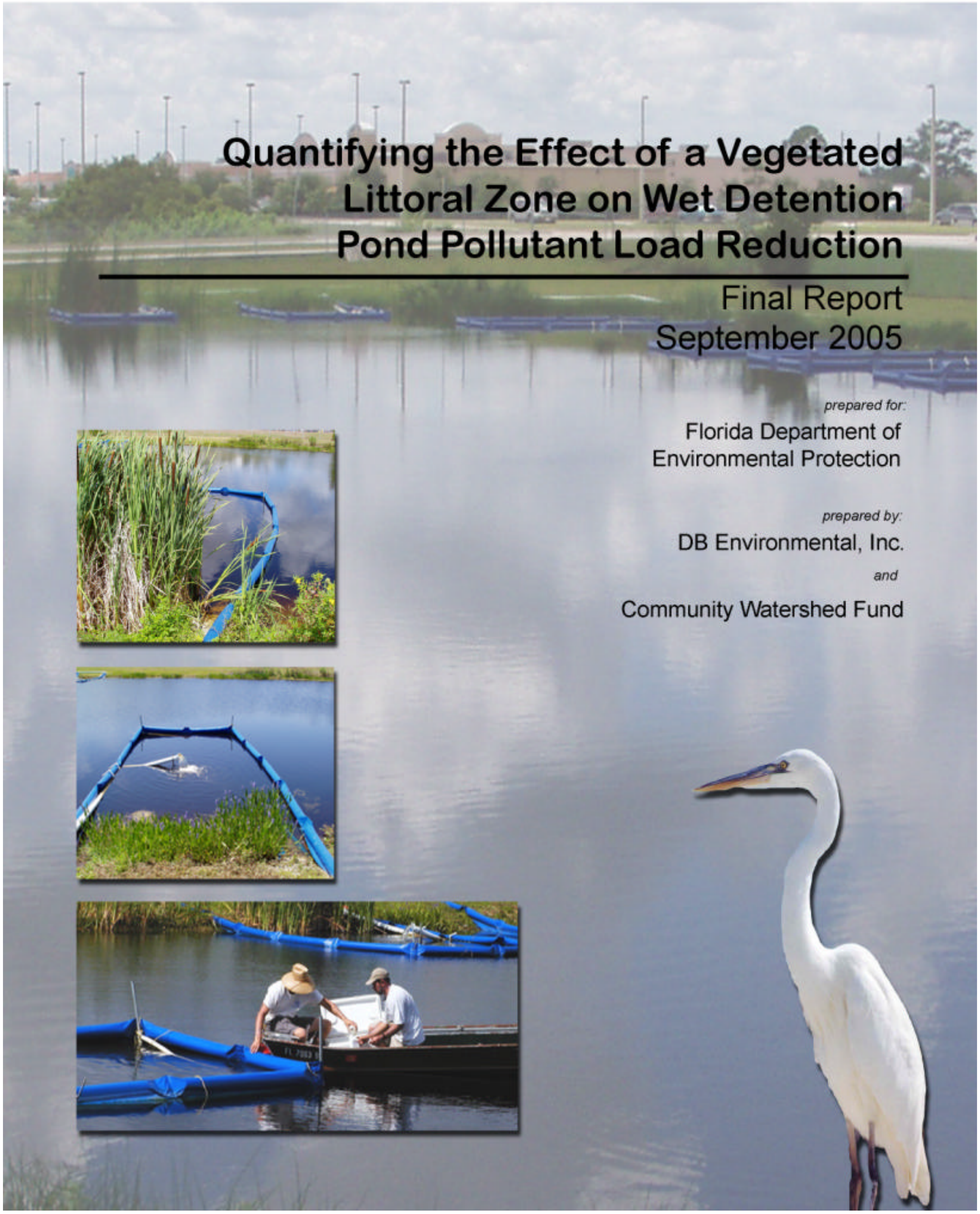
9-1-2005

Quantifying the Effect of a Vegetated Littoral Zone on Wet Detention Pond Pollutant Load Reduction (2005)

Stormwater Academy



Quantifying the Effect of a Vegetated Littoral Zone on Wet Detention Pond Pollutant Load Reduction

Final Report
September 2005

prepared for:
Florida Department of Environmental Protection

prepared by:
DB Environmental, Inc.
and
Community Watershed Fund

Table of Contents

List of Tables

List of Figures

Executive Summary

This report describes an investigation sponsored by the Florida Department of Environmental Protection (FDEP), in which DB Environmental, Inc., with assistance from Community Watershed Fund, evaluated the potential of littoral zone vegetation to enhance contaminant removal performance of a wet detention pond.

For this effort, we constructed an experimental facility at a 1 hectare wet detention pond in Brevard Co, Florida that contained pre-existing littoral vegetation (distinct stands of cattail (*Typha* sp.) and pickerelweed (*Pontederia cordata*)) in addition to an unvegetated shoreline. Ten compartments, 3.7 m by 9.0 m, were deployed within the facility, effectively isolating sections of the pond. Each compartment contained both littoral and deepwater areas, with the littoral zone typically comprising 20% of the surface area of each compartment.

We utilized these compartments to assess contaminant removal during nine simulated storm events from May through December 2004. For each event, we fed pond waters into all compartments simultaneously over a 9-hour period. Native contaminant concentrations in the pond waters were low, so during each simulated storm event we utilized a spiking solution to amend compartment inflows with the following constituents: chemical oxygen demand (COD), 20 mg/L; ammonia-N (NH_3-N), 2 mg/L; nitrate-N (NO_3-N), 2 mg/L; soluble reactive P (SRP), 0.4 mg/L; copper (Cu), 0.1 mg/L; and lead (Pb), 0.1 mg/L.

Inflow and outflow constituent concentrations were measured during each simulated event. The parameters measured were COD, total suspended solids (TSS), total P (TP), SRP, total kjeldahl nitrogen (TKN), nitrite + nitrate-N (NO_2 + NO_3-N), NH_3-N, Cu and Pb. During inter-event periods, which typically lasted two weeks, we also collected littoral zone and open water samples within each compartment to characterize temporal and spatial variations in contaminant concentrations.

We examined the contaminant removal effectiveness of several treatments in this study: compartments with unvegetated vs. vegetated (cattail or pickerelweed) littoral zones; compartments with unvegetated littoral zones that subsequently were planted with cattail or

pickerelweed; and compartments with littoral zones containing cattail where the macrophytes were killed with an herbicide mid-way through the study.

Those contaminants exhibiting highest removal rates during the study, based on mean concentration reductions during the inter-event periods in the littoral region of unvegetated compartments, were NO_2 + NO_3-N (98%), Pb (93%), SRP (89%), Cu (88%) and NH_3-N (87%). Moderate removal rates were observed for TP (63%) and TKN (37%), while relatively poor removal was documented for TSS (27%) and COD (10%). Percentage contaminant removal rates in compartments with vegetated littoral zones were comparable to those in unvegetated compartments.

During inter-event periods, water quality often improved more rapidly and to a greater extent in the shallow littoral region than in the deeper open water region of the compartments. This difference was statistically significant for TP and NH_3-N in unvegetated and pickerelweed compartments. Contaminant removal effectiveness within littoral and open water regions, however, was not consistently influenced by presence of either cattail or pickerelweed, whether in existing stands or newly planted.

Presence of vegetation had little long-term effect on contaminant removal rates, although we did observe some short-term differences between treatments. Herbiciding of cattails resulted in a short-term increase in littoral and open water TP and SRP concentrations, but little or no effect on TSS, COD, N or metals concentrations. Additionally, while few water chemistry differences were noted, we did observe in the final months of the study that unvegetated compartments developed a higher standing crop of filamentous algae than vegetated compartments. Similarly, at this time the herbicided cattail exhibited the highest cover of floating duckweed among treatments.

Contaminant removal effectiveness probably was related to the chemical form and concentration of the constituent in the inflow waters. Native COD and organic N in the pond waters were relatively recalcitrant, whereas the spiked aliquots of COD (fructose) and N (NO_2 + NO_3-N, NH_3-N) were readily removed within the compartments. Inflow TSS concentrations to

the compartments were typically 10 mg/L or less, much lower than the average TSS levels found in central Florida urban runoff. These low inflow TSS levels probably explain the low percentage removal rates for this constituent. Additionally, due to low TSS levels, most of the contaminants were provided to the compartments in a dissolved form. This study therefore provides an extensive data record on removal of dissolved nutrients and metals under low TSS conditions, information that should prove useful for wet detention pond performance modeling and design purposes.

Data from this study do not support the hypothesis that littoral zone emergent vegetation, either existing or newly-planted, enhances pollutant reduction in a wet detention pond. However, it should be noted that due to the low TSS levels in the simulated runoff, this study does not represent a definitive evaluation of effects of vegetation on littoral zone pollutant removal effectiveness. Pollutant removal performance of the various treatments (e.g. littoral vs. open water; vegetated vs. non-vegetated compartments) might differ with high inflow particulate concentrations, a situation where sedimentation, rather than biological treatment, would be the dominant removal process for the bulk of the contaminants.

Our experimental facility proved flexible and effective for testing different vegetation treatments that received comparable pollutant loads under replicated conditions. In a final section of this report, we recommend several investigations, such as replicating this effort in ponds with different soil conditions, and evaluating contaminant removal performance under high TSS inflow loads, that should further define littoral zone and macrophyte vegetation effects on detention pond water quality.

Acknowledgements

This report was funded by a TMDL Urban Nonpoint Source Management Research grant from the Florida Department of Environmental Protection (FDEP) Bureau of Watershed Management. We wish to thank Eric Livingston and his colleagues at FDEP for their funding support, and their helpful review comments on a draft version of this report. We thank Brevard County Stormwater Utility Bureau personnel for their assistance in selecting a study site, and for their suggestion to evaluate the impacts of cattail herbiciding on water quality.

Introduction

Wet detention ponds are a common and effective Best Management Practice for reducing stormwater pollutant loads (USEPA 1999a and b, USEPA 2002, Strecker et al. 2004). The primary pollutant load reduction mechanism is sedimentation, which removes particulates, organic matter, and metals. Dissolved nutrients and metals are removed through biological uptake by aquatic plants and microorganisms, as well as by physico-chemical processes such as adsorption and precipitation. Pollutant removal efficiencies for wet detention ponds are highly variable, ranging from 10 to 90 percent (Table 1).

Table 1. Removal efficiencies for wet detention ponds[1].

Parameter	Removal Efficiency (%)
TSS	40 TO 94
COD	20 TO 40
TP	10 TO 90
SRP	40 TO 93
TN	10 TO 33
Cu	26 TO 90
Pb	29 TO 90

[1] England 2001, EPA 199, 2002; Heaney etal. 1999, Center for Watershed Protection (no date)

A vegetated littoral fringe is, explicitly or implicitly, presumed to enhance wet detention pond pollutant reduction (USEPA 1999a and b, Barr Engineering 2001, City of Houston *et al.* 2001, USEPA 2002). The vegetated littoral fringe is expected to act like a wetland treatment system, removing sediments, nutrients, metals, and organic contaminants by filtration, biological uptake, and degradation. To this end, various agencies require or recommend that wet detention ponds have a vegetated littoral fringe (e.g., Florida Development Manual, 1988, Maryland Department of the Environment 2000, Barr Engineering 2001, City of Houston *et al.* 2001, USEPA 2002, St. Johns River Water Management District 2003). Guidelines typically include a 3 to 4.5 m wide littoral zone that occupies 20 to 50 percent of the permanent pool

water surface area. DEP's guidelines for wet detention ponds include a shallow littoral zone with aquatic macrophytes that cover a minimum of 30% of the ponds' surface area.

Aquatic vegetation is indeed effective at the uptake and removal of pollutants as evidenced by an extensive literature regarding the use of natural and constructed wetlands for treating stormwater runoff, domestic and industrial wastewater, and acid mine drainage (Hammer 1988, Moshiri 1993, Kent 1994, Kadlec and Knight 1995). Specific to stormwater, Kent *et al.* (1997) demonstrated that biological processes contribute significantly to the removal of nutrients and metals from stormwater. Pollutant reduction performance varied with plant species, and the pollutants were removed to live shoots, below ground tissues, and the sediments. Similarly, Johengen and LaRock (1993) found that vegetated mesocosms had greater stormwater nutrient removal efficiencies than non-vegetated mesocosms. Nevertheless, much of wetland-facilitated reduction in nutrients and metals in stormwater may be effected by sediment chemistry (Johengen and LaRock 1993, DeBusk et al. 1996).

Vegetated littoral zones constitute a relatively small portion of wet detention ponds. Consequently, significant vegetation-mediated enhancement of wet detention pond pollutant reduction processes is not a forgone conclusion. In fact, studies supporting the efficacy of littoral zone vegetation in a wet detention pond are noticeably scarce and oblique. Stoker (1997) demonstrated that a single wet detention pond with a planted littoral zone exceeded the average pollutant removal efficiency of various structural stormwater control systems. Rushton (1997) suggested that intentionally excluding littoral zone vegetation from wet detention ponds would decrease pollutant removal and lead to lowered dissolved oxygen levels. Harper (2002) used a mass balance water quality model to conclude that littoral zone vegetation would provide little direct uptake of pollutants from the water column, although he acknowledged that indirect water quality benefits might accrue.

Conversely, vegetated littoral zone maintenance activities may diminish wet detention pond pollutant reduction. Herbicide is routinely applied to the margins of wet detention ponds to eliminate unwanted vegetation. Herbicide application, in and of itself, introduces additional pollutants to the wet detention pond. Additionally, nutrients and metals leach from dying and

decomposing aerial plant parts to the water column. To our understanding, the potential impacts of vegetation maintenance activities have not been investigated.

Another issue that has not been investigated is the affect of a vegetated littoral zone on algal growth. Rushton (1997) suggested that intentionally excluding littoral zone vegetation from wet detention ponds would stimulate algal blooms. Certainly, the nutrient-enriched water in the permanent pool of a wet detention pond favors algal growth, and algal growth may elevate pond total suspended solid, biochemical oxygen demand, and nutrient levels. Mechanistically, littoral zone vegetation could assimilate nutrients, thereby limiting nutrients available to algae. Limiting algal growth has the secondary benefit of maintaining pond aesthetics, an important consideration in residential and commercial areas.

Varying climate and pollutant load hinder *in-situ* evaluation of the effects of littoral zone vegetation on wet detention pond performance. In Florida storm events occur with an unpredictable frequency, and are especially infrequent from November through May. Stormwater pollutant concentrations vary with the severity of the event, the inter-event period, and activities in the watershed. For example, Rushton (1997) found that nitrate, phosphate, suspended solids, zinc, lead, and copper concentrations in untreated stormwater varied by up to 3,000 percent over a four-month period.

One way to overcome the hindrance of variable climate and pollutant load is to simulate storm events in replicated, *in-situ* compartments. We used this approach to evaluate the effects of littoral zone vegetation on wet detention pond pollutant reduction. Ten enclosed compartments were constructed in a Brevard County wet detention pond. Some of the compartments had littoral zones vegetated with pickerelweed (*Pontederia cordata*) or cattail (*Typha domingensis*), and others were non-vegetated. Stormwater withdrawn from the pond was spiked with dissolved nutrients, metals, and an oxygen demanding substance and pumped into each compartment. Samples were collected over an eight month period from compartment effluents during simulated storm events, and from within the compartments between events.

Several factors, both practical and theoretical, influenced our decision to utilize only dissolved constituents in our spiking solution. We investigated the potential for using street sweepings from nearby municipalities as a particle source, but upon examination this material was found to be very heterogeneous, consisting primarily of sand and leaves, a mixture that would have been impossible to spike in a quantitative fashion. Our second thought was to utilize a commercially available source of particulate matter, but it was unclear as to what type of particles (organic vs. inorganic), and what size fraction(s) should be utilized. Moreover, we were concerned that by incorporating particulate matter in our spike, selected dissolved constituents (e.g., metals) would immediately absorb onto the particles, leaving no dissolved compounds in the solution. For these reasons, we limited our spike to dissolved constituents.

Objectives

Our exploratory study had three primary objectives, and one secondary objective. First, and most importantly, we wished to determine if littoral zone vegetation enhanced reduction of dissolved pollutants in a wet detention pond, and if vegetation type was important. This was evaluated by comparing pollutant reduction processes in compartments encompassing pickerelweed and cattail with non-vegetated compartments. Second, we wished to determine if planting non-vegetated wet detention ponds with pickerelweed and cattail would enhance near-term pollutant reduction processes. And third, we wished to determine if herbicide application to cattails diminished pollutant reduction processes. Cattails often are controlled with herbicides in wet detention facilities in order to encourage proliferation of more desirable emergent macrophytes. Finally, and of secondary interest, we wished to determine if littoral zone macrophyte vegetation limited algae growth.

Materials and Methods

Study Site

The study was conducted in a wet detention pond in Melbourne, Florida (latitude 28° 10.689' N, longitude 080° 40.347' W). Constructed in 1997, the 1 ha site has a 0.36 ha pool (38 x 95 m), a maximum depth of 6m and a littoral bench that extends 1.8 m from the pond edge with a slope of 10:1 (Photo 1). Portions of the bench are occupied by pickerelweed (*Pontederia cordata*) and cattail (*Typha* sp.), while other areas are non-vegetated. The study pond receives stormwater from a 0.23 ha wet detention pond located to the south, which in turn receives stormwater from a four lane divided highway. The system is designed to accommodate runoff generated by the 25-year, 24 hour storm, with recovery of the storage volume within 14 days. Water flows out of the study pond to the northeast through a riser and inverted release pipe with aluminum skimmer. Higher flows pass through a trash rack installed on the riser.

Photo 1. The 1 ha wet detention pond used for the study site

Field and Laboratory Methodology

Ten rectangular compartments were constructed within the pond using geosynthetic floating booms and barriers. The barriers were equipped with a weighted chain along the bottom. Additionally, scuba divers placed sand bags along the bottom edge of the barriers to ensure the compartments were hydraulically separate from the pond proper. The compartments were located away from the inflow and outflow structures so as not to interfere with the pond's designed hydraulic function (Figure 1; Photo 2). Each compartment encompassed 3.7 m of shoreline and extended perpendicularly 9 m toward the center of the pond. Maximum compartment depth was 3.4 m, and the volume was approximately 100 m^3.

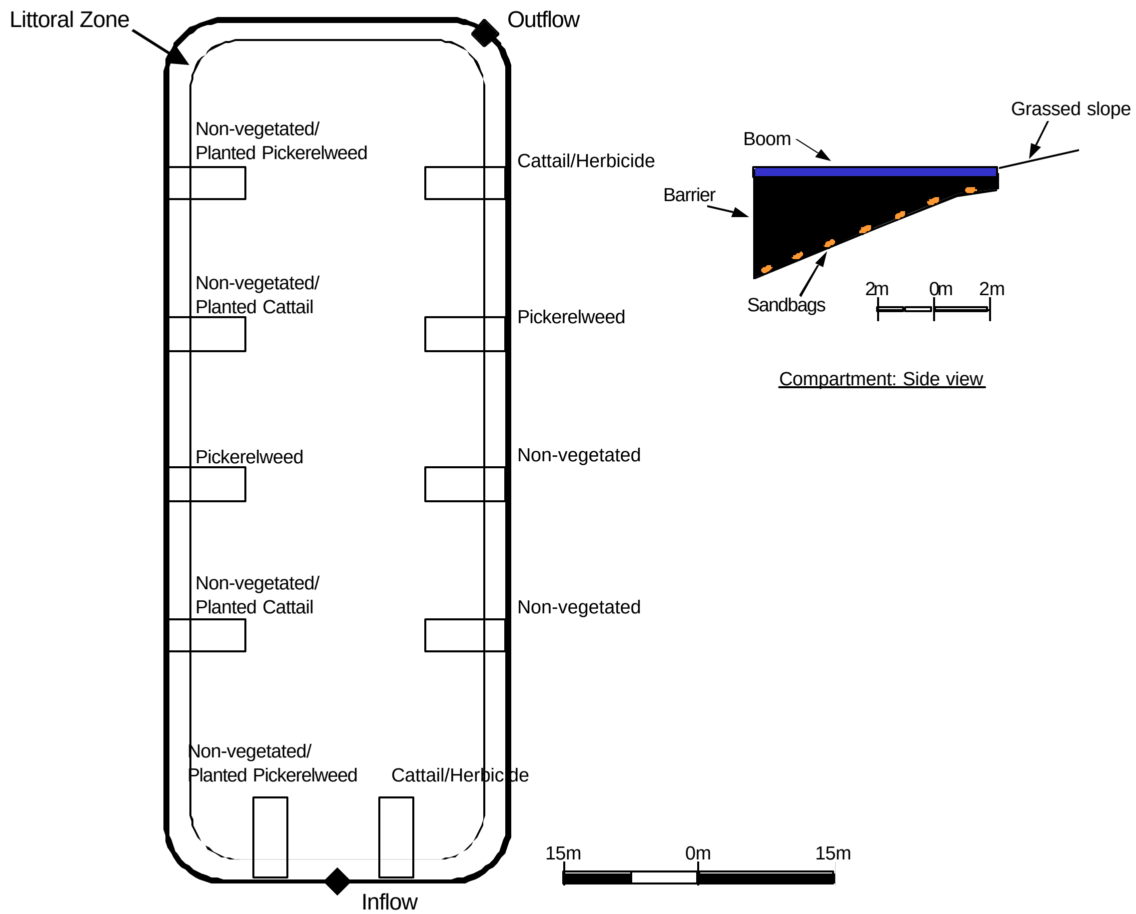


Figure 1. Wet detention pond littoral zone vegetation study configuration**.**

Photo 2. Side view of compartments, with the residential and commercial drainage basin in the background.

Outflows were inserted through the barrier 15 cm below the water surface at the deep end of the compartments. The outflows were constructed of 10 cm diameter PVC pipe with a threaded cap, and were open only during simulated storm events.

The compartments were initially constructed to encompass pickerelweed (n =2), cattail (n = 2), or non-vegetated littoral zone (n = 6, Figure 2; Photo 3). After two simulated storm events, two of the non-vegetated compartments were planted with pickerelweed and two were planted with cattail. The two existing cattail compartments were treated with herbicide (glyphosate) after the fifth simulated storm event.

Photo 3. View of unvegetated, pickerelweed and cattail compartments. The pickerelweed compartment photo depicts inflow during a simulated storm event.

The compartments containing each plant type (cattail or pickerelweed) visually appeared to contain a comparable density of plants, although no direct measurements of plant density or standing crop were performed during the study. Similarly, all compartments appeared to

contain comparable soils, but soils were not characterized with respect to either chemical or physical characteristics.

A pollutant spike solution mimicking stormwater concentrations (Table 2; Bingham 1994, Harper 1994) was fashioned in a 200 L polyethylene drum containing pond water. The solution then was transferred to two 200 L holding drums fitted with fountain pumps. Venturi force was used to draw the spike solution from the holding drums into a 10 cm trash pump for mixing with pond water and distribution to the compartments (Photo 4). Water flowed from the pond, and from the pump to the compartments, through three 15 cm diameter PVC lines. One line supplied the four compartments to the east, one line the four compartments to the west, and one line to the two compartments to the south. The main lines teed off to a 10 cm diameter PVC line that extended along the inside edge of a boom and terminated above the water surface in the center of compartment. The pumping flow rate was 190 liters per second for the entire system, 3 liters per second to each compartment. Each supply line was calibrated at the start of each simulated pumping event to ensure equal flow. The duration of pumping events was nine hours, which potentially resulted in one volume exchange per compartment.

It should be noted that one of our simulated storm events (20 July 2004) coincided with a natural storm event (85 mm rain) in the pond's watershed. Runoff from the drainage basin enters the 1 ha pond through several large subsurface inflow culverts, the closest one being about 8 m from our pump intake. Therefore, at least a portion of the pollutant load to the pond (following some dilution) was diverted to our compartments on that sampling date. Some pollutant loading from the shoreline to the compartments also likely occurred during this and other rain events. The pond's banks consist of grassed berms of moderate slope, and only a small area (6 m length, at most) of the bank drains towards the pond (and compartments). We therefore believe pollutant loading during the study from the pond bank/shoreline to the compartments was minimal.

Table 2. Spike solution composition and inflow runoff target concentrations. Solution components were mixed in 200L of pond water. Lead chloride was dissolved by mixing with deionized water and acidifying to pH 2 with muriatic acid to effect dissolution.

Chemical Compound	Mass (g)	Target Concentration
Fructose	2520	20 mg COD / L
Ammonium nitrate	720	2 mg N / L as nitrate
		2 mg N / L as ammonium
Potassium phosphate	219	400 µg P / L as PO_4
Copper sulfate	48	100 µg Cu / L
Lead chloride	23	100 µg Pb / L

The compartment's littoral zones and open water areas were sampled 4 May 2004. Eight sampling sequences, comprised of simulated storm events and inter-events, were initiated 19 May 2004 and terminated 1 December 2004. Simulated storm event grab samples were collected at 3, 6, and 9 hours at the compartment outflow 15 cm below the water surface. One, seven, and 14-day[1] inter-event grab samples were collected from open water (near compartment outflow) and littoral zone locations within the compartments. The open water samples were a composite of a sample collected 15 cm beneath the surface and 30 cm above the bottom. A single littoral sample was collected midway between the surface and bottom, a depth of about 15 cm. Temperature, dissolved oxygen, and *p*H measurements were made *in situ* coincident with pollutant sampling using a Hach Sension 156 Multi-Parameter Meter. Grab samples were analyzed for nutrients, metals, total suspended solids (TSS) and chemical oxygen demand (COD) using EPA-approved methods (Table 3).

[1] After the second simulated storm event, the third inter-event samples were collected at 37 days to accommodate pickerelweed and cattail planting and grow-in.

Table 3. Analytical methods used during project.

Parameter	Matrix	Method	Laboratory
Chemical Oxygen Demand	Water	SOP AN0006	PPB Environmental
Total Suspended Solids	Water	EPA 160.2	DB Environmental, Inc
Total Kjeldahl Nitrogen	Water	SOP AN0020	PPB Environmental
Nitrate + Nitrite	Water	SOP AN0017	PPB Environmental
Ammonia	Water	SOP AN0015	PPB Environmental
Total Phosphorus	Water	EPA 365.2 / SM4500-P F	DB Environmental, Inc
Soluble Reactive Phosphorus	Water	DBE SOP OPO_4 / SM4500-P F	DB Environmental, Inc
Copper	Water	EPA 200.7	Sanders Laboratory
Lead	Water	EPA 200.7	Sanders Laboratory

Photo 4. Water pumping (left) and pollutant spiking infrastructure (right).

Data Analyses

Results were evaluated primarily using graphical analyses. Example graphical comparisons included:

- Compartment inflow vs. outflow contaminant concentrations during each 9 hour pumping event
- Day 14 inter-event contaminant concentrations for littoral and open water areas
- Changes in contaminant concentrations over time at littoral and open water locations during each inter-event period

Percentage reductions for pollutants are provided in tabular form for inter-event periods for both littoral and open waters. The baseline, or “time 0” value for this calculation was the 9-hour

"inflow" sample collected from each compartment during the simulated storm event period. In some instances, the percentage removal calculations for certain constituents in the data tables are shown as negative values. This indicates that compartment internal or outflow concentrations exceeded inflow concentrations on that date.

For selected comparisons, nonparametric statistics were used to verify graphical interpretations. In some instances, e.g., small sample sizes, evaluations were effected through direct comparison of individual values. Indications of variance also are provided on bar graphs, in which error bars are used to represent +/_ one standard deviation. No error bars were utilized on line graphs in order to ensure legibility.

For TP and SRP we calculated the first order removal rates (k, day^{-1}) observed during the inter-event periods:

$$\frac{(C - C^*)}{(C_i - C^*)} = e^{-kt} \qquad (1)$$

Where C is the concentration at time t, and C* and C_i represent event background (lower limit) and initial concentrations, respectively. C* was set at the lowest observed concentrations (29 µg/L for TP and 1 µg/L for SRP). Initial concentrations were different for each treatment. The equation normalizes each event concentration change to the fraction of total pollutant removed during the event.

Microsoft ® Office Excel 2003 Solver routine was employed to determine k based on minimizing the sum of squared error (SSE).

$$SSE = \sum \left[\frac{(C - C^*)}{(C_i - C^*)} - e^{-kt} \right] \qquad (2)$$

Results and Discussion

Observations on Stormwater Mixing Within the Compartments

Our simulated storm events were designed to introduce contaminant-laden waters into the compartments with sufficient mixing so that the entire compartment water volume, including both littoral and open water regions, would be exchanged during each nine-hour pumping event. To demonstrate that the introduced stormwater indeed was mixing well within the compartments, we introduced a dye tracer, Rhodamine WT, into several compartments during a simulated event. The batch introduction of the tracer into a pickerelweed compartment, depicted in Photo 5, demonstrates rapid mixing throughout the system. In all trials, the dye tracer was dispersed throughout the compartments, and began exiting the outflow ports within twenty minutes of injection (Photo 6).

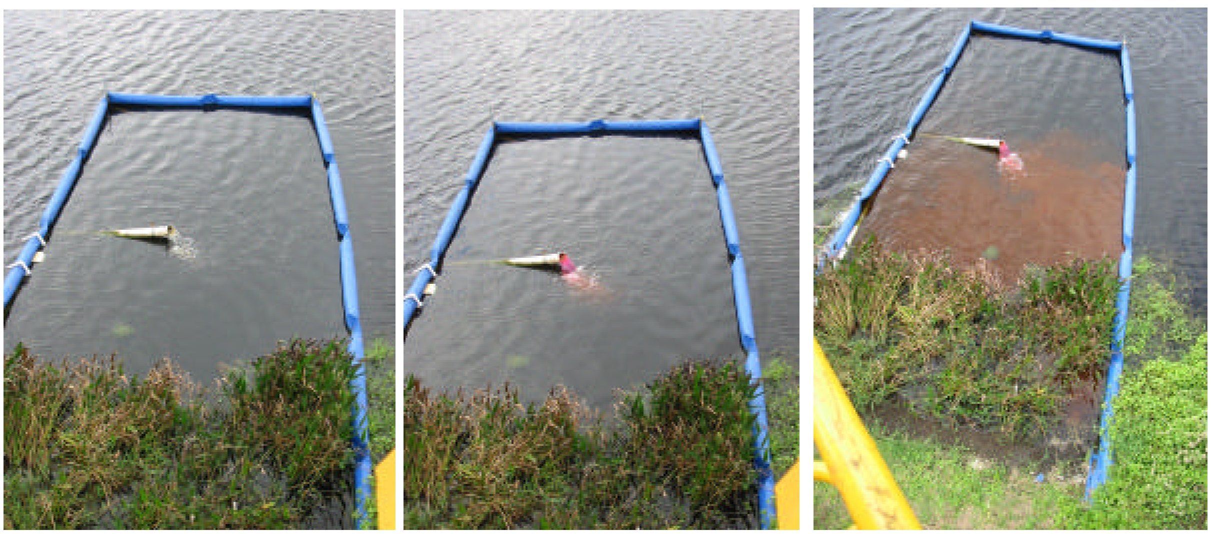


Photo 5. Dispersal of a Rhodamine WT dye tracer throughout a pickerelweed compartment. The tracer was uniformly distributed (based on visual observations) throughout the compartment within 20 minutes after the onset of tracer injection. Note the presence of the dye in the littoral region.

Photo 6. Dispersal of a Rhodamine WT dye tracer throughout a cattail compartment. The tracer was uniformly distributed throughout the compartment within 20 minutes after the onset of tracer injection. Note the presence of the dye in the compartment outflow at the top of the photo (right).

Visual observations of the Rhodamine WT tracer from an aerial "lift bucket" not only indicated rapid, thorough mixing, but also demonstrated that the compartment barriers provided a tight hydraulic seal, preventing water exchange between the internal portion of the compartment and the pond proper. The outflow port (Photo 6) was the only location where Rhodamine WT was observed to exit the compartments during the tracer tests.

Approach for Characterizing Pollutant Removal Among Experimental Treatments

We implemented a number of management approaches, such as macrophyte planting and herbiciding, to various compartments during the study. To simplify the data interpretation, we separated the findings into three treatment comparisons. In the first, we compared the pollutant removal performance of unvegetated compartments with those containing pre-existing stands of cattail (*Typha spp.)* and pickerelweed (*Pontederia cordata).* This comparison among three treatments was performed for five simulated storm events, after which time herbicide was applied to the cattails. For the final four storm events, therefore, the unvegetated compartments were compared only with pickerelweed.

For the second comparison, we evaluated the performance of duplicate unvegetated compartments with duplicate compartments containing existing stands of cattail. After five storm events, the cattails were killed with an herbicide, and for four storm events we assessed the impacts of the dying vegetation on water quality.

In the third comparison, we evaluated the pollutant removal performance of six unvegetated compartments for two storm events, after which time two of the unvegetated compartments were planted with cattail, and two others were planted with pickerelweed. The performance of these newly-vegetated compartments, and the remaining two unvegetated compartments, were then evaluated for seven simulated storm events.

The above approach resulted in some duplication of data in both figures and tables among the three comparisons. However, due to the dramatic management changes imposed on selected compartments at various times during the study (e.g., macrophyte planting, cattail herbiciding), we believe that interpretation of results is rendered too difficult if the data are presented in a more condensed form (e.g., with all treatments included on a particular graph or table).

Contaminant Removal Performance of Unvegetated, Cattail and Pickerelweed Compartments

Phosphorus

The inflow TP feedwater concentrations during the simulated storm events were fairly consistent, averaging 418 µg/L and ranging from approximately 350 to 580 µg/L (Figure 2). Observed inter- and intra-event fluctuations for inflow P levels likely were due to slight variations in the spiking solution feed rate, and/or temporal changes in the native pond water P concentrations during the eight month study. During each simulated storm event, the outflow P concentrations gradually increased with time, with the TP concentrations after 9 hours of pumping approaching the inflow concentration (Figure 2). This outflow concentration increase was expected, since the pumping rate and duration were selected to exchange the entire volume

of the compartments during each event. Mean outflow TP concentrations (sum of 3, 6 and 9 hour samples) were comparable among compartments, ranging from 280 to 290 µg/L (Table 4).

It should be noted that some direct short-circuiting of the inflow stormwater to the compartment outflows was noted in the tracer evaluation (Photo 6), which is the likely cause of the 9 hour outflow TP concentrations being consistently lower than the inflow concentrations. Had a complete water exchange been accomplished, the outflow concentration would be identical to the concentration of the inflow feedwater upon completion of the pumping event. Additionally, differential short-circuiting among compartments also may have resulted in between-treatment differences in outflow contaminant concentrations during the storm events. This potential hydraulic effect suggests that our inter-event monitoring under stagnant conditions (days 1 – 14) provides a better indication of contaminant removal efficiency of the various treatments than the outflow measurements performed during the pumping events.

We compared day 14 (two weeks after cessation of storm event pumping) concentrations for both littoral and open water locations in order to generally characterize pollutant concentrations during the stagnant, inter-event periods (Figure 3). Note that the May 4, 2004 sampling date represents constituent concentrations in the compartments prior to the first simulated storm event (Figure 3). Similarly, the day 14 open water and littoral data provided for November 17, 2004 represent the inter-event period between storms eight and nine (a day 14 sample after event nine was not collected). For the initial sampling on May 4, littoral TP concentrations were markedly lower than open water TP levels, with comparable values observed among treatments. This trend in higher open water TP concentrations continued throughout the study, with cattails often providing lowest day 14 TP concentrations (Table 4; Figure 3). Additionally, the variability in TP levels between duplicate compartments, expressed as error bars (i.e., standard deviations) on the graphs, was typically higher in open water than littoral sampling locations (Figure 3).

Total P concentration changes during each inter-event period, from day 0 (represented by the 9 hour outflow sample concentration during the pumping event) through day 14, are provided in Figures 4 and 5. For the open water region, a gradual decline in TP levels with time was

observed for events 1 – 4. After this time, there often was a marked drop in concentration at day 7 (Figure 4). This dramatic TP concentration reduction at day 7 was more pronounced for the littoral zone sampling locations (Figure 5).

A continuous record of outflow and inter-event compartment TP concentrations for the nine events is depicted in Figure 6. The sawtooth pattern reflects the effective TP removal performance within the compartments during each inter-event period. For both littoral and open water regions, there was a slight increasing trend in water column TP concentrations during the study.

Soluble reactive P concentrations of water fed into the compartments were slightly lower than TP levels, probably due to the presence of native particulate and dissolved organic P in the pond waters (Figures 2 and 7). Little SRP was detected in the littoral zone of the compartments on May 4, 2004, prior to the first storm event (Figure 8). By contrast, open water SRP levels in the compartments at this time were as high as 20 µg/L. Pickerelweed typically exhibited the highest SRP concentrations among treatments during the first few events, and this trend persisted, at least in the littoral zone, for the entire study (Figure 8).

Soluble reactive P was more labile than total P during the inter-event periods, with marked concentration declines occurring between days 0 and 1 in both open water and littoral regions (Table 5; Figures 9 and 10). For most sampling dates, SRP levels were comparable among the three treatments.

General trends in SRP inflow, outflow and within-compartment concentrations are provided in Figure 11. All treatments were quite effective at removing SRP during inter-event periods, although there was a gradual accumulation of SRP in the compartments during the course of the study. We generally observed little difference among vegetated and unvegetated treatments with respect to TP and SRP removal. All compartments, however, provided effective percentage reductions of these constituents. In the littoral zone of the unvegetated compartments, for example, TP and SRP reduction during the 14 day interevent period

averaged 63 and 89%. Percentage reduction of these respective constituents in the open water regions was 51% and 81%.

It should be noted that contaminant reduction effectiveness within a compartment can be quantified by the final open water or littoral concentration achieved by day 14, as well as by how rapidly this reduction occurs within the inter-event period. For example, both TP and SRP exhibited declines in concentration with time for most events, although in some cases the concentration reduction occurred more quickly than for others. In order to quantify this concentration reduction rate, we used the TP and SRP data to fit exponential decay curves (equation 1). The resulting k values provide an approximation of how rapidly the constituent concentration declines, with higher k values denoting more rapid concentration reductions (Figure 12).

During events 1 - 5, k values for TP typically were less than 0.1, with the cattail treatment generally providing slightly higher values than the other treatments (Figure 13). K values were lower during the latter events (6 – 8), with unvegetated compartments exhibiting slightly higher K values than the pickerelweed compartments. K values for SRP during events 1 – 5 were markedly higher (ranging up to 0.4), indicating the more rapid removal of SRP than TP from the compartments (Figure 14). As noted with TP, the unvegetated compartments exhibited a slightly high k value than those containing macrophytes. An exception was the cattail open water treatment, which provided the highest k value during events 1 – 5 (Figure 14). Note that storm event #9 is not included in the mean k value calculation for the latter events, since a day 14 sample was not collected for this final event.

Chemical Oxygen Demand

The native pond waters contained relatively high and variable COD concentrations in the range of 50 – 80 mg/L. Our COD spike was only 20 mg/L, so during periods in which the pond water concentrations dropped more rapidly (due, for example, to dilution) than those in the compartments, the outflow COD levels during the pumping events at times exceeded the inflow concentrations (Figure 15). Prior to the initiation of pumping (May 4), highest COD concentrations among treatments were observed in the unvegetated compartments (Figure 16).

Small percentages of COD were removed during some inter-event periods (e.g., events 5 and 7), but for most monitoring periods the COD reduction was minimal (Table 6; Figs. 17 and 18). Overall, COD removal averaged only about 10 - 18% in the littoral regions and 11 – 15% in the open water areas. Upon completion of the final pumping event, the resulting littoral and open water COD levels were comparable to those observed prior to the beginning of the study (Figure 19).

The labile fructose spike that we added to the inflow waters probably accounted for the bulk of the COD removed from the system. The composition of the native COD within (and entering) the pond is unknown, but it clearly is quite recalcitrant.

Total Suspended Solids

Native pond water TSS levels were consistently low. Despite the prevailing low background TSS concentrations, we did not amend the inflow waters with TSS during the study, because we were concerned that high particle concentrations would interact with (e.g., adsorb) the dissolved metals (Cu and Pb) added to the spiking solution. As a result, the pumped inflow TSS levels typically were low, ranging from 2.0 to 10.0 mg/L (Figure 20). Prior to initiation of the pumping events on May 4, open water TSS concentrations ranged from 7.0 to 10.0 mg/L, whereas littoral TSS levels were lower, at 2.0 – 3.0 mg/L (Figure 21).

Total suspended solids removal performance within the compartments varied widely among events. On dates when inflow TSS values were lower than approximately 5.0 mg/L, little decrease in TSS levels was observed during the inter-event period. By contrast, during pumping events with higher inflow TSS levels, effective TSS reduction was observed in both littoral and open water locations (Figs. 22 and 23). We observed little difference between the vegetated and unvegetated treatments with respect to TSS removal (Table 7), although on some dates in the littoral region planted with pickerelweed we did observe some small concentration spikes (Figures 22 and 23).

Over the nine storm events, TSS reductions in the unvegetated and pickerelweed littoral zones averaged 27 and 28%, respectively. Open water TSS reductions for these respective treatments averaged 7 and 12%. Total suspended solids concentrations within the compartments varied during the nine pumping events, but there was no clear increasing or decreasing trend in TSS levels during this assessment (Figure 24).

Nitrogen

Mean TKN concentrations in the compartment inflows averaged 1.77 - 2.00 mg/L, with slightly lower values noted from compartment outflows during the pumping events (Figure 25). Prior to the initiation of the first event on May 4, TKN concentrations in the littoral region were approximately half of those in open water (Figure 26). Effective TKN removal was observed in the open water during the inter-event period, with pickerelweed providing slightly lower outflow TKN concentrations than the unvegetated compartments on selected dates (Table 8; Figure 27). In the littoral, moderate TKN concentration reductions were observed, with TKN removal comparable among treatments (Figure 28). Mean percentage TKN removal rates for all storm events for the unvegetated and pickerelweed compartments were 37 and 39% in the littoral region, and 21 and 32% for open water. Over the course of the nine pumping events, we observed a slight increase in compartment TKN concentrations, both in open water and littoral locations (Figure 29).

Nitrite + Nitrate-N (NO_2 + NO_3-N) levels in the pumped inflow waters typically ranged from 0.5 to 1.00 mg/L (Figure 30). Background NO_2 + NO_3-N concentrations in the compartments at both littoral and open water locations were less than 0.01 mg/L on May 4, prior to the initiation of the first pumping event (Figure 31). All compartments were quite effective at removing NO_2 + NO_3-N (Table 9). Day 14 NO_2 + NO_3-N concentrations for most pumping events were less than 0.01 mg/L, with the exception of events 5 and 8, where NO_2 + NO_3-N levels in the pickerelweed open water and littoral regions were 0.04 – 0.05 mg/L (Figure 31).

The removal of NO_2 + NO_3-N from the compartments during the inter-event periods was rapid. For both littoral and open water locations, NO_2 + NO_3-N levels dropped to extremely low levels by day 7, and in some cases, within the first day after cessation of pumping (Figs. 32 and 33).

Mean $NO_2 + NO_3$-N reductions for both unvegetated and vegetated treatments, at littoral and open water locations, ranged from 96 – 98%. No long-term trend in compartment $NO_2 + NO_3$-N concentrations were observed in either littoral or open water locations (Figure 34).

As with $NO_2 + NO_3$-N, influent NH_3-N concentrations in the inflow ranged from approximately 0.5 – 1.0 mg/L (Figure 35). Initial NH_3-N concentrations on May 4 were markedly higher in the open water region than the littoral, particularly for the vegetated treatments (Figure 36). This pattern persisted through the remainder of the study, with day 14 NH_3-N concentrations in the littoral consistently lower than open water NH_3-N concentrations (Table 10). For the September and October inter-event periods, day 14 NH_3-N levels for pickerelweed were lower than those for the unvegetated compartments (Figure 36).

NH_3-N levels varied considerably with time during many of the inter-event periods. For some events the decline in NH_3-N concentrations was steady, whereas during other periods NH_3-N levels fluctuated with time (Figs. 37 and 38). Differences among treatments in NH_3-N concentrations were not consistent, with both unvegetated and pickerelweed compartments providing an 87% NH_3-N reduction in the littoral during the nine events. Mean NH_3-N removal rates were lower (75 – 78%) at open water locations. We observed no marked changes or trends in compartment NH_3-N levels during the assessment period (Figure 39).

Metals

Copper concentrations in the compartment inflow waters typically ranged from 40 – 100 µg/L (Figure 40). Prior to the first pumping event, compartment Cu levels ranged from 5 to 10 µg/L, with highest concentrations observed in the cattail open water region (Figure 41). Day 14 Cu concentrations were generally comparable between open water and littoral sites for the remainder of the study. Similarly, we observed no substantial treatment differences in Cu concentrations at day 14 throughout the study (Figure 41).

Water column Cu levels were effectively reduced in both open water and littoral regions during the inter-event periods, with all treatments exhibiting comparable performance (Table 11; Figs. 42 and 43). Mean Cu removal among all nine events for both unvegetated and pickerelweed

compartments ranged from 84 – 88% at littoral and open water locations. Copper concentrations remained low throughout the study, with all compartments effectively reducing the pumped inflow spikes to extremely low (sub-10 µg/L) concentrations (Figs. 41 and 44).

Inflow lead levels were quite low during the first two pumping events, due to precipitation of Pb in our spiking container. Following event 2, we altered the formulation of our spiking solution, and inflow Pb levels typically ranged from 40 to 100 µg/L after that time (Figure 45). Background Pb concentrations in the compartments (May 4) were quite low, at less than 2 µg/L (Figure 46). Upon initiation of the simulated storm events, day 14 Pb levels were only slightly elevated, averaging less than 5 µg/L (Figure 46).

The decline in Pb concentrations was quite rapid during the inter-event periods, both in the open water and littoral regions (Table 12; Figs. 47 and 48). Inflow Pb levels typically were reduced to below 20 µg/L within 7 days after each pumping event. Mean Pb reductions for all events ranged from 91 – 93%. We detected no differences in P concentrations among treatments during the study. As was noted for Cu, water column Pb levels exhibited a “sawtooth” pattern during the eight month assessment, with the high inflow storm event spikes rapidly reduced to background levels during the interevent periods (Figure 49).

Other Chemical and Physical Constituents

The pH of the pumped inflow waters was circumneutral (mean of 6.98), but slightly acidic relative to the existing waters in the compartments (Table 13). During each inter-event period the pH gradually increased, with pH increases slightly greater in the littoral than in open water locations. Additionally, the pH elevations during events 1-5 were greater than those observed during events 6 – 9 (Table 13).

Temperatures of the pumped inflows were higher during events 1-5 than during events 6 – 9 (29 vs. 26 °C). During the former period, temperatures gradually increased during inter-event periods, whereas later in the season temperatures declined during the 14 day period between storm events (Table 14).

Inflow dissolved oxygen (DO) concentrations averaged 4.2 mg/L, with compartment outflows ranging approximately 50% lower (Table 15). DO levels increased at both littoral and open water locations during the periods between pumping. The observed elevation in DO was higher in unvegetated systems than in the macrophyte compartments, and also was higher in the littoral zone than in the open water locations (Table 15). The averaging of surface and bottom DO measurements at the open water location probably accounted for the lower observed DO values at this site.

Oxidation-reduction potential (ORP) of the littoral sediment-water interface was consistently higher in the unvegetated compartments than in the pickerelweed compartments. Fewer measurements were available for the cattail compartments, but these ORP values were comparable to those of the unvegetated compartments (Table 16).

During the final months of the study, we observed a difference in algal colonization of water columns of the unvegetated vs. vegetated compartments. We therefore performed chlorophyll *a* and secchi depth sampling on several dates late in the study period. Mean secchi depths in the pickerelweed compartment were comparable to those in the unvegetated compartments (Table 17). By contrast, mean chlorophyll *a* levels were markedly lower in the pickerelweed (25.8 µg/L) than in the unvegetated (34.6 µg/L) compartments (Table 17).

Contaminant Removal Performance of Unvegetated, Cattail and Herbicided Cattail Compartments

In this section we compare the performance of duplicate unvegetated compartments with duplicate compartments that contained existing stands of cattail. After five storm events, the cattails were killed with an herbicide (Photo 7), and for the next four storm events we assessed the impacts of the dying vegetation on water quality.

Photo 7. A comparison of herbicided and planted cattail compartments on October 7, 2004. Herbicide was applied on September 13, 2004.

Phosphorus

The inflow TP concentrations during the pumping events averaged 392 and 450 µg/L for events 1 – 5 and 6 – 9, respectively (Table 18; Figure 50). Outflow concentrations during these events were comparable between treatments. Prior to the initiation of the initial pumping event (May 4, 2004) TP concentrations in the open water were approximately double the concentrations in the littoral zone (Figure 51). Total P levels in the unvegetated and existing cattail compartments were comparable at this time.

During events 1 – 5, day 14 TP concentrations in the existing cattail compartments were either similar, or slightly lower than those in the unvegetated compartments (Figure 51). Following the herbicide application on September 13, 2004, TP concentrations within the cattail compartments tended to be higher than the unvegetated compartments. On average, TP concentrations within the littoral zone were lower than those in the open water region for both treatments throughout the study (Table 18; Figure 51).

Figures 52 and 53 depict TP concentration changes during each inter-event period. During Events 1 – 5 both the open water and littoral regions of the unvegetated and existing cattail treatments provided comparable TP reductions. A marked decrease in TP concentrations often occurred by day 7 for both treatments. During events 6 – 9, day 7 TP levels in the herbicided cattail typically were higher than those in open water. These differences were less pronounced by day 14.

A continuous record of inflow, outflow and inter-event compartment TP concentrations for the nine events is depicted in Figure 54. The sawtooth pattern reflects the effective TP removal performance within the compartments during each inter-event period. For both littoral and open water regions, there was a slight increasing trend in water column TP concentrations during the study.

During pumping events, inflow SRP concentrations average 274 and 328 µg/L for events 1 – 5 and 6 – 9, respectively (Figure 55). During most events, outflow SRP levels approached inflow values by the 9th hour of pumping. Prior to the first pumping event, little SRP was detected in the unvegetated compartments at both the open water and littoral regions (Figure 56). At this time, a higher average SRP concentration was observed in the open water region than the littoral region of the existing cattail treatment. After initiation of the storm events, we observed few differences in SRP concentrations between the unvegetated and existing cattail compartments (Figure 56). After herbicide application, the day 14 SRP concentrations in the cattail treatments typically were higher than in the unvegetated treatments (Figure 56).

During events 1 – 5, a consistent decline in SRP concentrations occurred with time during interevent periods (Figs. 57 and 58). SRP concentrations were comparable between the open water and littoral regions during this period. However, after herbicide application the average SRP concentrations in the unvegetated compartments were lower than in the cattail compartments, particularly on day 7 (Table 19; Figs. 57 and 58).

Figure 59 depicts a continuous record of outflow and inter-event compartment SRP concentrations for the nine events. We observed a slight increasing trend in water column SRP concentrations, particularly in the herbicided cattail treatment, during the latter part of the study.

During events 1 - 5, k values for TP were slightly less than 0.1, with the existing cattail treatment generally providing slightly higher values than the unvegetated treatment (Figure 60). K values were lower during the latter events (6 – 8), with unvegetated compartments exhibiting slightly

higher K values than the herbicided cattail compartments. K values for SRP during events 1 – 5 were markedly higher (ranging up to 0.4), indicative of the more rapid removal of SRP than TP from the compartments (Figure 61). The unvegetated compartments exhibited a slightly higher k value than the herbicided cattail compartments during events 6 - 8. Higher k values were observed in the littoral region than in the open water region for all treatments.

Chemical Oxygen Demand

The pond waters contained relatively high and variable COD concentrations in the range of 50 – 80 mg/L (Figure 62). Prior to the initiation of pumping (May 4), highest littoral and open water COD concentrations were observed in the unvegetated compartments (Figure 63).

Small reductions in COD occurred during selected inter-event periods (e.g., events 5 and 8), but for most monitoring periods the COD reduction was minimal (Figs. 64 and 65). COD removal achieved by day 14 ranged from 8 - 20%. (Table 20). Upon completion of the final pumping event, the resulting littoral and open water COD levels were comparable to those observed prior to the beginning of the study (Figure 66).

Total Suspended Solids

The pumped inflow TSS levels typically were low, ranging from 2.0 to 10.0 mg/L (Figure 67). Prior to the initiation of the pumping events on May 4, open water TSS concentrations ranged from 7.0 to 8.5 mg/L, whereas littoral TSS levels were lower, at 2.0 – 3.0 mg/L (Figure 68).

Total suspended solids removal performance within the compartments varied widely among events, with percentage TSS removal rates highest when inflow TSS concentrations were high (Figs. 69 and 70). We observed little difference between the unvegetated, existing cattail and herbicided cattail treatments with respect to TSS removal (Table 21). However, on selected events (e.g., events 7 and 8) following herbicide application, cattail compartment TSS levels exceeded those in the unvegetated compartments (Figs. 69 and 70). Total suspended solids concentrations within the compartments varied temporally during the nine pumping events, but there was no clear increasing or decreasing trend in TSS levels during this assessment (Figure 71).

Nitrogen

Total Kjeldahl nitrogen concentrations in the compartment inflows averaged 2.00 mg/L during events 1 - 5, with slightly lower values noted from compartment outflows during the pumping events (Figure 72). Prior to the initiation of the first event on May 4, TKN concentrations in the littoral region were approximately half of those in open water (Figure 73). During the interevent periods, TKN concentrations declined gradually among all compartments (Figure 74 and 75). On average the TKN concentrations were slightly lower in the littoral region than the open water region (Table 22). Over the course of the nine pumping events, we observed a slight increase in compartment TKN concentrations, both in open water and littoral locations (Figure 76).

Nitrate + Nitrite-N (NO_2 + NO_3-N) levels in the pumped inflow waters typically ranged from 0.5 to 1.00 mg/L (Figure 77). Background NO_2 + NO_3-N concentrations in the compartments at both littoral and open water locations were less than 0.01 mg/L on May 4, prior to the initiation of the first pumping event (Figure 78). All compartments were quite effective at removing NO_2 + NO_3-N (Table 23). Day 14 NO_2 + NO_3-N concentrations for most pumping events were less than 0.02 mg/L, with the exception of events 5 and 8, where NO_2 + NO_3-N levels in the open water and littoral regions of the herbicided cattail compartments were 0.02 – 0.06 mg/L (Figure 78).

The removal of NO_2 + NO_3-N from the compartments during the inter-event periods was rapid. For both littoral and open water locations, NO_2 + NO_3-N levels dropped to extremely low levels by day 7, and in some cases, within one day after the pumping event (Figs. 79 and 80). No short-term herbicide effects, or long-term trends in compartment NO_2 + NO_3-N concentrations were observed in either littoral or open water locations (Figure 81).

As with NO_2 + NO_3-N, influent NH_3-N concentrations in the inflow ranged from approximately 0.5 – 1.0 mg/L (Figure 82). Initial NH_3-N concentrations on May 4 were higher in the open water region than the littoral, particularly for the existing cattail treatment (Figure 83). Day 14 NH_3-N concentrations in the littoral were consistently lower than open water NH_3-N concentrations throughout the remainder of the study.

NH_3-N levels varied markedly with time during many of the inter-event periods (Table 24). On some events the decline in NH_3-N concentrations was steady, whereas during other periods NH_3-N levels fluctuated with time (Figs. 84 and 85). Differences among treatments in NH_3-N concentrations were not consistent. We observed no consistent changes or trends in compartment NH_3-N levels during the assessment period (Figure 86).

Metals

Copper concentrations in the compartment inflow waters typically ranged from 40 – 100 µg/L (Figure 87). Prior to the first pumping event, compartment Cu levels ranged from 5 to 10 µg/L, with highest concentrations observed in the existing cattail littoral region (Figure 88). Day 14 Cu concentrations generally were comparable between open water and littoral sites for the remainder of the study. Similarly, we observed no substantial treatment differences in Cu concentrations at day 14 throughout the study (Figure 88).

Water column Cu levels were effectively reduced in both open water and littoral regions during the inter-event periods, with all treatments exhibiting comparable performance (Table 25; Figs. 89 and 90). Copper concentrations remained low throughout the study, with all compartments reducing the pumped inflow spikes to extremely low (sub-10 µg/L) concentrations (Figs 88 and 91).

Following event 2, inflow Pb levels typically ranged from 40 to 100 µg/L (Figure 92). Background Pb concentrations in the compartments (May 4) were quite low, averaging less than 2 µg/L (Figure 93). Upon initiation of the simulated storm events that incorporated the "improved" spiking solution (8/4/04), day 14 Pb levels in the compartments were only slightly elevated, averaging less than 6 µg/L (Figure 93).

The decline in Pb concentrations was quite rapid during the inter-event periods, both in the open water and littoral regions (Figs. 94 and 95). Inflow Pb levels typically were reduced to below 20 µg/L, and in most cases less than 10 µg/L, within 7 days after each pumping event. We detected no differences in Pb concentrations among treatments during these periods (Table

26). As was noted for Cu, the high inflow storm event Pb spikes were rapidly reduced to background levels during the interevent periods (Figure 96).

Other Chemical and Physical Constituents

The pH of the pumped inflow waters typically was circumneutral. During events 1 – 5 the pH at both littoral and open water locations gradually increased following cessation of pumping (Table 27). The pH increases were slightly greater in the littoral than in open water locations. The herbicide application had a notable effect on water column pH. For events 6 – 9, both littoral and open water pH values in the herbicided cattail treatment remained lower than those in the unvegetated systems (Table 27).

Temperatures of the pumped inflows were higher during events 1 - 5 than during events 6 – 9 (29 vs. 26 °C). We observed no difference in water column temperatures between unvegetated and the cattail (existing and herbicided) treatments (Table 28).

Inflow dissolved oxygen (DO) concentrations averaged 4.2 mg/L for events 1 – 5 and 4.0 mg/L for events 6 – 9, with compartment outflows approximately 50% lower (Table 29). DO levels increased at both littoral and open water locations during interevent periods, with the cattail compartments (both existing and herbicided) exhibiting slightly lower DOs than those in the unvegetated compartments. Both existing and herbicided cattails exhibited lower ORP levels at the sediment–water interface than did unvegetated compartments (Table 30). Secchi depths and chlorophyll *a* concentrations in the compartments varied somewhat over time, but between-treatment differences (herbicided cattail vs. unvegetated) were inconsistent (Table 31).

Contaminant Removal Performance of Unvegetated, Planted Cattail and Planted Pickerelweed Compartments

We initiated this study with a total of six unvegetated compartments. The contaminant removal performance of these six unvegetated compartments was monitored for two events, after which time four of the compartments were planted with macrophytes (two in cattail, two in pickerelweed). The macrophytes were planted in late June, and became well established within three weeks (Photo 8), after which time compartment monitoring was resumed. In depicting the

inflow and outflow constituent concentrations (Figure 97), we averaged the results from all six of the unvegetated compartments for the first two events. For inter-event comparisons, by contrast, constituent concentrations from the various "unvegetated" treatments during the first two storm events are displayed separately.

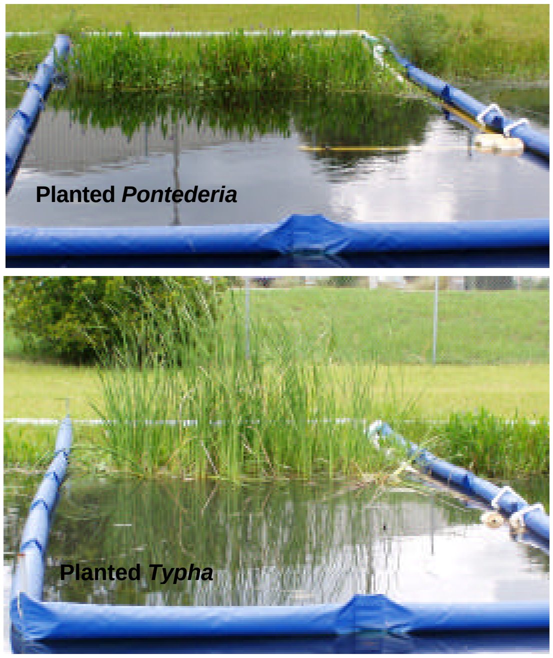


Photo 8. Cattail (*Typha latifolia*) and pickerelweed (*Pontederia cordata*) three weeks after planting into previously unvegetated compartments.

Phosphorus

The inflow TP feedwater concentrations during the simulated storm events averaged 373 and 430 µg/L for events 1 - 2 and 3 - 9, respectively (Figure 97, Table 31). Mean outflow TP concentrations (sum of 3, 6 and 9 hour samples) were comparable among compartments, ranging from 270 to 300 µg/L (Table 32).

For the first two events, the two compartments that we selected to be unvegetated for the duration of the study provided slightly lower (for day 14) open water TP concentrations than the four compartments that later were planted with macrophytes (Table 32; Figure 98). With the exception of two later inter-event periods, 9/16 and 10/6, these same two unvegetated compartments continued to provide lowest open water TP concentrations throughout the study (Figure 98). Similarly, despite the planting of macrophytes after storm event 2, the day 14 water column TP levels generally were comparable among treatments

Figures 99 and 100 depict TP concentration changes during each inter-event period. A moderate decrease in TP concentrations was observed in most treatments by day 7 following each event. Total P reductions generally were slightly greater in the littoral than open water regions throughout the study (Table 32).

A continuous record of outflow and inter-event compartment TP concentrations for the nine events is depicted in Figure 101. The resulting pattern reflects the effective TP removal performance within the compartments during each inter-event period. For both littoral and open water regions, there was a slight increasing trend in water column TP concentrations during the study.

During pumping events, inflow SRP concentrations averaged 273 and 306 µg/L for events 1 – 2 and 3 - 9, respectively (Table 32; Figure 102Prior to the first pumping event, SRP concentrations within the littoral zone of all unvegetated compartments were less than 10 µg/L (Figure 103). By contrast, open water SRP concentrations in the unplanted pickerelweed and unplanted cattail treatments at this time were markedly higher than those in the two compartments that remained unvegetated throughout the study. After initiation of the storm events, average open water SRP concentrations usually were higher than the littoral region (Figure 103). However, once the macrophytes were planted, the pickerelweed and cattail compartments exhibited higher SRP concentrations than the unvegetated compartments during four of the seven events (Figure 103).

During inter-event periods, we observed a gradual decline in SRP concentrations from day 0 (represented by the 9 hour outflow sample concentration during the pumping event) to day 14 (Figures 104 and 105). Day 14 SRP concentrations were slightly lower in the littoral than in open water regions (Table 33). In general, SRP concentration differences between the unvegetated and planted macrophyte treatments were slight (Figures 104 and 105).

Figure 106 depicts a continuous record of inflow, outflow and inter-event compartment SRP concentrations for the nine events. For both littoral and open water regions, there was a slight increasing trend in water column SRP concentrations during the study.

During events 1 - 2, k values for TP were less than 0.1, with the compartments selected to remain unvegetated during the duration of the study providing higher values than the other unvegetated treatments (Figure 107). After the macrophytes were planted (events 3 – 8), the unvegetated compartments continued to exhibit slightly higher k values than the macrophyte compartments. K values for SRP typically were higher than those for TP (Figs. 107 and 108). Although k values for events 3 – 8 (after planting) were higher than those for events 1 – 2, macrophyte k values remained slightly lower than those for unvegetated compartments during the latter portion of the study.

Chemical Oxygen Demand

Compartment inflow and outflow COD concentrations were comparable, particularly during events 5 – 9 of the study (Figure 109). Prior to the initiation of pumping (May 4), highest COD concentrations among treatments were observed in the compartments that were to remain unvegetated throughout the project (Figure 110).

Small percentages of COD were removed during some inter-event periods (e.g., events 5 and 7), but for most monitoring periods the COD reduction was minimal (Figs. 111 and 112). Overall, day 14 COD reductions ranged from –2 to 17%. Observed treatment differences in COD removal were negligible. (Table 34). Upon completion of the final pumping event, the resulting littoral and open water COD levels were comparable to those observed prior to the beginning of the study (Figure 113).

Total Suspended Solids

We observed some variation in the inflow and outflow TSS concentrations during the study, but this was due to temporal variations in native pond water TSS levels since inflows were not spiked for TSS during the simulated events (Figure 114). Prior to beginning of the pumping events on May 4, open water TSS concentrations ranged from 7.0 to 12 mg/L, whereas littoral TSS levels were lower, at 3.0 – 4.0 mg/L (Figure 119).

As noted in previous sections, TSS removal performance within the compartments varied widely among events (Figs. 116 and 117). For five of the nine events (events 2, 4, 5, 8 and 9)

open water TSS concentrations were higher on day 1 than day 0 (represented by the 9 hour outflow sample concentration during the pumping event). This same pattern was noted during events 4, 8 and 9 within the littoral region (Figures 116 and 117). TSS removal among planted and unvegetated treatments was comparable (Table 35).

TSS concentrations within the compartments varied during the nine pumping events, but there was no clear increasing or decreasing trend in TSS levels during this assessment (Figure 118).

Nitrogen

Total Kjeldahl nitrogen concentrations in the compartment inflows averaged 1.6 and 2.0 mg/L for events 1 - 2 and 3 - 9, respectively, with slightly lower values noted from compartment outflows during the pumping events (Table 36; Figure 119). On May 4, prior to the initiation of the first event, TKN concentrations in the littoral region were approximately 50% of those in open water (Figure 120). Following macrophyte planting, TKN removal remained greater in the littoral than the open water region (Table 36; Figure 119). Differences in TKN removal among the planted and unvegetated treatments were inconsistent, and generally minimal (Figures 121 and 122). Over the course of the nine pumping events, we observed a slight increase in compartment TKN concentrations, both in open water and littoral locations (Figure 123).

Nitrite + Nitrate-N levels in the pumped inflow waters were slightly higher than those in the outflows (Figure 124). Background NO_2 + NO_3-N concentrations in the compartments at both littoral and open water locations were less than 0.01 mg/L on May 4, prior to the initiation of the first pumping event (Figure 125). All compartments were quite effective at removing NO_2 + NO_3-N (Table 37). Day 14 NO_2 + NO_3-N concentrations for most pumping events were less than 0.01 mg/L within both regions. Exceptions to this were events 2 and 8 within the open water region and events 2, 5, and 8 within the littoral region (Figure 125).

The removal of NO_2 + NO_3-N from the compartments during the inter-event periods was rapid (Figs. 126 and 127). Differences in NO_2 + NO_3-N removal among treatments were comparable, with unvegetated and planted compartments providing 98 – 99% NO_2 + NO_3-N reductions by day 14 (Table 37). No long-term trend in compartment NO_2 + NO_3-N concentrations were observed in either littoral or open water locations (Figure 128).

NH_3-N concentrations in the compartment inflows ranged from approximately 0.5 – 1.0 mg/L (Figure 129). For the unvegetated compartments that were later planted with macrophytes, initial open water NH_3-N concentrations on May 4 were markedly higher than for the unvegetated "control" treatment (Table 38; Figure 130). Throughout the remainder of the study, day 14 NH_3-N concentrations in the littoral were consistently lower than open water NH_3-N concentrations. For the August 27 inter-event period, day 14 NH_3-N levels for all treatments were noticeably elevated, ranging from 0.3 – 0.4 mg/L. For the next two inter-event periods (9/16 and 10/6), open water NH_3-N concentrations were again elevated, primarily in the unvegetated, rather than planted compartments (Figure 130).

NH_3-N levels varied considerably with time during many of the inter-event periods. On some events the decline in NH_3-N concentrations was steady, whereas during other periods NH_3-N levels fluctuated with time (Figs. 131 and 132). Differences in NH_3-N concentrations between planted and unvegetated compartments were not consistent. We observed no marked changes or trends in compartment NH_3-N levels during the assessment period (Figure 133).

Metals

Copper concentrations in the compartment inflow waters averaged 60 and 80 µg/L for events 1 – 2 and 3 – 9, respectively (Table 39). Outflow concentrations were lower, typically ranging from 40 – 60 µg/L (Figure 134). Prior to the first pumping event, compartment Cu levels ranged from 4 to 6 µg/L (Figure 135). Day 14 Cu concentrations generally were comparable between open water and littoral sites for the remainder of the study.

For most events, we observed a sharp decline in Cu concentrations by day 7 of the inter-event periods, with little difference in Cu removal as a function of vegetation presence (Figs. 136 and 137). During events 3 – 9 (following planting), Cu reductions were comparable among all treatments, ranging from 80 – 89% (Table 39). Copper concentrations remained low throughout the study, with all compartments reducing the pumped inflow spikes to extremely low (sub-10 µg/L) concentrations (Figure 138).

Following event 2, inflow Pb levels typically ranged from 40 to 100 µg/L (Figure 139). Background Pb concentrations in the compartments (May 4) were quite low, averaging less than 2 µg/L (Figure 140). Upon initiation of the simulated storm events that incorporated the "improved" spiking solution (8/4/04), day 14 Pb levels in the compartments were only slightly elevated, averaging less than 7 µg/L (Table 40; Figure 140).

Substantial reductions in Pb concentrations typically occurred by day 7 of the inter-event periods, both in the open water and littoral regions (Figs. 141 and 142). After macrophyte planting, both vegetated and unvegetated compartments provided effective Pb removal, in excess of 87% by day 14 of the inter-event period (Table 40). Throughout the study, the high inflow storm event Pb spikes were rapidly reduced to background levels during the interevent periods (Figure 143).

Other Chemical and Physical Constituents

During events 1 – 2, the pH at both littoral and open water locations of the six unvegetated compartments gradually increased after cessation of pumping. The pH increases were slightly greater in the littoral than in open water locations. Following planting, observed pH increases during the inter-event periods in the planted compartments were lower than those in the unvegetated compartments (Table 41).

Temperatures of the pumped inflows were slightly higher during events 1 - 2 than during events 3 – 9. We observed no difference in water column temperatures between unvegetated and planted compartments (Table 42).

Inflow dissolved oxygen (DO) concentrations averaged 4.9 mg/L for events 1 – 2 and 3.9 mg/L for events 3 – 9 (Table 43). DO levels varied considerably with time during the inter-event periods, and the presence of planted vegetation appeared to cause a slight reduction in DO relative to the concentrations observed in the unvegetated compartments (Table 43). Trends in ORP were comparable to those observed for water column DO, with ORP levels lower in the planted macrophyte compartments than in the unvegetated compartments (Table 44). Secchi depths and chlorophyll *a* concentrations in the compartments varied somewhat over time, but

between-treatment differences (planted cattail and planted pickerelweed vs. unvegetated) were inconsistent (Table 45).

Treatment Comparisons and Contaminant Removal Processes

Both vegetated and unvegetated compartments exhibited effective removal of most contaminants throughout the study. The contaminants for which we observed highest removal rates, based on mean concentration reductions during the inter-event periods in the littoral region of unvegetated compartments, were NO_2 + NO_3-N (98%), Pb (93%), SRP (89%), Cu (88%) and NH_3-N (87%). Moderate removal rates were observed for TP (63%) and TKN (37%), while relatively poor removal was documented for TSS (27%) and COD (10%). With the exception of N and the latter two parameters, these removal efficiencies fall within the broad range of expected contaminant removal effectiveness of wet detention ponds (Table 1). Our observed TP removal, for example, is similar to that predicted by a popular wet detention pond model, that suggests ~ 55 – 60% TP reduction can be achieved with 14 days residence time in a 3 m deep wet detention pond (Walker 1987).

Observed contaminant removal effectiveness likely was related to the concentration and chemical form of the constituent in the inflow waters. For example, greatest percentage TSS reductions were observed during events in which inflow TSS concentrations were high. Greater percentage TSS reductions probably would have been achieved if mean inflow TSS levels had been comparable to typical runoff concentrations in this region (e.g., average TSS in runoff from low-intensity commercial land use is 81 mg/L; Harper 1994). By contrast, observed COD and N removal rates likely were a function of the chemical form of these constituents. The native COD and organic N in the pond waters were relatively recalcitrant, whereas the spiked aliquots of COD and N (the inorganic forms NH_3-Nand NO_2 + NO_3-N), were more labile, and were readily removed within the compartments. Our higher than expected (Table 1) N removal rates probably were due the large fraction of the labile N forms in the compartment inflows.

We observed few differences in water quality between vegetated and unvegetated compartments. Apparent differences between mean values noted in the preceding sections were rarely statistically significant. For example, during inter-event periods we noted that water

quality often improved more rapidly and to a greater extent in the shallow littoral zone than in the deeper open water region of the compartments. Comparisons of mean inter-event period day 14 constituent concentrations at littoral and open water locations for all treatments do indicate slightly lower littoral concentrations for many constituents (Figures 144 - 146). We performed a suite of non-parameteric means tests (Wilcoxon Matched Pairs Test), and found significant differences between average littoral and open water TP concentrations in selected treatments (for unvegetated $p = 0.01$, existing pickerelweed $p = 0.02$ and planted cattail $p = 0.02$). (Figure 144). Significant differences between inter-event littoral and open water NH_3-N concentrations also were observed, but as with TP, these differences were confined primarily to those treatments (unvegetated $p = 0.027$ and existing pickerelweed $p = 0.008$) for which we had greatest replication over time (i.e., in operation for all nine storm events; (Figure 145)). None of the other constituents exhibited significant differences for this littoral vs. open water comparison.

There are two reasons why littoral treatment performance would be expected to exceed that of open water locations. First, sedimentation and accumulation of particulate matter and associated pollutants usually is greatest in the deep regions of wet detention ponds. Dissolved constituents, produced by the decomposition of accrued particulate matter, can diffuse from enriched sediments to the water column, thereby increasing water column pollutant levels (Fisher and Reddy 2001). Conversely, the high surface area (sediment surfaces, macrophyte stems) available for attachment of microbial populations in the littoral is thought to enhance immobilization and transformation of dissolved constituents. Grace (2003) demonstrated in laboratory incubations under oxic conditions that cattail litter rapidly immobilizes water column SRP.

It is important to note that potential water quality differences between the littoral and open water zones in our study may have been at least partially masked by hydraulic exchange between these regions. The littoral zone comprised 20% of the surface area, but a much smaller percentage of each compartment on a volume basis. It is probable that temperature gradients and/or wind caused bulk water movement between regions during inter-event periods, thereby diluting and masking the effects of pollutant treatment in the littoral.

Differences between the unvegetated and macrophyte-dominated littoral zones during this study generally were minimal within storm events, and inconsistent among storm events. The emergent macrophyte vegetation typically caused slightly lower water column DO concentrations, which is to be expected since the shading afforded by the macrophytes can reduce algal photosynthesis. A reduction in water column photosynthesic rates also likely explains the slightly lower pH conditions measured in macrophyte compartments. Additionally, litter production by macrophytes, and its subsequent decomposition, probably contributed to between-compartment microenvironmental differences such as reduced DO, pH and ORP values. Observed differences in water column COD, TSS, nutrients and metals between vegetated and unvegetated compartments were, however, slight.

Several factors may explain why the presence of emergent macrophytes in the littoral did not significantly influence concentrations of metals and nutrients in the water column. First, emergent macrophytes rely on root uptake to obtain nutrients, and it is possible that the soils in the littoral region were enriched (with N and P, for example) to the extent that no external (i.e., water column) nutrient supplies were required to support plant growth. Additionally, it should be noted that both vegetated and unvegetated littoral regions support populations of microbiota (algae, bacteria) in the water column and at the sediment-water interface. Such organisms can actively sequester and transform pollutants.

Indeed, the consistent reduction in levels of dissolved constituents loaded into the unvegetated compartments during nine storm events over an eight-month period suggests that either chemical sorption processes and/or biological uptake by algae and bacteria were prominent removal mechanisms. Late in the study, we observed differences in both unicellular and filamentous algae densities between unvegetated and selected macrophyte compartments. Water column chlorophyll *a* concentrations typically were higher in unvegetated than in pickerelweed compartments on several sampling dates during the final month of the study (Table 17). Additionally, moderate growths of filamentous algae were observed in unvegetated compartments, whereas little algae was observed in compartments with macrophyte vegetation (Photo 9).

Photo 9. Presence of filamentous algae following the 9th pumping event. Clockwise from top left, unvegetated, planted cattail and planted pickerelweed compartments.

To quantify these differences, we performed cover estimates for both filamentous algae and floating duckweed (*Lemna* sp.) in November 2004, and again in February 2005, two months after the final storm event. In November, only the unvegetated treatments contained a substantial standing crop of filamentous algae, which at this time covered 30% of the compartment surface area (Figure 147). Three treatments - the herbicided cattail, existing pickerelweed and planted pickerelweed - contained duckweed mats that covered from 8 to 34% of the water's surface. The herbicided cattail compartments exhibited the greatest duckweed cover. During February, following two months of stagnant conditions, both the filamentous algae and duckweed had expanded within the compartments, with the unvegetated treatments containing the greatest filamentous algae cover (~55%) and the herbicided cattail treatment containing the highest duckweed cover (~82%) (Figure 147).

The proliferation of filamentous algae and duckweed in the unvegetated and herbicided cattail compartments suggests that water column nutrients, sourced either from previous storm events or the decomposition of emergent vegetation, were of adequate concentration to support

growth of non-rooted plants. The herbiciding of cattails resulted in a short-term increase in littoral and open water TP and SRP levels, but had little or no effect on TSS, N species, COD, or metals. The water column pH declined, as did sediment-water interface ORP, immediately after herbicide application. While these effects on chemical constituent concentrations were subtle, it is interesting that they were pronounced enough to stimulate duckweed growth within the compartments. Hence, under certain nutrient loading regimes, the presence of healthy emergent vegetation may actually serve to reduce proliferation of filamentous algae and duckweed, probably due to competition for nutrients. This corroborates a previous suggestion that exclusion of littoral zone vegetation can stimulate algal blooms (Rushton 1997).

The loading rate of contaminants during simulated storm events, both on an instantaneous and cumulative basis, also likely influenced contaminant removal performance by selected compartments. We chose our inflow concentration spikes for dissolved constituents based on a prior evaluation of average runoff constituent concentrations in central Florida (Harper 1994). Under our concentration and loading regimes, essentially all of the NO_2 + NO_3-N (98%) was removed within the compartments during inter-event periods. Relative to unvegetated compartments, however, the macrophyte littoral regions contained a greater mass of leaf litter (which presumably would act as a favorable carbon source) as well as lower sediment-water interface ORP levels. Both of these factors would be expected to enhance removal of NO_2 + NO_3-N by denitrification (Lorenz and Biesboer 1987). It is likely that this higher potential for denitrification in the vegetated littoral was constrained by the NO_2 + NO_3-N supply. Hence, while no between-treatment differences in NO_2 + NO_3-N removal were observed in this study, such differences may be evident under higher NO_2 + NO_3-N loadings.

The continuous pollutant loading provided by the nine storm events also resulted in some accumulation of contaminants, such as TP, in the compartments over the course of the study (Figure 6). The cumulative P loading provided to the compartments during the nine simulated storm events was approximately 11 gP / m^2-yr, which represents a moderately high P loading to either wetland or lotic systems. Richardson and Qian (1999) suggested that freshwater marshes can receive P inputs of up to ~1 gP / m^2-yr without exhibiting significant change with respect to biological community structure. We observed biological responses to increased nutrient

availability late in our study. Filamentous algae were sparse in the study compartments throughout the first seven simulated storm events, and visibly increased during the last two storm events. It is possible that contaminant removal mechanisms in the compartments, either biological or physicochemical, had become saturated near the end of the study. The unvegetated compartments, as well as those with herbicided cattails, exhibited the most dramatic biological response (growth of non-rooted vegetation), which suggests that nutrient removal sinks in these compartments were the first to be exhausted. Since these responses were noted in the fall, an alternative explanation would be that the seasonal reduction in light and temperature compromised contaminant removal processes.

With respect to pollutant accumulation, we performed a suite of measurements to determine whether our simulated storm events had an adverse effect on the quality of the detention pond outflows. We measured water quality in the detention pond on two occasions (September 2003 and May 2004) prior to the first simulated storm event, and monitored the pond outflow on several dates in fall 2004. Near the end of the study, pond outflow concentrations for most constituents, including TP, COD, TSS, TKN, Cu and Pb, were comparable to or lower than the original background samples (Figs. 148 – 150). Concentrations of SRP, NH_3-N and NO_2 + NO_3-N peaked above background levels on several dates in fall 2004 (Figures 148 and 149). Because these parameters were rapidly removed in the compartments during inter-event periods (e.g. removal rates ranging from 87 – 98%), it is probable that the bulk pond environment also was effective at processing these constituents. During our simulated storm events, the compartment outflows contributed only a small flow relative to the entire volume of the detention pond. Therefore, the observed concentration peaks of SRP, NH_3-N and NO_2 + NO_3-N in the pond outflows were likely due to loadings of these constituents to the pond during natural high volume runoff events.

Another phenomenon observed late in the study was the senescence of pickerelweed, both in "planted" and "existing" compartments. This senescence may have caused the slight increasing trend in TP observed during the final inter-event periods. Other than this visual decline in pickerelweed in late fall, there was no evidence for either cattail or pickerelweed being a superior plant for enhancing water quality in pond littoral regions.

This exploratory study provided some useful insight into contaminant removal processes in wet detention ponds, particularly during inter-event periods. Much of the existing empirical and theoretical data on detention pond performance is related to pollutant removal associated with the settling of particulate matter. This study provides an extensive data record on removal of dissolved nutrients and metals under low TSS conditions. These data should prove useful for wet detention pond performance modeling and design purposes.

Table 4. Mean TP concentrations (µg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	Unvegetated			Existing Pickerelweed			Existing Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	392	78	-	392	78	-	392	78	-
Outflow	281	60	-	280	53	-	290	59	-
Littoral									
1 Day	310	74	-10	326	119	-16	325	103	-12
7 Day	117	20	58	124	26	56	115	31	60
14 Day	87	31	69	88	28	68	77	28	74
Open Water									
1 Day	310	72	-10	313	94	-12	321	83	-10
7 Day	197	59	30	190	41	32	152	29	48
14 Day	124	56	56	130	48	54	99	37	66

Events 6-9	Unvegetated			Existing Pickerelweed		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	450	59	-	450	59	-
Outflow	308	52	-	290	55	-
Littoral						
1 Day	393	77	-28	388	78	-34
7 Day	141	50	54	203	57	30
14 Day	117	18	62	132	8	55
Open Water						
1 Day	363	47	-18	356	44	-23
7 Day	166	50	46	224	54	23
14 Day	171	92	44	142	15	51

Table 5. Mean SRP concentrations (µg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Pickerelweed**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	274	74	-	274	74	-	274	74	-
Outflow	176	52	-	174	46	-	186	56	-
Littoral									
1 Day	111	26	37	121	25	31	118	26	36
7 Day	45	27	75	60	33	66	46	29	75
14 Day	16	13	91	26	18	85	17	15	91
Open Water									
1 Day	111	27	37	112	29	35	118	34	37
7 Day	82	41	53	81	30	54	61	32	67
14 Day	27	22	84	31	23	82	22	21	88

Events 6-9	**Unvegetated**			**Existing Pickerelweed**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	328	53	-	328	53	-
Outflow	215	52	-	197	48	-
Littoral						
1 Day	164	47	24	152	22	23
7 Day	64	34	70	100	38	49
14 Day	31	13	86	47	12	76
Open Water						
1 Day	157	44	27	154	15	22
7 Day	79	36	63	116	33	41
14 Day	48	25	78	53	9	73

Table 6. Mean COD concentrations (mg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period..

