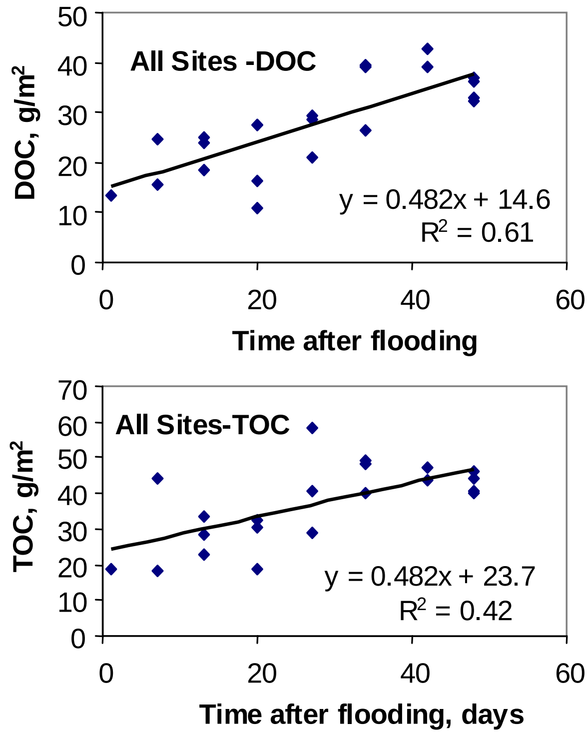


Figure 33 Mass DOC and TOC release during the first 48 days of flooding of the Jones Tract. Water depth for this period was estimated to be at 3.51 m.

General Discussion on Behavior of Organic Soils

Histosols (also known as peatlands or organic soils) are characterized with high organic matter (>12% total carbon) in the upper one meter of the profile. Soil formation is due to accumulation of partially decomposed organic matter, where peat decomposition processes can not keep up with primary productivity. Extensive areas of peatlands are found in northern parts of the U.S. (examples in Alaska and Minnesota) and in Canada. In southern large areas of the U.S., peatlands are found in the pocosins and Carolina bays of the southeast and the Everglades in south Florida. Surface horizons are usually well decomposed underlain by fibrous undecomposed peat. This differentiation is based on drained organic soils. Organic soils have high water-holding capacity and poor drainage. Upon flooding, these soils are rapidly reduced assuming intense anaerobic soil conditions, with Eh dropping to <-200 mV within a few days after flooding. Under a natural state, as mentioned earlier, peat forms as a result of plant litter accumulation from hydrophytic vegetation. Several million hectares of peatlands in North America, Europe, USSR and southeast Asia have been drained for farming. Organic soils are naturally productive and contain large amounts of organic carbon and associated nutrients.

When the flooded organic soils in the Delta were drained for agricultural purposes, the process of organic matter accumulation was completely reversed. Under drained conditions, peat soils can oxidize at a rate of about 3 cm per year. Converting these drained soils into water storage reservoirs will result in anaerobic conditions in soils, thus decreasing the overall decomposition process. Flooding results in solublization of organic matter and accumulation of partially decomposed organic compounds, thus contributing to dissolved organic matter.

Conclusions

The experimental mescosm study conducted during 2002-2004 showed rapid release of DOC during the first year that decreased significantly during the 2nd and d 3rd years (Table 5). The DOC flux rates shown in Table 5 represent average values for the whole year. Maximum flux rates represents summer and warmer conditions influencing the organic matter decomposition rate, while the minimum flux rates for any given year represents winter or more cooler conditions. Results show a positive relationship between DOC flux rates and temperature, with flux rates approximately increased by 1.5 to 2 times for every 10 C rise in temperature. This is typical of many biological systems and similar trends are reported for other systems (Reddy, 1982).

Table 5. Dissolved organic carbon (DOC) and total organic carbon (TOC) release rates from flooded peat soils in mescosms during 3 year study.

