FLOODPLAIN IMPACTS FROM CHANNELIZATION AND URBANIZATION: A CHARACTERIZATION OF THE TUMBLIN CREEK DELTA FLOODPLAIN, GAINESVILLE, FL

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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This document is dedicated to my lovely wife Jennifer, who has consistently supported, pushed, prodded and motivated me to utilize my full potential and take advantage of all opportunities afforded me. Secondly, this is dedicated to my officemates and friends for keeping me sane and Isabella and Sebastian for their expert assistance.

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Tumblin Creek is a heavily urbanized creek that discharges to a 30 acre delta floodplain before entering Bivens Arm Lake, Gainesville, Florida. Ditching and berm-creation over the past 60 years have hydrologically isolated a large area of the delta and restricted the flowpath where floodwaters historically would have spread out. The urban watershed contributes rapid storm flows and high sediment loads to the delta. Channelization and urbanization have directly impacted the delta and decreased its ability to retain sediments, nutrients and metals. This study surveyed the soils, water and vegetation to assess the historical changes to the delta and how these changes modified the sediment, nutrient and metal retention of the delta.

Tree root flare excavations combined with tree age dating indicate that the delta historically experienced little or no net sediment accretion and that this rate has increased in the time period of channel dredging and changes in agricultural and urban land-uses. Up to 1 m of sediments have been deposited in the region downstream of the channel in

the past 100 years, and this has caused a change in tree species from inundation tolerant species (obligate) to species that are less inundation tolerant (facultative).

Increased velocity and quantity of storm flows have created secondary incised channels within the delta that short-circuit creek flow to the lake. Soil surveys indicate that deposition of fine particles with high metal and P concentrations are mostly restricted to the westernmost region of the delta where longer detention times exist, while less reactive coarse particles make up the soils downstream of the dredged channel. Since a two hour detention time was found to remove virtually all of the particulate matter, phosphorus and metals from the water column it is likely that much of the pollutant load flowing into the delta from Tumblin Creek is carried directly to the lake through the incised channels and the adjacent delta provides little assimilative benefit.

Phosphorus isotherm studies indicate the region where the Tumblin Creek channel enters the delta floodplain is likely a constant source of soluble phosphorus. The region of the delta composed of finer particles with high phosphorus concentrations was found to retain soluble phosphorus most effectively. The increased loading of coarse particles which occurs in "flashy" watersheds decreases the delta's ability to retain soluble phosphorus. In contrast, the retention of fine particles with high phosphorus concentrations and sorptive capacity can improve water quality flowing to the lake.

CHAPTER 1
INTRODUCTION

Riparian wetlands provide several irreplaceable values. Some of the many benefits of riparian wetlands are flood control, groundwater recharge, dissipation of stream energy, wildlife and fish habitat, suspended sediment removal and other water quality improvements. Because riparian wetlands aid in such potentially important processes, modifications can have significant consequences. The Tumblin Creek delta floodplain wetland has been impacted from increased sediment, nutrient and metal loads as a result of urbanization and historic agriculture land-uses. These land-use impacts have caused modifications to the soils, vegetation, water and nutrient cycling. In addition, channelization of the delta floodplain decreased the exposure between streamflows and the delta which reduced the nutrient, sediment and metal retention of this ecosystem and potentially impacted the lake downstream. For this study, a timeline of the net sediment accretion rate was developed to understand how watershed modifications have impacted the sediment loading to the delta floodplain. The incoming stormwater was analyzed by settling time to characterize the current loading of particulate matter, nutrients and metals. This data is compared to soil concentration gradients of nutrients and metals to understand the long-term depositional characteristics within the delta floodplain and how this was impacted by channelization. The retention and mobilization of particulate matter, nutrients and metals was quantified within the delta floodplain along the changing hydrograph before during and after a storm and compared amongst areas impacted by channelization and regions where sheetflows occur. Furthermore, the retention of dissolved phosphate within the soils is compared amongst areas impacted by a range of nutrient, hydrological and sedimentation differences.

Introduction

In simple terms, riparian areas are defined as zones which are influenced by and have influence upon stream and river systems. These influences can be streamside hydrological influences on an adjacent forest community and concurrently, the litter input and shading that the adjacent forest contributes to the stream itself. Riparian zones are often thought of as an ecotone between land and water. Riparian wetlands are communities which fit the definition of a wetland based on soils, vegetation and hydrology that have a direct hydrological link to a stream or creek be it through surface flow or more diffuse, shallow groundwater inputs. More holistically, riparian wetlands should be thought of as an ecosystem that is an integral part of streams and watersheds as an interconnected unit. Therefore, successful watershed management must consider impacts to riparian wetlands to also be impacts to the stream itself and any other downstream receiving water bodies.

Floodplains and deltas are a type of riparian wetland that occur in regions where the confined flows of a river channel are exposed to a much larger area during peak flows, thus facilitating diffuse sheet-flows. Sheet flow runoff allows net deposition of sediments and prevents erosion by stabilizing flows through a large cross-section (Naiman and Décamps 1997). Sedimentation is one factor which causes spatial differences in soil physical and chemical properties depending on detention time. Initial deposition occurs at the first location where flows are allowed to stabilize and consists mostly of larger particles with less reactive surface area and further stabilization allows finer particles to settle, which have more reactive surface area (Cooper et al. 1987).

In a river/wetland system, Johnston (1993) found that inorganic P was highest further away from the river, mostly due to the higher reactivity of silts and clays with phosphorus and the longer time required for these small particles to settle. Organic P was also highest in this region because longer detention times indicated longer durations of flooding and therefore, organic matter accumulation (Johnston 1993). Once particles are deposited in the floodplain after a peak flow event, labile phosphorus may sorb or be released to the water column. Dissolved phosphorus loading at high concentrations can lead to soil sorption, while flows of low dissolved phosphorus can enable desorption from the soils (Logan 1982, Richardson 1985). Therefore, resident soils which had acted as a phosphorus sink in the previous storm and phosphorus loaded sediment which settled in that storm can now leach as dissolved phosphorus concentrations return to baseflow values.

Bulk density heterogeneity is partially shaped by sedimentation. Regions with high sedimentation have higher bulk density due to the inorganic composition of the sediment overwhelming any organic matter accumulation. In addition, soils dominated by coarse, unconsolidated soils are prone to being better drained. Johnston (1993) found that "the areas of lowest organic matter content reflected the position of current and past stream channels".

Floodplain dynamics inherently involve point-bar deposition, filling in of old channels and channel migration which guides vegetative succession (Shankman 1993). Sediment deposition, allows early successional flood-tolerant vegetative species to infiltrate, which are later replaced by later successional flood-intolerant species as deposition continues (Shankman 1993). These late-successional communities are reversible if they are located within a region where flooding can cause redistribution of matter, thus creating species heterogeneity (Décamps et al. 1988). Many studies have shown that channelization and flood-control create a mesic species homogenization of forested floodplains, which replaces the natural zonal variations (Décamps et al. 1988, Hughes and Cass 1997, Shankman 1993).

The mechanisms that make riparian wetlands so beneficial can also be the very agent that causes change when rates of certain processes change due to anthropogenic activity. By acting as sediment settling basins and assimilating soluble components, wetlands can be affected by elevated concentrations of nutrients, metals and other pollutants thus changing the characteristics of the soil. Saturation of these compounds in the soil can reduce the wetlands assimilative capacity and have ecological consequences on the wetland itself as well as downstream water bodies. Modifications to watersheds, stream channels and lakes including road construction, channelization, lack of streamside buffer zones and levee formation can have changes on several hydrologic parameters including duration, intensity, and timing of flooding. Increased flows and sediment loading from watershed modifications can overwhelm the ability of these wetlands to act as sediment traps and potentially cause increased sediment export.

This thesis is a case study on a heavily urbanized terminal delta floodplain in North Central Florida. The goal of this project is to quantify and understand transformations to this delta floodplain as caused by commonly encountered stressors, including channelization and urban land use. This assessment will detail the manifestation of these changes in the vegetation, soil, and water. Modifications to restore hydrology to the delta floodplain will be discussed and the potential consequences on water quality, soil and vegetative composition will be evaluated. An understanding of the specific changes caused by urbanization to the "beneficial" functions that riparian wetlands provide will aid in this restoration and be useful for other urban areas.

Watershed Description and Delta Floodplain History

The Tumblin Creek watershed is a 23 square kilometer watershed, which flows through southeast Gainesville, Florida. The source of baseflow in the creek consists of a series of springs and seeps at the base of the surficial aquifer, and further downstream, from permeable regions of the intermediate aquifer (CH2MHILL 2002). The present day headwaters of the creek are channelized through underground concrete culverts and emerge to the surface from a concrete pipe culvert (CH2MHILL 2002). Much of the creek is now composed of deeply incised channels with steep banks; and has been artificially straightened, confined and directed at sharp angles. Throughout the last several hundred meters before the creek enters the delta floodplain it is confined to a concrete channel and ultimately a box culvert as it passes underneath a highway.

Once the creek crosses underneath the highway it enters the historic delta. As a result of dredging, the creek is confined to a channel 300 meters further into the delta than it was historically as a result of dredging. This artificial channel is straight, of low topographic relief and consists of homogeneous sandy soils. Immediately adjacent to the west side of the creek is a spoil-pile containing materials excavated during creation and subsequent maintenance dredging. This spoil-pile is as high as 3.2 meters and runs the entire length of the dredged channel. On the east side of the creek a sewer line runs parallel to the creek for approximately 250 meters and is set above the surrounding elevation resulting in a physical barrier to storm flows entering the adjacent floodplain.

At the downstream terminus of the excavated channel, the creek enters a delta floodplain forest before entering Bivens Arm Lake approximately 300 meters downstream. The total elevation change across the watershed is 32 meters, from 51.8 meters at the headwaters of Tumblin Creek to 19.8 meters near Bivens Arm Lake. Bivens Arm Lake is presently considered a hypereutrophic lake based on high levels of nutrients, chlorophyll a and secchi depth (St. Johns River Water Management District [SJRWMD] 2000). However, anecdotal evidence from residents around the lake suggests that lake water quality has deteriorated in the past 50 years or more. Causes of the lakes eutrophication are uncertain but most likely a combination of nutrient loading and alterations to watershed hydrologic characteristics.

The delta floodplain forest has undergone significant anthropogenic modifications as the watershed was developed. The first images to be taken of the delta from 1937 (Figure 1-1), indicate a moderate amount of channelization which ends at the upstream boundary of the 30 acre delta floodplain (U.S. Department of Agriculture [USDA] 1937). The outline of the wetland is indicated as a change in texture due to a change in the predominant tree species from less inundation tolerant tree species such as *Quercus nigra* L., *Quercus laurifolia* Michx., *Liquidambar styraciflua* L., in the upland to predominantly *Fraxinus profunda* (Bush) Bush, *Nyssa sylvatica var. biflora* (Walt.) Sarg. and *Acer rubrum* L. in the wetland. During this time period, the entire delta appears un-channelized and presumably the flows from Tumblin Creek would have been diffuse throughout the entire delta floodplain. Agricultural fields are visible in the uplands and close to the edge of the surrounding wetland in the 1937 image. There is a small buffer zone of upland forest surrounding the wetland and land clearing appears to have removed all the trees in the surrounding upland area. Agricultural land clearing is evident in a small portion of the wetland itself on the northwest side of the channel.

Figure 1-2, taken in 1949 shows a small meander was cut in the channel slightly east of the 1937 channel and the channel was made more distinct (USDA 1949). The 1956 photograph in Figure 1-3, shows that the channel was lengthened drastically to the point it is today (USDA 1956). Also at this time, further land clearing is evident in the northwest region of the delta. This region is included in the St. Johns River Water Management District's land use designations as a wetland. Therefore, the major dredging and channelization evident today, occurred between 1946 and 1956.

Aerial photography from 1961 (Figure 1-4) indicates that the channel was widened at the downstream terminus (USDA 1961). Urban development begins to appear east of the delta. During this time period there was a transition in land use surrounding the delta from agriculture to urbanization.

After 1961 and up until the next aerial image taken in 1974 (Figure 1-5) new spoil piles are visible towards the downstream terminus of the creek (USDA 1974). The large size of the present day spoil-pile could be explained by maintenance excavation of soils which had filled in the channel from upstream erosion. During this time period, a sewer pipe was installed along the eastern side of the creek above the existing elevation. The sewer pipe appears as a lighter colored line in the southeast corner of the delta and parallels the eastern side of the creek to the northeast. Further urbanization has continued in the northern portion and the only remnant of agricultural activity in the photographs are horse fields to the northwest of the delta, which are present today.

Figure 1-6 shows an image from 2000 as the delta floodplain appears today (U.S. Geological Survey [USGS] 2000). Urbanization has replaced most of the agriculture in the area, except the aforementioned horse field and much of the area has been reforested. The dredged channel appears more prominently carved today than it was historically. As a result of dredging the channel has been lengthened from the distance shown in yellow to the location it is today (Figure 1-7).

Figure 1-1. Aerial photograph of the Tumblin Creek delta floodplain taken in 12-20-1937.

The Tumblin Creek watershed is now composed of approximately 60% impervious surfaces as illustrated in Figure 1-8. Due to the high percentage of impervious surfaces, there is a large volume of surface runoff contributing to the creek flow during rainfall. This contributes to sharp increases in flow during storm events and a rapid return to baseflow. Bank instability and erosion are prevalent along the creek thus contributing suspended sediment loads (CH2MHILL 2002). Sand smothering from

Figure 1-2. Aerial photograph from 2-11-1949

Figure 1-3. Aerial photograph from 12-3-1956

Figure 1-4. Aerial photograph taken from 2-11-1961

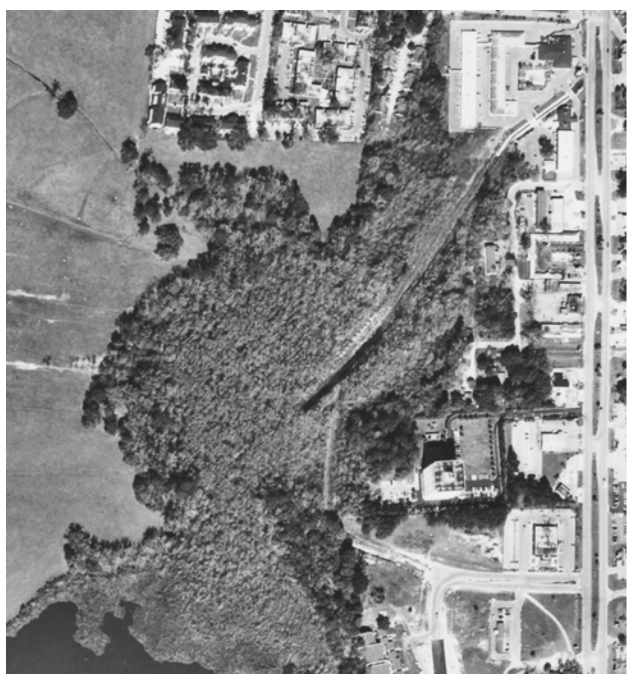


Figure 1-5. Aerial photograph taken from 2-4-1974

Figure 1-6. Aerial photograph taken in 2002

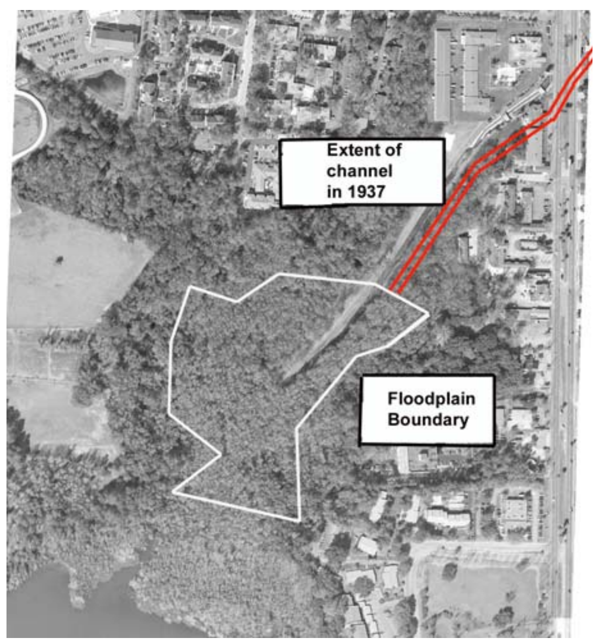


Figure 1-7. An aerial photograph from 2002, indicating the extent and location of the Tumblin Creek channel in 1937 shown in red. A rough boundary of the delta floodplain is indicated in white.

mobilized sediment has decimated habitat within the creek. Average scores of Four Rapid BioRecons in two different years indicate that all four sections, including the delta floodplain, were listed as impaired (CH2MHILL 2002). Results of habitat assessment of these four regions indicate that the delta floodplain had the highest habitat assessment score of any of the four sites sampled but was still listed as impaired by the Rapid BioRecon assessment (CH2MHILL 2002). Deductions from the deltas habitat scores were mostly due to habitat smothering.

The urban watershed of Tumblin Creek mobilizes sediment with high pollutant loads. Durell et al. (2004) found Bivens Arm and Tumblin Creek to “have the highest sediment contaminant concentrations of the locations sampled in the Gainesville area” including elevated concentrations of lead and cadmium. Furthermore they found that the sediment contaminant concentration is high enough for potential ecological harm, dependent on soil organic matter concentrations, which reduces the impact (Durell et al. 2004). Tumblin Creek had been previously listed as impaired for nutrients in 1998 but was recently delisted in 2002 and is in planning for being listed as impaired for biological oxygen demand and dissolved oxygen (Florida Department of Environmental Protection [FDEP] 2002).

Delta Floodplain Hydrology

The Tumblin Creek delta floodplain is a 30 acre riparian wetland which receives surface flow inputs from the main channel of Tumblin Creek as well as a few other surface-flow inputs (Figure 1-9). These other surface-flow inputs enter into the southwestern, northern and eastern portions of the delta.

There are a few distinct inflows to the southwestern portion of the delta. These inflows all merge downstream with the largest channel, before entering the lake. There is

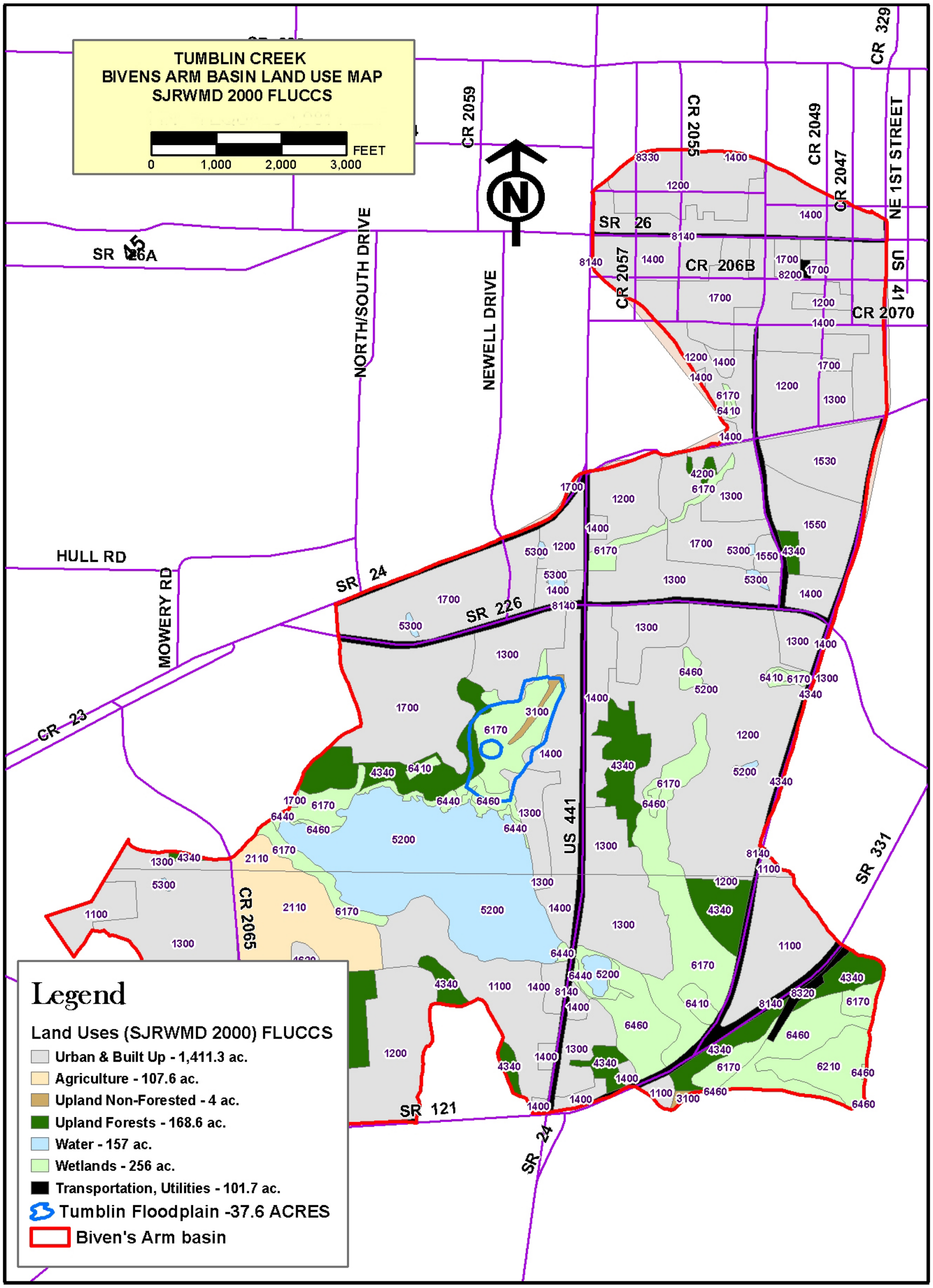


Figure 1-8. St. Johns River Water Management District's land use designations for the Bivens Arm Lake watershed

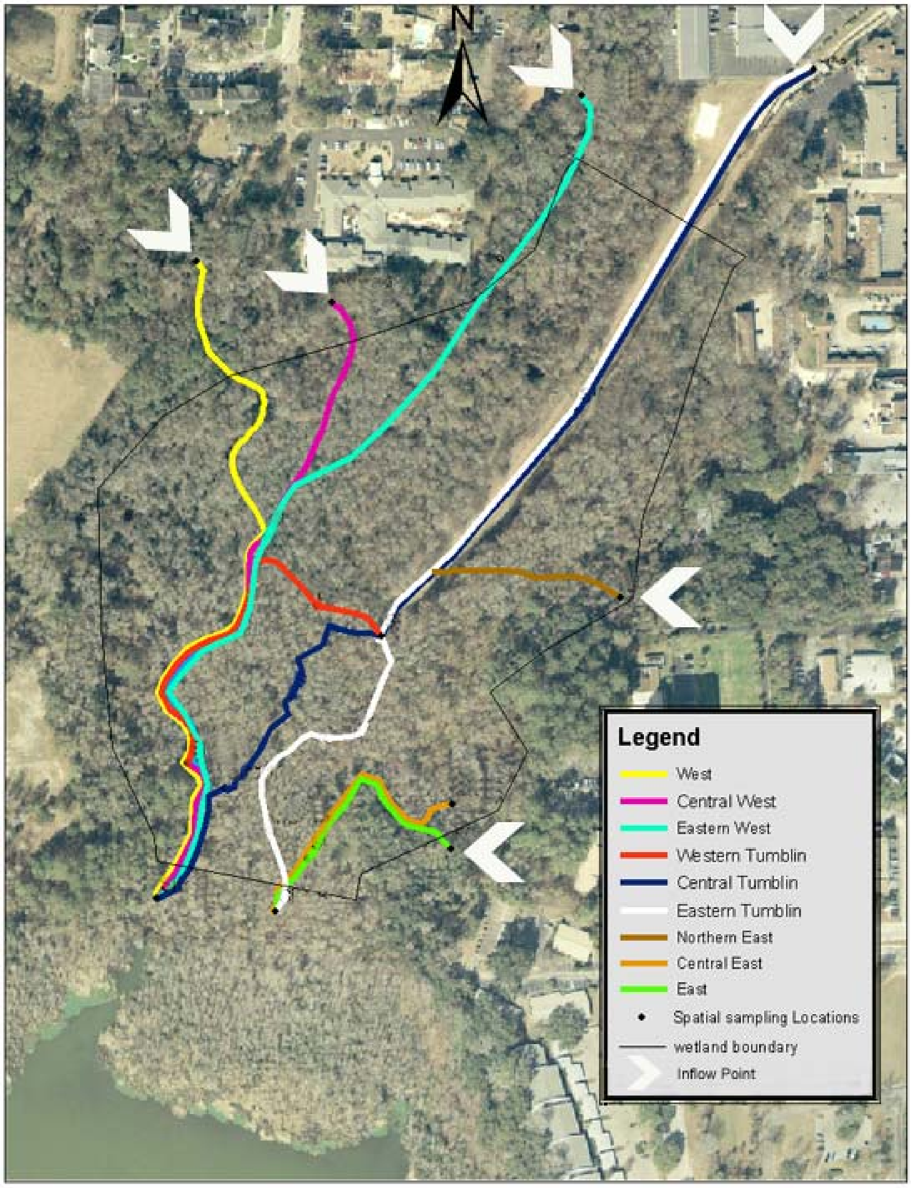


Figure 1-9. A visualization of the various flowpaths of the delta floodplain.

only one channel west of the spoil pile that has baseflow. This channel drains some of the University of Florida's Institute of Food and Agricultural Lands and storm runoff south of Archer Road near the Veterans Hospital. These inflows have the potential to be a source of nutrients from animal waste and other activities. Flows through this region are more akin to basin sheetflow, with few prominent channels. This is in contrast to the region between the downstream terminus of the dredged channel and the lake, where distinct channels are clearly visible.

Further north but still on the western side of the spoil-pile is another distinct region. Images from 1956 and 1961 (Figures 1-4 and 1-5) indicate that land clearing and most likely agricultural activities occurred in this region for a period of time. Today, a broken fence indicates the extent of this land clearing into the delta. Like the Southwest region of the delta, flows in this area are mostly diffuse with few distinct channels.

On the eastern side of the dredged Tumblin Creek channel there are a few small inflows. None of these inflows have baseflow but appear to have significant flow during storms. Most of the flow in this region is impeded from direct entry to the creek by the sewer line and is directed south eventually connecting to the creek through a single culvert. Debris in and around the culvert can cause water to stay ponded for several days after storm events.