Events 1-5	**Unvegetated**			**Existing Pickerelweed**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	71	34	-	71	34	-	71	34	-
Outflow	61	7	-	61	6	-	66	21	-
Littoral									
1 Day	58	7	4	58	7	6	60	7	9
7 Day	46	11	25	43	8	29	47	13	29
14 Day	55	10	10	52	9	15	53	4	20
Open Water									
1 Day	59	7	3	57	7	7	61	10	7
7 Day	47	13	22	46	9	25	47	7	29
14 Day	54	4	10	52	8	15	55	8	17

Events 6-9	**Unvegetated**			**Existing Pickerelweed**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	74	5	-	74	5	-
Outflow	68	8	-	66	8	-
Littoral						
1 Day	68	16	0	65	6	2
7 Day	56	7	18	57	7	14
14 Day	62	17	9	51	3	22
Open Water						
1 Day	66	7	4	63	5	3
7 Day	59	5	14	55	4	16
14 Day	60	14	12	57	8	14

Table 7. Mean TSS concentrations (mg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	Unvegetated			Existing Pickerelweed			Existing Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	5.0	1.2	-	5.0	1.2	-	5.0	1.2	-
Outflow	5.1	1.9	-	5.4	1.8	-	4.9	1.5	-
Littoral									
1 Day	7.0	2.8	-38	9.6	10.7	-80	8.7	4.8	-79
7 Day	3.2	1.7	36	3.0	3.4	45	2.4	1.0	51
14 Day	3.6	1.3	29	3.2	2.7	40	2.6	1.2	47
Open Water									
1 Day	7.1	3.4	-40	6.7	3.8	-26	7.1	3.1	-45
7 Day	4.1	3.3	18	4.3	2.8	20	3.5	2.2	28
14 Day	4.5	1.5	12	4.6	2.4	15	3.6	1.4	26

Events 6-9	Unvegetated			Existing Pickerelweed		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	5.3	2.7	-	5.3	2.7	-
Outflow	5.3	2.0	-	4.4	1.5	-
Littoral						
1 Day	6.6	2.4	-25	8.8	3.6	-100
7 Day	3.3	1.0	37	6.9	7.0	-57
14 Day	3.9	1.6	25	3.9	1.0	12
Open Water						
1 Day	6.6	1.3	-26	6.6	1.2	-49
7 Day	3.2	1.8	39	4.0	2.2	10
14 Day	5.2	2.4	1	4.1	1.5	8

Table 8. Mean TKN concentrations (mg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	Unvegetated			Existing Pickerelweed			Existing Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	1.999	1.701	-	1.999	1.701	-	1.999	1.701	-
Outflow	1.419	0.224	-	1.381	0.183	-	1.458	0.239	-
Littoral									
1 Day	1.564	0.365	-10	1.587	0.542	-15	1.548	0.405	-6
7 Day	0.846	0.098	40	0.758	0.100	45	0.870	0.356	40
14 Day	0.719	0.198	49	0.651	0.133	53	0.654	0.130	55
Open Water									
1 Day	1.502	0.251	-6	1.570	0.505	-14	1.722	0.484	-18
7 Day	1.229	0.325	13	1.060	0.210	23	0.916	0.116	37
14 Day	0.885	0.293	38	0.859	0.324	38	0.773	0.170	47

Events 6-9	Unvegetated			Existing Pickerelweed		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	1.774	0.234	-	1.774	0.234	-
Outflow	1.408	0.249	-	1.346	0.185	-
Littoral						
1 Day	1.950	1.163	-39	1.710	0.357	-27
7 Day	0.966	0.187	31	1.061	0.347	21
14 Day	1.093	0.255	22	1.060	0.166	21
Open Water						
1 Day	1.630	0.193	-16	1.586	0.234	-18
7 Day	1.173	0.442	17	1.120	0.258	17
14 Day	1.398	0.426	1	1.007	0.153	25

Table 9. Mean NO_2 + NO_3-N concentrations (mg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	Unvegetated			Existing Pickerelweed			Existing Cattail		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.903	1.519	-	0.903	1.519	-	0.903	1.519	-
Outflow	0.463	0.158	-	0.445	0.146	-	0.477	0.176	-
Littoral									
1 Day	0.228	0.218	51	0.189	0.232	57	0.182	0.225	62
7 Day	0.025	0.030	95	0.047	0.049	89	0.043	0.098	91
14 Day	0.008	0.009	98	0.013	0.018	97	0.008	0.015	98
Open Water									
1 Day	0.216	0.219	53	0.181	0.216	59	0.189	0.247	60
7 Day	0.021	0.022	96	0.040	0.048	91	0.019	0.028	96
14 Day	0.006	0.003	99	0.013	0.021	97	0.009	0.012	98

Events 6-9	Unvegetated			Existing Pickerelweed		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.750	0.162	-	0.750	0.162	-
Outflow	0.473	0.153	-	0.431	0.151	-
Littoral						
1 Day	0.162	0.270	66	0.171	0.268	60
7 Day	0.032	0.030	93	0.070	0.057	84
14 Day	0.012	0.013	97	0.020	0.031	95
Open Water						
1 Day	0.205	0.313	57	0.156	0.270	64
7 Day	0.030	0.030	94	0.056	0.052	87
14 Day	0.011	0.010	98	0.019	0.027	96

Table 10. Mean NH_3-N concentrations (mg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Pickerelweed**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.930	1.173	-	0.930	1.173	-	0.930	1.173	-
Outflow	0.475	0.145	-	0.479	0.139	-	0.522	0.175	-
Littoral									
1 Day	0.116	0.059	76	0.156	0.124	67	0.160	0.080	69
7 Day	0.090	0.139	81	0.073	0.109	85	0.070	0.116	87
14 Day	0.092	0.131	81	0.089	0.149	81	0.070	0.095	87
Open Water									
1 Day	0.133	0.044	72	0.156	0.135	67	0.199	0.118	62
7 Day	0.223	0.222	53	0.141	0.156	71	0.123	0.134	76
14 Day	0.137	0.159	71	0.157	0.180	67	0.088	0.082	83

Events 6-9	**Unvegetated**			**Existing Pickerelweed**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.838	0.151	-	0.838	0.151	-
Outflow	0.547	0.128	-	0.496	0.137	-
Littoral						
1 Day	0.195	0.151	64	0.184	0.047	63
7 Day	0.099	0.065	82	0.098	0.114	80
14 Day	0.034	0.023	94	0.028	0.016	94
Open Water						
1 Day	0.242	0.150	56	0.209	0.042	58
7 Day	0.139	0.070	75	0.132	0.108	73
14 Day	0.116	0.143	79	0.043	0.022	91

Table 11. Mean Cu concentrations (µg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Pickerelweed**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	75	62	-	75	62	-	75	62	-
Outflow	43	13	-	41	12	-	44	13	-
Littoral									
1 Day	48	11	-11	51	14	-25	53	14	-18
7 Day	11	5	74	12	5	70	12	5	73
14 Day	5	3	89	6	4	86	5	4	88
Open Water									
1 Day	47	11	-9	48	12	-17	50	13	-13
7 Day	12	6	71	13	5	69	12	5	73
14 Day	5	3	88	6	4	86	5	3	88

Events 6-9	**Unvegetated**			**Existing Pickerelweed**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	77	18	-	77	18	-
Outflow	49	13	-	44	13	-
Littoral						
1 Day	62	10	-25	56	10	-27
7 Day	15	7	69	15	5	65
14 Day	7	1	87	7	1	84
Open Water						
1 Day	58	8	-18	56	11	-26
7 Day	17	7	66	16	5	64
14 Day	7	1	86	8	1	83

Table 12. Mean Pb concentrations (µg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Pickerelweed**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	59	61	-	59	61	-	59	61	-
Outflow	35	27	-	34	26	-	35	27	-
Littoral									
1 Day	32	26	8	38	29	-13	36	29	-2
7 Day	4	3	89	5	4	84	4	3	88
14 Day	2	1	94	2	2	93	2	1	94
Open Water									
1 Day	32	26	8	33	27	3	34	28	4
7 Day	6	6	84	5	5	84	4	4	88
14 Day	2	1	94	3	2	91	2	1	94

Events 6-9	**Unvegetated**			**Existing Pickerelweed**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	96	14	-	96	14	-
Outflow	58	16	-	53	16	-
Littoral						
1 Day	62	8	-7	58	10	-10
7 Day	10	6	82	10	5	80
14 Day	4	1	93	4	1	92
Open Water						
1 Day	60	8	-4	59	8	-13
7 Day	12	7	79	11	4	79
14 Day	5	1	92	5	1	91

Table 13. Mean pH levels for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-5	Unvegetated		Existing Pickerelweed		Existing Cattail	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
Inflow	6.98	0.13	6.98	0.13	6.98	0.13
Outflow	6.99	0.15	6.91	0.14	6.86	0.15
Littoral						
1 Day	6.88	0.10	6.80	0.09	6.78	0.07
7 Day	7.39	0.32	7.26	0.27	7.18	0.20
14 Day	7.66	0.64	7.44	0.42	7.39	0.51
Open Water						
1 Day	6.86	0.06	6.81	0.09	6.77	0.12
7 Day	7.25	0.23	7.08	0.20	7.12	0.29
14 Day	7.54	0.49	7.30	0.34	7.25	0.42

Events 6-9	Unvegetated		Existing Pickerelweed	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	6.91	0.15	6.91	0.15
Outflow	7.00	0.12	6.95	0.10
Littoral				
1 Day	6.88	0.12	6.85	0.10
7 Day	7.18	0.16	6.92	0.20
14 Day	7.18	0.15	6.99	0.09
Open Water				
1 Day	6.89	0.12	6.85	0.14
7 Day	7.22	0.19	7.02	0.19
14 Day	7.13	0.20	7.01	0.11

Table 14. Mean water temperatures (°C) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-5	Unvegetated		Existing Pickerelweed		Existing Cattail	
	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.
Inflow	29.2	2.1	29.2	2.1	29.2	2.1
Outflow	28.7	1.9	28.6	1.8	28.7	1.8
Littoral						
1 Day	30.1	2.3	29.8	2.1	29.6	2.1
7 Day	29.5	1.2	29.2	1.2	29.6	1.5
14 Day	31.9	1.7	31.9	1.4	32.0	1.3
Open Water						
1 Day	29.7	1.9	29.6	1.8	29.8	1.9
7 Day	29.2	1.3	29.1	1.3	29.2	1.4
14 Day	32.3	2.3	32.1	2.2	32.2	2.3

Events 6-9	Unvegetated		Existing Pickerelweed	
	Avg.	Stdev.	Avg.	Stdev.
Inflow	26.4	1.6	26.4	1.6
Outflow	26.3	1.5	26.2	1.5
Littoral				
1 Day	27.5	3.8	27.2	3.5
7 Day	25.2	2.9	25.3	2.9
14 Day	24.3	1.2	24.5	1.3
Open Water				
1 Day	27.1	3.7	26.5	3.3
7 Day	24.6	2.9	24.7	2.8
14 Day	23.3	1.2	23.4	1.3

Table 15. Mean DO concentrations (mg/L) for unvegetated, pickerelweed and cattail compartments during events 1 – 5 and for unvegetated and pickerelweed compartments during events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-5	**Unvegetated**		**Existing Pickerelweed**		**Existing Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
Inflow	4.16	0.91	4.16	0.91	4.16	0.91
Outflow	2.85	1.40	2.26	1.52	2.30	1.65
Littoral						
1 Day	3.04	2.45	1.87	1.44	1.64	1.71
7 Day	6.61	1.64	5.43	3.06	5.57	3.05
14 Day	7.95	1.75	6.34	1.54	5.85	1.53
Open Water						
1 Day	1.56	1.20	1.30	1.19	0.98	0.95
7 Day	3.29	0.93	3.26	1.30	2.84	1.12
14 Day	4.35	0.96	3.46	1.15	3.14	1.10

Events 6-9	**Unvegetated**		**Existing Pickerelweed**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	3.95	0.99	3.95	0.99
Outflow	2.66	1.07	2.09	0.90
Littoral				
1 Day	4.39	2.48	1.73	1.59
7 Day	5.36	1.91	3.92	2.20
14 Day	7.54	2.91	3.95	2.66
Open Water				
1 Day	1.68	1.38	0.91	1.05
7 Day	2.59	1.24	2.67	0.84
14 Day	3.15	1.69	2.40	1.57

Table 16. Sediment-water interface oxidation-reduction potential (ORP) (mV) in unvegetated, pickerelweed and cattail compartments during the final three months of the study.

Date	Unvegetated		Existing Pickerelweed		Existing Cattail	
	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.
8/4/2004	397.4	7.4	330.8	74.2	231.2	85.4
8/27/2004	272.1	24.1	20.2	7.5	159.7	12.0
9/16/2004	65.7	139.3	-10.5	54.7	-	-
10/6/2004	221.8	1.6	33.1	84.7	-	-
10/27/2004	156.5	91.4	112.7	127.3	-	-
11/17/2004	165.0	23.5	56.6	129.8	-	-
Average	**213.1**		**90.5**		**195.5**	

Table 17. Secchi depths and chlorophyll *a* concentrations (µg/L) for unvegetated and pickerelweed compartments during the final month of the study.

		Secchi (M) Open Water				Chl a (µg/L) Open Water			
		Unvegetated		Existing Pickerelweed		Unvegetated		Existing Pickerelweed	
		Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.
11/16/2004	Day 13	0.8	0.1	1.0	0.1	68	6	49	4
11/22/04	Day 0	0.7	0.0	0.8	0.0	-	-	-	-
11/23/2004	Day 1	0.6	0.1	0.6	0.1	21	9	10	0
11/26/04	Day 4	0.9	0.0	0.8	0.3	8	1	9	1
12/1/2004	Day 7	0.8	0.0	0.9	0.1	41	49	35	24
Average		**0.7**	**-**	**0.8**	**-**	**34.6**	**-**	**25.8**	**-**

Table 18. Mean TP concentrations (µg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	392	78	-	392	78	-
Outflow	281	60	-	290	59	-
Littoral						
1 Day	310	74	-10	325	103	-12
7 Day	117	20	58	115	31	60
14 Day	87	31	69	77	28	74
Open Water						
1 Day	317	64	-13	321	83	-10
7 Day	203	44	28	152	29	48
14 Day	145	46	48	99	37	66

Events 6-9	**Unvegetated**			**Herbicided Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	450	59	-	450	59	-
Outflow	308	52	-	330	44	-
Littoral						
1 Day	393	77	-28	432	77	-31
7 Day	141	50	54	271	68	18
14 Day	117	18	62	169	20	49
Open Water						
1 Day	363	47	-18	411	20	-24
7 Day	166	50	46	343	115	-4
14 Day	171	92	44	196	38	41

Table 19. Mean SRP concentrations (µg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	274	74	-	274	74	-
Outflow	176	52	-	186	56	-
Littoral						
1 Day	115	27	35	118	26	36
7 Day	58	37	67	46	29	75
14 Day	27	24	85	17	15	91
Open Water						
1 Day	111	27	37	118	34	37
7 Day	87	41	50	61	32	67
14 Day	40	22	77	22	21	88

Events 6-9	**Unvegetated**			**Herbicided Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	328	53	-	328	53	-
Outflow	215	52	-	223	50	-
Littoral						
1 Day	164	47	24	177	40	21
7 Day	64	34	70	138	52	38
14 Day	31	13	86	62	11	72
Open Water						
1 Day	157	44	27	183	28	18
7 Day	79	36	63	152	49	32
14 Day	48	25	78	75	20	67

Table 20. Mean COD concentrations (mg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	71	34	-	71	34	-
Outflow	61	7	-	66	21	-
Littoral						
1 Day	58	7	4	60	7	9
7 Day	46	11	25	47	13	29
14 Day	55	10	10	53	4	20
Open Water						
1 Day	59	7	2	61	10	7
7 Day	52	12	15	47	7	29
14 Day	56	5	8	55	8	17

Events 6-9	**Unvegetated**			**Herbicided Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	74	5	-	74	5	-
Outflow	68	8	-	69	7	-
Littoral						
1 Day	68	16	0	67	5	4
7 Day	56	7	18	58	13	17
14 Day	62	17	9	58	6	16
Open Water						
1 Day	66	7	4	65	7	6
7 Day	59	5	14	59	8	15
14 Day	60	14	12	61	9	13

Table 21. Mean TSS concentrations (mg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	Unvegetated			Existing Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	5.0	1.2	-	5.0	1.2	-
Outflow	5.1	1.9	-	4.9	1.5	-
Littoral						
1 Day	7.2	3.2	-43	8.7	4.8	-79
7 Day	4.0	1.9	20	2.4	1.0	51
14 Day	3.8	1.6	24	2.6	1.2	47
Open Water						
1 Day	7.1	3.4	-40	7.1	3.1	-45
7 Day	4.6	3.3	8	3.5	2.2	28
14 Day	4.7	1.5	6	3.6	1.4	26

Events 6-9	Unvegetated			Herbicided Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	5.3	2.7	-	5.3	2.7	-
Outflow	5.3	2.0	-	5.0	1.9	-
Littoral						
1 Day	6.6	2.4	-25	8.7	4.7	-72
7 Day	3.3	1.0	37	5.2	3.0	-3
14 Day	3.9	1.6	25	4.6	2.1	8
Open Water						
1 Day	6.6	1.3	-26	7.1	1.1	-41
7 Day	3.2	1.8	39	5.6	3.4	-12
14 Day	5.2	2.4	1	5.3	1.8	-5

Table 22. Mean TKN concentrations (mg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	Unvegetated			Existing Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	1.999	1.701	-	1.999	1.701	-
Outflow	1.419	0.224	-	1.458	0.239	-
Littoral						
1 Day	1.564	0.365	-10	1.548	0.405	-6
7 Day	0.846	0.098	40	0.870	0.356	40
14 Day	0.719	0.198	49	0.654	0.130	55
Open Water						
1 Day	1.610	0.391	-13	1.722	0.484	-18.134
7 Day	1.142	0.277	20	0.916	0.116	37.160
14 Day	0.903	0.262	36	0.773	0.170	46.970

Events 6-9	Unvegetated			Herbicided Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	1.774	0.234	-	1.774	0.234	-
Outflow	1.408	0.249	-	1.447	0.136	-
Littoral						
1 Day	1.950	1.163	-39	1.805	0.303	-25
7 Day	0.966	0.187	31	1.099	0.519	24
14 Day	1.093	0.255	22	1.087	0.170	25
Open Water						
1 Day	1.630	0.193	-16	1.663	0.254	-15
7 Day	1.173	0.442	17	1.360	0.434	6
14 Day	1.398	0.426	1	1.122	0.118	22

Table 23. Mean NO_2 + NO_3-N concentrations (mg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.903	1.519	-	0.903	1.519	-
Outflow	0.463	0.158	-	0.477	0.176	-
Littoral						
1 Day	0.201	0.233	56	0.182	0.225	62
7 Day	0.041	0.063	91	0.043	0.098	91
14 Day	0.006	0.006	99	0.008	0.015	98
Open Water						
1 Day	0.216	0.219	53	0.189	0.247	60
7 Day	0.039	0.022	92	0.019	0.028	96
14 Day	0.005	0.003	99	0.009	0.012	98

Events 6-9	**Unvegetated**			**Herbicided Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.750	0.162	-	0.750	0.162	-
Outflow	0.473	0.153	-	0.482	0.151	-
Littoral						
1 Day	0.162	0.270	65.714	0.252	0.471	48
7 Day	0.032	0.030	93.181	0.038	0.048	92
14 Day	0.012	0.013	97.427	0.023	0.034	95
Open Water						
1 Day	0.205	0.313	57	0.171	0.299	64
7 Day	0.030	0.030	94	0.031	0.042	94
14 Day	0.011	0.010	98	0.020	0.031	96

Table 24. Mean NH_3-N concentrations (mg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	Unvegetated			Existing Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	0.930	1.173	-	0.930	1.173	-
Outflow	0.475	0.145	-	0.522	0.175	-
Littoral						
1 Day	0.116	0.059	76	0.160	0.080	69
7 Day	0.090	0.139	81	0.070	0.116	87
14 Day	0.092	0.131	81	0.070	0.095	87
Open Water						
1 Day	0.198	0.130	58	0.199	0.118	62
7 Day	0.188	0.196	60	0.123	0.134	76
14 Day	0.127	0.141	73	0.088	0.082	83

Events 6-9	Unvegetated			Herbicided Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	0.838	0.151	-	0.838	0.151	-
Outflow	0.547	0.128	-	0.544	0.148	-
Littoral						
1 Day	0.195	0.151	64	0.240	0.063	56
7 Day	0.099	0.065	82	0.171	0.223	69
14 Day	0.034	0.023	94	0.022	0.022	96
Open Water						
1 Day	0.242	0.150	56	0.255	0.055	53
7 Day	0.139	0.070	75	0.200	0.226	63
14 Day	0.116	0.143	79	0.025	0.016	95

Table 25. Mean Cu concentrations (µg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	75	62	-	75	62	-
Outflow	43	13	-	44	13	-
Littoral						
1 Day	48	11	-11	53	14	-18
7 Day	11	5	74	12	5	73
14 Day	5	3	89	5	4	88
Open Water						
1 Day	49	11	-14	50	13	-13
7 Day	14	7	68	12	5	73
14 Day	6	4	86	5	3	88

Events 6-9	**Unvegetated**			**Herbicided Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	77	18	-	77	18	-
Outflow	49	13	-	50	13	-
	77	18	-	77	18	-
Littoral						
1 Day	62	10	-25	61	12	-23
7 Day	15	7	69	16	6	68
14 Day	7	1	87	6	2	88
Open Water						
1 Day	58	8	-18	61	4	-22
7 Day	17	7	66	16	6	68
14 Day	7	1	86	7	2	87

Table 26. Mean Pb concentrations (µg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-5	**Unvegetated**			**Existing Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	59	61	-	59	61	-
Outflow	35	27	-	35	27	-
Littoral						
1 Day	33	26	6	36	29	-2
7 Day	4	3	88	4	3	88
14 Day	2	2	93	2	1	94
Open Water						
1 Day	32	26	8	34	28	4
7 Day	5	6	85	4	4	88
14 Day	3	1	93	2	1	94

Events 6-9	**Unvegetated**			**Herbicided Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	96	14	-	96	14	-
Outflow	58	16	-	59	15	-
Littoral						
1 Day	62	8	-7	61	12	-3
7 Day	10	6	82	11	4	82
14 Day	4	1	93	5	1	92
Open Water						
1 Day	60	8	-4	64	5	-8
7 Day	12	7	79	12	4	81
14 Day	5	1	92	5	1	91

Table 27. Mean pH levels for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-5	**Unvegetated**		**Existing Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	6.98	0.13	6.98	0.13
Outflow	6.99	0.15	6.86	0.15
Littoral				
1 Day	6.88	0.10	6.78	0.07
7 Day	7.39	0.32	7.18	0.20
14 Day	7.66	0.64	7.39	0.51
Open Water				
1 Day	6.84	0.08	6.77	0.12
7 Day	7.13	0.26	7.12	0.29
14 Day	7.27	0.58	7.25	0.42

Events 6-9	**Unvegetated**		**Herbicided Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	6.91	0.15	6.91	0.15
Outflow	7.00	0.12	6.89	0.15
Littoral				
1 Day	6.88	0.12	6.77	0.15
7 Day	7.18	0.16	6.97	0.24
14 Day	7.18	0.15	6.85	0.11
Open Water				
1 Day	6.89	0.12	6.73	0.12
7 Day	7.22	0.19	7.00	0.12
14 Day	7.13	0.20	6.87	0.13

Table 28. Mean water temperatures (°C) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-5	Unvegetated		Existing Cattail	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	29.2	2.1	29.2	2.1
Outflow	28.7	1.9	28.7	1.8
Littoral				
1 Day	30.0	2.1	29.6	2.1
7 Day	29.4	1.1	29.6	1.5
14 Day	31.8	1.3	32.0	1.3
Open Water				
1 Day	29.7	1.9	29.8	1.9
7 Day	29.2	1.3	29.2	1.4
14 Day	31.9	2.3	32.2	2.3

Events 6-9	Unvegetated		Herbicided Cattail	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	26.4	1.6	26.4	1.6
Outflow	26.3	1.5	26.3	1.5
Littoral				
1 Day	27.5	3.8	27.5	3.8
7 Day	25.2	2.9	25.5	3.0
14 Day	24.3	1.2	24.9	1.8
Open Water				
1 Day	27.1	3.7	26.7	3.4
7 Day	24.6	2.9	24.6	2.9
14 Day	23.3	1.2	23.2	1.3

Table 29. Mean DO concentrations (mg/L) for unvegetated, existing cattail and herbicided cattail compartments during events 1 – 5 and events 6 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-5	**Unvegetated**		**Existing Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	4.16	0.91	4.16	0.91
Outflow	2.85	1.40	2.30	1.65
Littoral				
1 Day	3.04	2.45	1.64	1.71
7 Day	6.61	1.64	5.57	3.05
14 Day	7.95	1.75	5.85	1.53
Open Water				
1 Day	1.49	1.11	0.98	0.95
7 Day	3.81	1.30	2.84	1.12
14 Day	4.03	1.17	3.14	1.10

Events 6-9	**Unvegetated**		**Herbicided Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**
Inflow	3.95	0.99	3.95	0.99
Outflow	2.66	1.07	2.04	1.11
Littoral				
1 Day	4.39	2.48	2.12	2.12
7 Day	5.36	1.91	5.45	2.02
14 Day	7.54	2.91	3.81	2.05
Open Water				
1 Day	1.68	1.38	0.92	0.82
7 Day	2.59	1.24	2.77	1.77
14 Day	3.15	1.69	1.74	0.99

Table 30. Sediment-water interface oxidation-reduction potential (ORP) in unvegetated, existing cattail and herbicided cattail compartments during the final three months of the study..

Date	Unvegetated		Existing Cattail		Herbicided Cattail	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
8/4/2004	397.4	7.4	231.2	85.4		
8/27/2004	272.1	24.1	159.7	12.0		
9/16/2004	65.7	139.3			-14.2	46.5
10/6/2004	221.8	1.6			-10.4	53.8
10/27/2004	156.5	91.4			230.0	239.6
11/17/2004	165.0	23.5			125.1	123.1
Average	**213.1**	**-**	**195.5**	**-**	**82.6**	**-**

Table 31. Secchi depths and chlorophyll *a* concentrations (μg/L) for unvegetated and herbicided cattail compartments during the final month of the study.

		Secchi (M) Open Water				Chl a (μg/L) Open Water			
		Unvegetated		**Herbicided Cattail**		**Unvegetated**		**Herbicided Cattail**	
		Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
11/16/2004	Day 13	0.8	0.1	0.9	0.0	68	6	52	38
11/22/2004	Day 0	0.7	0.0	0.9	0.1	-	-	-	-
11/23/2004	Day 1	0.6	0.1	0.6	0.0	21	9	13	8
11/26/2004	Day 4	0.9	0.0	0.9	0.1	8	1	12	6
12/1/2004	Day 7	0.8	0.0	0.6	0.3	41	49	69	68
Average		**0.7**	**-**	**0.8**	**-**	**34.6**	**-**	**36.4**	**-**

Table 32. Mean TP concentrations (µg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	Unvegetated			Unvegetated Pickerelweed			Unvegetated Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	373	48	-	373	48	-	373	48	-
Outflow	270	64	-	298	46	-	273	48	-
Littoral									
1 Day	256	47	5	272	42	9	269	31	1
7 Day	125	22	54	193	13	35	191	37	30
14 Day	74	43	72	116	40	61	126	60	54
Open Water									
1 Day	258	19	4	262	6	12	289	25	-6
7 Day	201	45	26	221	12	26	213	15	22
14 Day	79	29	71	164	47	45	146	47	47

Events 3-9	Unvegetated			Planted Pickerelweed			Planted Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	430	78	-	430	78	-	430	78	-
Outflow	300	55	-	298	56	-	290	55	-
Littoral									
1 Day	373	74	-24	382	75	-28	365	55	-26
7 Day	129	41	57	214	138	28	200	81	31
14 Day	106	21	64	125	35	58	134	39	54
Open Water									
1 Day	355	58	-19	367	51	-23	366	57	-26
7 Day	178	59	41	223	63	25	254	82	12
14 Day	163	71	46	151	28	49	178	36	39

Table 33. Mean SRP concentrations (µg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	**Unvegetated**			**Unvegetated Pickerelweed**			**Unvegetated Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	273	123	-	273	123	-	273	123	-
Outflow	187	58	-	196	49	-	188	51	-
Littoral									
1 Day	119	34	36	127	41	35	132	35	30
7 Day	58	31	69	96	36	51	93	47	50
14 Day	15	14	92	44	32	78	44	41	77
Open Water									
1 Day	122	34	35	125	37	36	138	35	26
7 Day	114	35	39	123	9	37	126	31	33
14 Day	20	19	89	57	38	71	52	44	72

Events 3-9	**Unvegetated**			**Planted Pickerelweed**			**Planted Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	306	74	-	306	74	-	306	74	-
Outflow	195	55	-	195	52	-	176	46	-
Littoral									
1 Day	139	47	29	149	49	24	123	30	30
7 Day	52	32	74	82	45	58	77	47	56
14 Day	24	14	88	42	26	79	44	32	75
Open Water									
1 Day	134	44	32	156	45	20	133	38	24
7 Day	71	34	64	96	43	51	95	43	46
14 Day	40	25	79	52	22	73	53	30	70

Table 34. Mean COD concentrations (mg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	Unvegetated			Unvegetated Pickerelweed			Unvegetated Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	66.4	21.1	-	66.4	21.1	-	66.4	21.1	-
Outflow	58.3	6.0	-	61.3	6.0	-	59.2	4.0	-
Littoral									
1 Day	58	5	1	60	8	2	56	7	5
7 Day	51	7	12	50	6	18	52	2	13
14 Day	60	3	-2	56	3	9	60	6	-1
Open Water									
1 Day	55	3	6	58	9	6	58	8	2
7 Day	52	12	11	49	4	20	59	15	1
14 Day	54	3	8	57	5	7	58	5	3

Events 3-9	Unvegetated			Planted Pickerelweed			Planted Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	74	27	-	74	27	-	74	27	-
Outflow	66	8	-	65	8	-	68	21	-
Littoral									
1 Day	64	14	3	65	9	0	63	5	7
7 Day	50	12	24	55	14	16	53	7	22
14 Day	57	15	14	53	7	17	56	10	18
Open Water									
1 Day	64	8	3	63	6	3	63	6	8
7 Day	53	12	20	60	10	8	55	9	20
14 Day	58	10	12	56	7	14	55	8	19

Table 35. Mean TSS concentrations (mg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	**Unvegetated**			**Unvegetated Pickerelweed**			**Unvegetated Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	4.0	2.0	-	4.0	2.0	-	4.0	2.0	-
Outflow	3.9	1.5	-	4.9	1.0	-	3.8	1.0	-
Littoral									
1 Day	4.5	1.0	-16	4.3	1.6	12	3.4	0.8	11
7 Day	4.2	1.7	-9	5.2	1.3	-6	5.0	2.4	-29
14 Day	4.2	1.7	-10	3.8	1.2	23	4.5	3.5	-18
Open Water									
1 Day	4	1	0	4.1	0.9	16	3.6	1.3	7
7 Day	2.6	1.2	33	3.5	1.6	29	3.9	1.8	-2
14 Day	3.5	1.4	11	4.5	1.5	8	4.9	3.8	-29

Events 3-9	**Unvegetated**			**Planted Pickerelweed**			**Planted Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	5.5	2.1	-	5.5	2.1	-	5.5	2.1	-
Outflow	5.5	1.9	-	4.9	1.6	-	5.6	1.5	-
Littoral									
1 Day	7.5	2.5	-36	7.7	2.1	-57	8.5	2.7	-52
7 Day	3.0	1.3	46	6.0	6.5	-21	5.2	2.8	7
14 Day	3.6	1.3	35	4.3	2.3	12	3.8	1.1	32
Open Water									
1 Day	7.7	2.2	-40	7.3	1.5	-48	8.6	2.3	-53
7 Day	4.0	3.0	27	5.2	2.9	-6	6.9	3.2	-24
14 Day	5.2	1.8	6	4.3	1.7	14	5.2	2.0	7

Table 36. Mean TKN concentrations (mg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	Unvegetated			Unvegetated Pickerelweed			Unvegetated Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	1.616	0.096	-	1.616	0.096	-	1.616	0.096	-
Outflow	1.298	0.146	-	1.421	0.156	-	1.281	0.146	-
Littoral									
1 Day	1.273	0.148	2	1.300	0.173	9	1.170	0.183	9
7 Day	0.813	0.125	37	0.888	0.050	38	0.878	0.153	31
14 Day	0.658	0.208	49	0.758	0.241	47	0.733	0.318	43
Open Water									
1 Day	1.365	0.350	-5	1.293	0.213	9	1.325	0.158	-3
7 Day	1.203	0.266	7	1.175	0.377	17	1.015	0.131	21
14 Day	0.688	0.283	47	0.823	0.339	42	0.753	0.239	41

Events 3-9	Unvegetated			Planted Pickerelweed			Planted Cattail		
	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red	Avg.	Stdev.	% Red
Inflow	1.980	1.438	-	1.980	1.438	-	1.980	1.438	-
Outflow	1.447	0.244	-	1.408	0.230	-	1.399	0.204	-
Littoral									
1 Day	1.868	0.884	-29	1.700	0.371	-21	1.701	0.308	-22
7 Day	0.924	0.155	36	1.118	0.562	21	1.046	0.214	25
14 Day	0.927	0.279	36	0.883	0.195	37	0.841	0.128	40
Open Water									
1 Day	1.614	0.161	-12	1.719	0.274	-22	1.709	0.398	-22
7 Day	1.204	0.404	17	1.164	0.243	17	1.230	0.273	12
14 Day	1.208	0.383	17	0.972	0.153	31	1.065	0.187	24

Table 37. Mean NO_2 + NO_3-N concentrations (mg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	Unvegetated			Unvegetated Pickerelweed			Unvegetated Cattail		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.734	0.283	-	0.734	0.283	-	0.734	0.283	-
Outflow	0.494	0.176	-	0.512	0.171	-	0.471	0.161	-
Littoral									
1 Day	0.400	0.168	19	0.421	0.246	18	0.409	0.266	13
7 Day	0.049	0.036	90	0.097	0.103	81	0.106	0.102	78
14 Day	0.009	0.013	98	0.007	0.009	99	0.006	0.005	99
Open Water									
1 Day	0.385	0.201	22	0.429	0.231	16	0.376	0.271	20
7 Day	0.039	0.025	92	0.090	0.094	82	0.113	0.121	76
14 Day	0.004	0.005	99	0.004	0.003	99	0.008	0.009	98

Events 3-9	Unvegetated			Planted Pickerelweed			Planted Cattail		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.866	1.284	-	0.866	1.284	-	0.866	1.284	-
Outflow	0.460	0.149	-	0.442	0.160	-	0.377	0.131	-
Littoral									
1 Day	0.140	0.222	70	0.136	0.251	69	0.067	0.152	82
7 Day	0.023	0.026	95	0.035	0.037	92	0.014	0.019	96
14 Day	0.010	0.010	98	0.007	0.005	98	0.005	0.001	99
Open Water									
1 Day	0.162	0.255	65	0.130	0.252	71	0.064	0.149	83
7 Day	0.021	0.025	95	0.030	0.032	93	0.014	0.017	96
14 Day	0.008	0.007	98	0.006	0.003	99	0.005	0.003	99

Table 38. Mean NH_3-N concentrations (mg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	**Unvegetated**			**Unvegetated Pickerelweed**			**Unvegetated Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.676	0.095	-	0.676	0.095	-	0.676	0.095	-
Outflow	0.418	0.134	-	0.473	0.125	-	0.423	0.141	-
Littoral									
1 Day	0.087	0.009	79	0.102	0.038	79	0.107	0.040	75
7 Day	0.035	0.029	92	0.023	0.006	95	0.029	0.015	93
14 Day	0.016	0.007	96	0.015	0.004	97	0.026	0.026	94
Open Water									
1 Day	0.116	0.025	72	0.113	0.072	76	0.123	0.063	71
7 Day	0.290	0.250	31	0.281	0.317	41	0.187	0.143	56
14 Day	0.015	0.004	96	0.032	0.026	93	0.054	0.043	87

Events 3-9	**Unvegetated**			**Planted Pickerelweed**			**Planted Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	0.949	0.987	-	0.949	0.987	-	0.949	0.987	-
Outflow	0.533	0.134	-	0.514	0.146	-	0.470	0.144	
Littoral									
1 Day	0.169	0.123	68	0.226	0.103	56	0.191	0.103	59
7 Day	0.111	0.119	79	0.080	0.087	84	0.064	0.090	86
14 Day	0.088	0.118	83	0.069	0.106	87	0.071	0.122	85
Open Water									
1 Day	0.200	0.125	62	0.272	0.098	47	0.247	0.144	48
7 Day	0.156	0.143	71	0.103	0.105	80	0.093	0.113	80
14 Day	0.168	0.154	69	0.104	0.137	80	0.087	0.134	81

Table 39. Mean Cu concentrations (µg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	**Unvegetated**			**Unvegetated Pickerelweed**			**Unvegetated Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	60	8	-	60	8	-	60	8	-
Outflow	36	10	-	37	8	-	35	9	-
Littoral									
1 Day	36	2	0	38	2	-3	38	2	-9
7 Day	14	1	63	17	2	53	19	5	45
14 Day	6	4	84	9	7	76	10	7	71
Open Water									
1 Day	36	3	2	39	4	-4	38	3	-9
7 Day	15	1	59	18	2	52	19	4	45
14 Day	6	4	83	9	7	77	6	6	84

Events 3-9	**Unvegetated**			**Planted Pickerelweed**			**Planted Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	80	53	-	80	53	-	80	53	-
Outflow	48	13	-	47	13	-	41	12	-
Littoral									
1 Day	59	9	-22	59	11	-27	53	8	-29
7 Day	13	7	74	15	7	68	12	6	70
14 Day	5	2	89	10	6	80	7	4	84
Open Water									
1 Day	56	7	-16	60	8	-29	53	7	-30
7 Day	14	8	71	16	7	66	13	7	69
14 Day	6	2	88	8	3	84	7	4	83

Table 40. Mean Pb concentrations (µg/L) for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations. Contaminant removal (percentage reduction) also is provided for days 1, 7 and 14 of the inter-event period.

Events 1-2	**Unvegetated**			**Unvegetated Pickerelweed**			**Unvegetated Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	8	4	-	8	4	-	8	4	-
Outflow	5	3	-	5	3	-	5	3	-
Littoral									
1 Day	4	2	33	3	1	44	4	2	22
7 Day	1	0	81	1	0	81	1	1	72
14 Day	1	0	81	1	0	81	1	0	78
Open Water									
1 Day	3	2	38	4	2	34	4	2	22
7 Day	1	1	76	1	1	77	1	1	72
14 Day	1	0	81	1	0	81	1	1	83

Events 3-9	**Unvegetated**			**Planted Pickerelweed**			**Planted Cattail**		
	Avg.	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**	**Avg.**	**Stdev.**	**% Red**
Inflow	95	38	-	95	38	-	95	38	-
Outflow	57	15	-	54	15	-	60	80	-
Littoral									
1 Day	57	11	-2	58	14	-7	54	10	11
7 Day	8	5	85	9	4	84	9	4	85
14 Day	3	1	94	7	7	87	4	3	93
Open Water									
1 Day	57	10	0	60	12	-11	54	8	10
7 Day	11	7	81	10	6	81	11	6	82
14 Day	4	1	93	5	2	91	5	2	92

Table 41. Mean pH levels for six unvegetated compartments during events 1 - 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-2	Unvegetated		Unvegetated Pickerelweed		Unvegetated Cattail	
	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.
Inflow	7.03	0.12	7.03	0.12	7.03	0.12
Outflow	7.01	0.13	6.87	0.10	6.89	0.11
Littoral						
1 Day	6.94	0.06	6.85	0.11	6.83	0.05
7 Day	7.43	0.39	7.58	0.20	7.62	0.32
14 Day	8.20	0.69	7.86	0.55	7.86	0.58
Open Water						
1 Day	6.90	0.04	6.90	0.04	6.84	0.04
7 Day	7.16	0.09	7.07	0.11	7.06	0.23
14 Day	7.93	0.53	7.47	0.41	7.45	0.52

Events 3-9	Unvegetated		Planted Pickerelweed		Planted Cattail	
	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.
Inflow	6.93	0.14	6.93	0.14	6.93	0.14
Outflow	6.99	0.14	6.91	0.14	6.89	0.13
Littoral						
1 Day	6.86	0.11	6.87	0.11	6.84	0.11
7 Day	7.26	0.24	7.15	0.25	7.08	0.23
14 Day	7.24	0.21	7.07	0.24	7.05	0.19
Open Water						
1 Day	6.87	0.10	6.90	0.12	6.83	0.11
7 Day	7.26	0.23	7.10	0.25	6.97	0.20
14 Day	7.21	0.23	6.86	0.56	6.97	0.18

Table 42. Mean water temperatures (°C) for six unvegetated compartments during events 1 – 2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-2	**Unvegetated**		**Unvegetated Pickerelweed**		**Unvegetated Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
Inflow	28.3	14.1	28.3	14.1	28.3	14.1
Outflow	27.3	2.1	27.1	2.1	27.2	2.2
Littoral						
1 Day	29.7	0.6	29.1	1.1	29.4	0.8
7 Day	30.4	0.6	30.1	0.9	29.8	0.7
14 Day	32.0	1.4	32.2	1.3	32.1	1.4
Open Water						
1 Day	29.3	0.5	29.0	0.7	29.0	0.6
7 Day	30.2	0.6	29.7	0.7	29.7	0.8
14 Day	33.3	2.9	32.6	2.1	32.5	2.0

Events 3-9	**Unvegetated**		**Planted Pickerelweed**		**Planted Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
Inflow	27.8	2.3	27.8	2.3	27.8	2.3
Outflow	27.7	2.1	27.5	2.2	27.5	2.2
Littoral						
1 Day	28.8	3.7	28.5	3.4	28.4	3.3
7 Day	26.8	2.9	27.0	2.8	26.9	3.0
14 Day	28.1	4.3	28.0	3.8	27.9	3.8
Open Water						
1 Day	28.3	3.5	27.9	3.2	28.0	3.1
7 Day	26.3	3.1	26.6	3.0	26.6	3.0
14 Day	27.5	4.6	27.4	4.1	27.4	4.0

Table 43. Mean DO concentrations (mg/L) for six unvegetated compartments during events 1-2 and for unvegetated, planted pickerelweed, and planted cattail compartments during events 3 – 9. Values represent compartment inflow and outflow concentrations, as well as inter-event littoral and open water concentrations.

Events 1-2	**Unvegetated**		**Unvegetated Pickerelweed**		**Unvegetated Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
Inflow	4.88	0.56	4.88	0.56	4.88	0.56
Outflow	4.92	0.41	4.46	0.42	4.19	1.08
Littoral						
1 Day	2.90	0.01	3.52	0.05	3.14	2.36
7 Day	8.04	0.91	10.37	2.44	10.43	0.57
14 Day	7.37	1.34	7.74	1.08	8.29	1.78
Open Water						
1 Day	1.11	0.01	1.74	0.04	1.31	0.66
7 Day	4.19	0.23	4.92	0.75	5.49	0.11
14 Day	4.09	0.54	4.10	1.08	3.91	1.70

Events 3-9	**Unvegetated**		**Planted Pickerelweed**		**Planted Cattail**	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
Inflow	3.94	0.94	3.94	0.94	3.94	0.94
Outflow	2.45	0.98	2.10	0.79	1.44	0.80
Littoral						
1 Day	3.83	2.64	3.42	1.64	2.53	2.06
7 Day	5.69	1.76	7.02	2.46	6.30	2.34
14 Day	7.94	2.41	6.53	2.51	6.24	2.68
Open Water						
1 Day	1.69	1.32	1.37	1.22	1.40	1.54
7 Day	2.76	1.08	3.70	1.33	3.84	1.17
14 Day	3.84	1.56	3.08	1.84	3.27	1.52

Table 44. Sediment-water interface oxidation-reduction potential (ORP) in unvegetated, planted pickerelweed and planted cattail compartments during the final three months of the study.

Date	Unvegetated		Planted Pickerelweed		Planted Cattail	
	Avg.	**Stdev.**	**Avg.**	**Stdev.**	**Avg.**	**Stdev.**
8/4/2004	397.4	7.4	185.8	296.7	373.5	39.5
8/27/2004	272.1	24.1	14.4	2.3	80.0	58.5
9/16/2004	65.7	139.3	28.6	0.2	74.3	99.3
10/6/2004	221.8	1.6	19.0	4.1	10.4	19.9
10/27/2004	156.5	91.4	94.8	71.0	125.1	90.5
11/17/2004	165.0	23.5	50.1	57.3	72.8	54.0
Average	**213.1**	**-**	**65.5**	**-**	**122.7**	-

Table 45. Secchi depths and chlorophyll *a* concentrations (µg/L) for unvegetated and pickerelweed compartments during the final month of the study.

		Secchi (M) Open Water						Chl a (µg/L) Open Water					
		Unvegetated		Planted Pickerelweed		Planted Cattail		Unvegetated		Planted Pickerelweed		Planted Cattail	
		Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.
1/16/20004	Day 13	0.8	0.1	0.9	0.1	0.8	0.0	68	6	66	2	49	5
11/22/2004	Day 0	0.7	0.0	0.9	0.1	0.8	0.0	-	-	-	-	-	-
11/23/2004	Day 1	0.6	0.1	0.6	0.1	0.5	0.0	21	9	11	2	15	1
11/26/2004	Day 4	0.9	0.0	0.8	0.1	0.6	0.1	8	1	10	3	17	3
12/1/2004	Day 7	0.8	0.0	0.7	0.1	0.8	0.1	41	49	52	30	32	20
Average		**0.7**	**-**	**0.7**	**-**	**0.7**	**-**	**34.6**	**-**	**34.8**	**-**	**28.3**	**-**

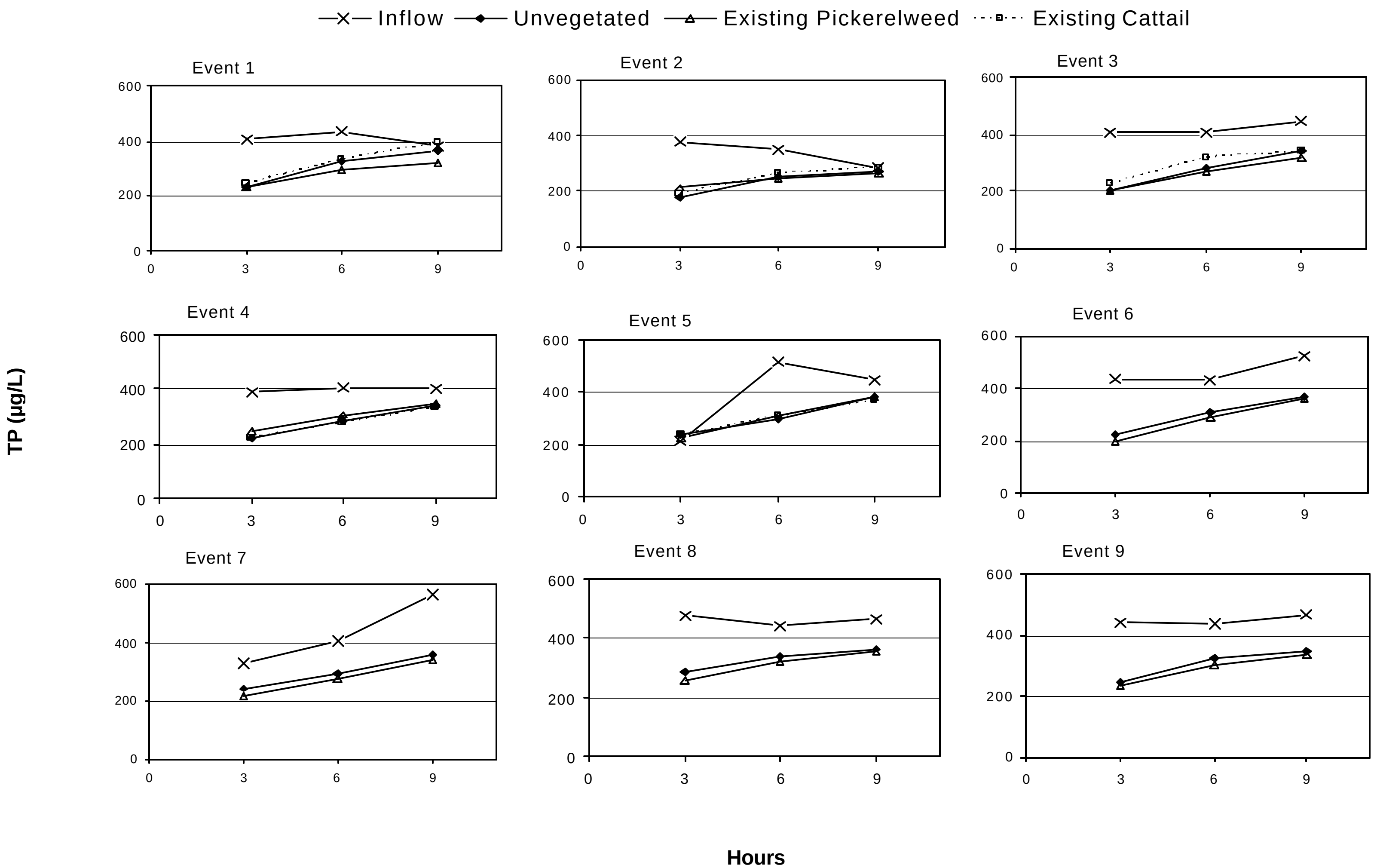
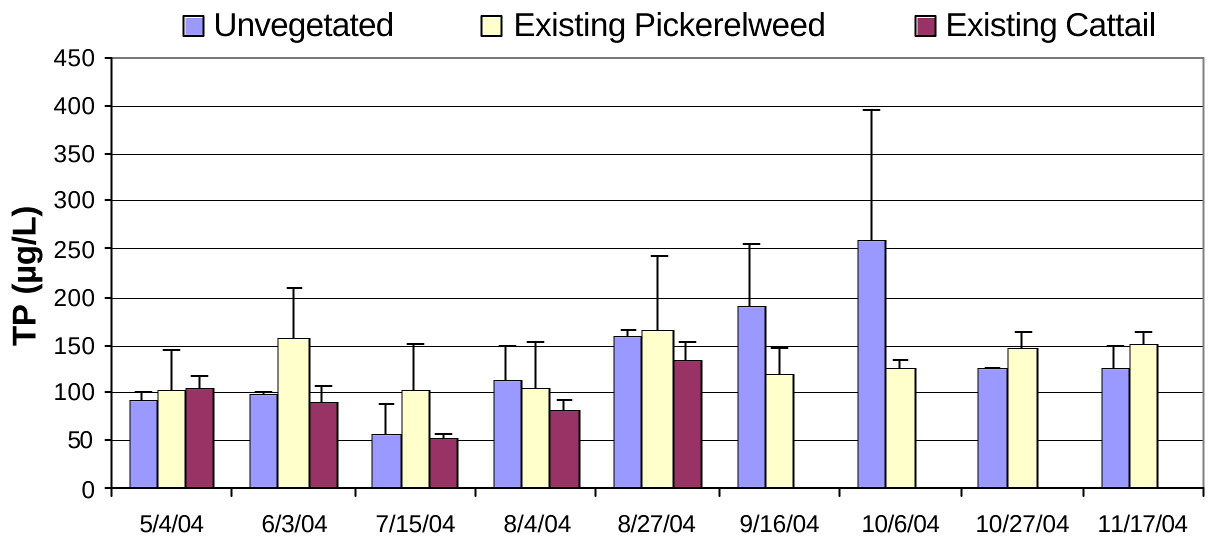


Figure 2. Inflow and outflow TP concentrations (µg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.

Open Water



Littoral

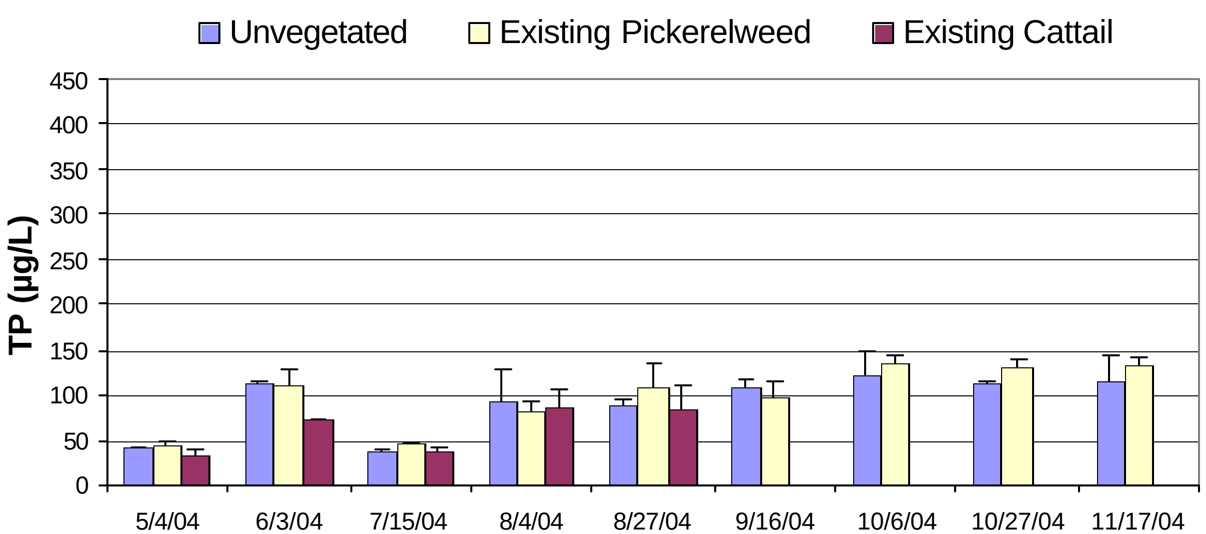


Figure 3. Open water and littoral TP concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

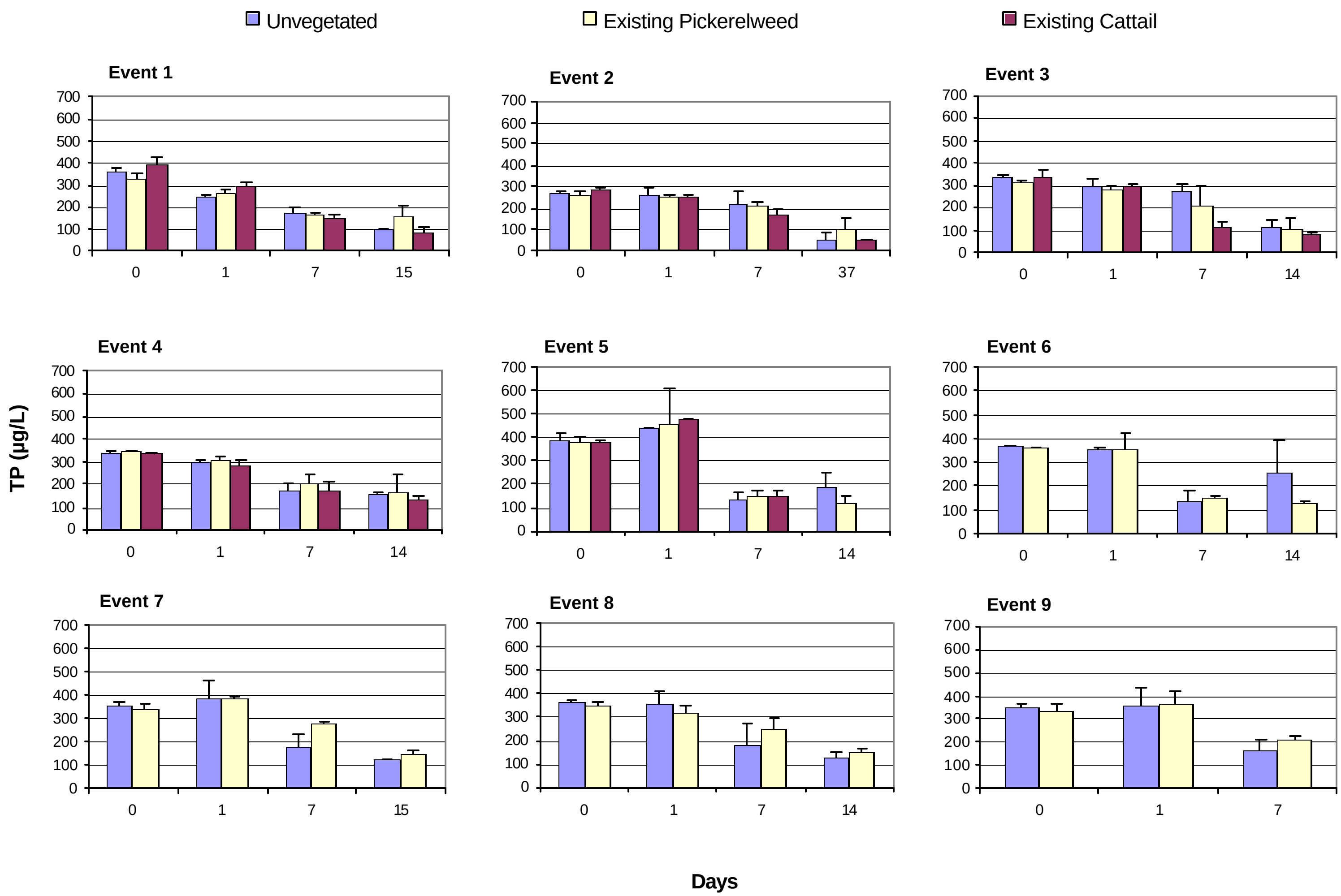


Figure 4. Open water TP concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

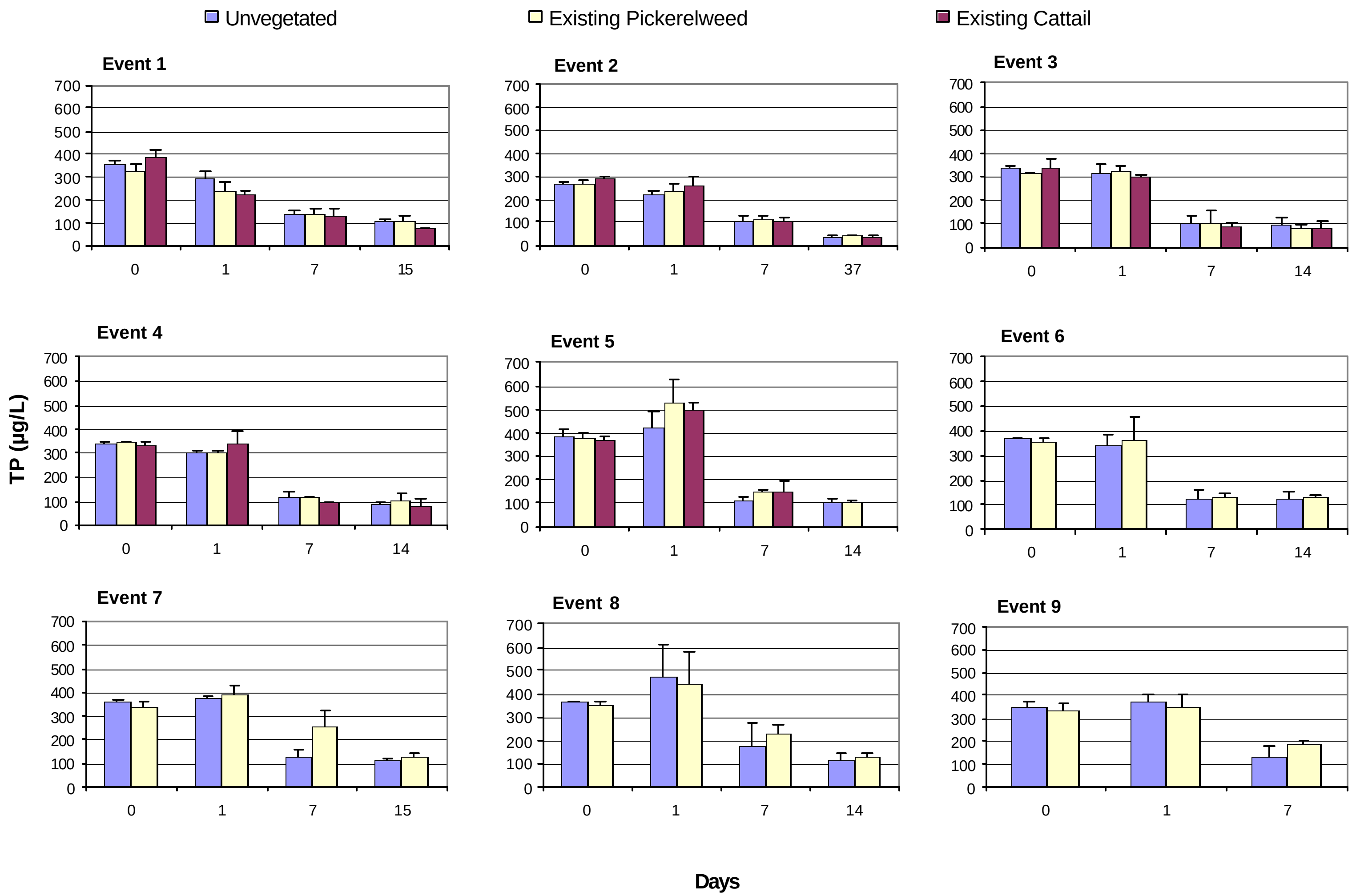
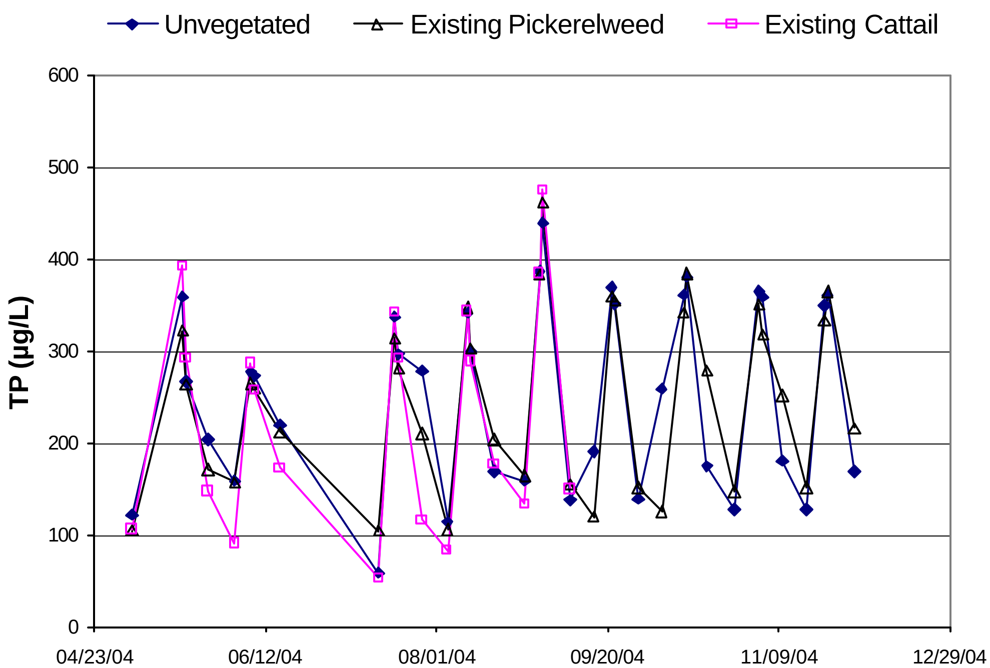


Figure 5. Littoral TP concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

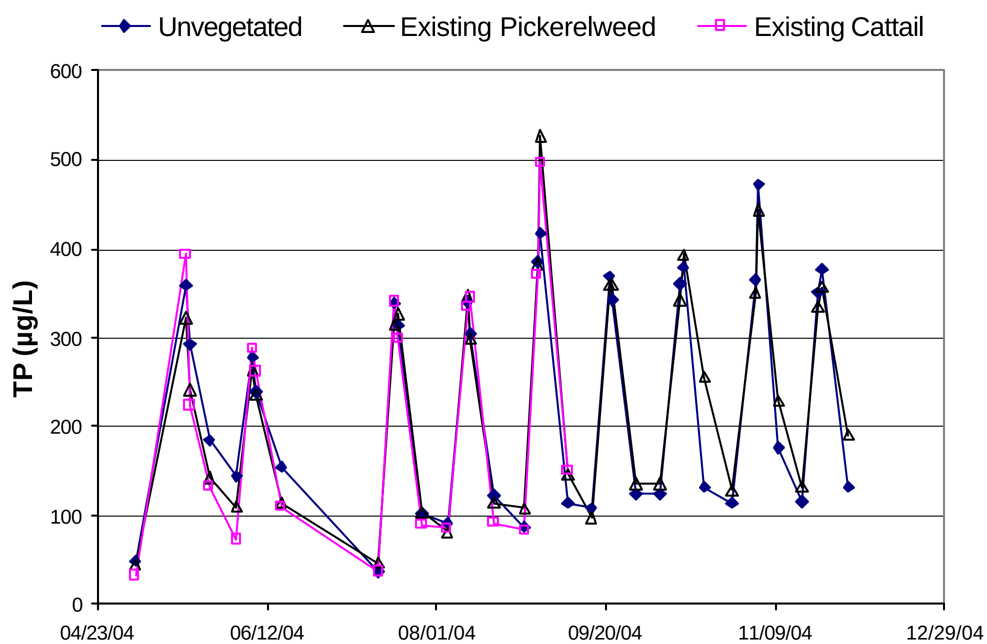


Figure 6. Total P concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

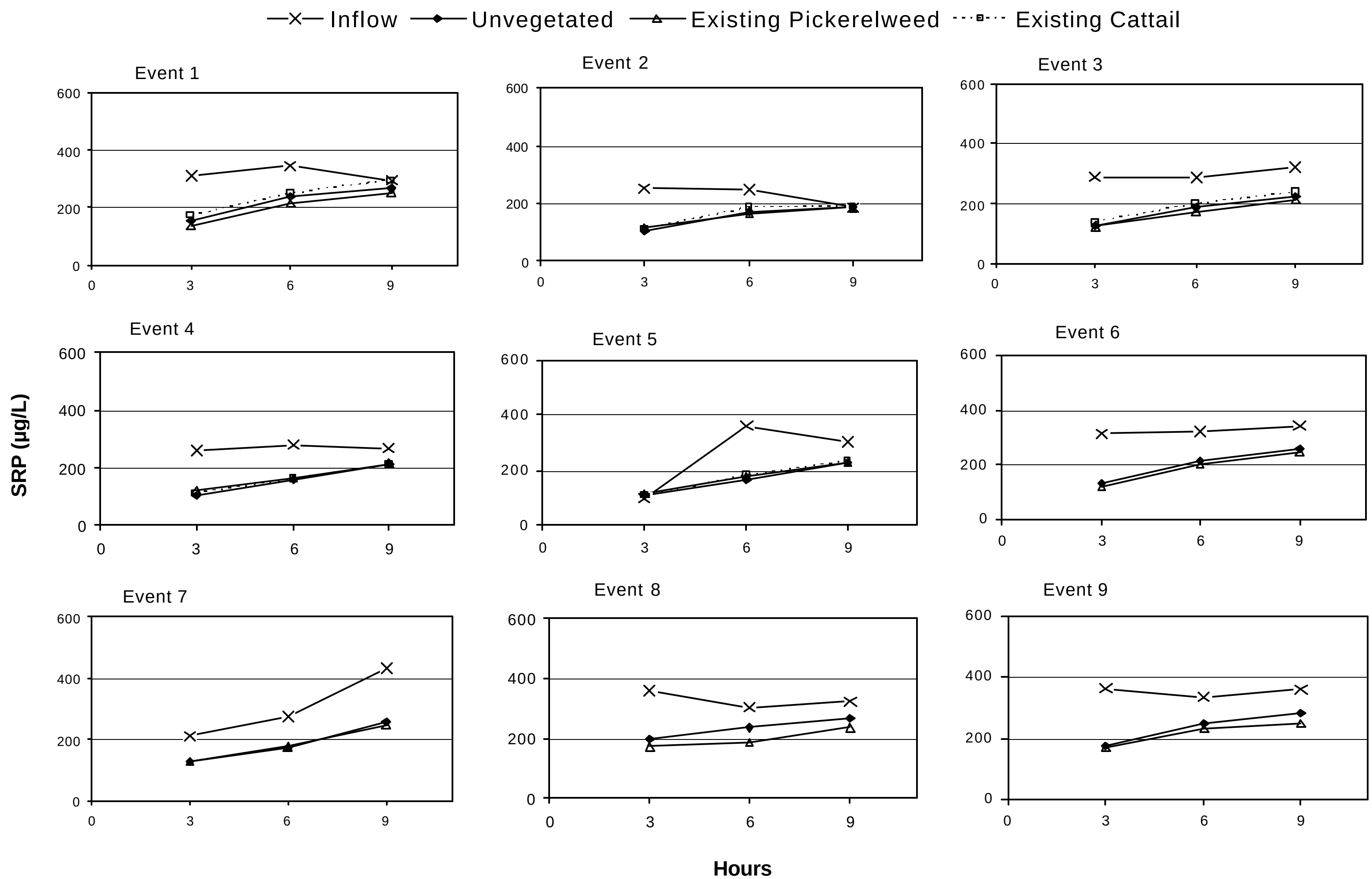
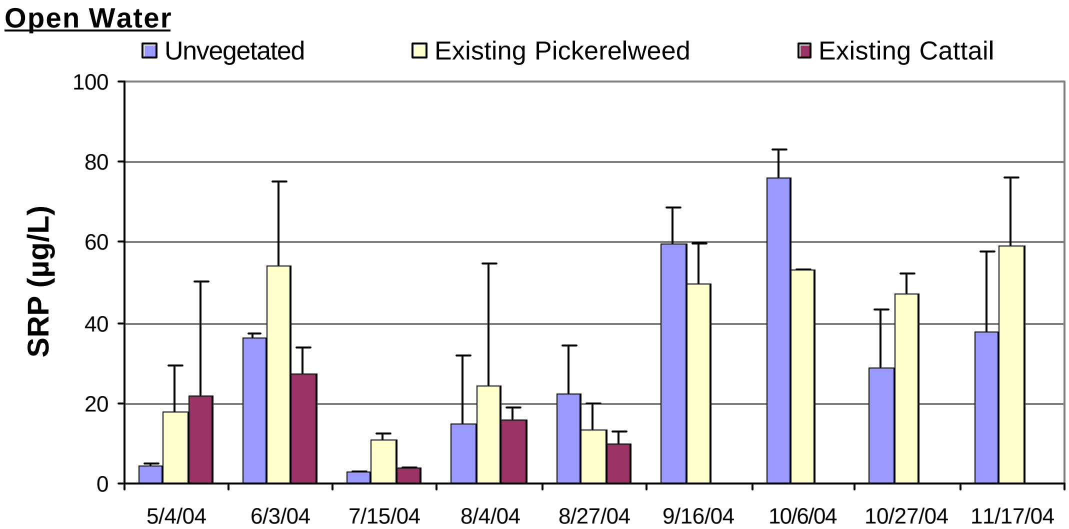


Figure 7. Inflow and outflow SRP concentrations (µg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.



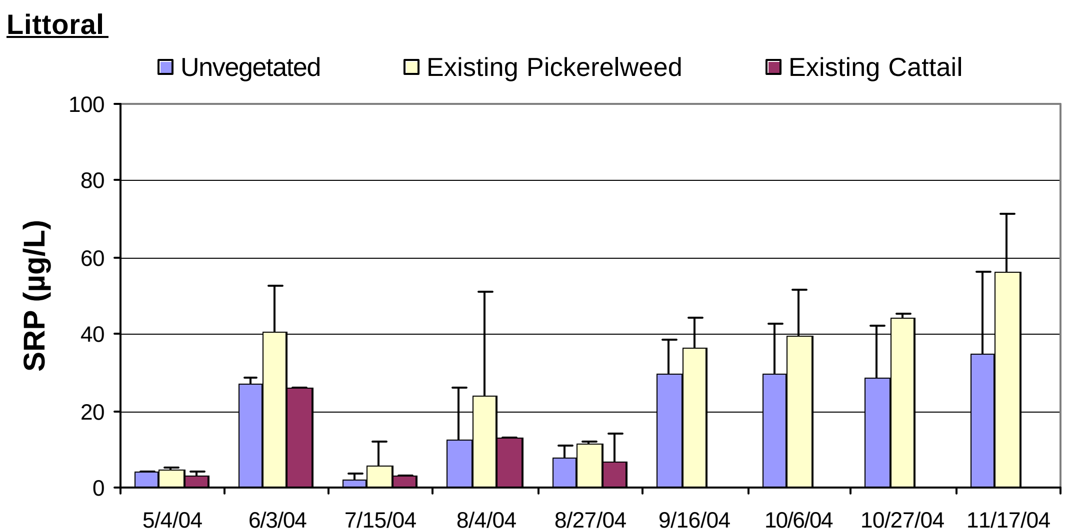


Figure 8. Open water and littoral SRP concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

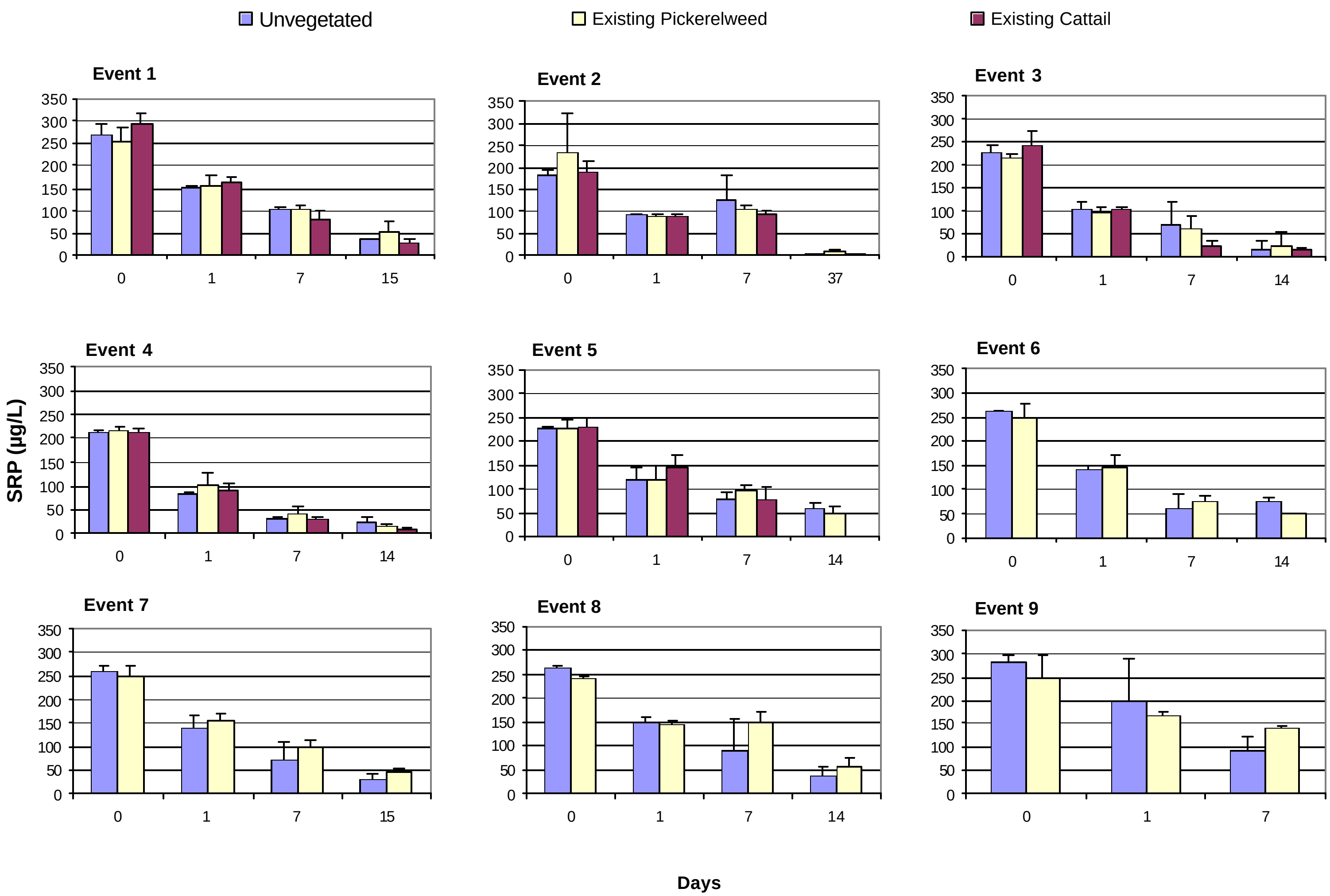


Figure 9. Open water SRP concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

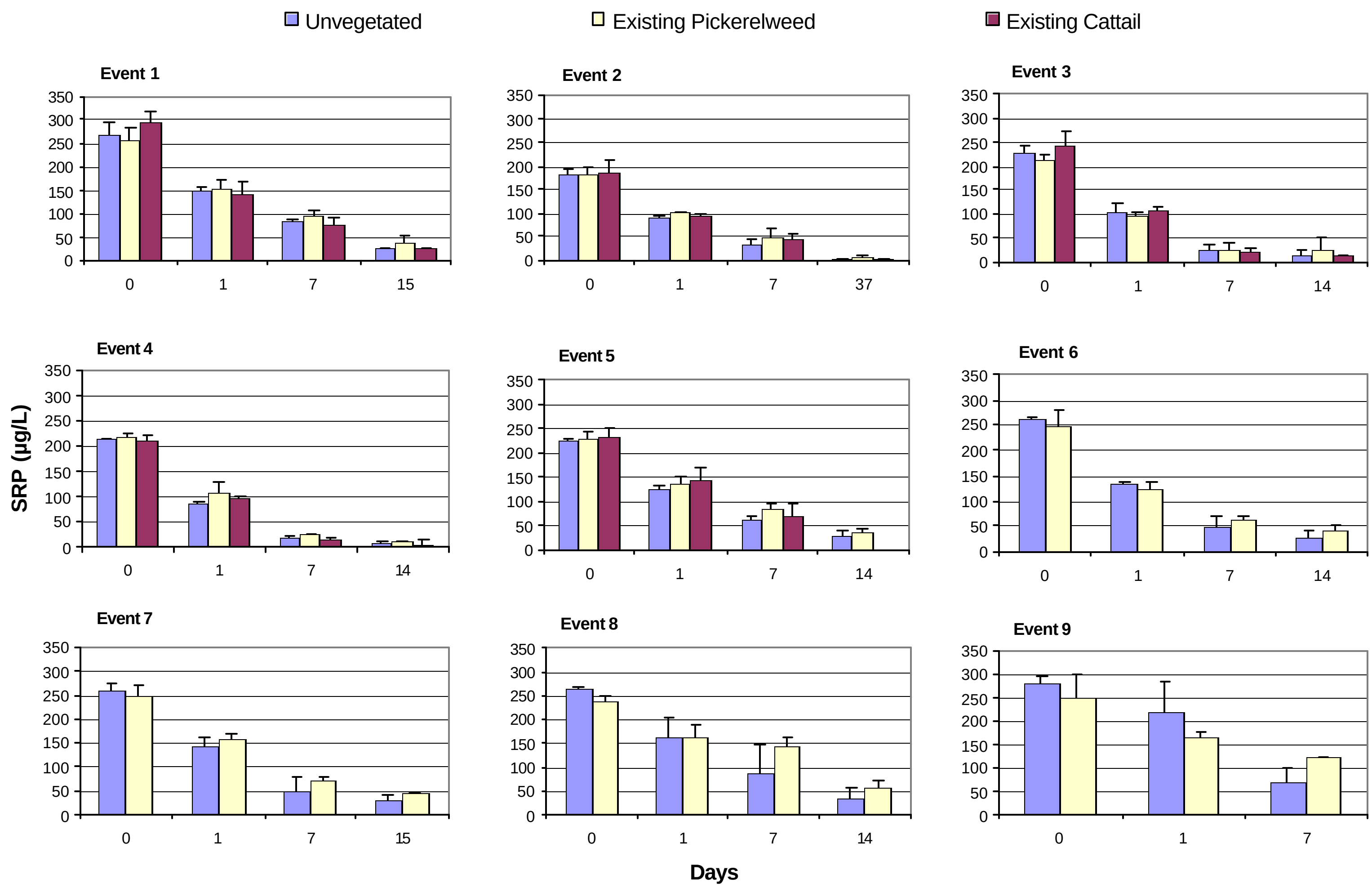
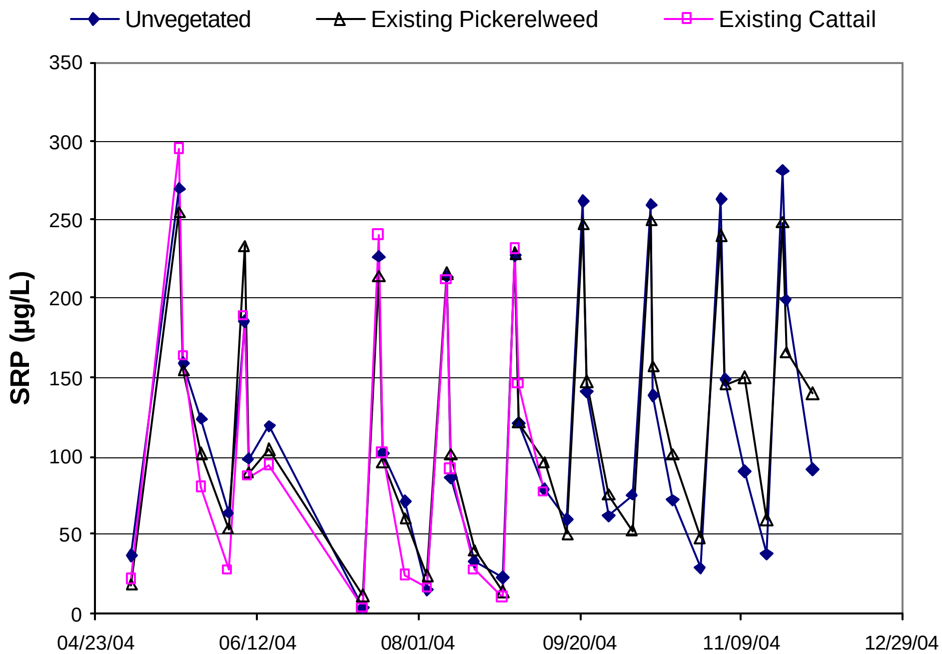


Figure 10. Littoral SRP concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

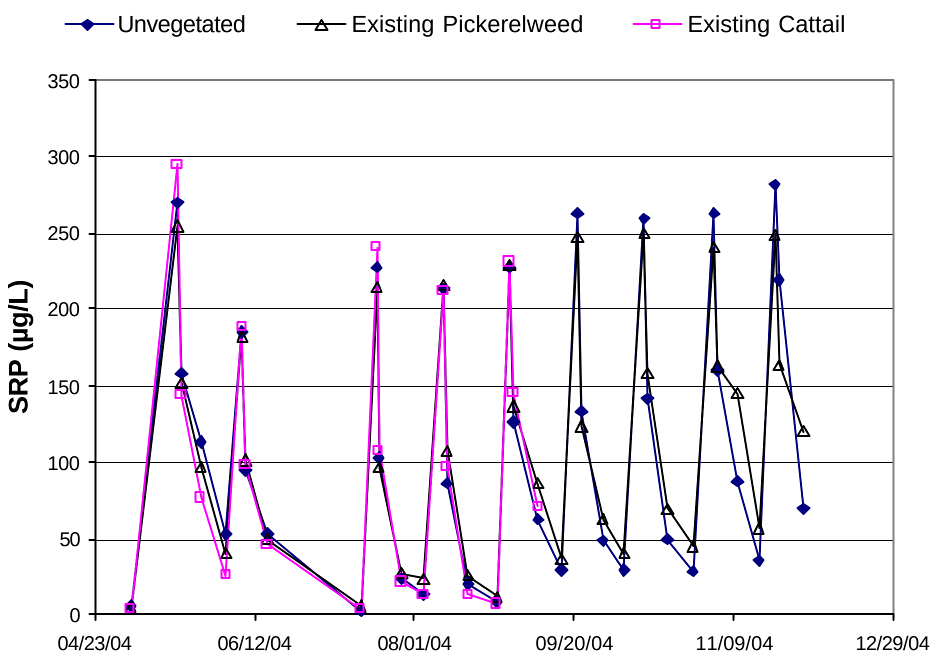


Figure 11. Total SRP concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

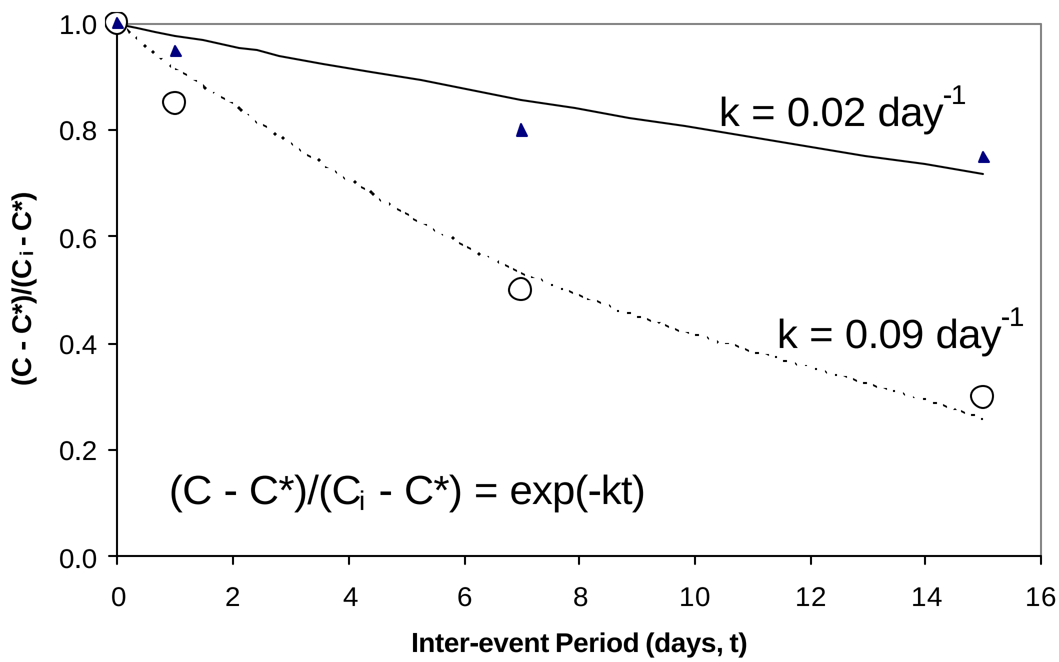


Figure 12. Two curves depicting the hypothetical reduction in concentration of a pollutant during an inter-event period. Mean concentrations from duplicate mesocosms were normalized to the initial concentration (C_i) of water collected immediately after storm flows ceased. A background concentration, C*, equivalent to the lowest observed concentration during the study period, was also subtracted from both initial and observed concentrations. The two curves depict exponential decay equations fit to the (hypothetical) observed data, where k represents the removal rate constant (day^{-1}). Values for k were selected by the Solver routine in Excel to minimize the squared differences between observed data and the decay model equation. Higher k values reflect a more rapid pollutant removal rate.