Year	Average g DOC/m^{2}day	SD	Max g DOC/m^{2}day	Min g DOC/m^{2}day
2002	0.612	0.229	1.098	0.403
2003	0.380	0.160	0.642	0216
2004*	0.146	0.05	0.231	0.087

*****TOC flux rates

Flooding well drained peat soils results in a flush of DOC release from soil to the overlying water column. Under drained conditions, microbial biomass contains both aerobic bacteria and fungi. Upon flooding and creating anaerobic soil conditions much of these active microbial populations die and the metabolic activities switch over to facultative and anaerobic bacteria. As a result, microbial groups that depend on oxygen as their terminal electron acceptor during respiration, now depend on alternate electron acceptors. Organic matter decomposition under these conditions is typically slower and results in solubilization of organic matter and accumulation of dissolved organic compounds. Thus, flux of DOC from soil to overlying water column is rapid during the first few months of flooding and decreases with time. Depending on environmental conditions and hydrology, initial flush of DOC may sustain a few months to 1-2 years, as observed in the mesocosm study (Table 5). Once the system reaches steady state, the flux from soil to overlying water column will depend on production of DOC within the soil profile. In addition, deposition of macrophyte detrital matter and dead algal cells on the soil surface may prevent the flux of DOC from soil. However, at that time, DOC generation in the water column will depend on the decomposition of detrital matter. The DOC concentration of water column is inversely related to the dissolved oxygen concentration of the water column.

Results presented in this report suggest that the initial "tea bag" effect sustains about 2 years. In relation to the first year DOC flux rates, the rates decreased approximately by about 40% after 2 years of flooding and by about 70% after 3 years of flooding. Average DOC flux from the mesocosm experiments during the first year was 0.612 g C/m^2 day, while the DOC release rates from the Jones Tract flooding during first 2 months of flooding was 0.48 g C/m^2 day.

The DOC flux rates obtained from mesocosms provide reasonable estimates, albeit these rates may represent the upper end of the scale. The mesocosm water column is operated as a static system and lacks typical hydrodynamic events observed under field conditions. Under field conditions it is likely that the DOC turnover rates will be higher than those obtained in the mesocosm experiments.

Additional Data Needs

The following additional information is needed to determine the long-term steady state flux of DOC and TOC release potential from peat soils to the overlying water column.

- Spatial variability of soil properties at the proposed reservoir sites. Basic soil properties such as organic matter content (loss on ignition), extractable carbon and nutrients and drained and flooded conditions.
- Characterization of peat soil, with respect to organic matter fractions. At the minimum determine the labile portions of carbon that can be potentially broken down into DOC.
- Chemical characterization peat soil. Cellulose-lignin ratios. Use NMR techniques to determine organic matter fractions.
- Determine the bulk density of soil column and estimate the total carbon storage in soil.
- Characterize dissolved organic matter using NMR techniques.
- Determine the biodegradability of the TOC and DOC in the water column.
- Soil oxygen demand (SOD) and biochemical oxygen demand (BOD) can provide some simple indication of the biodegradability of soil and water carbon pools.
- Maximum DOC leaching potential of peat soils and how soil properties affect DOC release.
- Determine the influence of prior soil conditions and agricultural management practices on labile pools of organic matter.
- Continue to monitor mescosm tanks for DOC and TOC with hydraulic retention times typical of proposed reservoirs. At the minimum, samples should be analyzed for TOC. Frequency of samples should be increase to once a week, at least for a period of one year to determine the temporal effects on TOC flux.

- Physico-chemical environment of the water column should be monitored. At the minimum dissolved oxygen and temperature should be monitored on a continuous basis.
- Determine the role of abiotic breakdown of DOC and TOC.
- Biotic breakdown of DOC and TOC, including enzymatic hydrolysis and microbial breakdown.
- Redox regulation soil organic breakdown and DOC generation. This should include hydrology and water table fluctuations, alternate flooding and draining, role of alternate metabolic pathways including sulfate reduction and methanogenesis.
- Relative DOC flux from plankton/macrophytes and soil needs to be determined.
- Although controlled experiments provide useful information, it is important to conduct field studies under more realistic conditions. Jones Tract data provides some of that information. Techniques are available to measure DOC fluxes under field conditions. Consider constructing a pilot scale reservoir (approximately 10 acres) and monitor water quality parameters. This will give more reliable information that can relate to full scale reservoirs.

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