The main channel of Tumblin Creek provides a majority of the flow into the delta due to a much larger drainage area. Approximately 300 meters into the delta, the channelization of Tumblin Creek ceases as does the spoil-pile to the west (Figure 1-7). The transition from unconfined channelized flow to a delta floodplain forest has created an area of localized sedimentation. Sediment in this mound is mostly comprised of sand-sized particles that settle rapidly from the water column as creek energy dissipates. Sediment accumulation is visually apparent due to the telephone pole-like appearance of *N. sylvatica var. biflora*, as caused by the sand smothering of the trees buttress.

The sediment mound downstream of the channel creates a resistance to flow. The resistance has formed a secondary flow channel ninety degrees to the west and during storm events, flow travels around the spoil-pile. This secondary flow channel floods the otherwise hydrologically isolated delta region. Although some of the flow meanders around this sediment plume, the intensity and energy of storm events has scoured several channels through the sediment plume. The elevation difference between these channels and the surrounding banks is often close to a meter and therefore contributes to restricting flows even after the man-made channel ends. One of these channels carries the majority of the baseflow from Tumblin Creek, although during storms the entire delta is underwater. This channel is well defined and incised throughout the entire flowpath from the end of the channel to the lake. Therefore, it is presumed that flows in this region downstream of the channel, are predominantly focused through these incised channels.

Objectives and Statements

Riparian wetlands have the potential to retain sediments, nutrients and metal pollutants from impacting downstream water bodies. Many of these ecosystems have been modified by channelization and other activities within the watershed. The impacts to the Tumblin Creek delta floodplain from channelization and urban and historic agriculture land-uses have likely changed the characteristics of the soils, vegetation and water. It is important to understand what these changes are and how this modifies sediment, nutrient and pollutant retention of these ecosystems. There were two objectives that this research set out to address. These objectives and associated statements are as follows.

Objective 1: Characterize the stormflow particulate matter entering the Tumblin Creek delta floodplain and quantify the role of the delta as a source or sink of nutrients, particulate matter and trace metals.

- **Statement 1:** The majority of suspended sediment (by mass) transported to the Tumblin Creek delta floodplain are composed of coarse particles.

- **Statement 2:** Particles that require longer to settle will have higher concentrations of phosphorus and metals.
- **Statement 3:** Regions of the delta floodplain where sheetflows exist will retain more phosphorus, nitrogen and particulate matter than areas where incised channels exist.

Objective 2: Assess the impacts of urban land-uses and channelization on the soils of delta floodplains.

- **Statement 1:** The soil elevation downstream of the dredged channels will be higher in elevation than surrounding regions.
- **Statement 2:** The net sediment accretion rate has increased in the time period of channel dredging and land-use changes.
- **Statement 3:** The soils downstream of the dredged channel to the lake will have low concentrations of phosphorus and metals, while regions of the delta floodplain composed of longer detention times will have higher soil concentrations of phosphorus and metals.
- **Statement 4:** Soluble phosphorus retention will be greatest where fine particles settle and lessened at the end of the channel where coarse particles settle.

Chapter 2 discusses Objective 1 and its associated statements. Chapter 3 discusses Objective 2 and the subsequent statements. Chapter 4 summarizes the findings from chapters 2 and 3 and provides several conceptual restoration plans to improve the function of the delta floodplain, based on the findings of this research.

CHAPTER 2
STORMWATER CHARACTERIZATION AND BASEFLOW WATER QUALITY CONDITION

Flow-through wetlands are often characterized as sources, sinks or transformers. This nomenclature primarily refers to the fate of nitrogen, phosphorus and carbon as they are released, retained and/or converted between organic and inorganic forms (Mitsch and Gosselink 2000). The degree of export to downstream water bodies can play a crucial role in the trophic condition that develops in these downstream ecosystems. As such, an understanding of whether a particular wetland acts as a source, sink or transformer is essential to assess the functioning of the wetland within a larger watershed context. In urban watersheds, floodplains, deltas and other riparian wetlands have the potential to retain and bury anthropogenic pollutants thereby reducing impacts to downstream water-bodies. The role of a wetland with regard to nutrient and pollutant removal depends on many characteristics of the soils, hydrology and biota present. In urban and agricultural watersheds each of these three components can be modified so as to alter the functioning of the wetland ecosystem. Bivens Arm Lake has been affected by high metal concentrations and eutrophication likely from flows passing through the Tumblin Creek delta floodplain (Durell et al. 2004). This chapter quantifies the role of the Tumblin Creek delta floodplain as a source or sink of nutrients and trace metals to the downstream Bivens Arm Lake and relates this to hydrologic and sediment loading modifications as a result of channelization and urbanization.

Introduction

During flooding periods, the water from a river enters a floodplain. The water entering the floodplain goes through physical and chemical changes as it interacts with the soils and the biota and much of it is eventually released to downstream waterbodies. This exchange can potentially remove nutrients, trace metals and particulate matter, so as to protect the water quality of downstream ecosystems.

Erosion of particles from the watershed can be a large source of particulate nitrogen and phosphorus to a water body. Suspended sediments which are mobilized in storms have a higher concentration of particulate phosphorus than the soils they are derived from due to the selective mobility of finer particles (Sharpley 1980). Particulate phosphorus has been found to comprise 85% of the total phosphorus in runoff (Cooke 1988). In urban watersheds, retention of mobilized particulates can be reduced as vegetated riparian zones are replaced by impervious surfaces and storm-drain networks. As much as 97% of the total retained suspended matter flux during flooding can be trapped in vegetated riparian areas (Brunet et al. 1994). Furthermore, agricultural and urban watersheds may have higher concentrations of phosphorus sorbed to the suspended sediment due to fertilizer applications, sewage leaks, etc. When the vegetated riparian zone is replaced by rapidly drained impervious surfaces, the suspended matter and high particulate nutrient loads from urban and agricultural watersheds are not retained and instead can be directed to depositional regions and waterbodies downstream.

Particulate removal occurs in floodplains when previously turbulent stream-flows are converted into lower energy sheet-flows (Naiman and Décamps 1997). The removal of larger sand-sized particles is usually accomplished rapidly at the stream-floodplain/delta boundary while finer particles require longer periods of non-turbulent flow before they are settled (Cooper et al. 1987). These finer particles have higher concentrations of associated phosphorus (Cooper et al. 1987, Naiman and Décamps 1997), nitrogen (Martinelli et al. 2003) and trace metals (Walling and Moorehead 1989) than coarser particles due to their larger surface area.

Whether a stream and the associated riparian zone are a sink for particulate matter depends on several factors. Seasonal changes in hydrology cause alternating periods of particulate matter retention and release. Brunet and Astin (2000) found particulate matter retention of a riparian floodplain ecosystem during low water as well as flooding periods, while high mobilization occurred during increased rainfall in the autumn. Periods of particulate matter retention primarily occur at a hydrologic threshold when widespread floodplain inundation occurs (Brunet and Astin 2000, Cooke 1988, Villar et al. 2002). Intermediate flows facilitate in-stream mobility without sufficient overbank flooding to facilitate floodplain retention (Villar et al. 2002). When flooding is sufficient for widespread floodplain inundation to occur, these ecosystems consistently act as sinks of particulate matter (Brunet et al. 1994, Tockner et al. 1999, Villar et al. 2002). Periods of flooding make up the most significant particulate matter loads to an aquatic ecosystem and particulate phosphorus concentrations can be 1,500 to 15,000 times higher than baseflow (Brunet and Astin 1998). Concurrently, the highest floodplain retention of particulate matter occurs in these periods of flooding with reported values as high as 89% of the annual total floodplain suspended sediment retention (Brunet and Astin 2000). Therefore during periods of flooding, the floodplain retains a majority of the suspended sediment which could otherwise enter downstream ecosystems.

One of the most prominent removal mechanisms for nutrients is particulate settling within the delta or floodplain. After settling, the deposited sediments and associated nutrients and trace metals are subsequently buried due to further sedimentation and organic matter accumulation (Brinson et al. 1984). Particulate phosphorus associated with suspended matter is most often the predominant form of total phosphorus (TP) in runoff and floodplains are effective sinks for suspended matter (Johnston 1993, Tockner et al. 1999, Villar and Bonetto 2000, Villar et al. 2002). Furthermore, floodplains have been shown to be sinks for particulate nitrogen (Brunet et al. 1994, Villar et al. 2002) and particulate metals (Villar et al. 2002).

Although floodplains may act as effective sinks for particulate matter and particulate nutrients through settling, they may still be sources of total phosphorus and nitrogen via release of dissolved forms of these nutrients. Nitrate concentrations are consistently removed in floodplains as a result of conditions facilitating denitrification and can thus be an important permanent nitrogen sink (Chung et al. 2004, Bonetto et al. 1994, Brinson et al. 1984, Tockner et al. 1999, Villar and Bonetto 2000). Retention of Ammonium and dissolved phosphate occur on exchange sites within the soil and in soil water (Brinson et al. 1984, Reddy et al. 1998). Although denitrification and retention of dissolved nitrogen and phosphorus occur to some extent in floodplains, some studies have indicated that water entering the streams from floodplains is enriched in higher soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN) than inflows (Bonetto et al. 1994, Brunet and Astin 2000). The release of higher concentrations of dissolved nutrients leaving the floodplain than entered can be due to decomposition of fine organic particles which settled in the floodplain from previous floods (Brunet and

Astin 2000), anaerobic micro-environments associated with settled total suspended solids (TSS) releasing dissolved inorganic phosphorus (DIP) (Cooke 1998) and historically loaded soils due to agriculture (Pant and Reddy 2003).

Flood control measures where channels are dredged and confined as occurred in the Tumblin Creek delta floodplain are common practices in urban watersheds. These watersheds have higher intensity storm runoff events, which further facilitate channel incising and stream-bank collapse in the stream and delta floodplain itself. As a result of higher energy flows, some areas of the delta floodplain could mobilize sediment and particulate pollutants, thus becoming a source. Channel confinement within the delta floodplain, decreases the detention time of floodwaters by improving drainage and reducing overbank flooding. A reduced detention time decreases the potential for long-term widespread inundation which is required for net sediment retention of a stream-delta floodplain ecosystem.

Retention of total phosphorus, nitrogen and trace metals should most closely mirror the retention of suspended solids within the Tumblin Creek delta floodplain. The deposition of fine particulate matter which contains the highest concentrations of phosphorus, nitrogen and trace metals requires a longer detention time for the particles to be removed from the water column. As a result of channelization, the potential for the delta to remove the high sediment loads and the associated nutrients from an urban watershed will be decreased. Channelization, which has reduced the detention time of portions of the delta, will also reduce the contact time between floodwater and the soils and soil biota which are essential for the removal of soluble nutrients.

The present study seeks to understand how a channelized flow regime and urbanized watershed will change the nutrient, sediment and trace metal retention of the Tumblin Creek delta floodplain. This study characterized the metal, nutrient and settling time of particulate matter which entered the delta during storm events and characterized retention and release of nutrients and particulate matter within the delta during stormflow, post-storm and baseflow periods.

Objective 1: Characterize the stormflow particulate matter entering the Tumblin Creek delta floodplain and quantify the role of the delta as a source or sink of nutrients, particulate matter and trace metals.

- **Statement 1:** The majority of the suspended sediment (by mass) transported to the Tumblin Creek delta floodplain are composed of coarse particles.
- **Statement 2:** Particles which require longer to settle will have higher concentrations of phosphorus and metals.
- **Statement 3:** Regions of the delta floodplain where sheetflows exist will retain phosphorus, nitrogen and particulate matter more completely than where incised channels exist.

Materials and Methods

Suspended Sediment Settling Experiment

The aim of this study was to assess the sediment, particulate phosphorus and particulate metals loads that are entering the delta during storm events and understand the time period required to deposit these particles. This will aid in understanding the distribution of these particles within the delta and the proportion entering the lake.

Suspended sediment sampling

Three storms were sampled for this experiment. The storms occurred on the dates of 11/4/03, 11/5/03 and 11/19/03 and had rainfall of 0.229, 3.20 and 1.91 centimeters respectively. The three storm events cover a range of rainfall depths in order to characterize an average sediment concentration and distribution entering the delta. A timeline of the three rainfall events compared to the depths of rain is shown in Figure 2-1. The average daily discharge of the period of sampling is indicated in Figure 2-2.

Approximately 20 liters were sampled to assess the water quality entering the delta from the main channel during peak flow. The location where the samples were taken was in Tumblin Creek approximately 100 meters upstream from the delta floodplain. This stretch of the channel is confined in a concrete drainage ditch.

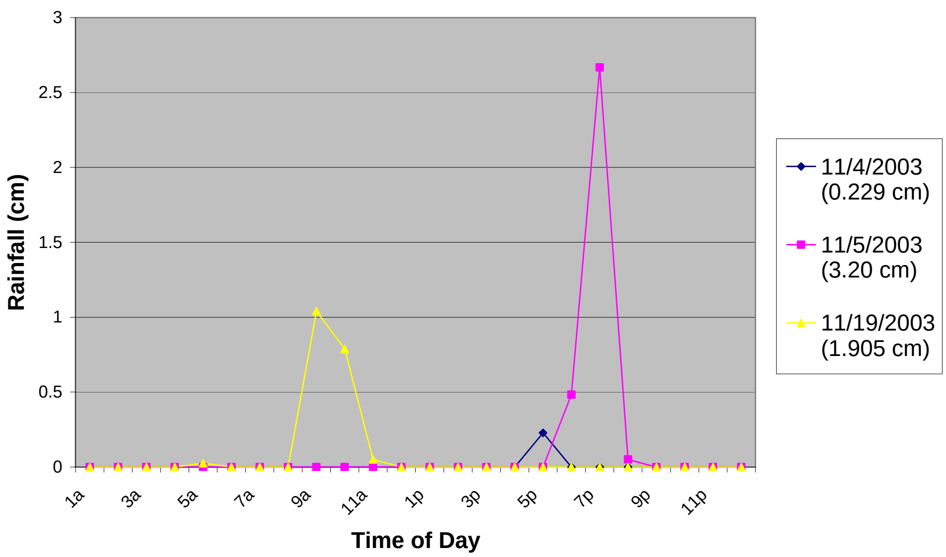


Figure 2-1. Hourly rainfall rate of the three storms sampled

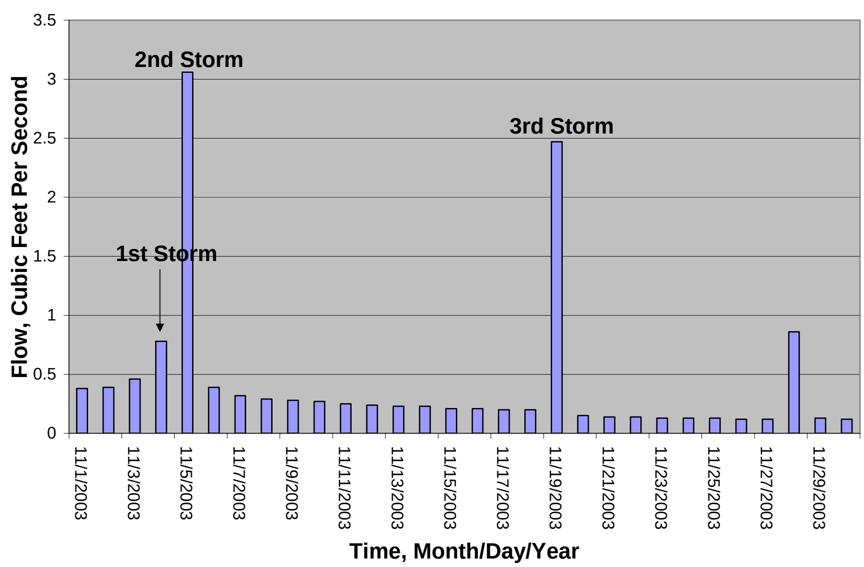


Figure 2-2. Average daily discharge on the days when the sampled storms occurred.

Suspended sediment fractionation and analysis

Suspended sediments were fractionated from the stormwater based on settling time. The four time periods which were sampled for settled particles were one minute, two hours, 24 hours and particles which took greater than 24 hours to settle. In the laboratory, recently collected stormwater was agitated to resuspend all particles, and then allowed to rest. After 1 minute, water and suspended sediment particles were rapidly siphoned off allowing only settled particles to remain. Settled particles were poured into a small pre-weighed container ensuring that all of the sediment was transferred. The decanted solution was agitated again then allowed to settle for 2 hours. After 2 hours, water and remaining suspended sediments were siphoned off and settled sediments were treated similarly to the first time step. This was repeated again for a 24 hour settling period. After 24 hours, water and suspended solids remaining were mixed and a one Liter aliquot of the water was filtered for TSS analysis as discussed in the site water characterization methods section. This TSS analysis was done in triplicate. All settled sediment samples were dried at 70 ^{o}C for 24 hours prior to measuring dry weights.

After drying, settled sediments were then pulverized on a shaker with ceramic balls for 20 minutes and then passed through a #100 mesh sieve. Nutrient and metal concentrations of settled sediments and sediments trapped in filter paper were then analyzed. This analysis was conducted on a 2 g. sample unless 2 g. of sediment wasn't collected in which case the entire sample was used. Samples were combusted at 550 ^{o}C for 4 hours, digested with 6.0 M HCl, according to Anderson (1976). Samples were then filtered through a 0.45 μm membrane and analyzed for Phosphorous, Zinc, Copper, Iron, Aluminum, Cadmium, Nickel, Lead, and Chromium with an inductively coupled argon plasma atomic emission spectrophotometer (Method 200.7.; U.S. Environmental

Protection Agency [USEPA], 1991). The extraction was done at the University of Florida Wetland Biogeochemistry Laboratory and the analyses were done at the University of Florida Analytical Research Laboratory.

Site Water Characterization

The objective of this portion of the study was to quantify total nitrogen, total phosphorus and total suspended solid concentrations at discrete locations along flowpaths to understand where sources and sinks occur. These data were analyzed to decipher the relationship between delta floodplain changes and nutrient and sediment retention.

Field sampling

Samples were collected throughout the delta floodplain at the sites indicated in Figure 2-3. Inputs to the delta were determined from visual identification of incised channels and man-made flow directing devices. Flowpaths were determined from incised channels, debris and sediment deposition and elevation gradients.

Baseflow samples were collected when no rain event had occurred for at least 5 days and post-storm samples were taken the day following a storm. Base flow and post storm water samples were taken by hand in a 1 Liter bottle. The bottle was rinsed three times with site water before the sample was taken. Samples were taken in the deepest portion of the stream without disturbing the stream bottom sediment so as to be representative of the water column. The sample bottle was submerged in the water upside-down and then inverted below the water surface. Three base flow samples were collected and two post-storm samples were collected on (10/3/03, 10/20/03, 11/11/03) and (10/8/03, 11/20/03) respectively.

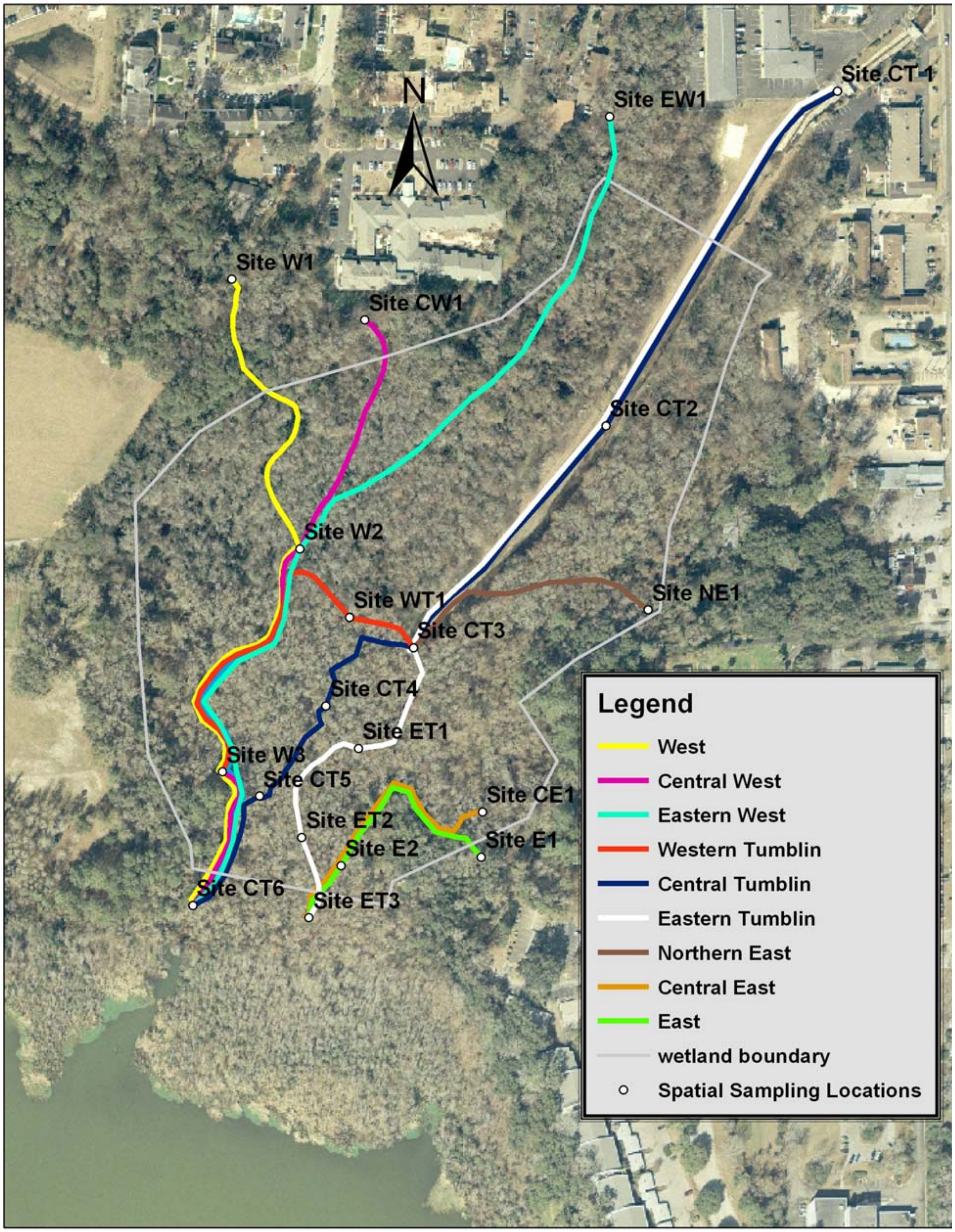


Figure 2-3. An aerial photograph which details the various flowpath locations and sampling site locations for the spatial water sampling survey.

There were two storm events sampled for the spatial water quality sampling study. The hourly rainfall depth and average daily discharge are indicated in Figure 2-4 and 2-5 respectively. The first storm depth was 0.838 centimeters and the second storm was 1.91 centimeters.

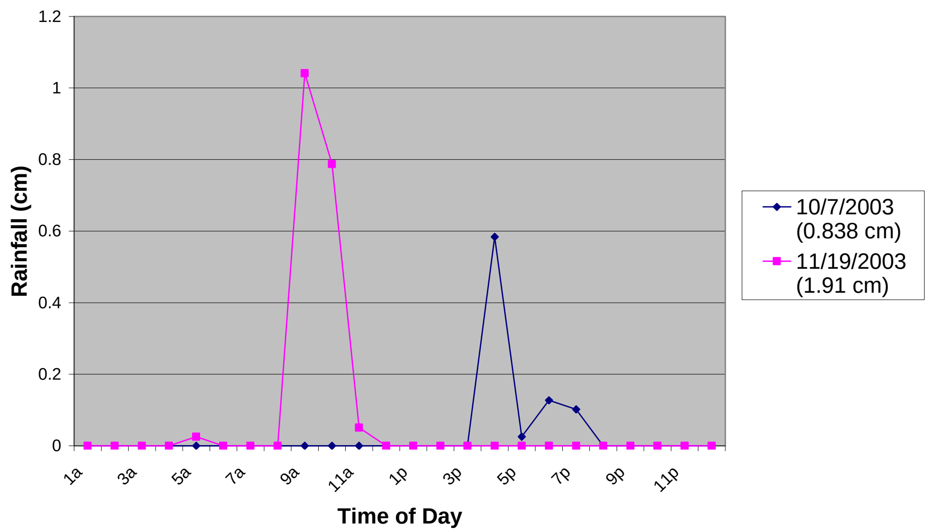


Figure 2-4. Hourly rainfall rate of the two storms sampled.

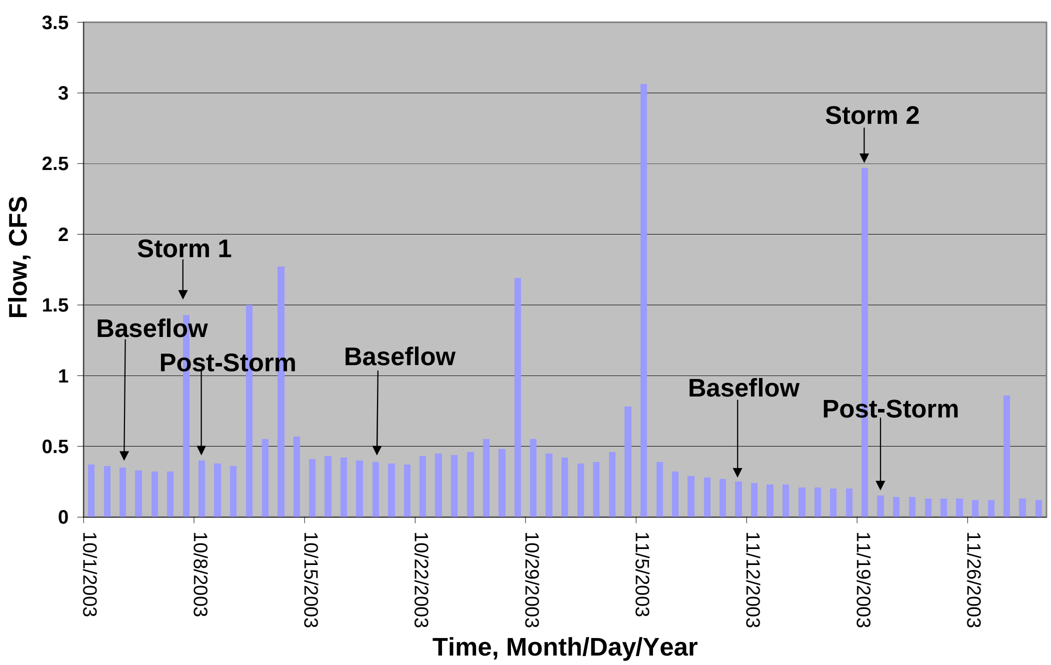


Figure 2-5. Average daily discharge of Tumblin Creek on the days when the storm event sampling occurred.