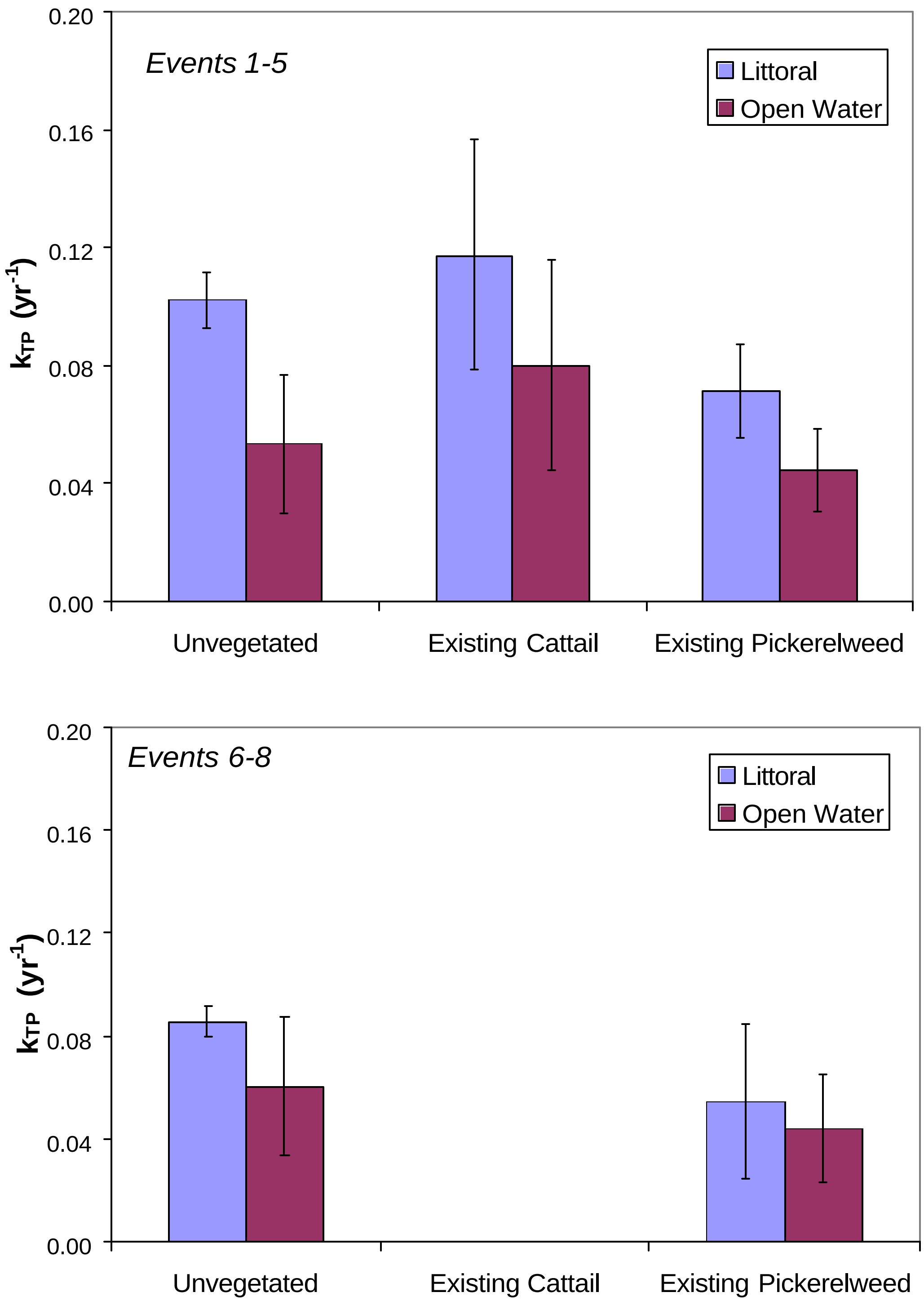


Figure 13. Mean calculated k values for TP for events 1 – 5 and events 6 – 8 in vegetated, cattail and pickerelweed compartments.

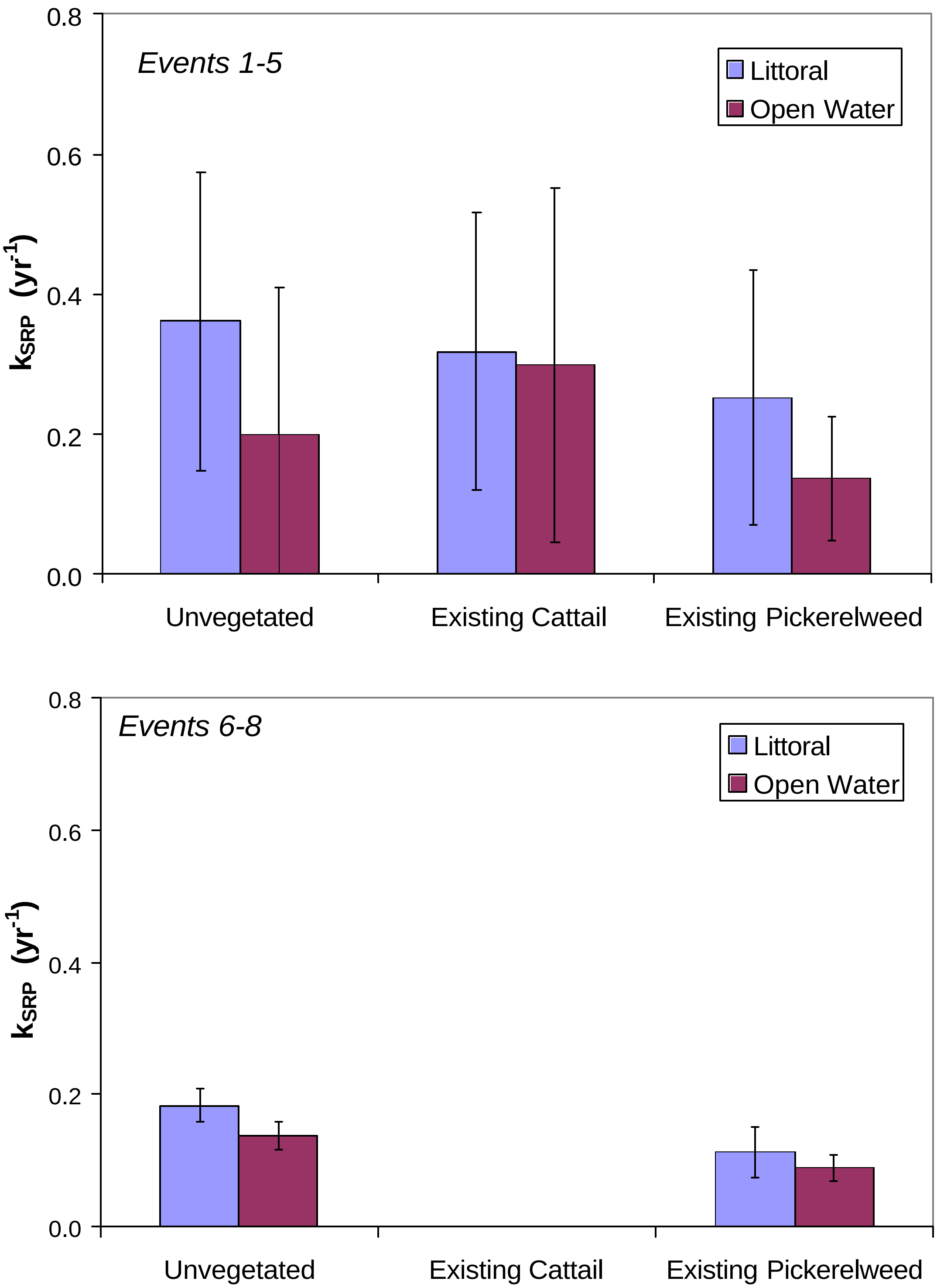


Figure 14. Mean calculated k values for SRP for events 1 – 5 and events 6 – 8 in vegetated, cattail and pickerelweed compartments.

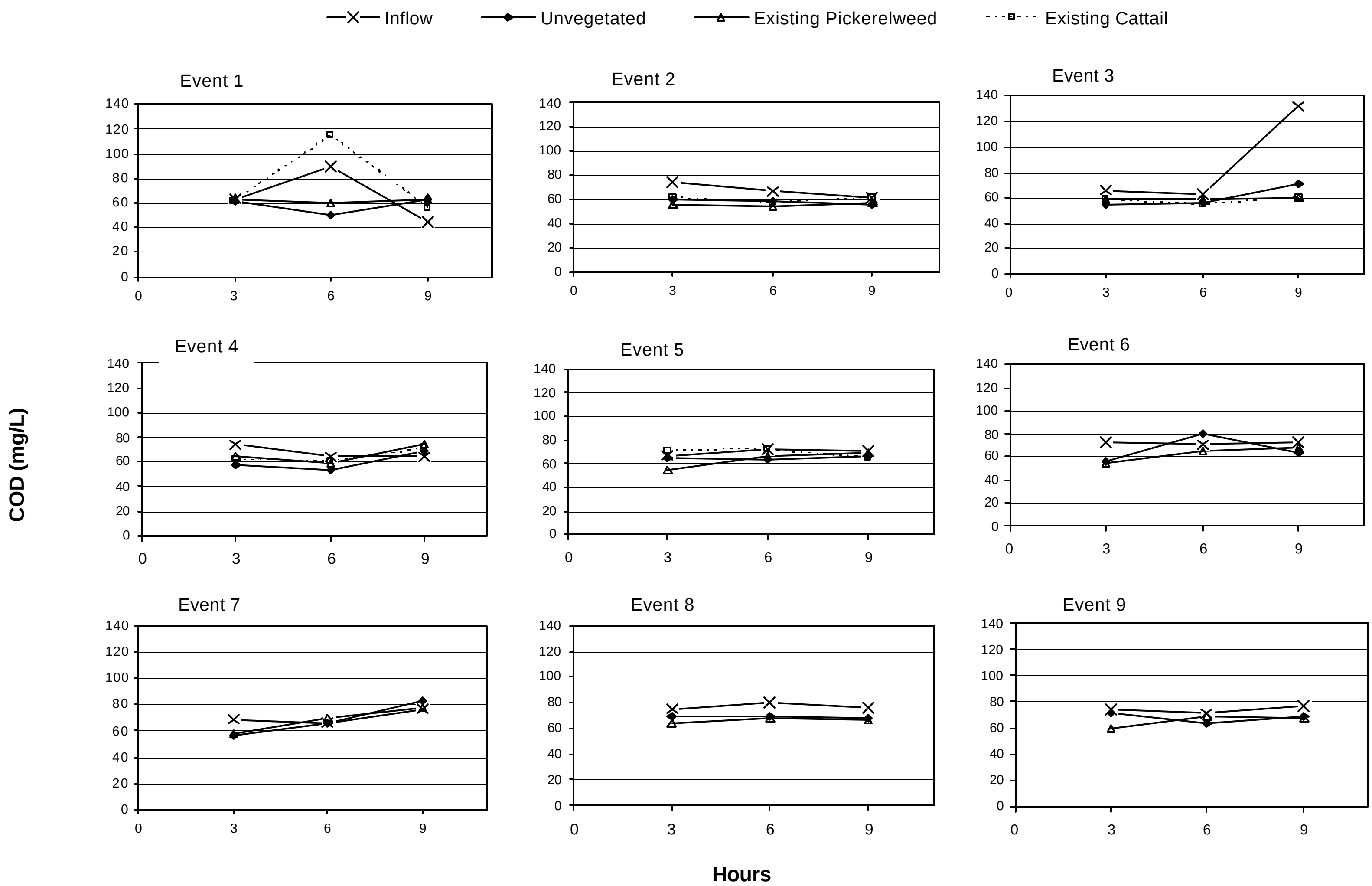


Figure 15. Inflow and outflow COD concentrations (mg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.

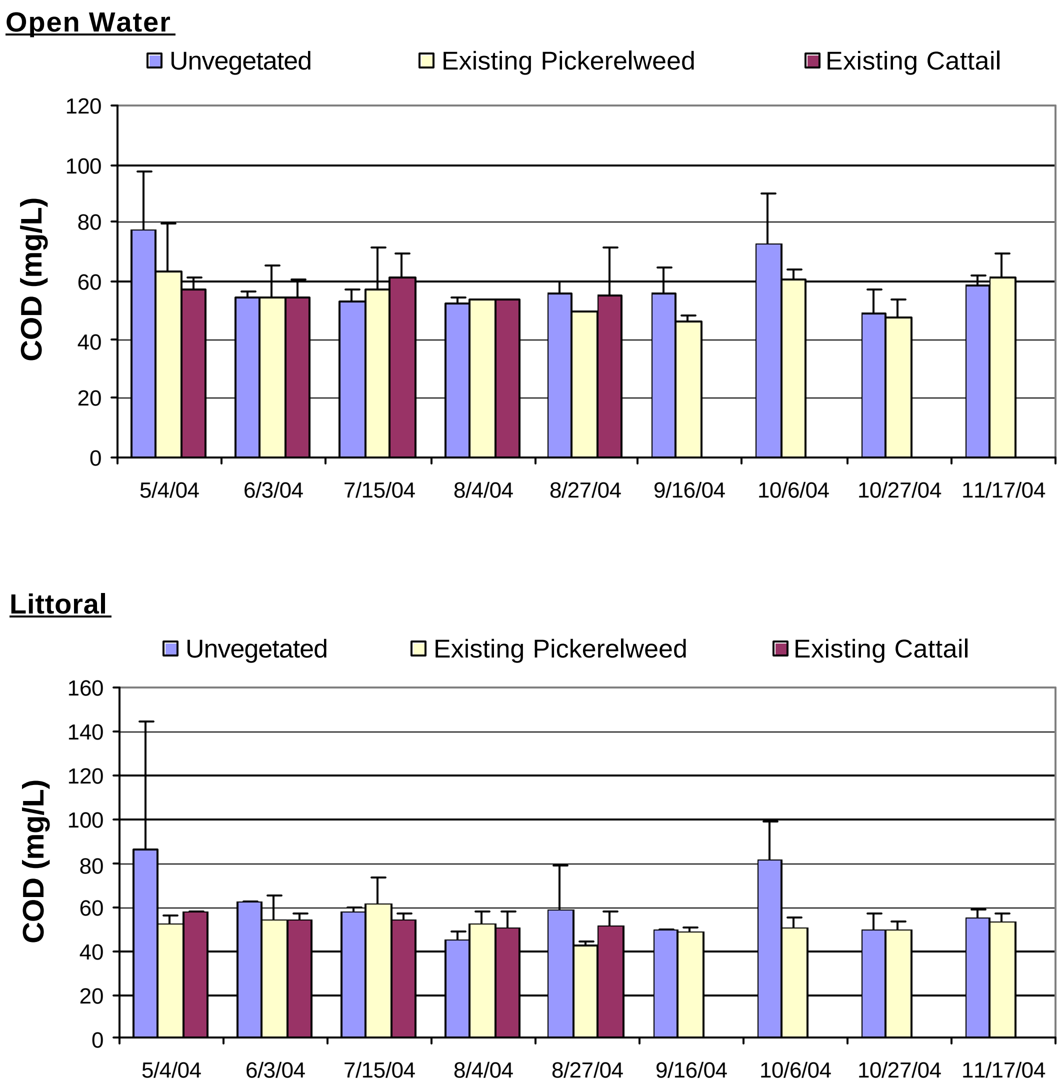


Figure 16. Open water and littoral COD concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

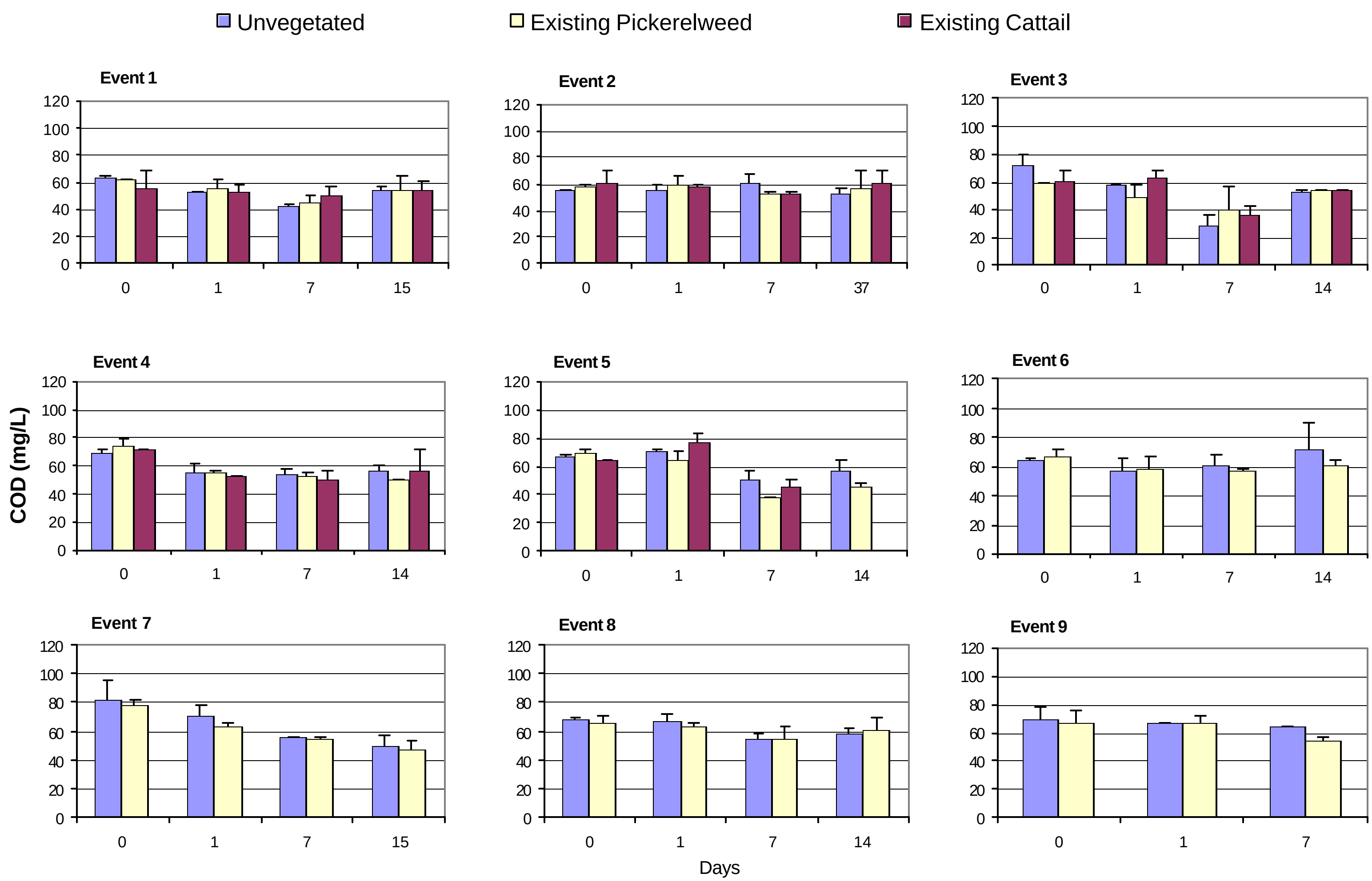


Figure 17. Open water COD concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

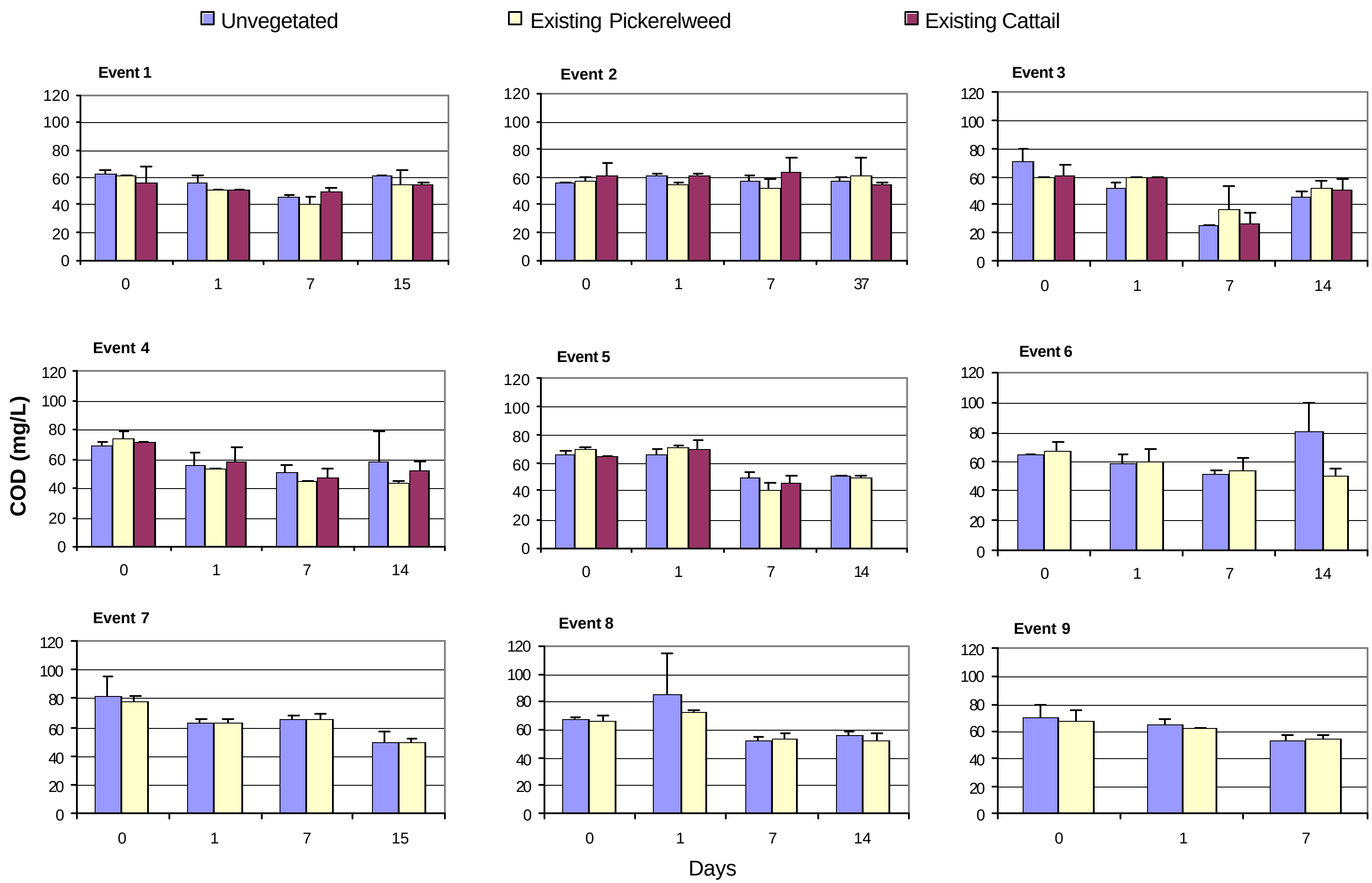
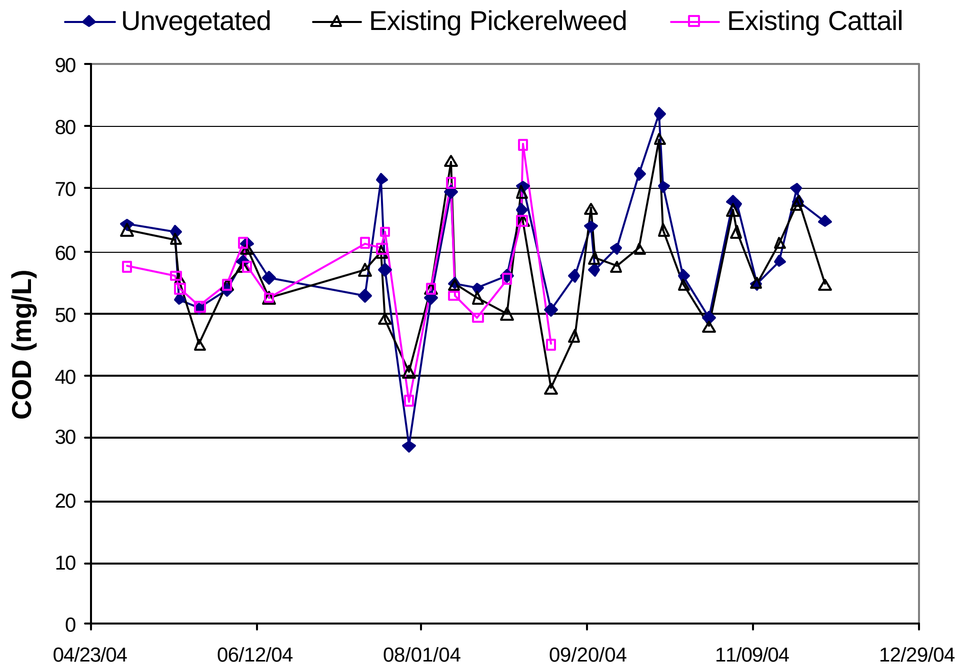


Figure 18. Littoral COD concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

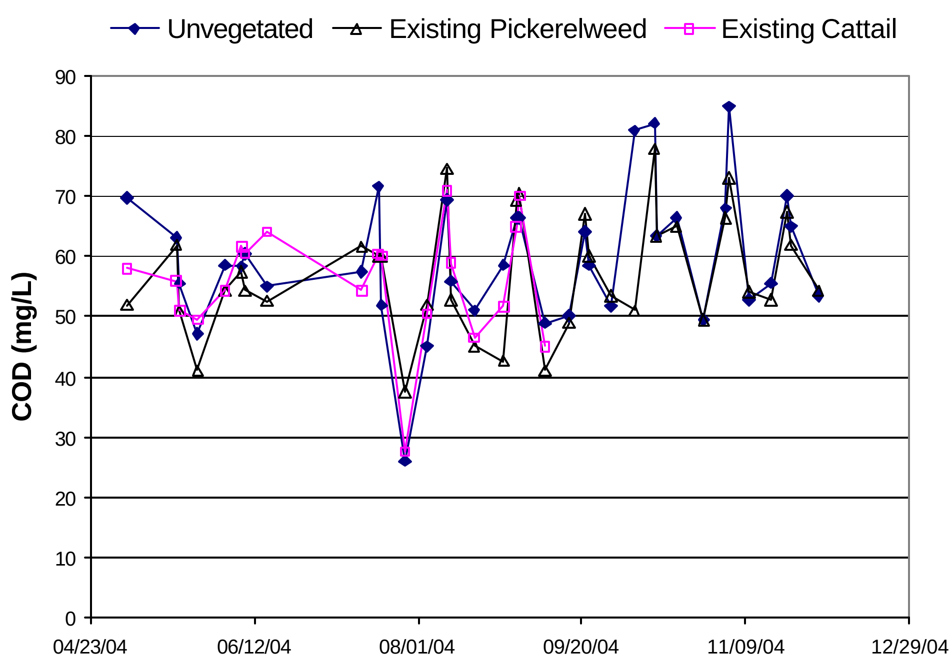


Figure 19. COD concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

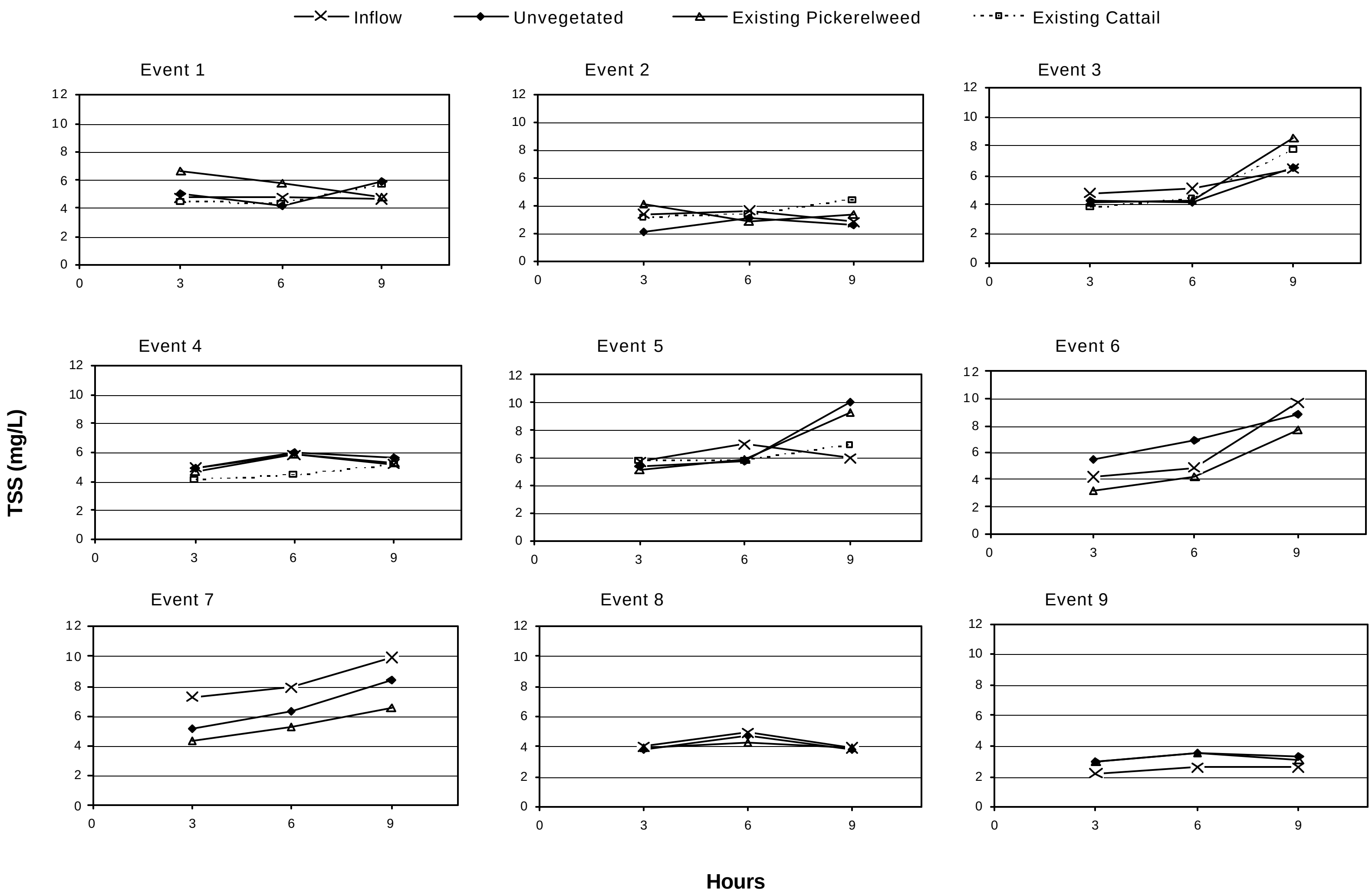
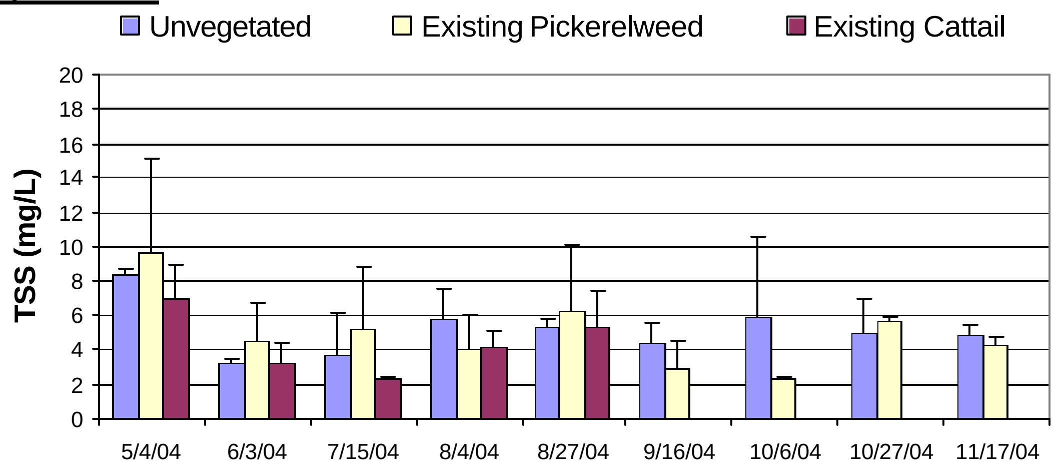


Figure 20. Inflow and outflow TSS concentrations (mg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.

Open Water



Littoral

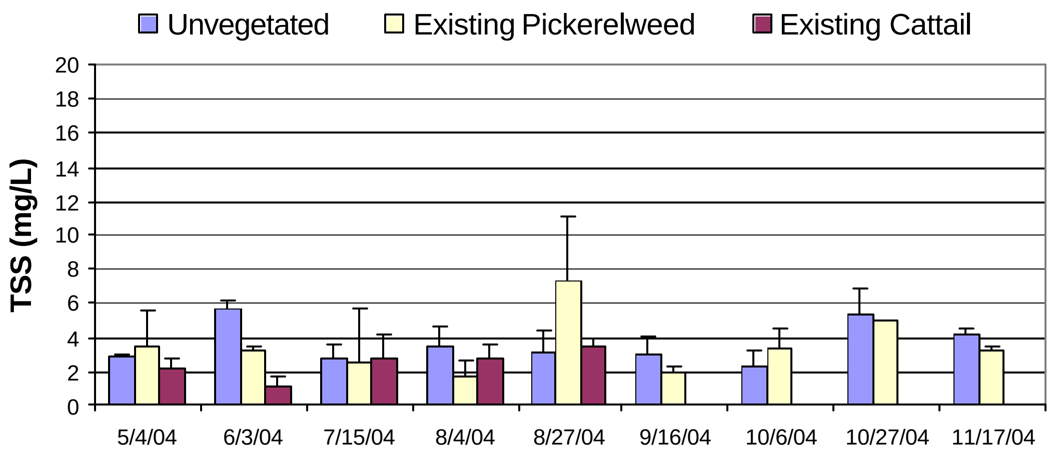


Figure 21. Open water and littoral TSS concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

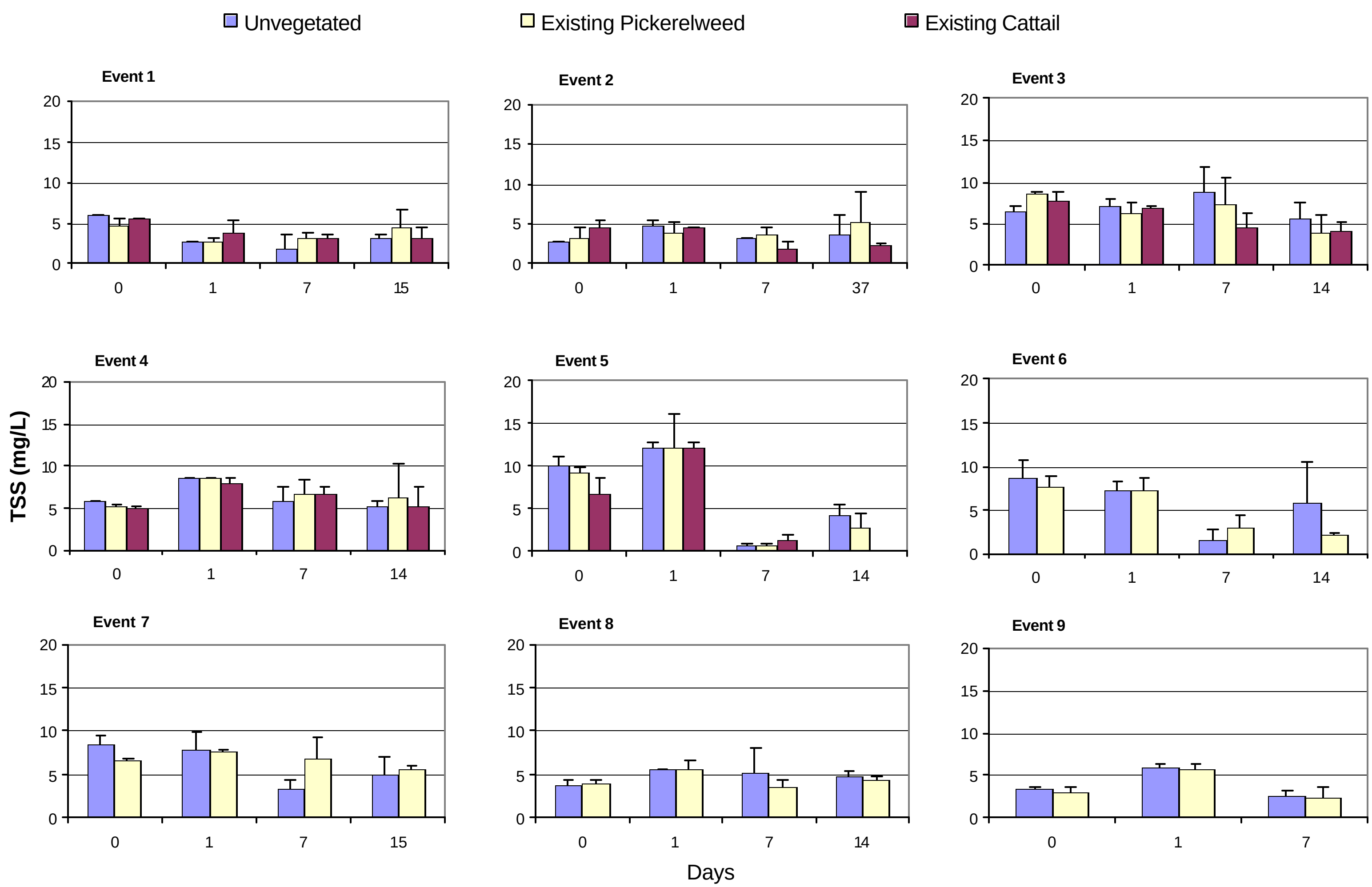


Figure 22. Open water TSS concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

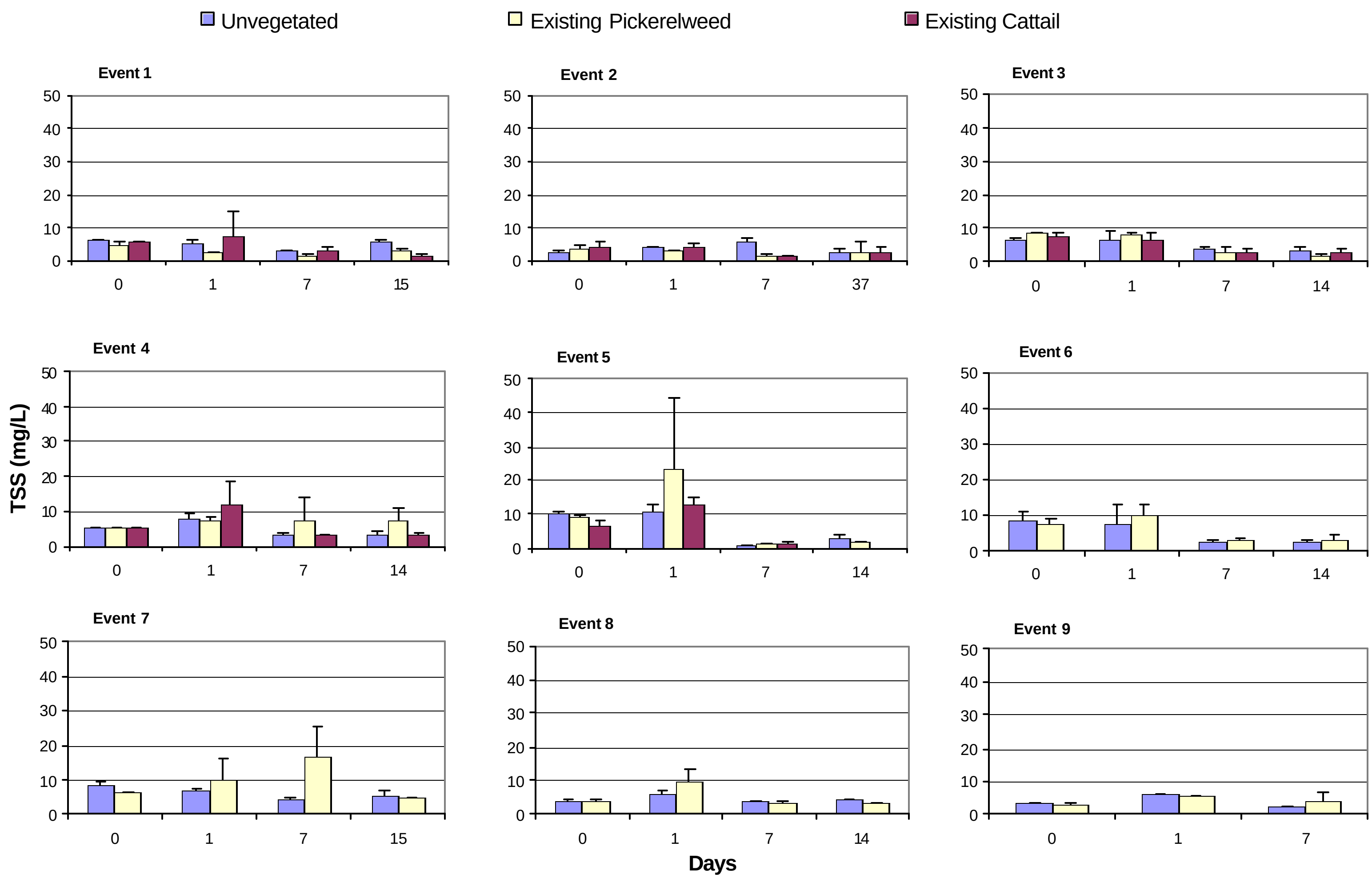
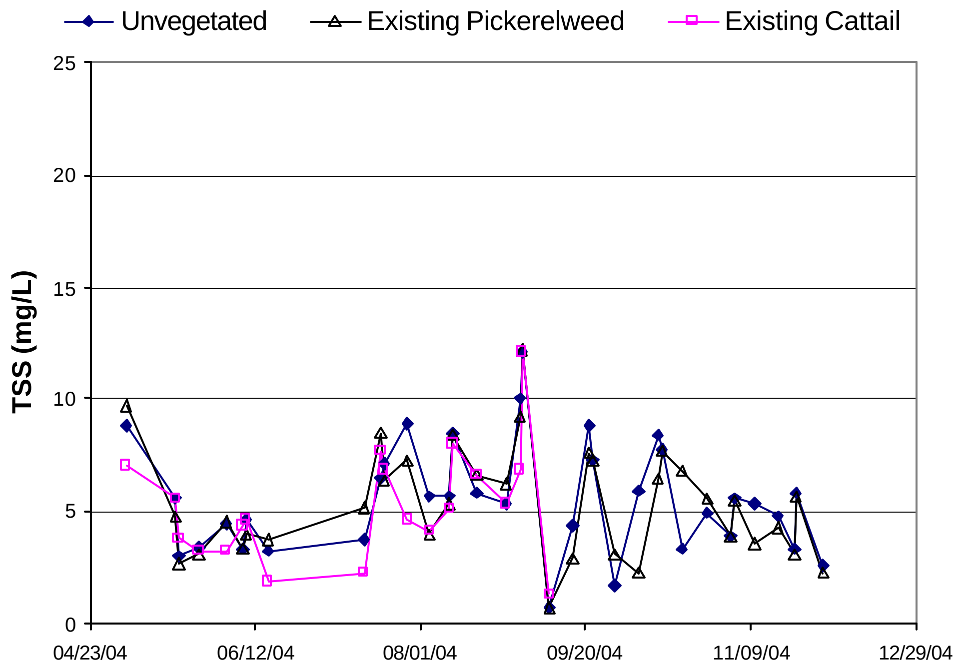


Figure 23. Littoral TSS concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

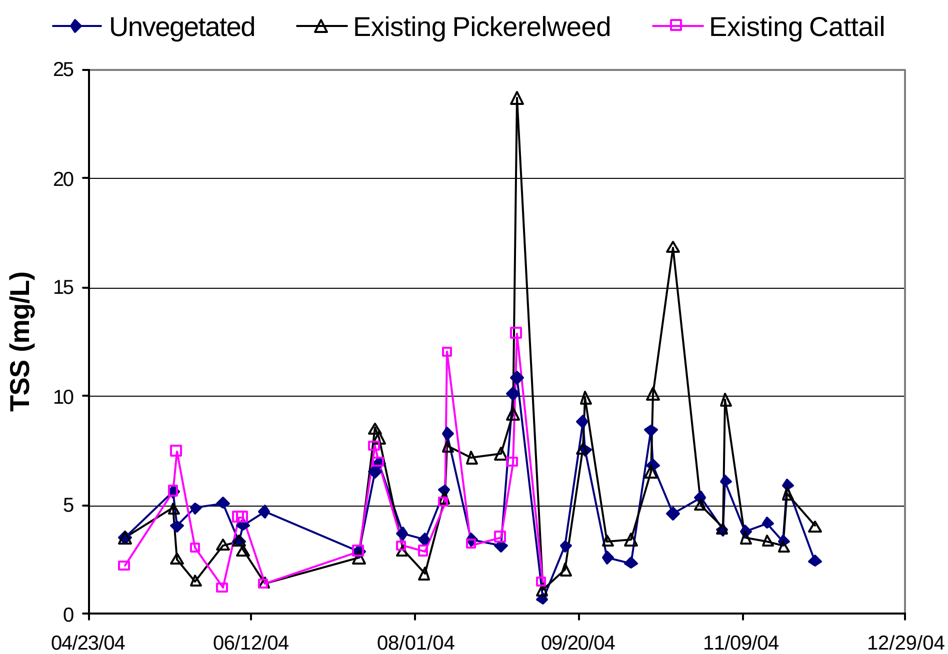


Figure 24. TSS concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

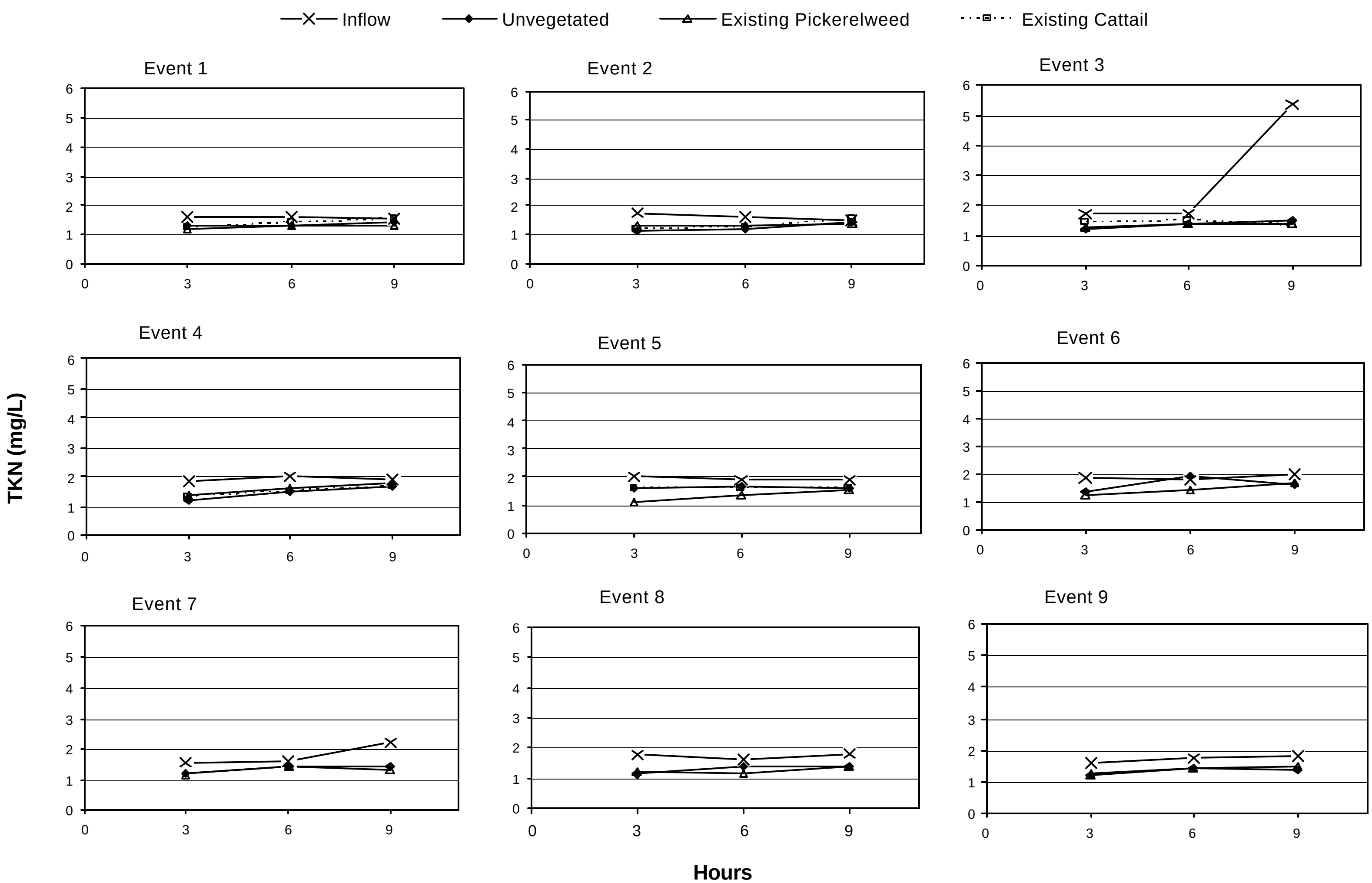
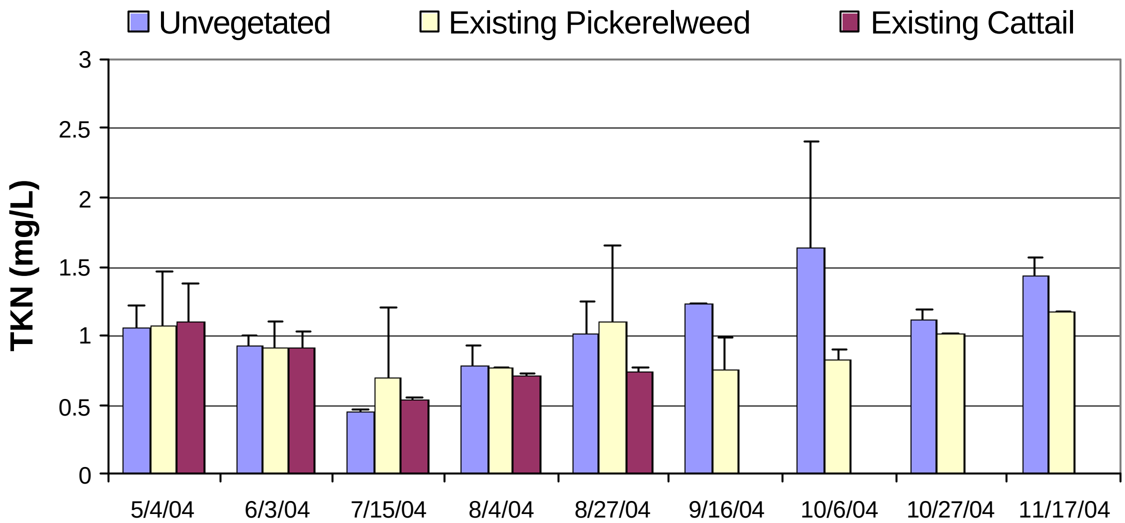


Figure 25. Inflow and outflow TKN concentrations (mg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.

Open Water



Littoral

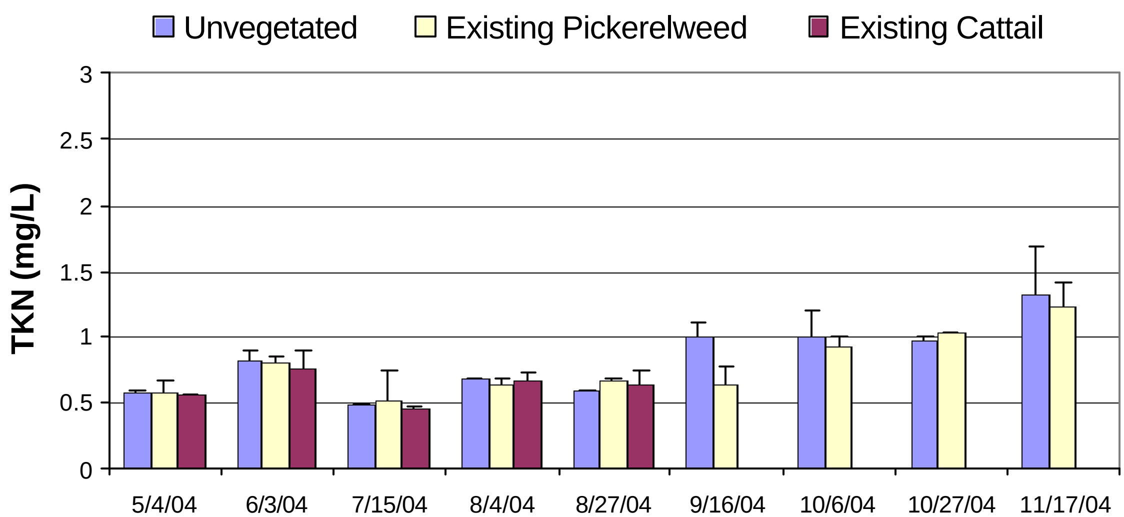


Figure 26. Open water and littoral TKN concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

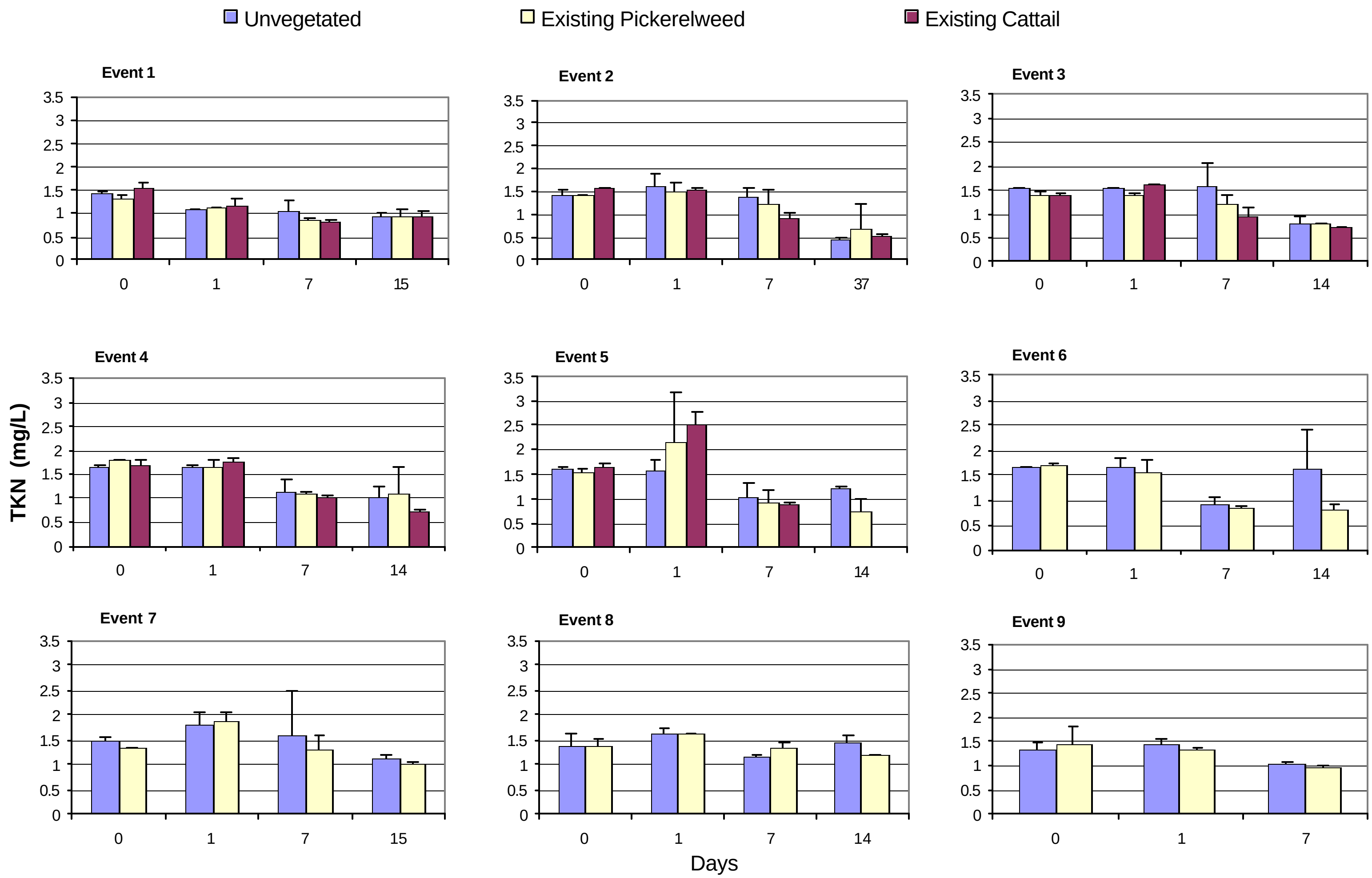


Figure 27. Open water TKN concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

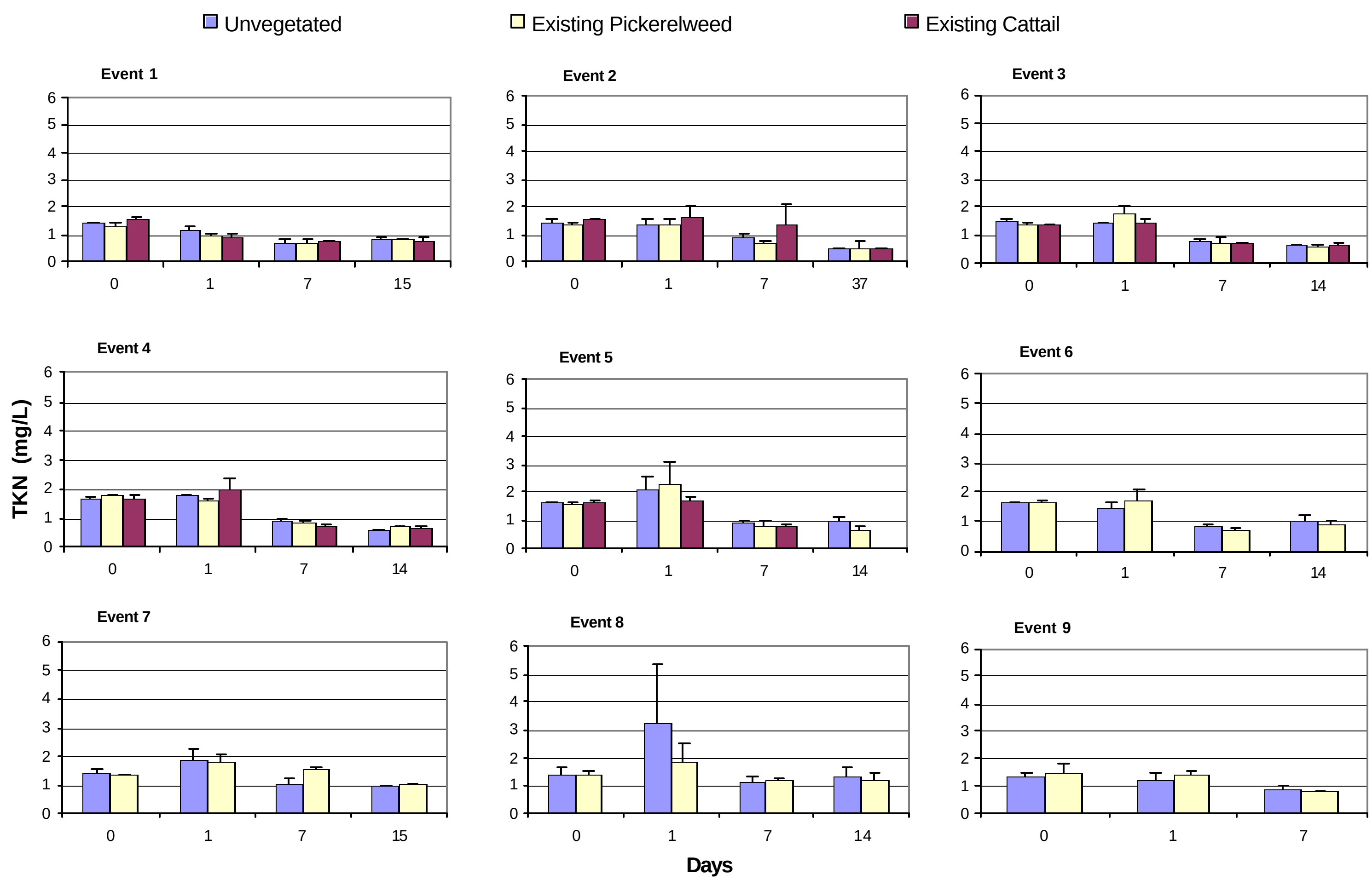
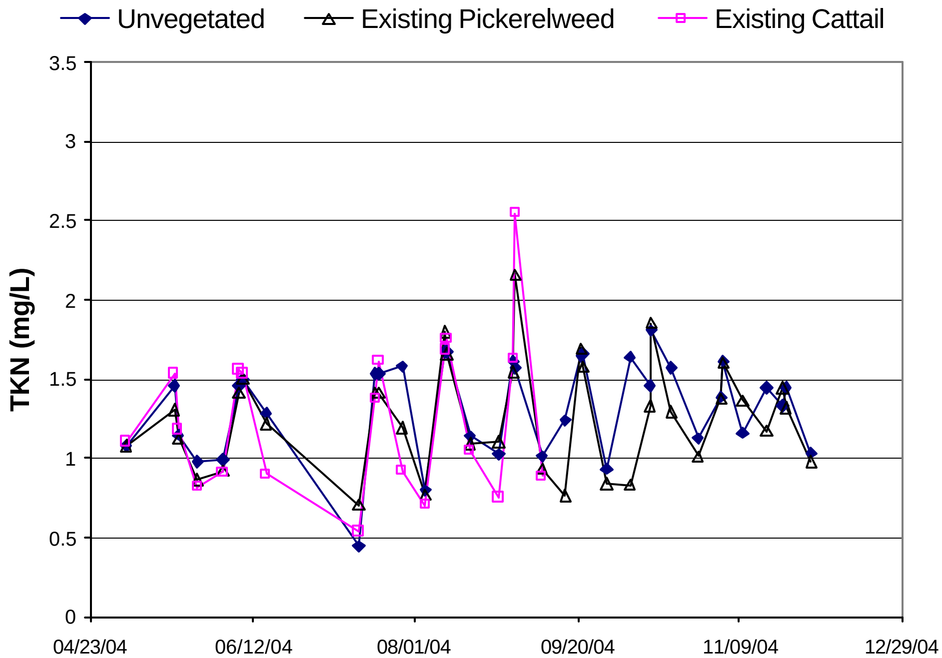


Figure 28. Littoral TKN concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

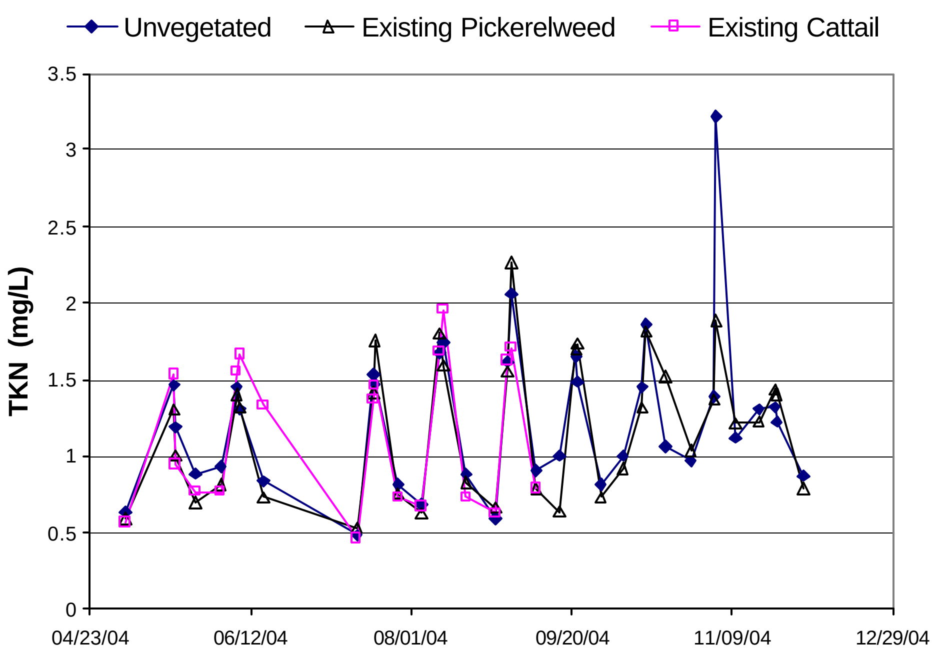


Figure 29. TKN concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

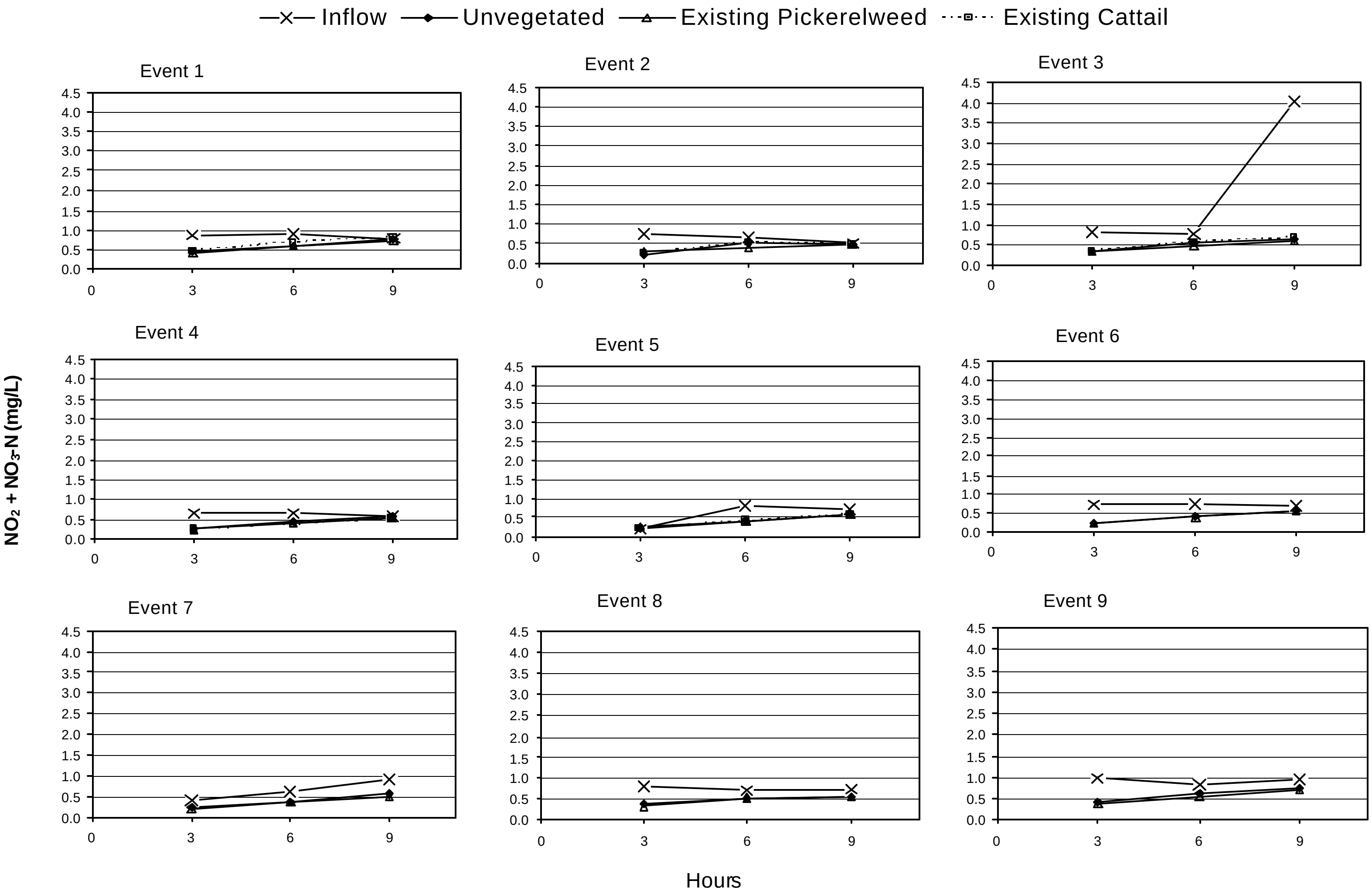
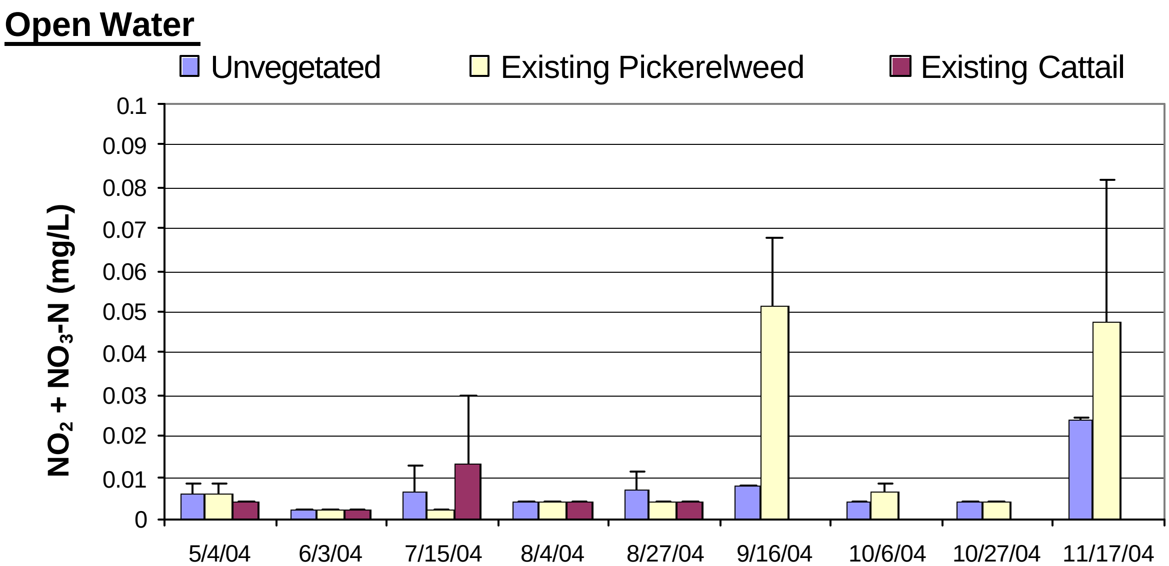


Figure 30. Inflow and outflow NO_2 + NO_3-N concentrations (mg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.



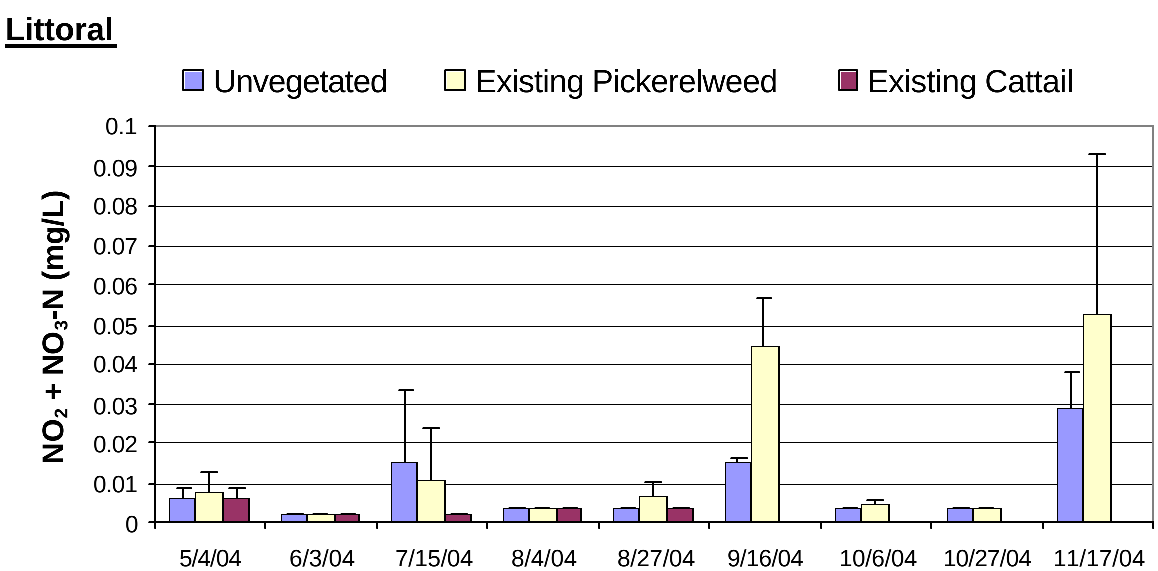


Figure 31. Open water and littoral NO_2 + NO_3-N concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

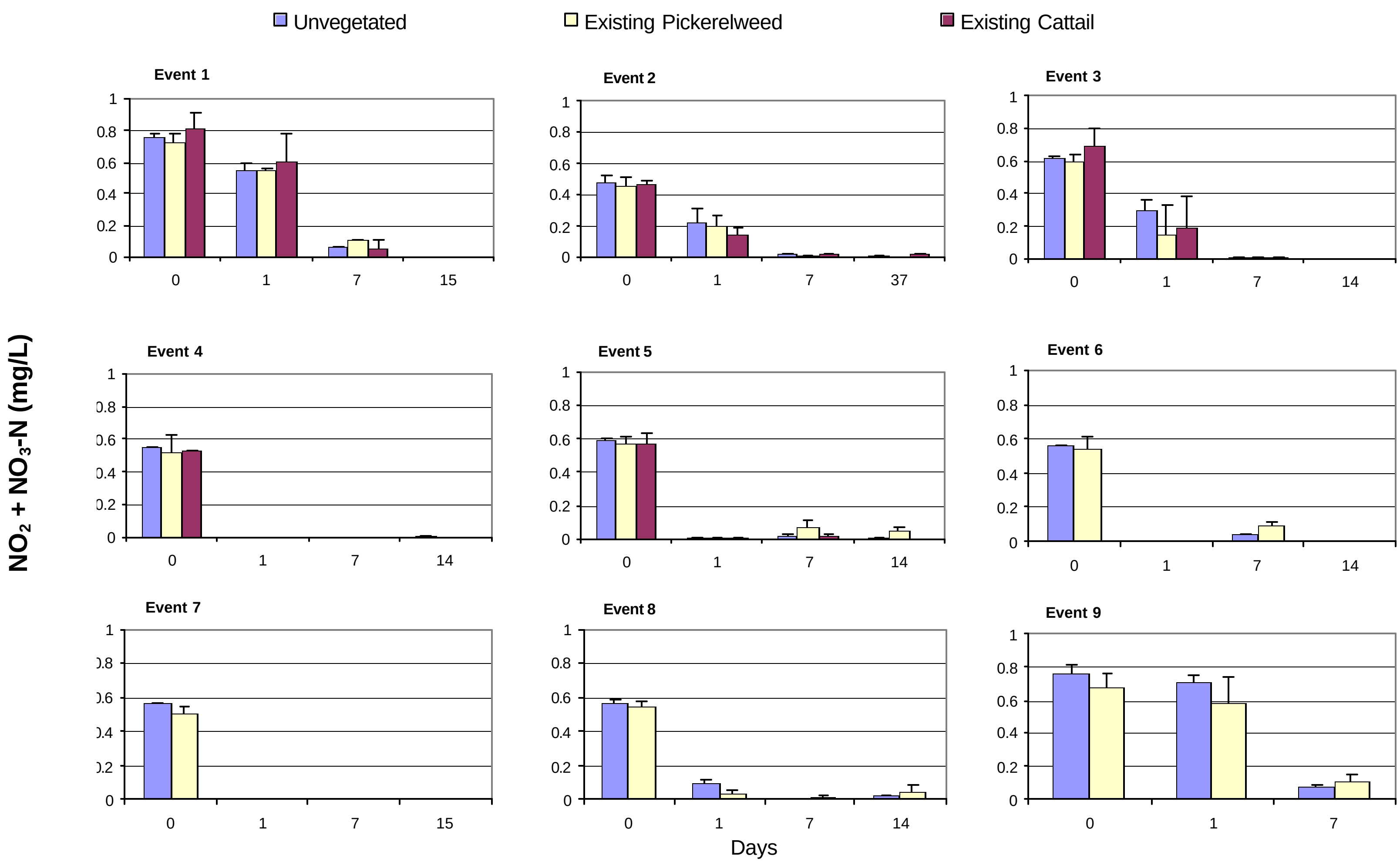


Figure 32. Open water $NO_2 + NO_3$-N concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

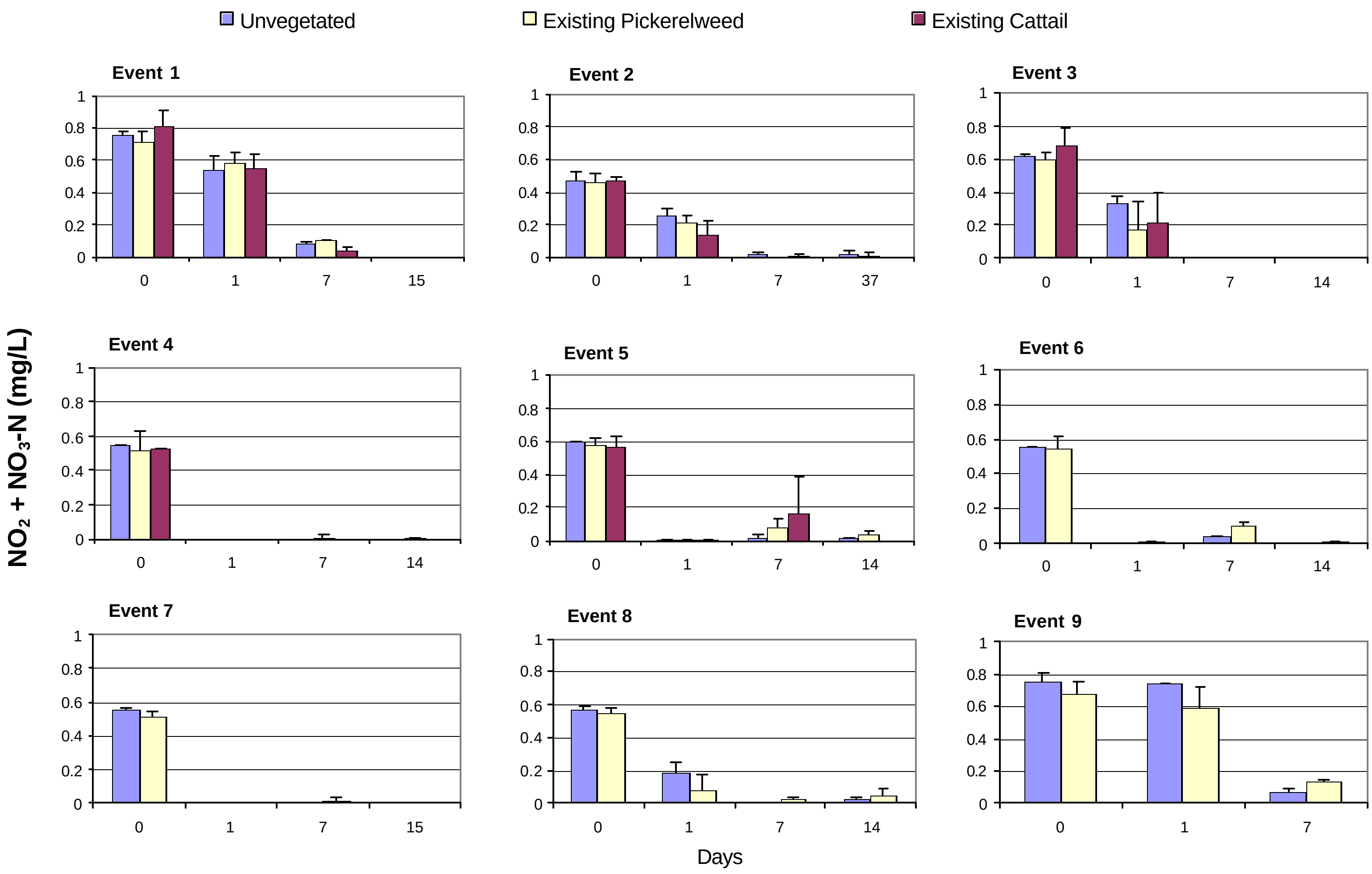
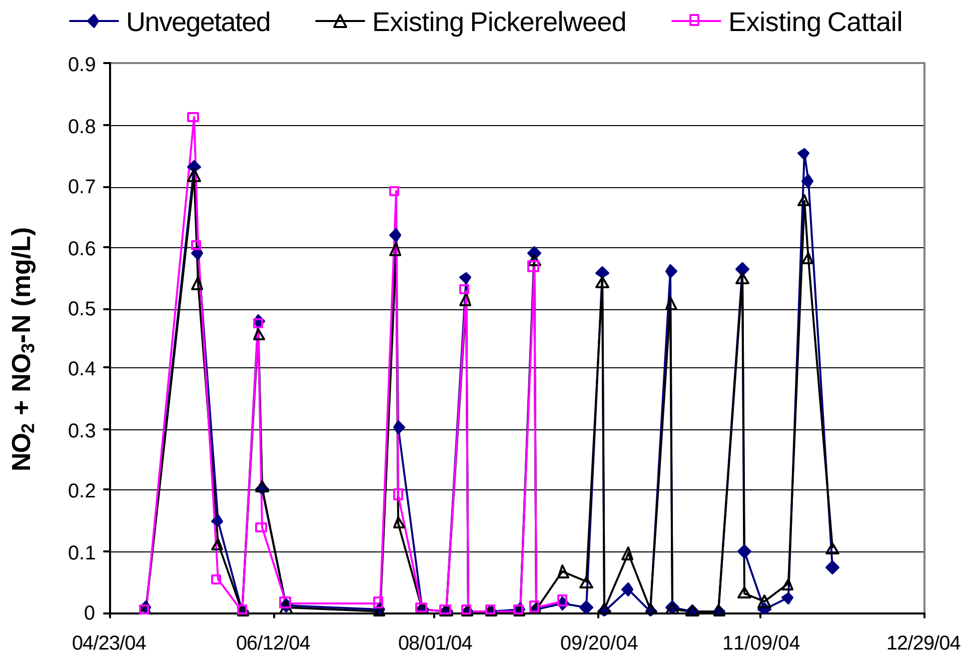


Figure 33. Littoral $NO_2 + NO_3$-N concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

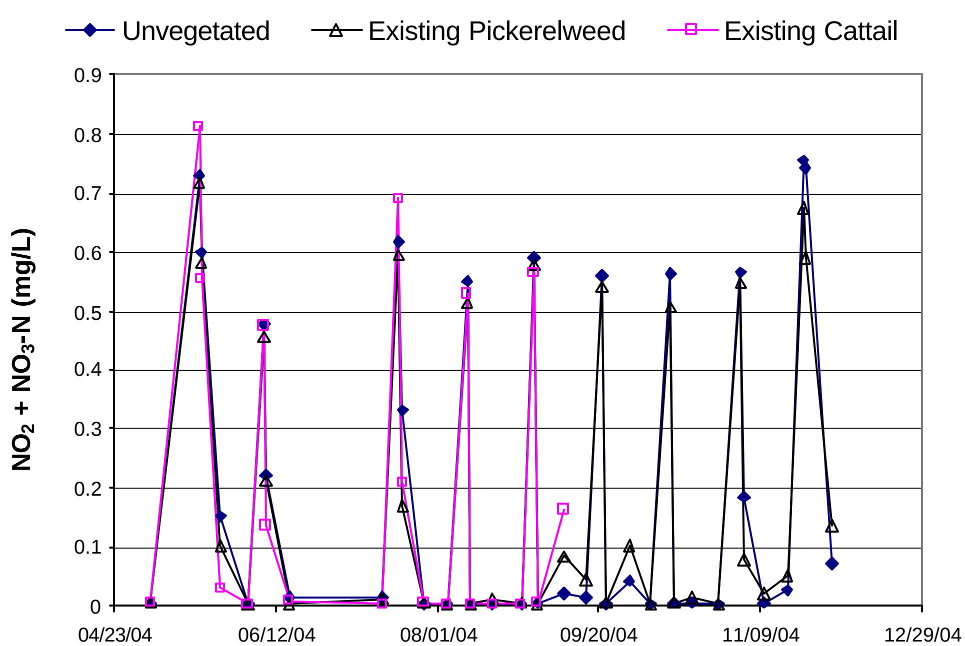


Figure 34. NO_2 + NO_3-N concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

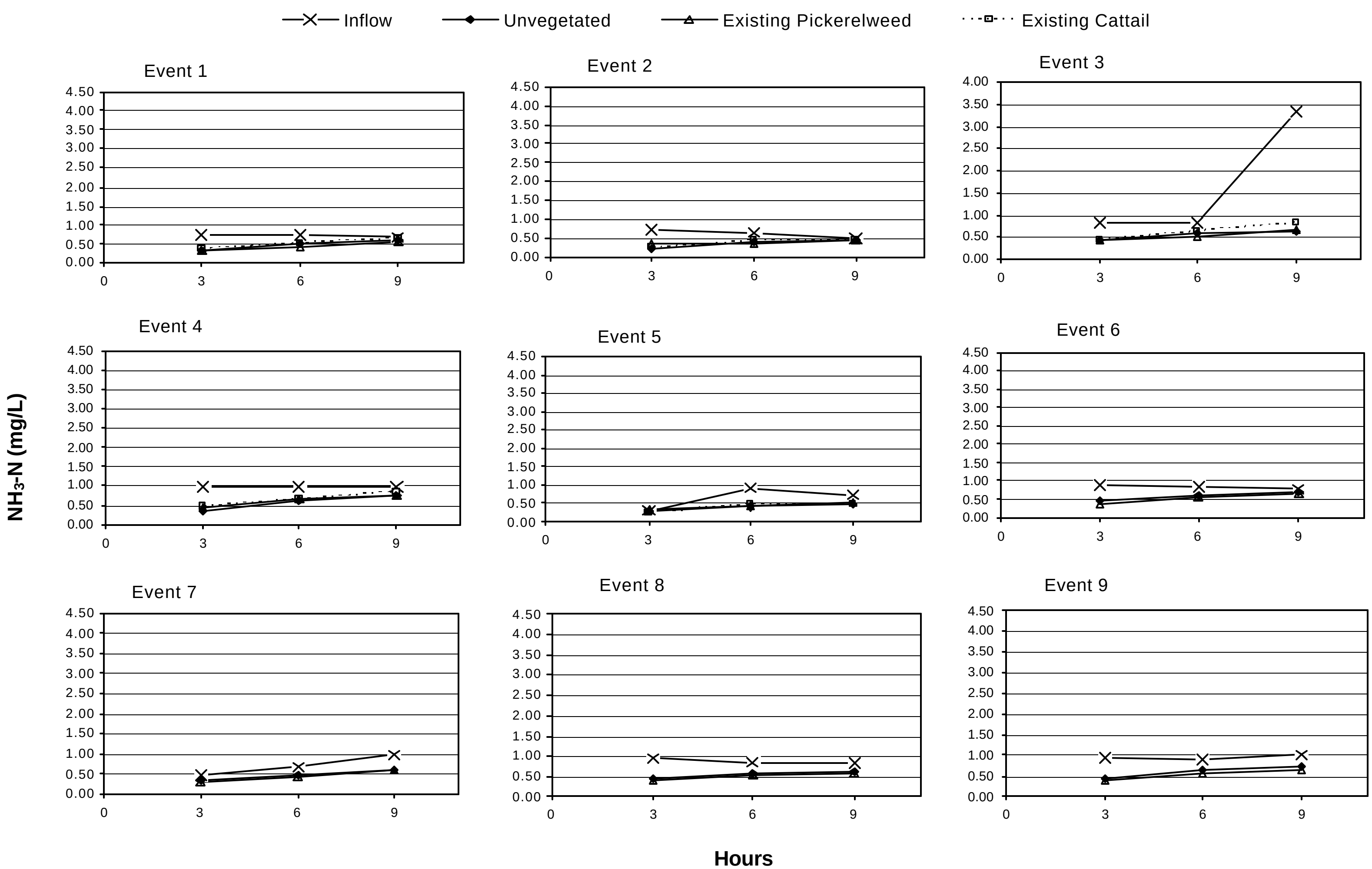
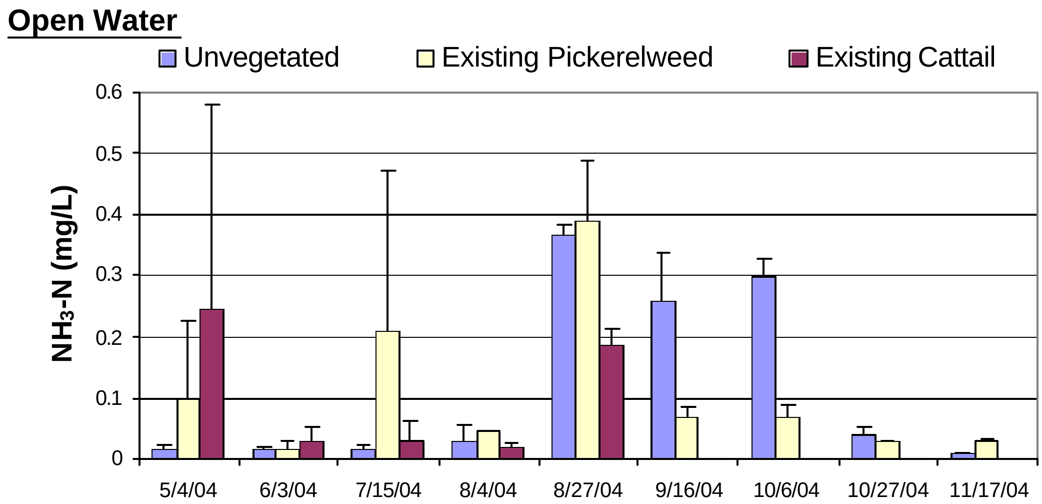


Figure 35. Inflow and outflow NH_3-N concentrations (mg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.