Storm event samples were taken using modified 1 Liter sample bottles (Figure 2-6). Two holes were drilled in the lid and two pieces of laboratory tubing were placed in these holes. A thinly sliced section of rubber tubing was placed around the tubes on either side of the holes to keep the tubes in place for turbulent storms. One tube operated as a vent and was fixed straight up. The other tube operated as an intake tube and was looped around and sealed to the side of the bottle. These bottles were strapped to a metal pole which was inserted in the ground. The bottles were placed at a level slightly above the present water or ground surface where they would be expected to fill in a storm but not baseflow. This was determined from the height of the incised channel and debris piles. As water levels rise above the bend in the input hose, a siphon develops and a discrete subsurface water sample is collected. Slow diffusion of surrounding water into the sample through the small tube would still occur as long as the floodwaters are sufficiently high. However, it is believed that although some diffusion occurs, the change in concentration will be minimized and therefore this sample represents a snapshot of the rising stormwater. Storm samples were collected within 24 hours of the storm and the TN and TP samples were acidified upon returning to the laboratory.

Water analysis

Baseflow and stormflow water samples were analyzed for TKN, nitrate-nitrite, TP and TSS. Sub-samples were filtered through 0.45 μM filter paper and the nitrate-nitrite was analyzed utilizing a rapid-flow analyzer (Method 353.2; USEPA, 1983). Another sub-sample was analyzed for Total Kjeldahl Nitrogen (TKN) analysis using a sulfuric acid digestion (Method 351.2; USEPA 1993B). Total nitrogen concentration was calculated by adding the results of TKN and nitrate-nitrite concentrations. Total

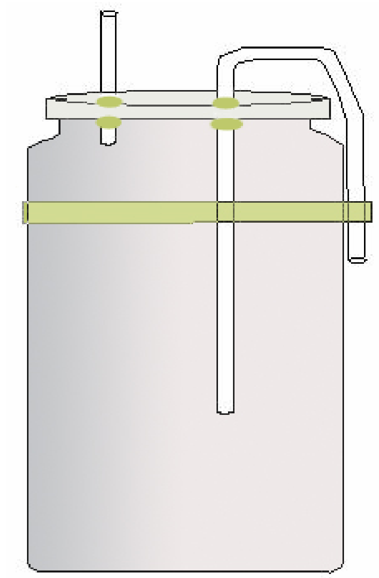


Figure 2-6. An illustration of the apparatus used to sample storm events.

phosphorus (TP) was measured using an inductively coupled argon plasma atomic emission spectrophotometer (Method 200.7; USEPA, 1991). TP and nitrate-nitrite analysis was done at the University of Florida Analytical Research Laboratory.

TSS quantification was conducted on all of the water samples. Filters were prepped by washing with 100 ml. DI water, then dried at 60 ^{o}C and weighed. Water samples were run through the filter. The volume of water filtered was determined by filtering until the flow of water became extremely sluggish. Filters were rinsed and removed, then dried at 60 ^{o}C and weighed again. Changes in filter weight divided by the volume filtered was used to quantify the total suspended solids in each sample.

Results

Particulate Fractionation by Settling Time

Total suspended sediment concentration of individual storms and average concentrations are shown in Table 2-1. The average concentration of suspended sediment sampled during the three storm events was 625.5 mg/l. The larger particles which settled in the one minute time period had a concentration of 414.9 mg/l and accounted for the majority (66%) of the suspended sediment by mass. Particles which settled in the two hour time period accounted for 26% of the suspended sediment and had a concentration of 166.4 mg/l. The finer particles which settled in the 24 hour time period and the >24 hour time period had concentrations of 40.3 and 6.7 mg/l, which makes up 6% and 1% of the total sediment concentration respectively. The average sediment distribution of the three storms is displayed in Figure 2-7.

The large difference in rainfall between the three storm events likely contributed to the variability in the amount and distribution of sediment mobilized as evidenced in the large standard deviation. The smallest storm (Storm 1), which did not drastically increase stormflows tended to mobilize a higher fraction of finer particulate matter (the 24 hour and >24 hour time periods), with not much mobility of the larger particles (1 minute and 2 hour). The opposite is true of the large storm (Storm 2) and the intermediate storm (Storm 3), which tended to have higher concentrations of the larger particles (1 minute and 2 hour). This is consistent with Sharpley (1980) and Cooke (1988), who concluded that storm energy is positively correlated with coarse particle mobility as a result of bank collapse and other factors. The smallest storm had only 2% of the concentration of suspended matter (19.4 mg/l) when compared to the intermediate (791.7 mg/l) and large storm (896.8 mg/l) sampling events. The large storm had half an inch more rainfall than the intermediate storm, although the two storms had comparable suspended sediment concentrations.

The average concentration of phosphorus sorbed to particles of different settling fractions ranged from 4845 mg/kg to 10,061 mg/kg (Figure 2-8). The larger particles

Table 2-1. Total suspended solids concentration by individual storm.

	1 min	2 hour	24 hour	>24 hour	Total
Storm 1 (mg/l)	1.10	0.30	9.80	8.20	19.4
Storm 2 (mg/l)	501	312	73.9	9.10	896
Storm 3 (mg/l)	577	166	43.4	4.70	791
Average (mg/l) ± 1 S.D.	414 ± 313	161 ± 156	40.3 ± 32.1	6.70 ± 2.30	625

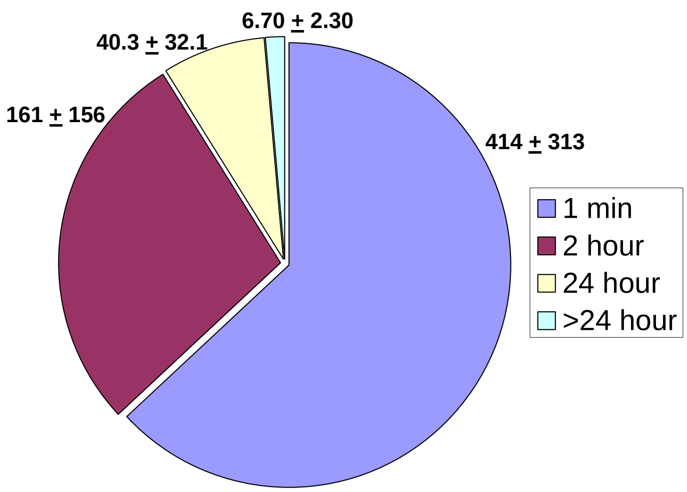


Figure 2-7. Average total suspended solids concentration (mg/l ± 1 S.D.) by settling time.

(one minute fraction) had the lowest concentration of phosphorus (4845 mg/kg), while the finer particles (2 hr, 24 hr, >24 hr) on average had higher concentrations (10,061, 6708, 7205 mg/kg respectively) attributing to their larger reactive surface area and potentially the mineralogy. Particles which settled in the two hour time period were typically the most enriched with phosphorus.

Average particulate phosphorus mass per volume of water values by settling time ranged from 0.05 mg/l to 2.01 mg/l (Figure 2-9). Because the 1 minute settling fraction makes up the majority of the total suspended sediment, it represents the largest store of particulate phosphorus (2.01 mg/l), even though the particles themselves have a low P concentration. The particles which require two hours to settle had the second highest

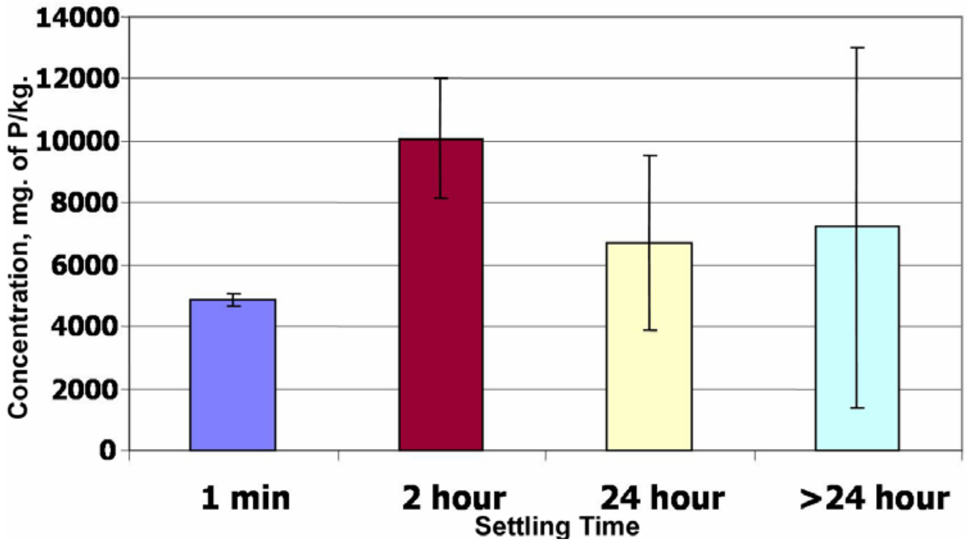


Figure 2-8. Phosphorus concentration by settling time

load of phosphorus per volume of water at 1.60 mg/l. The finer particles (24 hour and >24 hour) had a smaller portion of the particulate phosphorus distribution at 0.30 and 0.05 mg/l of water respectively.

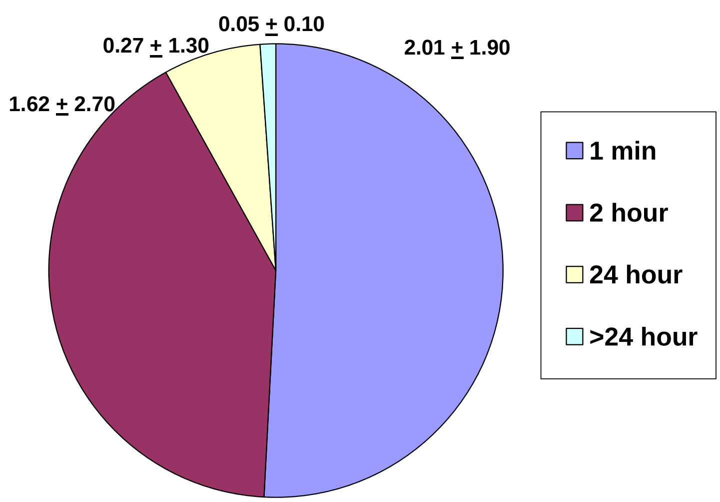


Figure 2-9. Average mass of particulate phosphorus per volume of water (mg/l ± 1 S.D.) by settling time.

The average trace metal concentration of the particles by settling time is indicated in Figure 2-10. In most instances (except copper), particles which settle in two hours had the highest concentrations of trace metals. In the case of copper, the finer particles (24 hours) had greater copper concentrations. Particles which settle rapidly in the delta (one minute) had the lowest concentrations of trace metals sampled, except for chromium and zinc. Finer particles (24 hours and >24 hours) often times had similar concentrations to the 2 hour settling particles (Aluminum, Copper, Lead and Iron); while some of the finer particles had lower concentrations (Chromium, Nickel, Zinc).

The total mass of trace metals per volume of water that settled within the given settling times are presented in Figure 2-11. For every metal sampled, the two hour particles carry the largest total mass of metals. The metal concentration of these 2 hour particles was sufficiently high so as to carry the largest total load, even though these particles composed only 26% of the total suspended sediment mass. The rapidly settling particles (one minute) always had the second highest mass load of metals sampled. The average mass of Al, Cu, Fe and Pb within the one minute settling fraction was (147, 0.09, 73.4 and 0.46 mg), which is in the same range as the mass within the two hour settling fraction (189, 0.11, 88.1 and 0.44 mg) respectively. In the instances of Cr, Ni and Zinc, the two hour settling particles composed a majority of the total metal load (4.40, 0.46 and 6.69 mg), which represents 78%, 73% and 60% of the metal load respectively.

The average phosphorus and trace metal concentration of suspended sediment by storm is quantified in Table 2-2. The small magnitude storm (storm 1) tended to mobilize particles which had higher concentrations of some of the metals analyzed (Iron, Nickel, Chromium, Zinc). The largest storm (storm 2) had the lowest sediment concentrations of analytes sampled except in the case of Copper and Lead. The intermediate storm (Storm 3) mobilized the highest concentrations of analytes sampled for phosphorus, Copper, Aluminum and Lead.

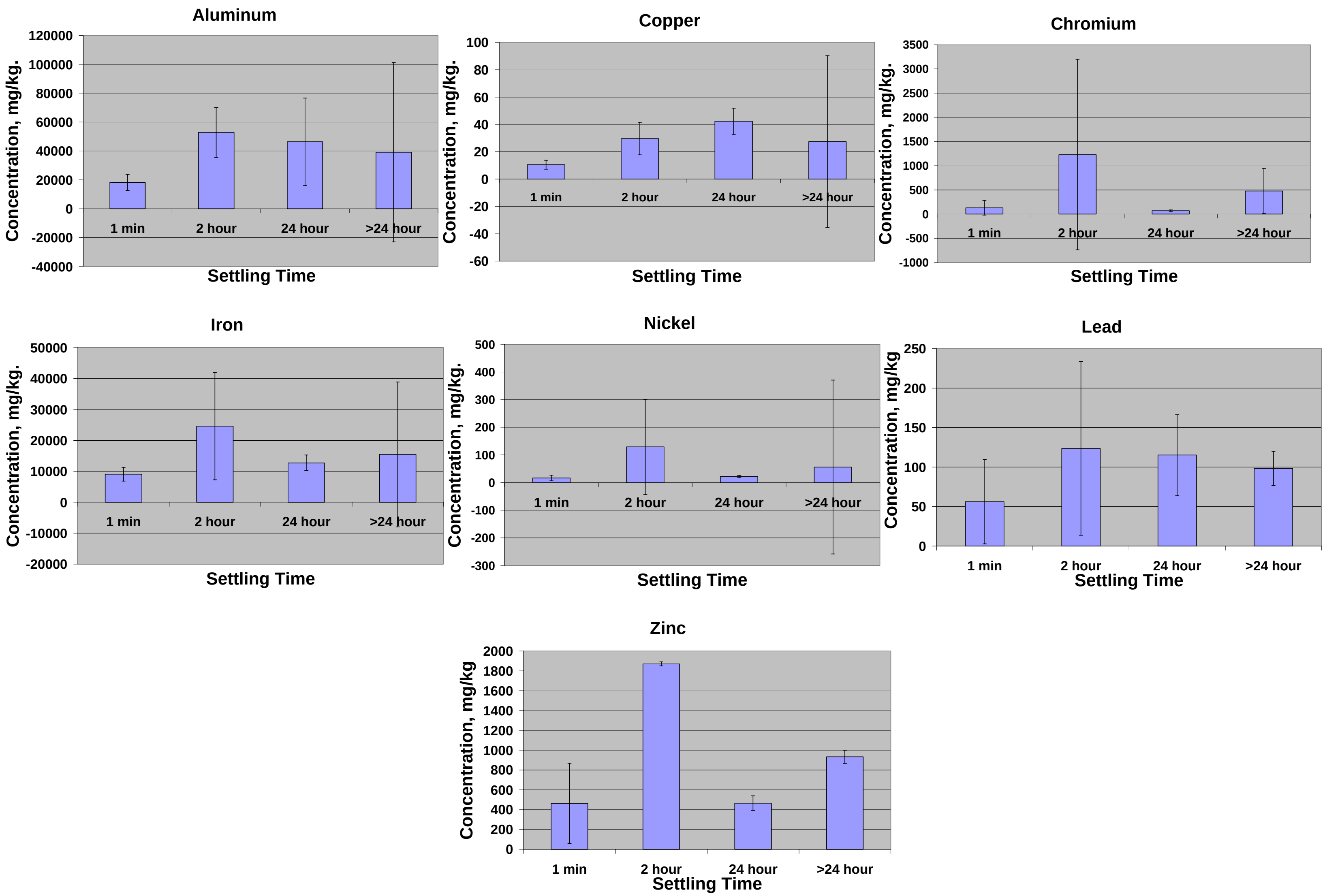


Figure 2-10. Trace metal concentration (mg of metal/kg of sediment ± 1 S.D.) by settling time.

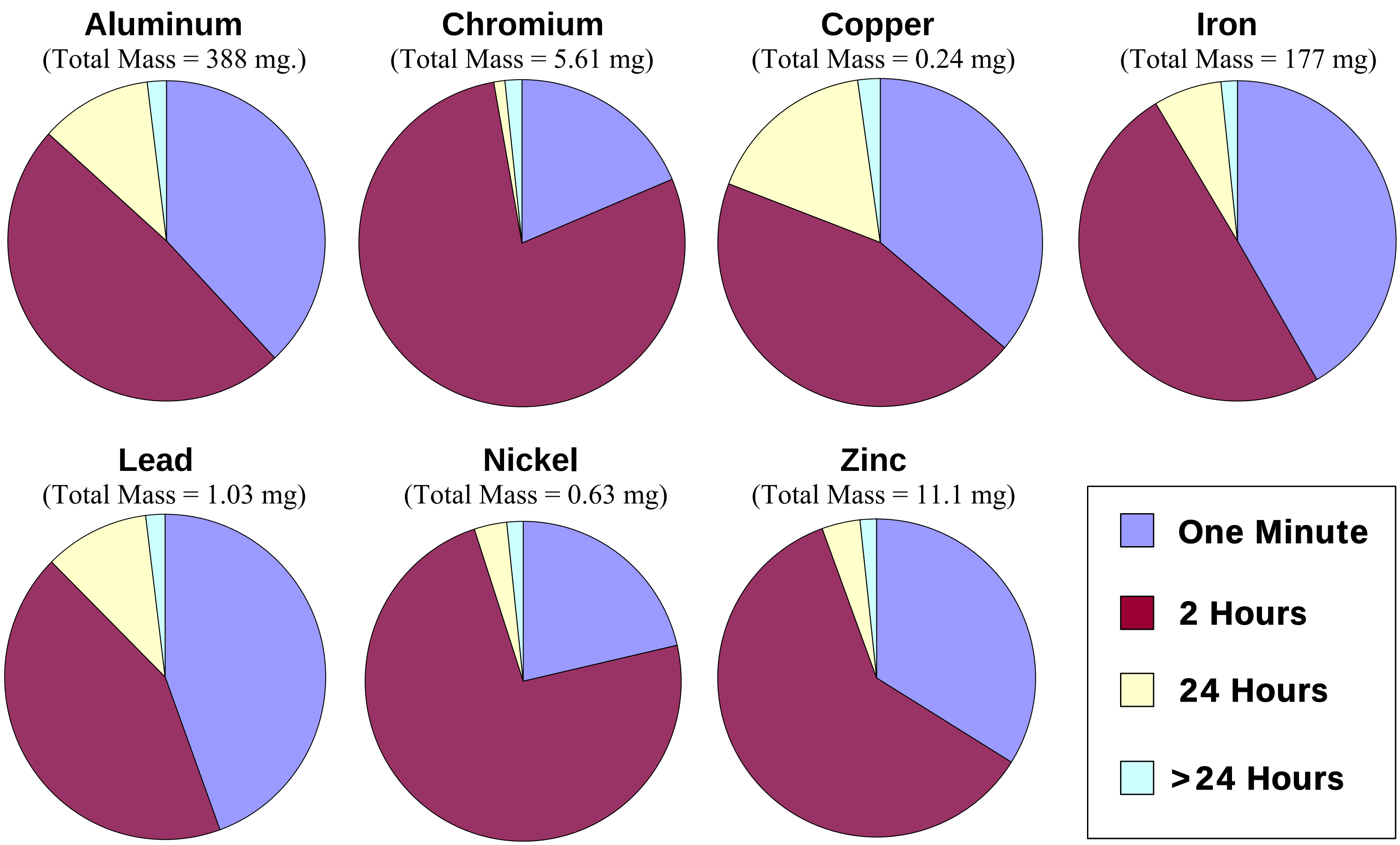


Figure 2-11. Average mass of trace metals per volume of water (mg/l) by settling time.

Table 2-2. Phosphorus and metal concentration (mg of analyte/kg of TSS) by storm.

	P (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Al (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Cr (mg/kg)
Storm 1	8764	639	0.0	26288	31373	717	18.2	876
Storm 2	4924	241	18.1	7874	22086	27.7	104	43.7
Storm 3	9525	536	29.7	14989	48345	42.9	135	94.5
Average ± 1 S.D.	7738 ± 2466	472 ± 207	15.9 ± 15.0	16384 ± 9286	33935 ± 13315	263 ± 394	85.6 ± 60.5	338 ± 467

The smallest storm (Storm 1) contributed a small fraction of the metal and phosphorus mass compared to the other two storms (Table 2-3). The intermediate storm (Storm 3) had a higher phosphorus and metal mass per volume of water than the largest storm (Storm 2).

Table 2-3. Mass of phosphorus and metal per volume of water (mg/l) by storm.

	P	Zn	Cu	Fe	Al	Ni	Pb	Cr
Storm 1 (mg/l)	0.17	0.01	0.00	0.51	0.61	0.01	0.00	0.02
Storm 2 (mg/l)	4.42	0.22	0.02	7.06	19.81	0.02	0.09	0.04
Storm 3 (mg/l)	7.55	0.43	0.02	11.9	38.3	0.03	0.11	0.07
Average ± 1 S.D.	4.05 ± 3.70	0.22 ± 0.21	0.01 ± 0.01	6.48 ± 5.71	19.6 ± 18.9	0.02 ± 0.01	0.07 ± 0.06	0.04 ± 0.03

Spatial Water Quality Sampling

Changes in concentration of TSS (Figure 2-12), TN (Figure 2-13) and TP (Figure 2-14) occurred as storm water flowed through the delta. The results are plotted as a concentration at a sampling point versus the distance upstream from the terminus of the flowpath. Because some flowpaths bifurcated, two sampling sites although they are in the same location within the delta may have different distance measurements due to different end-points. Because the elevation of sample bottles differed between sites and water flood elevation differed between storms, some sample bottles didn't fill for every storm. This is why some sampling sites had no samples on a given storm. Not all sites had baseflow or flow during the post-storm period and therefore no data is provided for these sites. In the graphic representation of the data, the flowpaths of the delta are divided into the Eastern Delta and the Western Delta. In each storm related figure, the two storm samples are averaged. The differences in magnitude of the storms attributed a large range, although trends of concentration change were consistent. The flowpath delineations, names and sampling sites used for this study and Figures 2-12, 2-13 and 2-14 are shown in Figure 2-3.

Total suspended solids spatial analysis

During baseflow (Figure 2-12a.), the TSS concentration entering the delta is greatest from Site W1 as opposed to the input from Tumblin Creek itself (Site CW1). Sediment transport is observed along both baseflow channels (Central Tumblin and West). The West channel appears to have sediment transport between site W1 and W2. This stream reach consist of a 3-5% slope tapering off into the delta floodplain. The portion of the delta between site W1, W2 and W3 is composed of very fine saturated soils and a sheet-flow regime. The water column is composed of a floc layer near the soil surface with fine particles in suspension and a zone above the floc layer with less suspended sediment. During low water periods the floc layer is indistinguishable from that of surface water and may become suspended into the water column during increased flow events. Ultimately, the suspended sediment concentration of the West flowpath drops between Site W2 and Site W3 to a value comparable to the inflow (Site W1) before entering Bivens Arm Lake (Site CT6). Along the central flowpath, the concentration of suspended sediment increases from sites CT3 to CT4 to CT5 indicating resuspension of sediments from within the delta. The decrease in TSS between site CT5 and CT6 indicate either sediment retention or dilution, where the central flowpath meets the western channel. During baseflow it appears that the delta is not a significant sink or source of TSS as the suspended sediment concentration at the lake (Site CT6) is comparable to the TSS concentration of the two flowpaths (West and Central).

The stormflow TSS concentrations for the western delta (Figure 2-12b.), indicate that the Tumblin Creek channel itself is a major source of suspended sediment. The concentration of suspended sediment entering from Tumblin Creek is 4600 mg/l, which is approximately 20 to 65 times higher than any other input to the delta. This flowpath also has the highest flow-volume entering the delta. Every one of the inputs to the delta experiences an initial decrease in TSS between the input and the next sample site (Site CT1-CT2, Site W1-W2, Site NE1-CT3 and Site EW1-W2). Internal sediment resuspension occurs for the Central Tumblin flowpath and the Western Tumblin flowpath. These two regions experience high volumes of rapid flows over sandy soils during storm events. The West flowpath increases in concentration between Site W2 and Site W3, which is likely due to the inputs from both Central Tumblin and Western Tumblin which join this flowpath between these two sampling sites. The concentration at the end of each of the flowpaths in the western delta (Site CT6) is much lower than any other site sampled within the delta at 7.6 mg/l. Therefore, although some internal resuspension occurs within the delta downstream of the dredged channel, the delta as a whole acts as a sink for suspended sediment during stormflow.

The eastern delta experiences sediment resuspension during stormflows (Figure 2-12c.) in the same region downstream where internal loading occurred in the western delta (Site CT3-ET1, ET1-ET2). The concentrations of suspended sediment entering from the East and Central East flowpaths are relatively low. The concentration of TSS at the end point of these three channels (Site ET3) is lower than any of the incoming concentrations and therefore the eastern delta is also a sink of suspended sediment during storms.

Post-storm changes in TSS concentration are similar to baseflow (Figure 2-12d.). Internal resuspension of sediment occurs through the zone downstream of the dredged channel (Site CT3-CT4, Site CT4-CT5, Site CT3-ET1 and Site ET1-ET2) and between Site W1 and W2. Total suspended solids concentrations at Site ET3 and Site CT6 are higher than any of the input concentrations and therefore the delta immediately after a storm acts as a source of suspended sediment in both the eastern and western delta.

Overall, total suspended solids concentrations significantly increase from baseflow to storm event conditions (Figure 2-15). From baseflow to storm conditions, the total suspended solids concentration increases from 11.4 mg/l to 212 mg/l and returns to a post-storm mean concentration of 5.90 mg/l.

Total phosphorus spatial analysis

During baseflow, the highest water column TP concentration entering the delta was at Site W1 in the western part of the delta. Site W1 also had the highest concentration of TSS during baseflow (Figure 2-13a). In this instance, unlike TSS, only the West flowpath and not the Central Tumblin flowpath had internal flux of total phosphorus to the water column (Site W1-W2). Although it is apparent that the water column at Site W2 has a high concentration of total phosphorus (most likely as a result of particulate phosphorus associated with the floc layer), the phosphorus is retained before reaching Site W3, which has a lower concentration than the input at Site W1. The central channel experiences very little change in total phosphorus along its entire flowpath. The concentration at Site CT6 is much lower than the input at Site W1, but represents a small increase from the concentration entering at Site CT1.