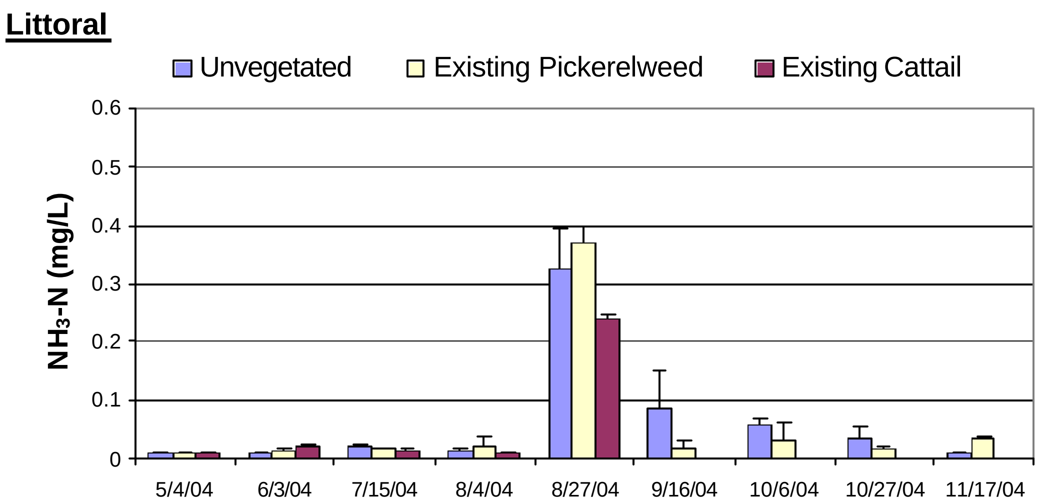


Figure 36. Open water and littoral NH_3-N concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

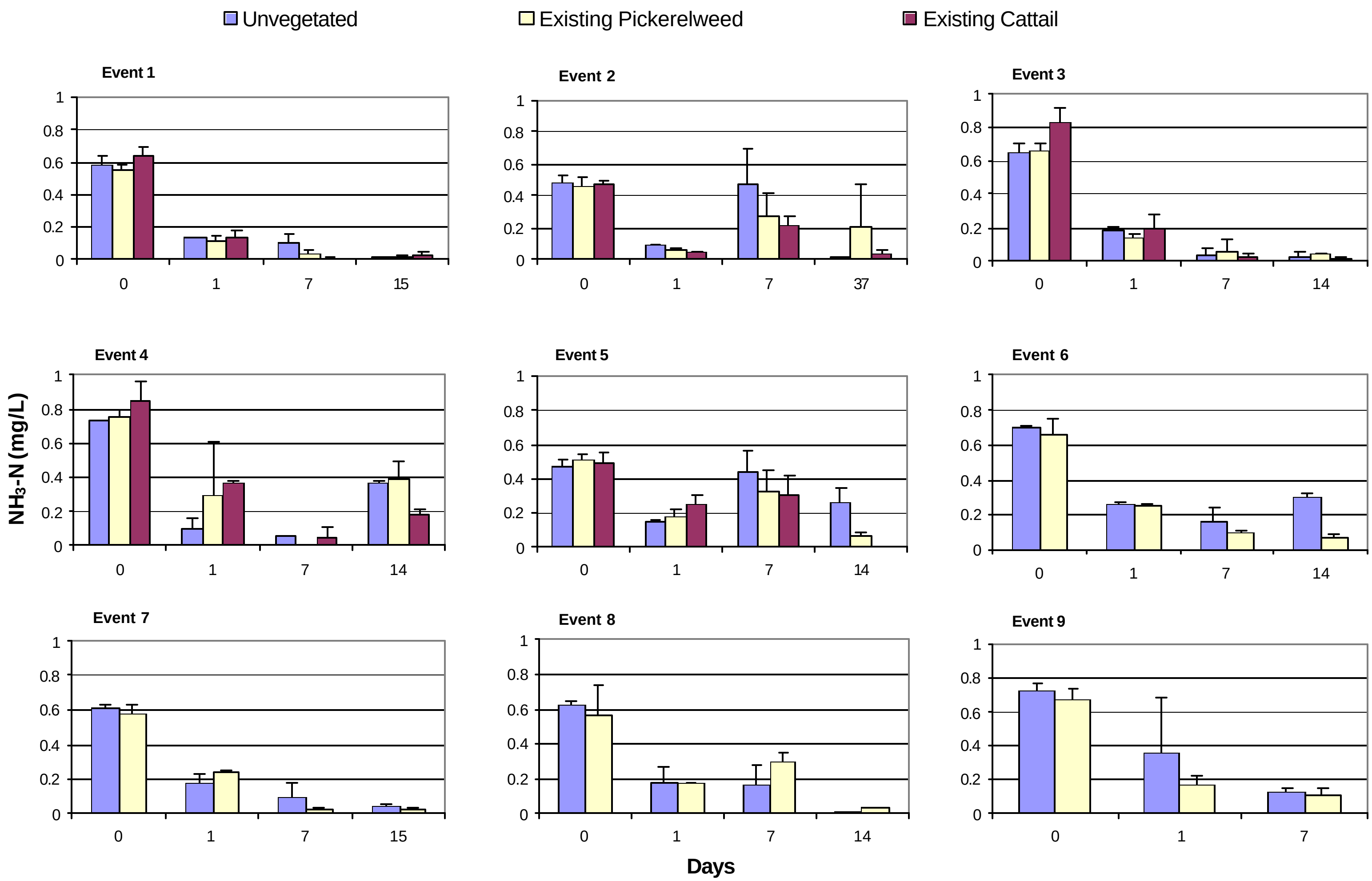


Figure 37. Open water NH_3-N concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

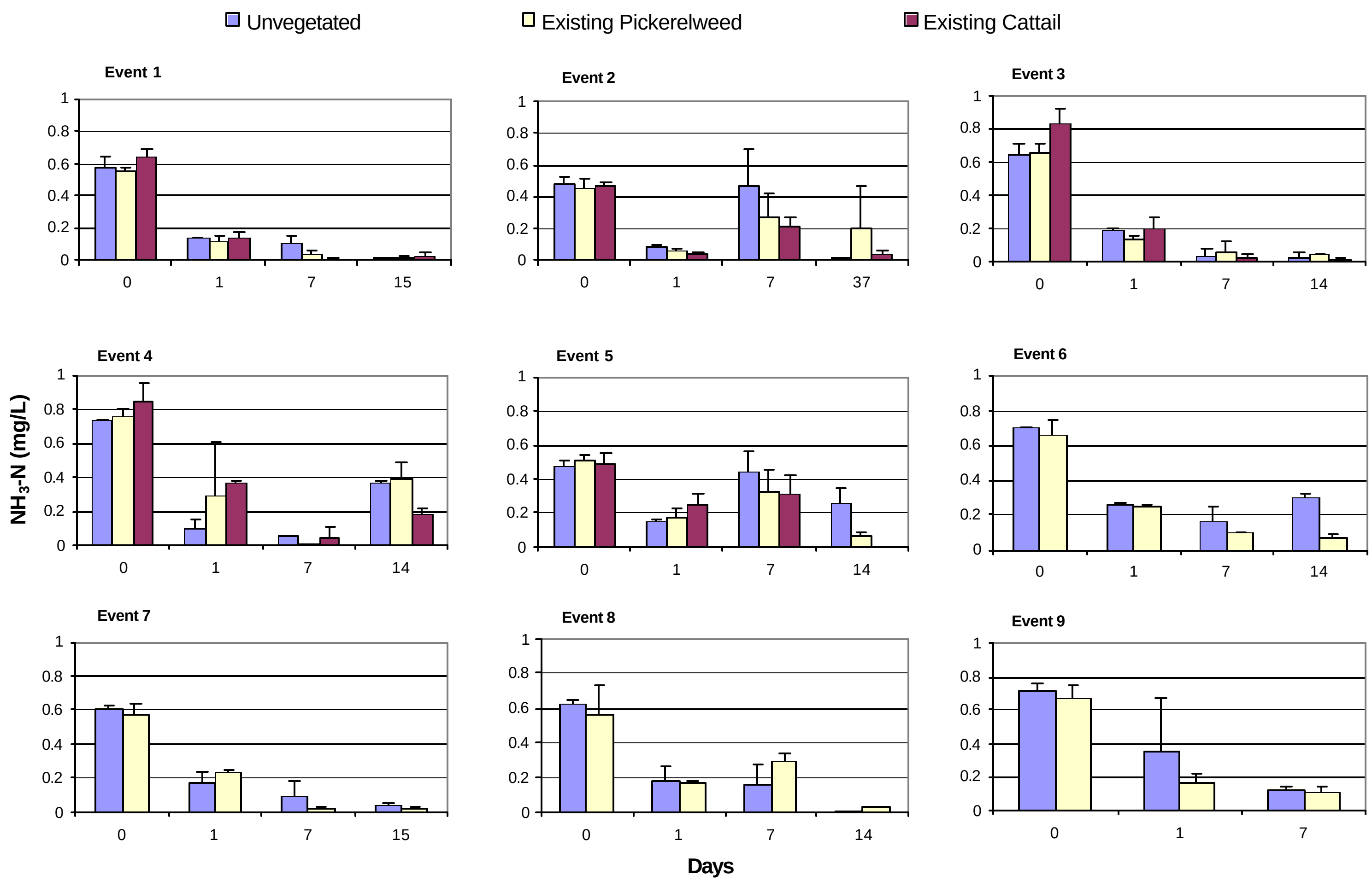
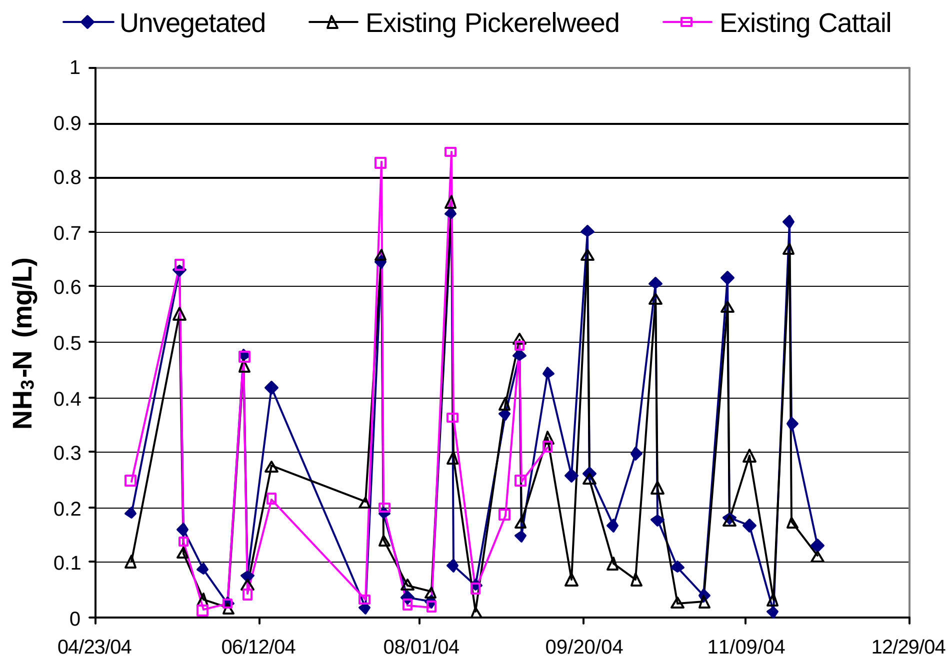


Figure 38. Littoral NH_3-N concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

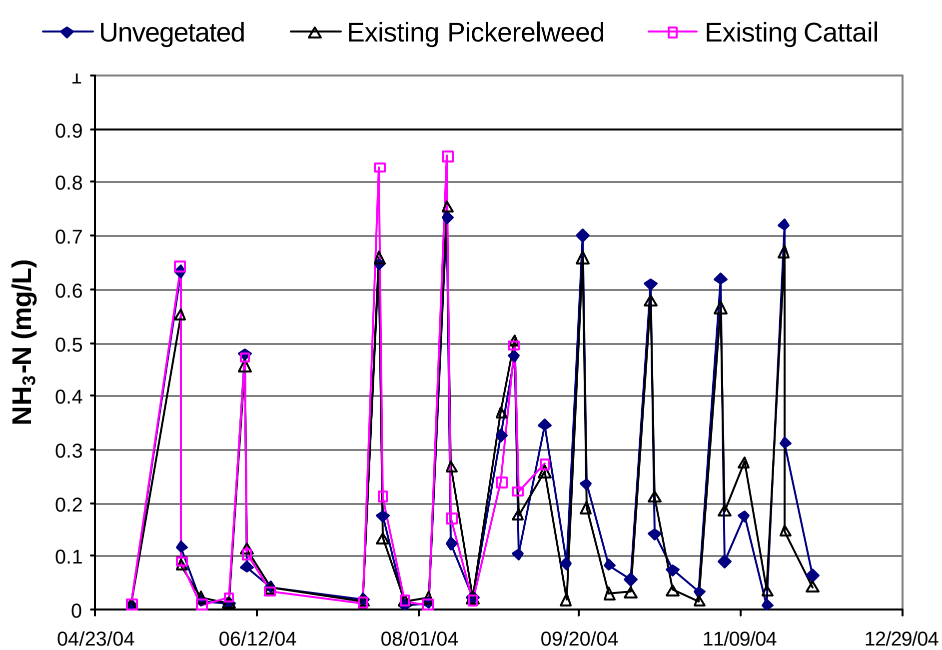


Figure 39. NH_3-N concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

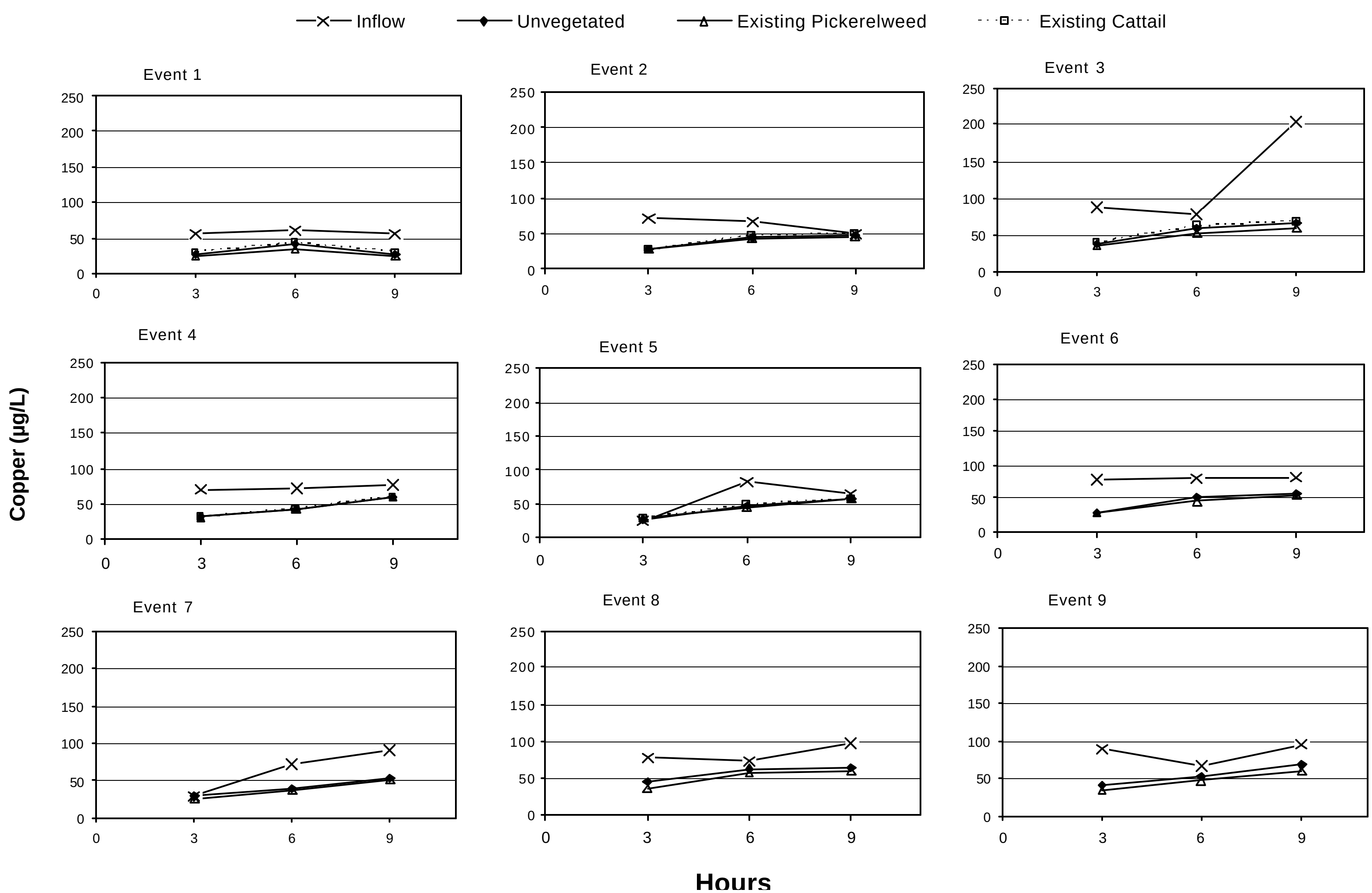
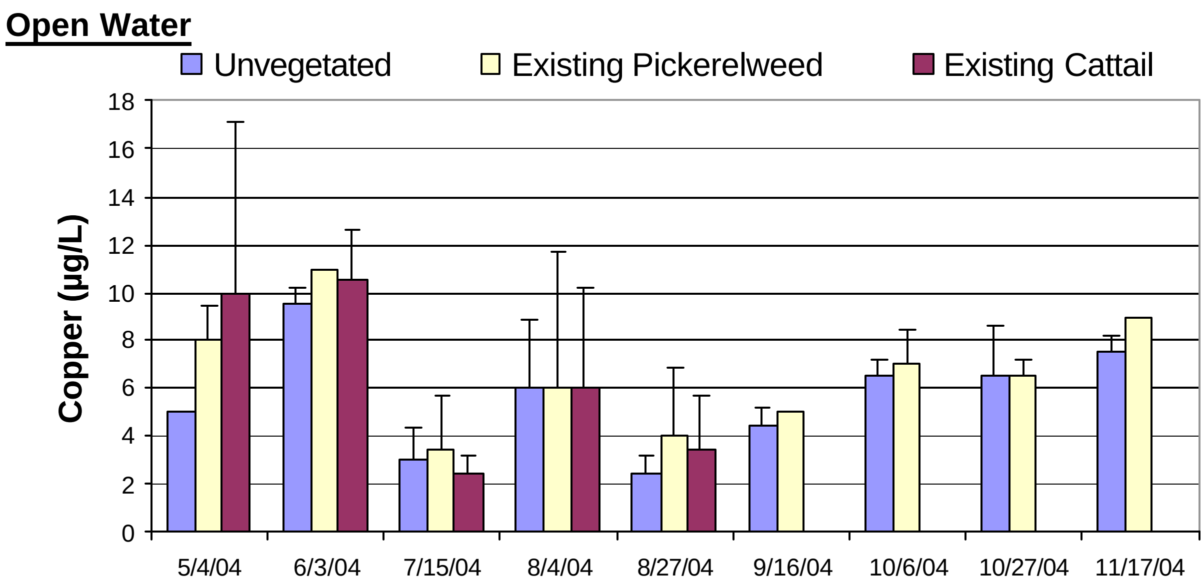


Figure 40. Inflow and outflow Cu concentrations (µg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.



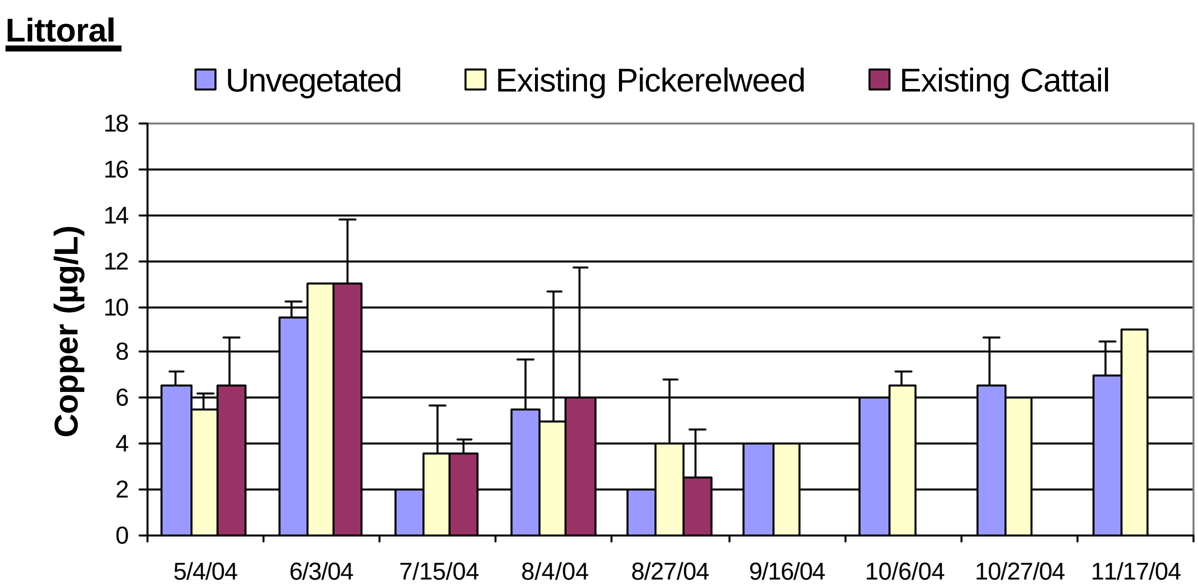


Figure 41. Open water and littoral Cu concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

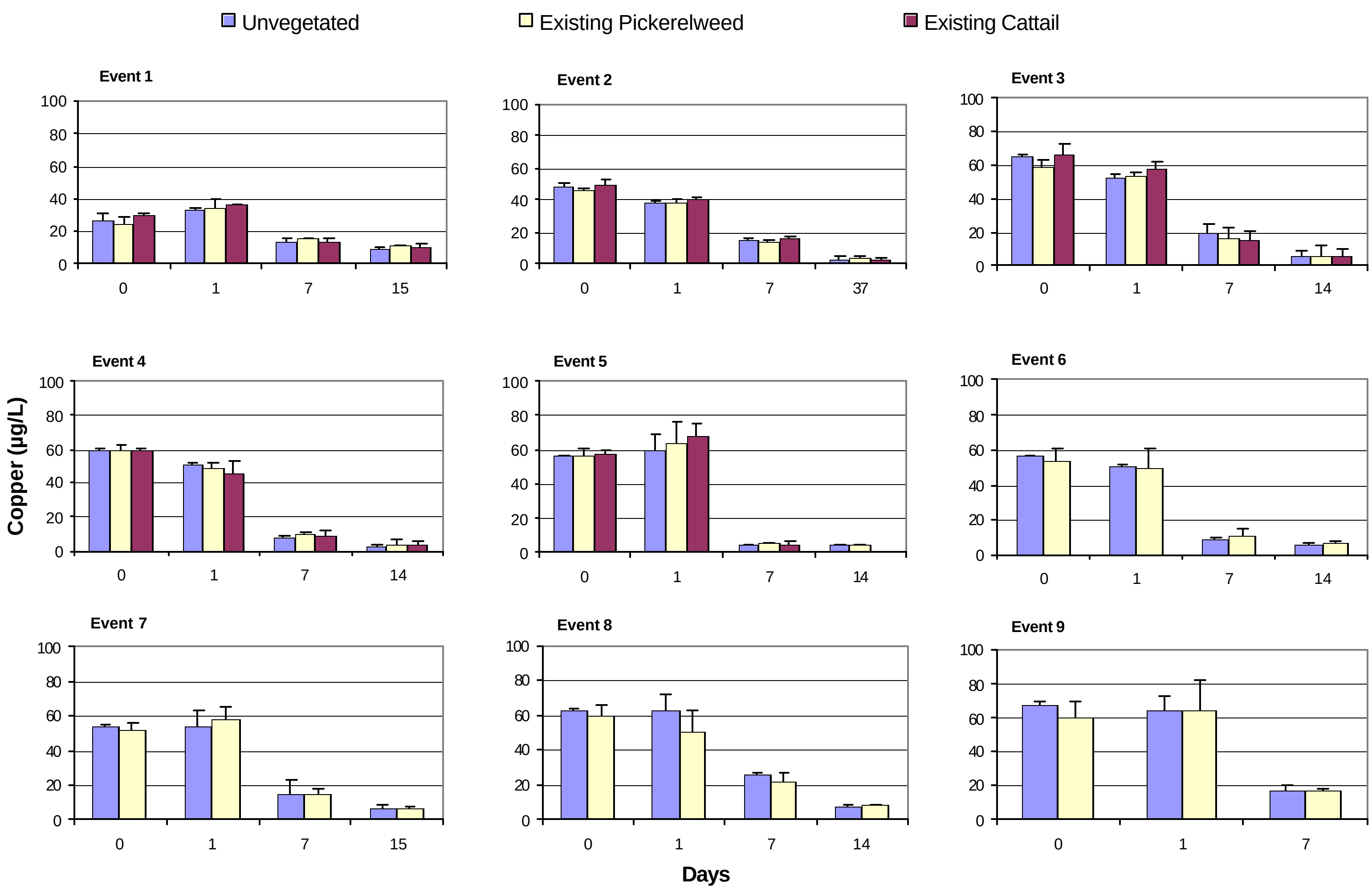


Figure 42. Open water Cu concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

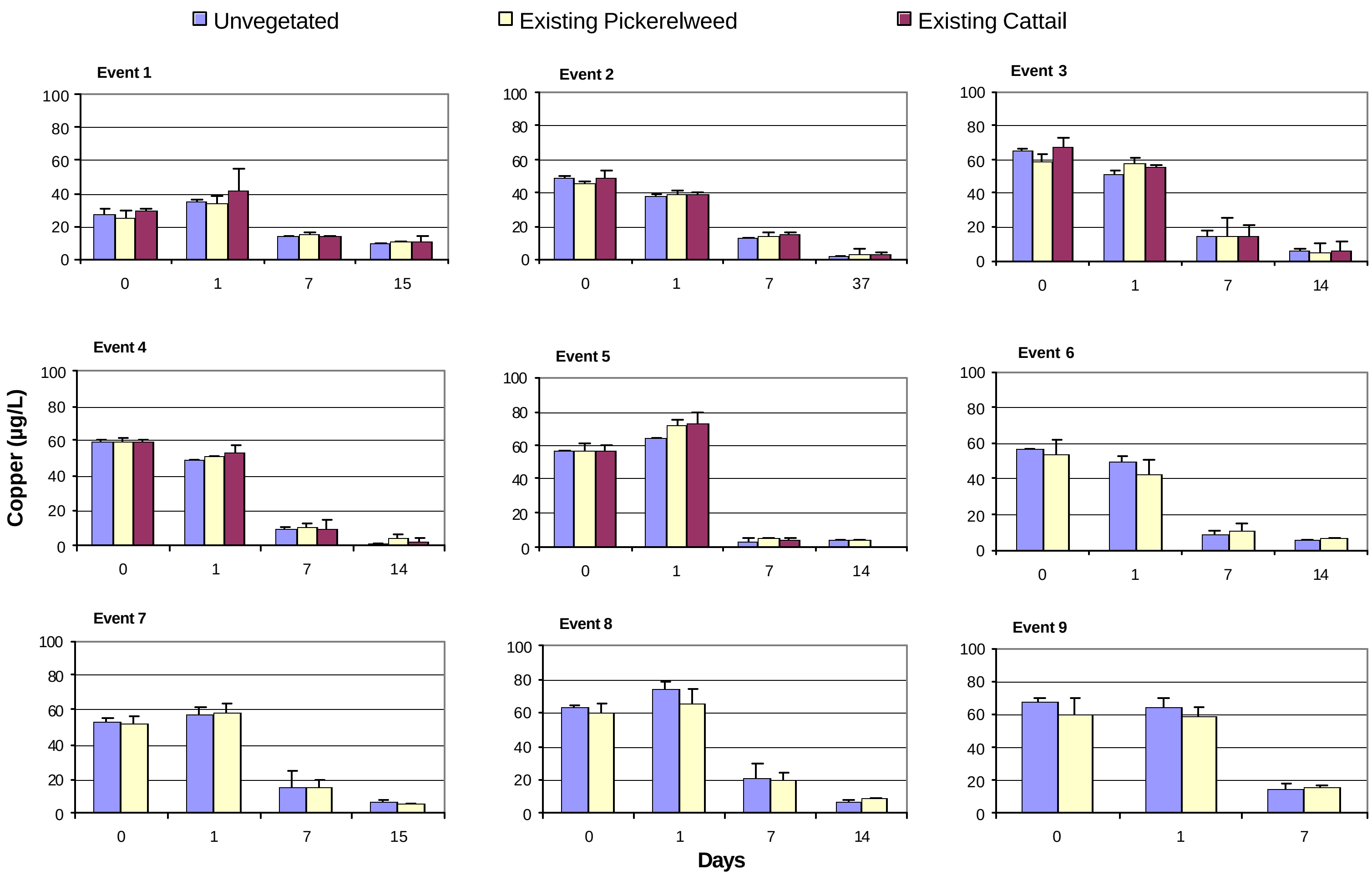
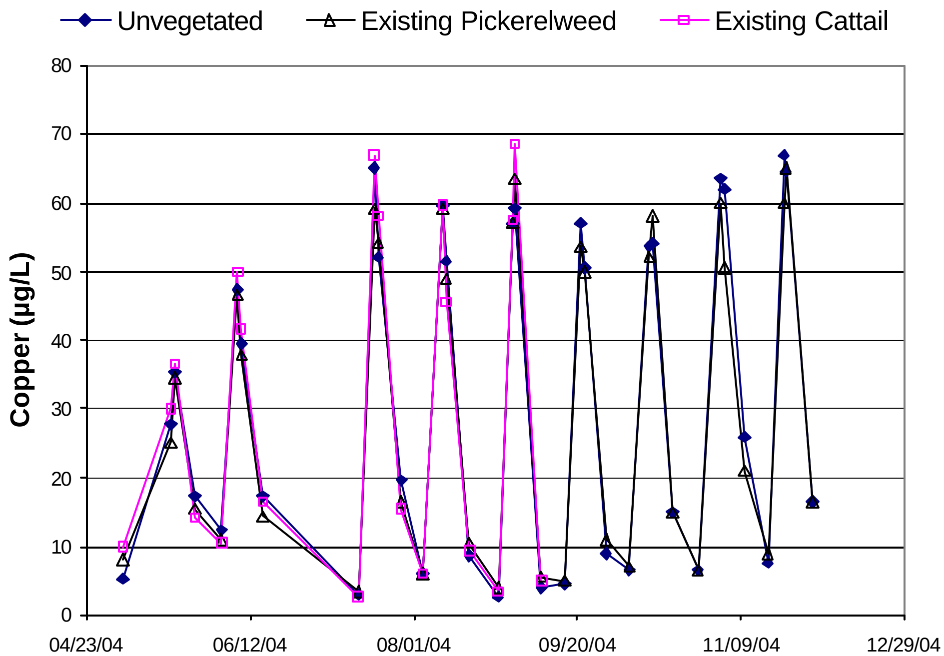


Figure 43. Littoral Cu concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

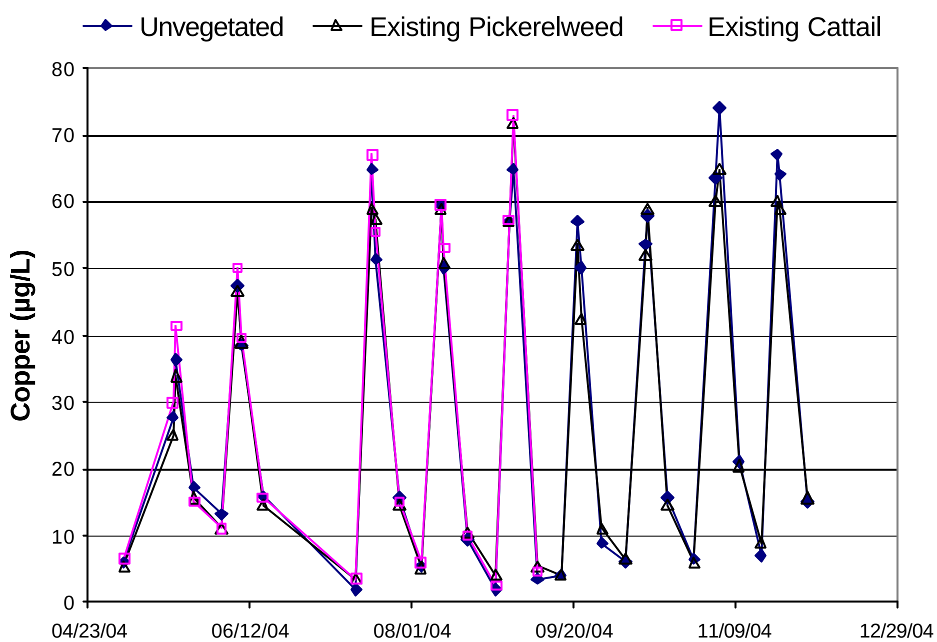


Figure 44. Cu concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

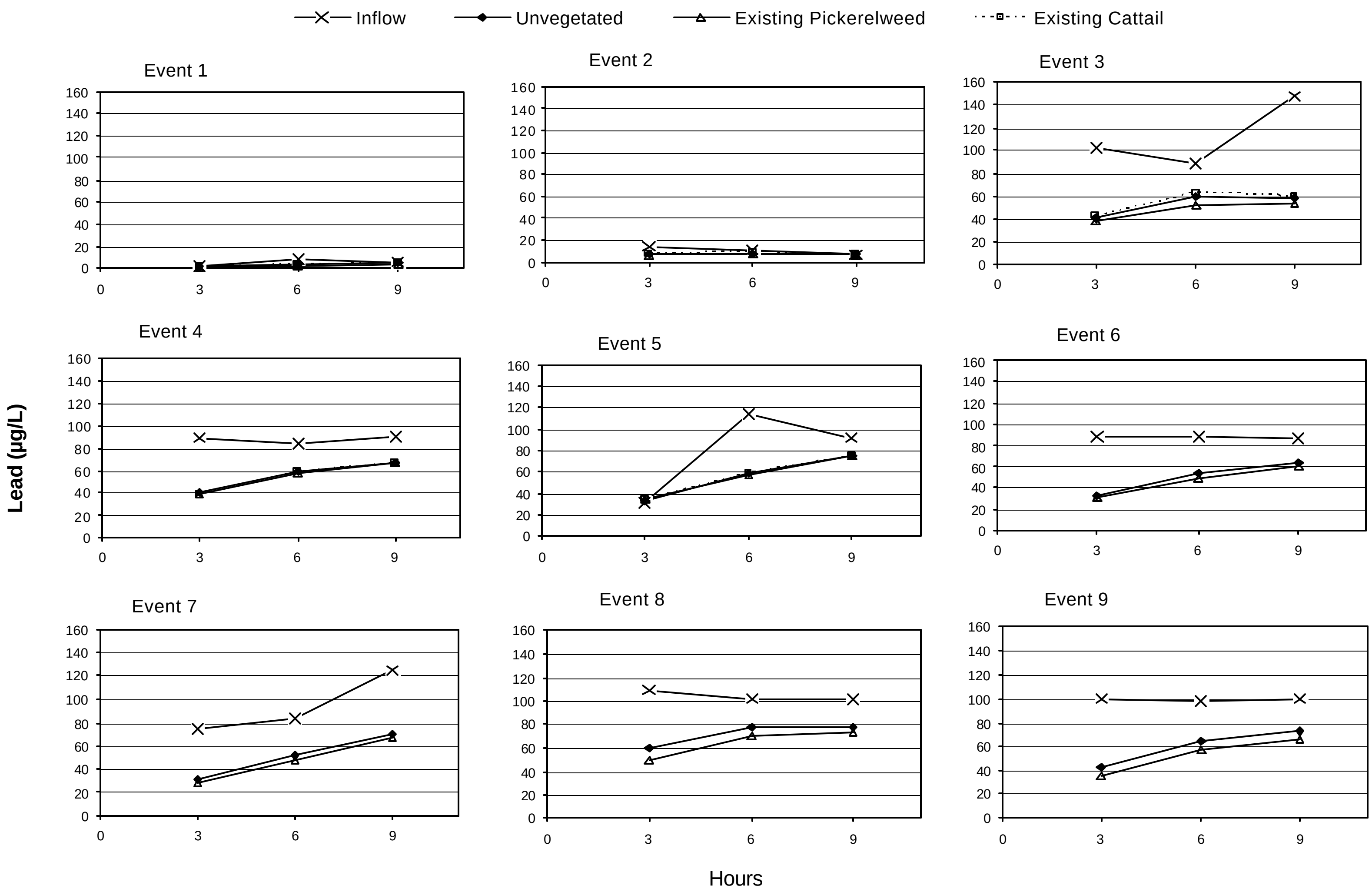
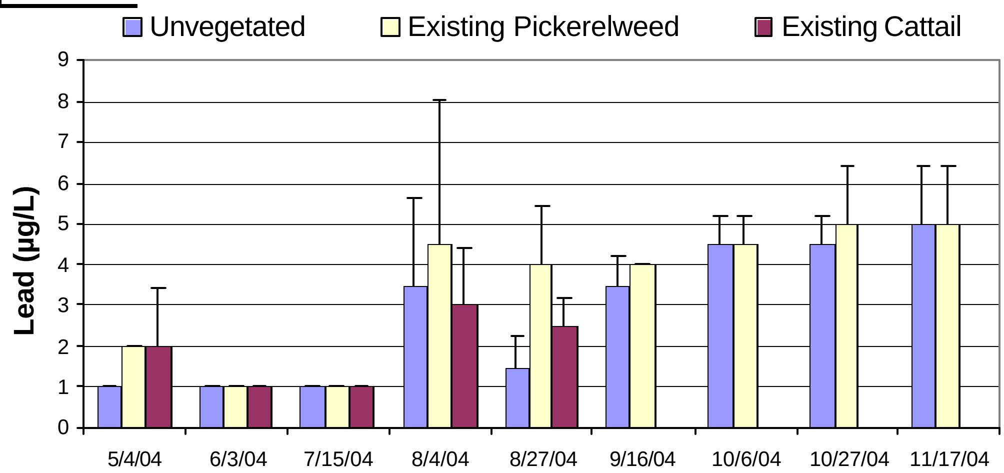


Figure 45. Inflow and outflow Pb concentrations (µg/L) during nine simulated storm events for unvegetated, pickerelweed and cattail compartments.

Open Water



Littoral

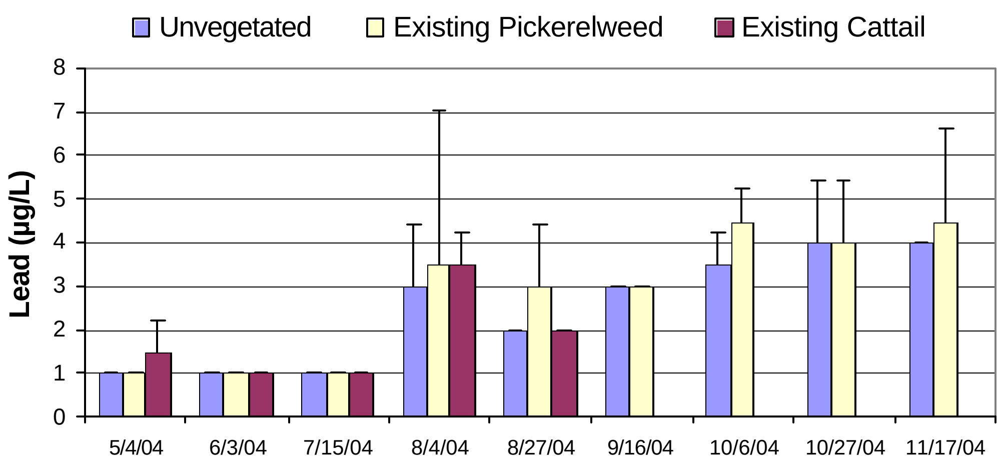


Figure 46. Open water and littoral Pb concentrations for unvegetated, pickerelweed and cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

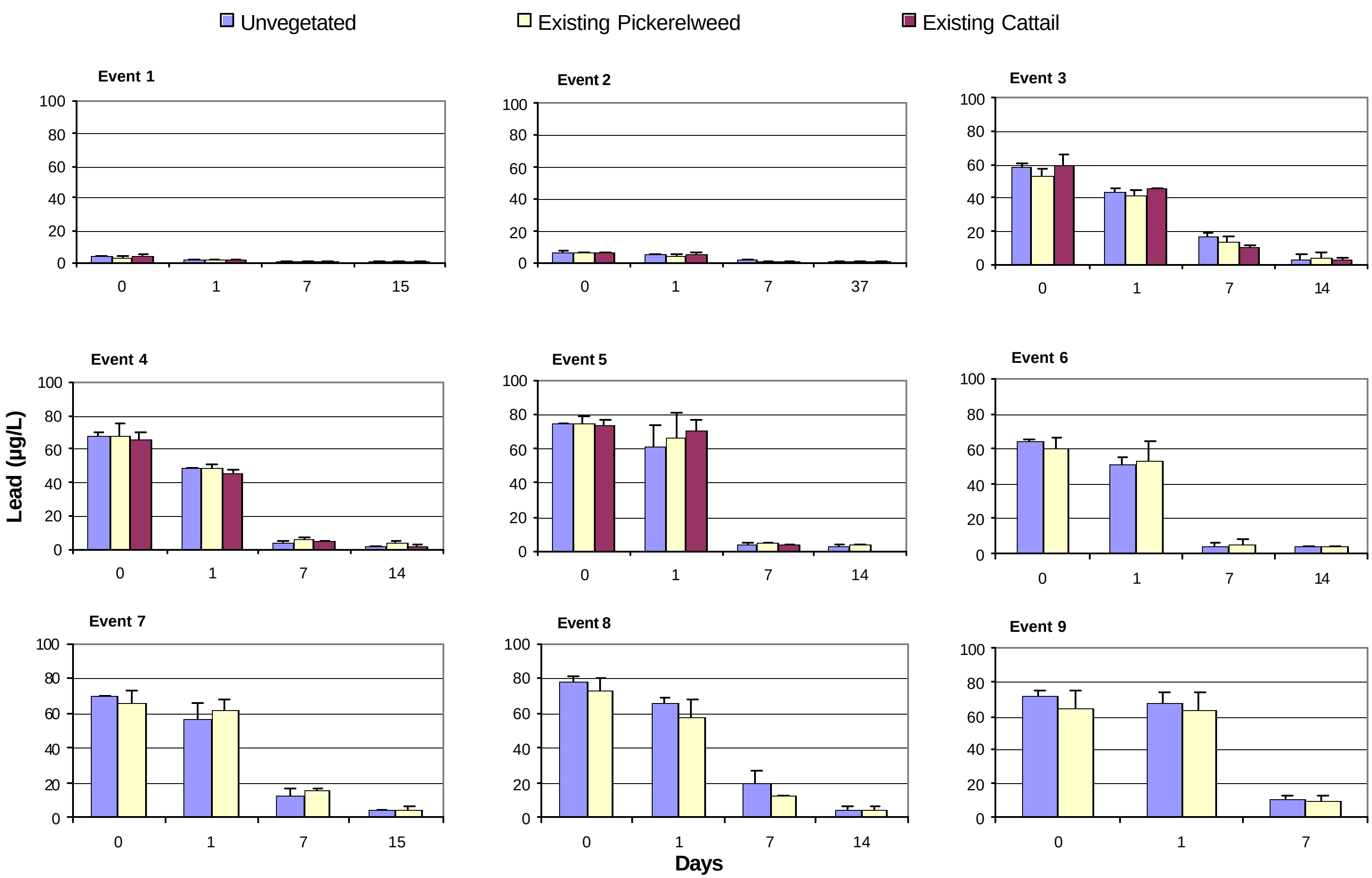


Figure 47. Open water Pb concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

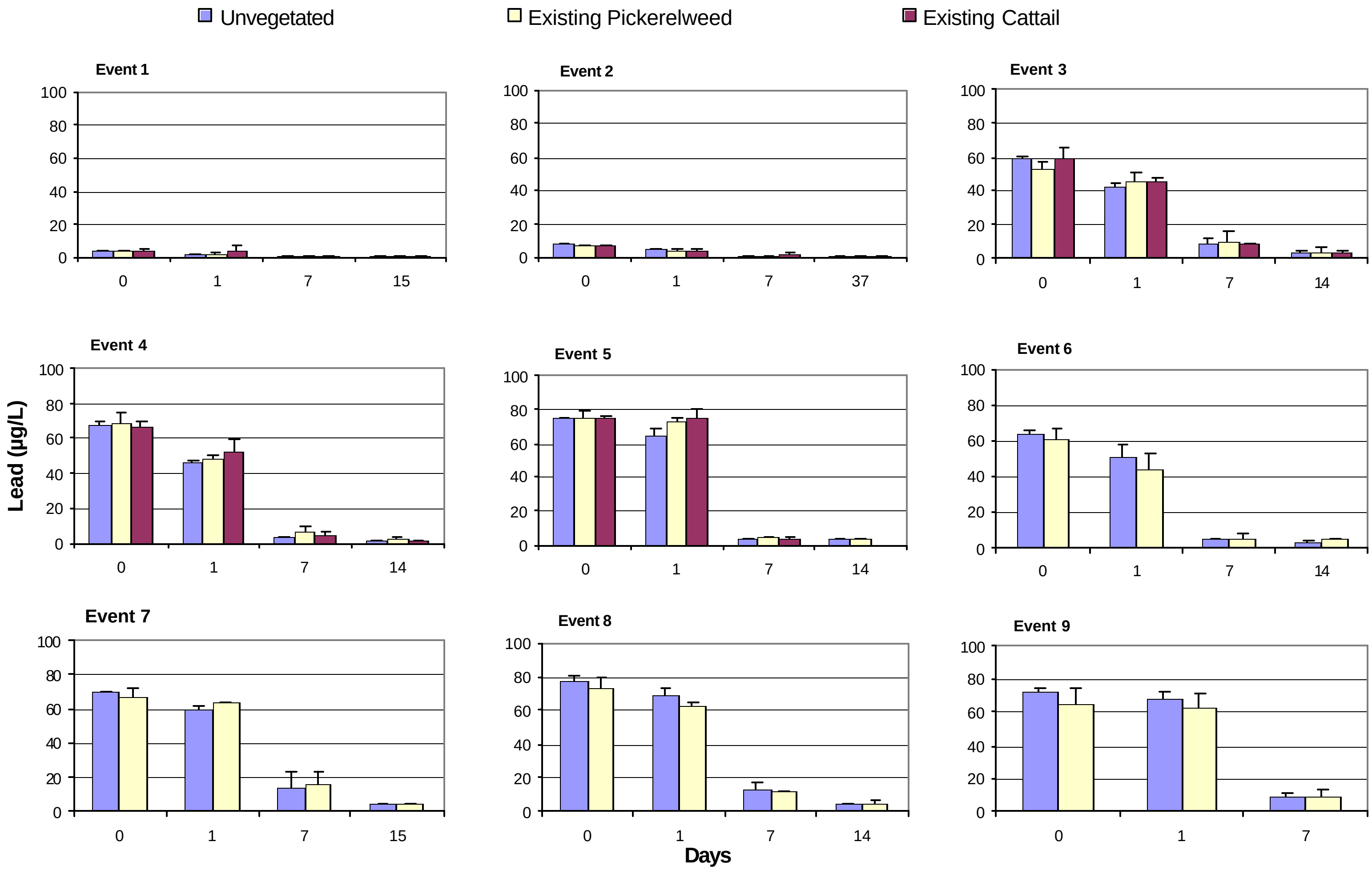
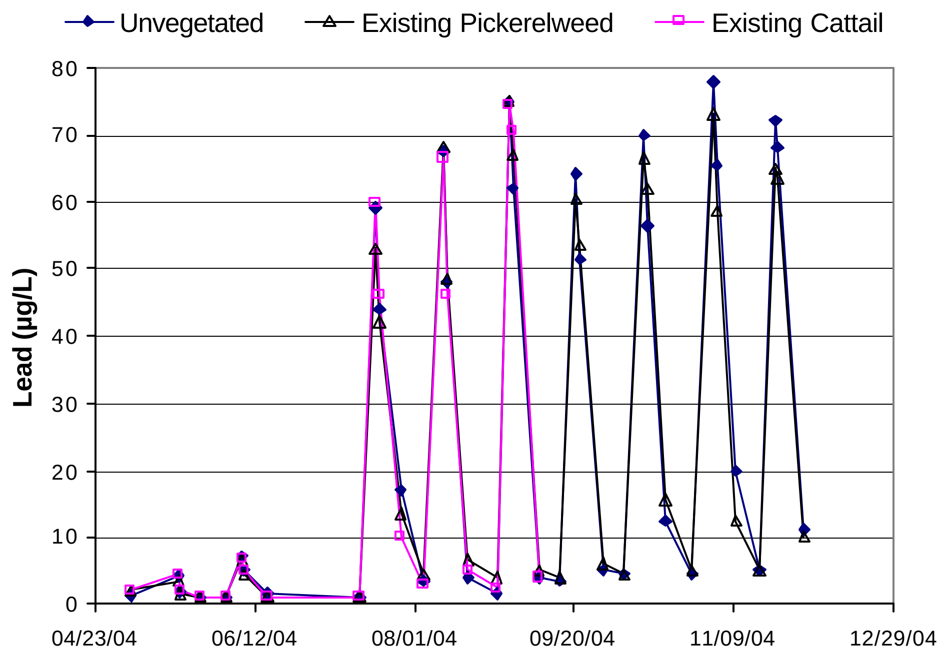


Figure 48. Littoral Pb concentrations for unvegetated, pickerelweed and cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

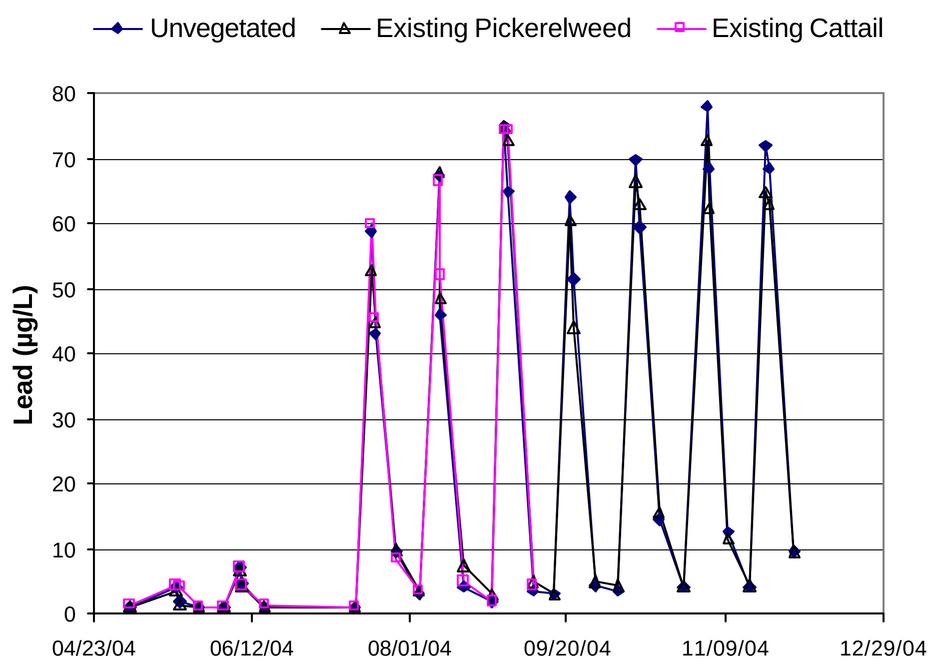


Figure 49. Pb concentrations for open water and littoral locations of unvegetated, pickerelweed and cattail compartments throughout the study.

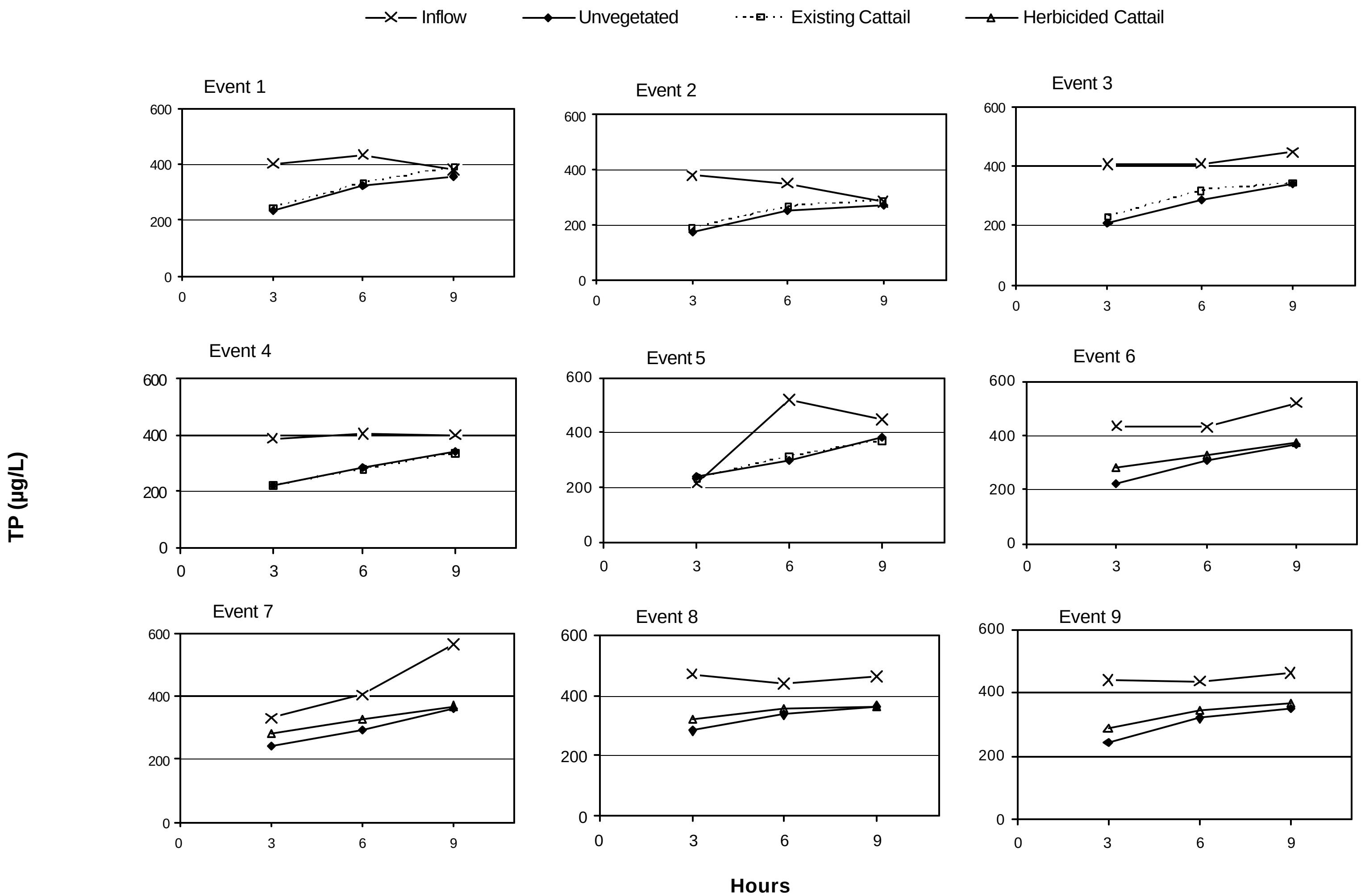


Figure 50. Inflow and outflow TP concentrations (µg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.

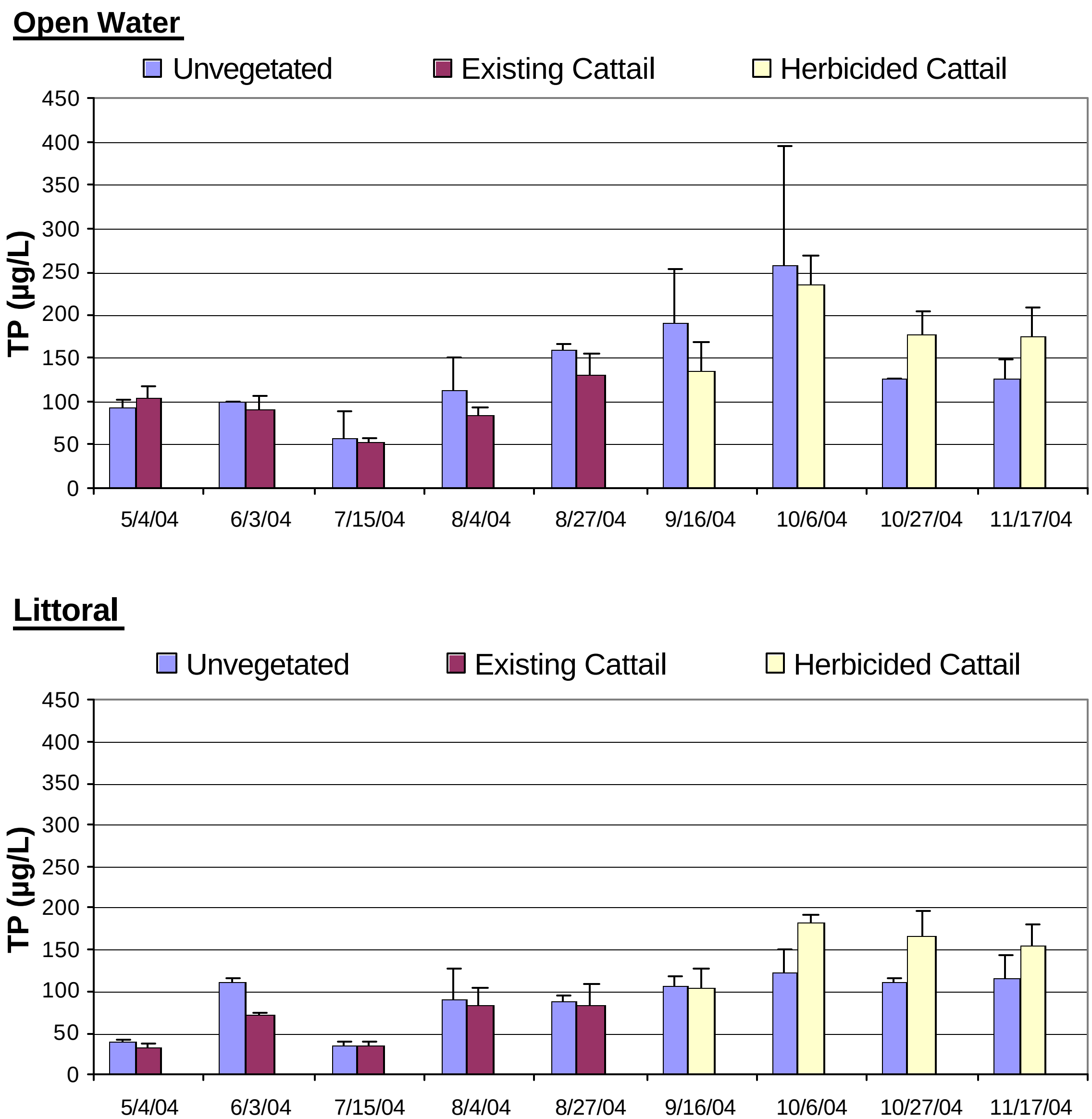


Figure 51. Open water and littoral TP concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

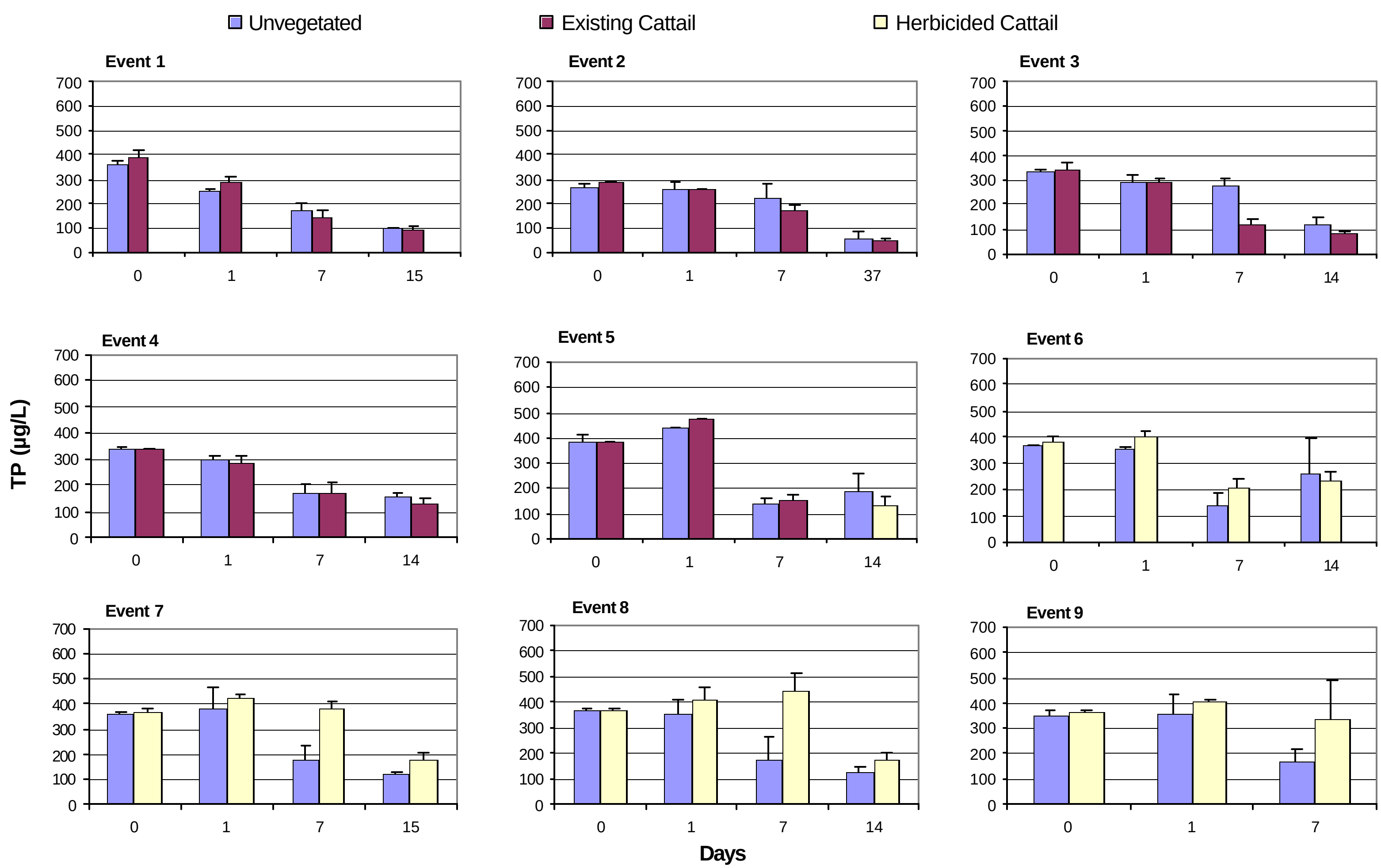


Figure 52. Open water TP concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

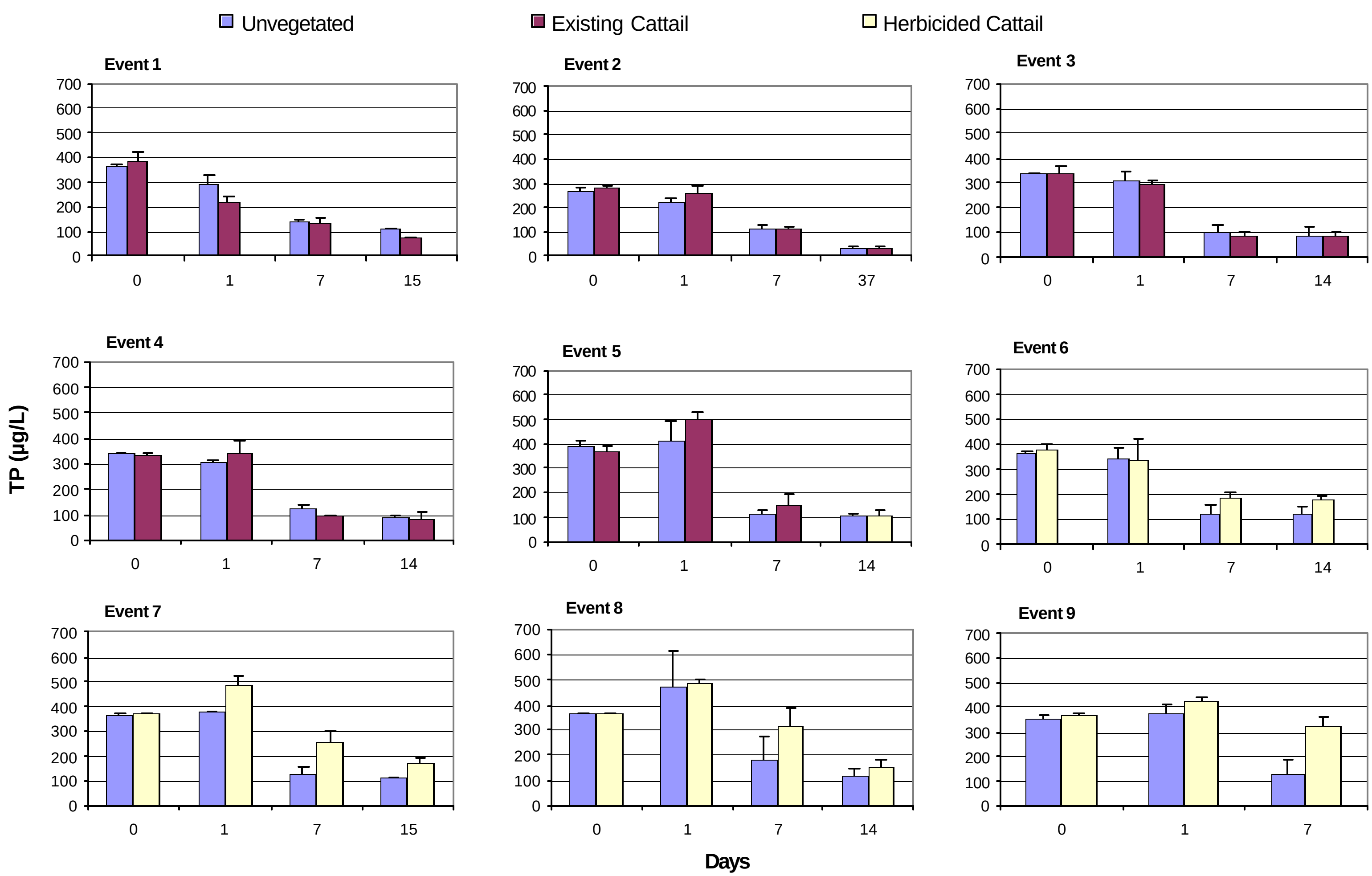
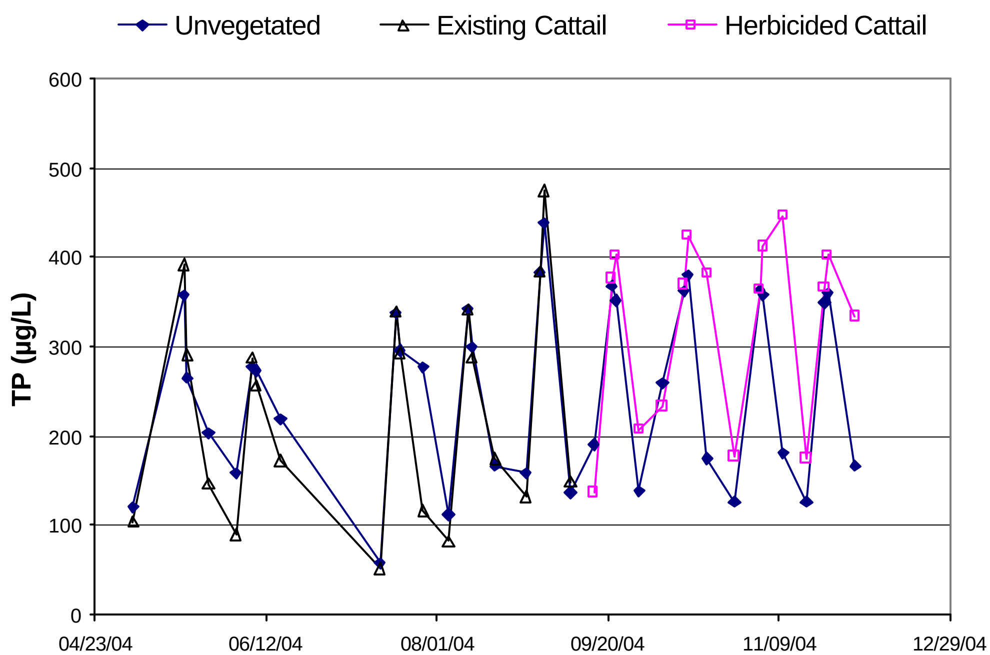


Figure 53. Littoral TP concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

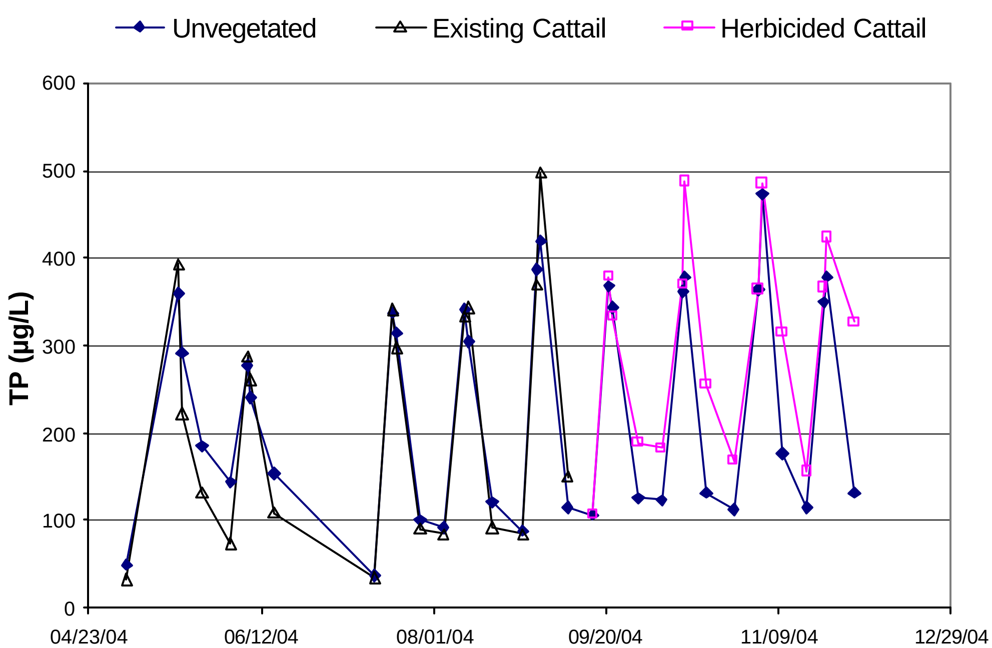


Figure 54. Total P concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

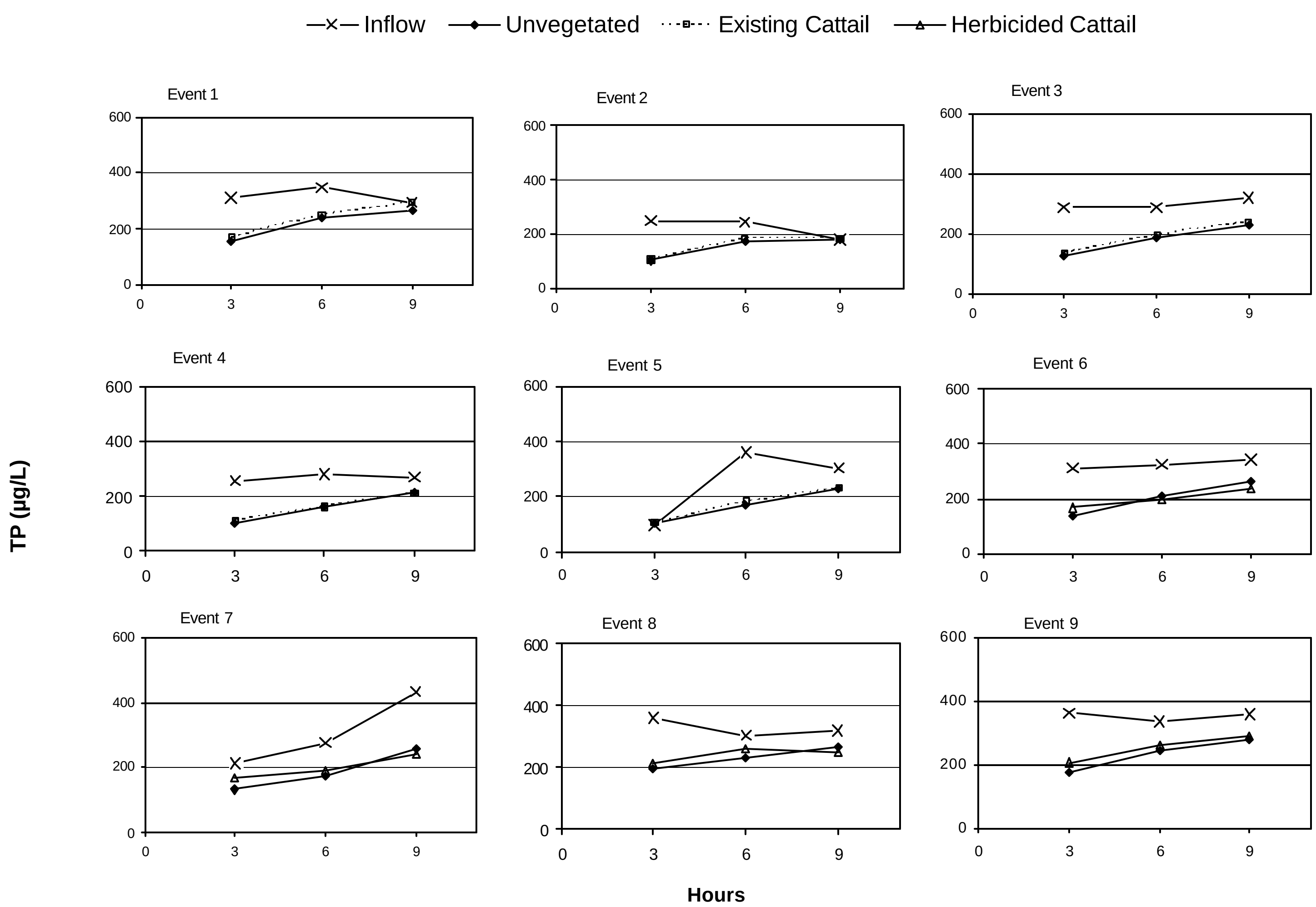
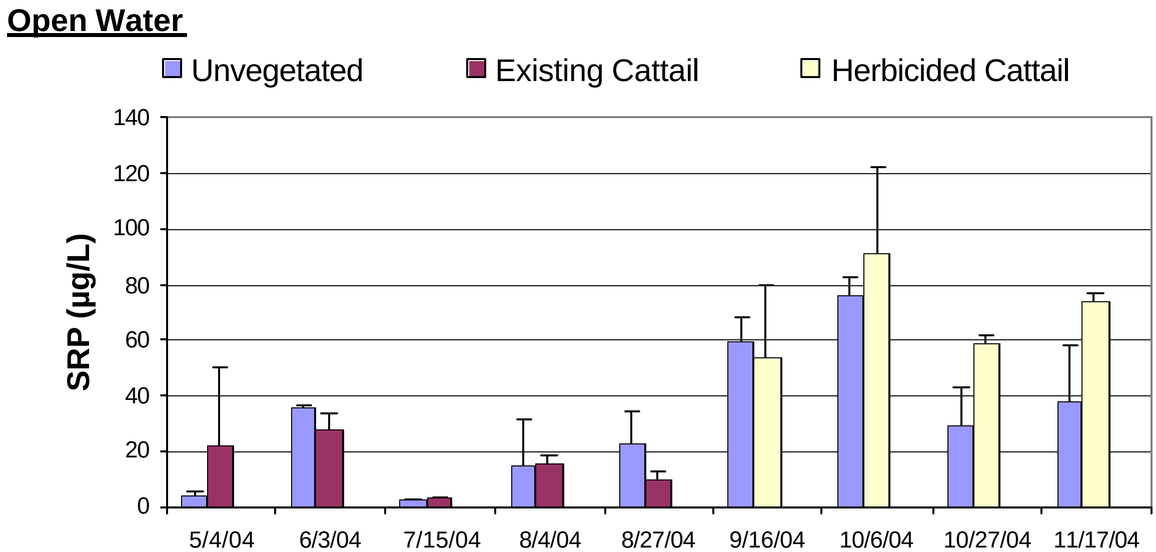


Figure 55. Inflow and outflow SRP concentrations (µg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.