Although the largest stormflow suspended solids concentration to the western delta was from Site CT1, the highest concentration of total phosphorus was found at Site W1 along the West flowpath (Figure 2-13b). This indicates that either particulate phosphorus is not the predominant TP source to this area or that the West flowpath imports particles with higher phosphorus concentrations than the Central Tumblin flowpath. The total phosphorus concentration of the West flowpath decreases from an initial concentration of 3.15 mg/l (Site W1) to 0.65 mg/l at Site W2. This decrease in TP concentration along the western flowpath could possibly be due to dilution from the input at Site EW1 along the Eastern West flowpath, although this flowpath appears to be much lower in volume than the West flowpath. The Central Tumblin and Western Tumblin flowpaths both have increases in TP concentration as water enters the delta floodplain downstream of the dredged channel indicating either flux of dissolved phosphorus from the sediments or suspension of particles containing P. Increasing suspended sediment concentrations along this same flow path would suggest that the increase in water column TP is associated with resuspension of particulate phosphorus (Figure 2-12b). This is a region of rapid flow over unconsolidated sandy soils and through incised channels, where sediment mobility is likely. The increase in concentration through this region causes all of the flowpaths to become higher in concentration than the initial concentrations entering the delta. A linear correlation between TSS concentration and TP concentration of the samples collected during the first storm and second storm, indicates r^2 values of 0.988 and 0.784 respectively (Table 2-4). Therefore, it is likely that the large amount of sediment retention that occurs in each of the flowpaths during a storm event before reaching the lake (Figure 2-12b), is decreasing the TP concentration entering the lake.

The eastern delta also experiences TP concentration increases during storms as the rapid flows from the dredged channel travel through the delta floodplain forest (Figure 2-13c). Changes in TP for the eastern delta closely follow TSS concentrations (Figure 2-12c). The concentration at the end of the flowpath is higher than the inputs at Site CE1 and Site E1 but lower than the input from Site CT1.

The TP profile of the delta in the post-storm period (Figure 2-13d) is similar to the values during baseflow (Figure 2-13a). This indicates that TP concentrations return to baseflow levels very rapidly after a storm event.

Overall, there is a significant increase in phosphorus concentration during the storm, which returns to values comparable to baseflow the next day (Figure 2-16). From baseflow to storm conditions, the total phosphorus concentration increases from 0.574 mg/l to 1.84 mg/l and returns to a post-storm mean concentration of 0.610 mg/l.

Total nitrogen spatial analysis

During baseflow conditions inputs from the west flowpath (Site W1) had the highest concentration of TN of any of the inflows to the delta (Figure 2-14a). The concentration of this flowpath decreased as the water traveled through the zone with sheet-flow hydrology and fine organic matter-rich soils (Site W1-W3). TN concentrations along the West flowpath were not highly correlated to TSS during baseflow, indicating a large dissolved component (Table 2-5). The TN concentration changes little along the Central Tumblin flowpath. Overall, the West flowpath appears to be a sink of TN during baseflow, while the Central Tumblin flowpath indicates no major change in TN concentration within the delta.

During storm events, west flowpath inputs (Site W1) had the highest concentrations of any flowpath entering the delta (Figure 2-14b). The correlations between TSS and TN during the first and second storm had r^2 values of 0.966 and 0.623 respectively (Table 2-4). This indicates that during storms, TN is composed mostly of particulate organic or inorganic forms, the extent of which depends on the storm itself. Each of the flowpaths initially decreased in TN concentration as water flowed through the region downstream of the dredged channel. The final concentration entering the lake (Site CT6) was lower than any of the initial concentrations entering the delta (Site CT1, W1 or EW1) indicating that the delta is likely acting as a sink for TN during storms.

The eastern delta experiences relatively small changes in TN concentration along each of the flowpaths (Figure 2-14c). The concentration at the end of each of these three flowpaths is lower than the inputs indicating that the eastern delta is also a sink of TN during storms.

In the post-storm period (Figure 2-14d), just as with baseflow conditions (Figure 2-14a), the West channel is an initial sink of TN, while little change occurs over the Central channel and the East-West channel. Similar to baseflow conditions there is a slight increase in TN at the end of the West and Central Tumblin flowpath before entering the lake. The similarities between post stormflow and baseflow indicate that TN concentrations rapidly return to baseflow values after a storm. Overall, the West flowpath acts as a sink for TN, while the Central Tumblin channel experiences little or no significant change in concentration across the delta floodplain.

Total nitrogen concentrations significantly increase from baseflow to storm event conditions (Figure 2-17). From baseflow to storm conditions, the total nitrogen concentration increases from 1.37 mg/l to 2.95 mg/l and returns to a post-storm mean concentration of 1.01 mg/l.

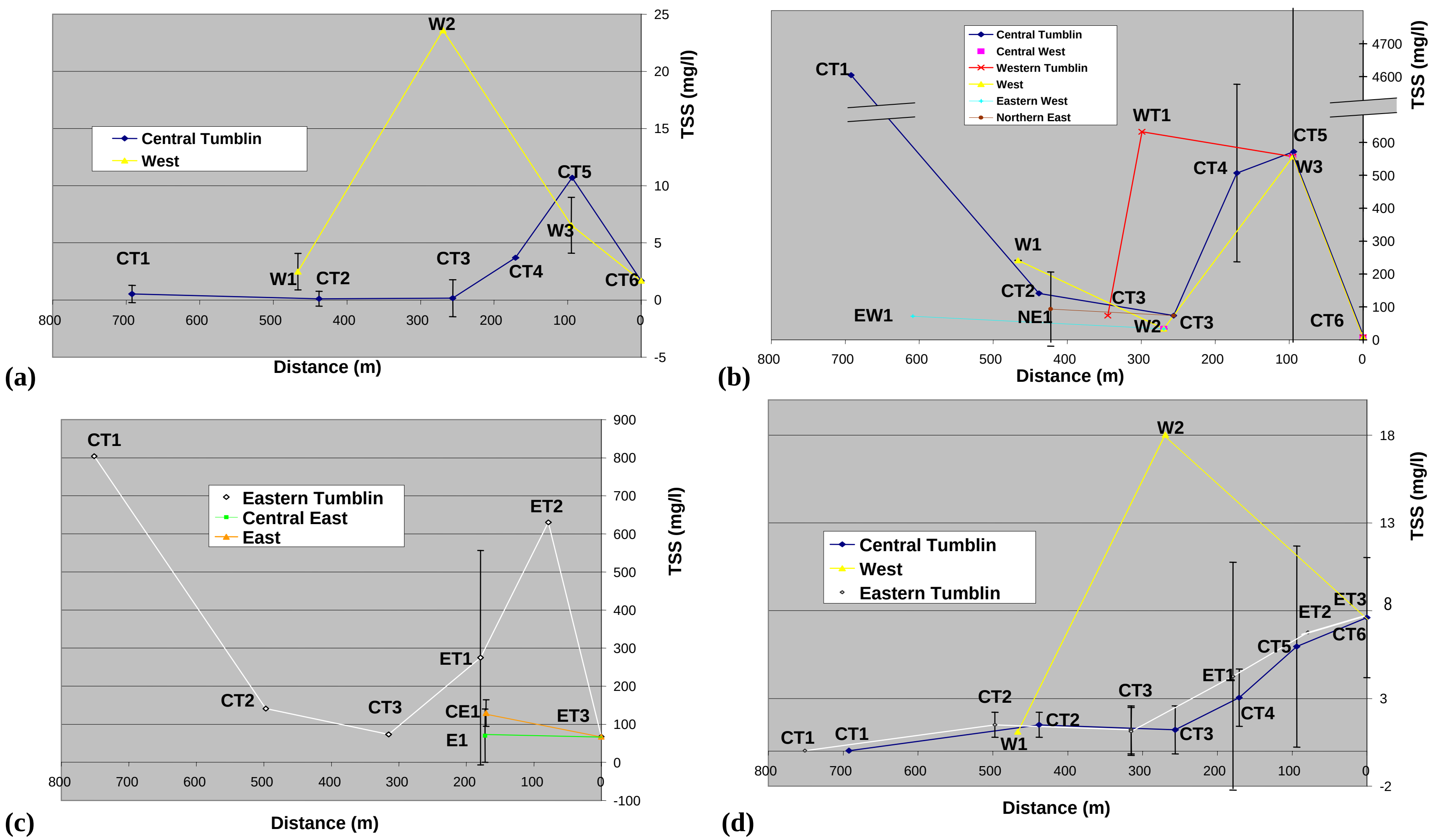
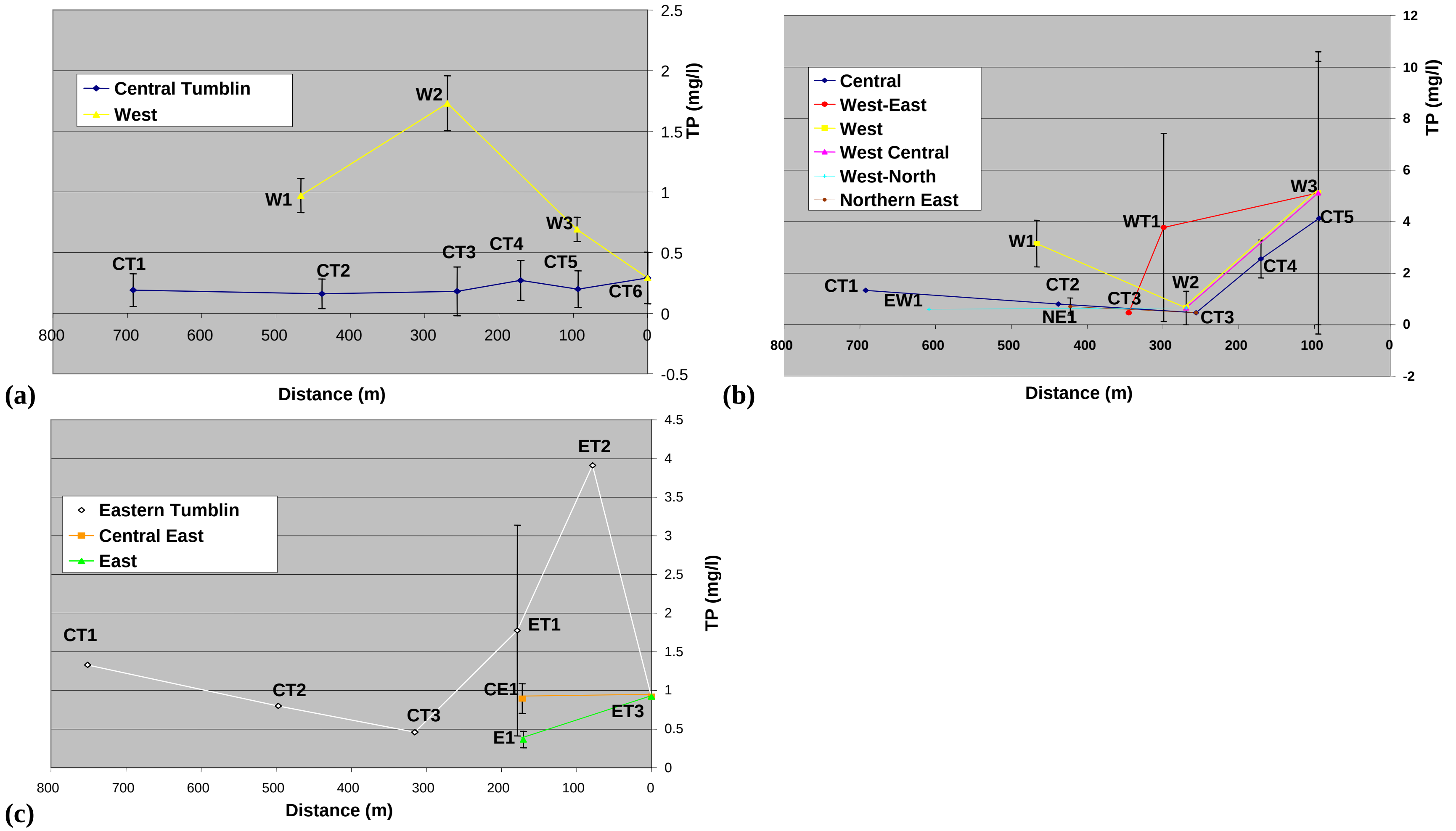


Figure 2-12. Total suspended solids concentrations (mean ± 1 range of two storms) by distance traveled within the delta for various flowpaths during a)Baseflow, b)Western delta stormflow, (c) Eastern delta stormflow and (d) Post-Storm (No baseflow occurs in the Eastern delta so no values are included)


(a)
Central Tumblin
West
W1
W2
W3
CT1
CT2
CT3
CT4
CT5
CT6
TP (mg/l)
Distance (m)
(b)
Central
West-East
West
West Central
West-North
Northern East
W1
WT1
W2
W3
CT1
CT2
CT3
CT4
CT5
EW1
NE1
TP (mg/l)
Distance (m)
(c)
Eastern Tumblin
Central East
East
CT1
CT2
CT3
ET1
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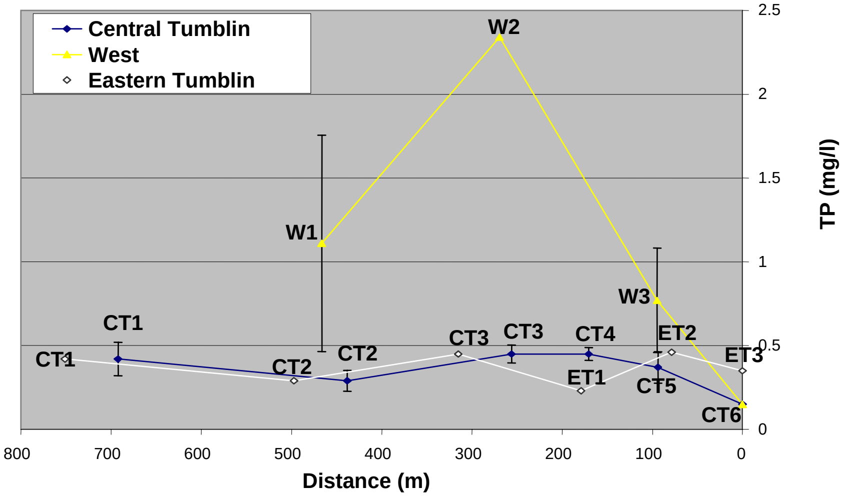
ET3
CE1
E1
TP (mg/l)
Distance (m)



(d)

Figure 2-13. Total phosphorus concentrations (mean $\pm$ 1 range of two storms) by distance traveled within the delta for various flowpaths during a)Baseflow, b)Western Delta stormflow, (c) Eastern Delta stormflow and (d) Post-Storm. (No baseflow occurs in the Eastern delta so no values are included)

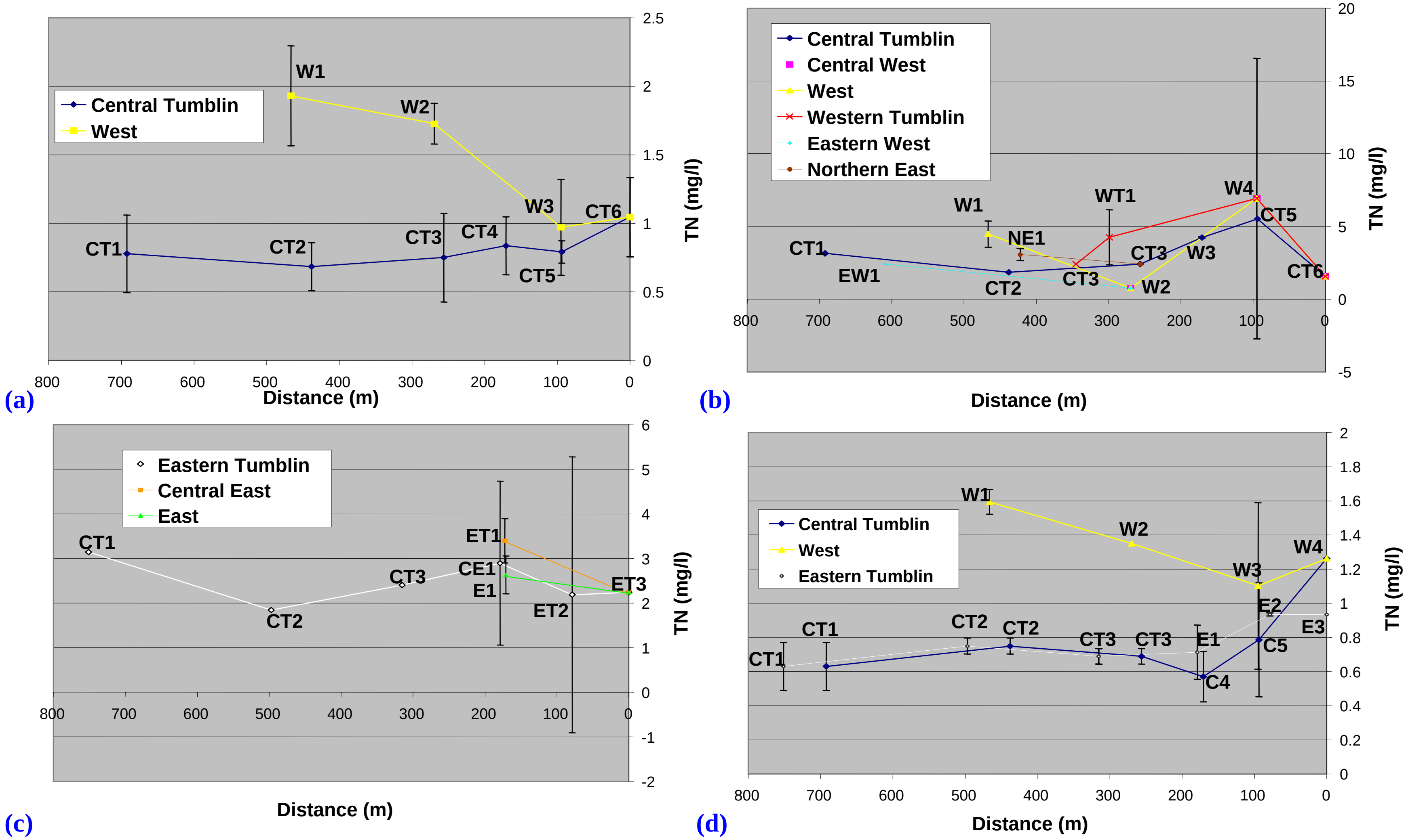


Figure 2-14. Total nitrogen concentrations (mean ± range of two storms) by distance traveled within the delta for various flowpaths during a)Baseflow, b)Western Delta stormflow, (c) Eastern Delta stormflow and (d) Post-Storm. (No baseflow occurs in the Eastern delta so no values are included)

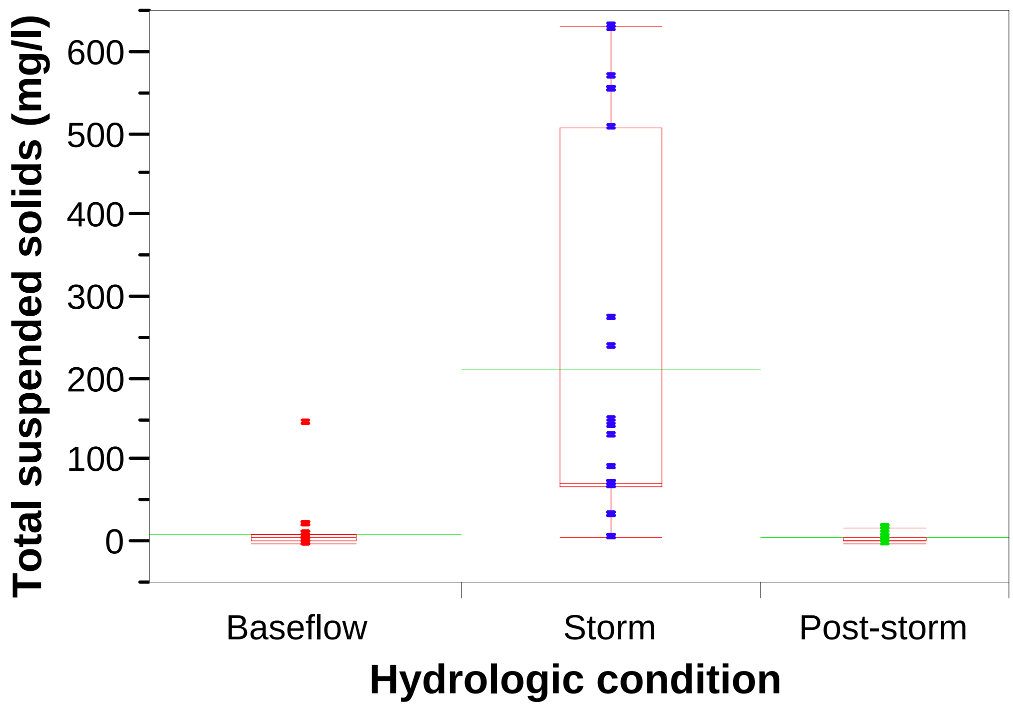


Figure 2-15. One-way analysis of total suspended solids by hydrologic condition (Baseflow n = 16, Storm n = 26, Post-storm n = 17).

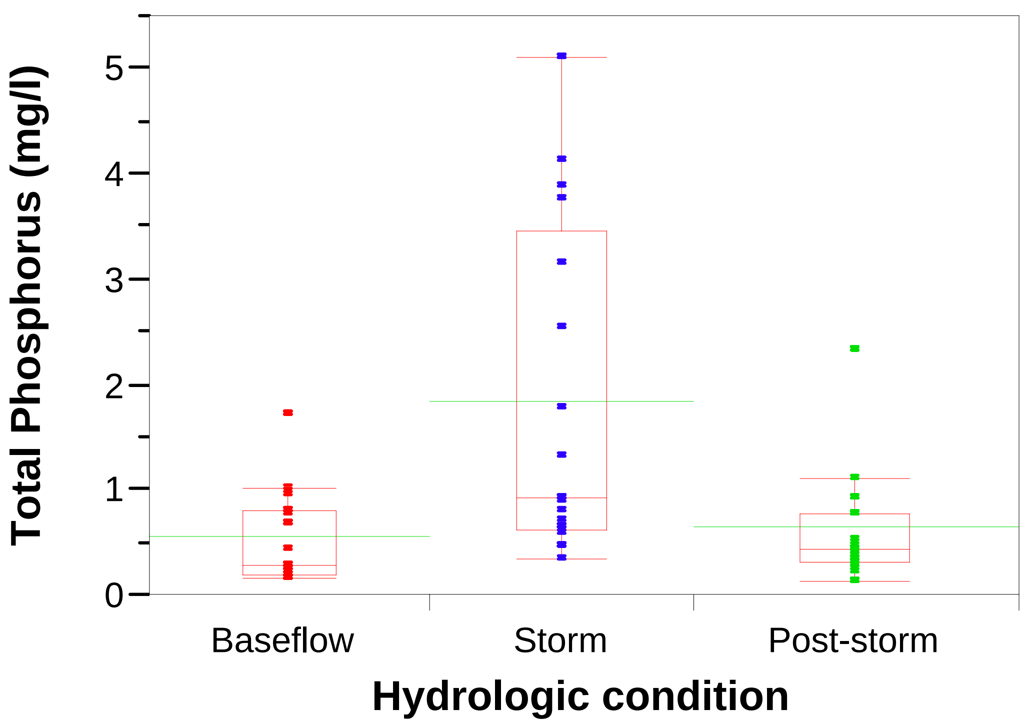


Figure 2-16. One-way analysis of total phosphorus by hydrologic condition. (Baseflow n = 16, Storm n = 26, Post-storm n = 17).

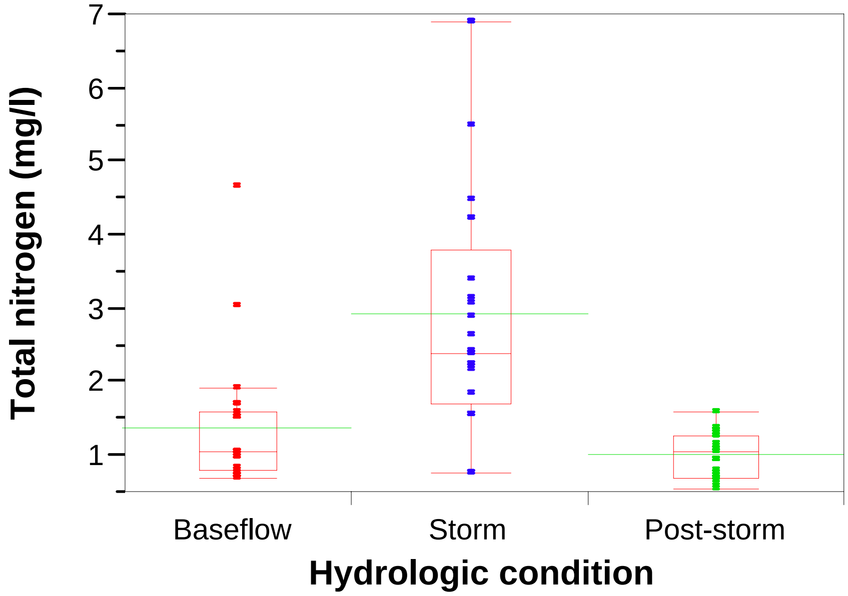


Figure 2-17. One-way analysis of total nitrogen by hydrologic condition. (Baseflow n = 16, Storm n = 26, Post-storm n = 17).

Table 2-4. Linear relationship between total phosphorus and total suspended sediments for baseflow, storm and post-storm hydrologic conditions.

	P value	r^2 value
Baseflow	0.000	0.952
Storm 1	0.000	0.988
Storm 2	0.000	0.784
Post-storm	0.001	0.404

Table 2-5. Linear relationship between total nitrogen and total suspended sediments for baseflow, storm and post-storm hydrologic conditions.

	P value	r^2 value
Baseflow	0.012	0.20
Storm 1	0.000	0.966
Storm 2	0.001	0.623
Post-storm	0.000	0.584

Conclusions

Floodplain wetlands and deltas retain particulate matter and the associated nutrients and pollutants through the maintenance of a sheetflow hydrologic regime. The transition from turbulent streamflows to quiescent sheetflows facilitates this sediment deposition. As a result, downstream water bodies receive decreased sediment, nutrient and pollutant loads. Channelization of these ecosystems reduces the detention time and restricts flows to a confined area thus reducing sheetflow and decreasing sediment deposition. The objectives and statements addressed in this section include:

Objective 1: Characterize the stormflow particulate matter entering the Tumblin Creek delta floodplain and quantify the role of the delta as a source or sink of nutrients, particulate matter and trace metals.