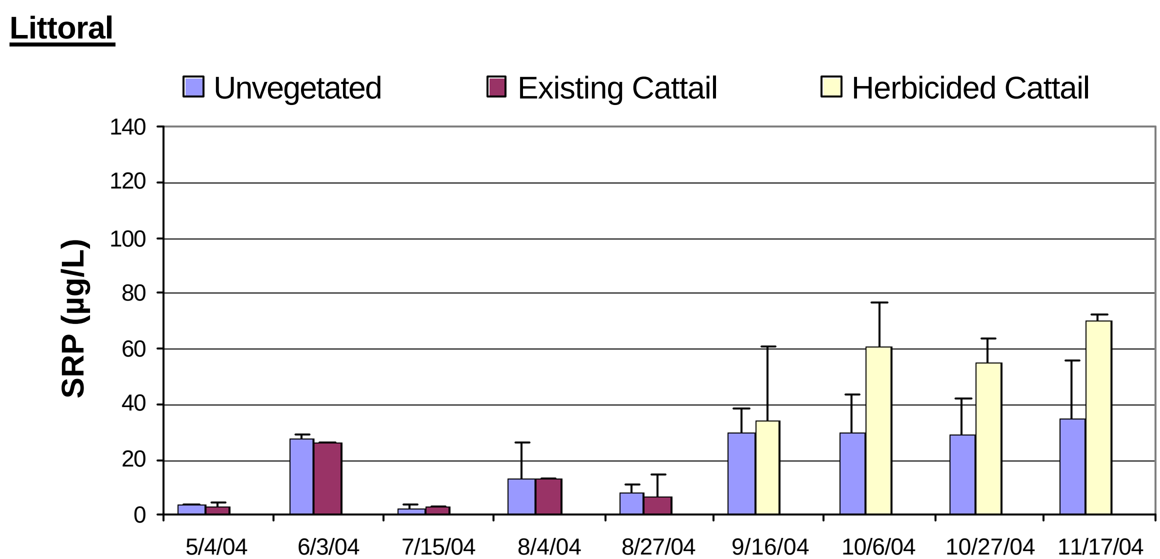


Figure 56. Open water and littoral SRP concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

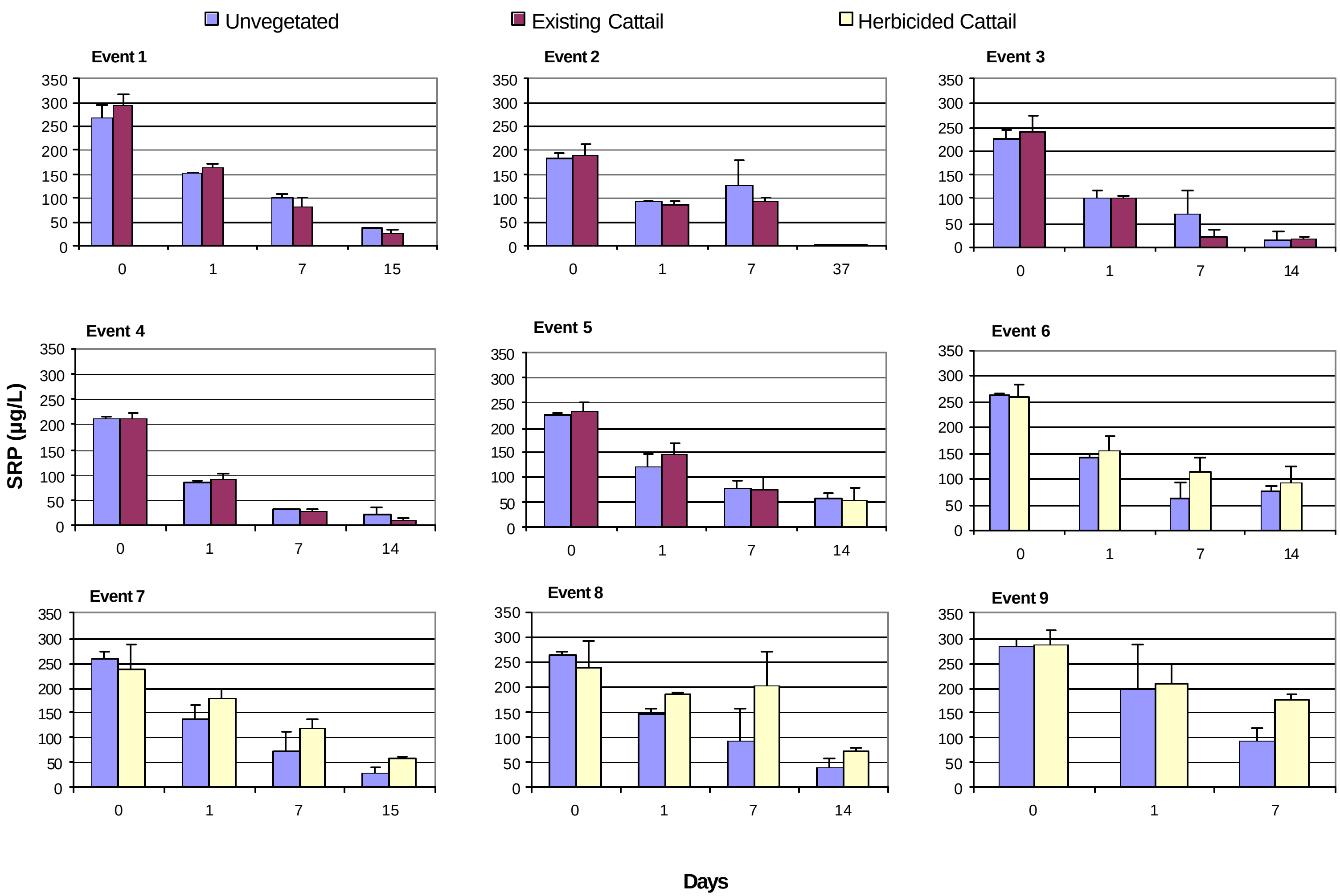


Figure 57. Open water SRP concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

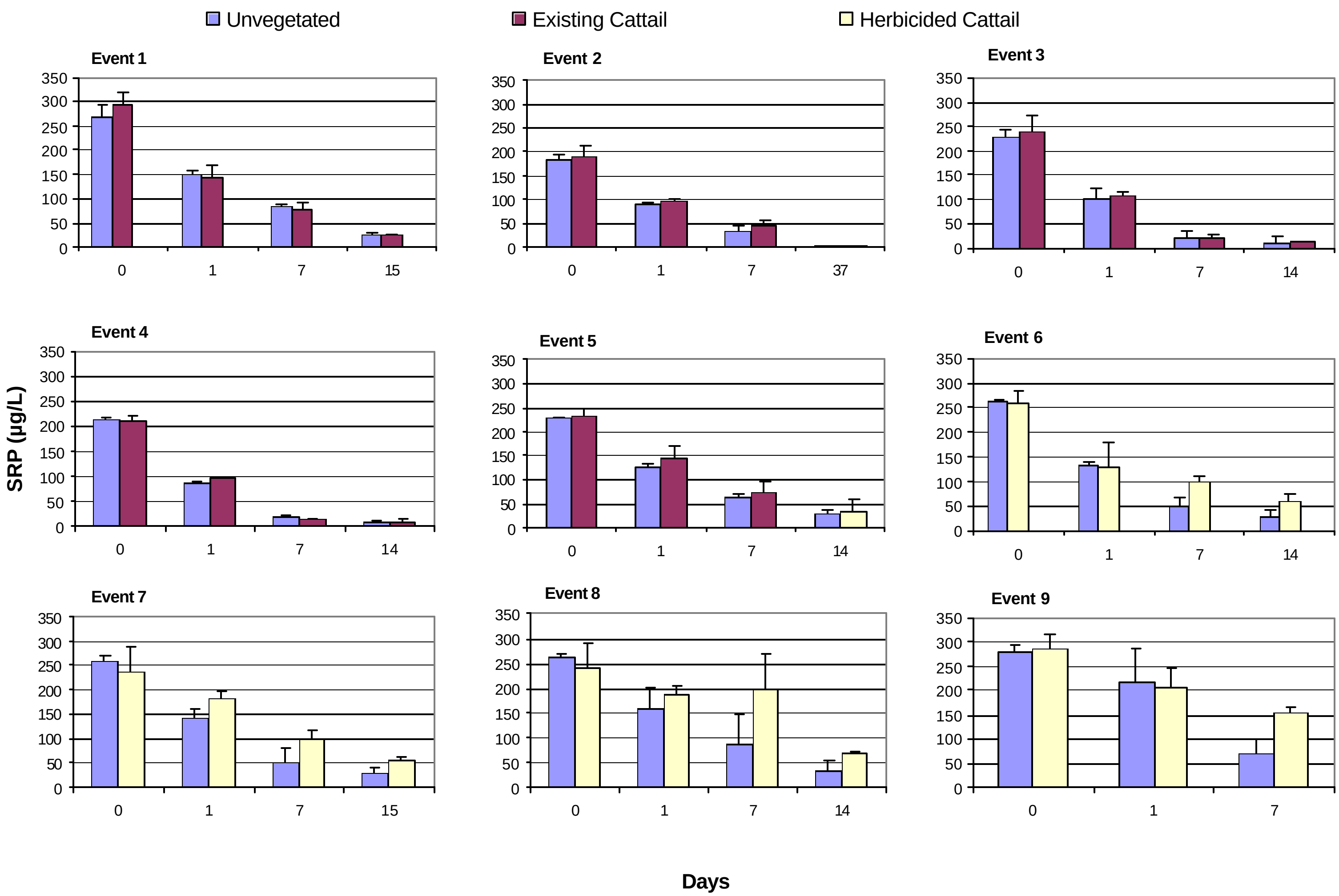
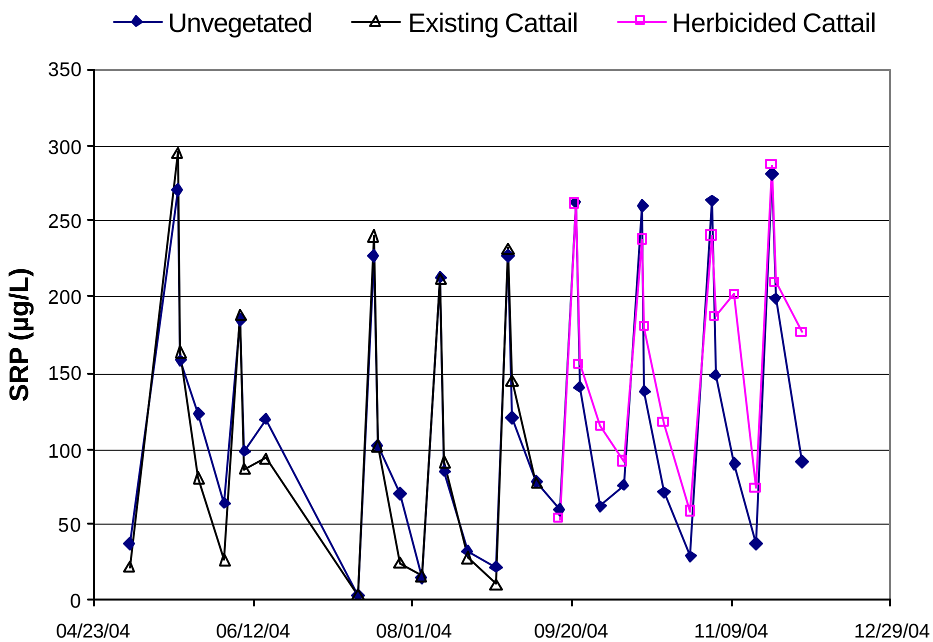


Figure 58. Littoral SRP concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

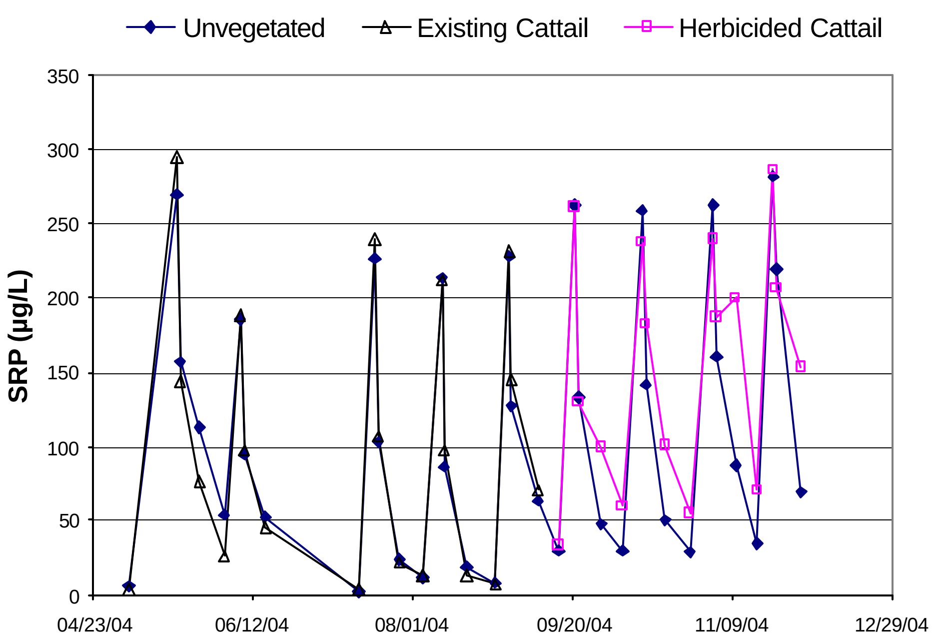


Figure 59. SRP concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

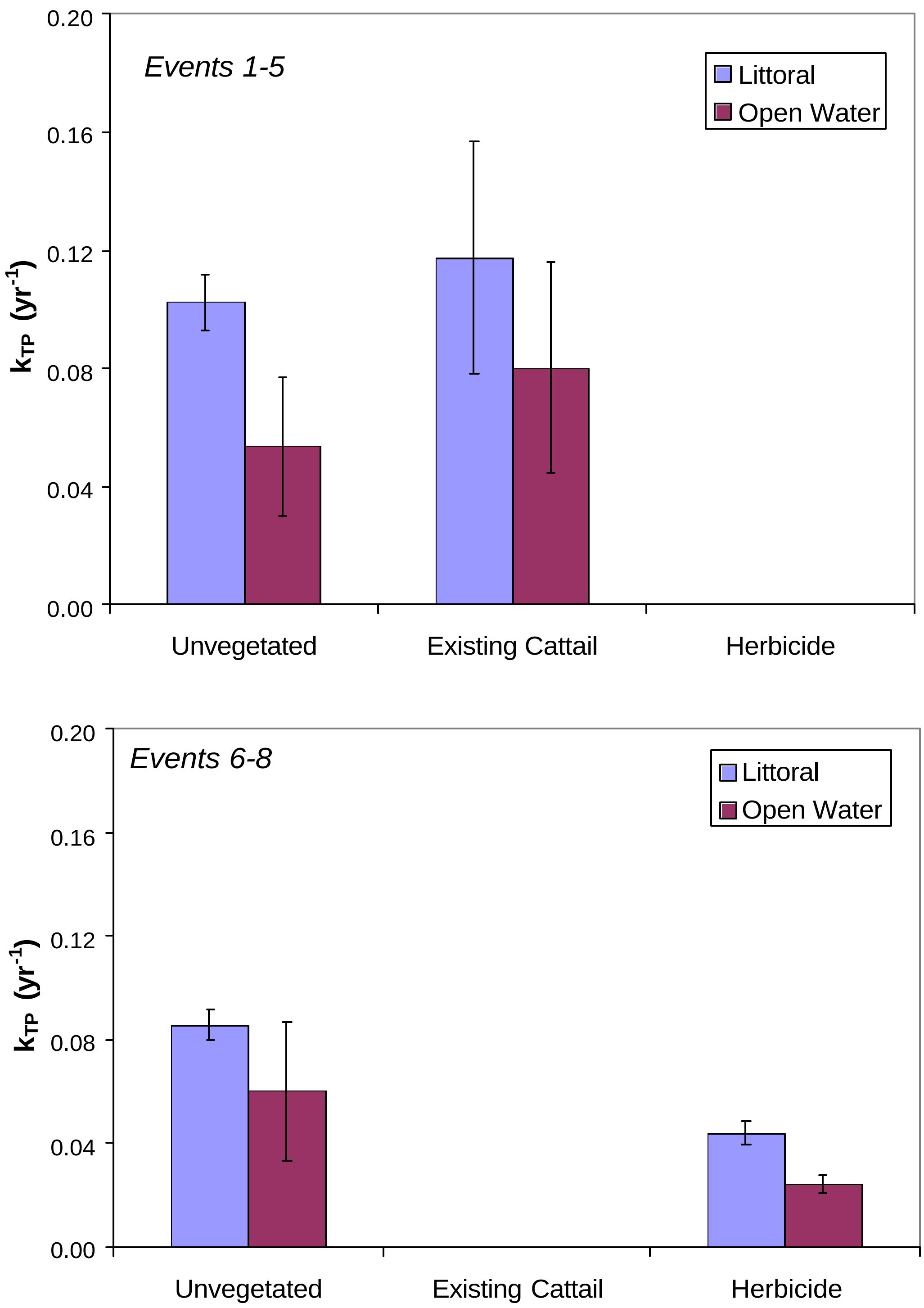


Figure 60. Mean calculated k values for TP for events 1 – 5 and events 6 – 8 in unvegetated, existing cattail and herbicided cattail compartments.

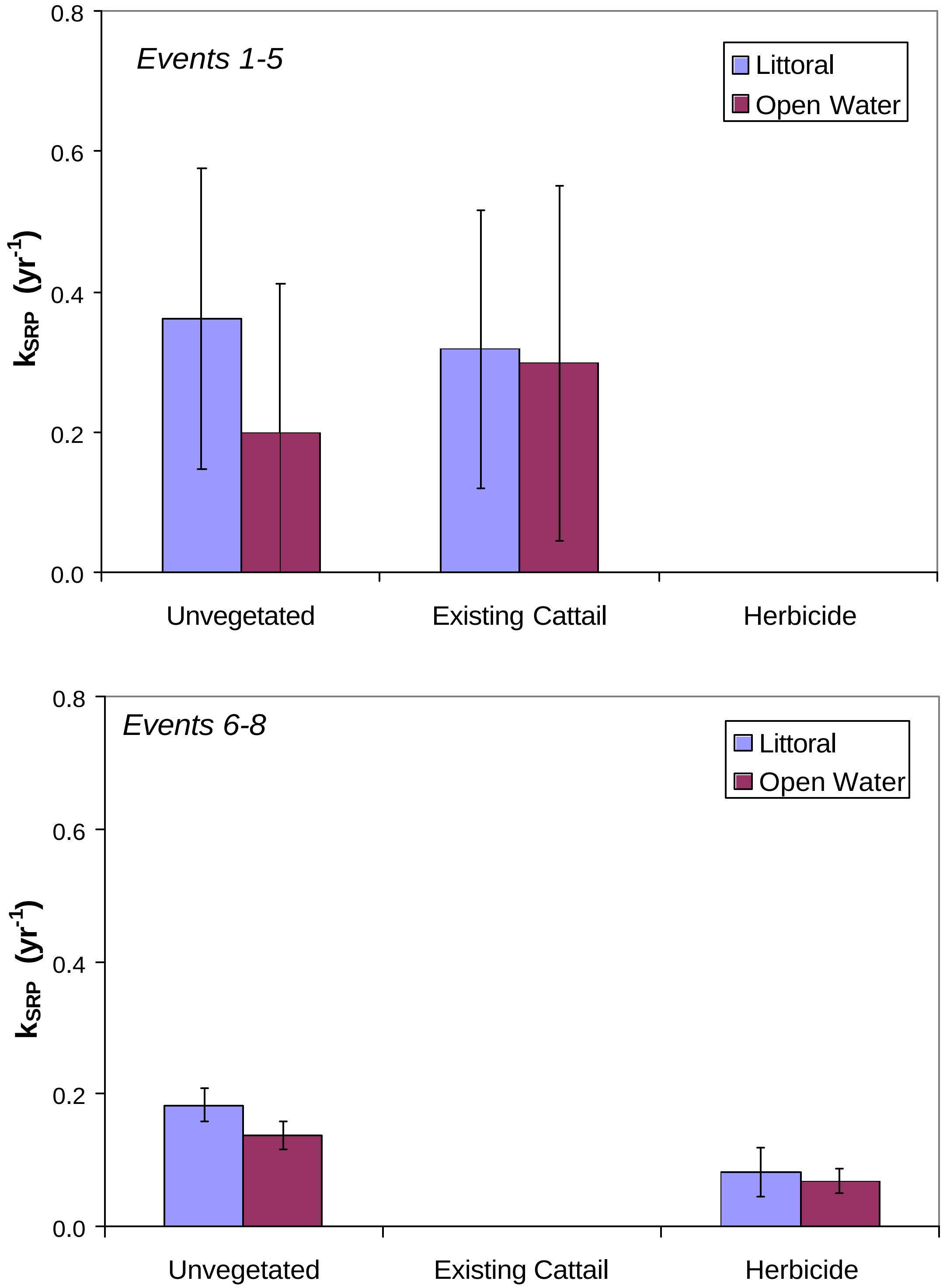


Figure 61. Mean calculated k values for SRP for events 1 – 5 and events 6 – 8 in unvegetated, existing cattail and herbicided cattail compartments**.**

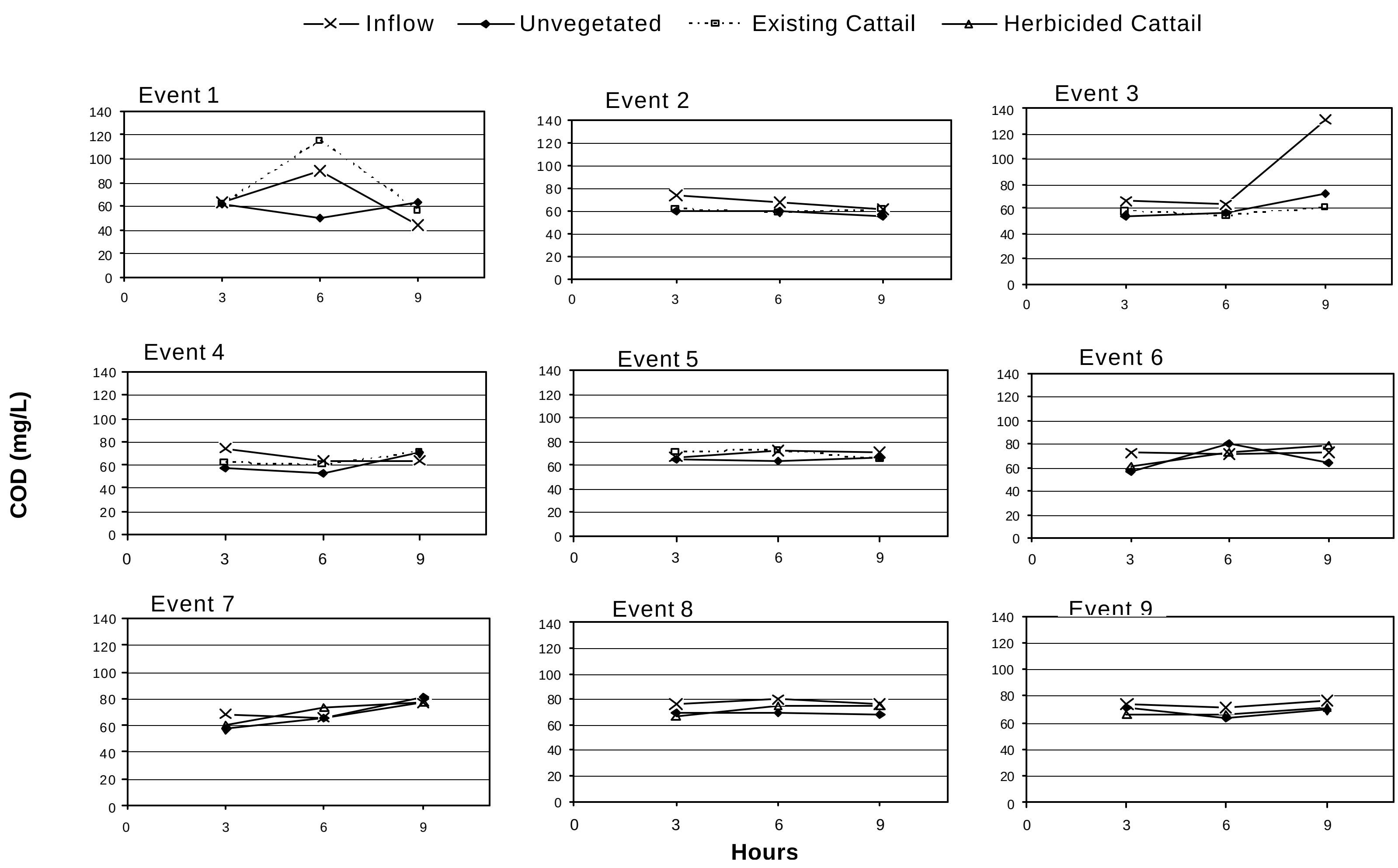
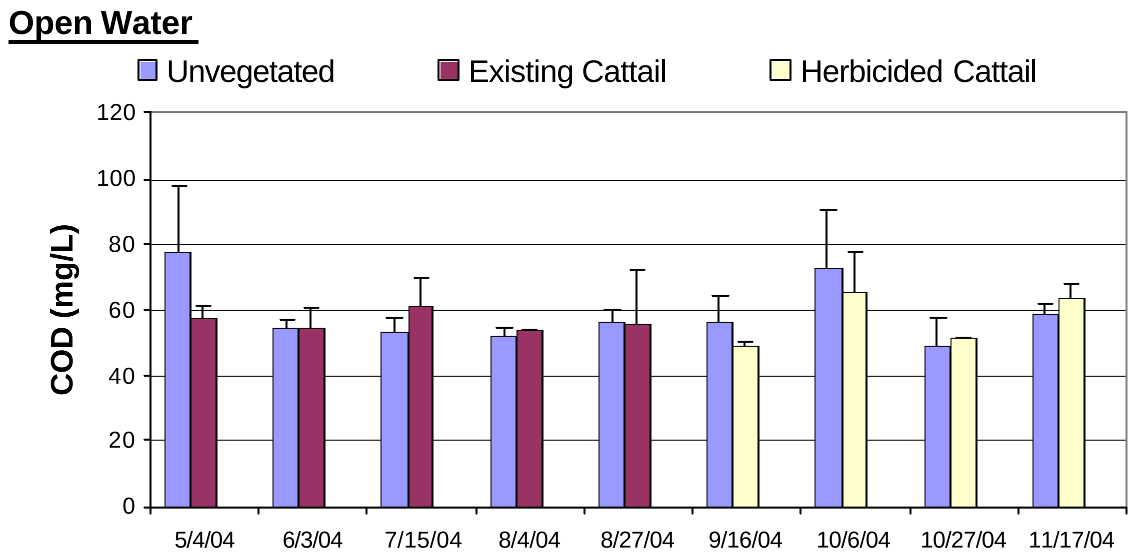


Figure 62. Inflow and outflow COD concentrations (mg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.



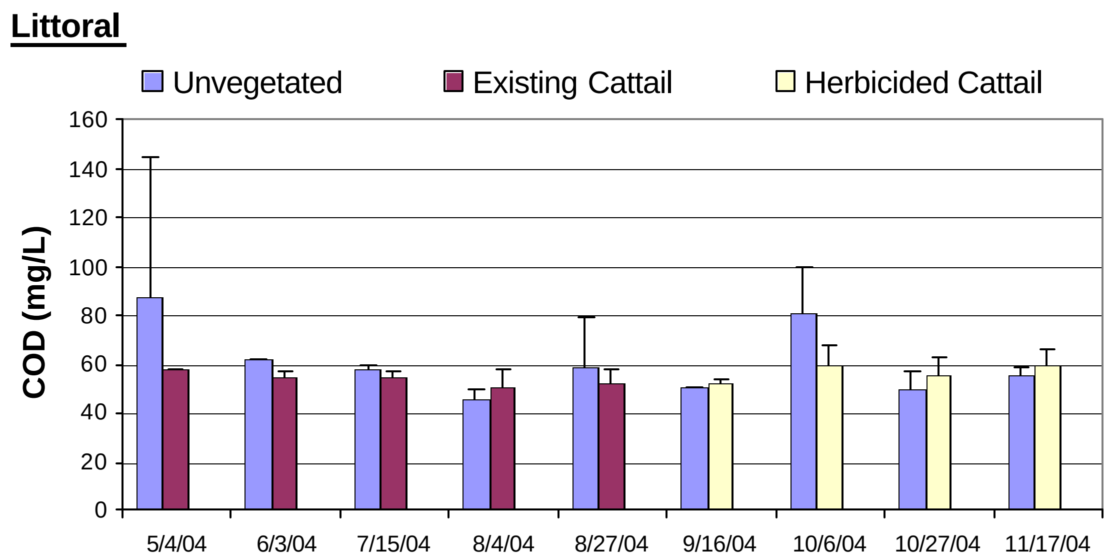


Figure 63. Open water and littoral COD concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

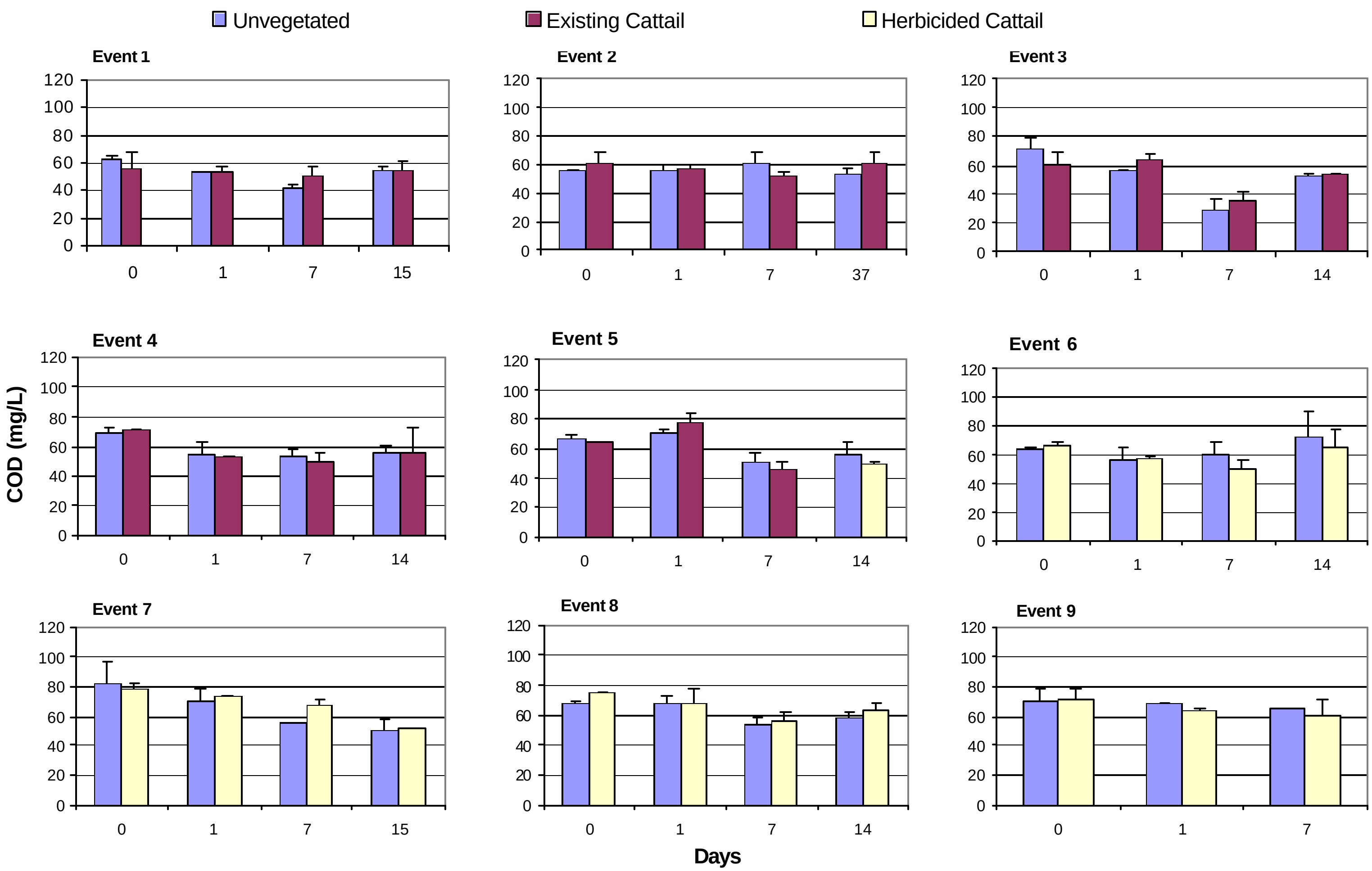


Figure 64. Open water COD concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

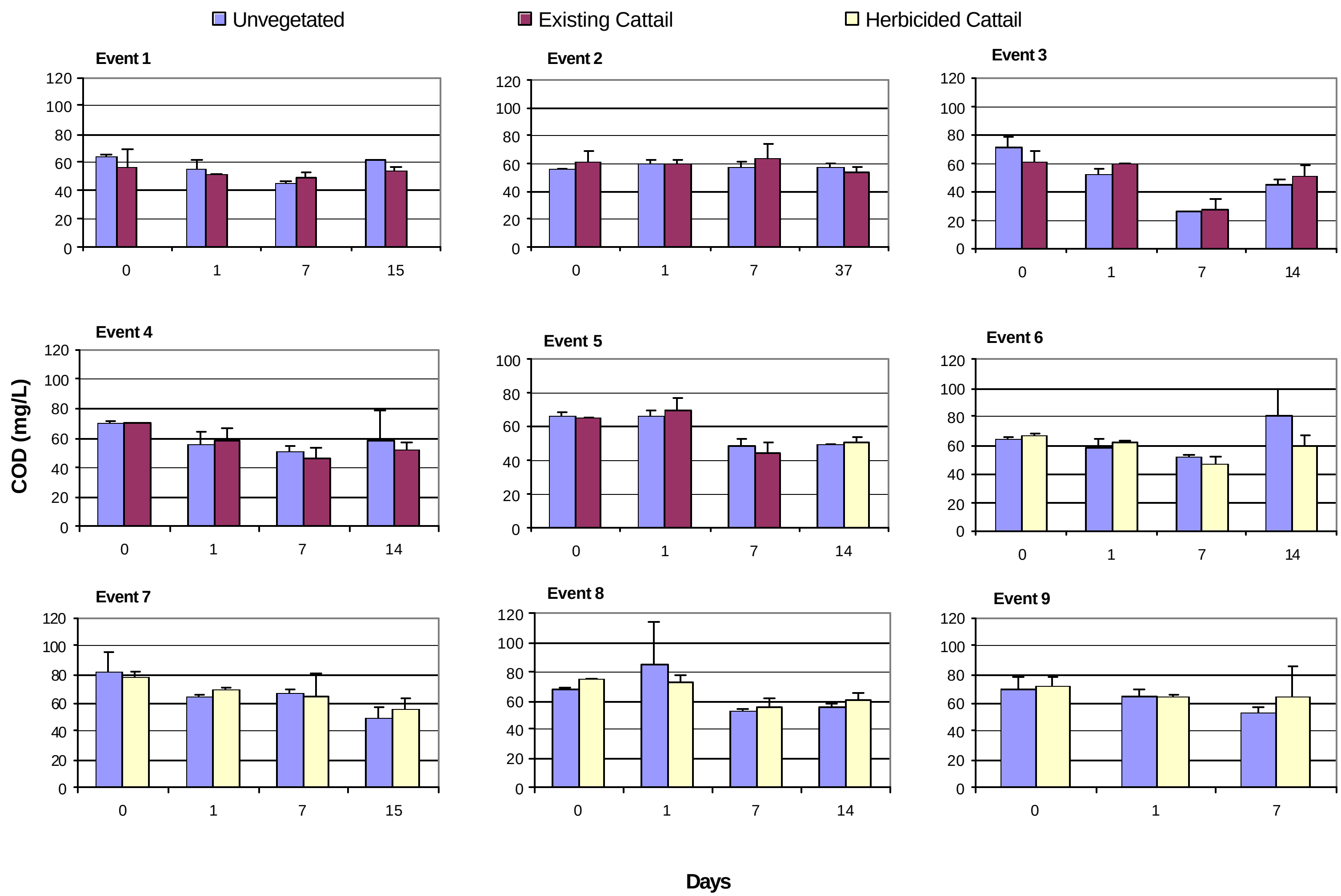
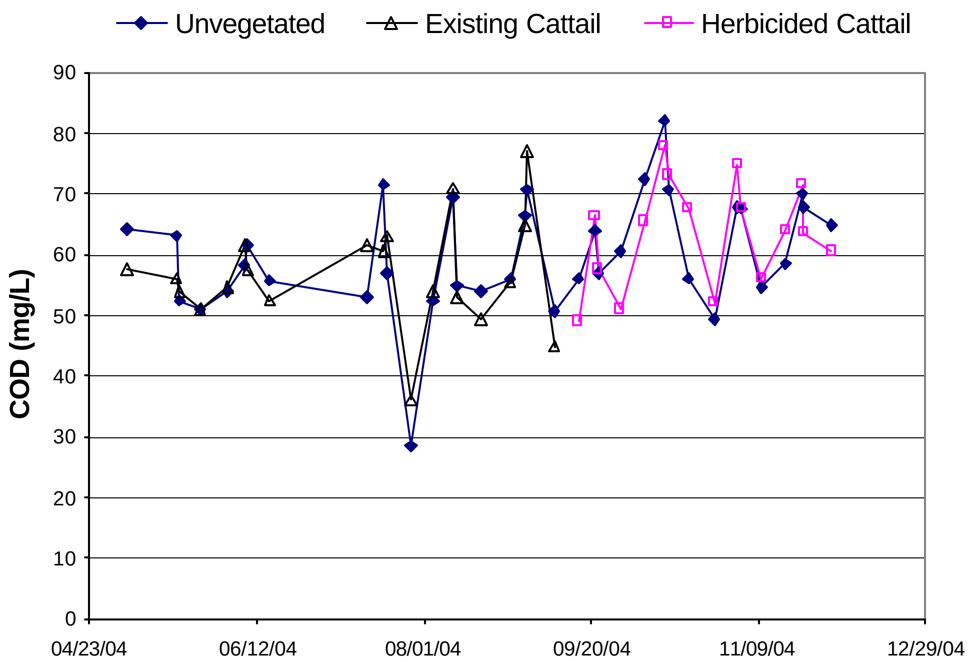


Figure 65. Littoral COD concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

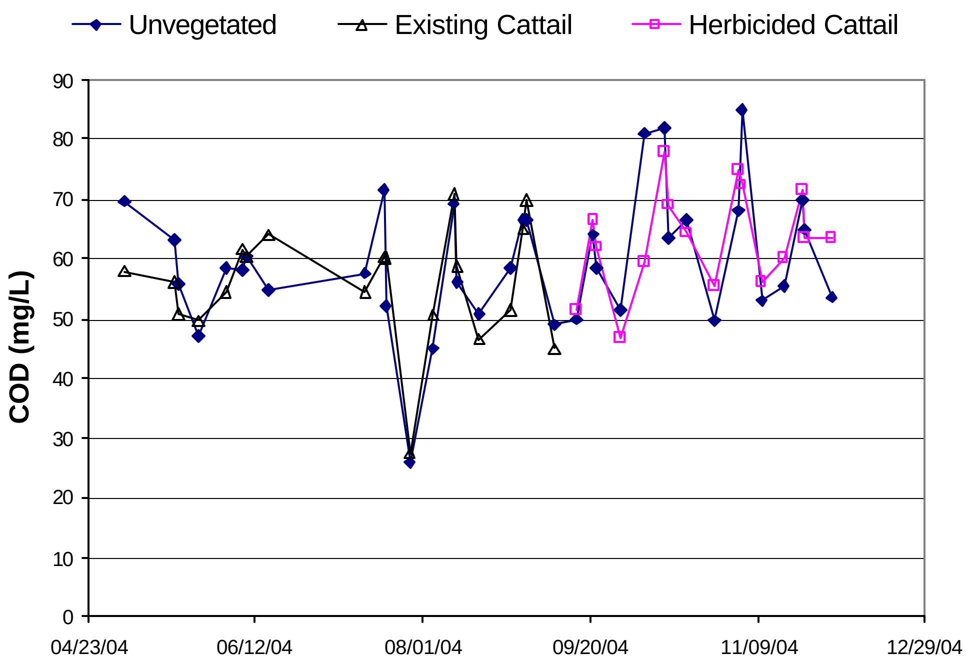


Figure 66. COD concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

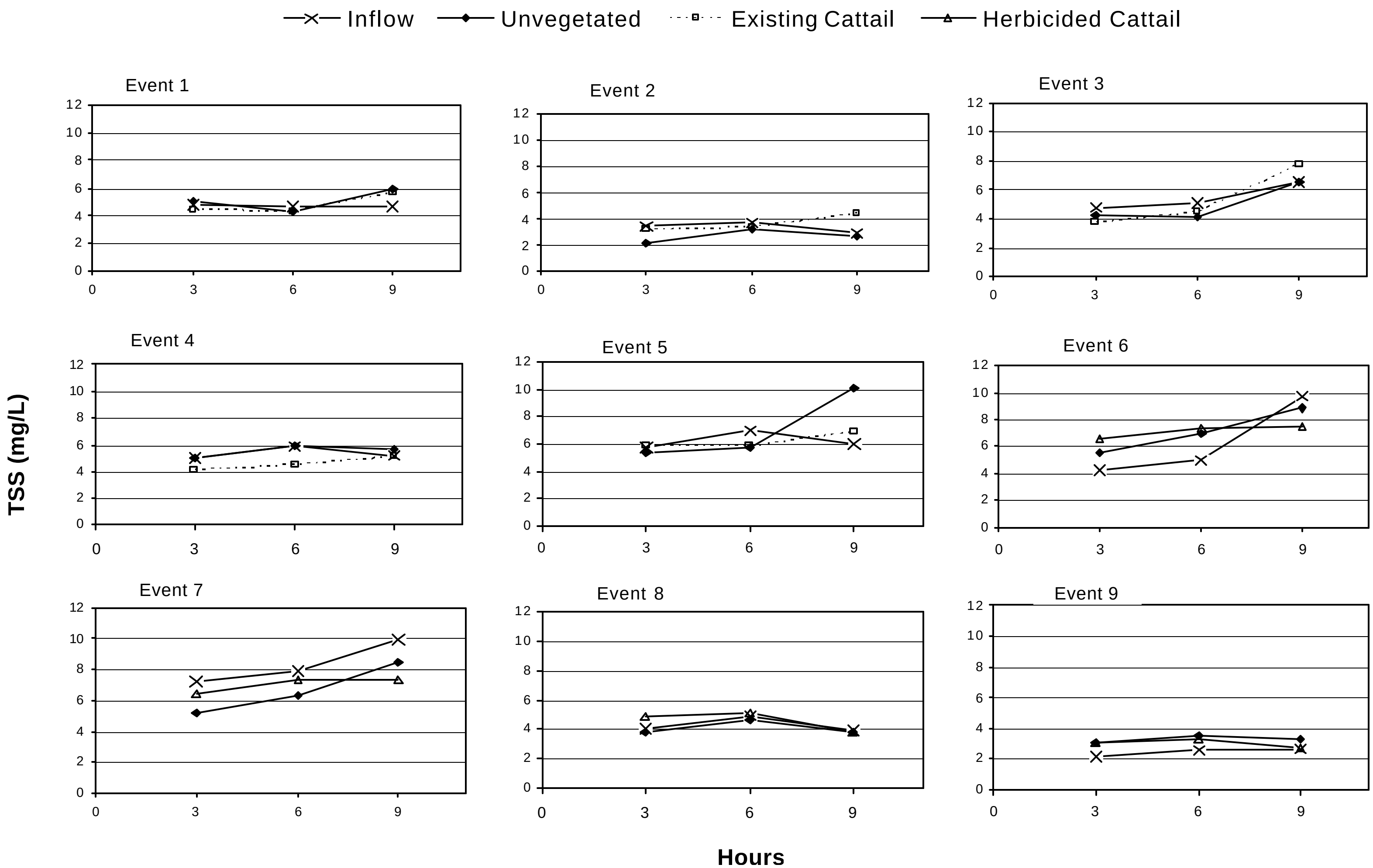
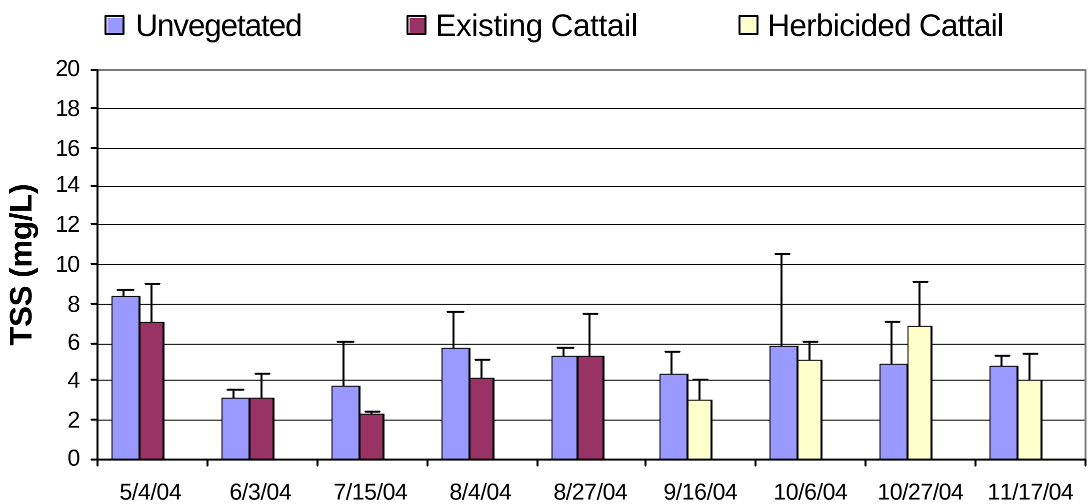


Figure 67. Inflow and outflow TSS concentrations (mg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.

Open Water



Littoral

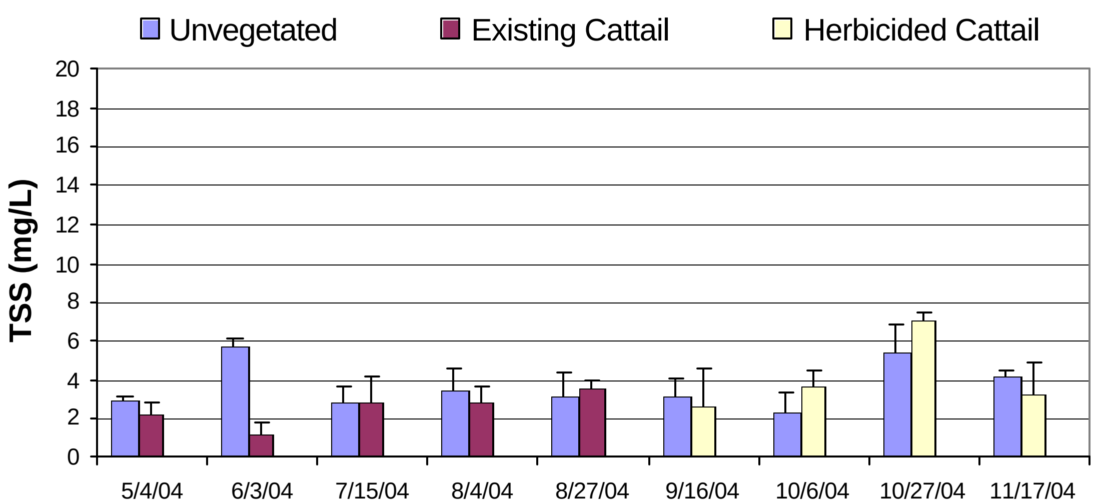


Figure 68. Open water and littoral TSS concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

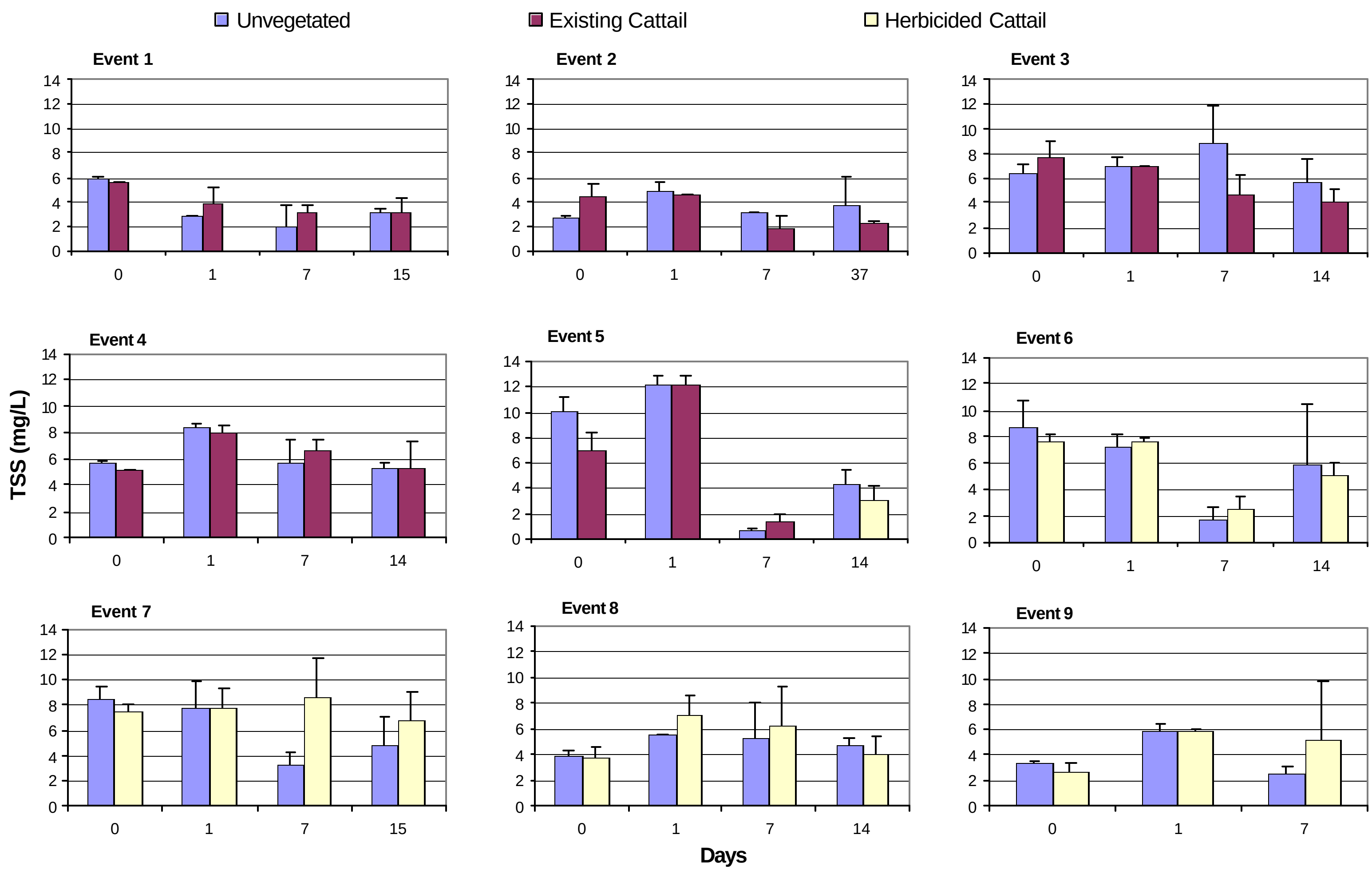


Figure 69. Open water TSS concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

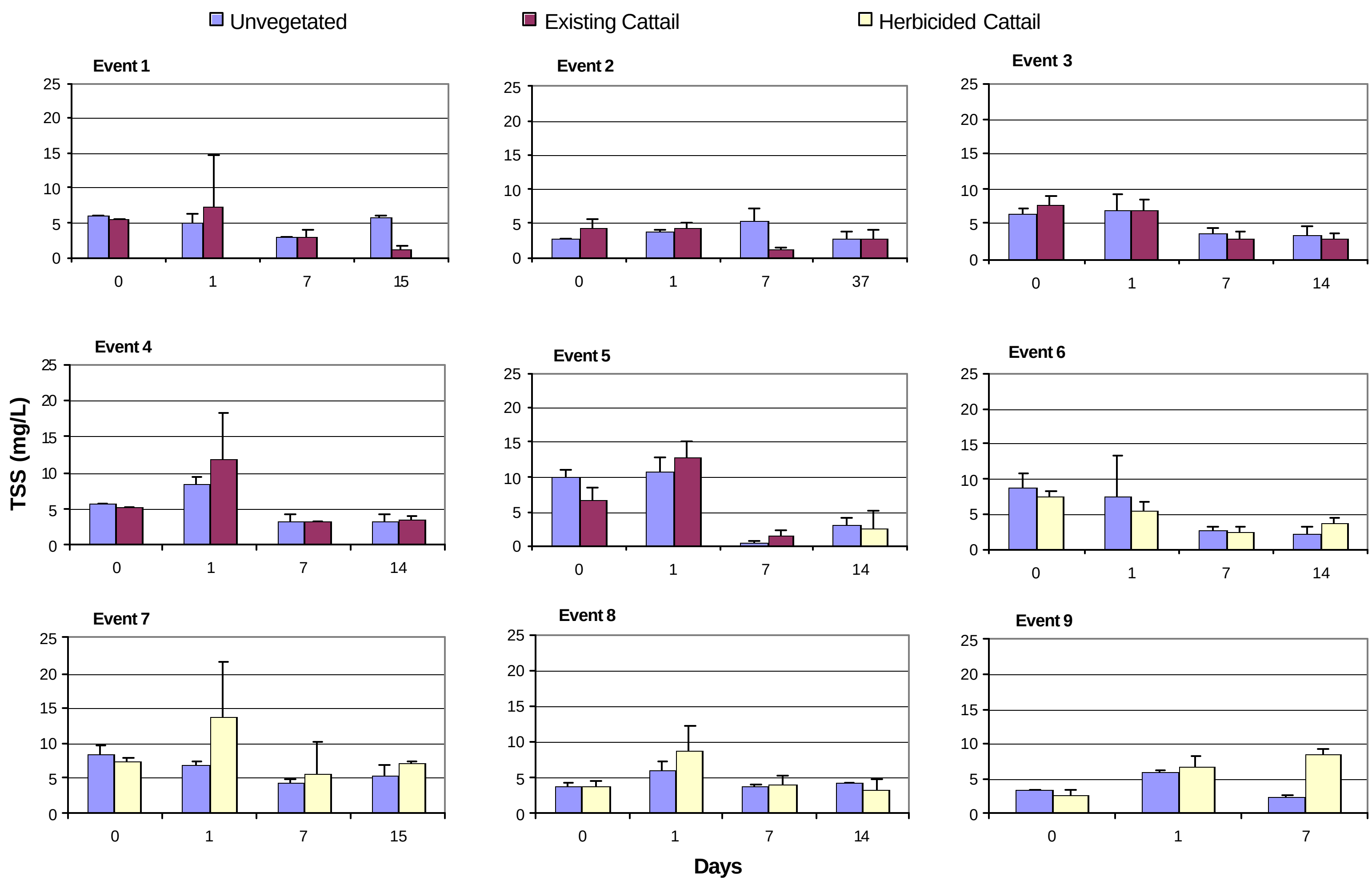
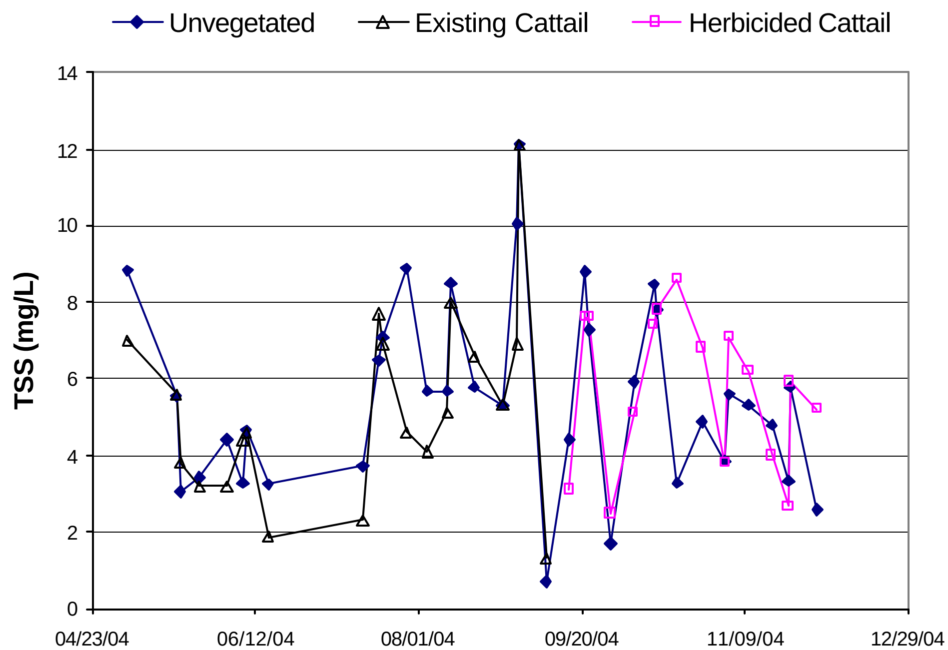


Figure 70. Littoral TSS concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

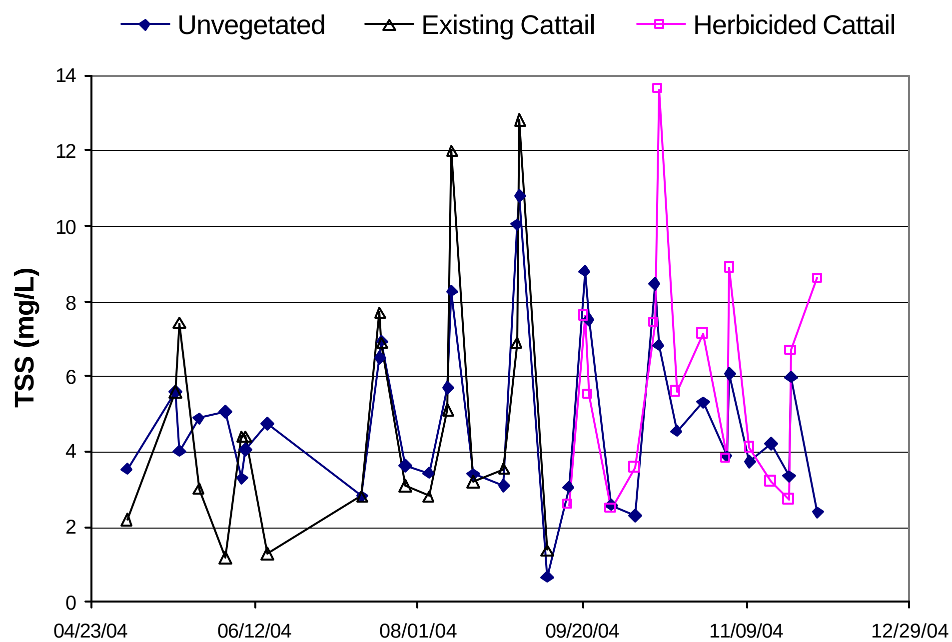


Figure 71. TSS concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

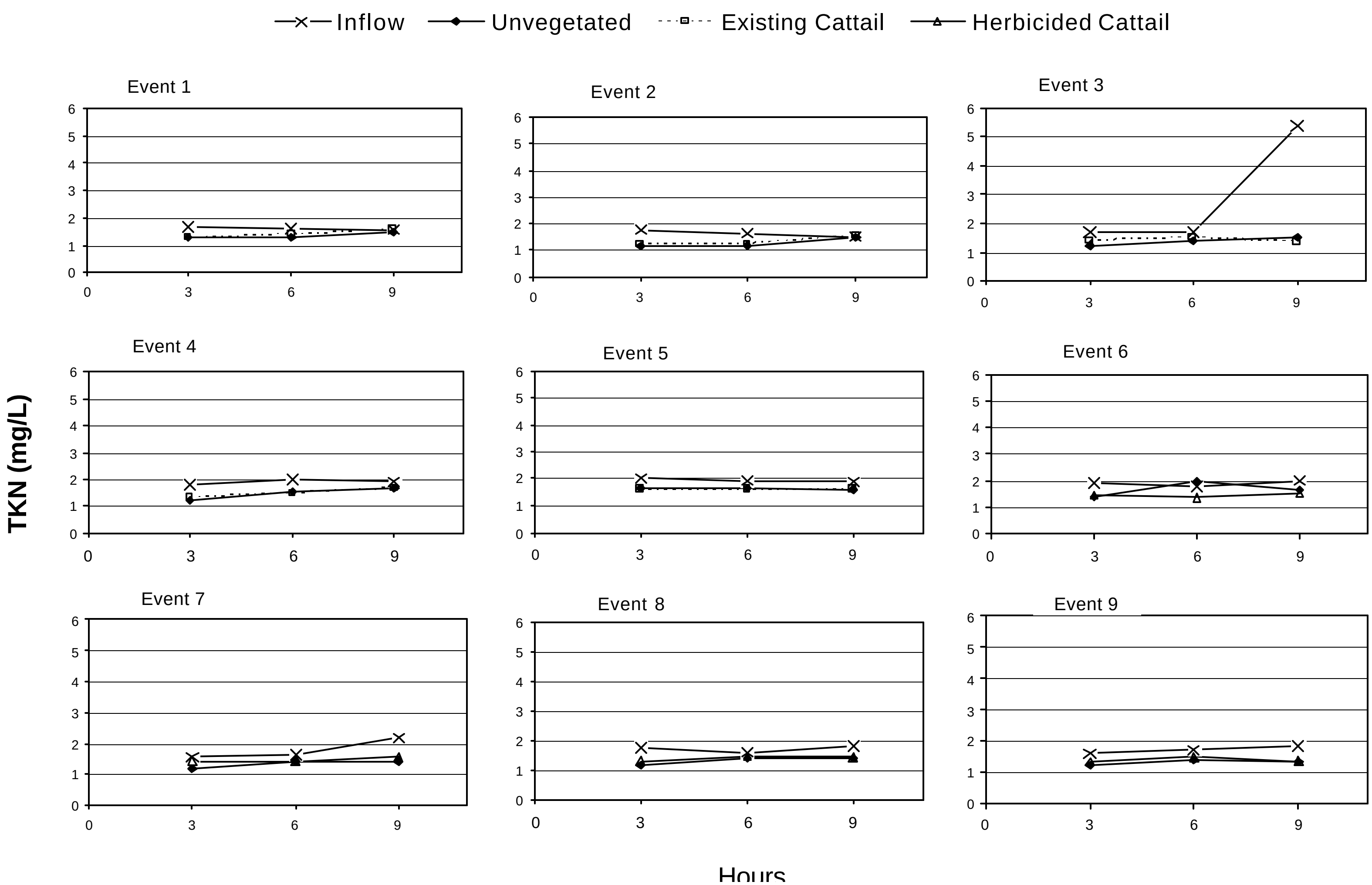
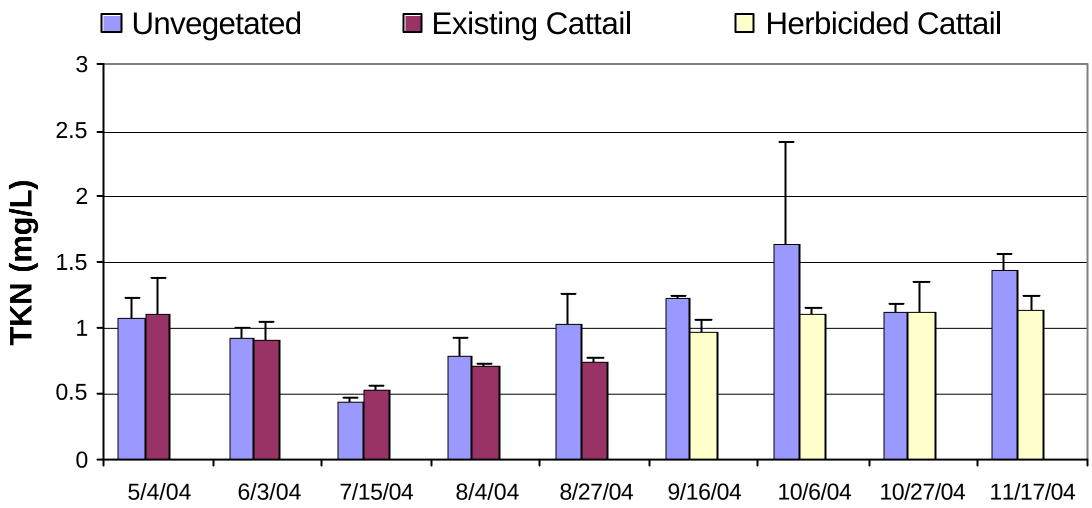


Figure 72. Inflow and outflow TKN concentrations (mg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.

Open Water



Littoral

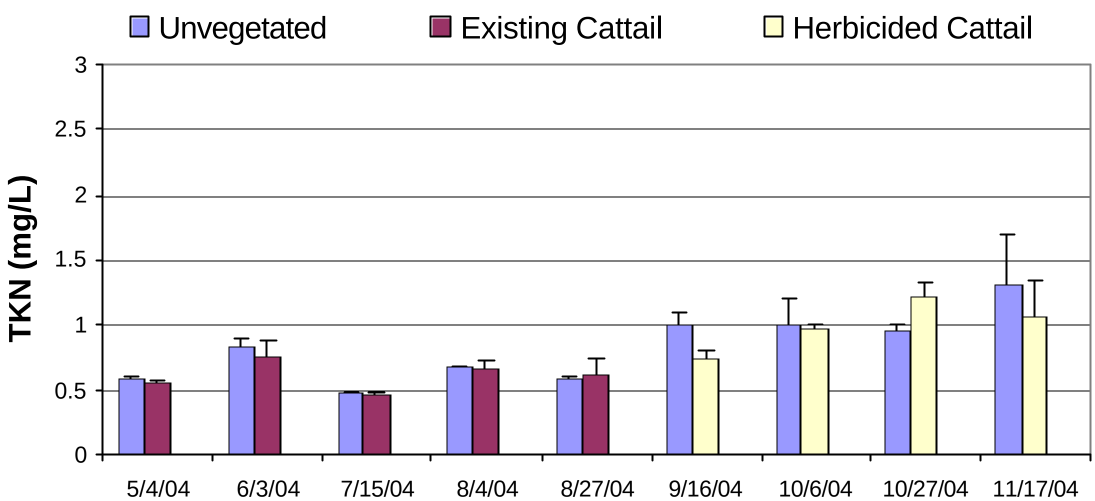


Figure 73. Open water and littoral TKN concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

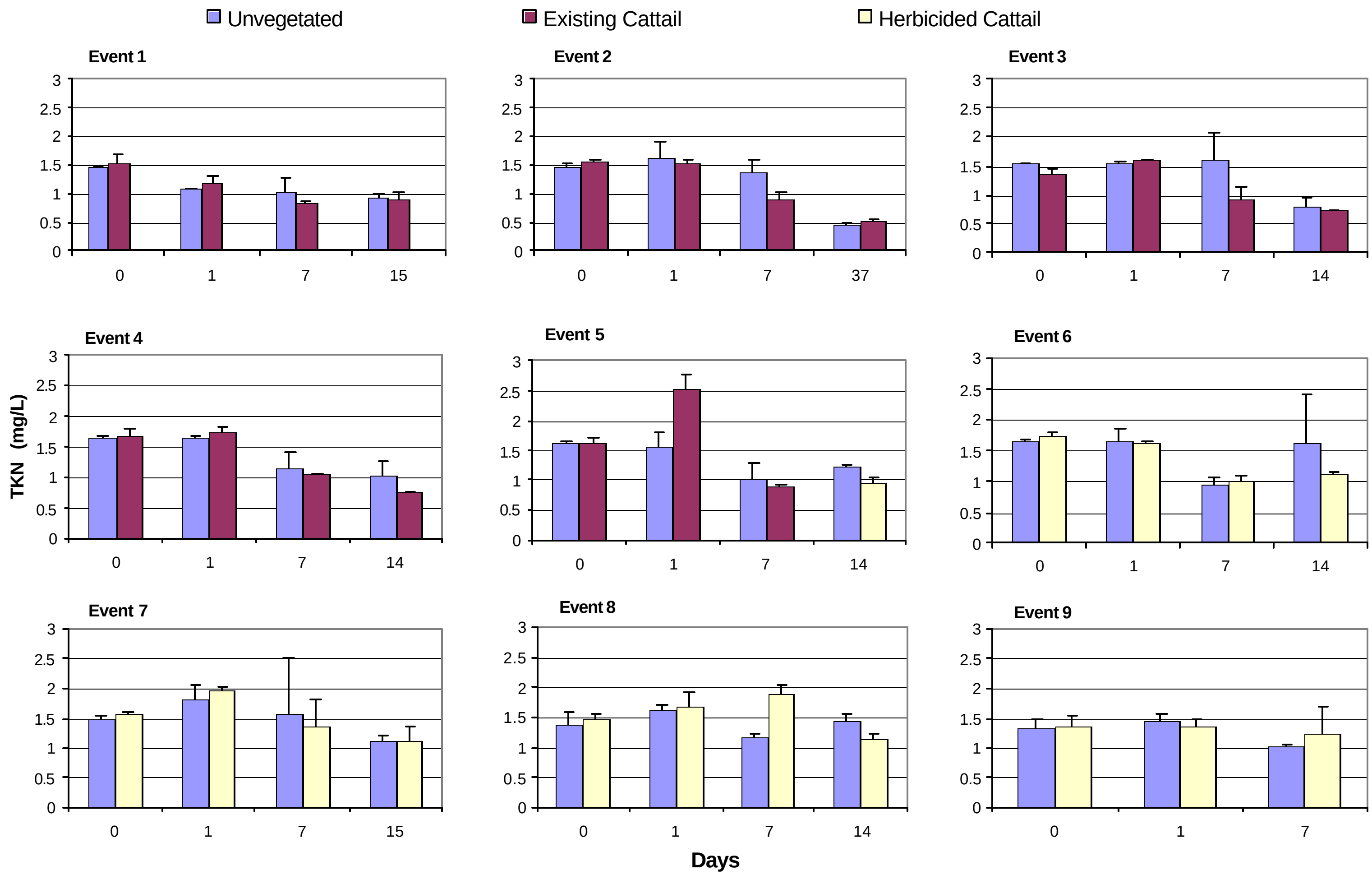


Figure 74. Open water TKN concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

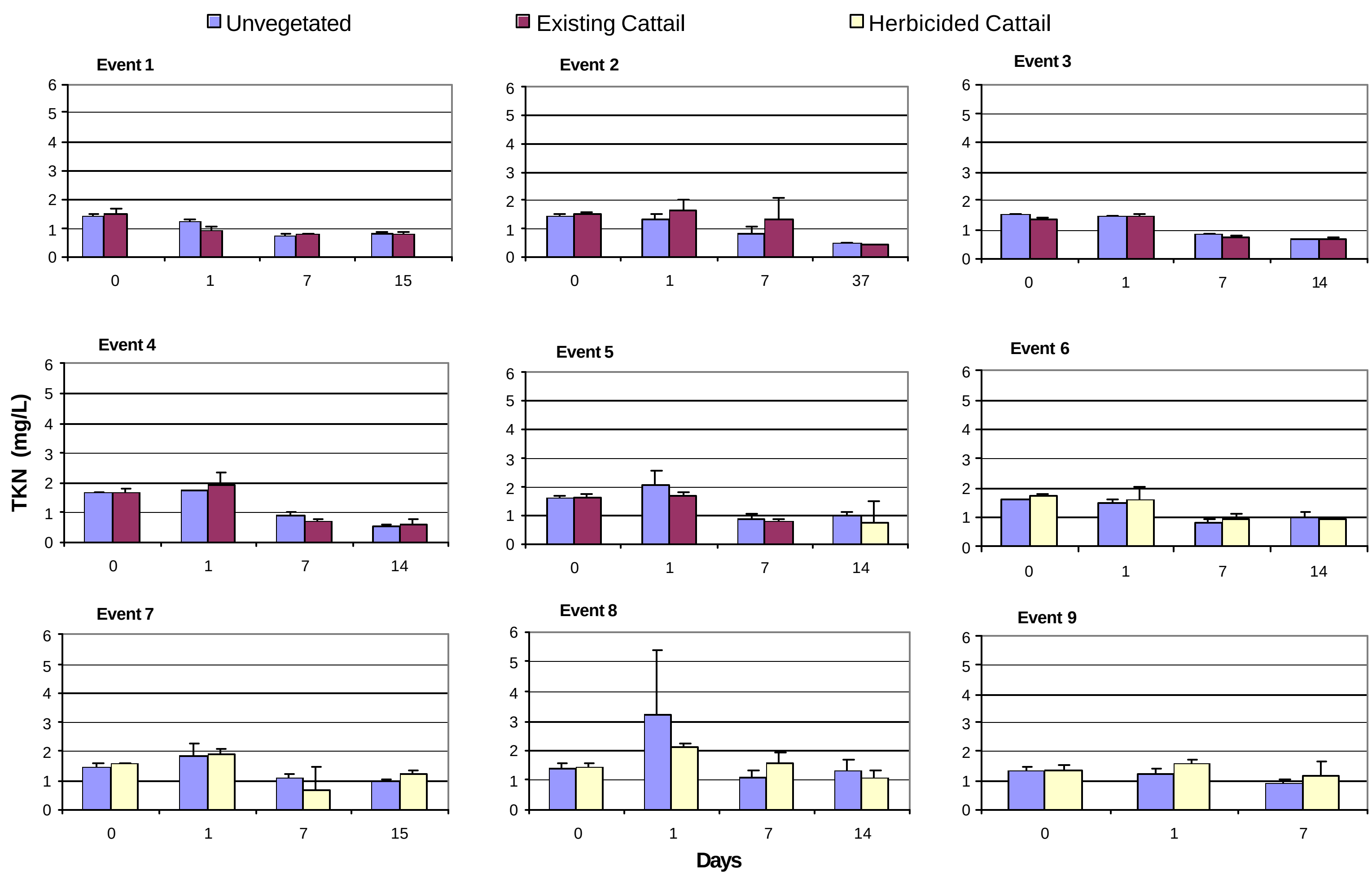
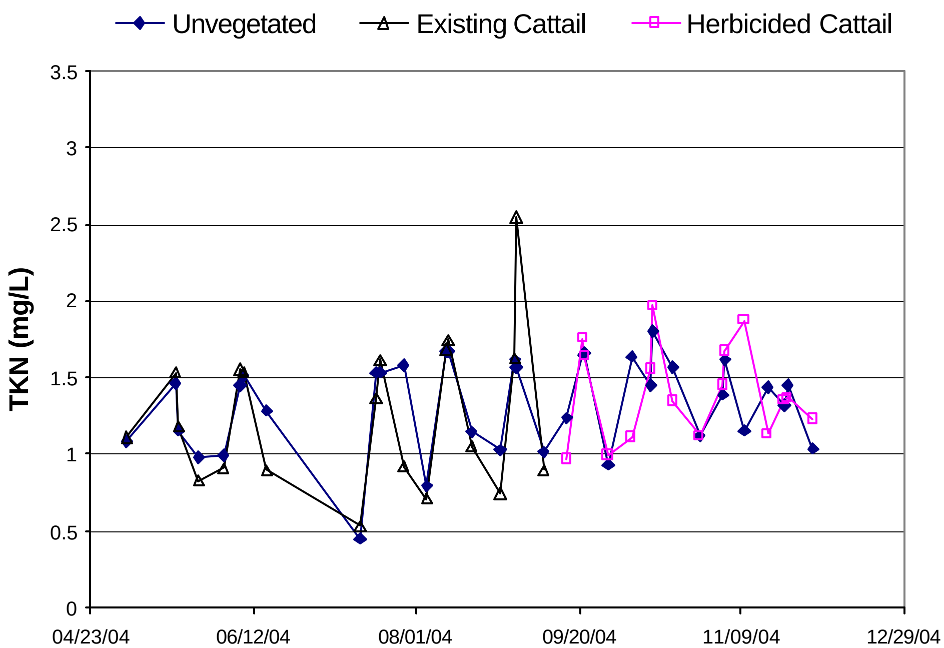


Figure 75. Littoral TKN concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

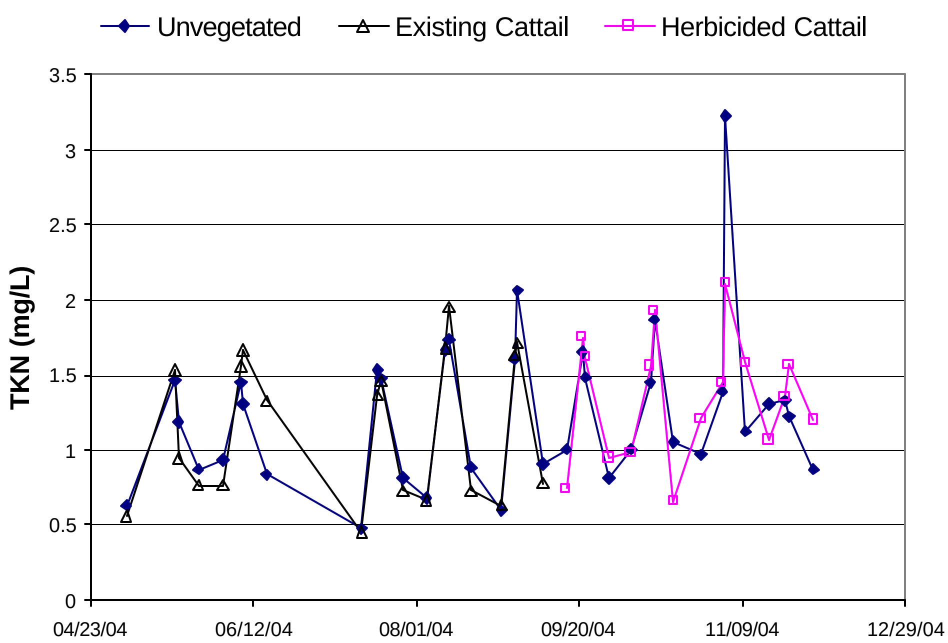


Figure 76. TKN concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

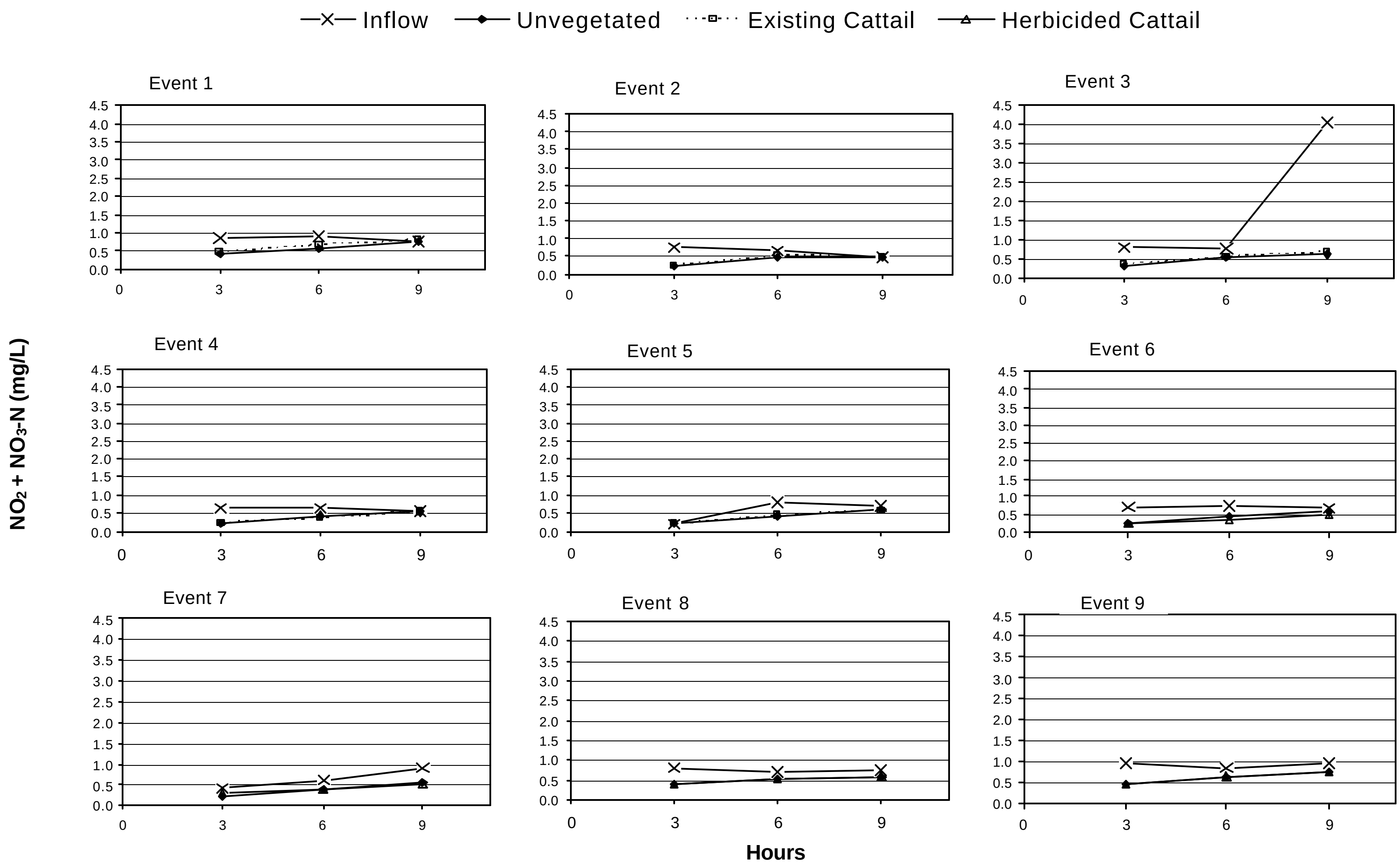


Figure 77. Inflow and outflow NO_2 + NO_3-N concentrations (mg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments**.**

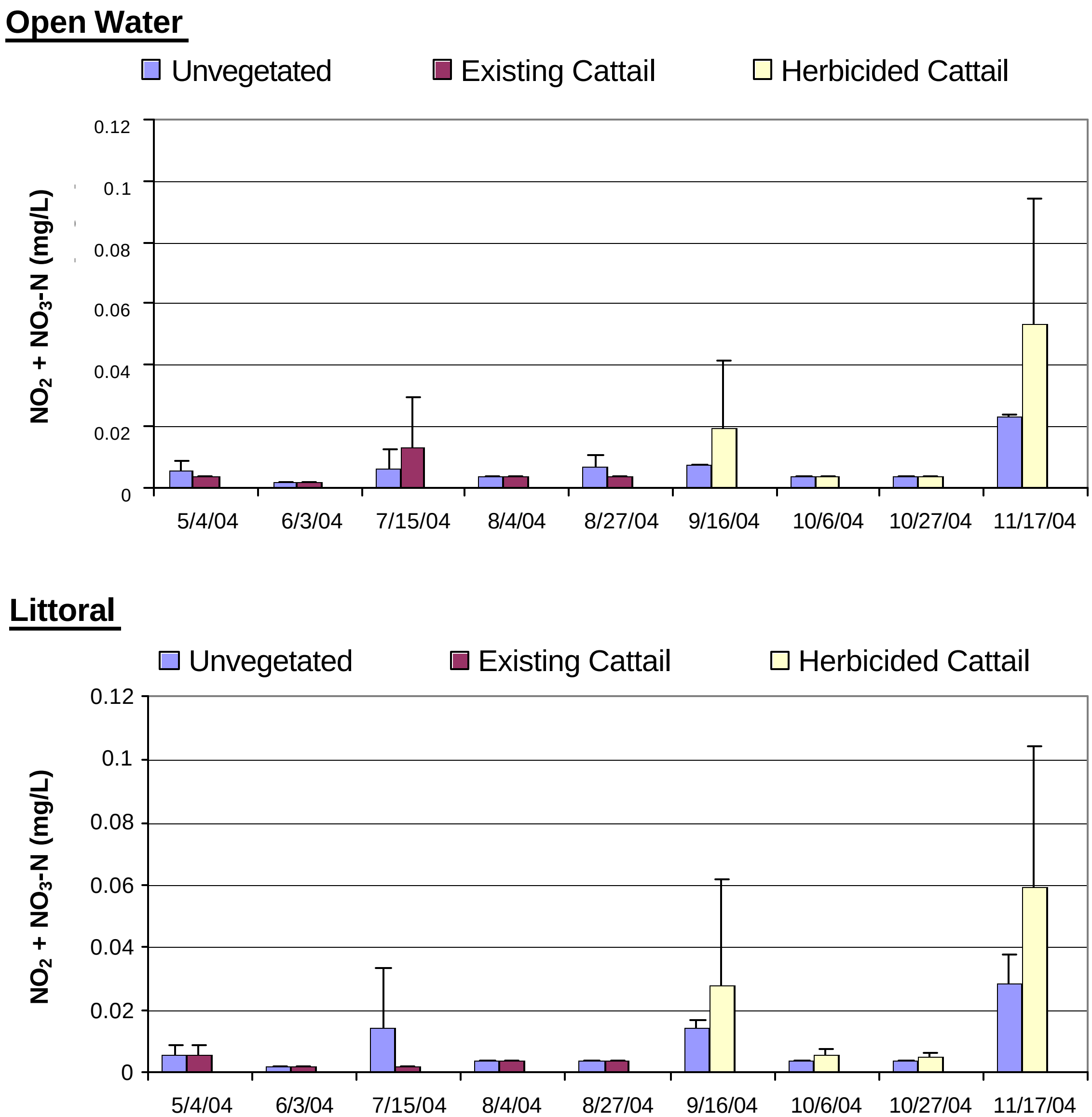


Figure 78. Open water and littoral NO_2 + NO_3-N concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

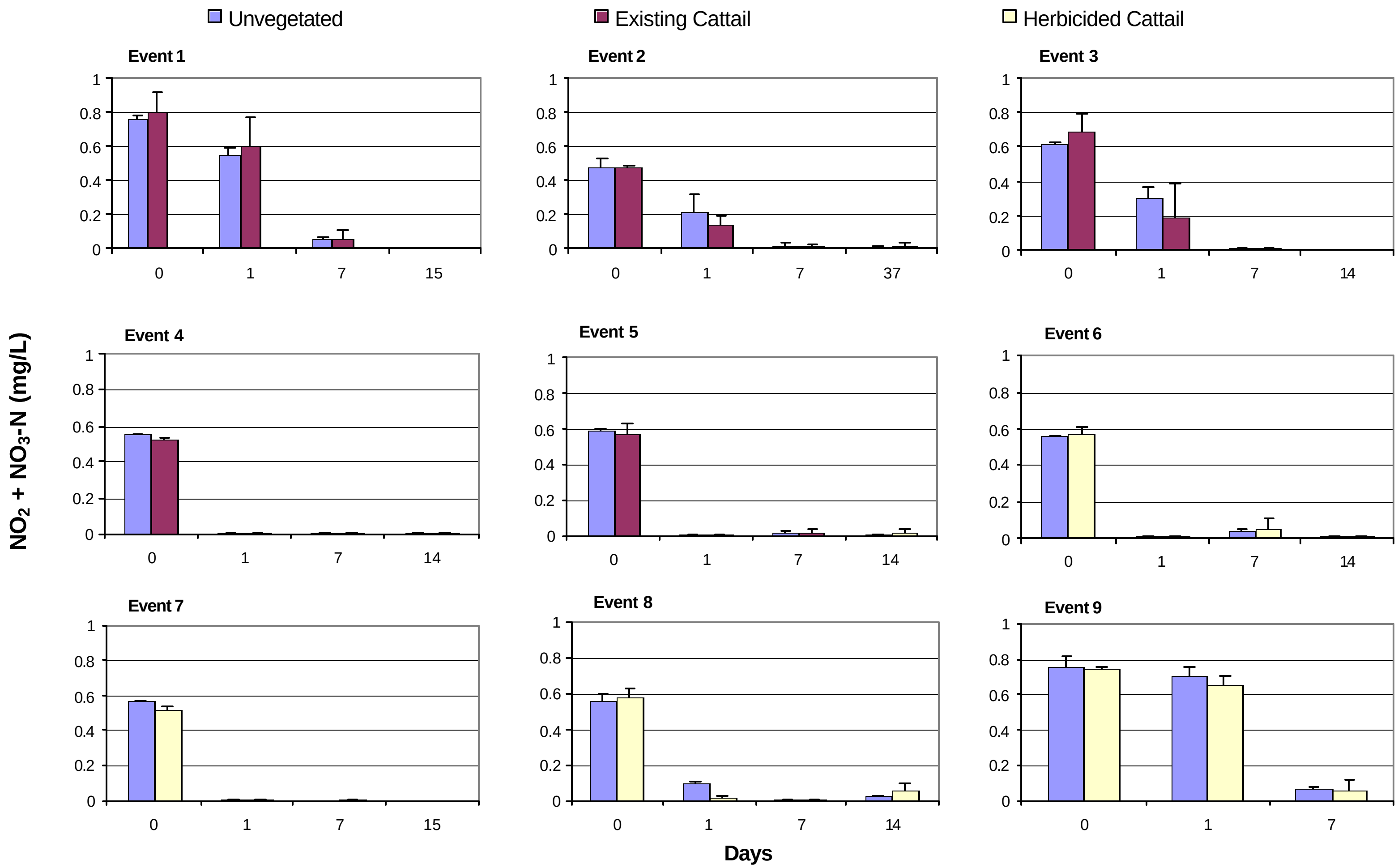


Figure 79. Open water NO_2 + NO_3-N concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

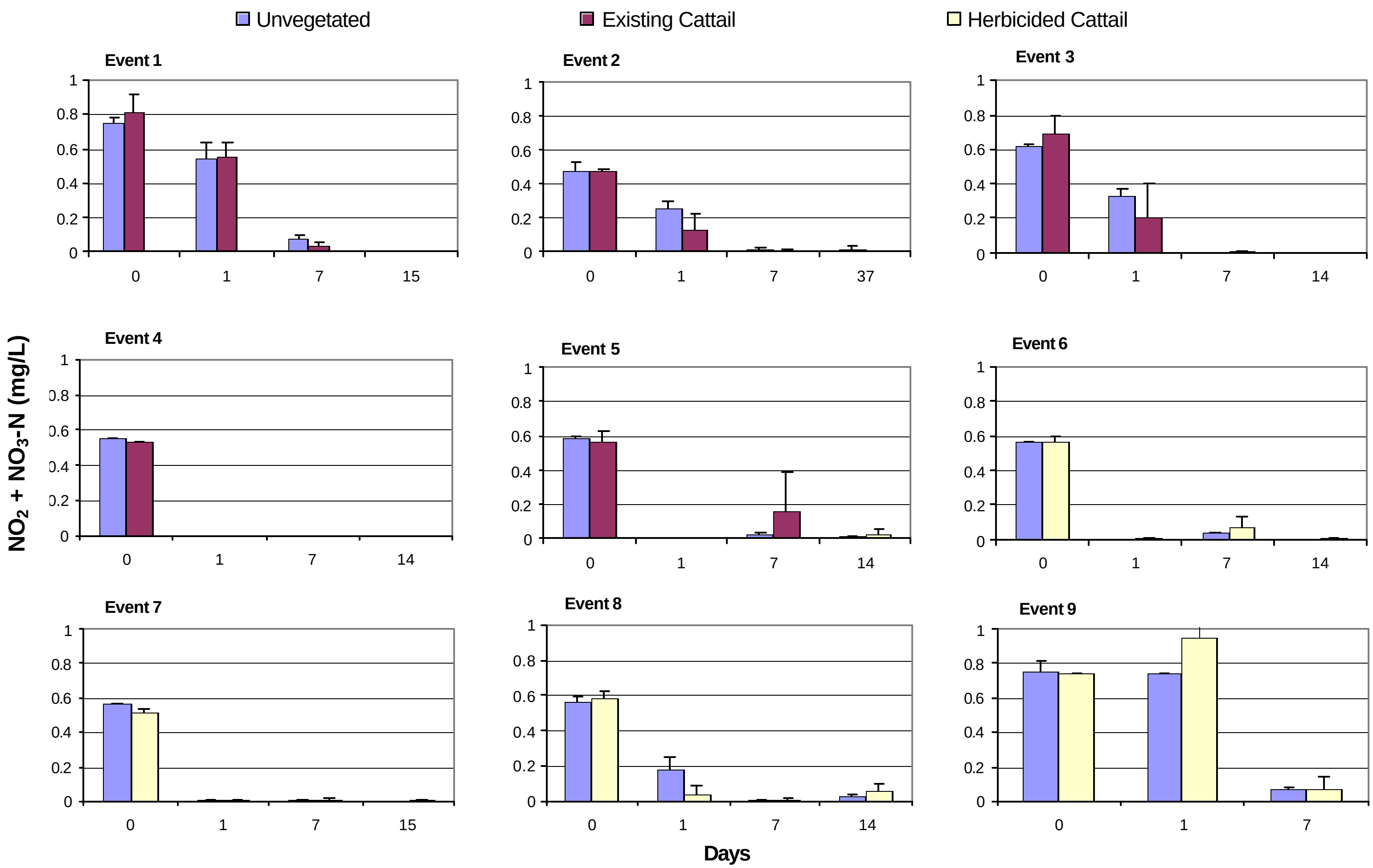
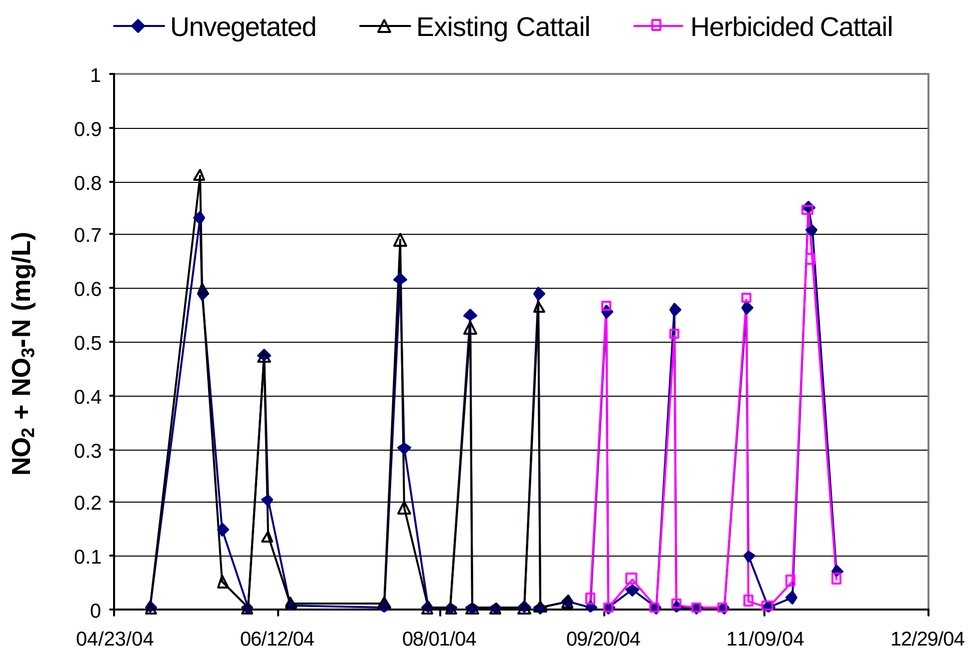


Figure 80. Littoral $NO_2 + NO_3$-N concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

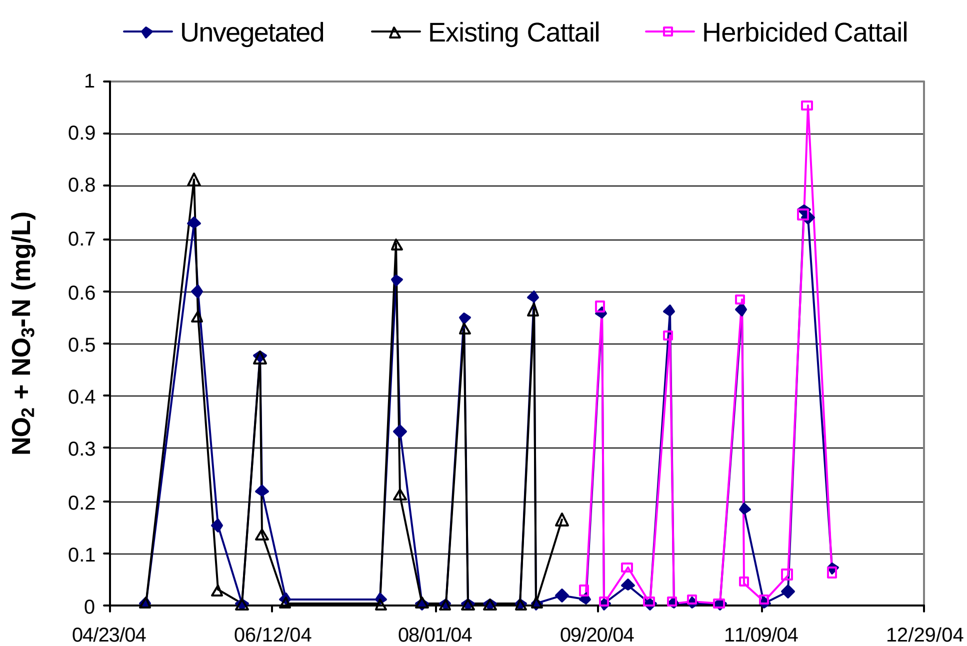


Figure 81. NO_2 + NO_3-N concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail throughout the study.