- **Statement 1:** The majority of suspended sediment (by mass) transported to the Tumblin Creek delta floodplain are composed of coarse particles.
- **Statement 2:** Particles that require longer to settle will have higher concentrations of phosphorus and metals.
- **Statement 3:** Regions of the delta floodplain where sheetflows exist will retain more phosphorus, nitrogen and particulate matter than areas where incised channels exist.

Baseflow and Post-Storm characterization

During baseflow conditions, the Central Tumblin flowpath acts as a source of sediment but not phosphorus or nitrogen as the flows travel through the most impacted area, located downstream of the dredged channel. This impacted area is composed of sandy sediments and incised channels which carry a majority of the water of Tumblin Creek during baseflow. This channelized flow regime is re-suspending the sediments during baseflow. These sediments are unreactive and most likely leached of labile phosphorus or nitrogen, which is why although TSS is increasing along this flow path an increase in TP or TN is not evident.

Water entering the West flowpath at Site W1 has the highest concentration of nutrients and sediments at baseflow. The watershed area for this inflow is much smaller than the watershed of Tumblin Creek, so although concentrations are higher along this flow path the total loading rate of the west flow may be less than other larger volume but lower concentration inputs would imply. The western portion of the delta is composed of flow over a large area with a few diffuse channels. The soils in this area are fine in texture, organic matter rich and easily disturbed. Even though the flow energy of this region is lessened due to the sheet-flow regime, particulate matter still appears to be re-suspended. The mobility of fine sediments in this region significantly increases the water column concentration of phosphorus, but not nitrogen along this flowpath. Total nitrogen traveling over this portion of the delta is assimilated during baseflow, even though sediments were mobilized. This indicates that during baseflow, the predominant form of TN is dissolved N, either organic or inorganic. The sediments of this part of the delta are high in organic matter content and anaerobic during flooded conditions, which facilitates TN removal through ammonium sorption and denitrification.

After the west and central baseflow channels merge, the sediment concentration decreases. The channel in this area is composed of large pools where sediment deposition is likely. Sediment deposition in this area during baseflow is potentially resuspended into the lake in subsequent storms. Regardless of future sediment mobility, suspended sediment concentration of the largest contributor to baseflow volume (Central Tumblin) is higher at this site than the inflow concentration (although the West channel slightly decreases in concentration). This indicates that the delta is a small source of sediment during baseflow. Although baseflow sediment concentrations increase, the delta is an effective sink for TP and TN during baseflow. The West flowpath is an effective sink for high phosphorus and nitrogen concentrations entering the delta, while the Central Tumblin flowpath has little change in TN and TP concentrations.

Post-storm conditions are very similar in concentration values and trends of baseflow indicating a quick return to baseflow conditions. The concentrations of TP, TN and TSS during the post-storm period are slightly lower than during baseflow. This could be as a result of flushing of the more mobile fractions of these analytes during the antecedent storm event.

Stormflow Characterization

Storm events represent the most significant inputs of TP, TN and especially TSS to the delta and potentially the lake. Total suspended solids loading to the delta during baseflow is negligible compared to stormflow periods. TP and TN concentrations entering the delta in storm events are on average 6 and 13 mg/l more than during baseflow respectively.

The coarse particles which settle rapidly make up on average 66% of the total suspended sediment composition entering the delta. These data confirm Statement 1 which asserts:

- **Statement 1:** The majority of suspended sediment (by mass) transported to the Tumblin Creek delta floodplain are composed of coarse particles.

Small storms contribute a fraction of the sediment concentration (2%) of the large storms, while sediment concentrations experience a diminishing return at high storm volumes. Lower energy storms differentially transport the finer particles which are more easily mobilized. Higher energy storms had sufficient energy to mobilize larger sediments. The mobilization of particulate phosphorus and trace metals from the watershed entering the delta depends on the energy of the storm as well as the time since previous rainfall. Because the smallest storm mobilized finer particles and not larger particles, the concentration of phosphorus and trace metals sorbed to those fine particles was often high. The largest storm occurred a day after this smaller storm. Sharpley (1980) found enrichment in runoff particulate phosphorus from the surrounding soils due to the preferential transport of fine particles, while no such enrichment occurred in successive storms. Although the largest storm had the highest concentration of particulate matter, the intermediate storm had a higher mass of phosphorus and trace metals per volume of water. The largest storm was mobilizing particles with lower concentrations of phosphorus and trace metals. This concentration difference is not due to particle size because the largest storm had higher fine sediment loads and lower coarse sediment loads than the intermediate storm. This is likely either due to flushing of nutrients from the previous storm or dependent on what portion of the storm hydrograph the water was sampled.

Within the delta, removal of this watershed-borne particulate matter, phosphorus and trace metals during storm events, would be more complete if the detention time were 2 hours (Table 2-4). This detention time is significant enough to remove some of the fine particles which contain the highest concentrations of particulate pollutants. Therefore, this study supports Statement 2 which asserts:

- **Statement 2:** Particles that require longer to settle will have higher concentrations of phosphorus and metals.

A further increase in detention time wouldn't remove a very significant additional portion of these pollutants. The channelized flow regime which is present in much of the delta is likely decreasing the detention time and maintaining higher velocities that are only effective at removing the particles in the one minute settling category. The retention of only the coarse particles wouldn't be nearly as effective at removing total nutrients and pollutants.

Table 2.6. Cumulative percentage removal of pollutant by settling time.

	One Minute	**2 Hours**
TSS	66%	92%
Zn	37%	95%
Cu	40%	83%
Fe	45%	93%
Al	42%	88%
Ni	24%	96%
Pb	49%	89%
Cr	21%	98%
P	50%	92%

Overwhelmingly the largest amount of sediment enters the delta from the main channel of Tumblin Creek during storms. Although this inflow has the highest sediment concentration, the water column TP and TN concentrations of the West flowpath are the highest. This is likely as a result of either a difference in suspended sediment phosphorus and nitrogen concentrations or significant soluble forms of TN and TP being present in the west flow path. The fact that stormflow TN and TP fluctuations of the West flowpath and Central flowpath are correlated with those of total suspended solids indicates the latter is true.

Each one of the flowpaths experiences an initial retention of nutrients as well as sediments upon entering the delta once turbulent stormflows are dissipated over a larger area. Deposition even occurs within the dredged channel itself. This is due to the deposition of the larger particles (one minute) and the associated nutrients. Retention of nitrogen and phosphorus is most rapid in the western portion of the delta where concentration values of total nitrogen rapidly decrease to the lowest levels in the delta and total phosphorus decreases significantly over a short distance. Although the inputs to this region are composed of the finer particles with higher nutrient concentrations, the sheet-flow regime effectively deposits these sediments over a short distance. Concentrations of all the constituents increase as the flows travel through the most impacted region of the delta downstream of the dredged channel. These two points confirm Statement 3 which asserts:

- **Statement 3:** Regions of the delta floodplain where sheetflows exist will retain more phosphorus, nitrogen and particulate matter than areas where incised channels exist.

The area downstream of the dredged channel is the deposition zone for the unreactive, unconsolidated sands. Increases in concentrations during storms through this area are due to increased sediment mobility from turbulent flows. Before the water enters the lake, the sediment and nitrogen concentrations decrease and likely the phosphorus as well. This is either due to sediment deposition in this zone or dilution from the lake, which is continuous with the delta at this point.

Summary

Storm events represent the most significant impacts to the delta and potentially the lake itself. Large storms are able to mobilize coarse sediment from stream-bank erosion, scour and bank collapse. In an impermeable urbanized watershed, stormflow rate and volume are greatly increased from historic conditions, thus increasing the export of coarse sediments to the delta. Coarse sediments represent the largest volume of sediment entering the delta and they have accumulated in a wide swath downstream of the dredged channel. Sediment and the associated nutrients deposited here are easily re-mobilized in storms when the channelized flows of Tumblin Creek enter the delta floodplain forest. This channelized flow regime has decreased the detention time of the delta thus reducing the retention of metals, phosphorus and sediments before entering Bivens Arm Lake. In contrast, the portion of the delta not as impacted by high volumes of coarse sediment and channelized flows retains nutrients and sediments in the time period of storm events.

CHAPTER 3
EFFECTS OF URBANIZATION ON DELTA FLOODPLAIN SOIL CHARACTERISTICS

Floodplains and river deltas are regions where deposition of watershed derived sediment occurs. Therefore, watershed land-use changes that affect suspended sediment characteristics and total quantity will be focused to these regions. Riparian wetlands can modify the water characteristics before it enters downstream ecosystems by removing suspended sediments, particulate pollutants and retaining and transforming nutrients. Modifications to the hydrology, and the sediment and nutrient loading to these ecosystems can alter their nutrient, metal and particulate matter retention and cycling. The sediments of the Tumblin Creek delta floodplain have been modified as a result of increased sediment and nutrient loading from urban and historic agricultural land-uses. Channelization has modified the hydrology and sediment deposition characteristics of the delta floodplain. This chapter analyzes modifications to the phosphorus sorption, elevation, nutrient and metal concentrations of the sediments of the Tumblin Creek delta floodplain as a result of channelization, urbanization and historic agricultural impacts.

Introduction

Watersheds having a high percentage of impervious surfaces are often characterized as “flashy” or having a “spiky” hydrograph. These urban watersheds are categorized by these descriptions due to the rapid rate with which they respond and return to base flow conditions after a storm event when compared to watersheds having a higher percentage of permeable surfaces. In urban watersheds storm flows are quicker to increase after a storm, flow-rate is much more rapid during storms, and base flow between storms is much lower than historic conditions. This is as a result of urban planning which focuses on rapid removal of water from the landscape in order to prevent flooding rather than facilitating infiltration on the site. Therefore, the energy and volume of storm flows is increased which facilitates erosion, sediment mobility, scour and bank collapse along the conduits the through which the stormwater is directed.

Agricultural land use, the principal land-use in the Tumblin Creek watershed between 50 and 150 years ago likely consisted of deforestation as well as soil disturbances and fertilizer applications. Historic photographs shown in Figures 1-2, 1-3 and 1-4 attest to the degree of land-clearing and lack of buffer zones that occurred in the Tumblin Creek watershed. Sediment mobility as a result of erosion of unconsolidated soils and a lack of vegetation is common in agricultural watersheds. Vegetated buffer zones can function to remove sediment from agricultural runoff before entering water bodies and stabilize shorelines (Cooper et al. 1987, Daniels and Gilliam 1996, Lowrance et al. 1986). A watershed devoid of vegetation and riparian buffer zones would therefore export increased sediment to creeks and ultimately downstream depositional areas.

Floodplain Delta Sedimentation Characteristics

Urban and agricultural watersheds contribute higher amounts of suspended sediment to downstream areas. Areas of a watershed with a higher topographic relief inherently contribute sediment to downstream zones. Landscapes such as deltas which have a lower slope and slower flow are regions of net sediment deposition. The net sediment accretion rate within deltas is a balance between erosion and deposition. The extent of deposition or erosion depends on the energy of storm flows, vegetative composition as well as the topographical gradient. In the Tumblin Creek delta floodplain, channelization through approximately half of the delta has focused much of the suspended sediment to settle downstream of the dredged channel and in the central part of the delta. Therefore, it is expected that this region will have a higher elevation than the surrounding delta, due to the focused sediment deposition. An analysis of net sediment deposition in the region downstream of the channel will indicate that the sediment accretion rate has increased within the time frame of land-use changes and dredging of the channel. Although net deposition has occurred in this downstream portion, differential erosion of the sedimentation plume has also occurred. Erosion within this sediment deposition plume has created several discrete, incised channels which carry a majority of the flow of the creek through the delta during base and moderate flow events. An analysis of the soil elevation across the delta will indicate the extent of the opposing forces of erosion and deposition as manifested in channel formation and soil elevation increases.

- **Statement 1:** The soil elevation downstream of the dredged channels will be higher in elevation than surrounding regions.
- **Statement 2:** The net sediment accretion rate has increased in the time period of channel dredging and land-use changes.
- **Statement 3:** The soils downstream of the dredged channel to the lake will have low concentrations of phosphorus and metals, while regions of the delta floodplain composed of longer detention times will have higher soil concentrations of phosphorus and metals.

Factors Affecting the Assimilative Capacity of the Delta Floodplain

Sediments that are transported from upstream watersheds, sort based on particle size when a sheet flow regime exists such as in a floodplain forest (Cooper et al. 1987). The concentrations of nutrients and adsorbed pollutants are higher in the finer particle fraction, which settle farthest from the stream bank due to the longer settling time. Therefore, removal of finer particles with higher concentrations of pollutants requires a longer detention time. There have been two major hydrologic disturbances which have occurred in the Tumblin Creek delta floodplain that have likely affected the ability of the delta to be a sink for these finer particles. Channel dredging and isolation of the upper western half of the delta by the channel and spoil-pile formation, provides a short-circuit path through approximately half of the delta and limits the area of exposure between floodwaters and the delta. Secondly, channel incising of the sediment plume continues the isolation of flow from the broader delta and focuses high energy flows rapidly towards Bivens Arm Lake. Both of these factors have decreased the detention time, thus finer particles with higher concentrations of phosphorus and metals are less likely to settle within the delta and instead move through the delta to the lake. Therefore, an analysis of the soil metal and phosphorus concentration gradients can indicate if the detention time is sufficient to remove finer particles with higher concentrations of metals and phosphorus.

The inherent sorting of suspended sediment within the floodplain delta based on particle size and density will cause a variation in the phosphorus sorption potential of the delta. Soils at the edge of a forested riparian zone adjacent to an agricultural drainage were composed primarily of sands, while silts and clays settled farther within the floodplain swamp (Cooper et al. 1987). Streams and stream banks within wetlands have been shown to have lower phosphorus sorption potential than surrounding wetlands (Axt and Walbridge 1999, Reddy et al. 1998). The sand-sized particles which settle out rapidly have a lower phosphorus sorption potential than do the finer silts and clays. Finer particles have a larger surface area and thus a potentially higher reactivity often resulting in increased phosphorus sorption capacity. Therefore, it is expected that the sand-sized soils which immediately settle at the edge of the Tumblin Creek delta floodplain should have lower phosphorus sorption potential than finer soils found in areas with longer detention times.

In addition to phosphorus sorption potential based on particle surface area, soil mineralogy and previous exposure to sources of P can influence soil sorption capacity. Fe, Al and Ca containing minerals and compounds within the soil matrix, bind dissolved phosphorus from the water column depending on the pH. Fe is a redox sensitive element which in reduced conditions, as often occurs in the soils of a wetland, converts Fe^{3+} to soluble Fe^{2+}, in turn releasing phosphorus into solution. Even in consistent pH and redox conditions, some forms of phosphorus bound within the soils are labile and in a constant state of flux with the porewater. The total amount of phosphorus sorption sites and the strength with which P sorbs to the soils depends on the soil mineralogy. Within the same soil of consistent mineralogy, the state of equilibrium shifts depending on the concentration gradient between the soils and the surrounding porewater. At high porewater concentrations of dissolved phosphorus the soils can act as a net sink, while the same soils would be a net source of phosphorus when dissolved phosphorus concentrations in the water are low (Reddy et al. 1998). The porewater dissolved phosphorus concentration at which no net exchange occurs between the soils and the porewater, is called the equilibrium phosphorus concentration (EPC_0) (Brady and Weil 2002). Because water column concentrations of dissolved phosphorus change from storm events to baseflow, it is important to consider the dynamic nature of phosphorus at concentrations above and below the EPC_0.

The EPC_0 of a soil can shift depending on the total number of available phosphorus sorption sites. Soils which have been historically loaded with phosphorus often become sources of phosphorus as sorption sites become saturated, thus increasing their EPC_0 value (Richardson 1985). Historic agricultural and urban land-uses as have occurred in the Tumblin Creek delta floodplain can cause soils to be loaded with phosphorus and decrease their ability to remove dissolved phosphorus from the water column. Also, an understanding of the equilibrium between the soils and the water column is crucial to understanding the potential for phosphorus release or retention if hydrologically isolated areas are reflooded as part of a restoration plan.

- **Statement 4:** Soluble phosphorus retention will be greatest where fine particles settle and lessened at the end of the channel where coarse particles settle.

Materials and Methods

To address hypotheses 2 and 4, a spatial survey using transects perpendicular to the predominant flowpath were used. The center-point of each transect was located 50 meters apart, starting at the upstream edge of the delta and terminating near the outflow into Bivens Arm Lake. The location of the ten transects are shown in Figure 3-1. The azimuth of each transect was perpendicular to the pre-dominant direction of flow through the delta. The ends of a given transect occurred when there was a noticeable change in topography and vegetation sufficient to indicate upland conditions. Elevation profiles and soil samples were collected at different intervals along these transects.

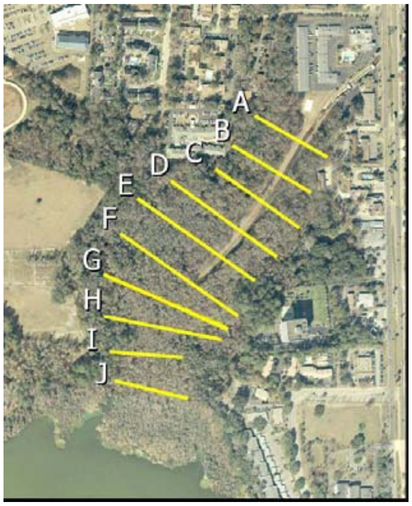


Figure 3-1. Location and numerical label of transects within the delta floodplain.

Elevation Survey

Soil elevation along transects was measured utilizing a laser level (Lasermark LMH series) and phili rod. The elevation surveys were done during the summer of 2003. Transect elevations were at first referenced to the top of the transect node and later corrected to actual elevation (NAVD 88) after transect nodes were surveyed by Causseaux and Ellington, Inc.

Elevation readings were taken every 5 meters on flat terrain and every meter when the elevation changed by more than 10%. In areas with diverse topography, such as an area of braided channels, readings were taken at more frequent intervals. Water depth measurements were also taken whenever water was present.

Soil Elevation Interpolations

The spatial Analyst extension of ArcView 9.0 (ESRI inc.) was utilized in order to interpolate the elevation profiles across transects and provide an elevation contour map for the entire delta floodplain. The spline interpolation was used with a spline type of tension, a weight of 1.5 and the number of points set to 1.

Soil Spatial Sampling

Soil samples were taken in the top 10 centimeters, every 20 meters along the transect. Where transects crossed the spoil-pile and the dredged channel of Tumblin Creek, only one sample was collected. A final soil sample was always taken at the end of each transect regardless of 20 meter intervals. Soil samples were taken with a 7 cm. diameter acrylic cylindrical coring tube. Three cores were collected in a 1 meter area at each location and these samples were composited in order to decrease variation. Soils were placed in 1 gallon Ziploc bags and transported within 4 hours to a 6 ^{o}C cooler at the laboratory

In the laboratory, the total sample weight of each composite was measured. Samples were then manually mixed to ensure uniformity and living roots were removed. A sub-sample of the soil was dried at 70 degrees Celsius for 24 hours, allowed to cool and re-weighed in order to calculate moisture content and bulk density. Oven-dried soil was then ground on a shaker with ceramic balls for 20 minutes to pass through a #100 mesh sieve. Approximately 200 milligrams of oven-dried soil was sub-sampled in order to measure loss on ignition. These sub-samples were ashed at 550 degrees Celsius for 3 hours and left in the furnace to cool overnight. Samples were placed in a desiccator for 30 minutes to bring to room temperature and then they were weighed. The weight difference before and after ashing was used to calculate organic matter content.

Sub-samples of ground and ashed samples were digested and analyzed for TP and metals according the methods listed in Anderson (1976) and extracted utilizing the TP ash method. The ashed soil was moistened with DDI water, and 20 milliliters of 6.0 M HCl was added. Samples were boiled at 100-120 degrees Celsius until dried. Once dry, the samples were heated for an additional 30 minutes. Samples were then moistened with

2-3 ml of DDI water and 2.25 milliliters of 6.0 M HCl. This extraction was then quickly brought to near boiling. The liquid was passed through a Whatman #41 filter paper, ensuring that filter and beaker were well rinsed then brought up to a volume of 50 milliliters with DDI water. Flasks were mixed and approximately 20 milliliters of solution was transferred to a scintillation vial for temporary storage. Solutions were then analyzed for total Phosphorous, Zinc, Copper, Iron, Aluminum, Cadmium, Nickel, Lead, and Chromium using an inductively coupled argon plasma atomic emission spectrophotometer (Method 200.7; USEPA, 1991). Extractions were done at the University of Florida Wetland Biogeochemistry Laboratory and analysis was done at the University of Florida Analytical Research Laboratory.

The concentrations of the extractions were adjusted to a mass per mass soil concentration of mg of extractant per kilogram of dry. Soil concentrations were further corrected for differences in bulk density and reported in g/cm2, assuming a depth of 10 centimeters to account for the higher variability in soil bulk density found through the site.

Soil Chemical and Physical Interpolations

All of the physical and chemical parameters of the soil surveys were incorporated into an ArcGIS database. The ArcGIS extension, Spatial Analyst was utilized in order to interpolate between the discrete soil sample locations and provide a map of soil characteristics for the entire delta. The spline interpolation was used with a spline type of tension, a weight of 1.5 and the number of points set to 1

Sediment Accretion Rate Determinants

Tree root flare elevation and tree age were used to develop a rate, depth and timeline of sedimentation in the region downstream of the dredged channel (Hupp and

Morris 1990, Wetlands Research Program [WRP] 1993). Soil depth to the root flare indicates the amount of net sediment that has accumulated from the time that the tree was first germinated. This procedure assumes that the root flare is at or near the surface of the soil when the tree is first developing. The age of the tree was measured using dendrochronological techniques. Excavation of the tree root flares and comparison of the ages indicated a sediment accretion rate and depth over time.

Trees which were located in the high sedimentation area immediately downstream of the end of the channel, likely where the greatest soil accumulation has occurred, were used for this study. This location is indicated in red in Figure 3-2. Soil around the tree was removed until the depth of the root flare could be determined. Adventitious roots were not included as part of the root flare. The elevation of the root flare was measured with a laser level and referenced to a transect node similar to the elevation survey. A small coring was taken from each excavated tree, scanned at high resolution (3200 dpi) and tree rings were counted to determine the age of the tree. The root-flare depths and tree ages were compared to determine a net sediment accretion rate.

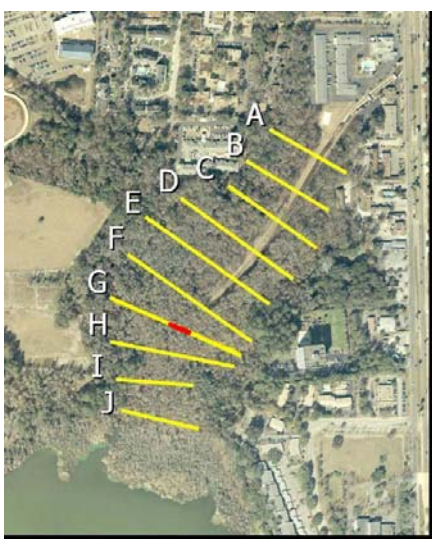


Figure 3-2. Location along transect where tree root-flair excavations occurred.

Phosphorus Isotherms

Phosphorus retention was determined on composites of soils from four distinct regions of the delta shown in Figure 3-3. These regions were chosen because they represent a range of impacts as well as present and future hydraulic connectivity should certain restoration efforts be implemented. All isotherms were done by the University of Florida Wetland Biogeochemistry Laboratory.

Single-point isotherms

Single point P sorption isotherms were utilized in order to understand the max P sorption capacity of the soils (Reddy et al. 1998). P sorption isotherms were analyzed by spiking a 1 g. soil sample with a solution of 1000 mg P/L as KH2PO4. The samples were equilibrated on an automatic shaker for 24 hours, centrifuged for 10 minutes at 6000 RPM and the solution was filtered through 0.45 µm filters. The filtrate was analyzed for SRP utilizing the ascorbic acid method on a Technicon Autoanalyzer (Method 365.1; USEPA, 1993A).

Multi-point isotherms

Multi point isotherms were also conducted at low P concentrations in order to effectively calculate the Equilibrium Phosphorus Concentration (EPC_0) (Brady and Weil 2002). Multi point P sorption isotherms utilized the same methods as single point isotherms only the soils were spiked with concentrations of 0, 0.1, 0.25, 0.5 and 1 mg P L-1.

The net phosphorus sorption on to the soil was calculated using Equation [3.1] (Reddy et al. 1998). Results of the isotherms were also corrected for bulk density differences between the four regions. Therefore the soil values are reported as mg P/cm3.

$$S' = [(Co * V) - (Ct * V)]/M \qquad [3.1]$$

Where

S' = phosphorus sorbed by solid phase (mg kg-1)

Co = initial concentration of P added to solution (mg l-1)

V = volume of extracting solution (l)

Ct = concentration of P in solution after 24 hours of equilibration (mg l-1)

M = mass of dry soil (kg)

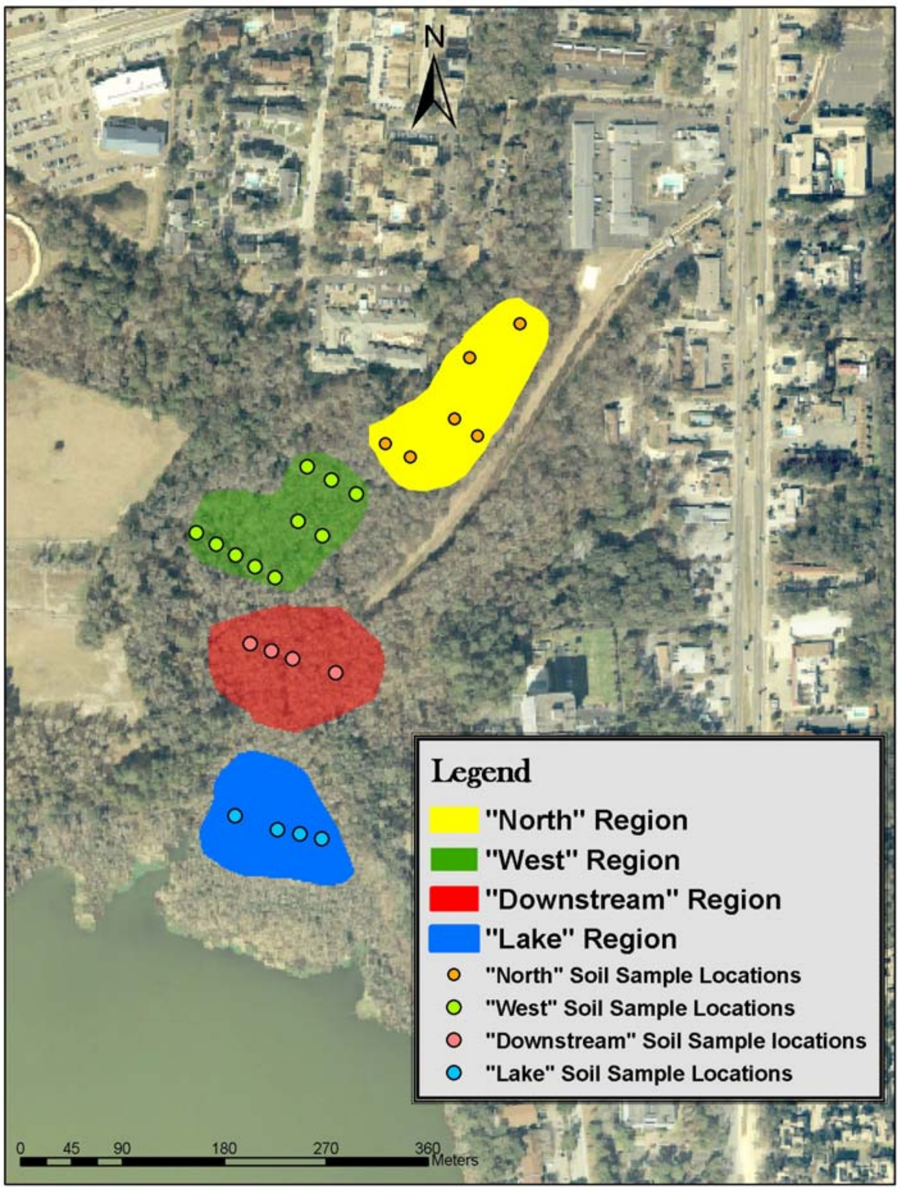


Figure 3-3. The locations of the soil samples which were composited in order to quantify phosphorus isotherms of four distinct regions of the delta floodplain.

Results

Soil Elevation

Results of the elevation surveys are shown as cross-sections in Figure 3-4. The spoil pile is clearly evident in transects A-F as the highest elevation. The dredged channel is the low elevation immediately to the right or east of the spoil-pile. The small elevation rise on the other side of the dredged channel is a sewer pipe which runs parallel to the channel and continues through to transect F. At transect F the sewer pipe runs in a more easterly direction away from the channel, crossing transect G at approximately 75 meters east of the transect node pin. Both the spoil-pile and the sewer pipe act as impoundments surrounding the Tumblin Creek channel. Therefore, flows from Tumblin Creek are confined and directed only inside the dredged channel through the delta from transect A through F. Downstream of transect F, the dredged channel and spoil-pile terminate, allowing previously confined flows to spread out into the forested delta floodplain. In transects G through J, a series of small, braided channels can be seen which carry flows down to Bivens Arm Lake. One channel which is particularly evident in transects I and J at -20 and -30 meters respectively, carries a majority of the base flow of Tumblin Creek.

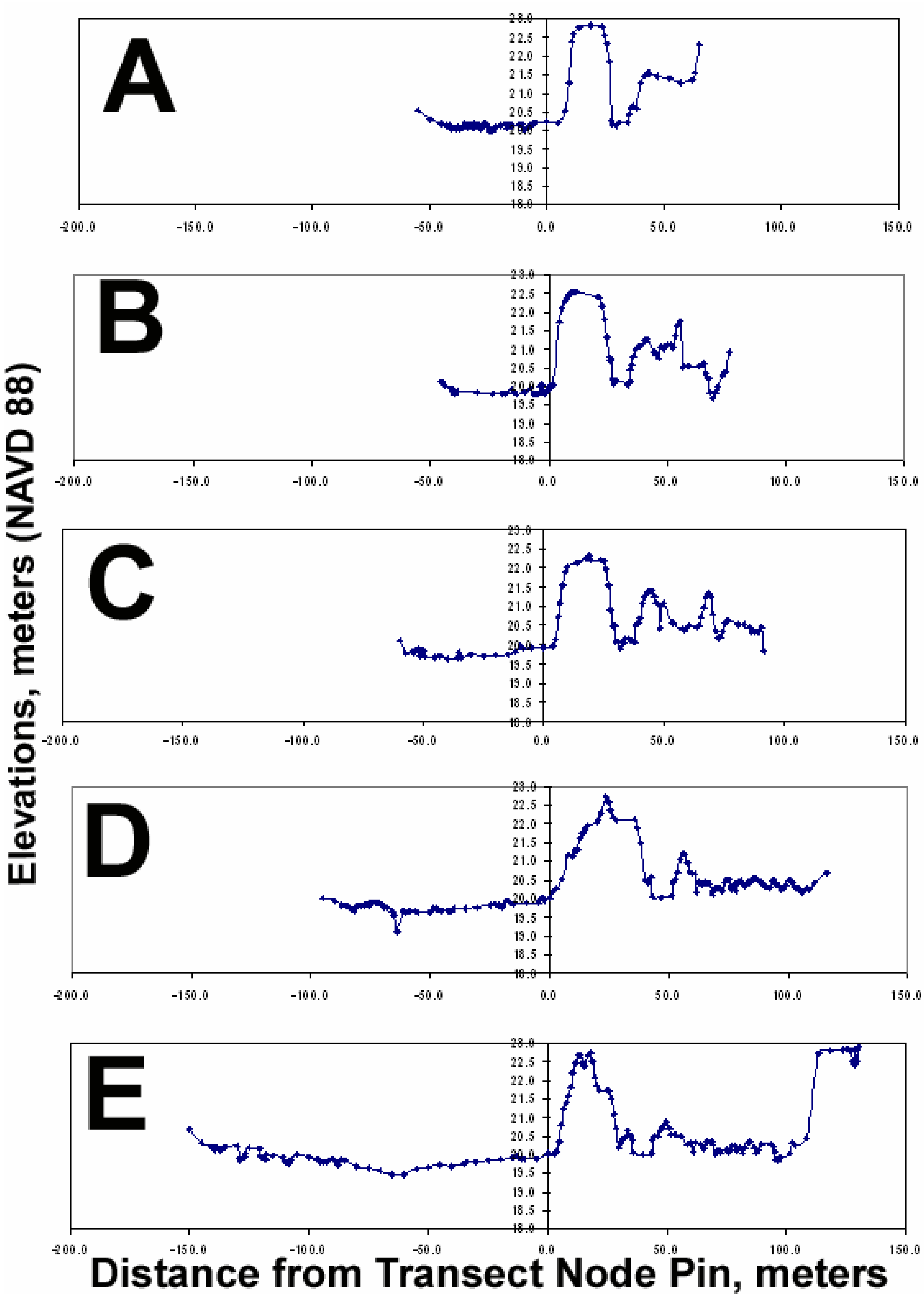
Soil elevations in the center of transects G and H, and to a lesser extent I and J, are higher than the majority of the area at the edge of these transects. The central area of transects G through J is the region where a majority of the water from Tumblin Creek travels and the region that would accrete the most sediment from the Tumblin Creek watershed.

The area west of the spoil pile on transects A through E, is not as impacted by sedimentation from Tumblin Creek. Much of these areas are characterized by consistently low elevation and small topographical relief. The elevation increases at the western upland edge and immediately adjacent to the spoil pile There are braided channels present at the upland edge of these transects but fewer channels are present in the central portion of transects A through F as there are in transects G through H.

Transects A through F east of the channel, are also less impacted by sediment input from Tumblin Creek than the downstream transects G through J. Elevations on these transects east of the channel are higher and the topographic relief is greater when compared to the same transects west of the spoil-pile except transect F. The elevation on Transect F east of the channel and sewer pipe, is comparable to the same transect west of the spoil-pile, indicating that a continuous basin likely occurred before channel dredging and sewer pipe installation.

An interpolation of the elevation surveys is shown in Figure 3-5. The spoil-pile is easily identified in varying shades of orange. East of the dredged channel is consistently higher elevation than west of the spoil-pile. There are a few pockets of lower elevation east of the channel, shown in light blue, which are immediately adjacent to land of similar elevation to the spoil-pile. As shown in the photograph from 1937, Figure 1-2, the original channel was present east of the channel that exists today. It is not known what kind of excavations or flood-control activities occurred in the delta prior to 1937 which could have raised the elevation.

West of the spoil pile consists of large areas of relatively low elevation which continues southward towards the lake. This low elevation area, is broken up by a circular zone of slightly higher elevation downstream of the dredged channel and a region of higher elevation to the east where the flows of Tumblin Creek have deposited sediment.


A
B
C
D
E
Elevations, meters (NAVD 88)
Distance from Transect Node Pin, meters
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
18.0
18.5
19.0
19.5
20.0
20.5
21.0
21.5
22.0
22.5
23.0

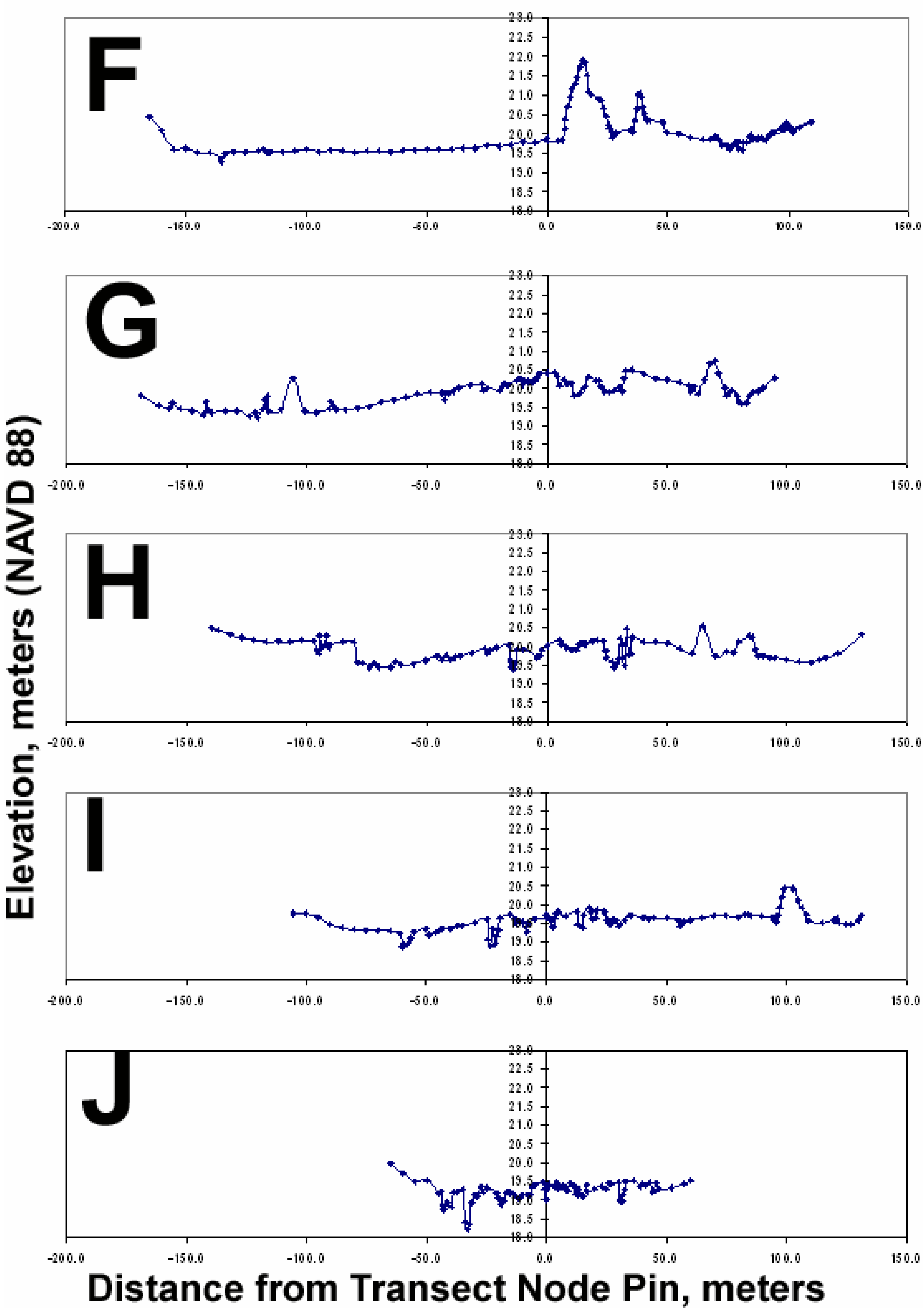


Figure 3-4. Elevation cross-sections of Transects A through J. All measurements are in meters. For the purposes of display, the graphs are skewed by 11:1.

This figure elucidates the circular sediment plume indicated by the higher elevation downstream of the dredged channel of Tumblin Creek. Due west of the end of the dredged channel is a lighter green region of higher elevation than the surroundings (20.3 to 20.8 meters). This corresponds to a flowpath that directs water west of the end of the dredged channel towards the region of low elevation. There are linear zones of increased elevation extending out from this circular region which correspond to some of the larger braided channels.

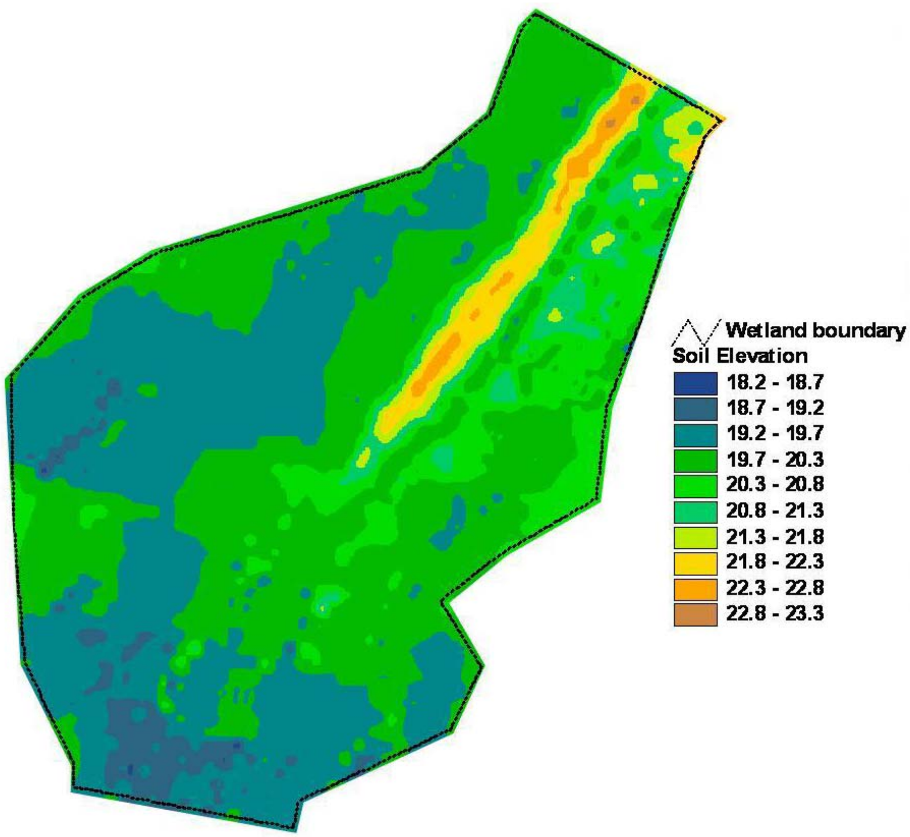


Figure 3-5. Interpolation of the elevation data in meters (NAVD88).

Sedimentation Timeline and Rate

Individual and average root flare elevations of the trees that were excavated are graphed along the surveyed transect in Figure 3-6. The three dominant species of trees surveyed had significantly different root-flare elevations. The average root-flare elevations of *Nyssa sylvatica var. biflora*, *Fraxinus profunda* and *Acer rubrum* were 19.12 ± 0.05 m, 19.61 ± 0.07 m and 20.05 ± 0.03 m respectively. The elevation difference between *Nyssa sylvatica var. biflora* and *Fraxinus profunda* was 49 cm. and the difference between *Fraxinus profunda* and *Acer rubrum* was 44 cm. The current average soil elevation along this transect was 20.17 m. Therefore, 1.05 meters of sediment had accumulated between the present day and the time period of the average age of the *Nyssa sylvatica var. biflora*.

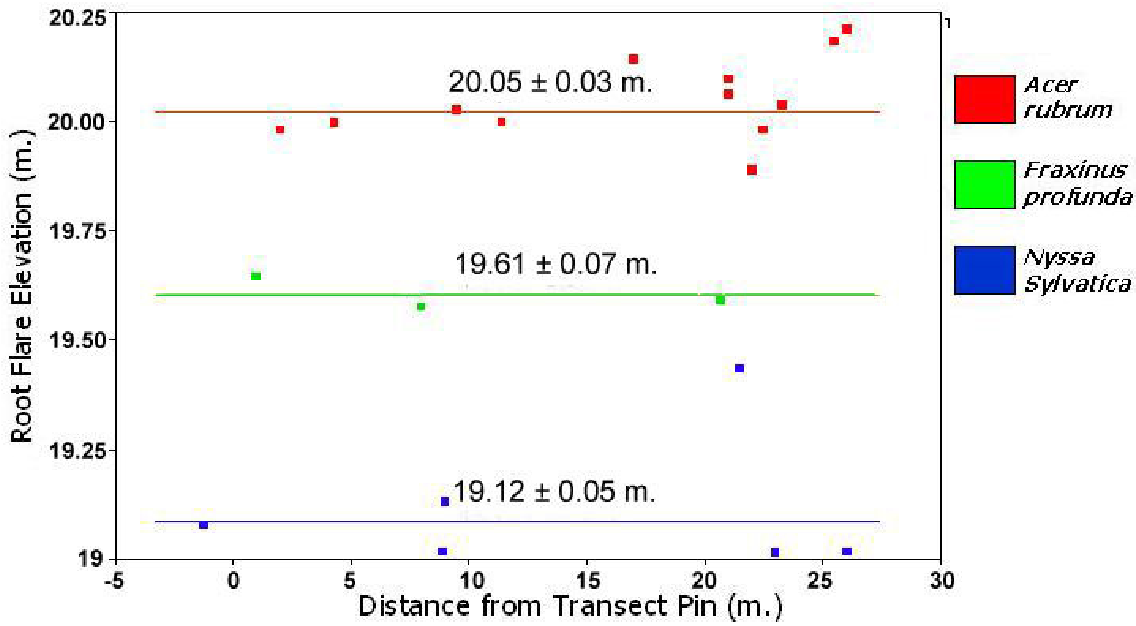


Figure 3-6. Individual and average elevations of the root flares of the three species of excavated trees along the transect.

Soil depth of the tree root flares are graphed against the age of the trees in Figure 3-7 along with a best fit line. The average age of the *Nyssa sylvatica var. biflora*, *Fraxinus profunda* and *Acer rubrum* was 121.7 ± 27.0, 69.7 ± 17.5 and 21.4 ± 8. Therefore an average of 1.05 meters of sediment had accumulated along this section of the transect in the past 121.7 ± 27.0 years. The best fit line indicates that approximately 125 years before present, the sediment accretion rate increased until about 30 years before present.

The slope of a derivative line through this time period indicated a sediment accretion rate of 1.51 cm/year. Since the 1970's (approximately 30 years ago) the sediment accretion rate in the region of the sediment plume appears to be decreasing as the best fit line indicates.

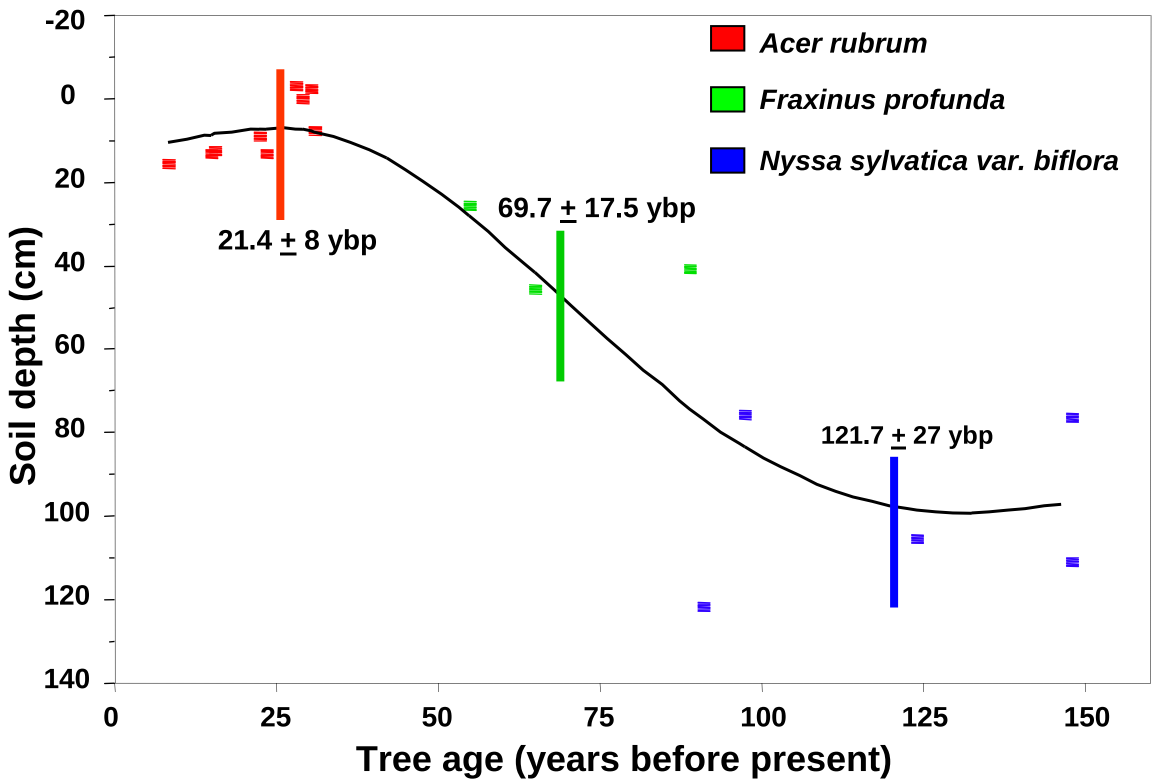


Figure 3-7. Tree root flare depth compared to tree age. Average age is shown in colored bars. The center of the colored bars is the average soil depth for the species. The line is a best-fit line drawn through the points.

Soil Physical Property Interpolations

Soil bulk density

Interpolation of the spatial sampling for soil bulk density is shown in Figure 3-8. The dredged channel and spoil-pile have some of the highest soil bulk densities of the delta. The bulk density downstream of the dredged channel all the way to the lake is higher than much of the surrounding area. Soils in the western portion of the delta generally have lower bulk density than much of the surroundings, with intermediate bulk densities at the northwestern portion of the delta and low bulk densities in the southwest portion of the delta.

There are three zones within the western portion of the delta that have higher bulk densities likely due to surface runoff into the delta. Due west of the terminus of the dredged channel is a zone with higher bulk density. This is the region where some of the stormflow is directed around the end of the berm and on occasion back to the north behind the berm. Immediately adjacent to the spoil-pile there is an area of increased bulk density possibly due to spill-over during previous maintenance dredging of the channel or erosion of the spoil-pile. The third zone of higher bulk density west of the delta is on the western edge of the delta which corresponds to a channelized input of storm water runoff.

The eastern edge of the delta consists of a linear zone of low to intermediate bulk density running parallel to the channel. This area runs just to the east of the sewer line and may represent higher organic matter accumulation in response to water impoundment or reduced erosion.

Soil organic matter content

Interpolated soil organic matter contents are inherently similar to the soil bulk density (Figure 2-9). The channel, spoil-pile and all the way downstream to the lake consist of low organic matter concentrations. The zone west of the spoil-pile has a higher organic matter content, which continues to the northern part of the delta and southward towards the lake. East of the delta the organic matter content is lower towards the northern portion of the delta and higher southward to the lake.

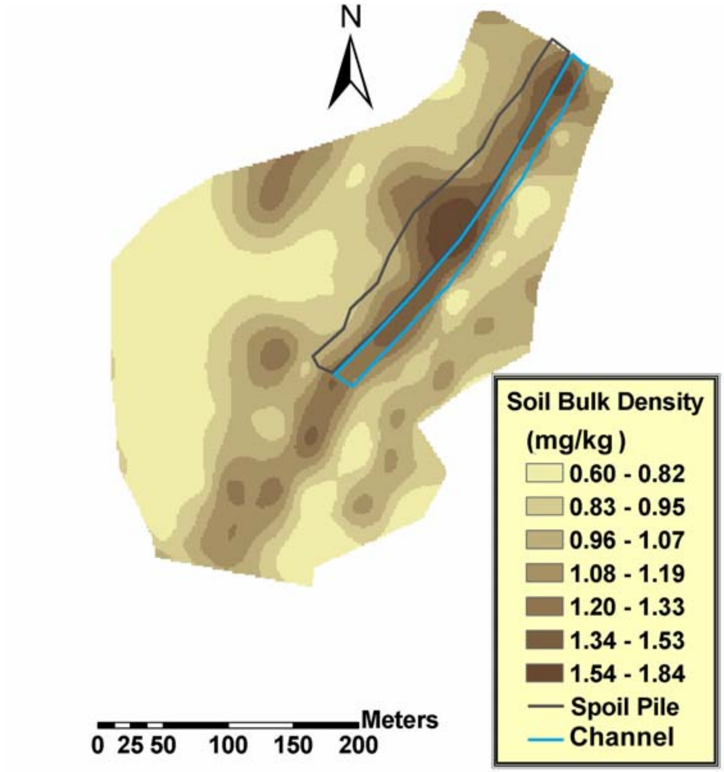


Figure 3-8. Interpolation of the soil bulk density measurements.

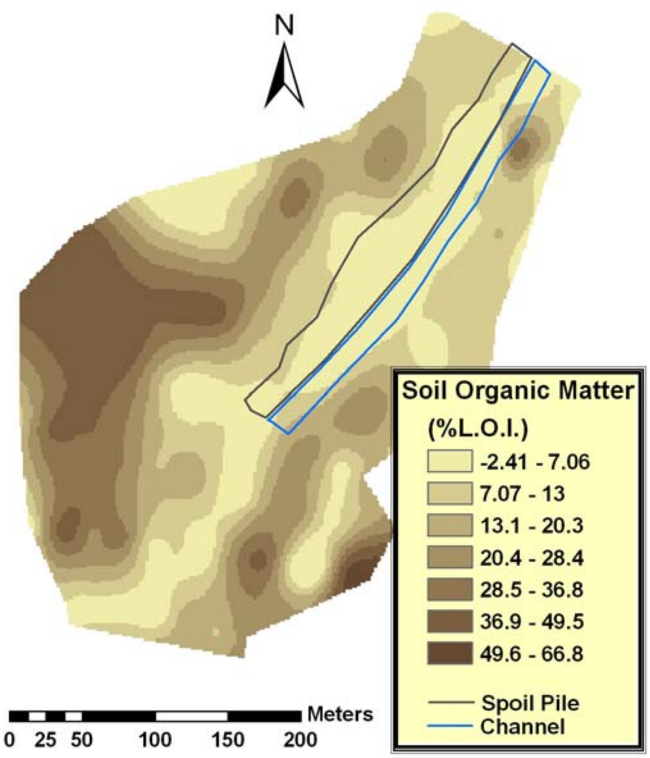


Figure 3-9. Interpolation of the soil organic matter content measurements.