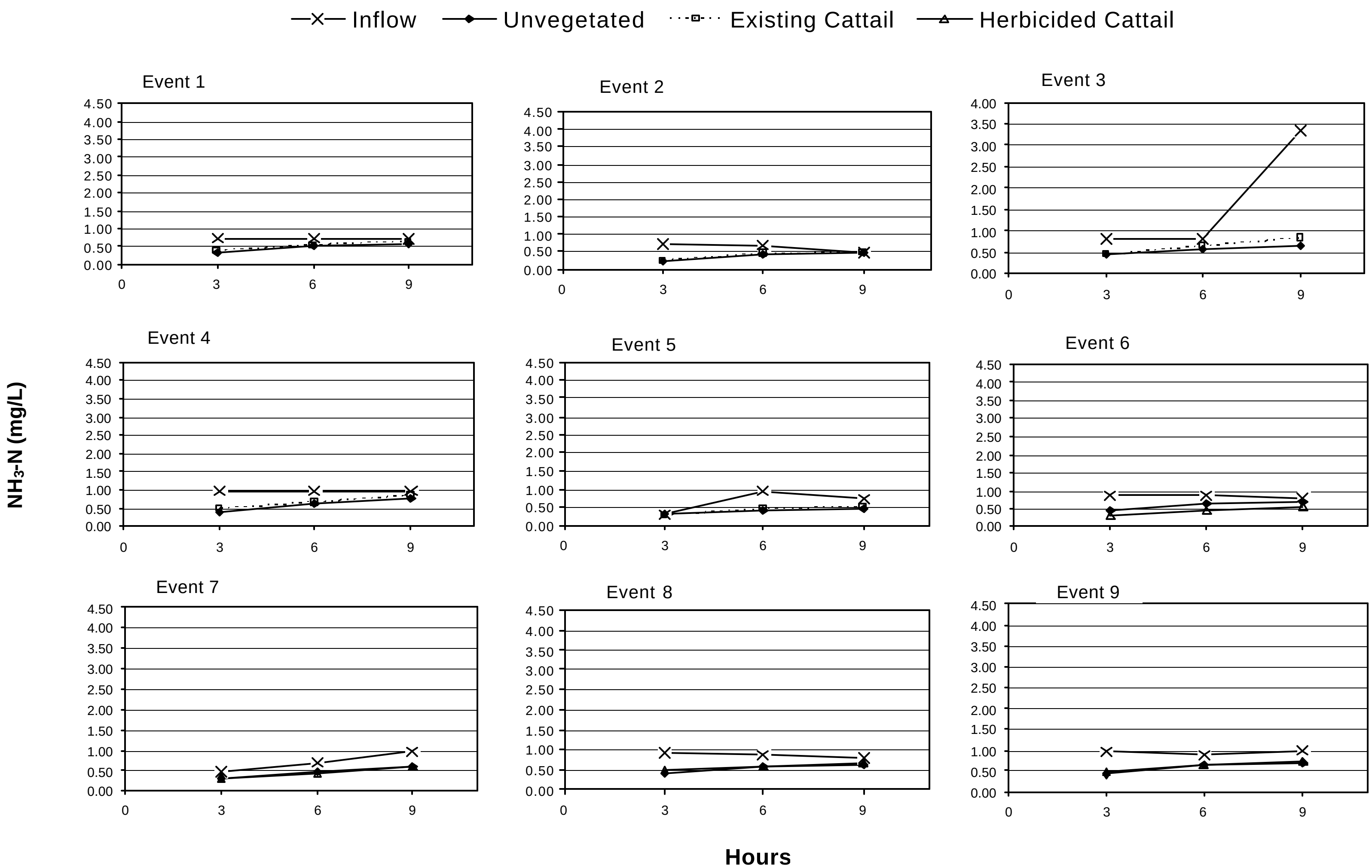
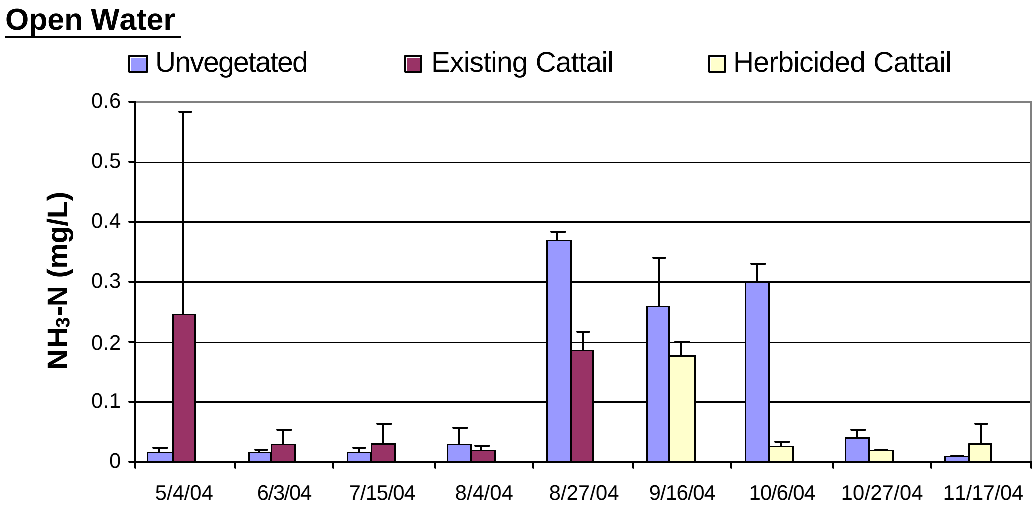


Figure 82. Inflow and outflow NH_3-N concentrations (mg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.



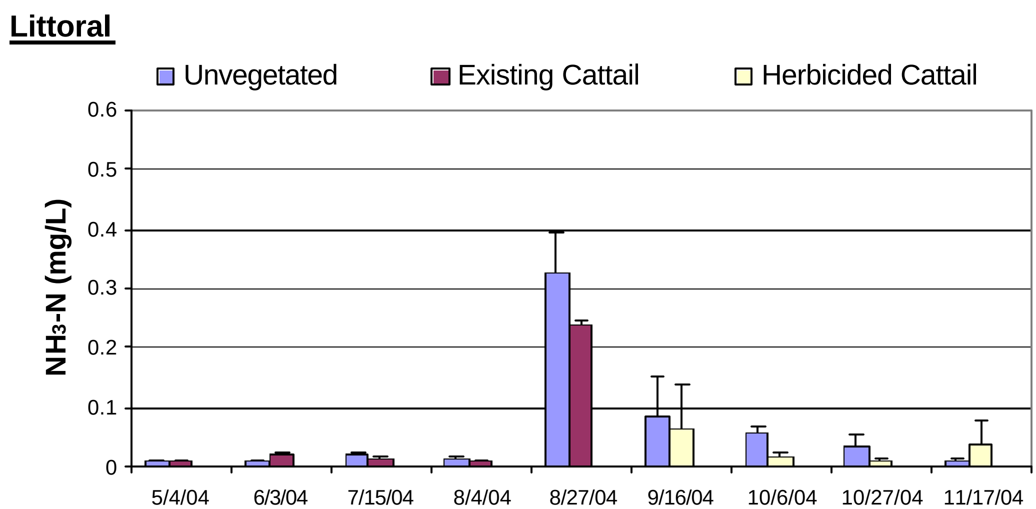


Figure 83. Open water and littoral NH_3-N concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

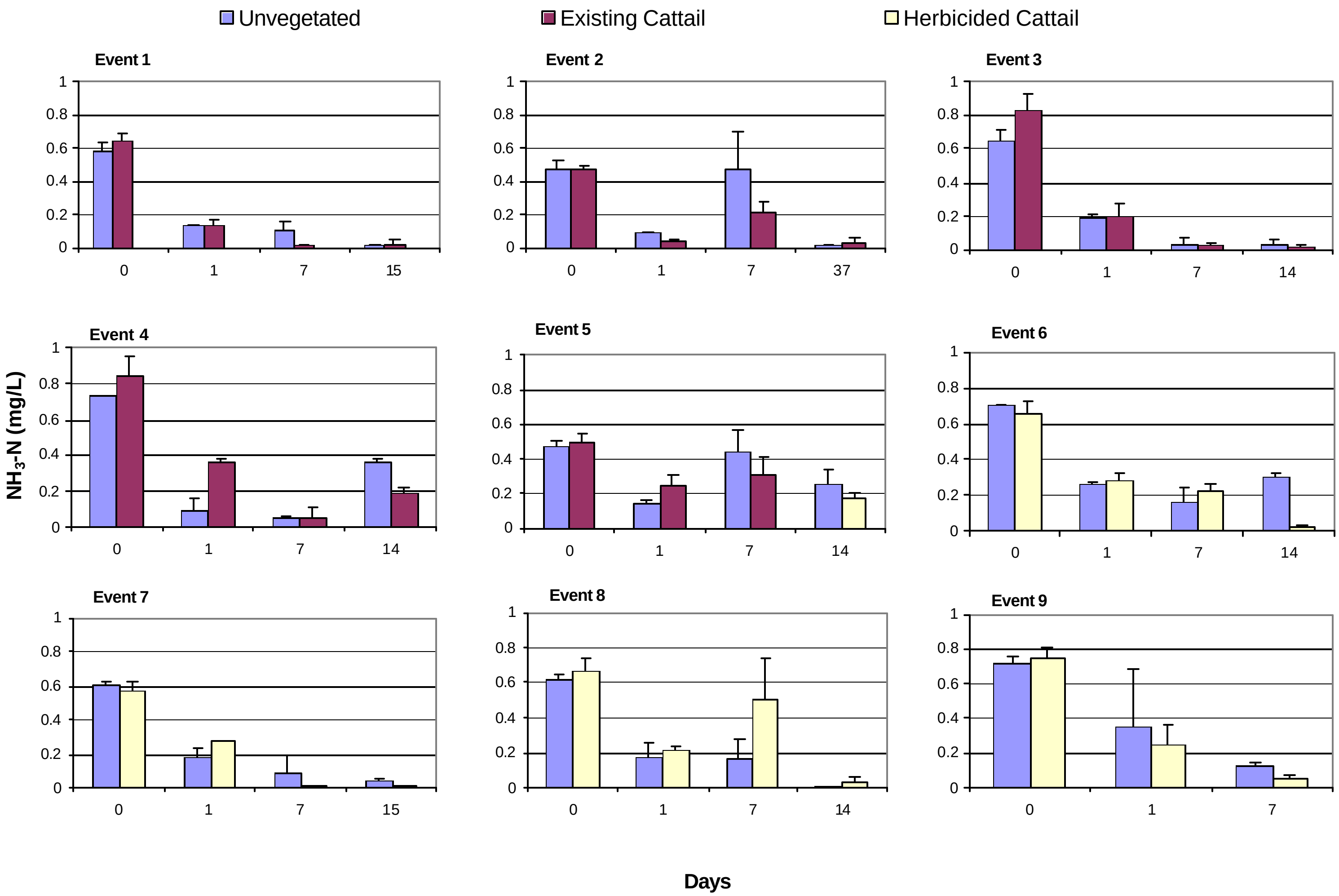


Figure 84. Open water NH_3-N concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

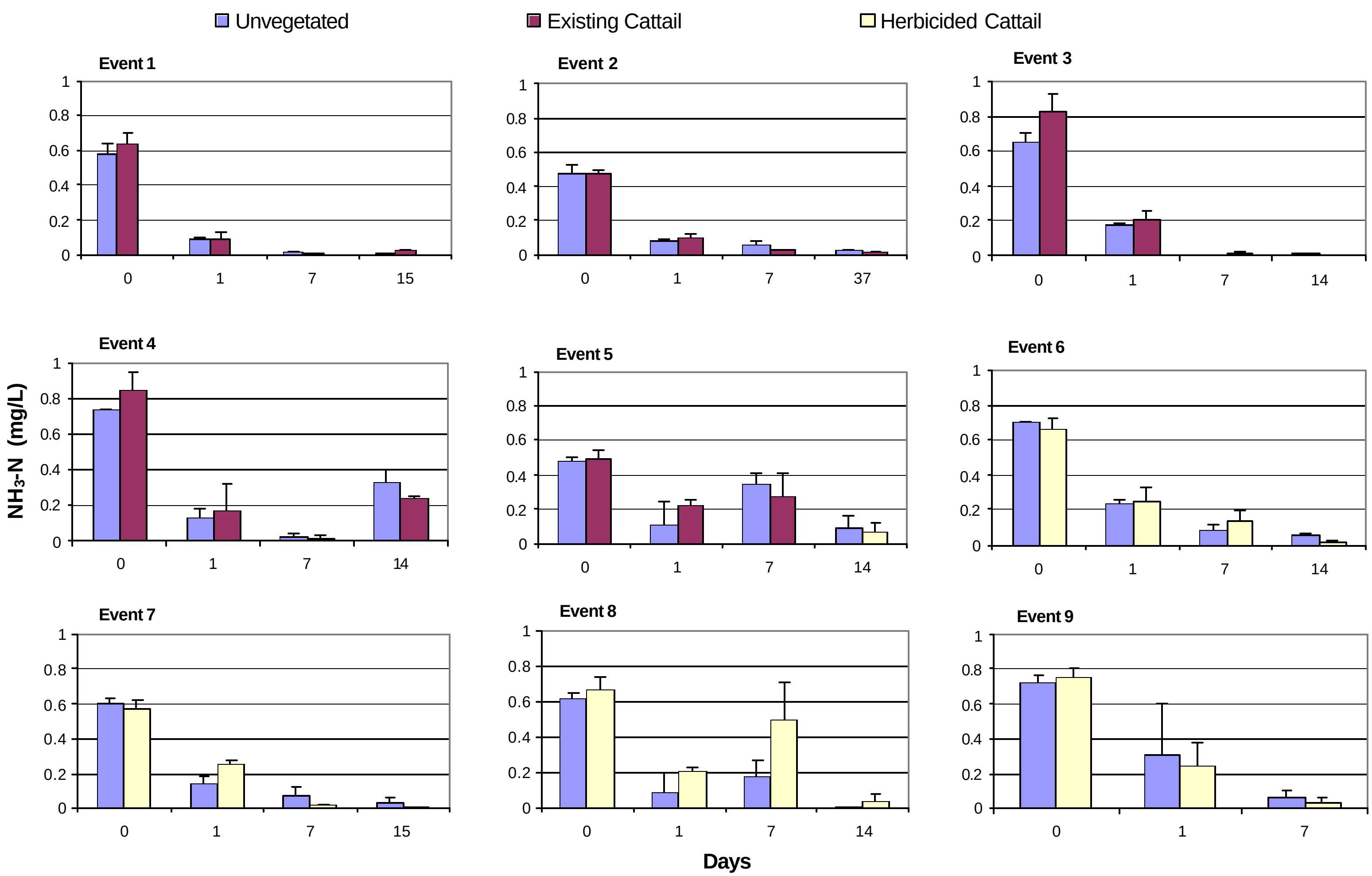
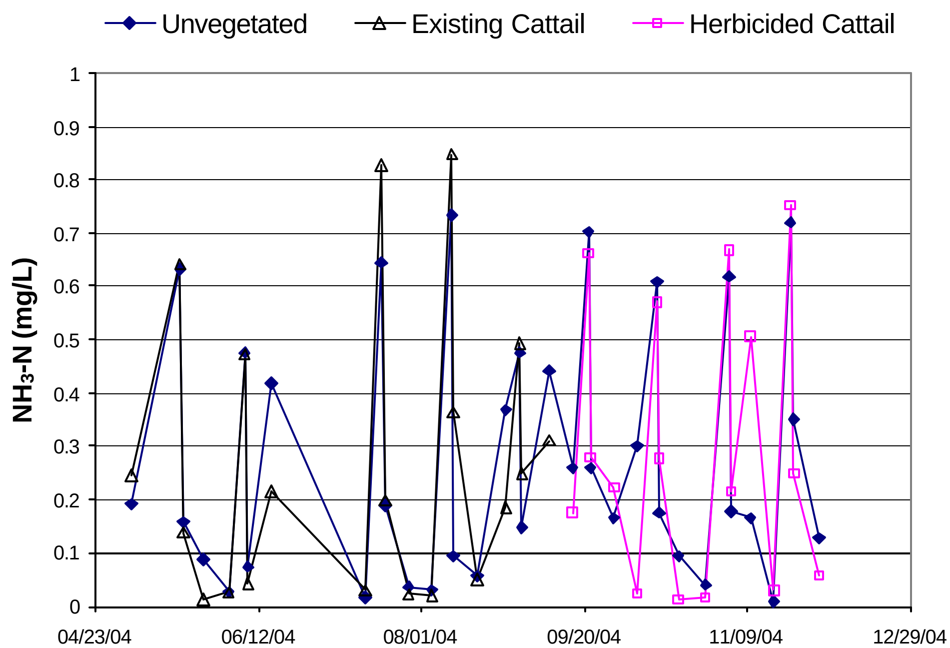


Figure 85. Littoral NH_3-N concentrations (mg/L) for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

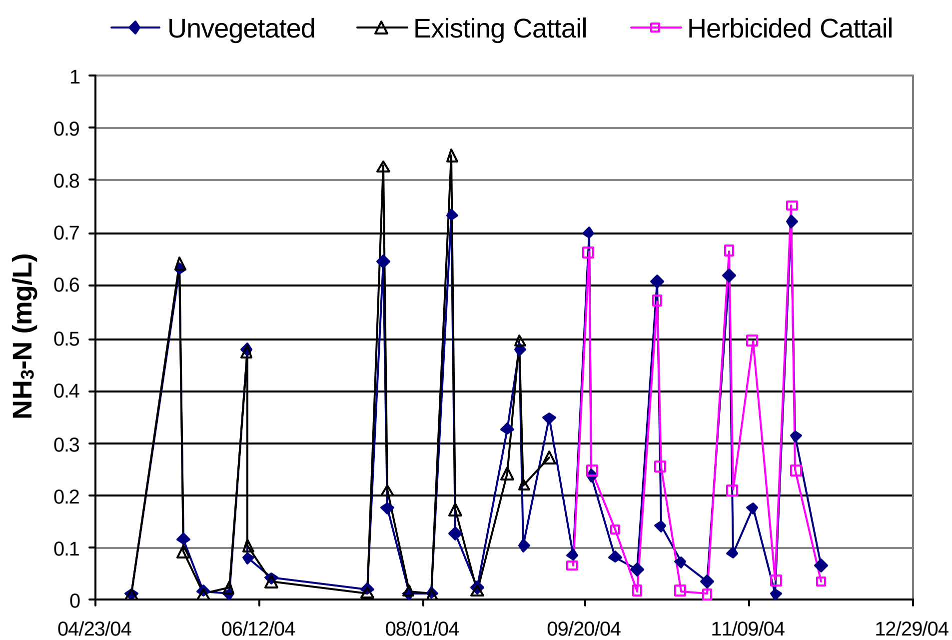


Figure 86. NH_3-N concentrations (mg/L) for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

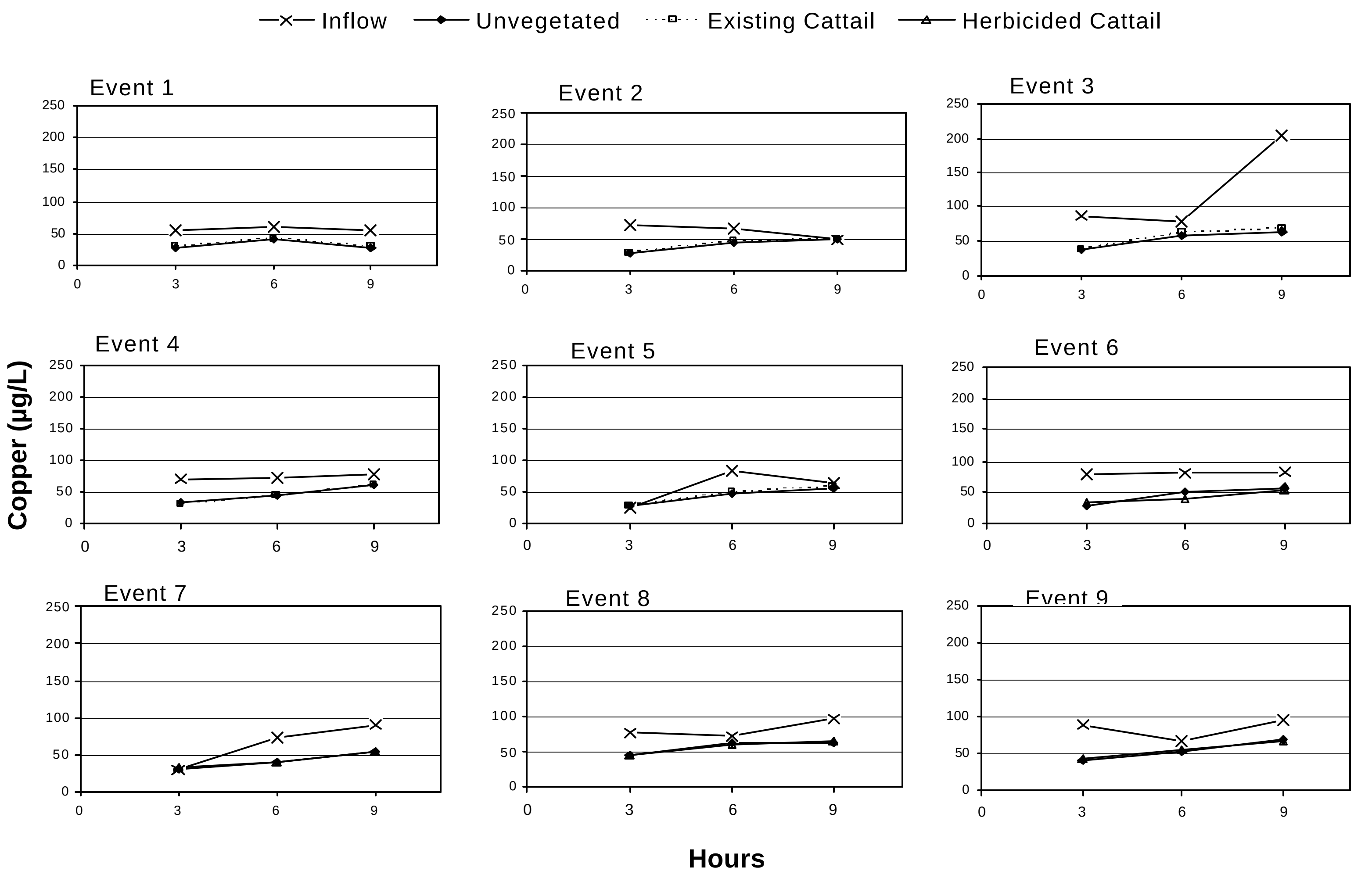
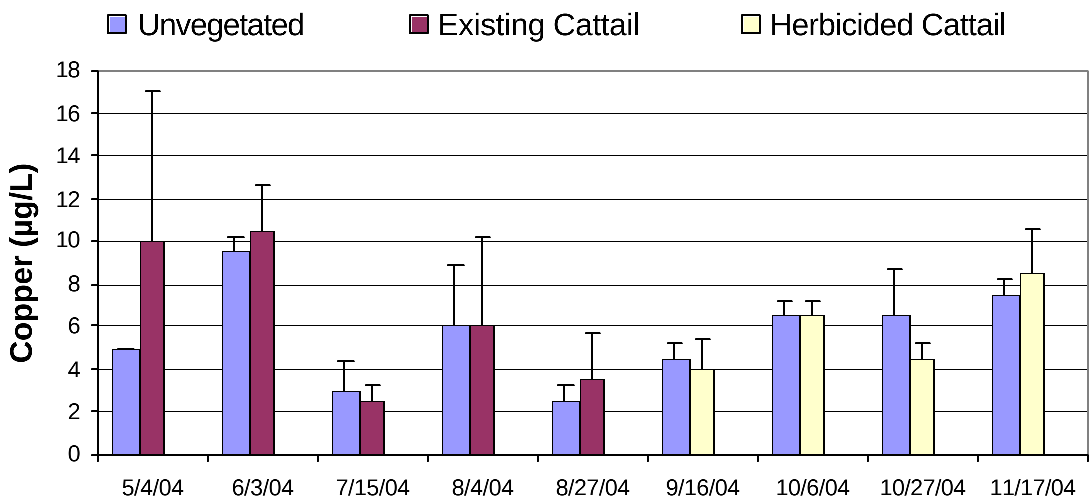


Figure 87. Inflow and outflow Cu concentrations (µg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.

Open Water



Littoral

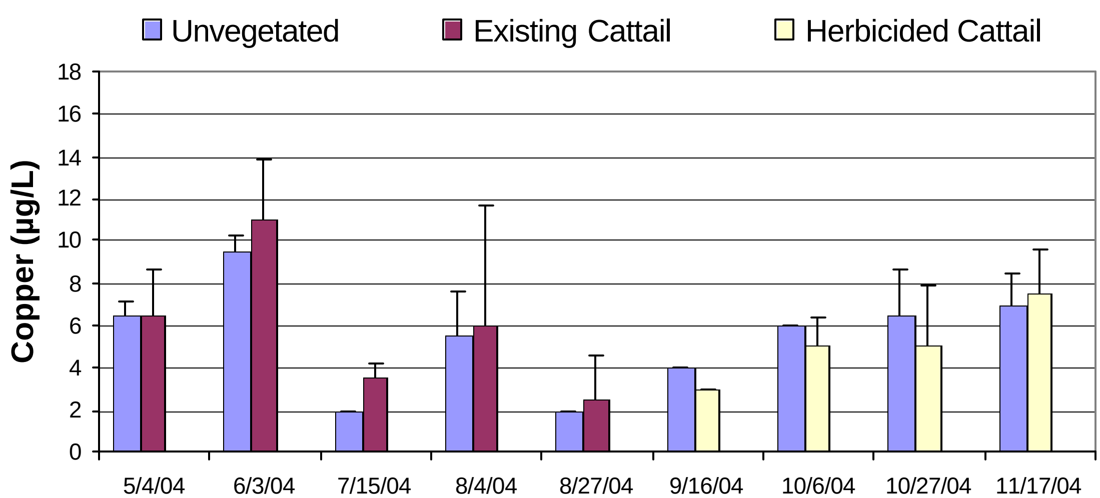


Figure 88. Open water and littoral Cu concentrations (µg/L) for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

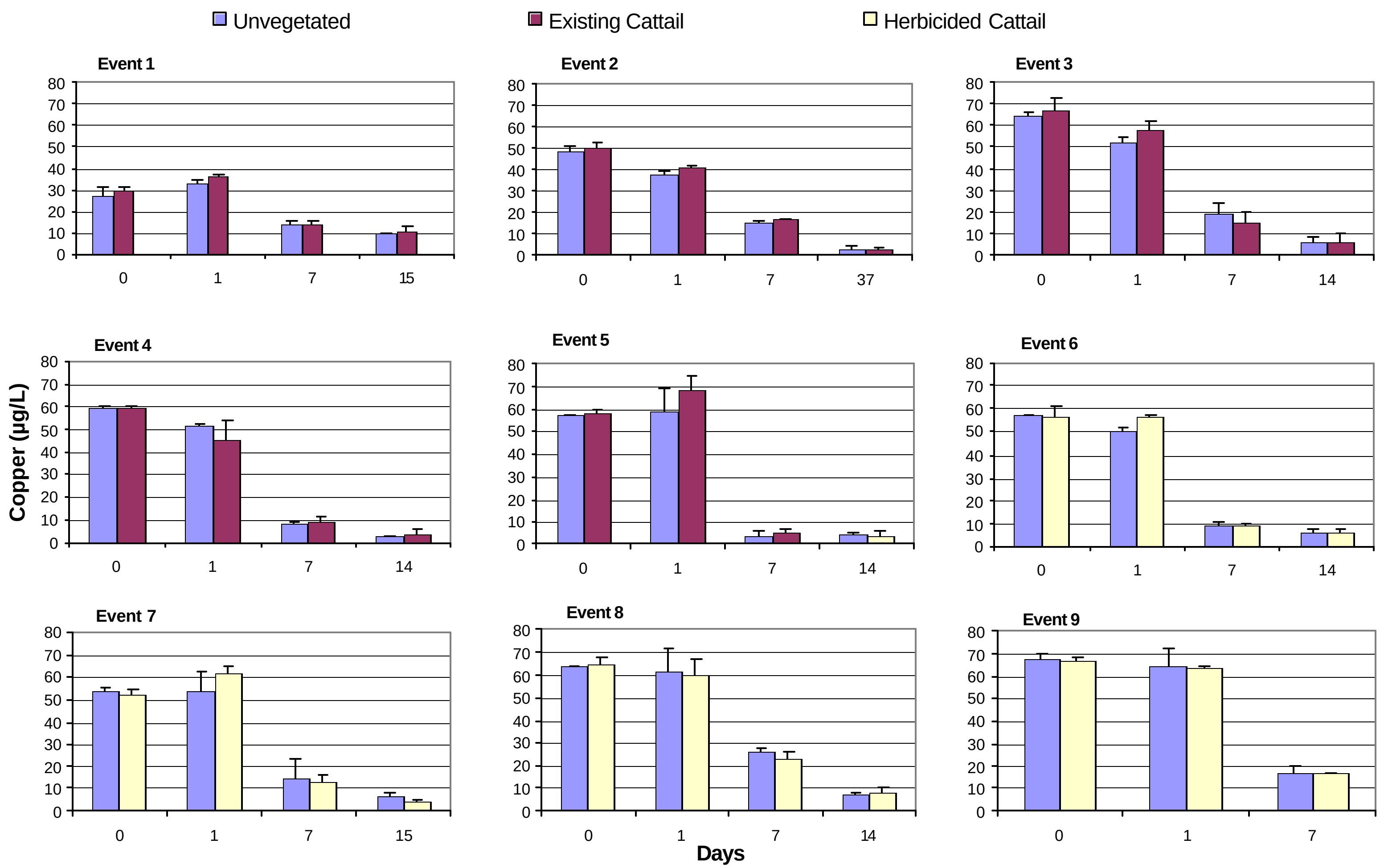


Figure 89. Open water Cu concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

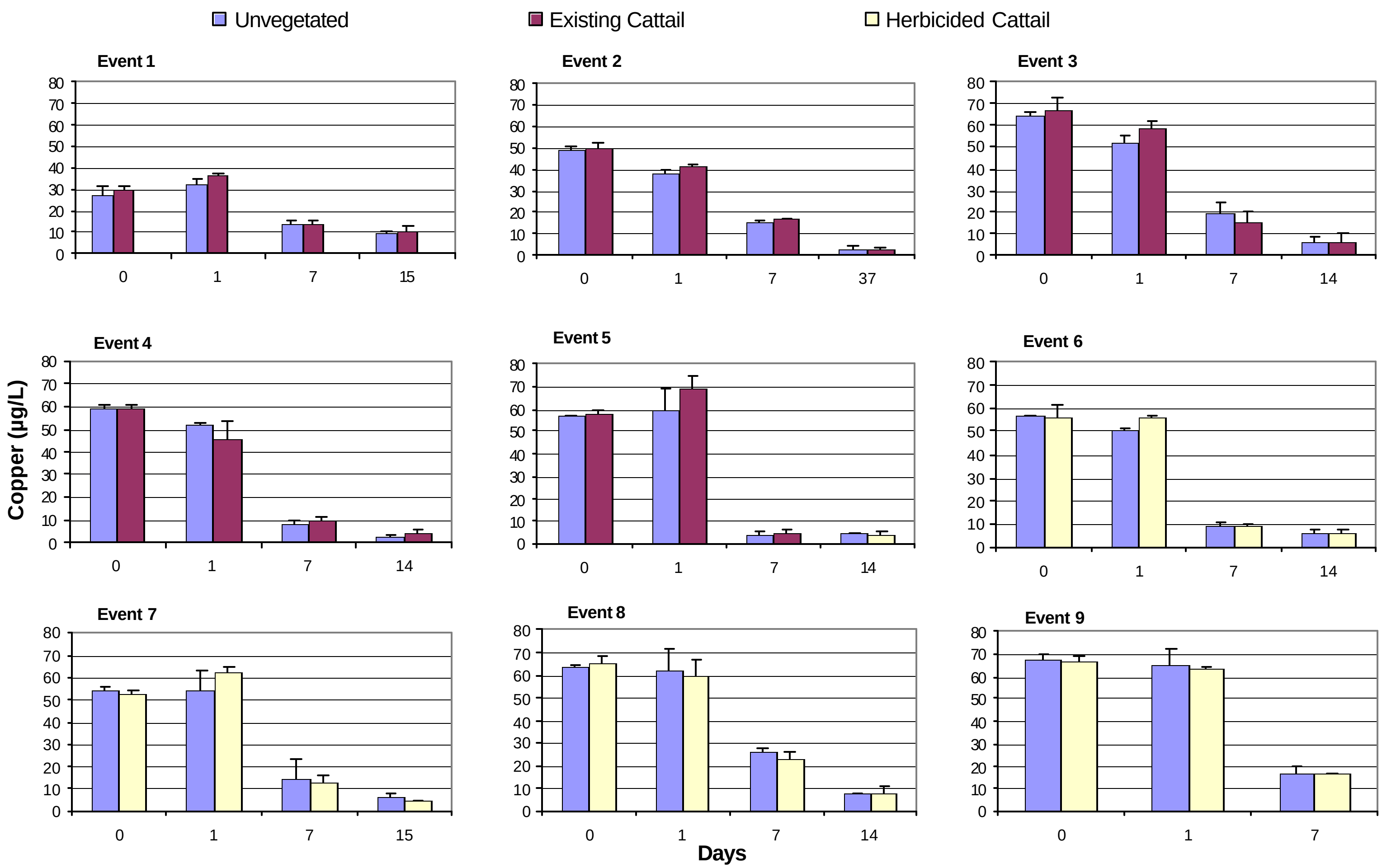
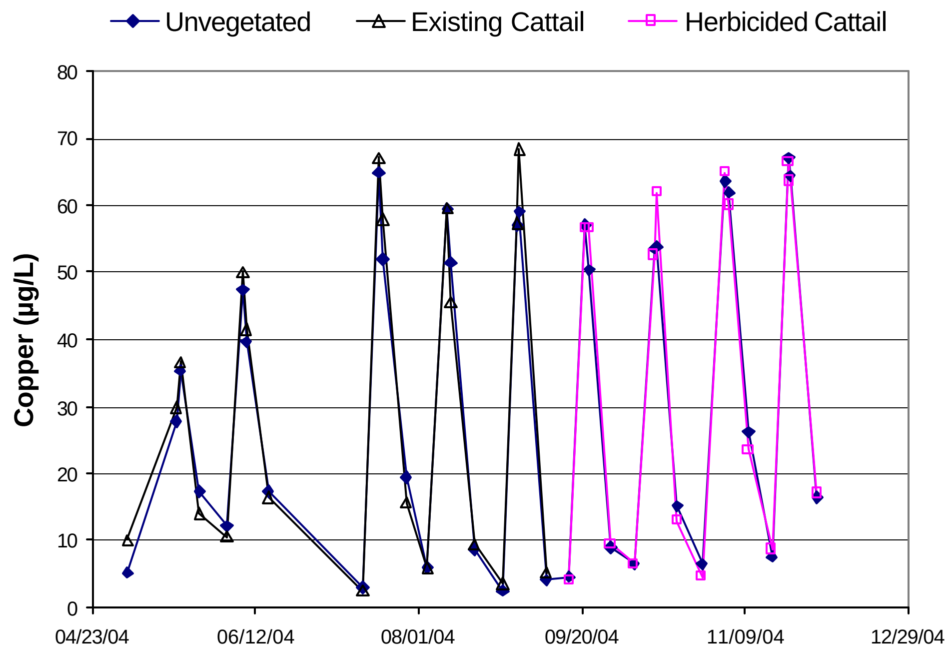


Figure 90. Littoral Cu concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

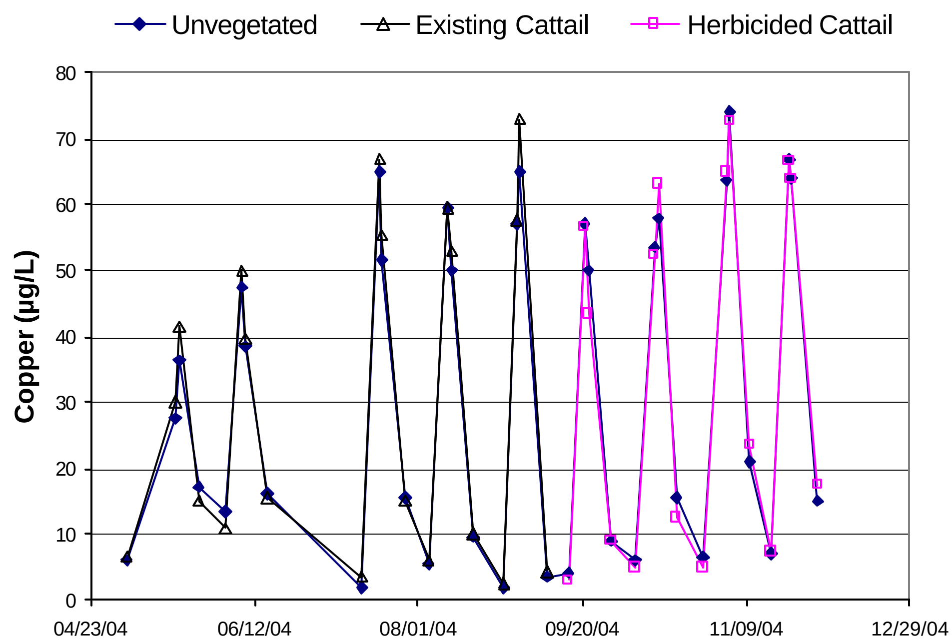


Figure 91. Cu concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

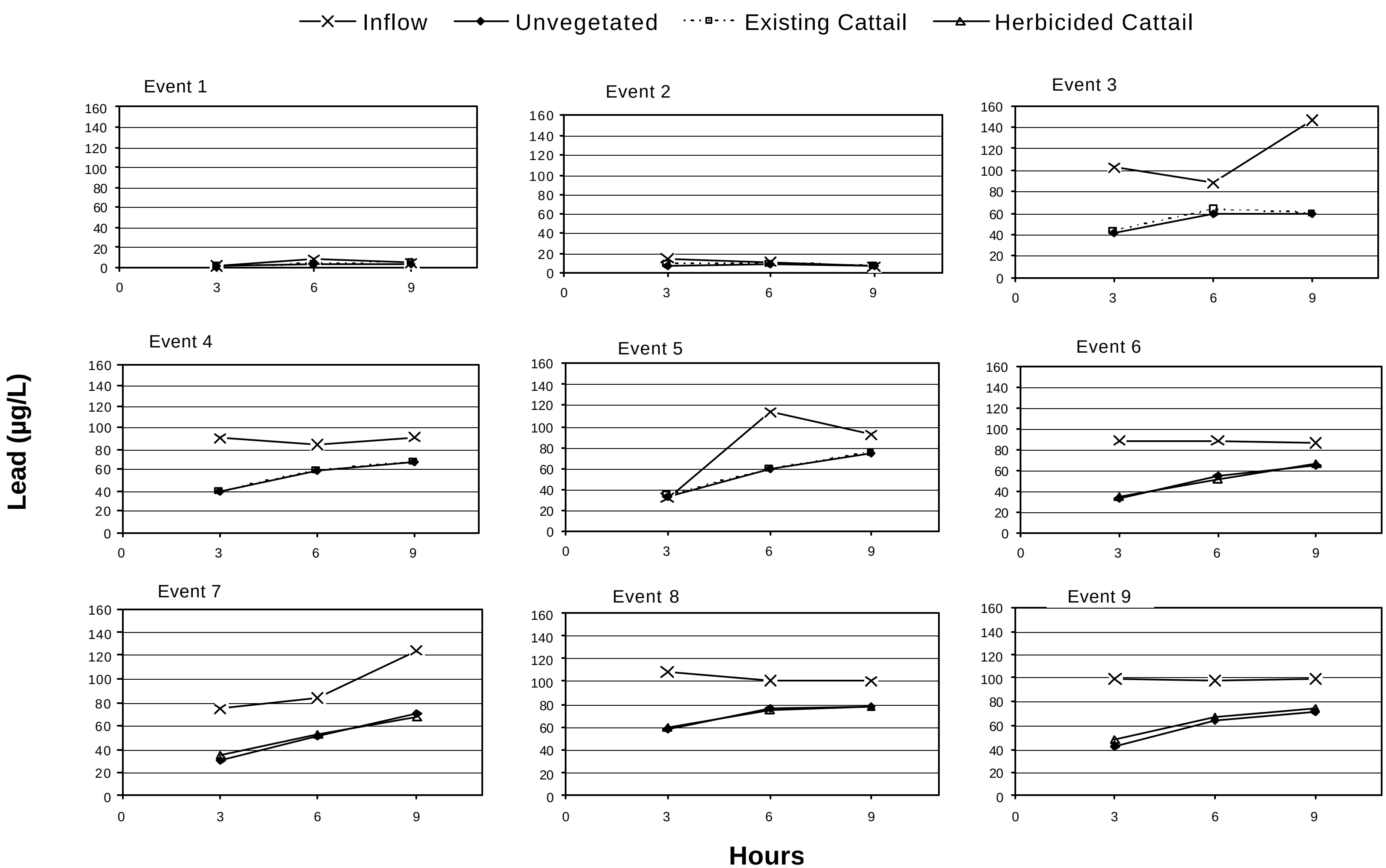


Figure 92. Inflow and outflow Pb concentrations (µg/L) during nine simulated storm events for unvegetated, existing cattail and herbicided cattail compartments.

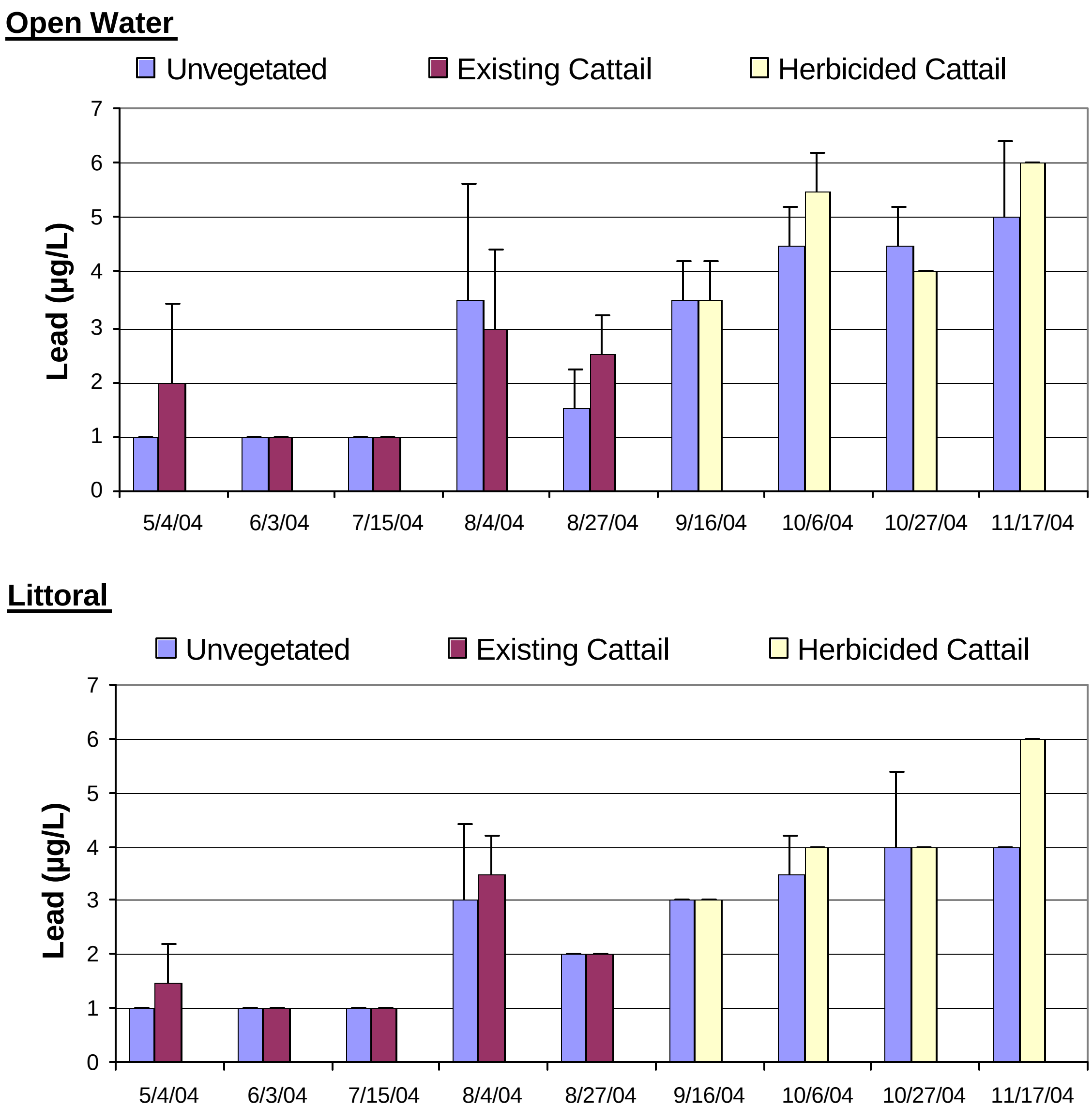


Figure 93. Open water and littoral Pb concentrations for unvegetated, existing cattail and herbicided cattail compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

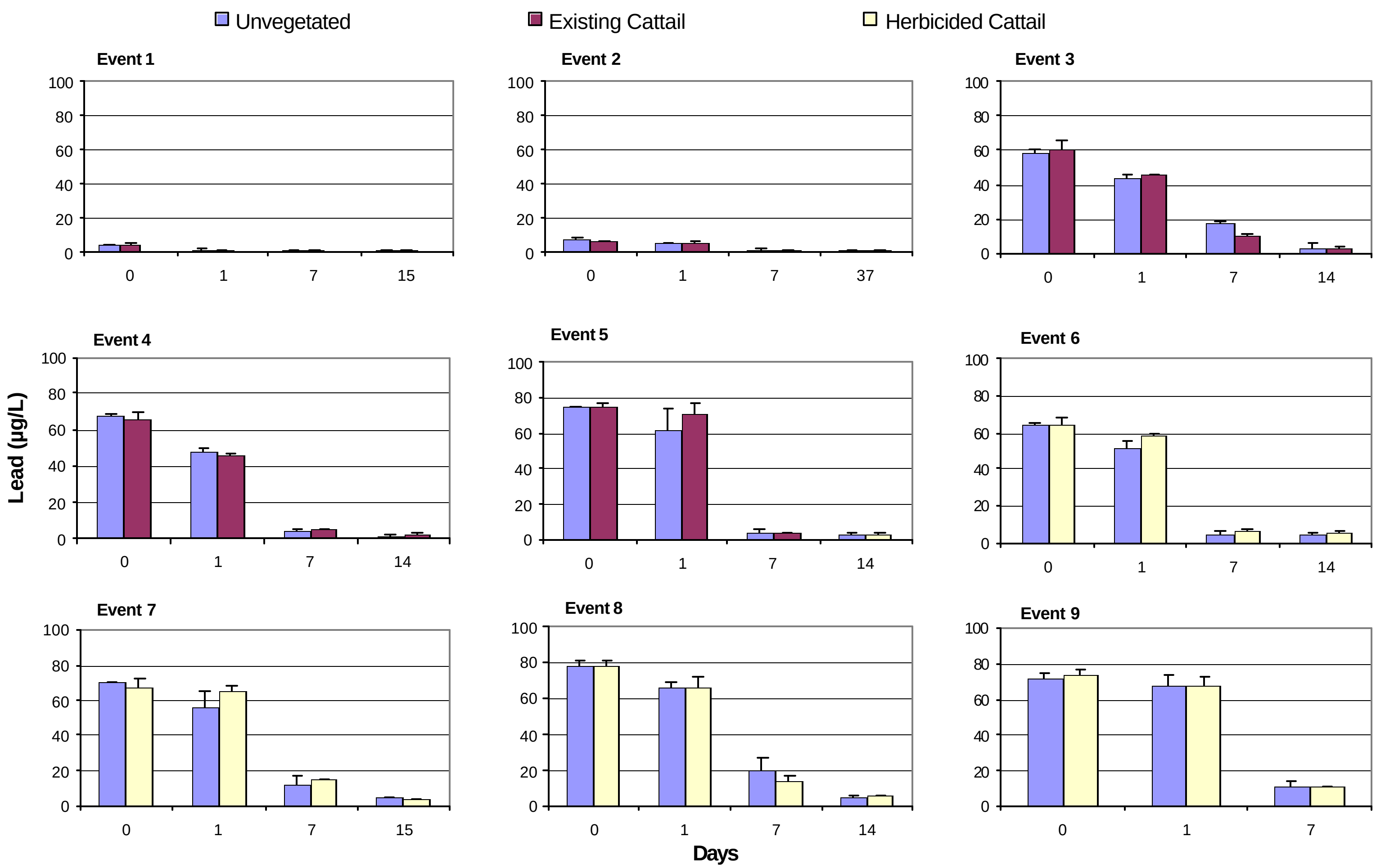


Figure 94. Open water Pb concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

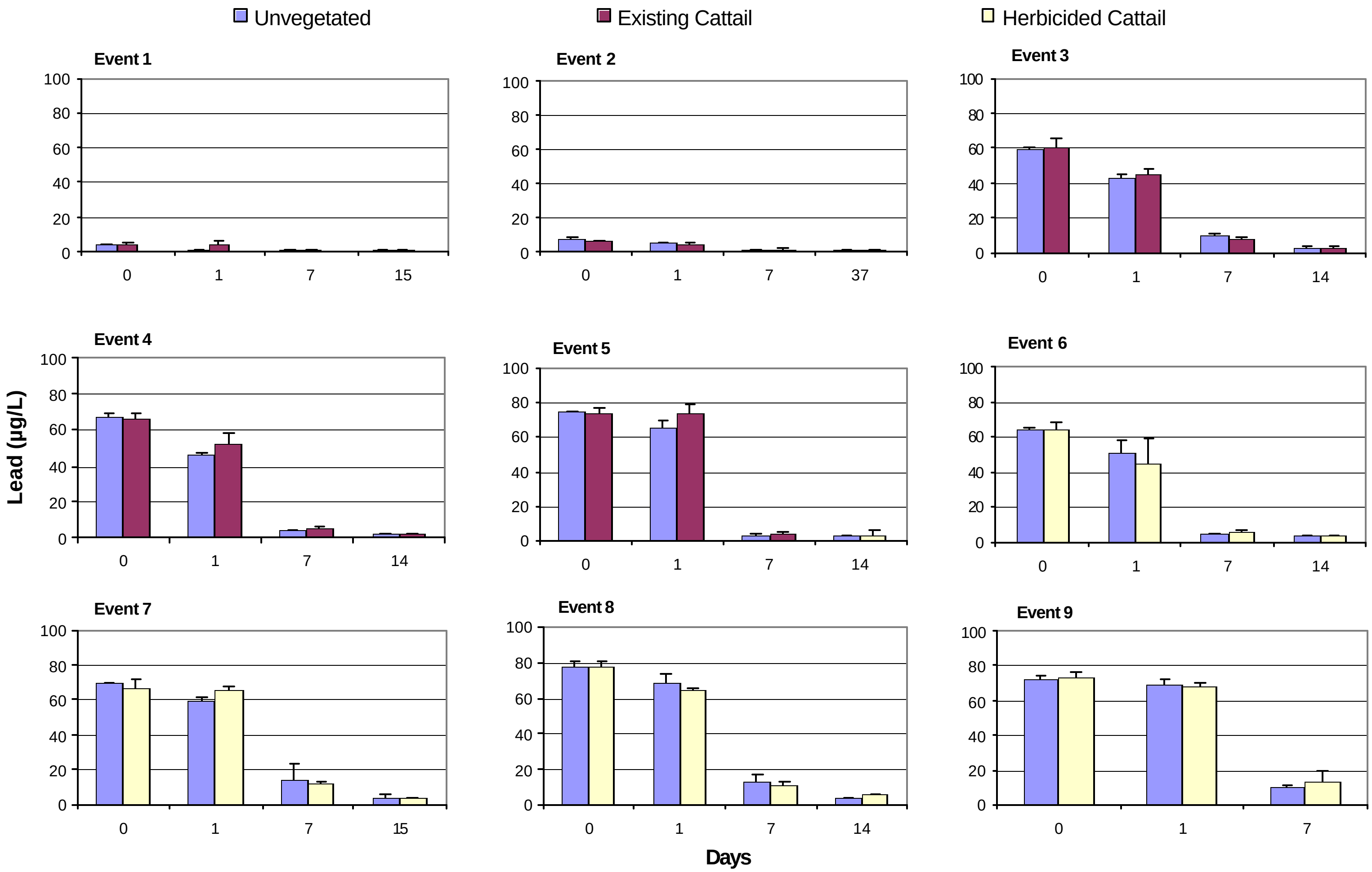
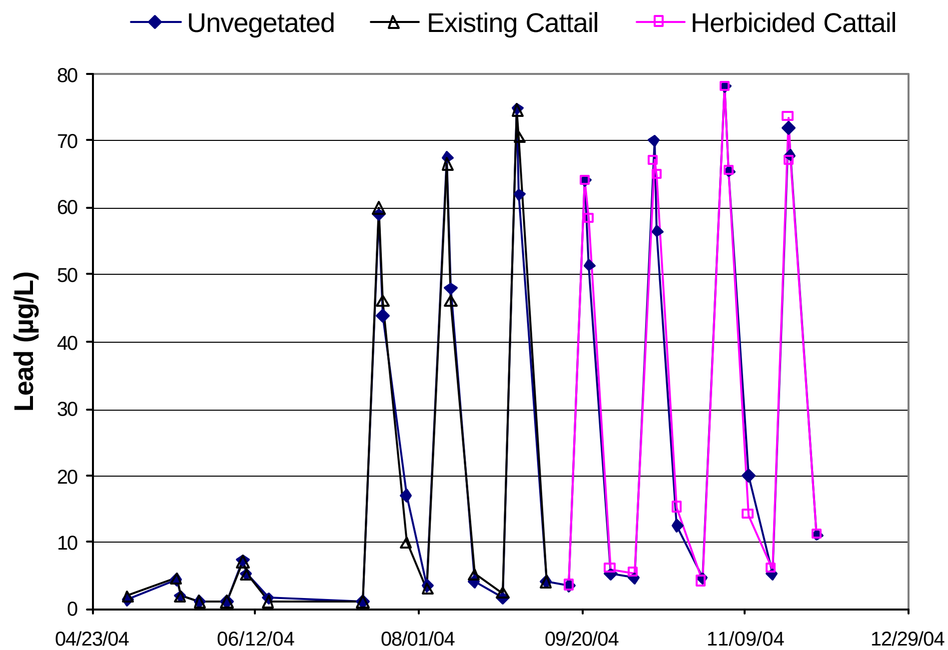


Figure 95. Littoral Pb concentrations for unvegetated, existing cattail and herbicided cattail compartments as a function of time during each inter-event period.

Open Water



Littoral

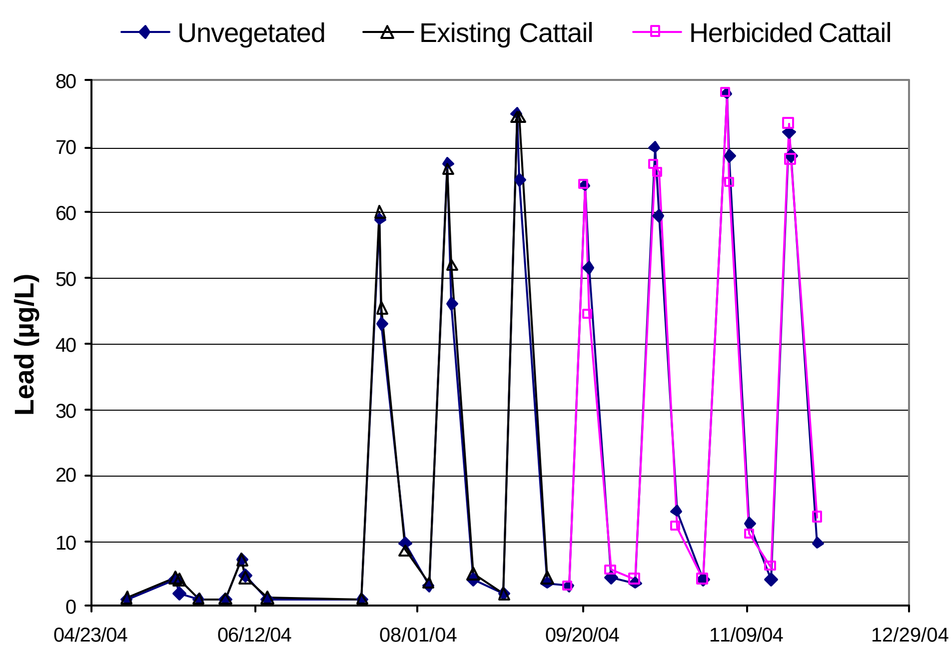


Figure 96. Pb concentrations for open water and littoral locations of unvegetated, existing cattail and herbicided cattail compartments throughout the study.

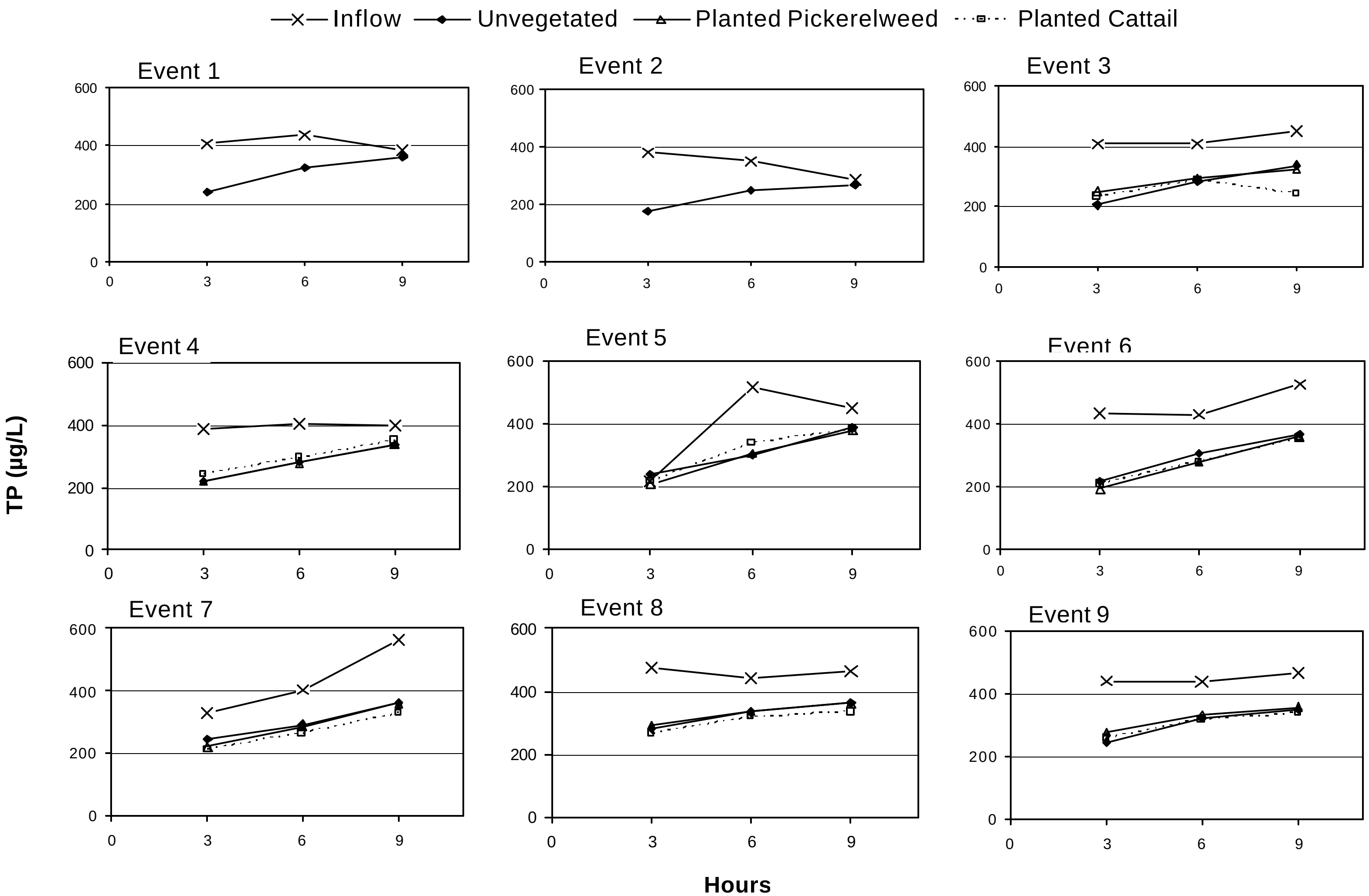


Figure 97. Inflow and outflow TP concentrations (µg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.

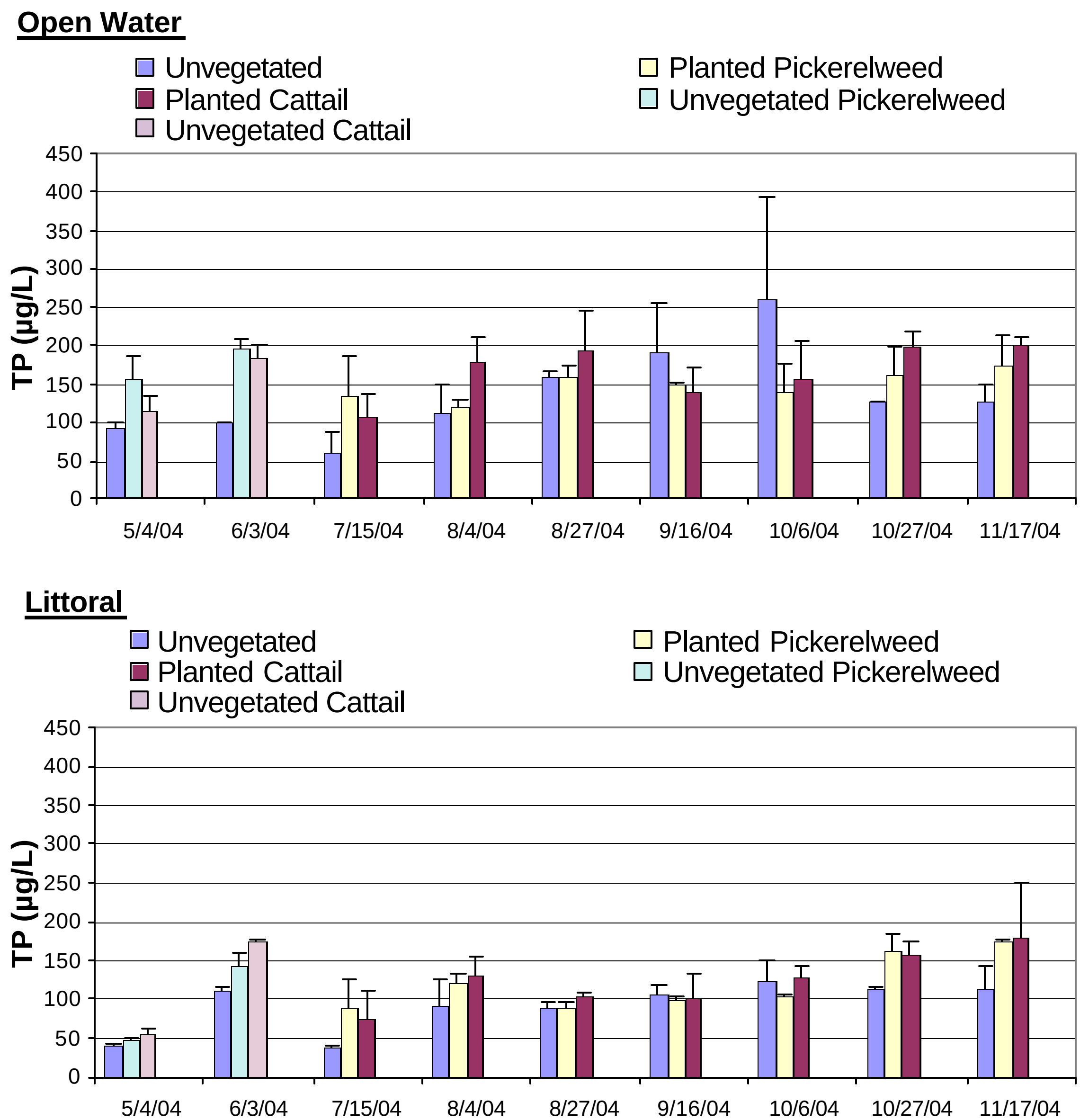


Figure 98. Open water and littoral TP concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

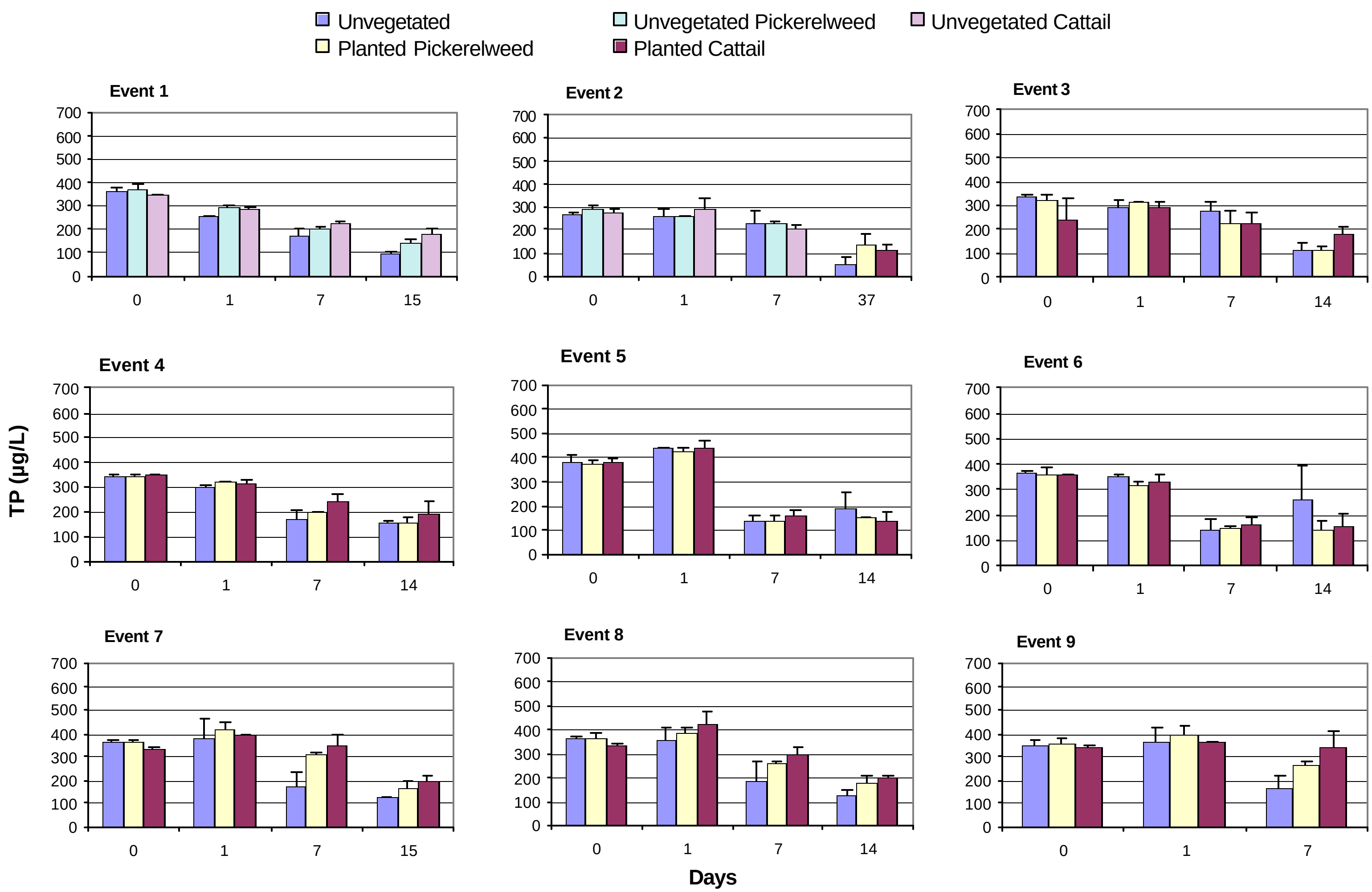


Figure 99. Open water TP concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period

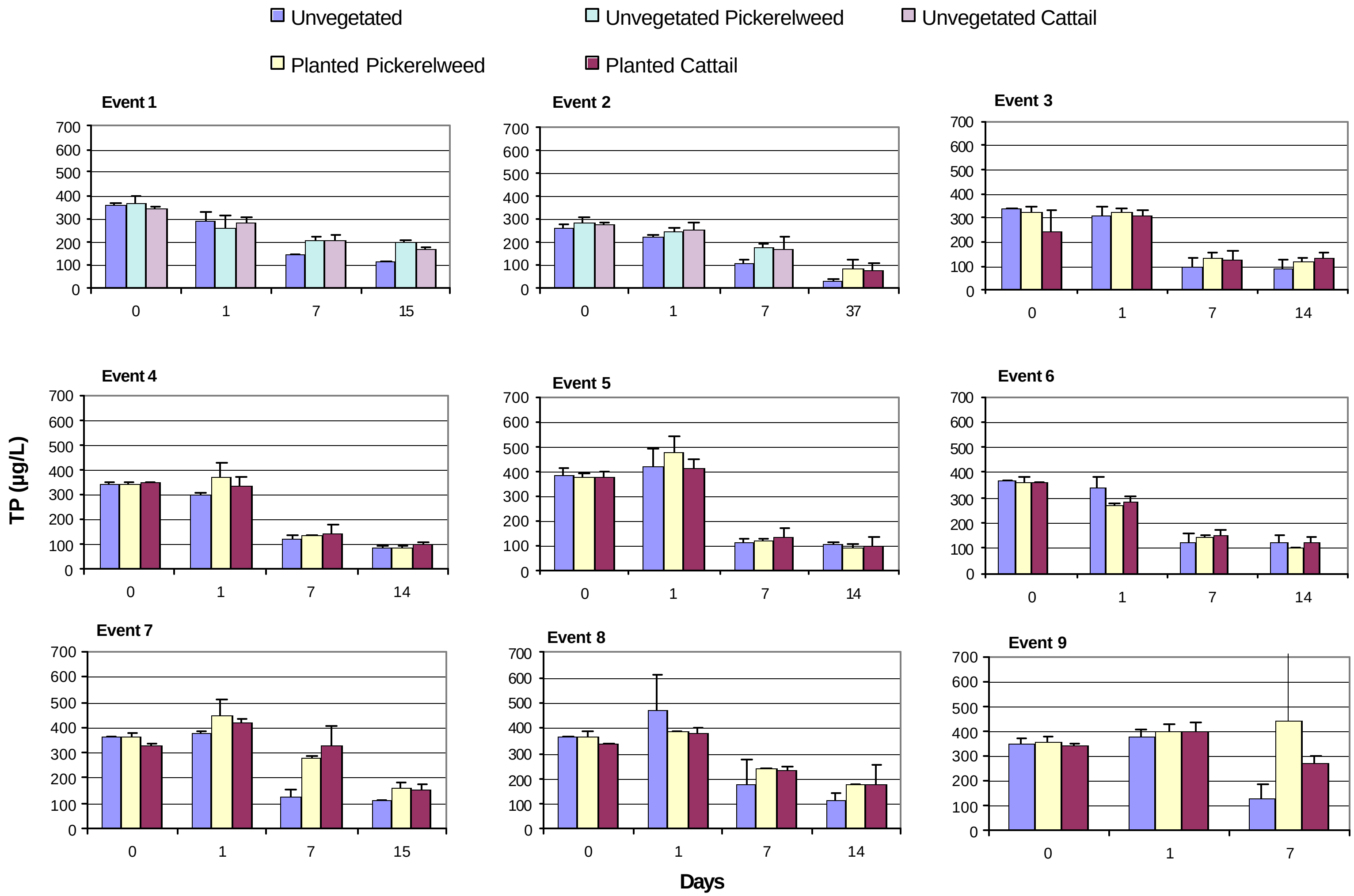
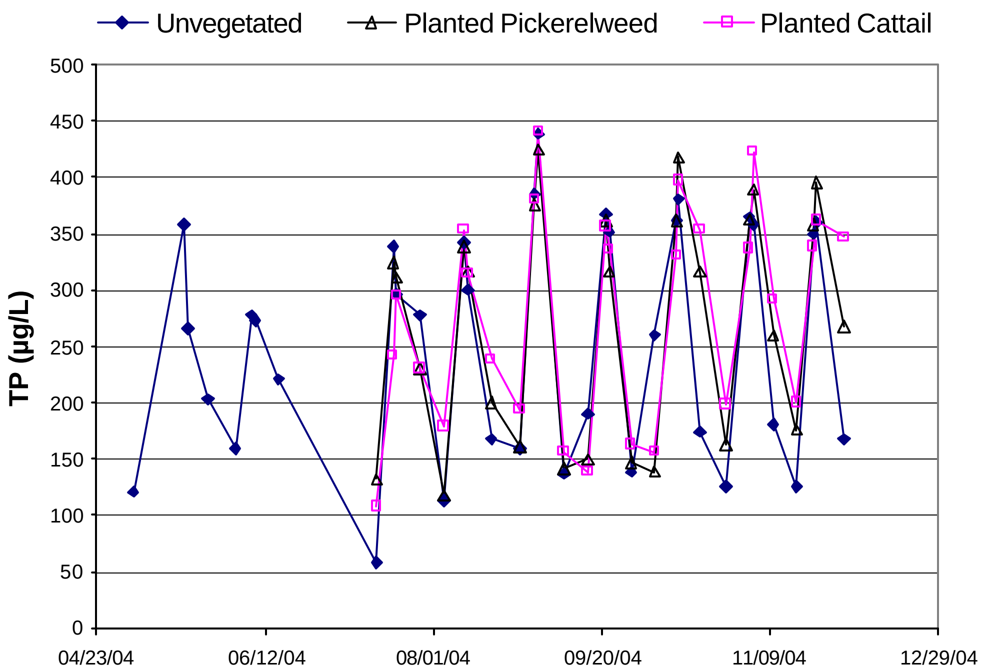


Figure 100. Littoral TP concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

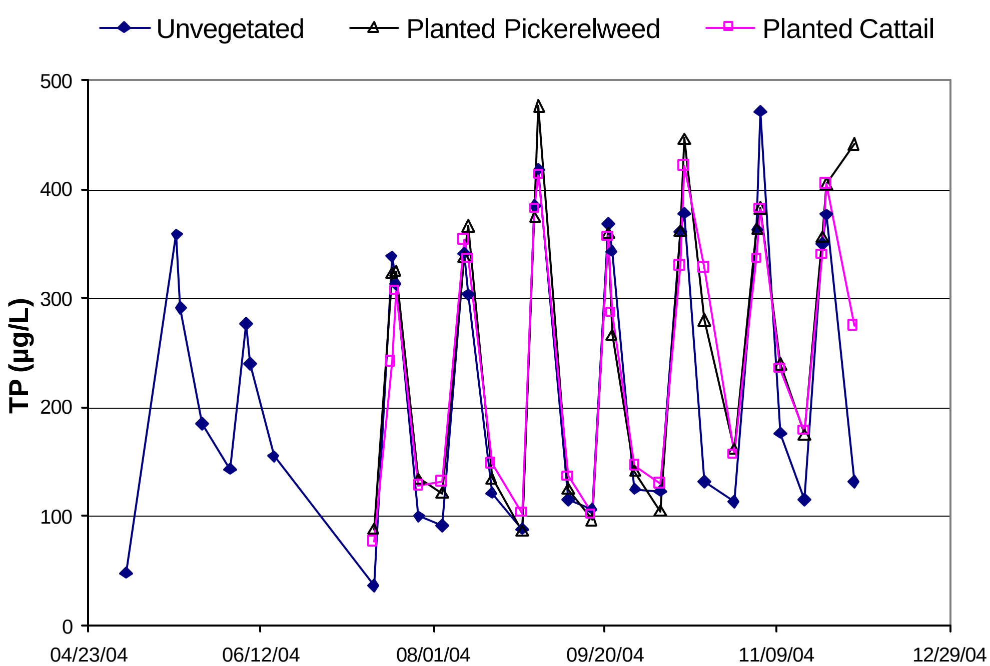


Figure 101. Total P concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

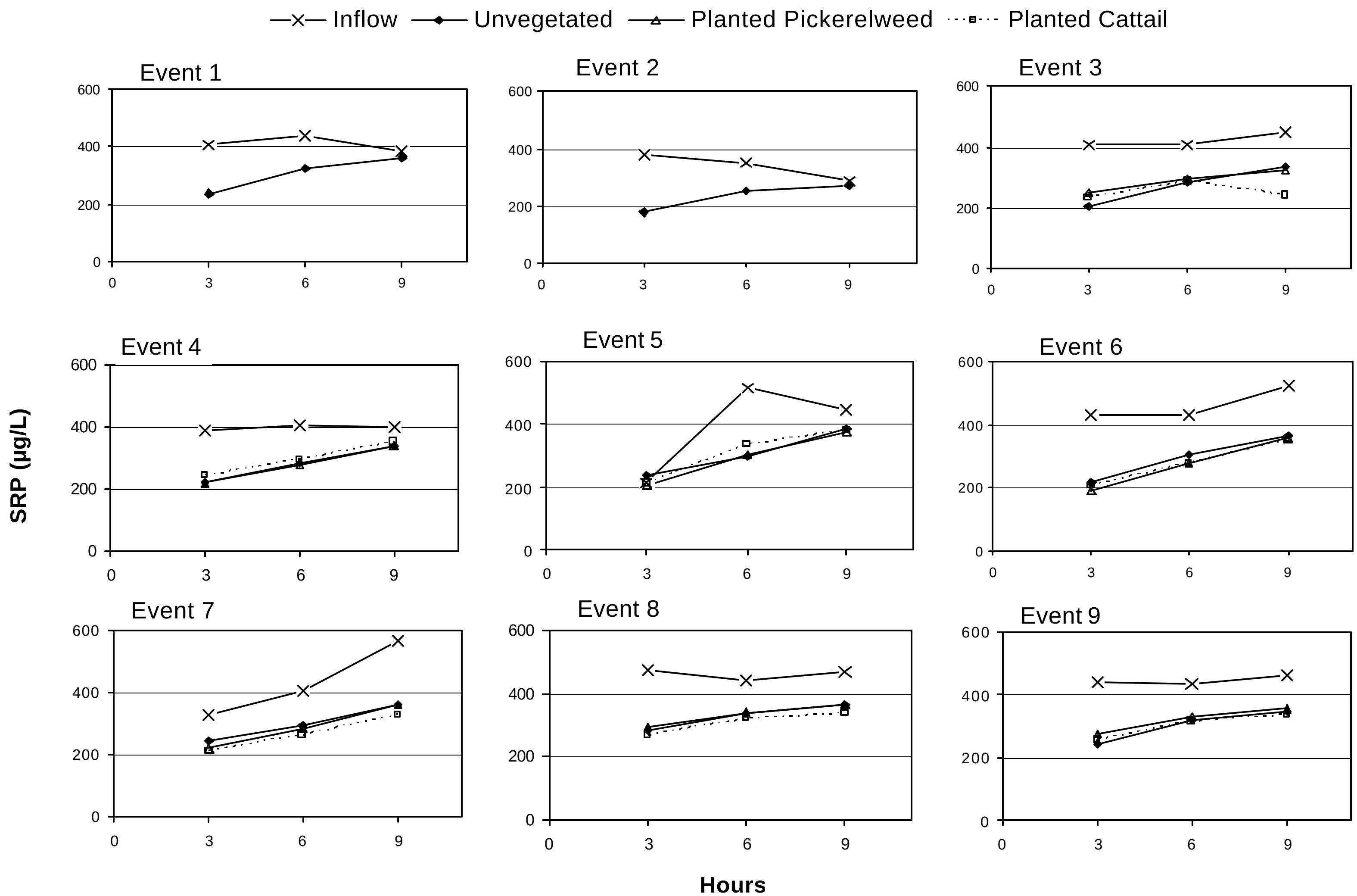
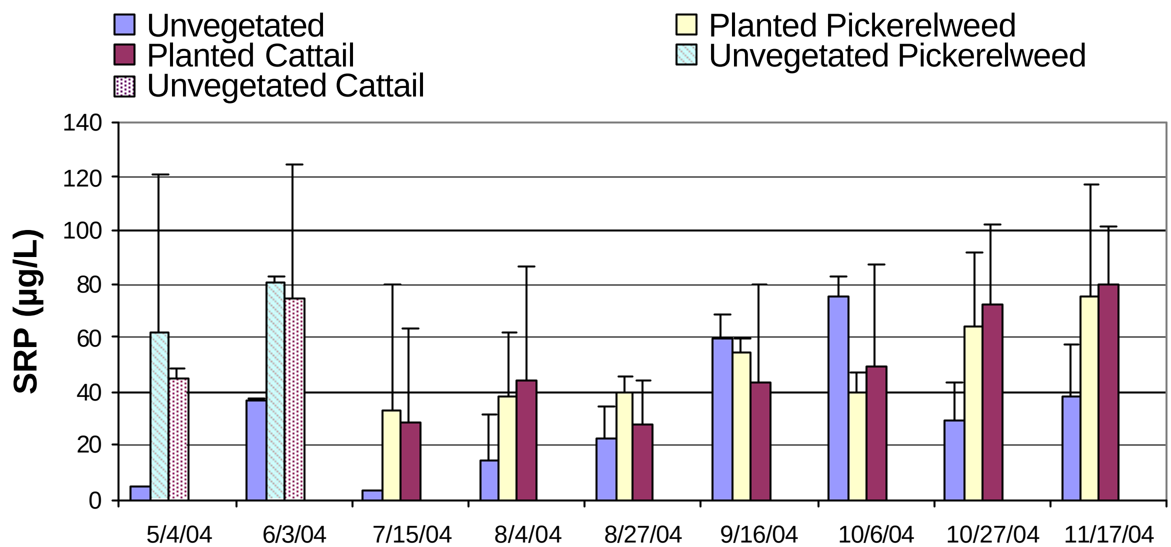


Figure 102. Inflow and outflow SRP concentrations (µg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.

Open Water



Littoral

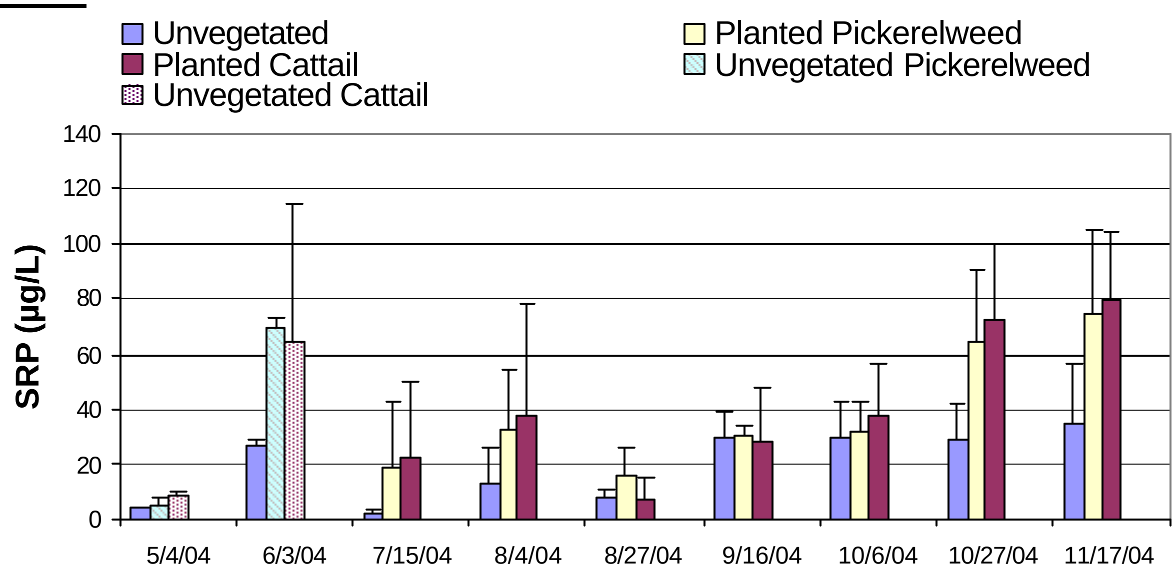


Figure 103. Open water and littoral SRP concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

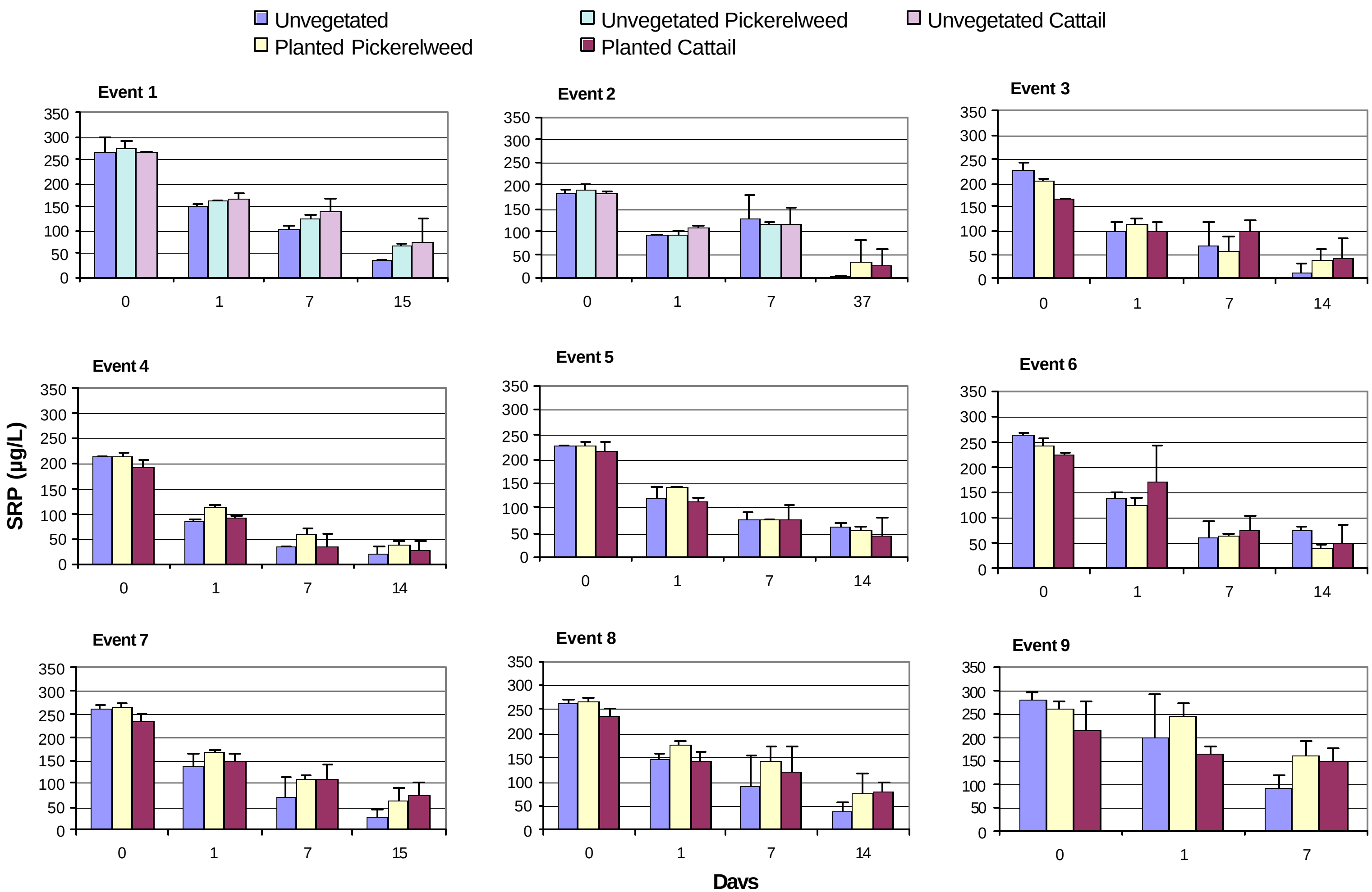


Figure 104. Open water SRP concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

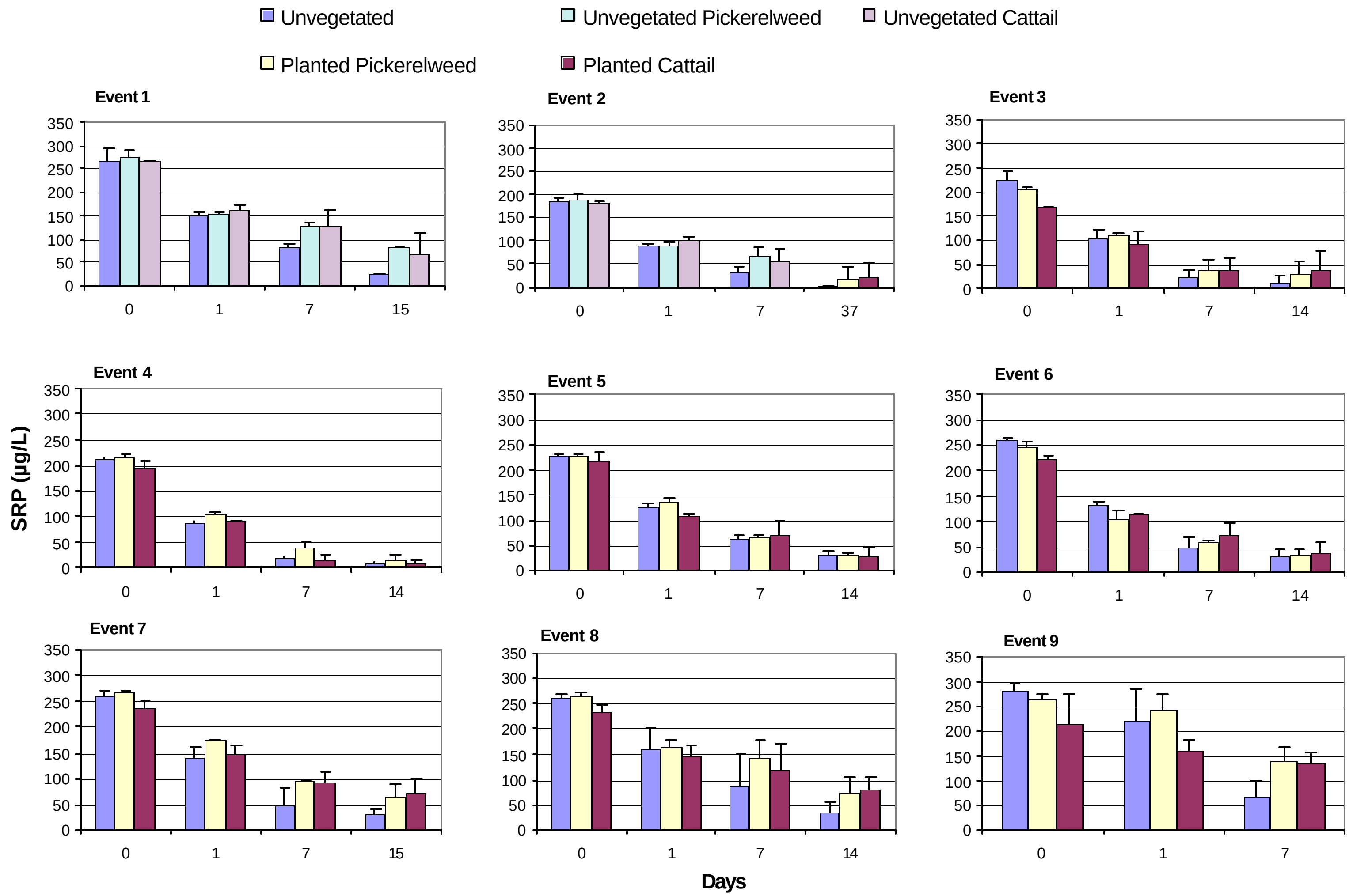
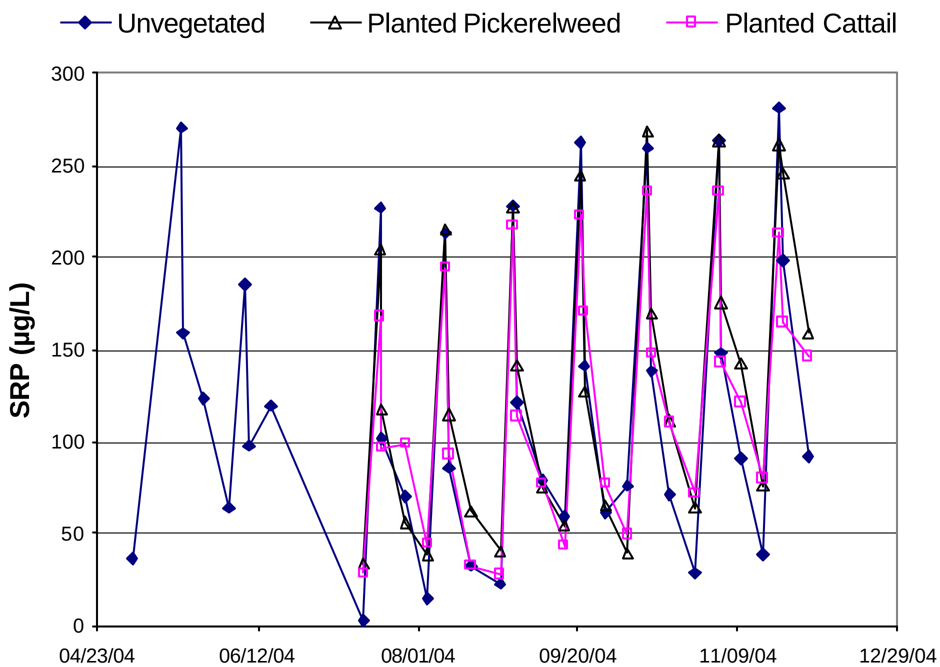


Figure 105. Littoral SRP concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

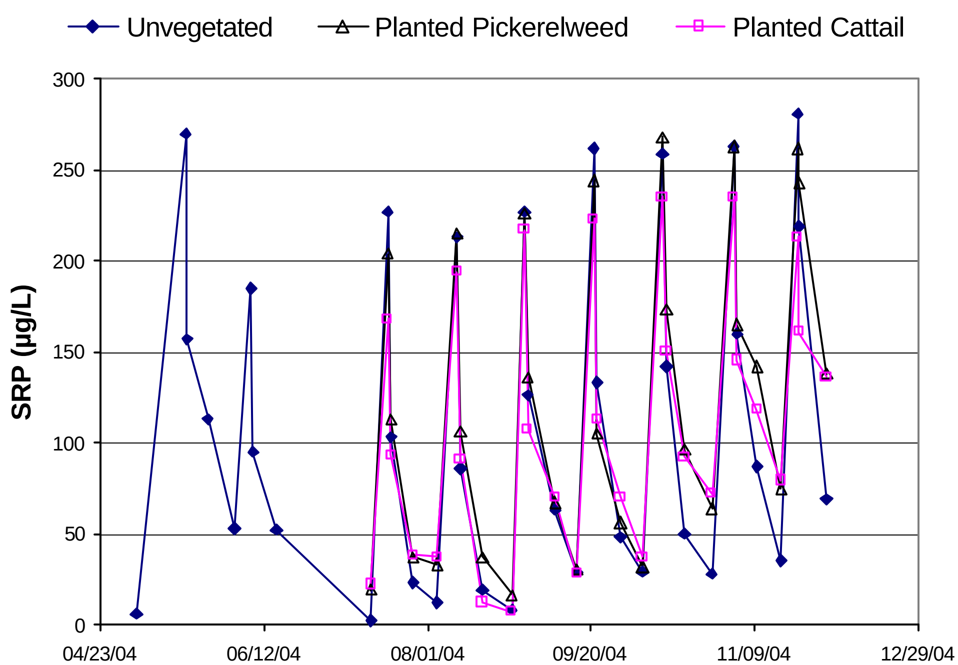


Figure 106. SRP concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

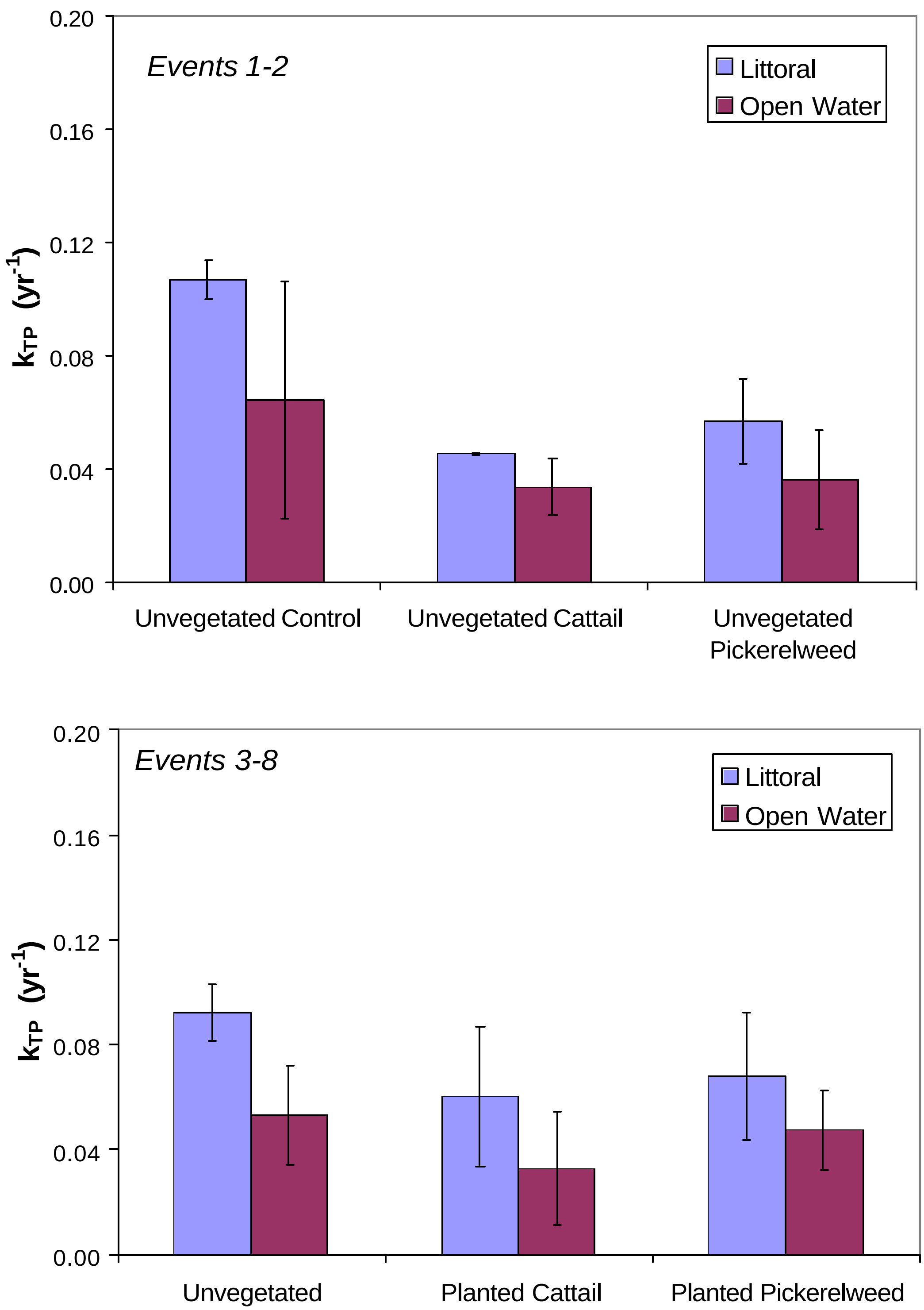


Figure 107. Mean calculated k values for TP for events 1 – 2 and events 3 – 8 in unvegetated, planted cattail and planted pickerelweed compartments.

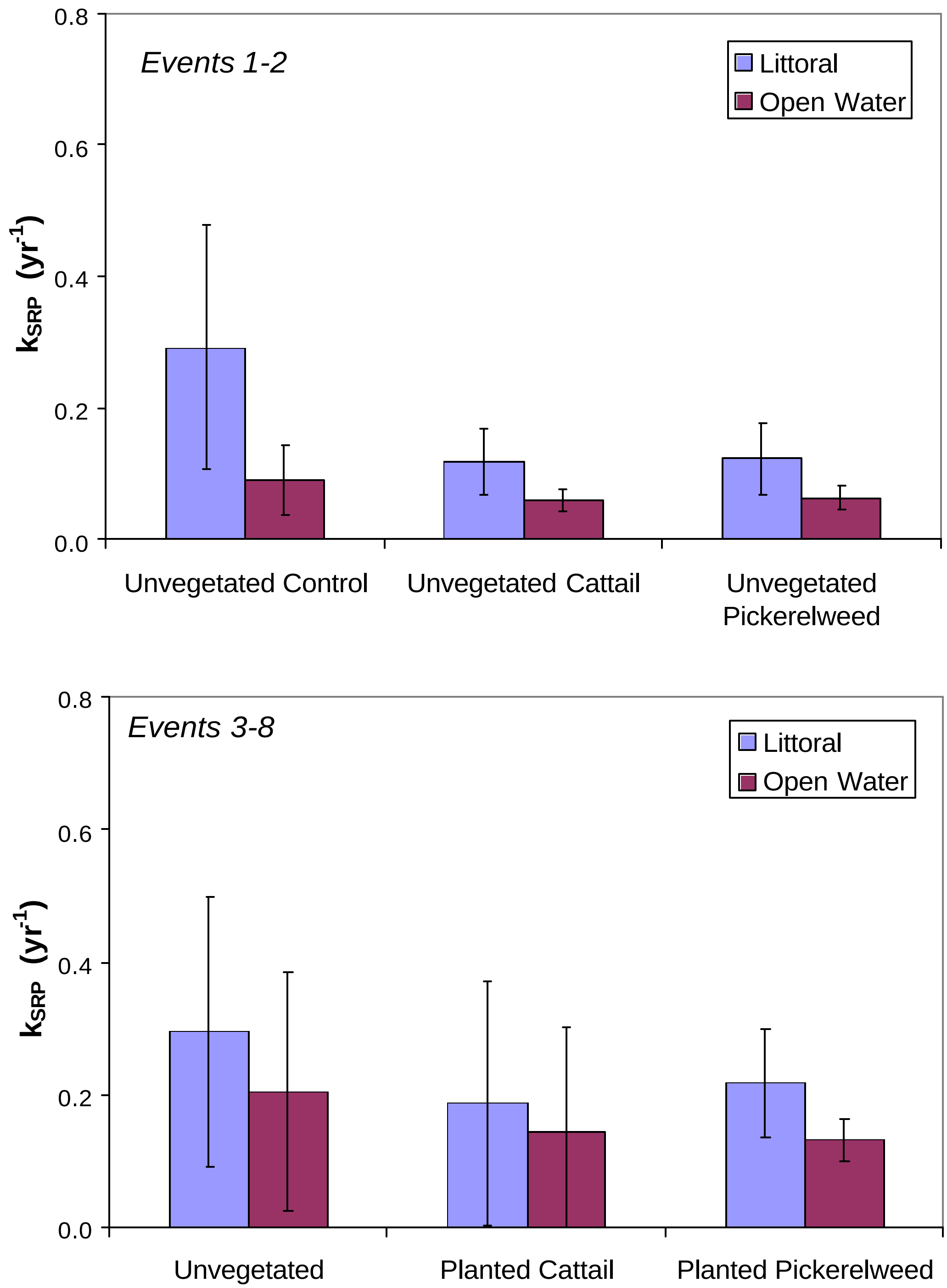


Figure 108. Mean calculated k values for SRP for events 1 – 2 and events 3 – 8 in unvegetated, planted cattail and planted pickerelweed compartments.

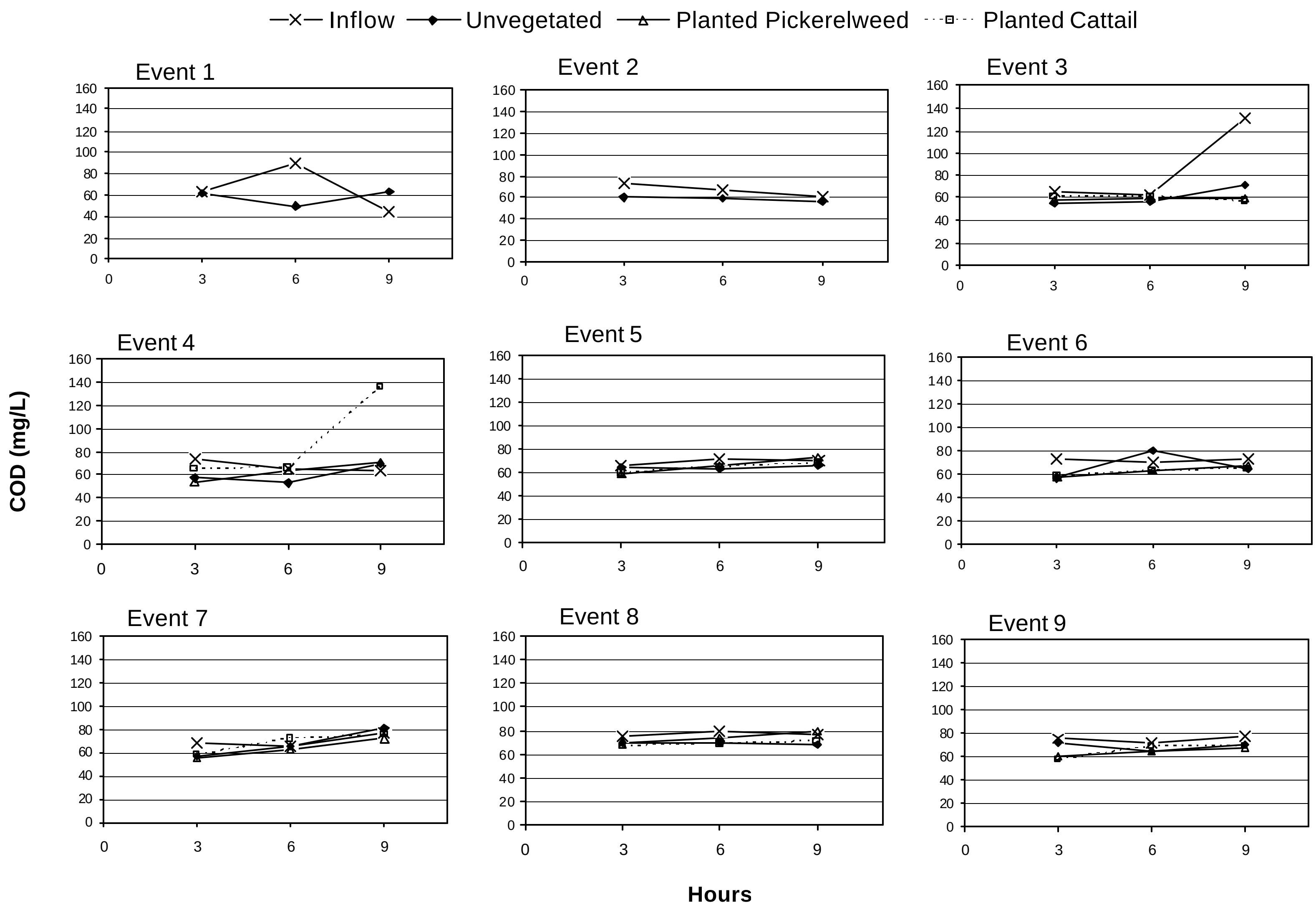
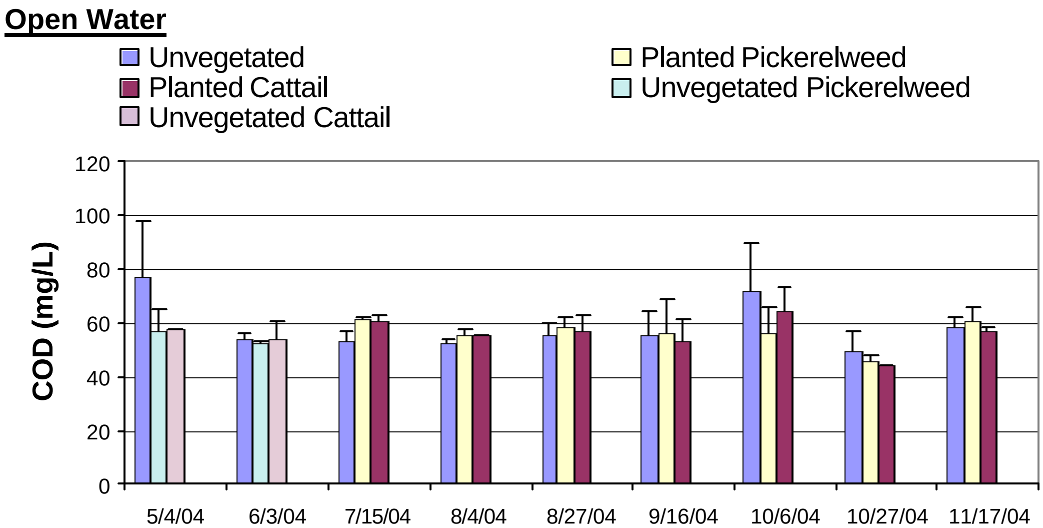


Figure 109. Inflow and outflow COD concentrations (mg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.



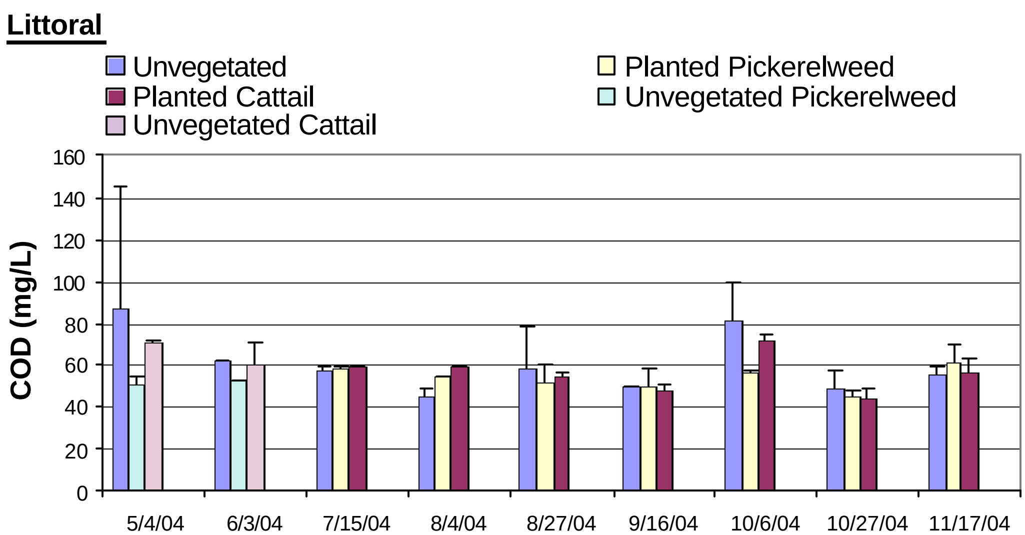


Figure 110. Open water and littoral COD concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

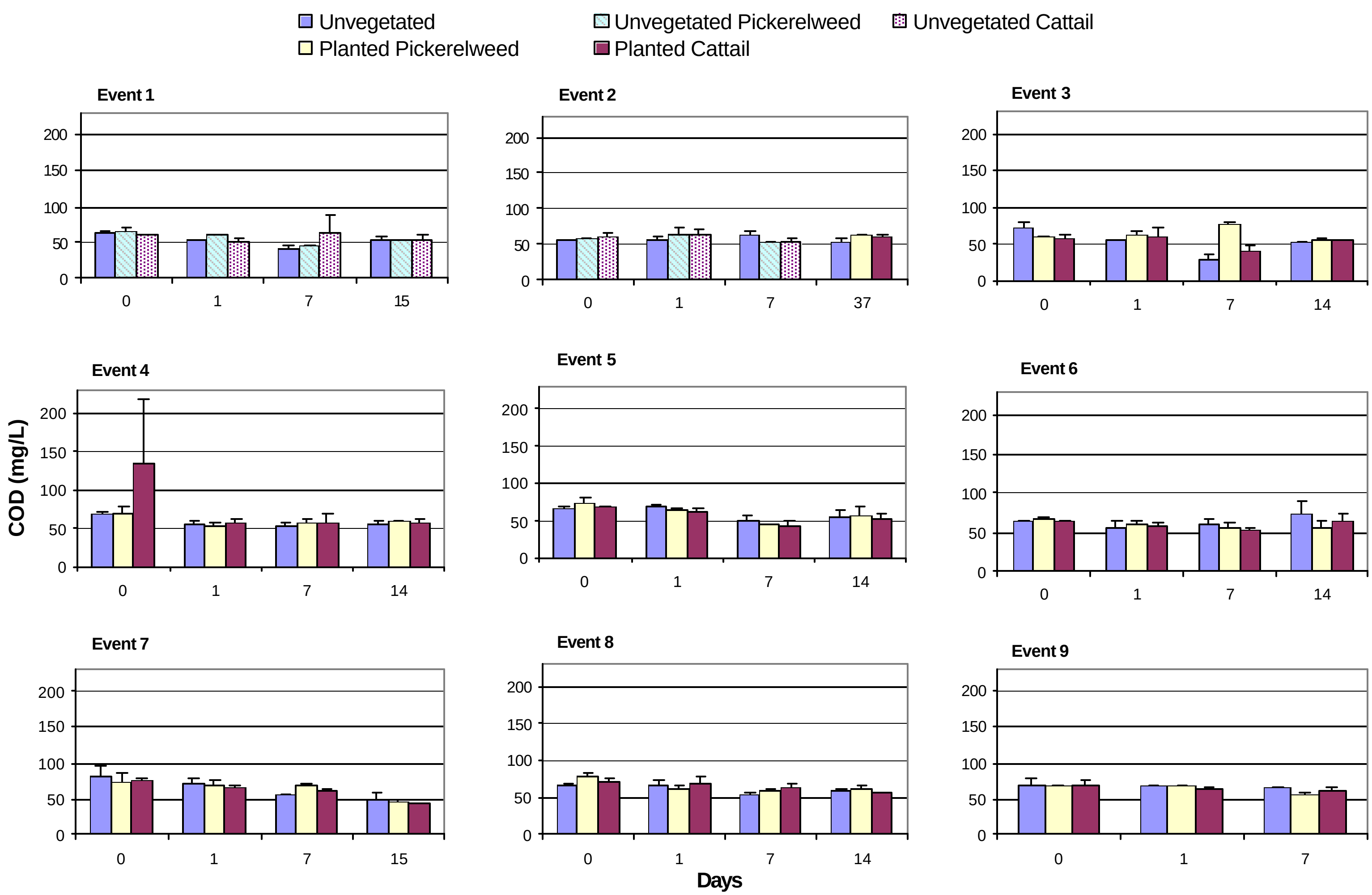


Figure 111. Open water COD concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

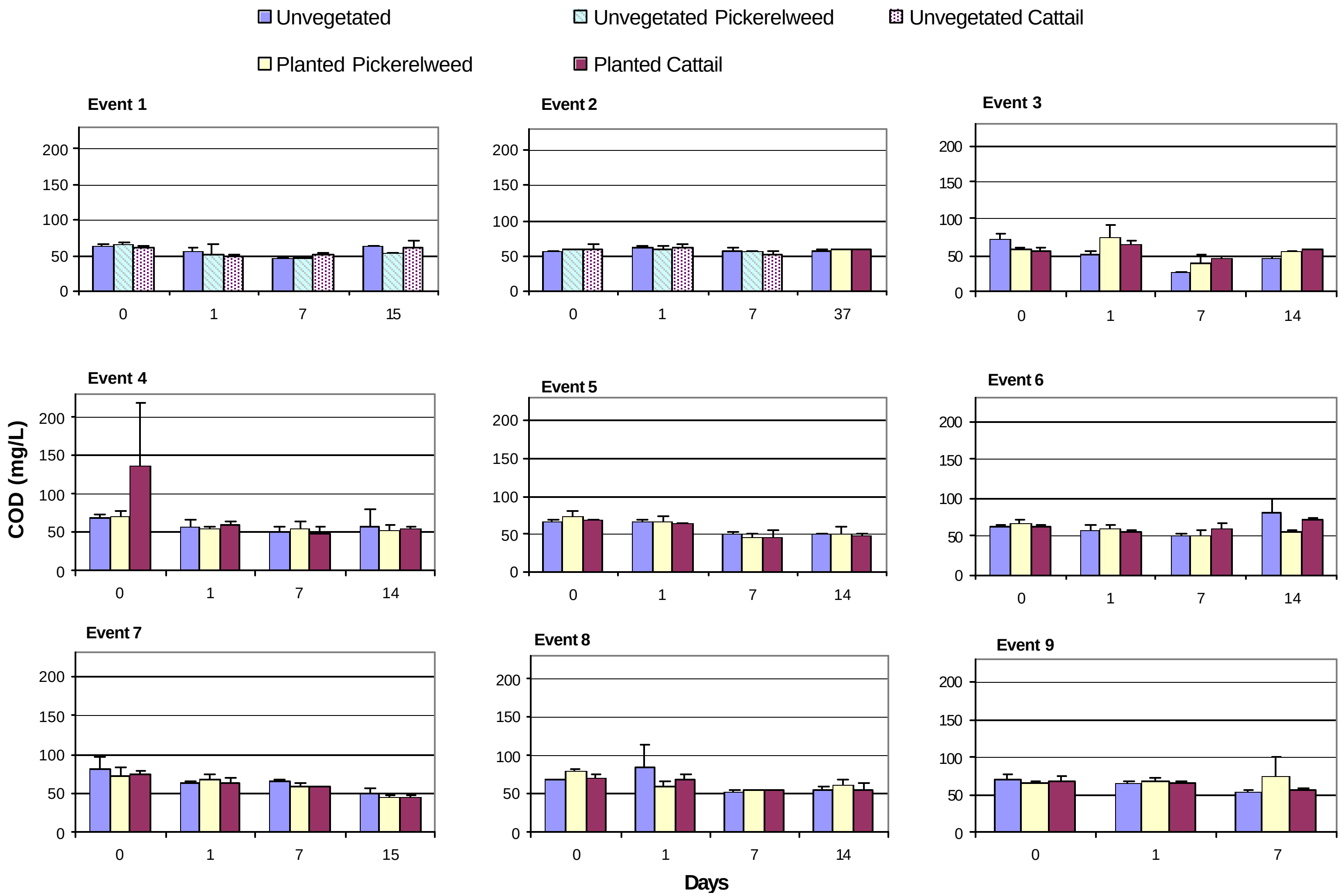
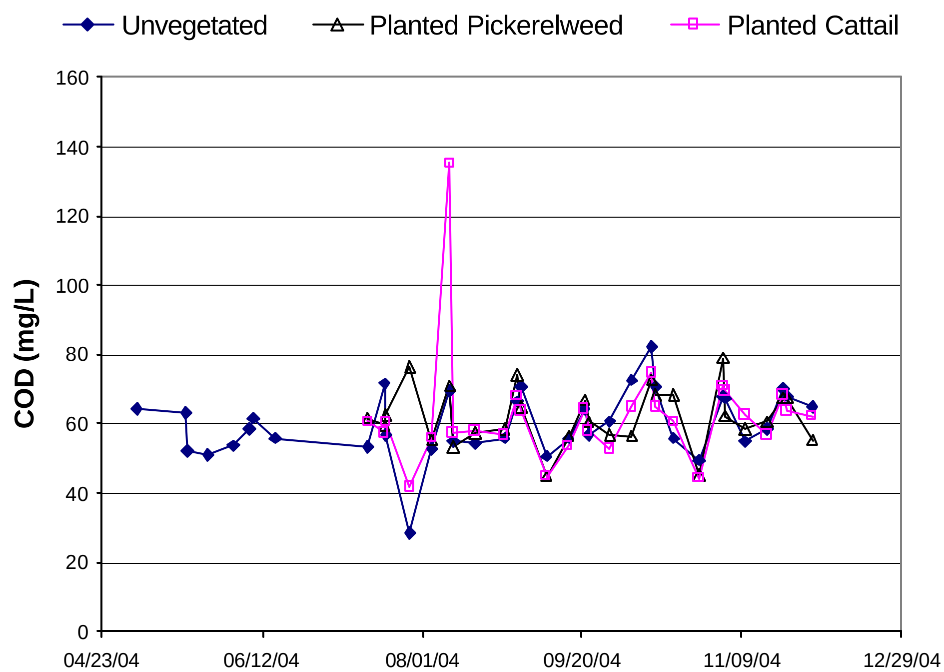


Figure 112. Littoral COD concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

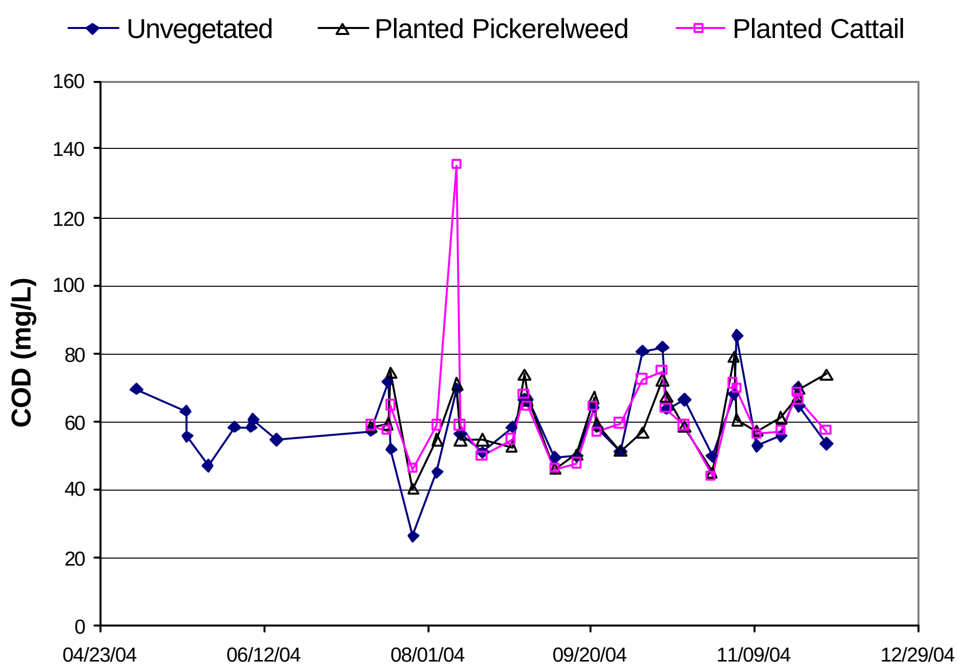


Figure 113. COD concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

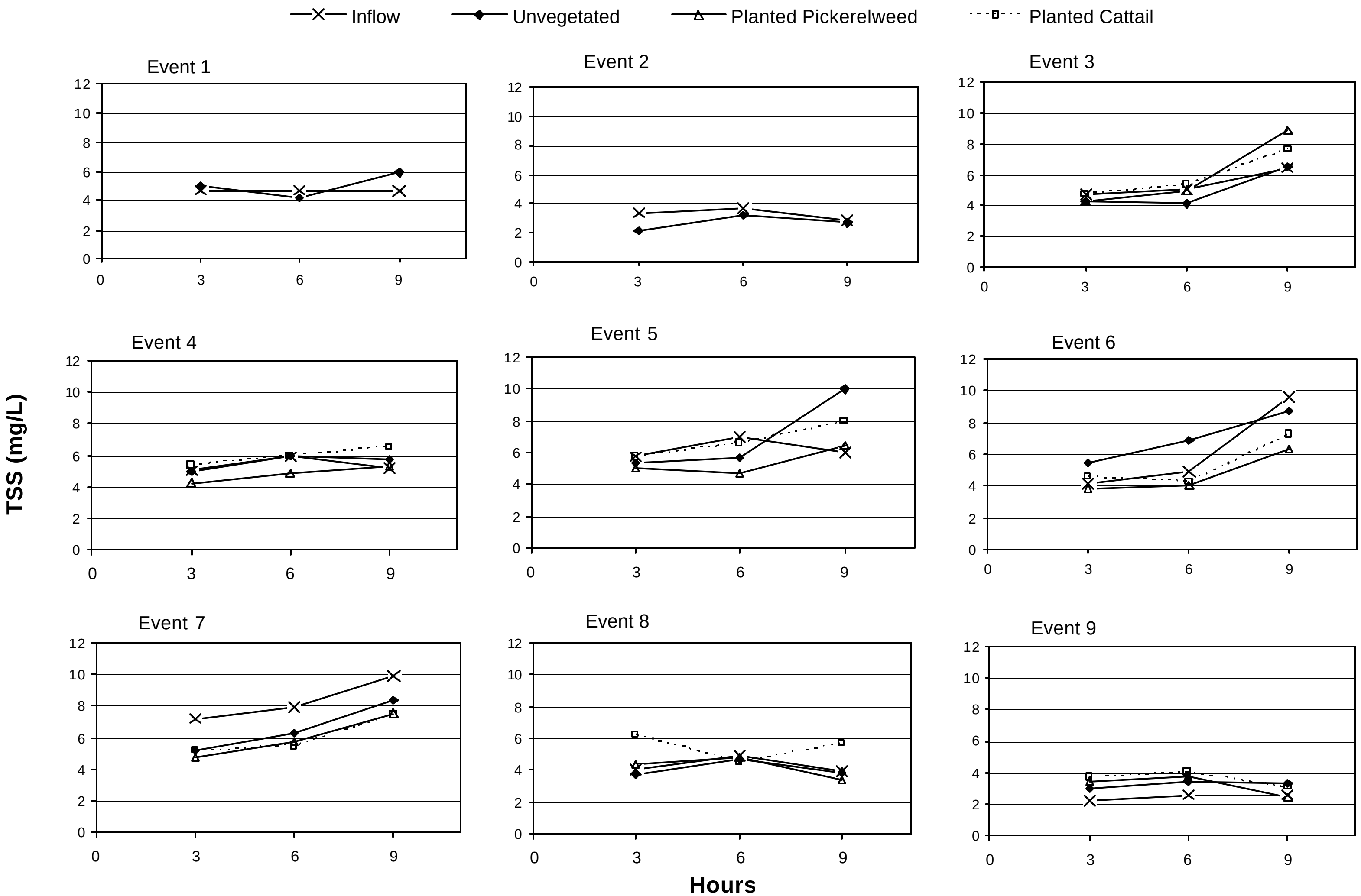
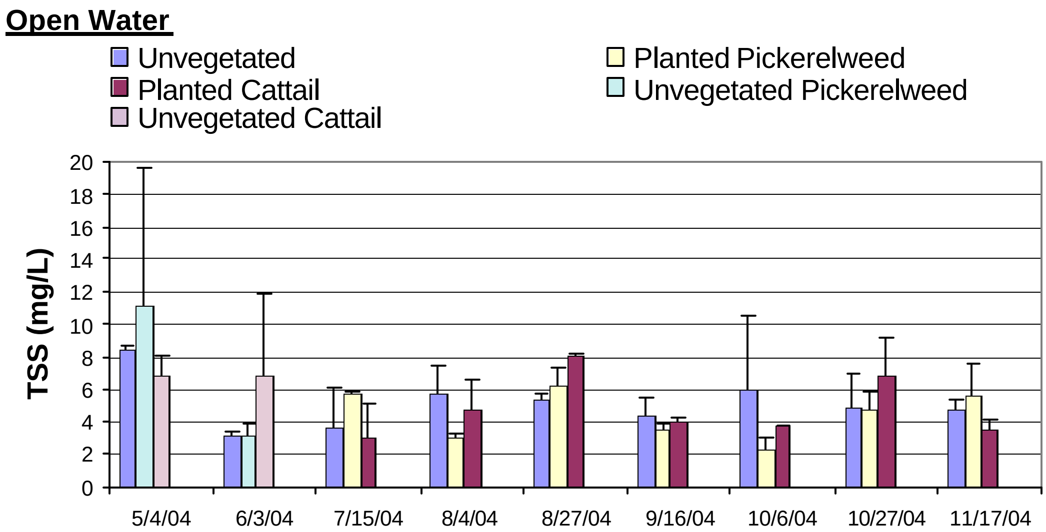


Figure 114. Inflow and outflow TSS concentrations (mg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.



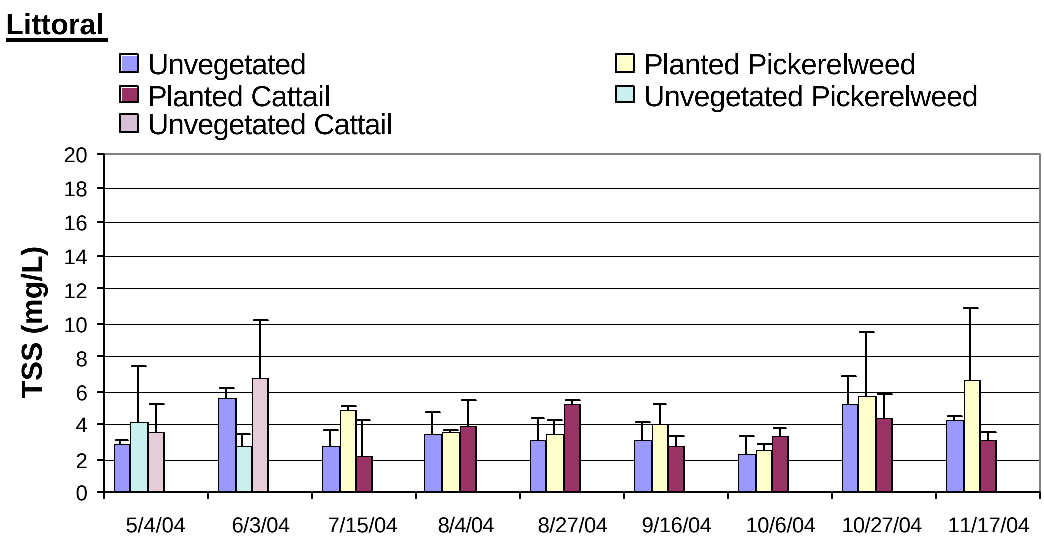


Figure 115. Open water and littoral TSS concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

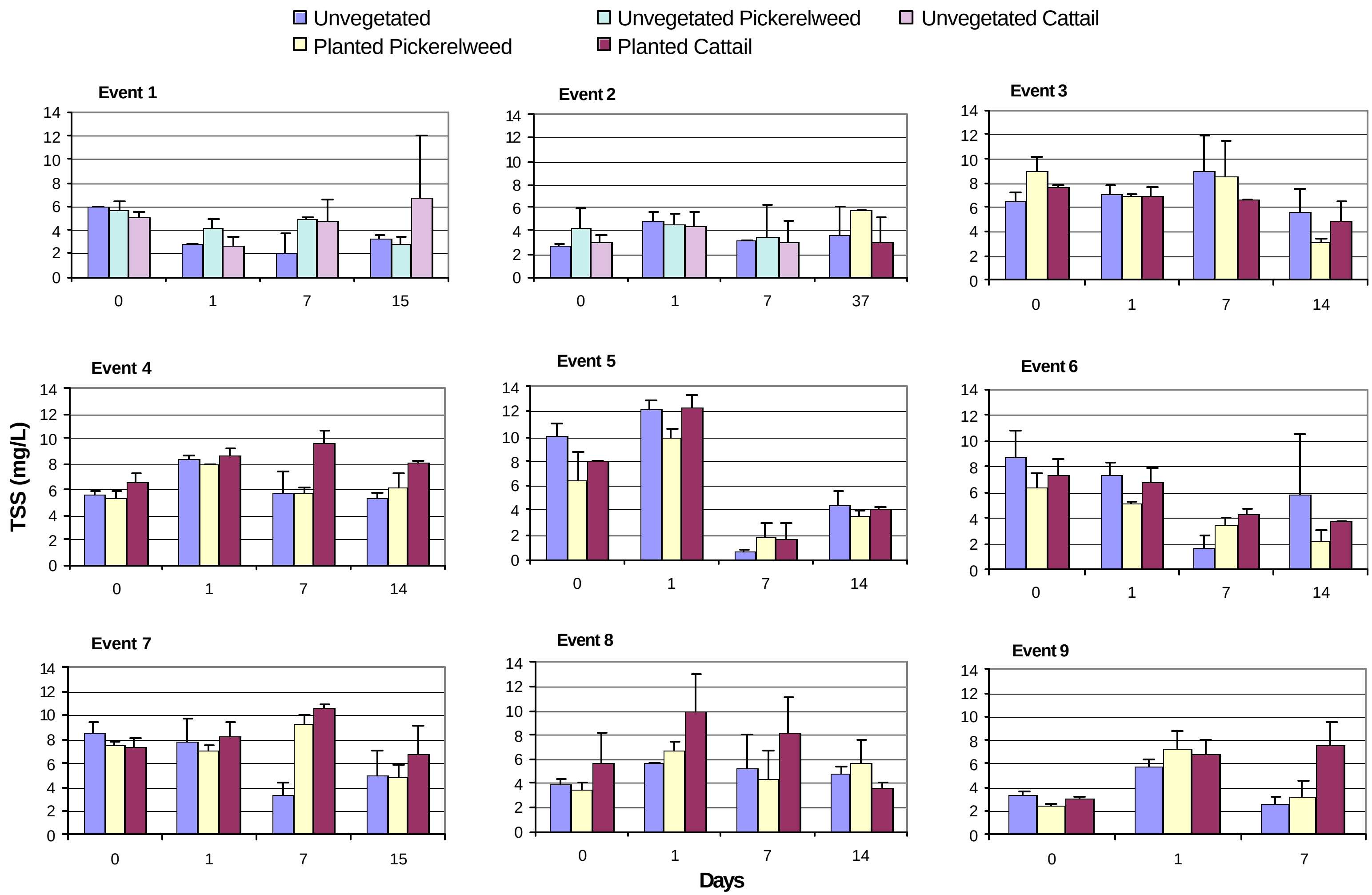


Figure 116. Open water TSS concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

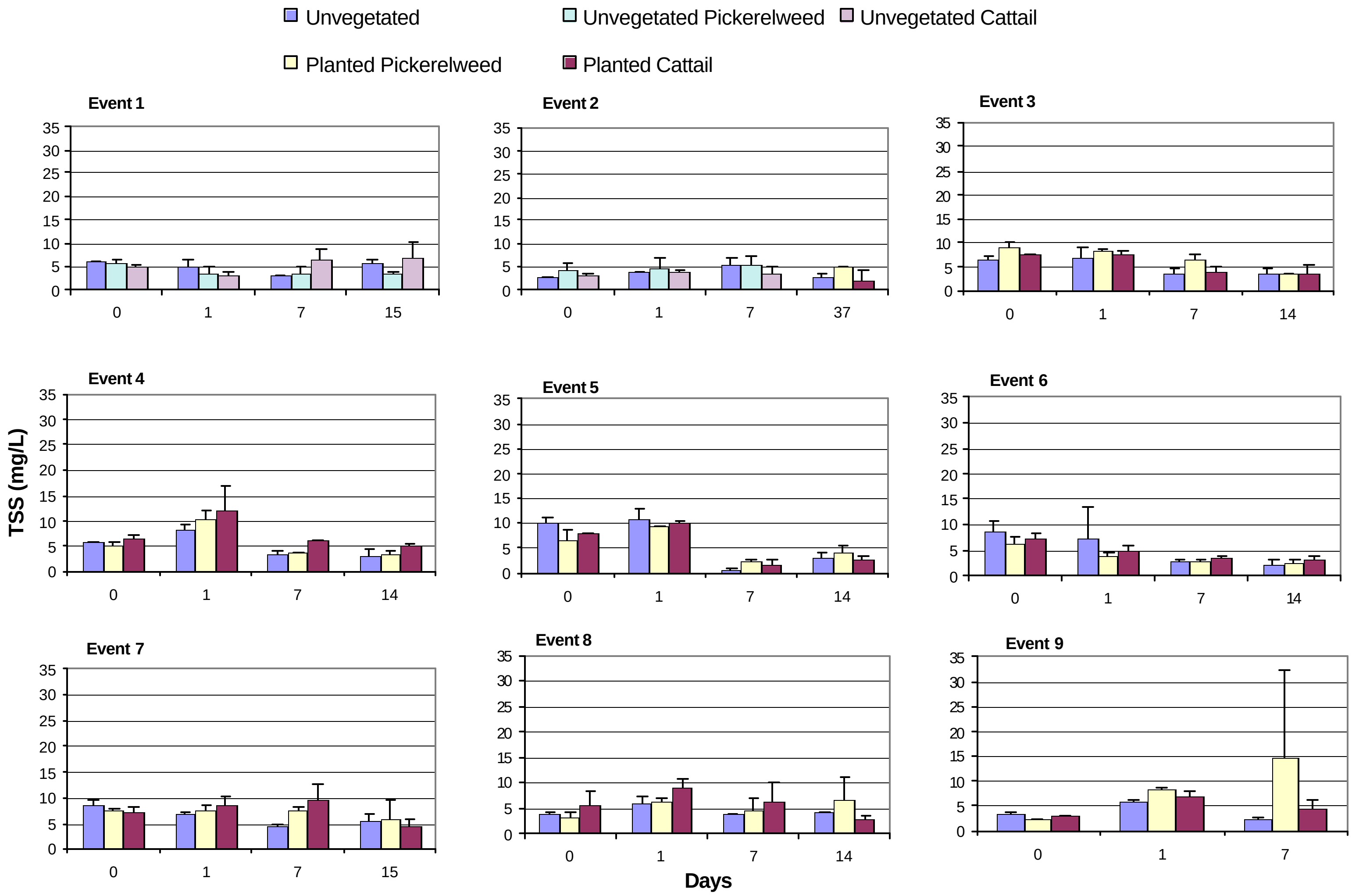
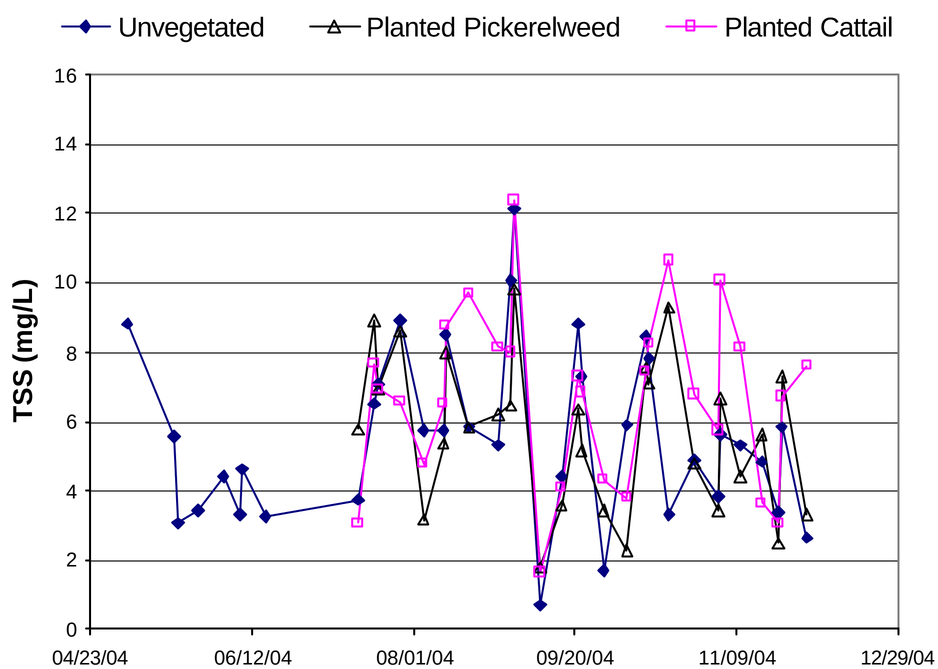


Figure 117. Littoral TSS concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

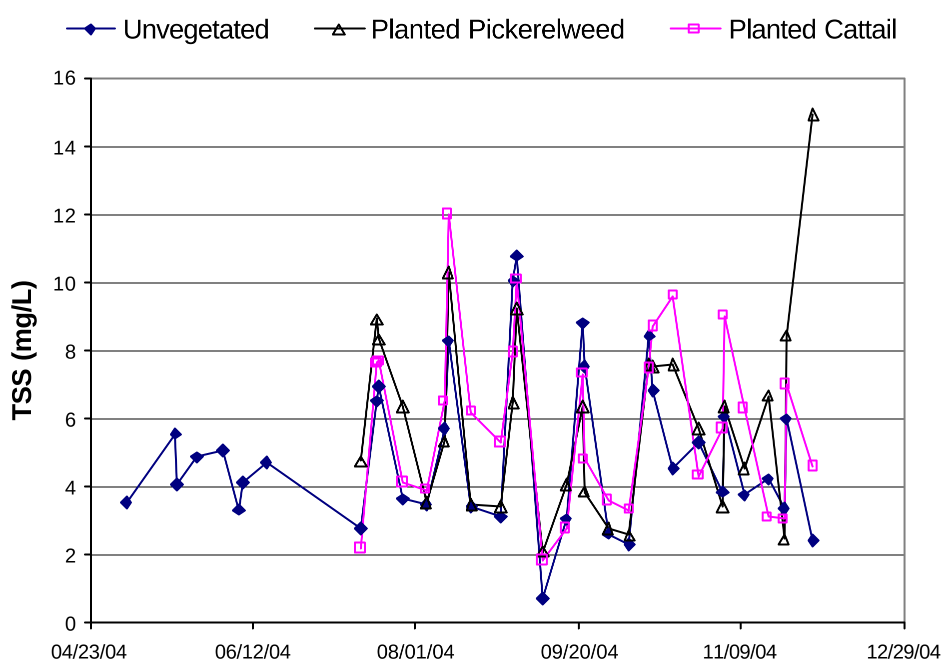


Figure 118. TSS concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

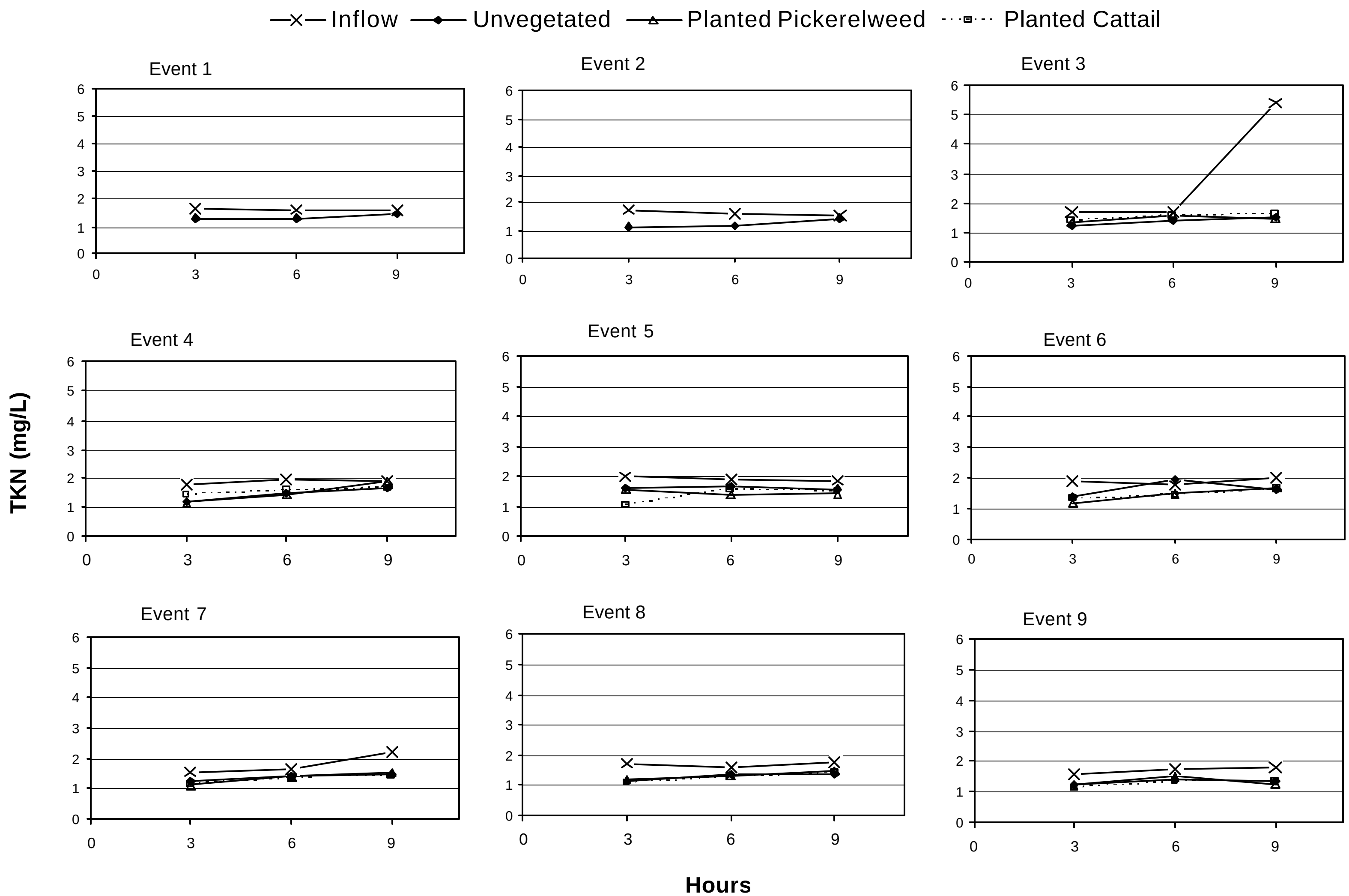
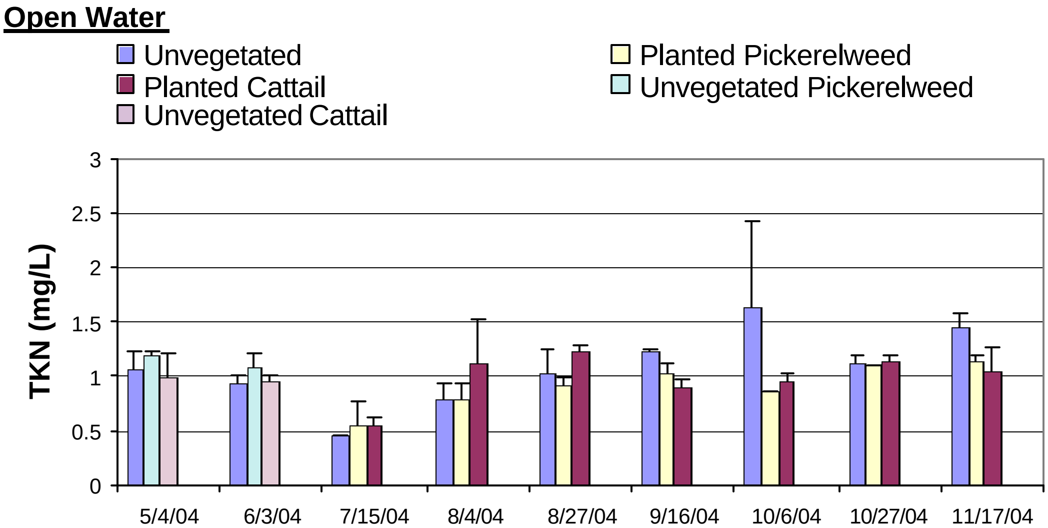


Figure 119. Inflow and outflow TKN concentrations (mg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.



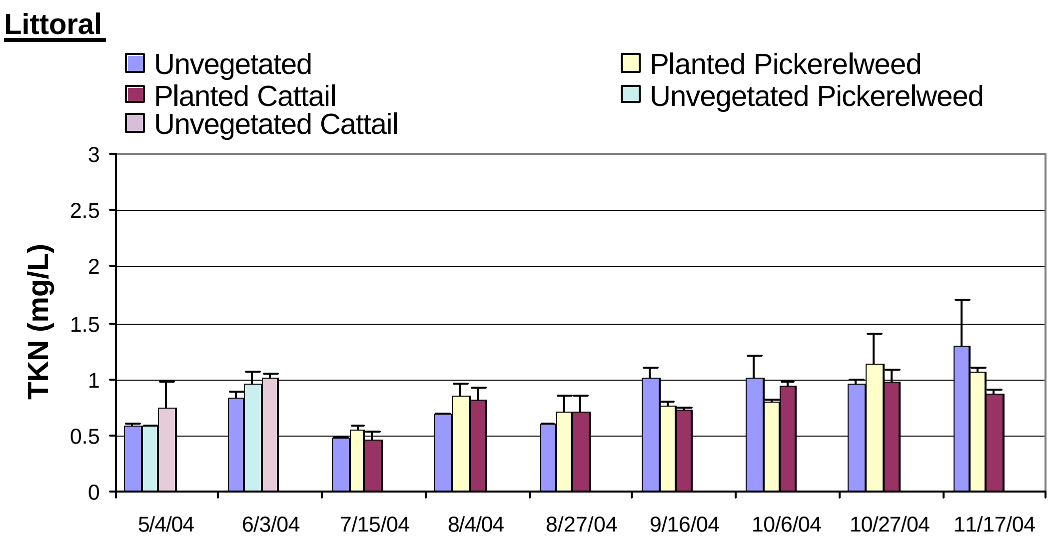


Figure 120. Open water and littoral TKN concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

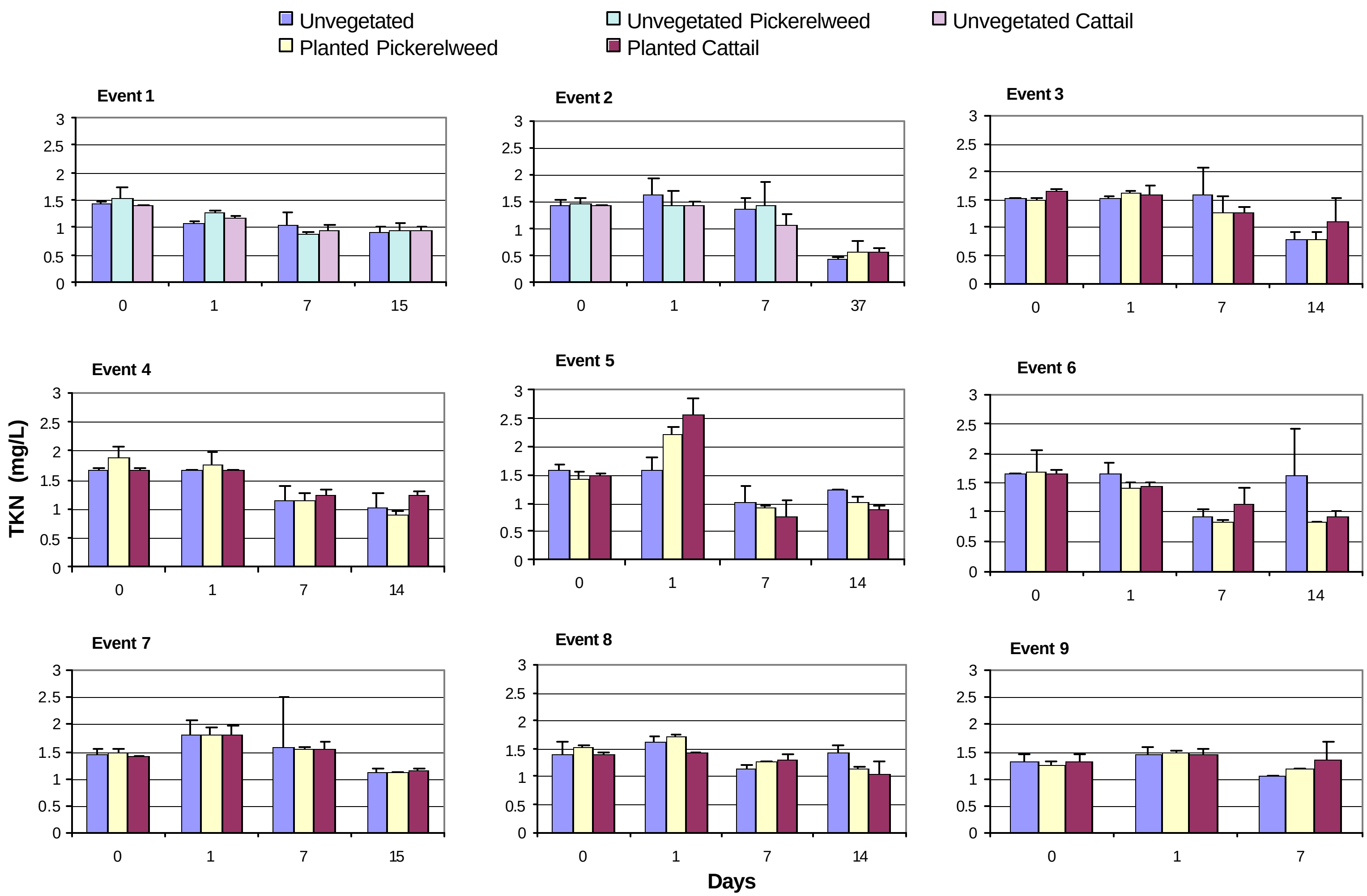


Figure 121. Open water TKN concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

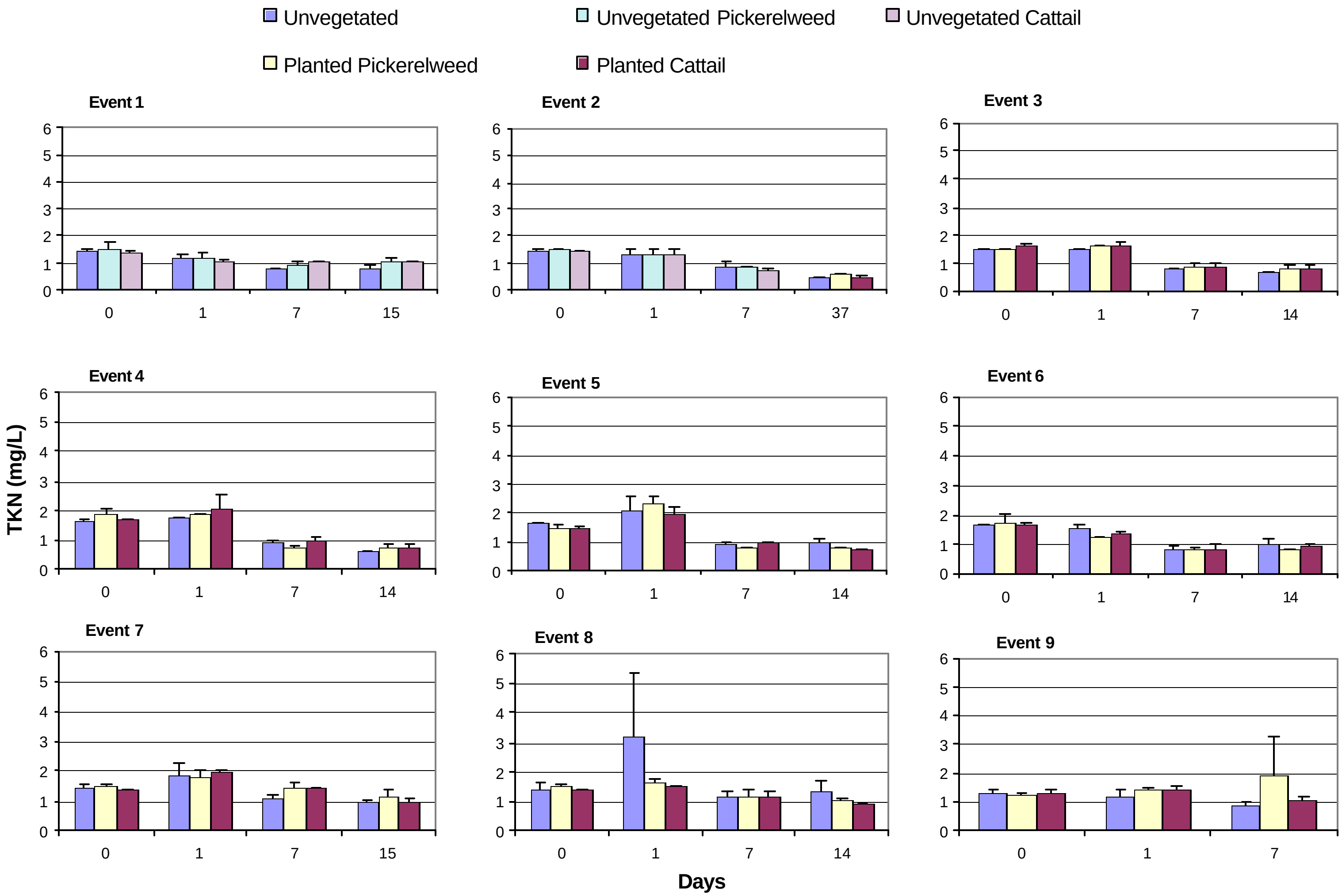
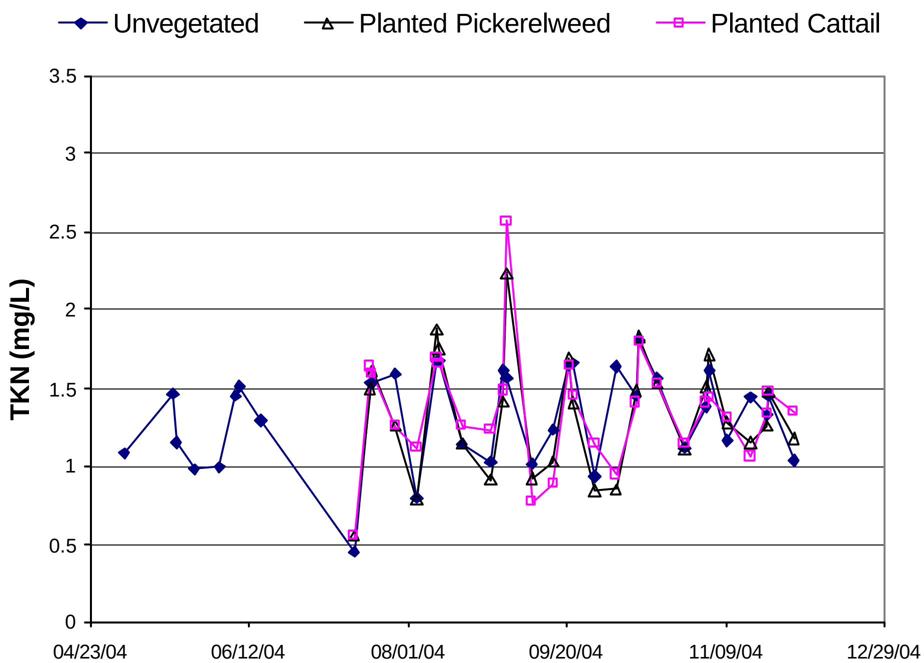


Figure 122. Littoral TKN concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

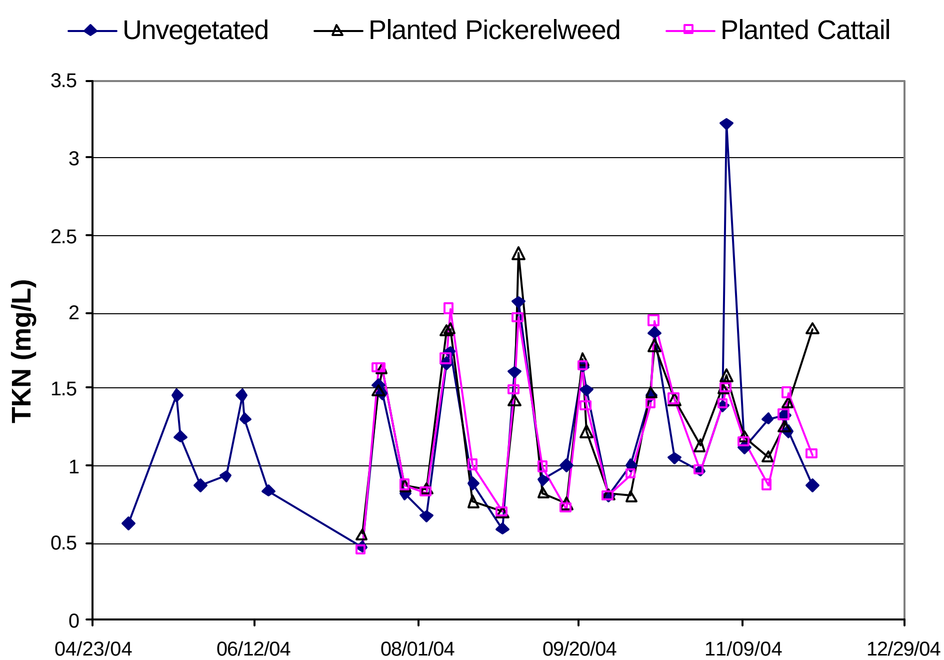


Figure 123. TKN concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

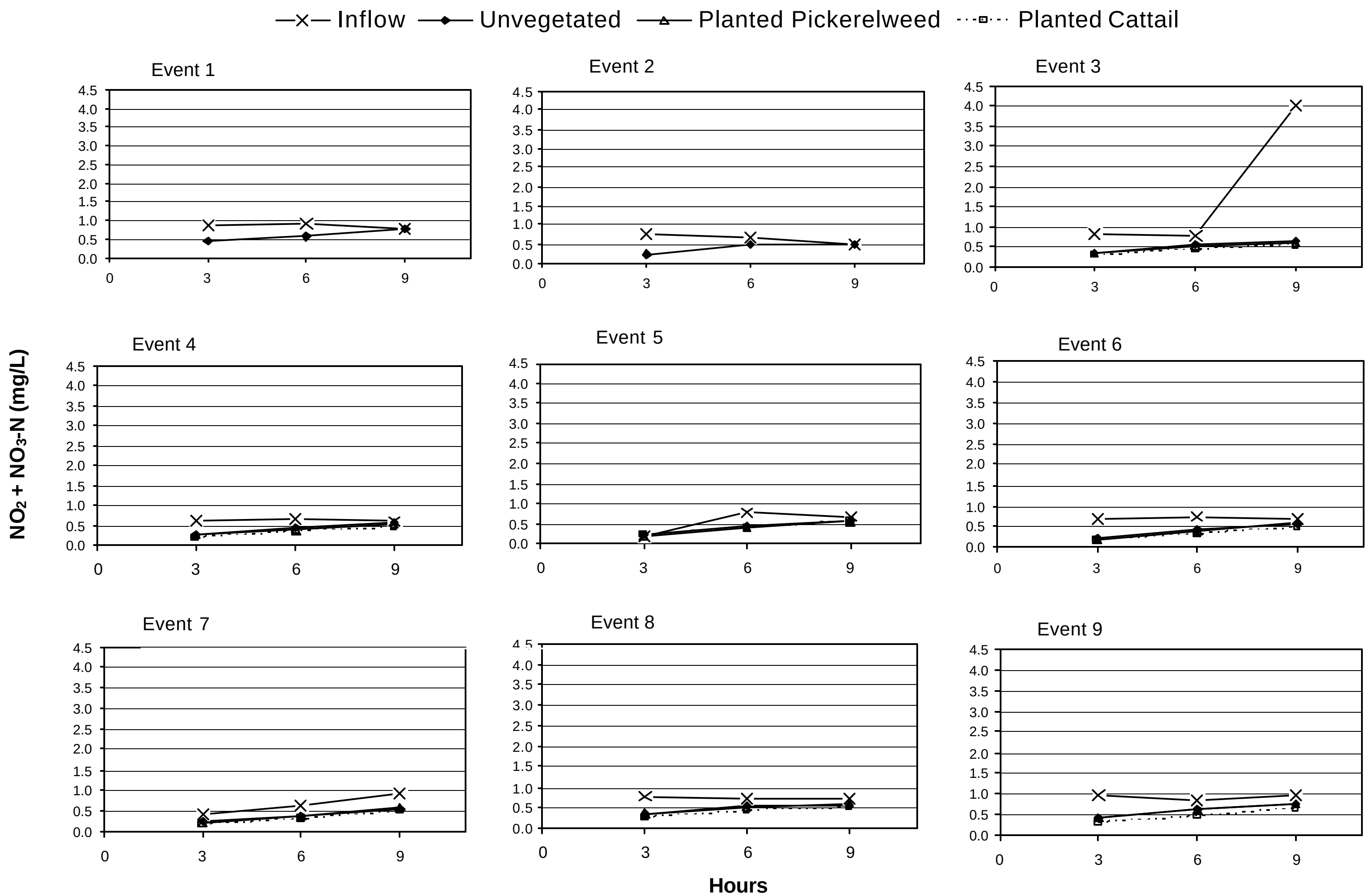


Figure 124. Inflow and outflow $NO_2 + NO_3$-N concentrations (mg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.