Soil Chemical Interpolations

Soil phosphorus concentrations

An interpolation of the soil phosphorus content on an aerial basis at a consistent depth of 10 cm. is shown in Figure 3-10. The highest amount of soil phosphorus is west of the spoil-pile which continues partially northward and southward towards the lake. Within this region, the same three areas that had higher bulk density and organic matter content tend to have lower phosphorus. Downstream of the dredged channel towards the lake are soils with low to intermediate phosphorus content. Immediately east of the dredged channel and continuing slightly upstream is another region which has a higher concentration of soil phosphorus. In the Northeast corner of the delta is another region with higher soil P than the surroundings.

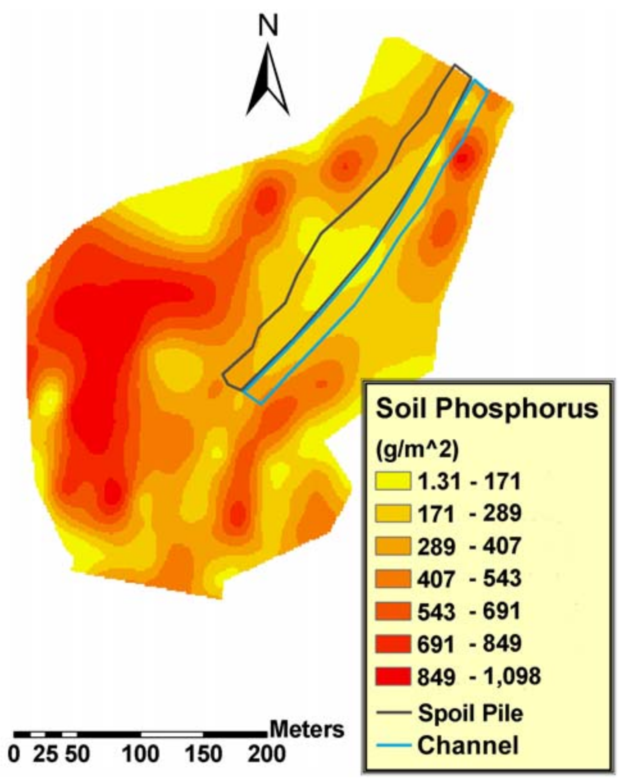
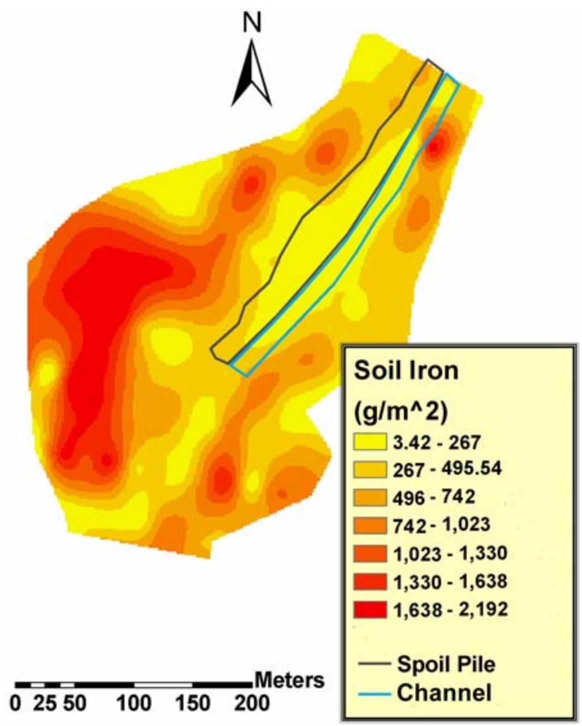


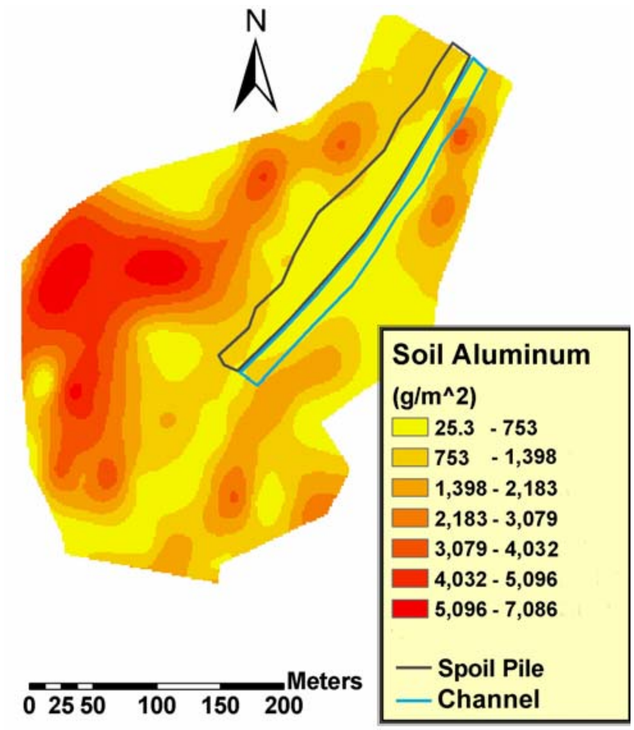
Figure 3-10. Interpolation of the soil phosphorus concentration measurements. Concentration is listed as mass of metal per surface area at a depth of 10 cm.

Soil iron and aluminum concentrations

Interpolated iron and aluminum content of the soil are shown in Figure 3-11. A large area of high iron and aluminum content exists in the western portion of the delta, corresponding to a zone of high concentration of soil phosphorus. High and intermediate Fe and Al contents also exist northward and southward from this western area. Relatively low concentrations of Fe and Al exist downstream of the channelized portion of the delta and southward towards the lake. The channel and spoil pile themselves also have lower concentrations of Fe and Al. East of the channel, downstream of the sewer pipe culvert exists a linear zone of intermediate Fe and Al concentrations. In the northeast portion of the delta exists two zones of higher Fe and Al content.



(a)

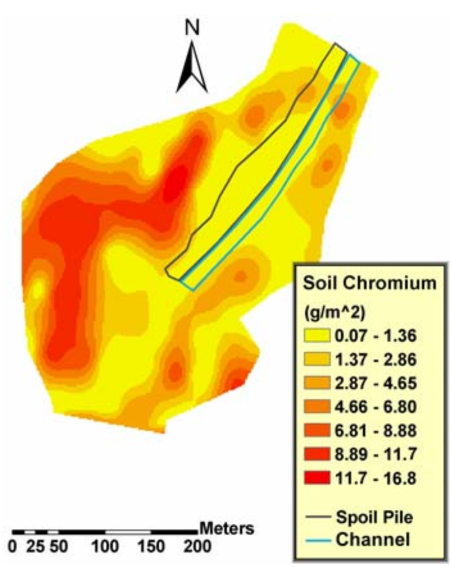


(b)

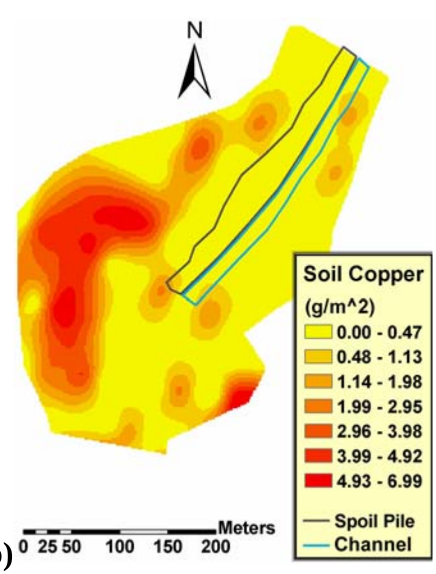
Figure 3-11. Interpolations of the soil (a) iron and (b) aluminum concentration measurements. Concentrations are listed as mass of metal per surface area at a depth of 10 cm.

Soil metal concentrations

Results of the soil survey for the metals Zn, Cu, Cr, Pb and Ni are shown in Figure 3-12.



(a)



(b)

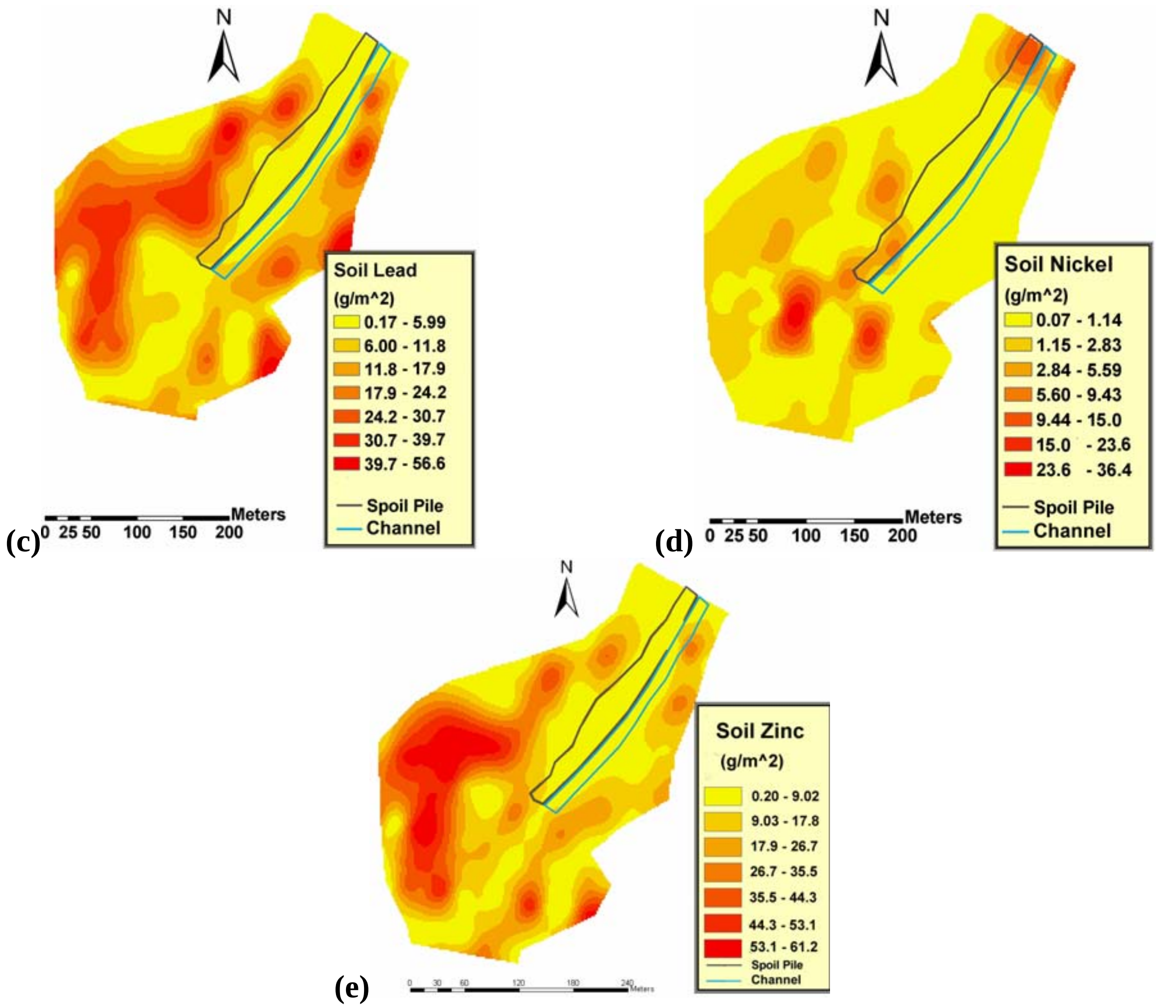


Figure 3-12. Interpolations of soil concentrations of (a)Chromium, (b)Copper, (c)Lead, (d)Nickel and (e)Zinc. Concentrations are listed as mass of metal per surface area at a depth of 10 cm.

Spatially, the concentration distribution of the various metals is similar. Consistently, the channel, spoil-pile and a path downstream towards the lake from the channel have relatively low concentrations. Higher concentrations of metals within the delta are primarily focused west of the spoil-pile. In each of the interpolations there is a small zone of lower concentration due west of the downstream portion of the channel. This zone is consistent with low organic matter content, high bulk density as well as low phosphorus, iron and aluminum concentrations. The zone east of the spoil-pile consists of low to intermediate concentrations of metals, with a linear zone of higher concentration consistently present south of the terminus of the channel. Interpolations of soil Ni concentrations diverge from the spatial trends found in the other soil metal concentrations and appear to be due to a more localized source.

Soil Phosphorus Isotherms

The four regions sampled for the phosphorus isotherms were previously shown in Figure 3-3. The state of equilibrium between the pore water and soils of these four regions is shown in Figure 3-13 along with the stormflow and base flow dissolved phosphate concentrations typically found in Tumblin Creek. The water column concentration where there is no net exchange between the soils and pore water is called the EPC_0 and is indicated in this figure as the x-axis intercept. Table 3-1 quantifies the EPC_0 of the four regions and predicted aerial mass of phosphorus exchange between soil and pore water during base flow and stormflow condition. Values for aerial mass are based on soils brought to complete equilibrium with the pore water. Flow rates of these four soil regions would be required to calculate a total mass of phosphorus export. The "West" soils had the lowest EPC_0 at 0.09 mg/l. The "Lake" soils had the second lowest EPC_0 at 0.22 mg/l, followed by the "Downstream" soils at 0.43 mg/l and finally the "North" soils at 0.52 mg/l. During base flow, all four of the soil regions are sources of phosphorus to the overlying water column based on inflow water concentrations in Tumblin Creek. The "West" soils would release a total of 0.2 g/m^3, the "Lake" soils 1.4 g/m^3, the "Downstream" soils 3.2 g/m^3 and the "North" soils 4.0 g/m^3 to reach equilibrium. During stormflow, the West-West region would be a sink of soluble reactive phosphorus, whereas the rest of the soils would continue to be a source. During a storm, the "West" region could retain up to 0.8 g/m^3 while the "Lake", "Downstream" and "West" soils release 0.3, 2.1 and 2.9 mg/m^3 respectively.

Results of the Langmuir model developed for the four regions based on multi-point isotherms and single point maximum sorption capacity are shown in Figure 3-14. This model provides an indication of the total number of P-sorption sites on a given soil. Through long-term P additions, P-sorption sites of a given soil become saturated and the soil can no longer sorb phosphorus unless some P is released or additional sorption sites are added. Once the soil becomes saturated with phosphorus no additional phosphorus is retained regardless of floodwater concentration.

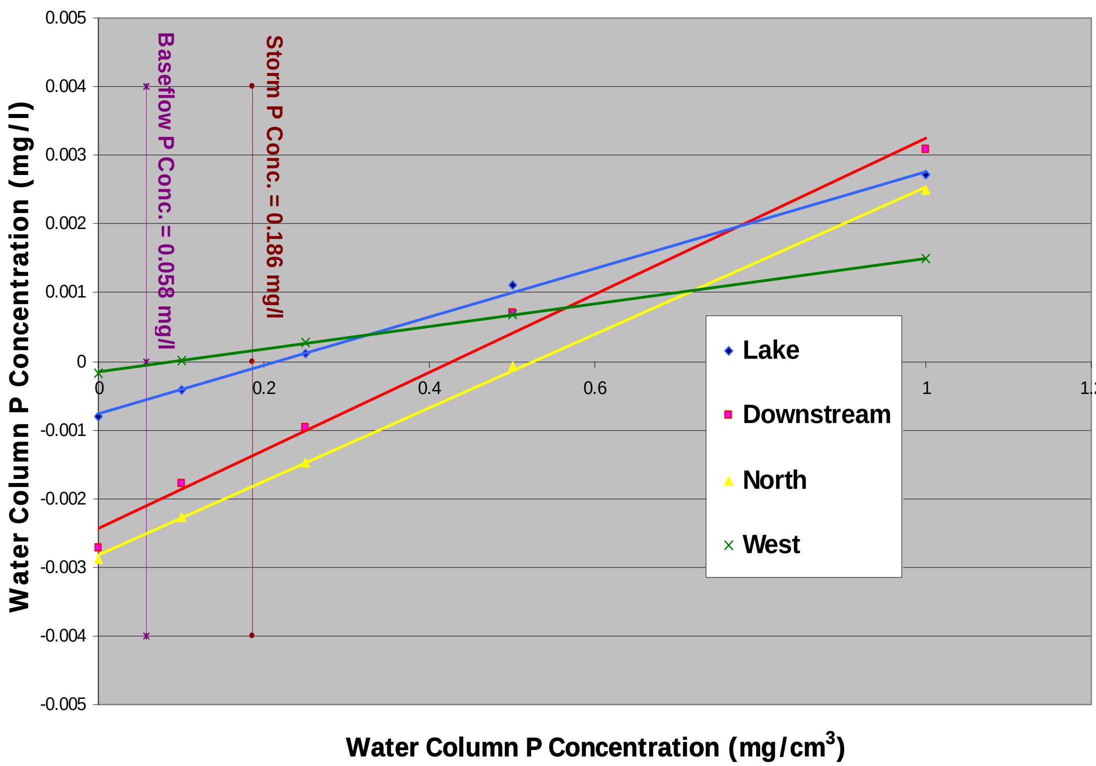


Figure 3-13. State of phosphorus equilibrium between the soil and water of four soils from the Tumblin Creek delta floodplain. The x-axis intercept of a given line represents the water column concentration where there is zero net P exchange between the soils and the water. Water column concentrations higher than the intercept represent net P sorption by soils and below the intercept, net P release from the soil region. Two relevant water column P concentrations are listed based on long-term samples collected in Tumblin Creek by the SJRWMD at state road 441.

Table 3-1. Porewater EPC_0 and the aerial mass of P exchange between the soils and water during base flow and stormflow based on multi-point isotherm results.

	Lake	Downstream	North	West
EPC_0 Value (mg/l)	0.23	0.42	0.52	0.13
Base flow P exchange (g/m^3)	-1.4	-3.2	-4.0	-0.2
Stormflow P exchange (g/m^3)	-0.3	-2.1	-2.9	0.8

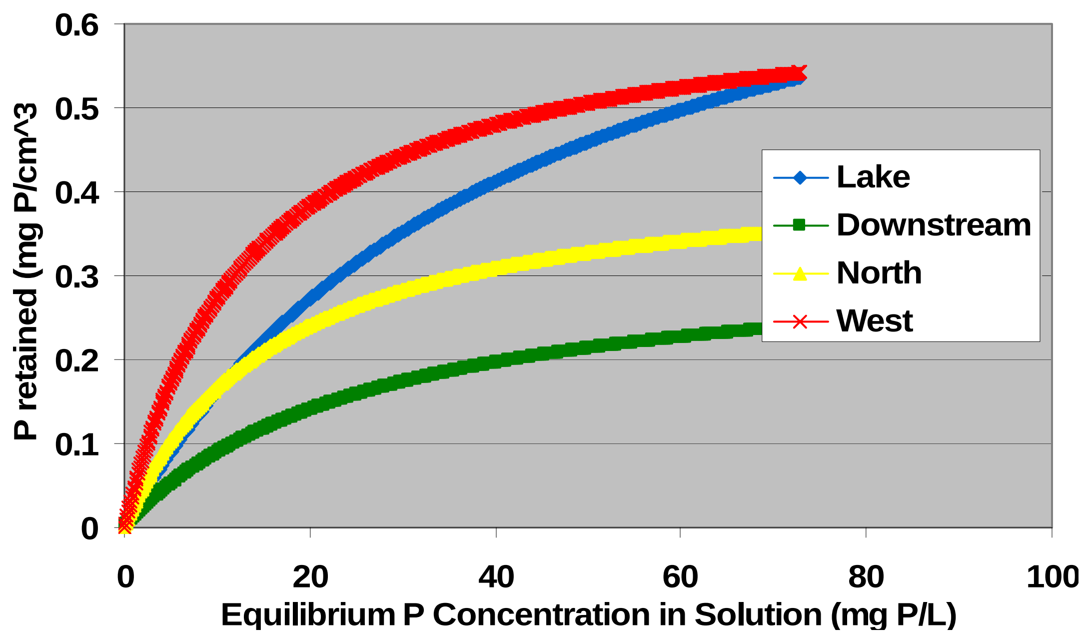


Figure 3-14. A Langmuir model of the four distinct soil regions over long-term Phosphorus loading.

The “West” and “Lake” soils have a similar maximum phosphorus sorption capacity. The “West” soils are more buffered towards phosphorus additions than the “Lake” soils or any other soils, as indicated by the initial slope of the line. This indicates that the “West” soils sorb more phosphorus to the soils per given increase in pore water P concentration than all other delta floodplain soils. The “North” soils have the second lowest maximum phosphorus sorptive capacity. Initially, phosphorus buffering capacity of the “North” soils is comparable to the “Lake” soils but there are less total P-sorption sites and the “North” soils would become saturated more quickly. The “Downstream” soils have the lowest P buffering capacity and the lowest total phosphorus sorption capacity.

Conclusions

Riparian wetlands possess unique characteristics within their soils and geomorphology that facilitate many functions which are beneficial to the protection of downstream water bodies. Modifications to the watersheds of these wetlands such as agricultural and urban land-uses can impart new soil and geomorphologic regimes that can impair the functions the wetland provides. An analysis of the physical and chemical properties of delta floodplain soils allows one to more clearly decipher the history of sedimentation in the region and the ensuing soil alterations. Objectives and statements addressed in this section included:

Objective 2: Assess the impacts of urban land-uses and channelization on the soils of delta floodplains.

- **Statement 1:** The soil elevation downstream of the dredged channels will be higher in elevation than surrounding regions.
- **Statement 2:** The net sediment accretion rate has increased in the time period of channel dredging and land-use changes.
- **Statement 3:** The soils downstream of the dredged channel to the lake will have low concentrations of phosphorus and metals, while regions of the delta floodplain composed of longer detention times will have higher soil concentrations of phosphorus and metals.
- **Statement 4:** Soluble phosphorus retention will be greatest where fine particles settle and lessened at the end of the channel where coarse particles settle.

The soil elevation cross-sections indicate that large areas of low elevation and low relief in the western portion of the delta have been partially or fully isolated from the flows of Tumblin Creek. Tumblin Creek currently enters the delta floodplain forest downstream of the dredged channel and enters a series of well-defined braided channels.

Braided channels are not as prevalent in this western region currently isolated by the spoil-pile. This western portion of the delta has a shallow flow regime through saturated soils with a few small, discrete channels that is likely similar to the flow regime before anthropogenic disturbances. Immediately downstream of the channel and spoil-pile, coarse sediments have accumulated raising the soil elevation as indicated in Statement 1 which asserts:

- **Statement 1:** The soil elevation downstream of the dredged channels will be higher in elevation than surrounding regions.

Sediment accretion is an inherent feature of floodplain and delta areas as previously confined flows are dispersed over larger areas. Excavation of tree root flares in the region downstream of the channel has indicated an increase in the sediment accretion rate from roughly zero to 1.5 cm/yr, which confirms statement 2 which asserts:

- **Statement 2:** The net sediment accretion rate has increased in the time period of channel dredging and land-use changes.

Realistically, the increase in the rate of sediment accretion would not occur in a straight line as indicated in Figure 3-7. Instead much of the sediment accumulation would be driven by larger events including agricultural land-clearing, channel dredging and more recently urbanization. Therefore, the soil elevation within the delta would most likely increase as a series of stair-steps correlating to these large events as shown in Figure 3-15. Agricultural land clearing and the ensuing sediment export appears to have increased the soil level of the sampled portion of the delta beginning 125 years ago. It is likely that the increased sediment export due to agriculture deposited throughout the entire delta. Channel dredging, which occurred between 48 and 55 years ago, has focused increased sediment loads to the area between the end of the channel and the lake rather than the entire delta floodplain. During this time frame soil elevation increase altered hydraulic characteristics of the site and facilitated the replacement of the obligate species *Fraxinus profunda* and *Nyssa sylvatica var. biflora* to the facultative species *Acer rubrum*. The sediment accretion rate continued to increase in this region until about 30 years ago and now appears to be stabilizing or possibly even eroding or subsiding today. Further data would need to be collected to correct for the inherent variance and determine if the net sediment accretion rate in this area was actually decreasing

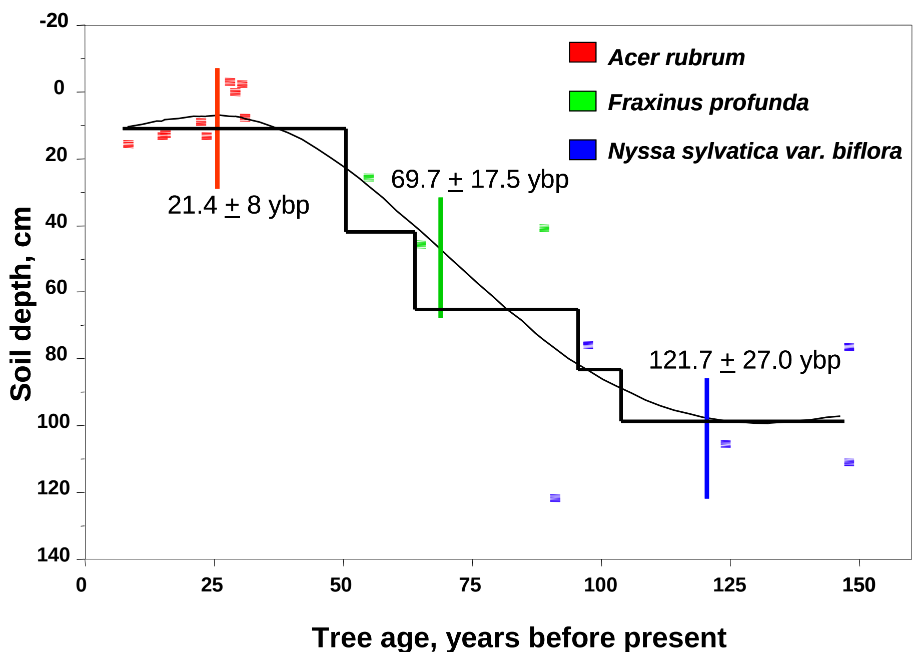


Figure 3-15. A timeline of sedimentation indicating the stair-step nature of sediment accretion.

Increases in flow velocity, volume and storm frequency in the impervious urbanized watershed has incised channels through this focused zone of sediment accumulation. The combination of an elevation increase as a result of sediment accretion and erosion of the channels during high energy storm events have facilitated the formation of well-defined channels with steep banks that carry a majority of the flows of Tumblin Creek directly to Bivens Arm Lake bypassing much of the delta.

The distribution and concentration gradients observed within soil surveys provide further indicators about the deposition/erosion characteristics of the delta. As discussed in Chapter 2, the majority of the suspended sediment by mass is composed of large sand-sized particles. Furthermore, there is an inverse relationship between particle size and phosphorus and metal concentration. The soil surveys indicate that downstream of the dredged channel is a zone of low phosphorus and low metal concentrations which corresponds to the deposition of larger less reactive particles. This region also has low organic matter content and a correspondingly high bulk density. The low organic matter content of this region is likely attributed to well drained sandy soils, incised channels present in this region, and possible translocation of litter during stormflows. This soil composition continues from the end of the dredged channel all the way to the edge of the delta. Therefore this study supports Statement 3, which asserts:

- **Statement 3:** The soils downstream of the dredged channel to the lake will have low concentrations of phosphorus and metals, while regions of the delta floodplain composed of longer detention times will have higher soil concentrations of phosphorus and metals.

When storm events exceed a certain volume, a significant portion of the flow is directed due west at the end of the dredged channel to areas of lower elevation west of the sediment plume. This has facilitated a new lobe of sand-sized sediment to deposit due west of the channel as evidenced in the soil concentration surveys. Although the tree root flare excavations tended to indicate that the sediment accretion rate was stabilizing in the sampled region south of the channel, much of the sediment may be getting redirected and depositing west of the end of the channel. This process of flow migration around raised elevation sediment depositions zones can be evidenced in the photograph from 1956 (Figure 1-4). This photograph indicates that a sediment plume had formed southeast of the end of the dredged channel. Today much of the flows and the resultant sediment plume are directed west of that original sediment plume and appear to be moving further westward. Therefore, it is not completely clear sedimentation in the delta is actually stabilizing as indicated by root-flare observations or if sediments are just being redirected as indicated by soil characteristics.

Beyond this newly emerging sediment plume, west of the end of the dredged channel, there is a large region of low bulk density, high organic matter content and high phosphorus and metal contents. This region is of low relief and lower elevation that facilitates dispersed sheet-flow and fine particle deposition. This area receives surface water inputs from parking lots and small agricultural operations to the west, but also much of the flows of Tumblin Creek are directed around the spoil-pile into this low elevation area during high flow events. There is one significant inflow in this western portion of the delta that also has base flow between storm events. During storms, this inflow has created its own sediment plume of larger particles midway up the western edge of the delta boundary as evidenced by soil surveys which indicates a higher bulk density. Beyond the sediment plume of both inflow from the western edge of the delta and Tumblin Creek, lies the region of high soil concentration of phosphorus and metals. This region has low bulk density and a high organic matter content, which combined with the lack of topographic relief, implies that it drains very slowly. Therefore due to the longer detention time of this region, it has become a settling area for the finer particles from both inflows, which has enriched the soil concentrations in phosphorus and metals. Therefore this study supports Statement 3 in full, which asserts:

- **Statement 3:** The soils downstream of the dredged channel to the lake will have low concentrations of phosphorus and metals, while regions of

> the delta floodplain composed of longer detention times will have higher soil concentrations of phosphorus and metals.

The main channel of Tumblin creek flows over Miocene deposits of the Hawthorn Group, which are often composed of clays and phosphates (Scott 1988). Incising of Tumblin Creek in the watershed, through the Hawthorn group, has been exacerbated by an increase in creek velocity facilitating scour and bank instabilities. In addition to high concentrations of phosphorus, this region of the Hawthorn group also has very high concentrations of Fe and Al. This most likely explains the extremely high concentrations of P, Fe and Al found within the soils of the Tumblin Creek delta floodplain. Hawthorn erosion within the stream bank combined with fine particle mobility throughout the watershed has enriched this western portion of the delta with finer particles bearing higher concentrations of metals and phosphorus. This region is the only area within the delta with a sufficient detention time to settle the finer particles from Tumblin Creek which contain higher concentrations of phosphorus and metals. The predominant flow path of Tumblin Creek, which flows straight to the lake, has too much energy to remove these fine particles within the delta as evidenced by the soil surveys.

Although particulate phosphorus retention relies primarily on hydrologic and geomorphologic characteristics of the receiving water body, soluble phosphorus retention in the soils depends on physical and chemical characteristics of the soils and the water column concentration of dissolved phosphorus. Floodplain surface soils are unique in that they are constantly being replaced by suspended sediment which are translocated from within the floodplain and imported to the floodplain from the watershed and creek systems. Differential distribution of sediment with regard to particle size as well as total volume of sediment has modified the phosphorus retention capabilities of the surface soils. Therefore this study supports Statement 4, which asserts:

- **Statement 4:** Soluble phosphorus retention will be greatest where fine particles settle and lessened at the end of the channel where coarse particles settle.

Soils in the western portion of the delta, composed of finer particles with the highest concentrations of soil phosphorus, were the least likely to release dissolved phosphorus within the typical range of water column phosphorus entering the delta. Secondarily, these soils had the most rapid uptake capacity for phosphorus and the highest maximum P retention. This indicates that enrichment of the delta soils with fine particles containing high concentrations of particulate phosphorus and associated sorption sites is a relatively stable process. Although during base flow conditions every one of the soil regions was a net source of phosphorus, this western portion of the delta was a net sink of phosphorus during storm events when most of the phosphorus loading occurs. Also, at equilibrium conditions, these western soils are a larger sink during the higher volume storm flow than they are a source during the low volume base flow.

Soils closest to the lake also show characteristics of a region composed of finer particles. Although these lake soils were a net source of dissolved phosphorus to the water column at equilibrium during both base flow and stormflow, their ability to retain phosphorus at varying water column concentrations most closely resembles the soils of the western region. These soils were sampled where soil phosphorus concentrations were comparable to the western region. This indicates that fine particle settling is occurring outside of the delta beyond the extensive sand plume or that these soils are enriched from lakeward inputs as this region is hydrologically contiguous with the lake.

Soils of the delta immediately downstream of the dredged channel are composed mostly of unreactive sands. These soils are a large source of dissolved phosphorus during base flow and storm flow as compared to the lake and western soils. Similarly these soils reached phosphorus saturation more rapidly than any other soil region of the delta and had the lowest phosphorus buffering capacity. During storm events it is likely that this sediment plume region is a net P sink for total phosphorus (SRP and particulate) but during baseflow or the later part of storm events, P release from these soils becomes a significant source of dissolved and bioavailable P to the water column and lake.

Soils in the northwest corner of the delta had unique isotherm results indicating a unique soil composition. The soils of this region had the highest concentration of easily desorbable phosphorus yet the second lowest maximum phosphorus sorption capacity. Part of this soil region is composed of the deepwater basin west of the spoil-pile and most likely accumulates fine particles from Tumblin Creek backflow around the spoil-pile. Some soils in this region have a higher elevation and intermediate concentrations of phosphorus and metals attesting to a lack of fine particle accumulation. Furthermore, soils in this portion of the delta have been historically modified in ways which are not completely understood. Firstly, as is shown in the aerial photographs from 1937 to 1961 (Figures 1-2, 1-3, 1-4 and 1-5), land clearing has occurred in this portion of the delta due to agricultural encroachment. It is not known what excavations occurred, or whether fertilizer was applied to this area to modify the soils. Secondly, it is possible that portions of the soils of this region are composed of eroded material from the adjacent spoil-pile. Excavation of the spoil-pile from the creek may have included phosphatic deposits which occur in Hawthorne geology as discussed above. Ultimately, isotherm results in this region suggest that reflooding of these soils by removal of the spoil-pile would release higher concentrations of phosphorus to the water column than the present flow regime.

Urbanization and agricultural land use have imported increased sediment loads to the delta floodplain that had raised the elevation and decreased the hydroperiod as channels had incised through this sediment plume. A decrease in hydroperiod limits the amount of fine particles which settle within the delta and facilitates settling to occur in downstream areas. The fine particles have higher dissolved phosphorus sorption potential and contain the highest concentrations of particulate phosphorus and metals. In impacted watersheds, the export of larger particles covers the soil surface and alters the hydrology so as to limit fine particle enrichment of the delta. Stabilization of flows and streams to limit the export of unreactive larger particles before entering the delta is essential to maintain soil composition and also long-term functioning of the delta.

CHAPTER 4
CONCLUSIONS AND CONCEPTUAL RESTORATION RECOMMENDATIONS

Conclusions

Modifications to the Tumblin Creek delta floodplain caused by land-use changes and channelization have altered vegetation, hydrology, water quality and soil composition. These modifications have impaired the function of the delta with regard to the retention of nutrients, particulate matter and trace metals. Maintaining the current watershed condition and channelization within the delta will likely continue to degrade functional benefits that the delta can provide. Implementation of upstream stormwater Best Management Practices and restoration of impacted areas within the delta will improve conditions and at least partially restore the inherent functionality of the delta.

Stormwater Characterization and Baseflow Water Quality Condition

The particles which are currently entering the delta in the stormflows are predominantly composed of rapidly settling particles. Therefore this study supports the first statement in Objective 1, which asserts:

- **Statement 1:** The majority of suspended sediment (by mass) transported to the Tumblin Creek delta floodplain are composed of coarse particles.

This finding helps to explain the significant sediment accretion of almost pure sands immediately downstream of the dredged channel. The course sediments also explain why there is a relatively localized sediment plume near the end of the channelized portion of Tumblin Creek, although it is apparent that this plume area is becoming incised by secondary flow channels and is being redistributed further into the delta. There is also a significant mass of finer particles which require longer settling periods and were found to be distributed in areas of the delta that are furthest away from input sources and in areas with the lowest elevation and longest duration of flooding.

Finer particles, which have a larger surface area to volume ratio, were found to contain higher concentrations of phosphorus, aluminum, chromium, copper, iron, nickel, lead and zinc than larger sand size particles. These findings supported Statement 2 of the first objective, which asserts:

- **Statement 2:** Particles that require longer to settle will have higher concentrations of phosphorus and metals.

In addition, a detention time of two hours would remove 92% of the particulate phosphorus and a range of 83-98% of metals from the water column. A detention time of one minute would remove 50% of the particulate phosphorus and a range of 21 to 49% of the trace metals sampled.

One of the beneficial water quality functions of a delta is their ability to at least initially trap a significant fraction of the suspended particulate matter and associated nutrients which occur during storm events. Deposition of particles can initially occur as turbulent flows entering the delta are slowed and energy in the water column is reduced. The effectiveness of the delta to retain particulate matter and nutrients is dependant on detention time and maximum contact area between floodwater and soils. In the Tumblin Creek delta floodplain, both of these factors have been impaired due to channelization and secondary channel formation within the sediment plume. Turbulence of the flow regime in this portion of the delta facilitates re-suspension of sediments and nutrients that are then likely exported to Bivens Arm Lake. The resuspension that occurs in this region is likely due to the high volume, rapid flow rate from the urban watershed, the confinement of flow in channels and the unconsolidated nature of the soils in this region. In the western portion of the delta, where longer detention times exist and high velocity flows have not yet become a factor, fine particle sediment deposition is occurring as confirmed by soil survey findings identified by higher concentrations of phosphorus and nitrogen in this region. These results support Objective 1, Statement 3, which asserts:

- **Statement 3:** Regions of the delta floodplain where sheetflows exist will retain more phosphorus, nitrogen and particulate matter than areas where incised channels exist.

Effects of Urbanization on Delta Floodplain Soil Characteristics

The region downstream of the dredged channel consisted of a zone of higher elevation than the surrounding areas. The data collected in this study confirms objective 2, Statement 1 which asserts:

- **Statement 1:** The soil elevation downstream of the dredged channels will be higher in elevation than surrounding regions.

The sediment mound was indicated by an elongated plume extending downstream from the end of the dredged channel in the elevation interpolations. Elevation cross-sections indicated higher elevation in the center of transects where Tumblin Creeks is restricted by the channel or within the plume by incised flow channels, but lower elevations at the edge of the transects. This cross section profile suggests that elevation increases were caused by sediments entering the delta from the main Tumblin Creek channel.

Historically, baseline sediment accretion rate downstream of the dredged channel appeared to be relatively balanced between erosion and deposition or at a relatively slow rate of accretion. Findings from this study suggest that the sediment accretion rate has increased appreciably over the past 100 years or during the period of agricultural and urban land-use change. These results support Statement two of objective two, which asserts:

- **Statement 2:** The net sediment accretion rate has increased in the time period of channel dredging and land-use changes.

Agricultural land-use involves major vegetation removal, soil disturbance and a loss of vegetated buffer areas surrounding Tumblin Creek. Over many years, the agricultural watershed exported a layer of sediment over a large area of the Tumblin Creek delta floodplain. Urban land-uses replaced un-vegetated agricultural fields with impervious surfaces and often limited vegetated riparian areas. This development of the watershed continued a net positive sediment accretion rate. After channel excavation, sediment accretion differentially increased the soil level of the specific region downstream of the channel. It is likely that the rate of soil level increase sped up during periods of watershed and delta disturbance, creating stair-step increases in soil level. The first large soil elevation increase was due to agricultural land-use, which contributed to the replacement of *Nyssa sylvatica var. biflora* with the *Fraxinus profunda*. Dredging of the channel through the delta, which directed the primary sedimentation delta to this region, likely caused additional incremental increases in elevation causing a further shift in species age class recruitment from obligate tree species *Fraxinus profunda* to *Acer rubrum* a facultative species.

This study tentatively indicates that the net sediment accretion rate of the delta appears to have returned to a baseline level or possibly even entered into a slight erosional/redistribution phase. Further data would be needed to correct for the inherent variability to prove that the net sediment accretion rate was actually decreasing. If the sediment accretion rate is decreasing, this indicates that either the urbanized watershed has stabilized with regard to landscape erosion or stream incising and therefore is not exporting significant quantities of sediment, or that sediment is currently being redirected to a new region to form a new sediment plume. Further investigation is required to determine which of these two explanations is more likely.

Soils of the region that have been restricted by channelization, or soils within the sediment plume, indicate a deposition of predominantly coarse sediments with relatively low phosphorus and metal concentrations. The portion of the delta not directly impacted by high sediment loads and channelization has sufficient detention time to remove the finer particles. Therefore, Objective 2, Statement 3 is supported by findings from this study, which asserts:

- **Statement 3:** The soils downstream of the dredged channel to the lake will have low concentrations of phosphorus and metals, while regions of the delta floodplain composed of longer detention times will have higher soil concentrations of phosphorus and metals.

Increasing watershed impermeability and channel confinement that occurs in urban watersheds causes stormwater runoff energy to increase. This increase in energy facilitates export of less mobile coarse particles to the Tumblin Creek delta floodplain. Secondarily, greater volumes of runoff increase stream velocity and can cause incising of channels within the watershed as well as through the sediment plume within the delta. The combination of an anthropogenically dredged channel and the formation of incised flow channels within the sedimentation plume have decreased the detention time of the delta and short-circuited much of the flows directly to the lake. The current flow regime has exacerbated sediment, phosphorus and metal export to Bivens Arm Lake which at least partially explains the high concentrations of metals found in the lake and nutrient inputs linked to the lakes eutrophication.

The widespread deposition of coarse particles throughout the delta has impaired the ability of the soils to retain soluble forms of phosphorus from the water column. Soils downstream of the dredged channel were found to be a consistent net source of soluble phosphorus to the water column under both baseflow and stormflow conditions. In contrast, fine textured soils deposited in the western delta were found to retain soluble phosphorus more effectively than the coarse particles. These data supports Objective 2, Statement 4, which asserts:

- **Statement 4:** Soluble phosphorus retention will be greatest where fine particles settle and lessened at the end of the channel where coarse particles settle.

Therefore, although the deposition of fine particles in the delta creates soils of high phosphorus concentration, this does not necessarily indicate an increased mobility of that phosphorus from the sediments. High surface area to volume ratios of finer sediments and higher metal concentrations associated with phosphorus sorption sites provide an increased sorptive capacity and long-term retention capacity of these soils. The continued import of high loads of coarse sediments due to watershed changes and delta channelization will continue to replace the soil surface with coarse particles and reduce the potential for soluble phosphorus retention within the delta before entering Bivens Arm Lake. For these reasons, implementation of best management practices within the watershed and restoration of the channel and spoil pile berm within the delta are recommended to improve wetland function and thereby water quality entering Bivens Arm Lake.

Conceptual Restoration Plans

Urbanization of the Tumblin Creek watershed and hydrological modifications to the delta itself have resulted in significant changes in soil elevation and reduced the capacity of the delta to improve water quality and retain fine sediments. Significant amounts of course particle sedimentation is occurring in the delta, providing improvements in suspended sediment water quality. Deposition of this easily settled particulate fraction within the delta has decreased the ability of the delta to retain finer textured particles and causes short circuiting of flows directly to Bivens Arm Lake. These impacts have modified delta soils, water, hydrology, geomorphology and vegetation. Several restoration scenarios are possible that can remediate for the aforementioned modifications and restore at least part of the functionality of the delta.

Coarse soils exported from the watershed are all directed and confined to deposit in the delta at the very bottom of this urbanized system. The large amount of coarse soils that have accumulated have raised the elevation in parts of the delta facilitating species succession, reduced detention time which has decreased sediment and nutrient retention and lessened the ability of the delta to retain soluble phosphorus. Stabilization and/or removal of the coarse sediments in the creek water column before entering the delta would reduce the impacts to the delta and improve water quality to Bivens Arm Lake. As mentioned previously, coarse particle settling would remove approximately 50% of the phosphorus and significant portions of the trace metals in stormwater. Source control of sediments is the most desirable approach to reduce sediment loading. However, the source of sediments in an urban watershed may not be from surface erosion of the landscape, but instead due to incising, bed scour and bank erosion of the stormwater conveyance channels due to the increased velocity of water in these creeks. To reduce this source of sedimentation, one large or many small stormwater basins upstream of the delta would be required to reach a new equilibrium within the stormwater conveyance channels so that additional soil erosion is minimized. Stabilization of the runoff flashiness of the watershed might also be achieved through increased watershed permeability, vegetated buffer zones and channel maintenance. However, retrofitting a highly developed watershed is often logistically difficult let alone costly; therefore integrating a sedimentation basin upstream of the delta is probably the more feasible option to include as part of any restoration plan.

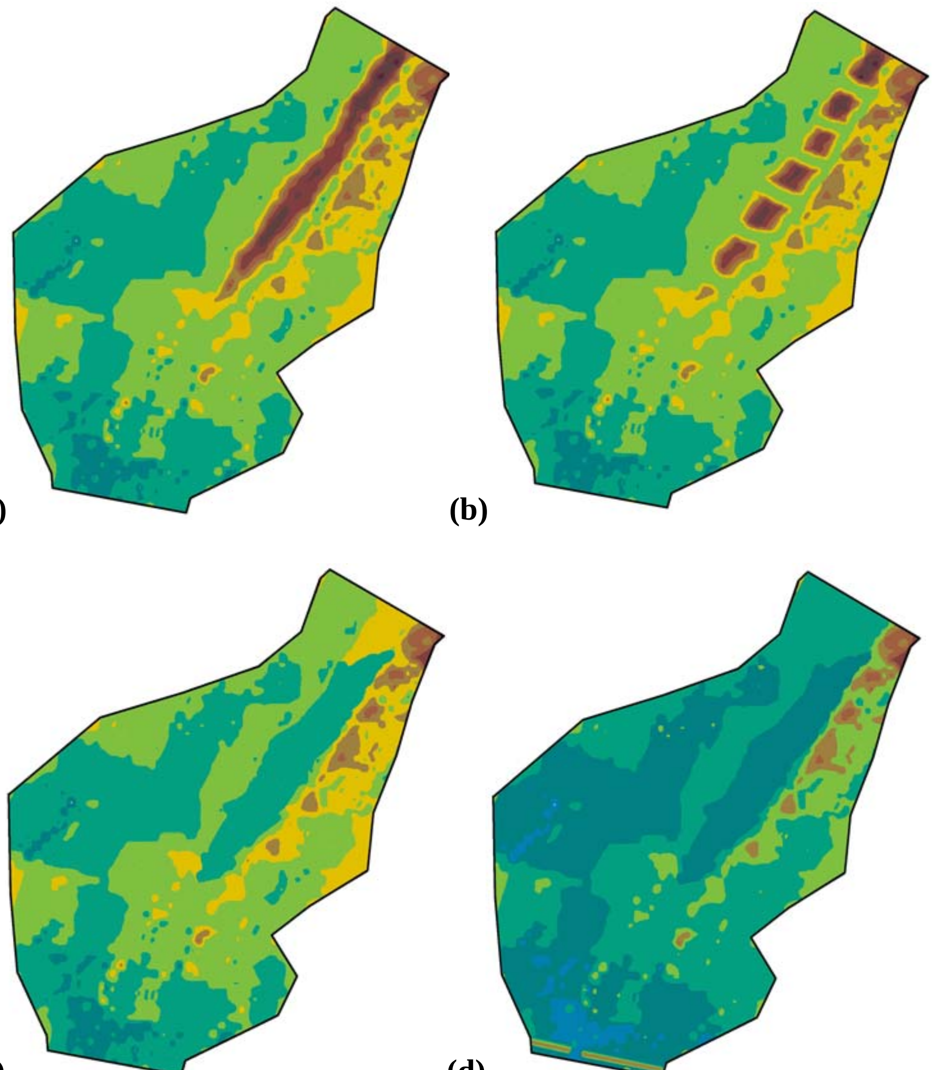
Although the removal of coarse materials is an essential portion of any restoration plan, full restoration would not be complete without modifications to increase the detention time of the delta. A combination of a pre-existing coarse matter removal mechanism and an increased detention time of the delta would facilitate the deposition of fine particulate matter throughout the delta. A longer, less confined and therefore less turbulent flowpath would improve the deltas ability to retain a majority of the particulate phosphorus, nitrogen and particulate matter. The increase in flooding duration would also facilitate prolonged anaerobic conditions, allowing for organic soils development and persistence of obligate wetland species.

Four restoration scenarios are presented with varying degrees of cost, complexity and expected effectiveness (Figure 4-1). The current state of the delta has a confined channel which bisects the delta for approximately 300 meters, while hydrologically isolating large areas (Figure 4-1a). Coarse textured sediment deposition primarily occurs downstream of the dredged channel in the center of the delta and fine textured sedimentation occurs in the western portion of the delta. All of the conceptual restoration ideas are predicated on the inclusion of an upstream sedimentation basin that will remove the course particulate fraction of storm flow suspended sediments. If this component of a treatment train is not implemented, any restoration efforts within the delta will be short lived or futile due to the rapid sedimentation that will likely occur.

The least intrusive intervention would be to perforate the spoil-pile within the delta using surface ditch connections, low water crossings or buried culverts. This effort would hydrologically reconnect the creek to the isolated portion of the delta (Figure 4-1b). This scenario would cost less than total spoil-pile removal and maintain upland vegetated islands within the delta. The detention time and delta area would be increased so as to facilitate the deposition of fine sediments downstream. Soil isotherm data from this area indicated an initial flux of dissolved P; however, it is expected that sediments in this area will in time become composed of fine soils similar to those along the western region of the delta or adjacent to the lake and therefore become a sink of water column dissolved P.

Full spoil-pile removal would be more costly but more effective than perforations (Figure 4-1c). It is assumed that the source of the spoil-pile is from creek sediments excavated during channel maintenance activities and deposited within the delta instead of being trucked out to minimize costs. Volume estimates for the berm are 12,718 m^3 based on an approximation of the historic delta to the east and west of the spoil-pile. This would bring 1.9 acres of the delta back to near pre-disturbance elevations and allow for the vegetative recruitment and restoration of this area as a wetland. Any residual coarse sediment making it to the delta would be deposited to the farthest upstream portion of the delta with fines depositing further downstream as would have occurred historically.

The last restoration scenario proposed combines complete spoil-pile removal with a weir to increase water depth (Figure 4-1d). The weir would be placed in a downstream portion of the delta that is partially constricted by naturally higher elevations to the east and west. The placement of this weir would ensure that floodwaters are retained in the delta for an extended amount of time necessary to remove particulates in the 2 hour settling time fraction. This would result in near complete mass removal of nutrients and metals before entering the lake. This restoration scenario would also raise the water depth within the sediment plume downstream of the dredged channel and increase hydroperiod of this region. This is the only scenario where restoration of the spoil pile region to the historic vegetative community might be possible. Due to the increase in elevation of this area by almost one meter, any diversion upstream of flows to the west of the pile will further decrease the duration and frequency of flooding in this area. As a result further shifts in vegetative composition are likely to occur. Removal of sediment in the spoil pile area may do more damage to the existing system then benefit. Therefore raising the water level in this area using a downstream weir is the only mechanism identified that will restore hydrophytic vegetation and surface-soil saturation in the area of the spoil pile. In each of the other restoration scenarios this region would act as an island with flows distributed around it. This would be the most costly restoration scenario and likely the most controversial. This scenario may fail over an extended time period as bed-flow and sediment migration within upstream parts of the delta are stopped and backed up behind the weir. This would create a raised elevation zone upstream of the weir indicating sediment removal no longer destined for the lake, but potentially resulting in decreased effectiveness over an extended time period. Further studies need to be done in order to understand the extent of bed-flow within the delta, and the degree of sediment plume stability downstream of the dredged channel under a less turbulent hydrological regime.



(a) (b) (c) (d)

Figure 4-1. An elevation interpolation of existing conditions and three restoration scenarios. .

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BIOGRAPHICAL SKETCH

Casey Schmidt was born and raised in a once isolated, forested valley of Spokane, Washington, with his parents Errol and Robin and his siblings Darby and Jake. Backpacking and family car-trips in a VW van with no back seats to beautiful western Washington and climbing trees in the forests at home, piqued his interest in nature. He attended college at the University of Washington in Seattle, where he received his Bachelor of Science in biology with a focus on conservation, evolution and ecology and a minor in fisheries in 2001. While there, he assisted in the Environmental Engineering Limnology Laboratory of Dr. Michael Brett comparing stream phosphorus transport to land use. He took a year off and worked for a private analytical laboratory. Casey matriculated at the University of Florida in Gainesville in 2002. Casey is making plans to continue his studies towards a PhD to answer some unresolved questions from his master's degree.