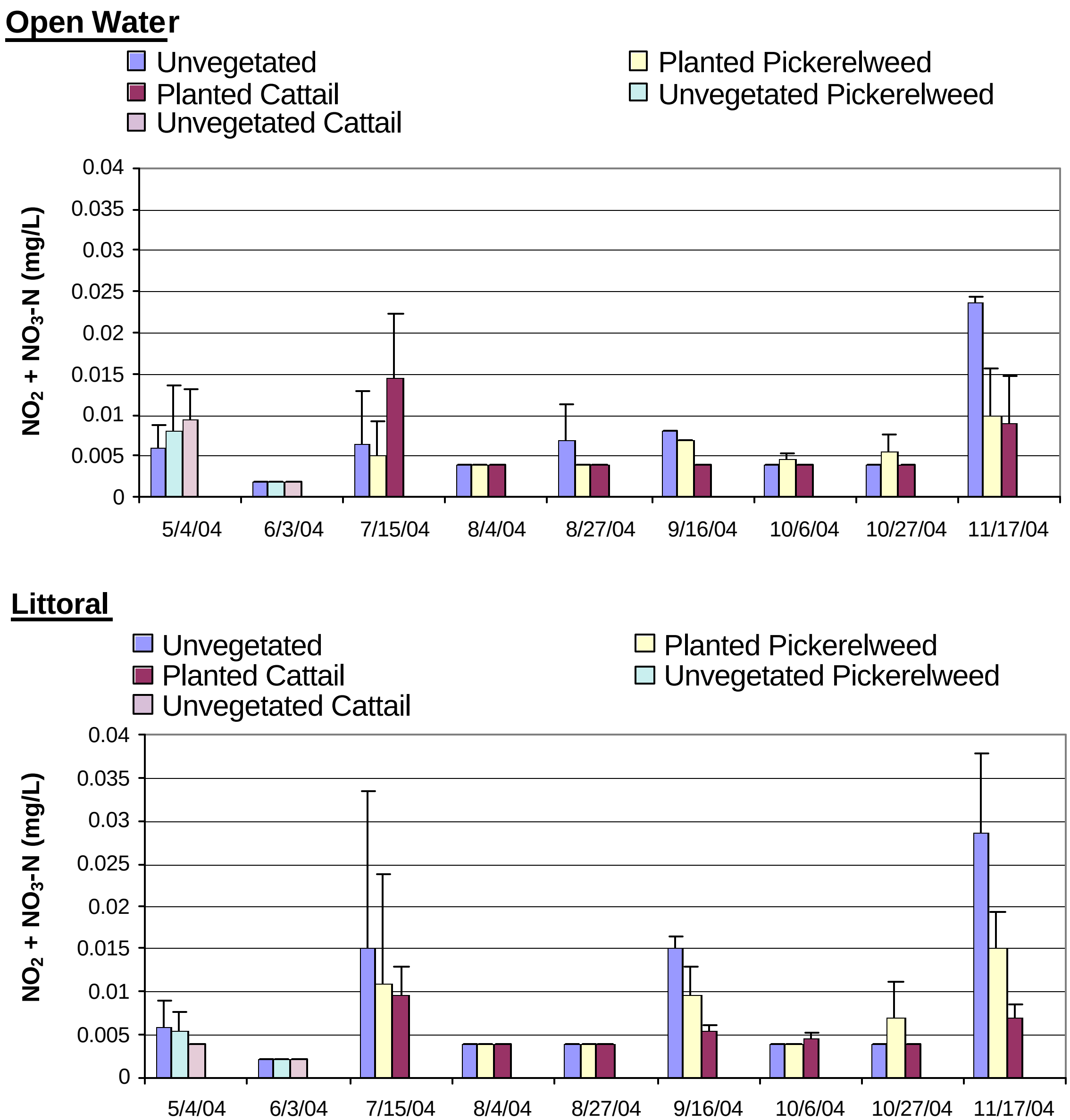


Figure 125. Open water and littoral $NO_2 + NO_3$-N concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

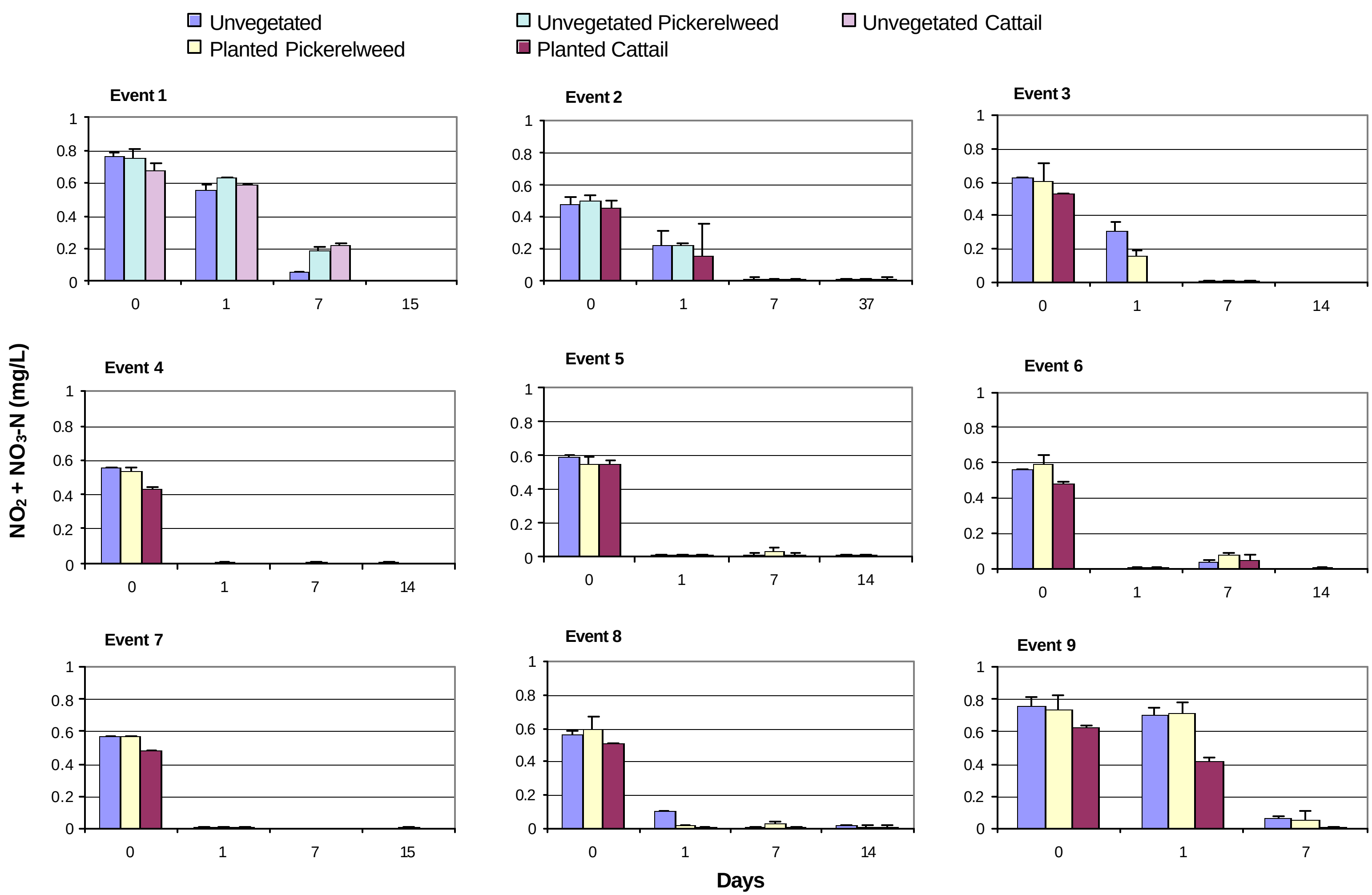


Figure 126. Open water NO_2 + NO_3-N concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

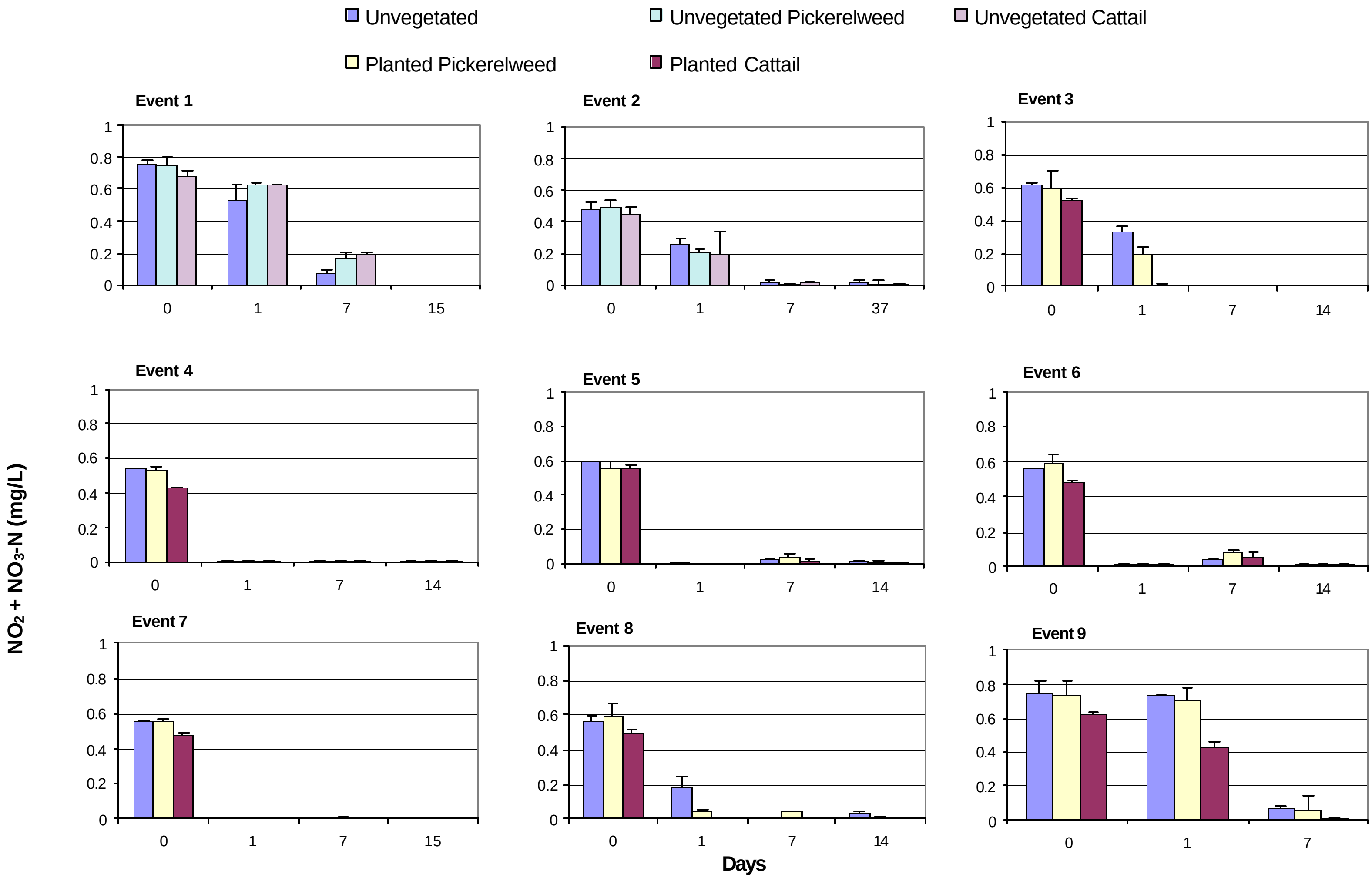
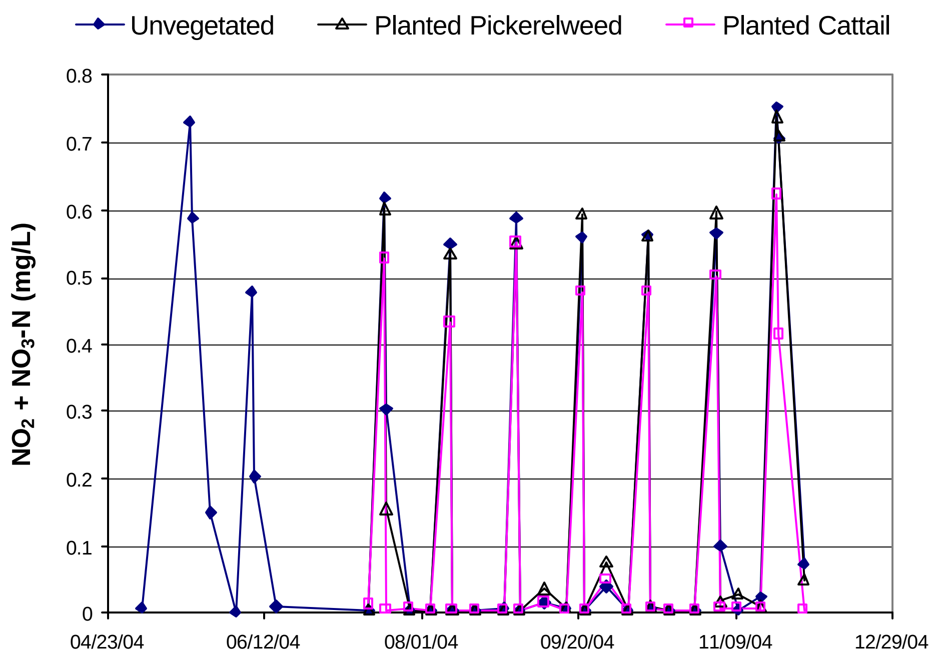


Figure 127. Littoral NO_2 + NO_3-N concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

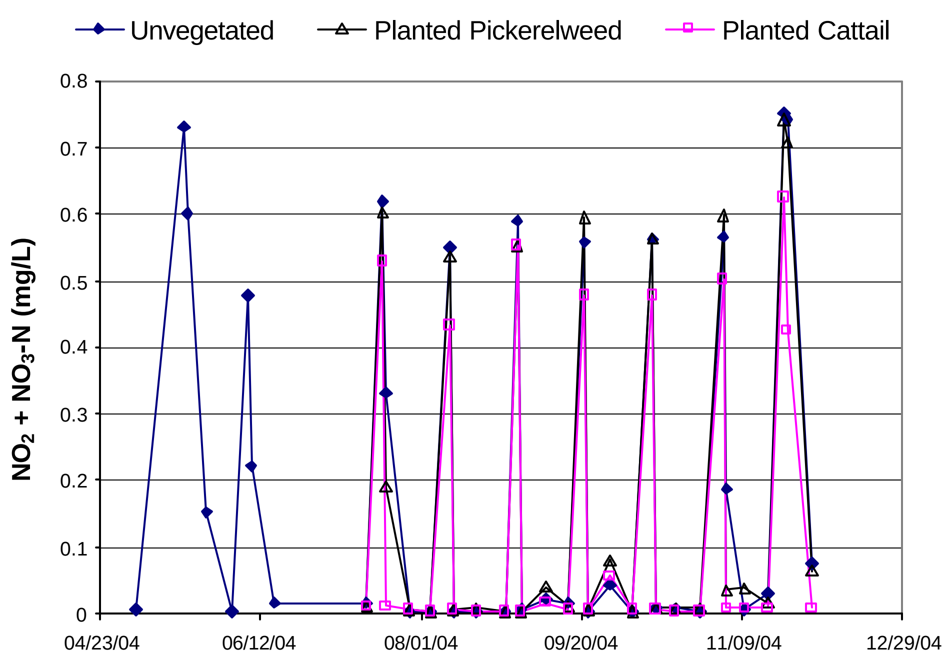


Figure 128. NO_2 + NO_3-N concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed throughout the study.

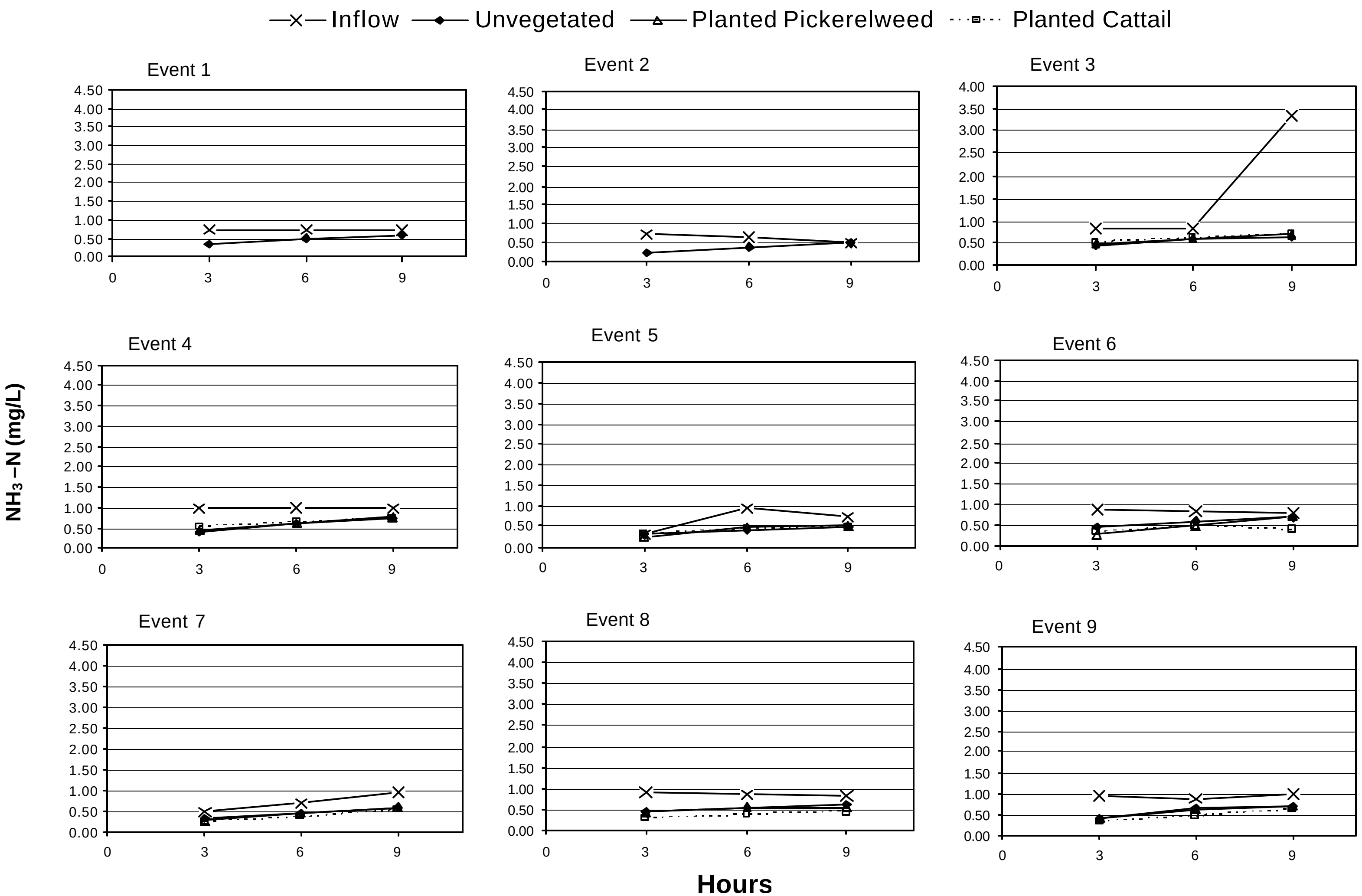
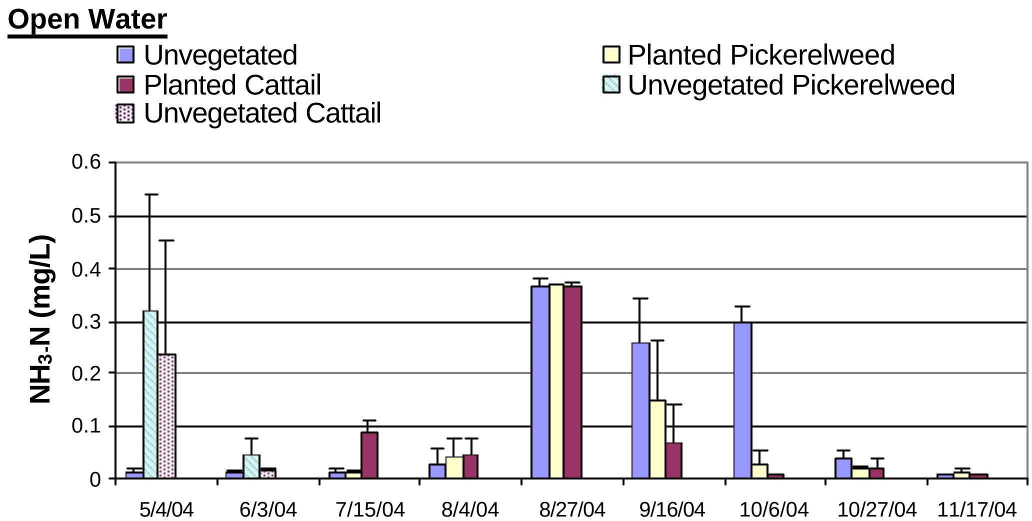


Figure 129. Inflow and outflow NH_3-N concentrations (mg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.



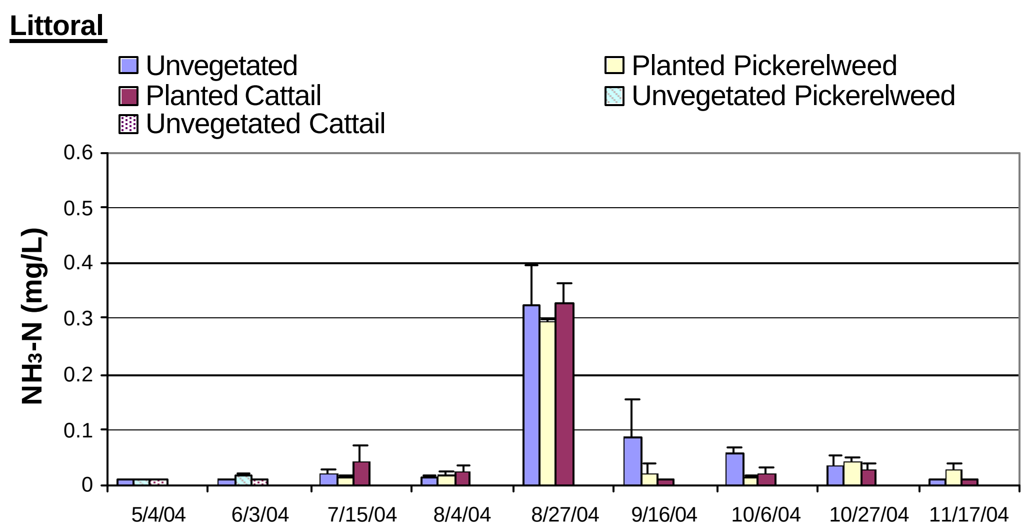


Figure 130. Open water and littoral NH_3-N concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

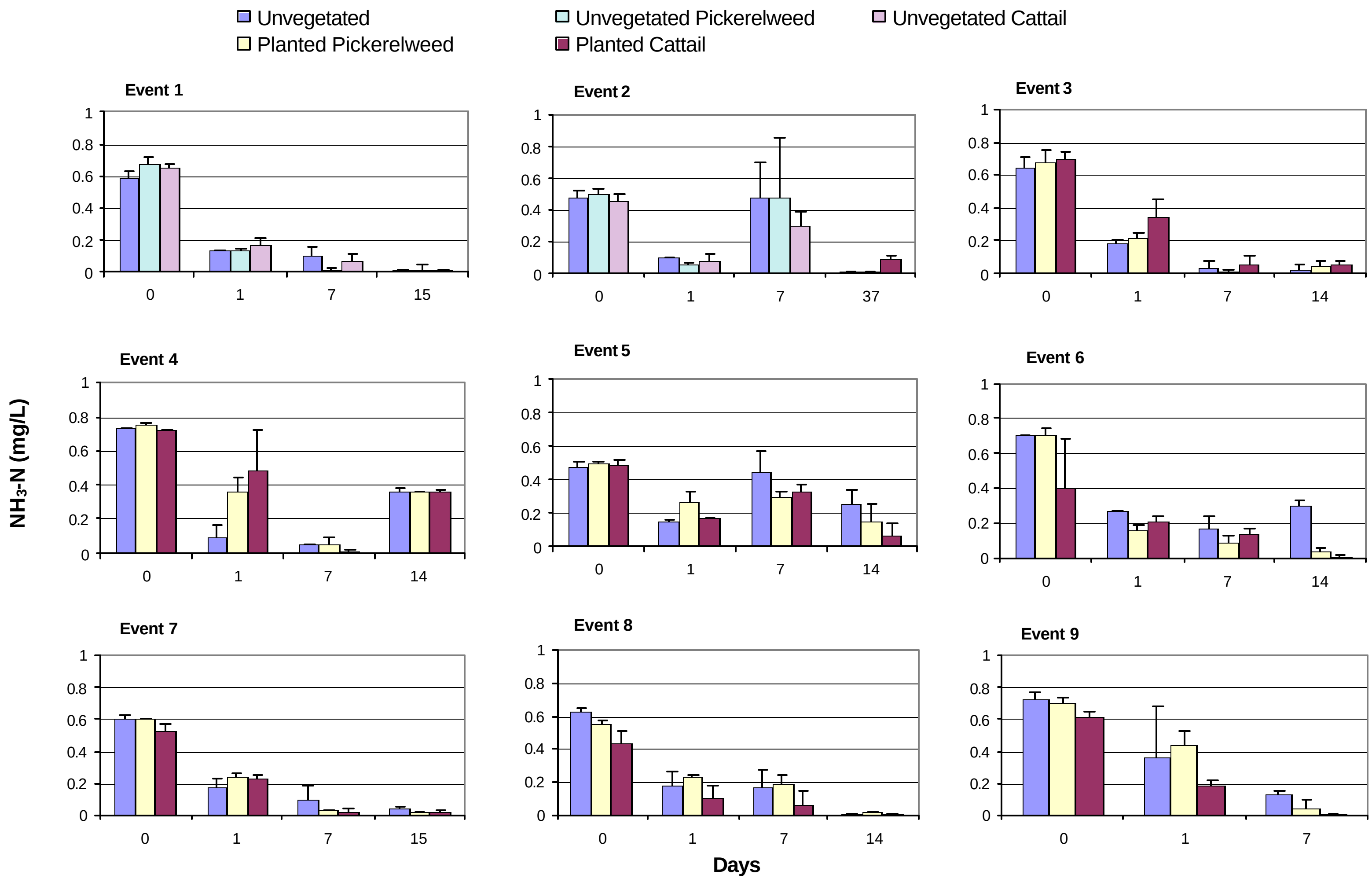


Figure 131. Open water NH_3-N concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

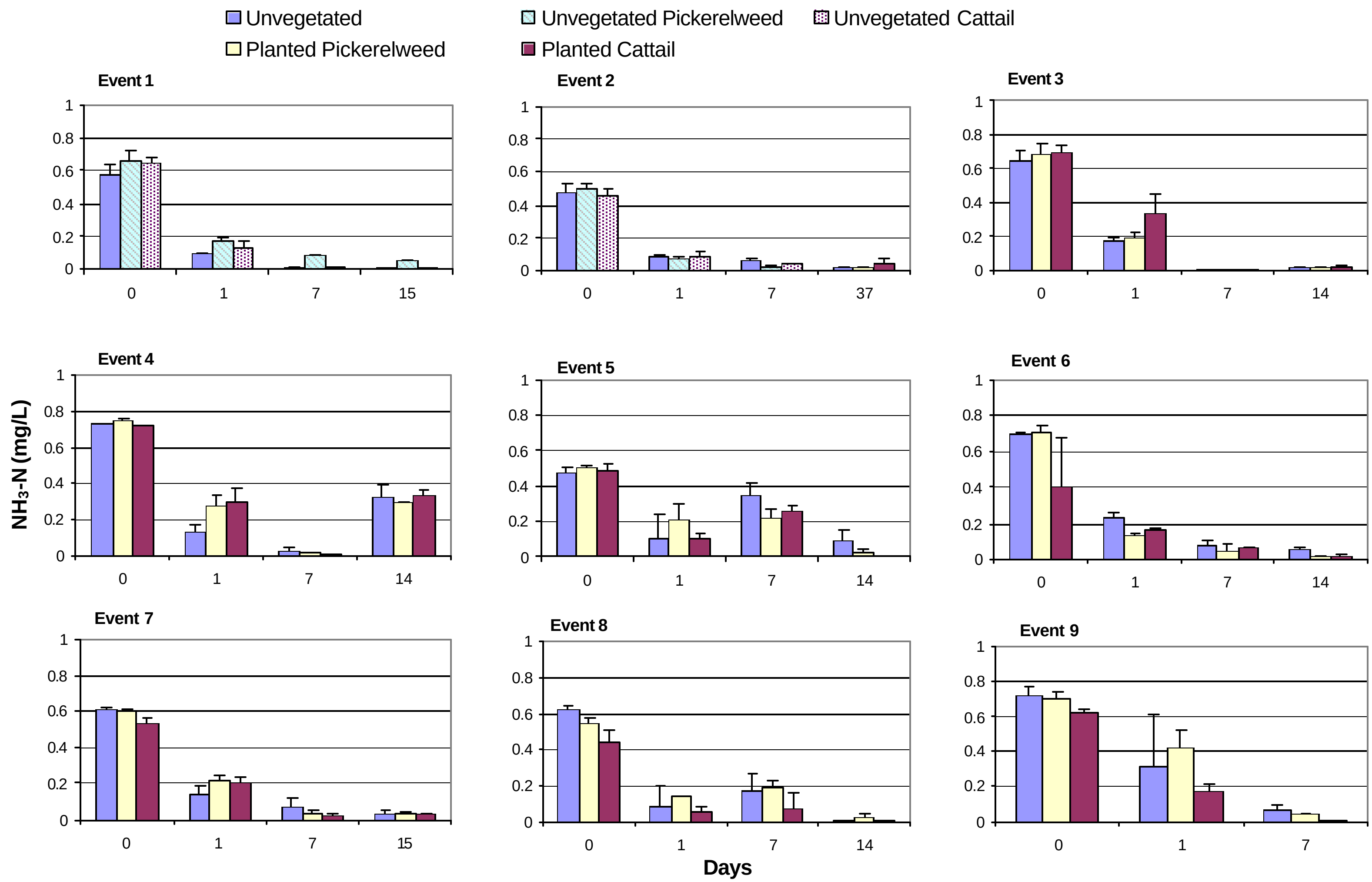
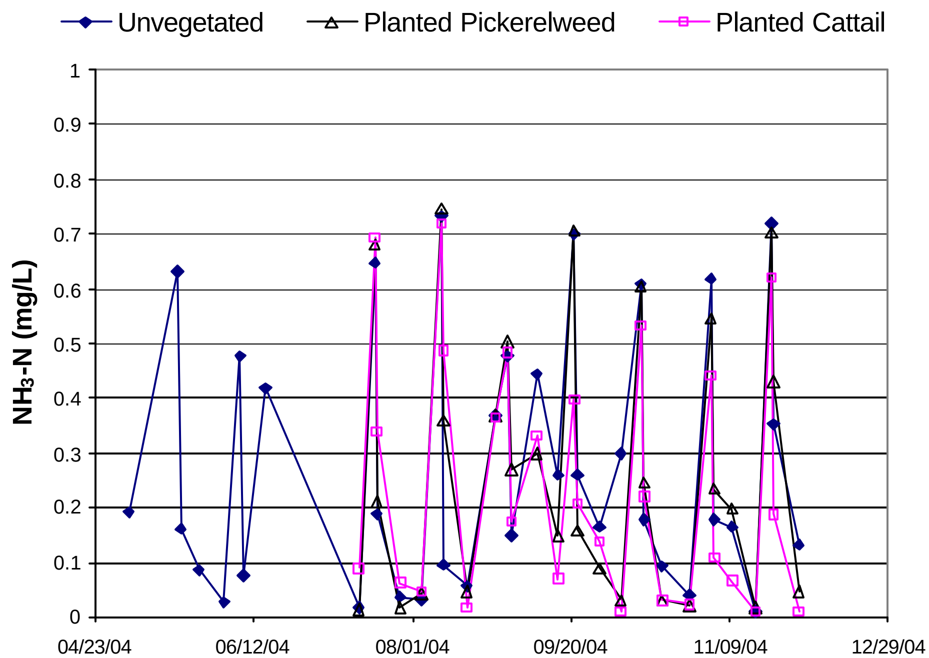


Figure 132. Littoral NH_3-N concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

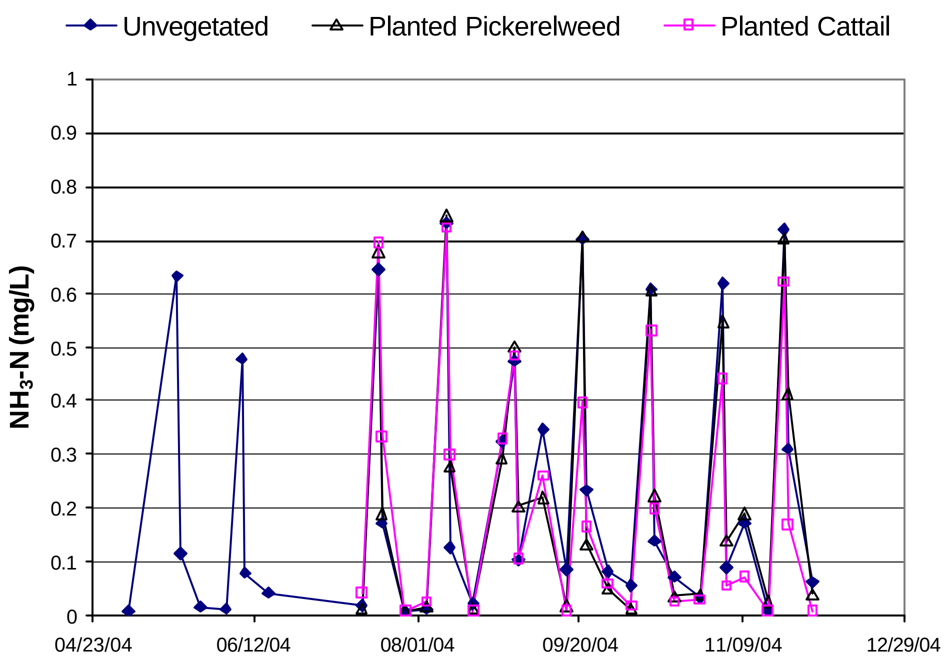


Figure 133. NH_3-N concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

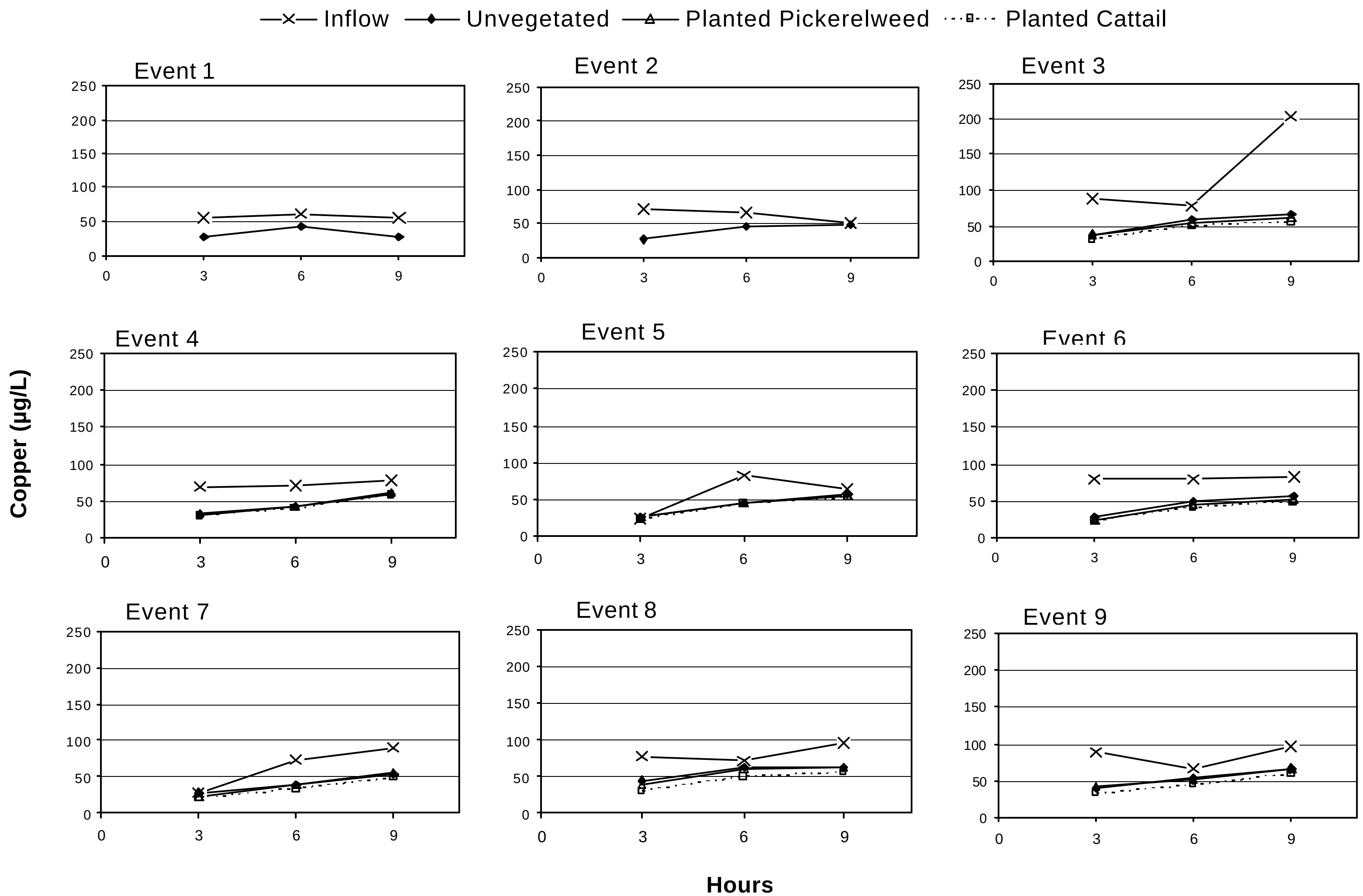
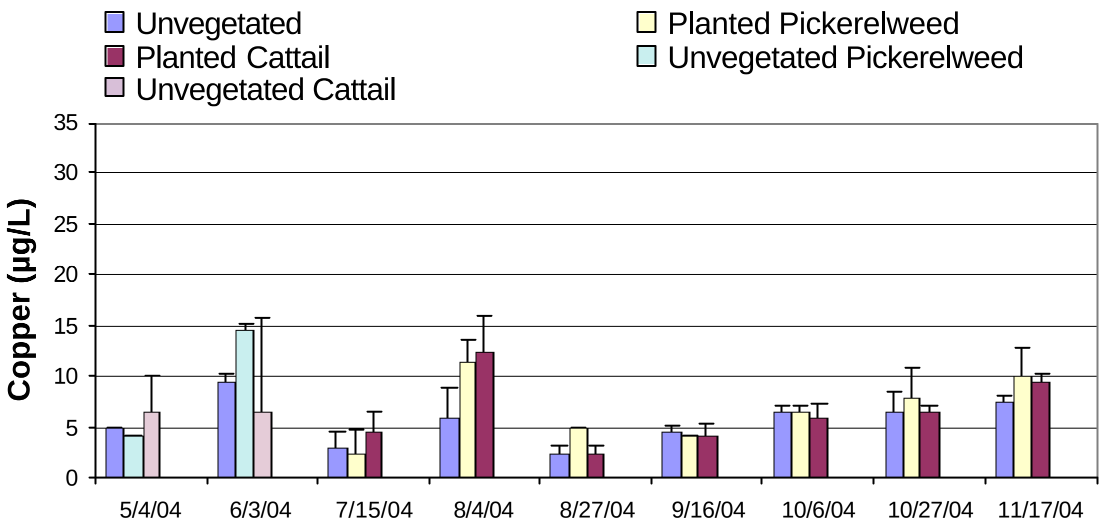


Figure 134. Inflow and outflow Cu concentrations (µg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.

Open Water



Littoral

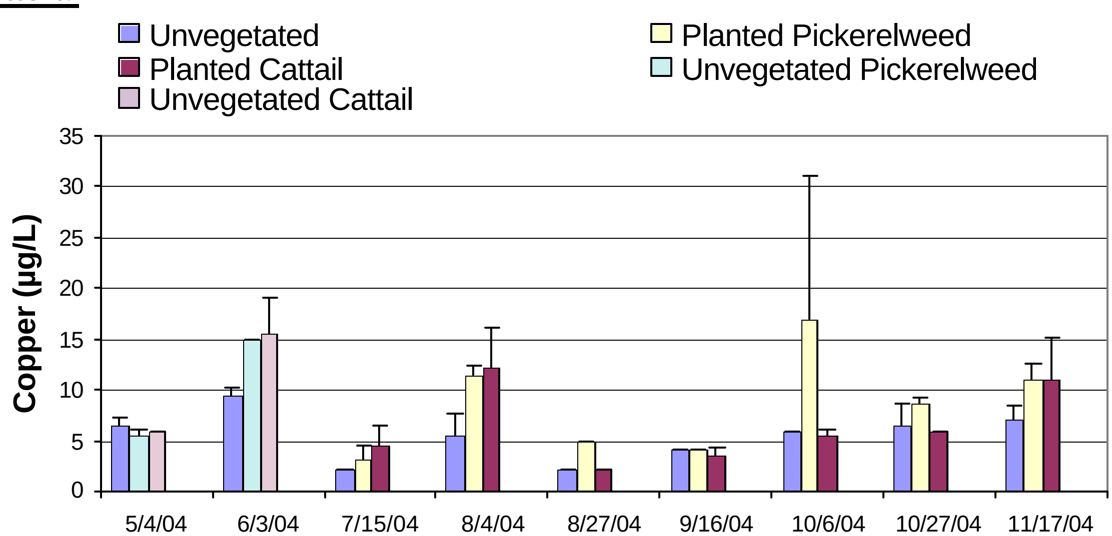


Figure 135. Open water and littoral Cu concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

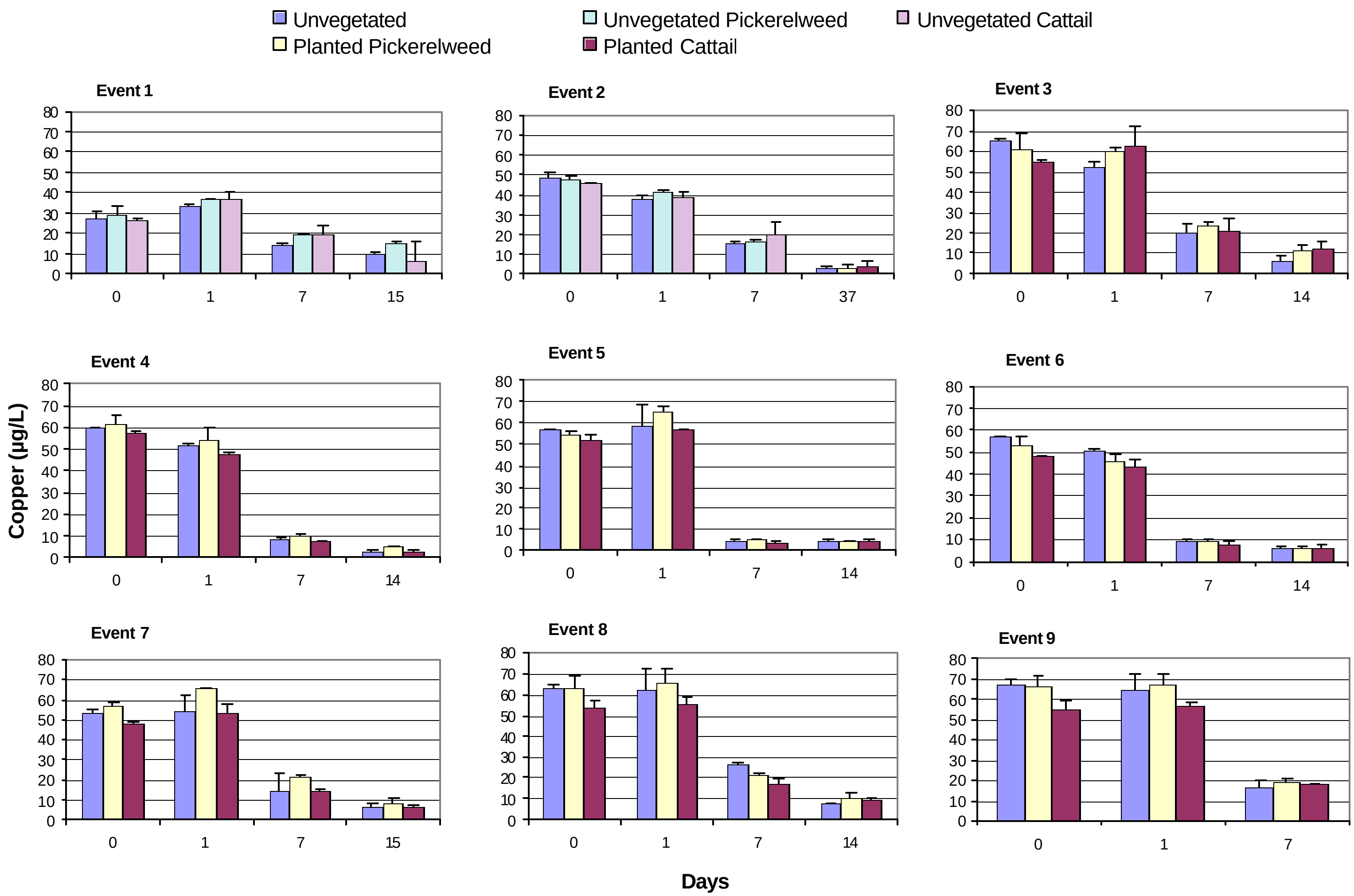


Figure 136. Open water Cu concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

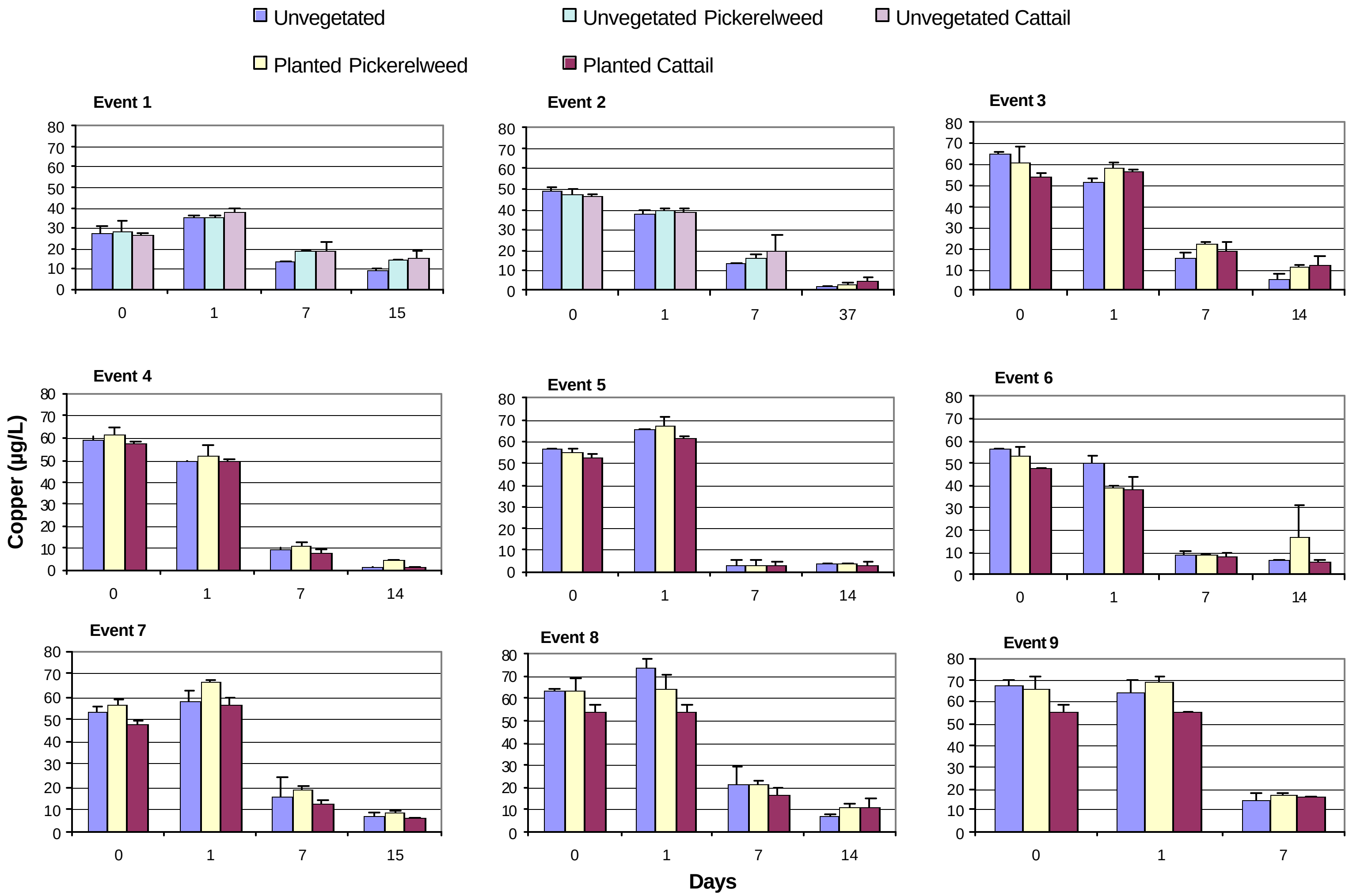
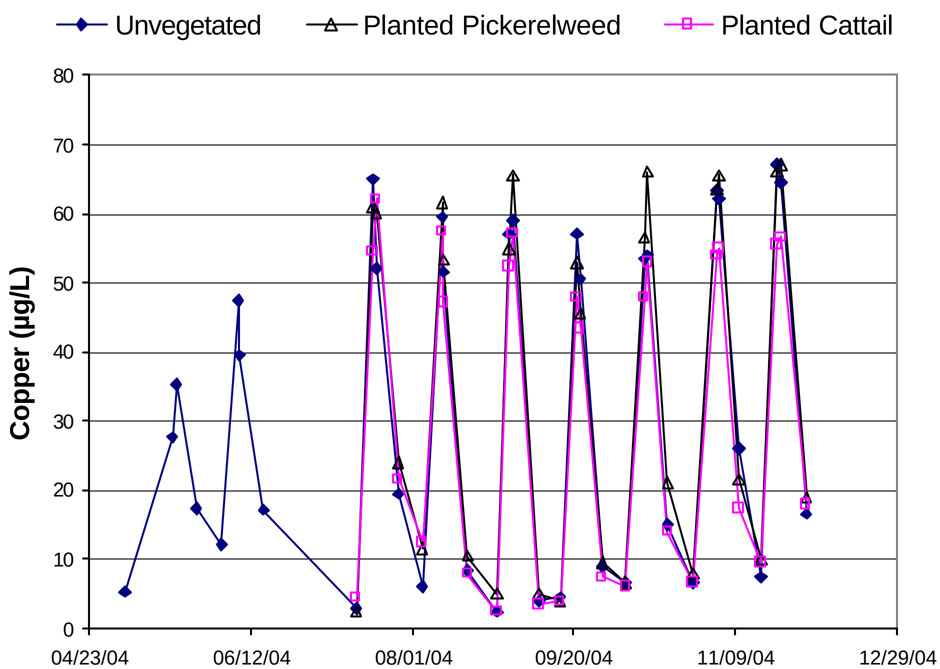


Figure 137. Littoral Cu concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

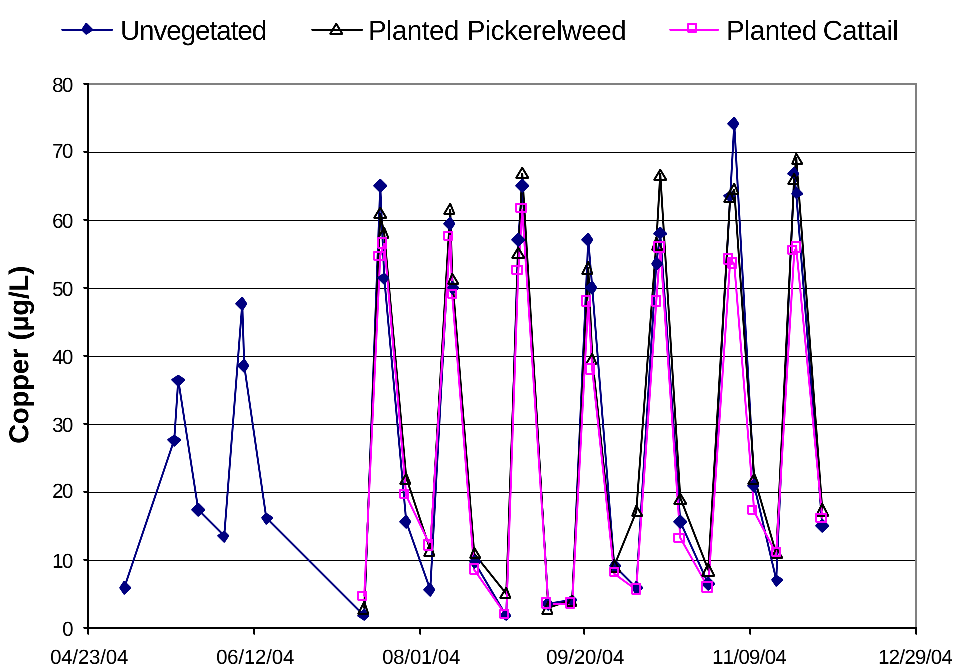


Figure 138. Cu concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

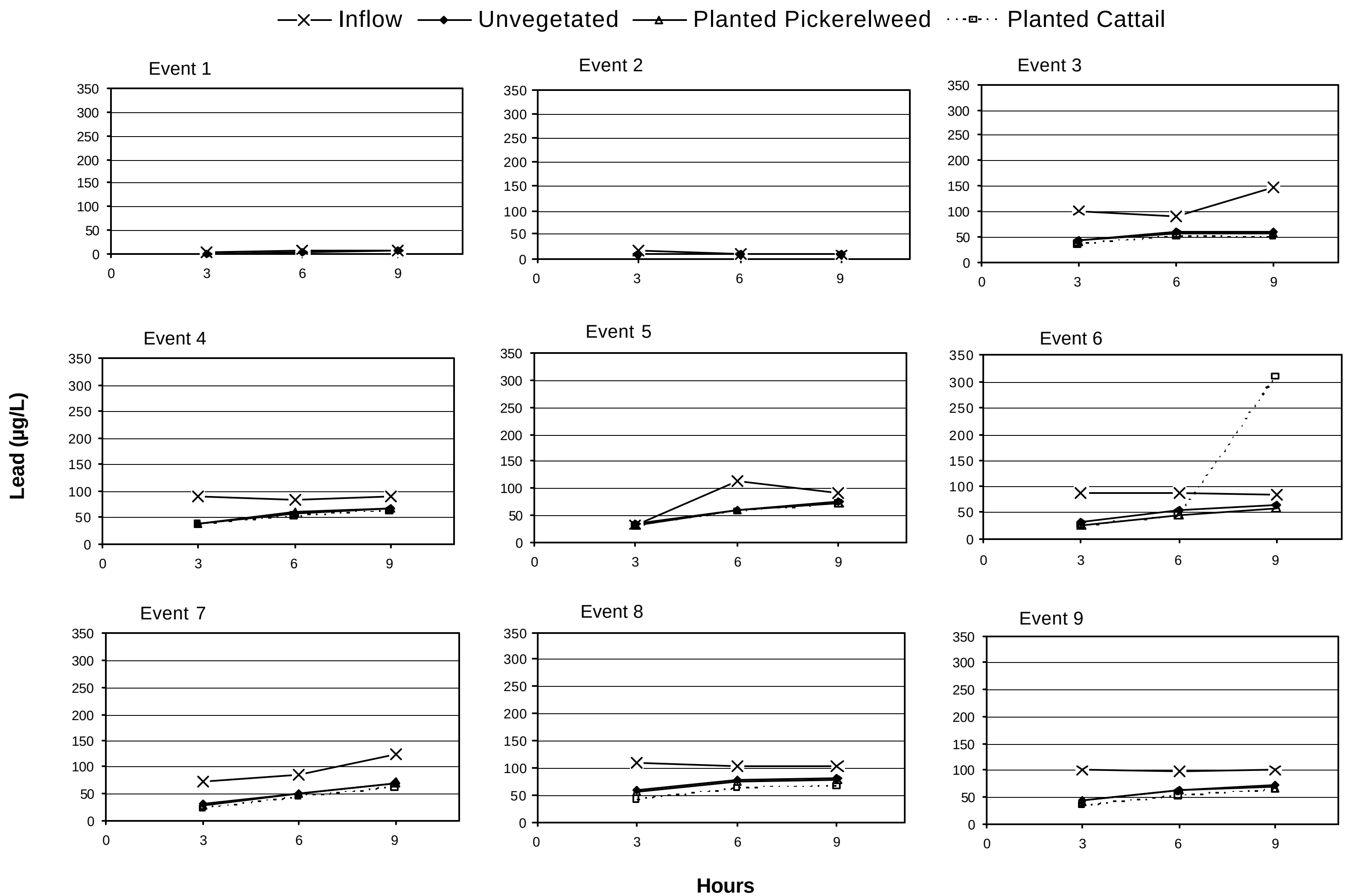
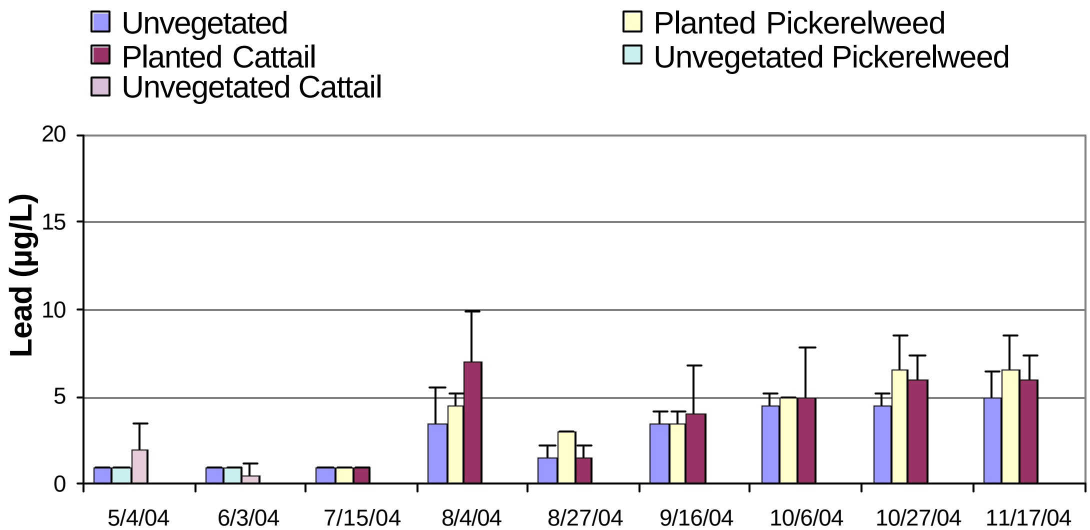


Figure 139. Inflow and outflow Pb concentrations (µg/L) during nine simulated storm events for unvegetated, planted cattail and planted pickerelweed compartments.

Open Water



Littoral

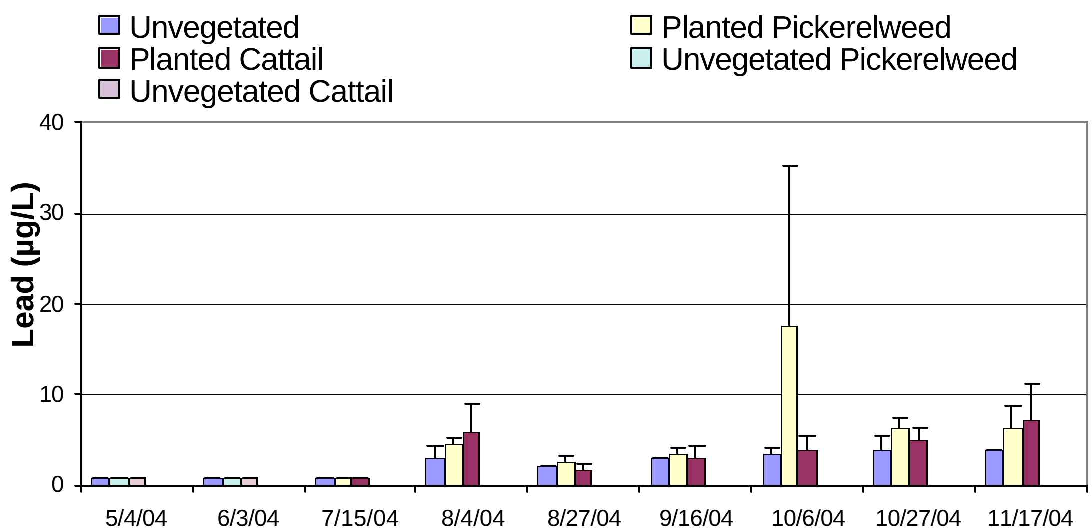


Figure 140. Open water and littoral Pb concentrations for unvegetated, planted cattail and planted pickerelweed compartments on day 14 of each inter-event period. The 5/4/04 values represent concentrations prior to the first pumping event.

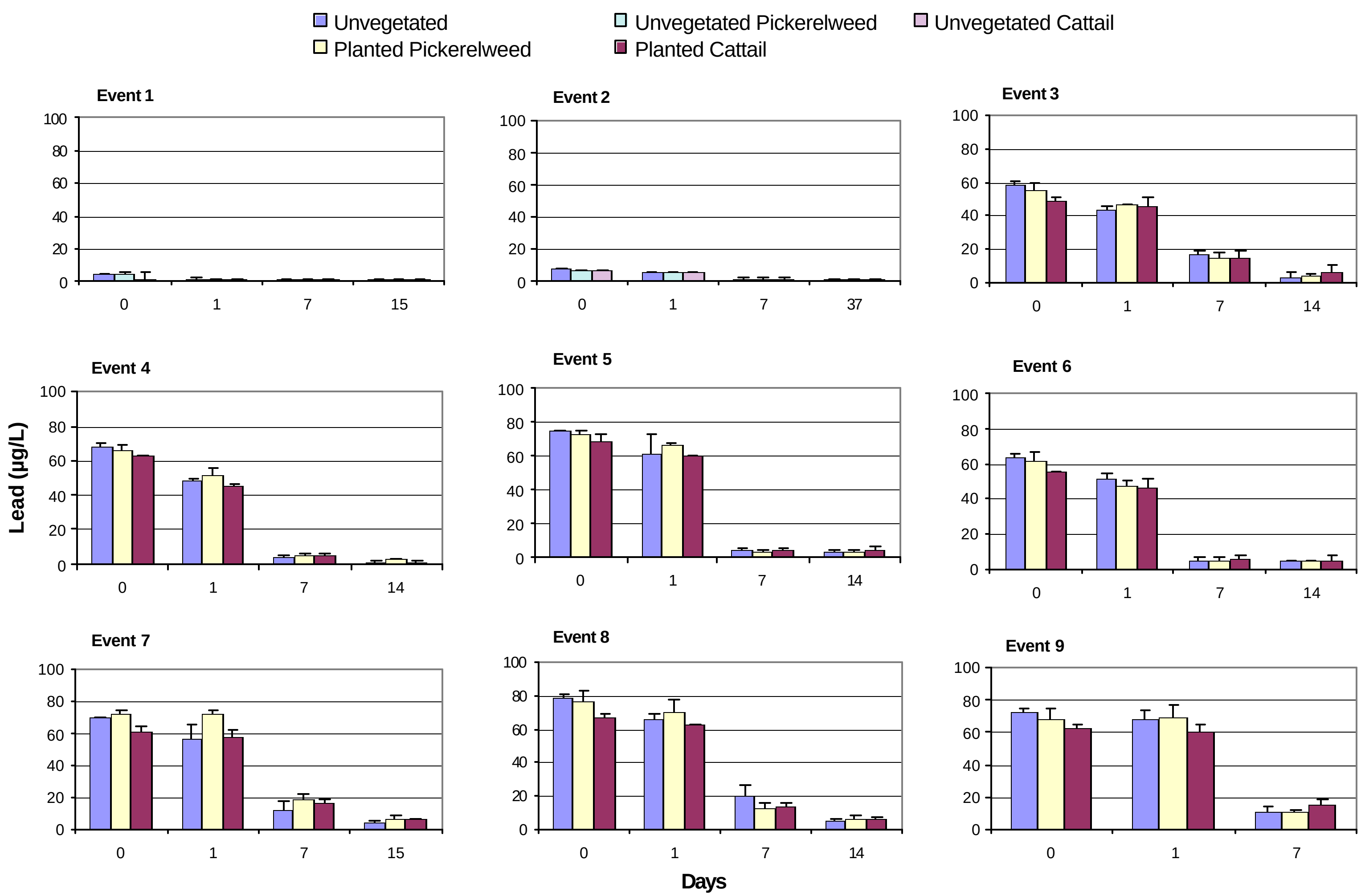


Figure 141. Open water Pb concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

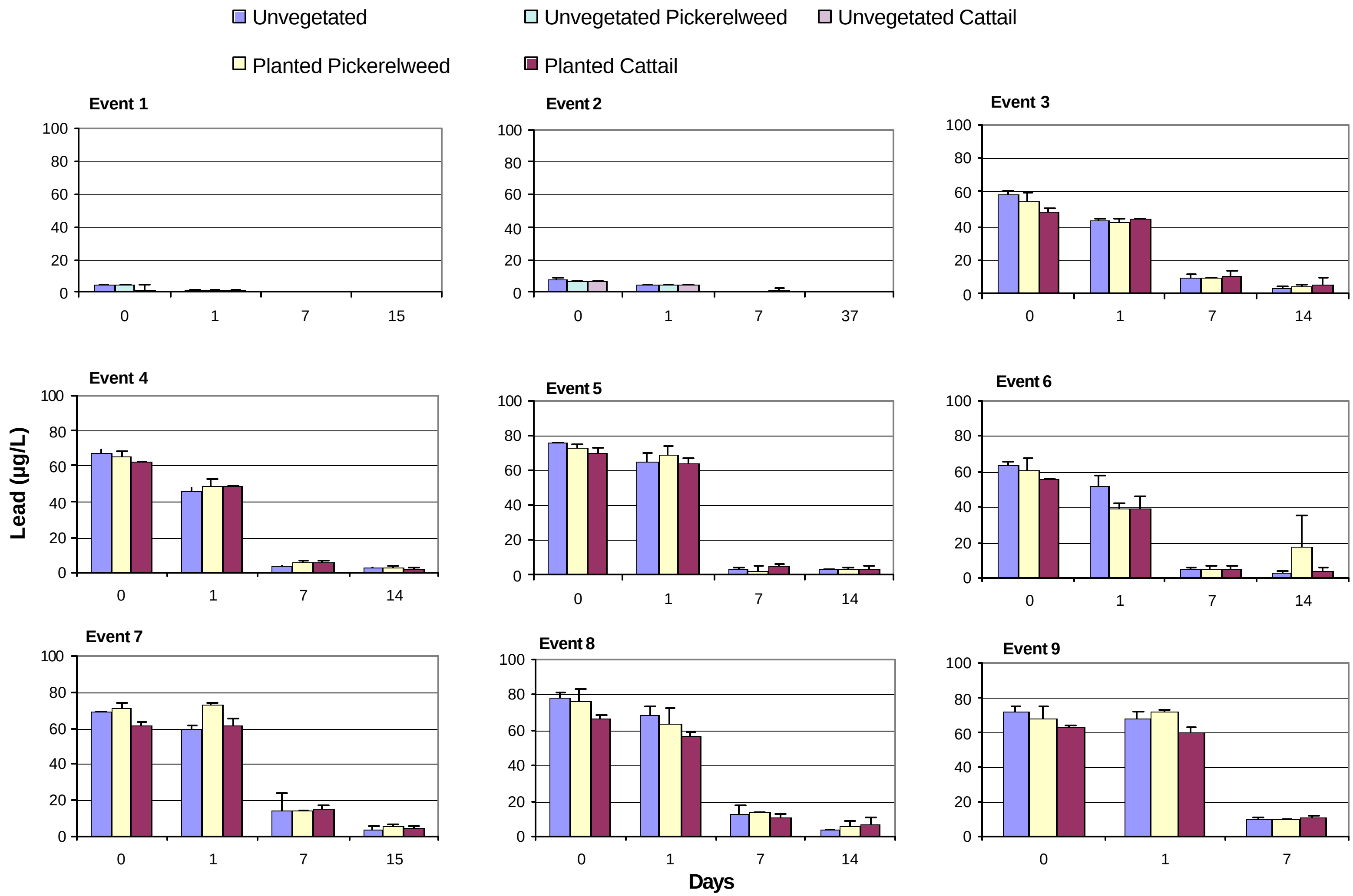
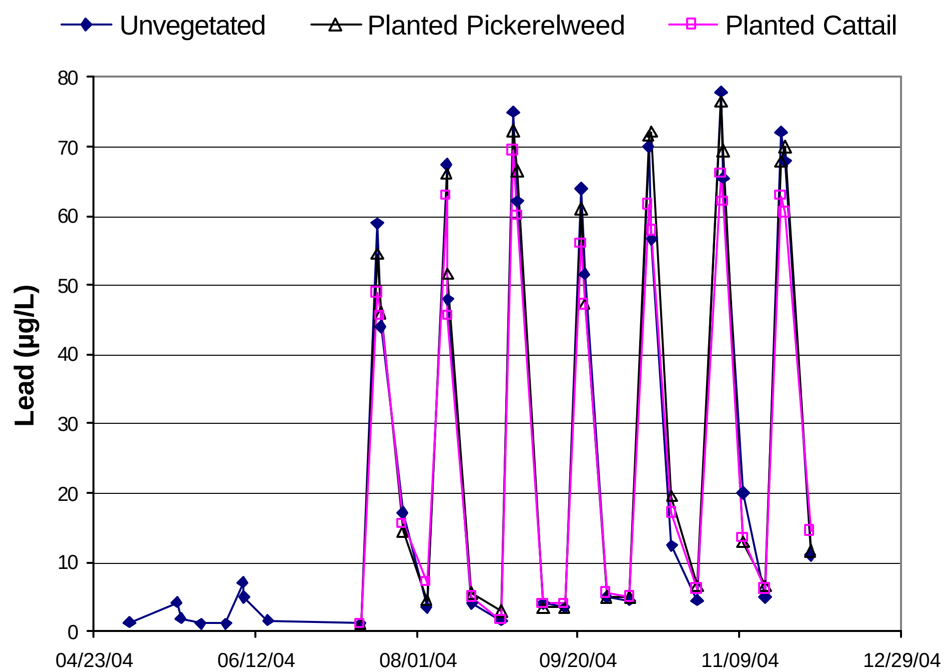


Figure 142. Littoral Pb concentrations for unvegetated, planted cattail and planted pickerelweed compartments as a function of time during each inter-event period.

Open Water



Littoral

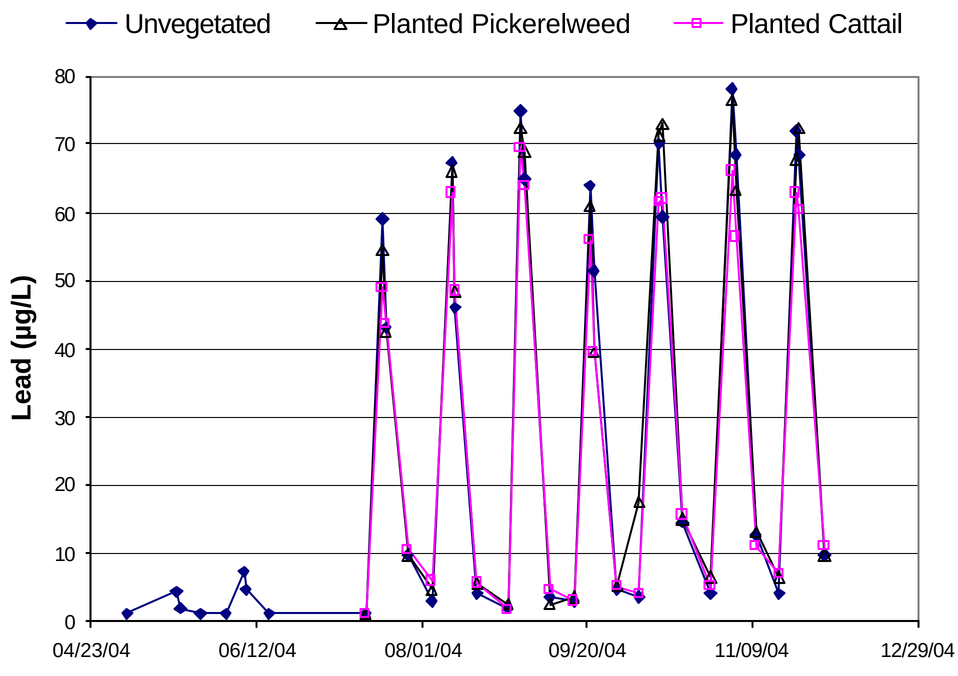


Figure 143. Pb concentrations for open water and littoral locations of unvegetated, planted cattail and planted pickerelweed compartments throughout the study.

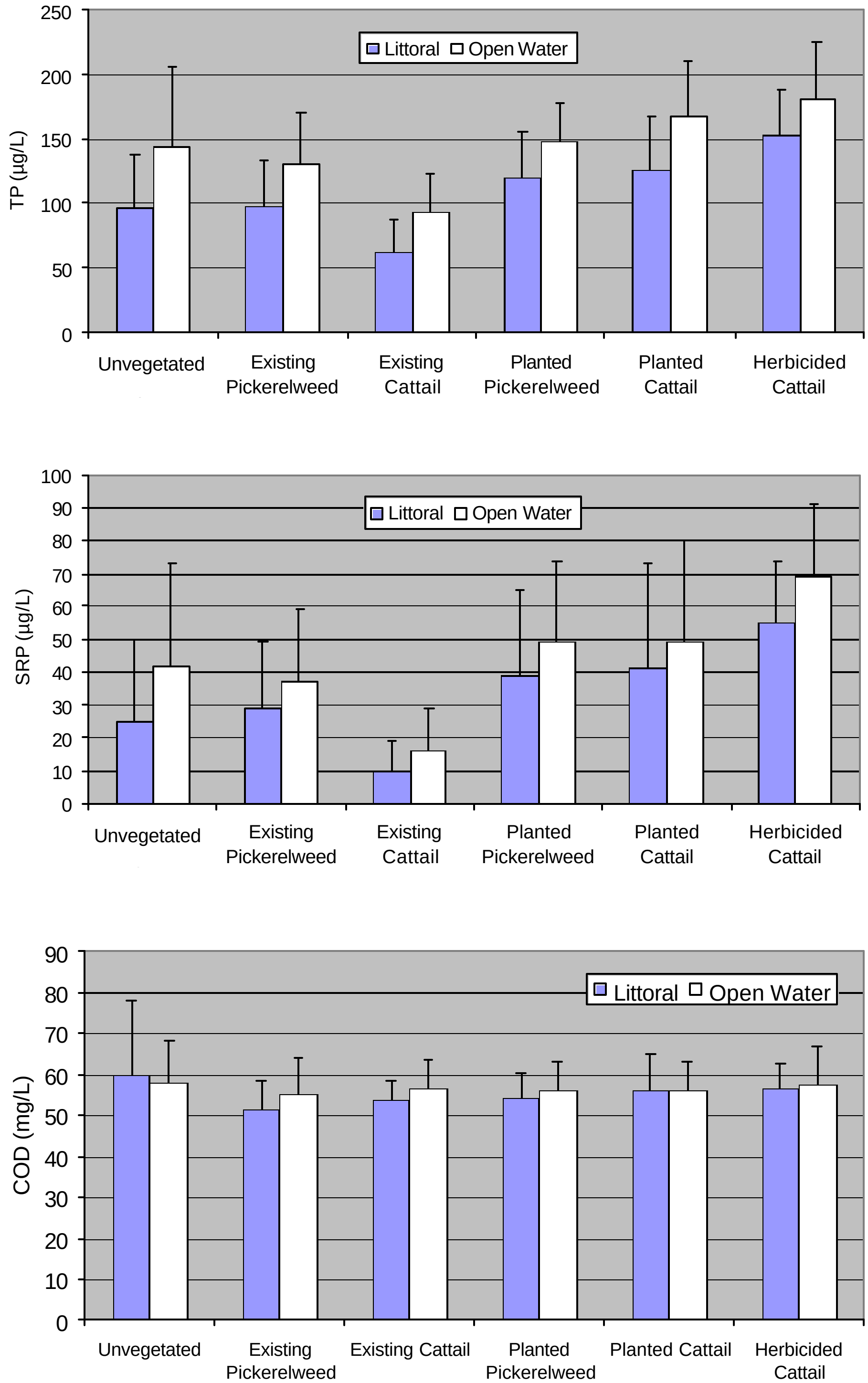


Figure 144. Average TP, SRP and COD inter-event concentrations (day 14) at littoral and open water locations during the study period. Error bars represent standard deviations calculated using values for individual compartments (n=2) and number of storm events (n = 9 for unvegetated and existing pickerelweed; n = 5 for existing cattail; n = 4 for herbicided cattail; n = 7 for planted pickerelweed and planted cattail).

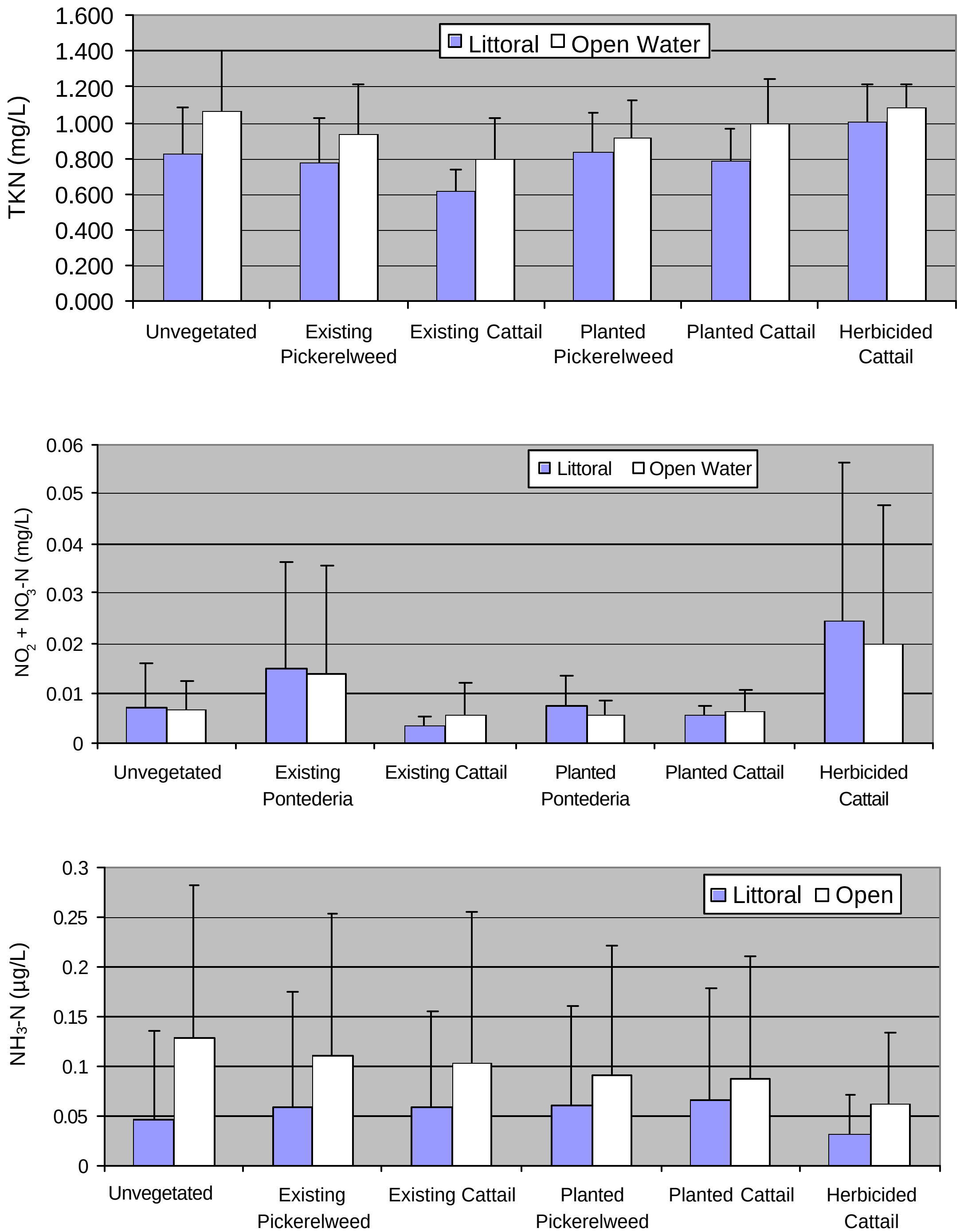


Figure 145. Average TKN, NO_2 + NO_3-N and NH_3-N inter-event concentrations (day 14) at littoral and open water locations during the study period. Error bars represent standard deviations calculated using values for individual compartments (n=2) and number of storm events (n = 9 for unvegetated and existing pickerelweed; n = 5 for existing cattail; n = 4 for herbicided cattail; n = 7 for planted pickerelweed and planted cattail).

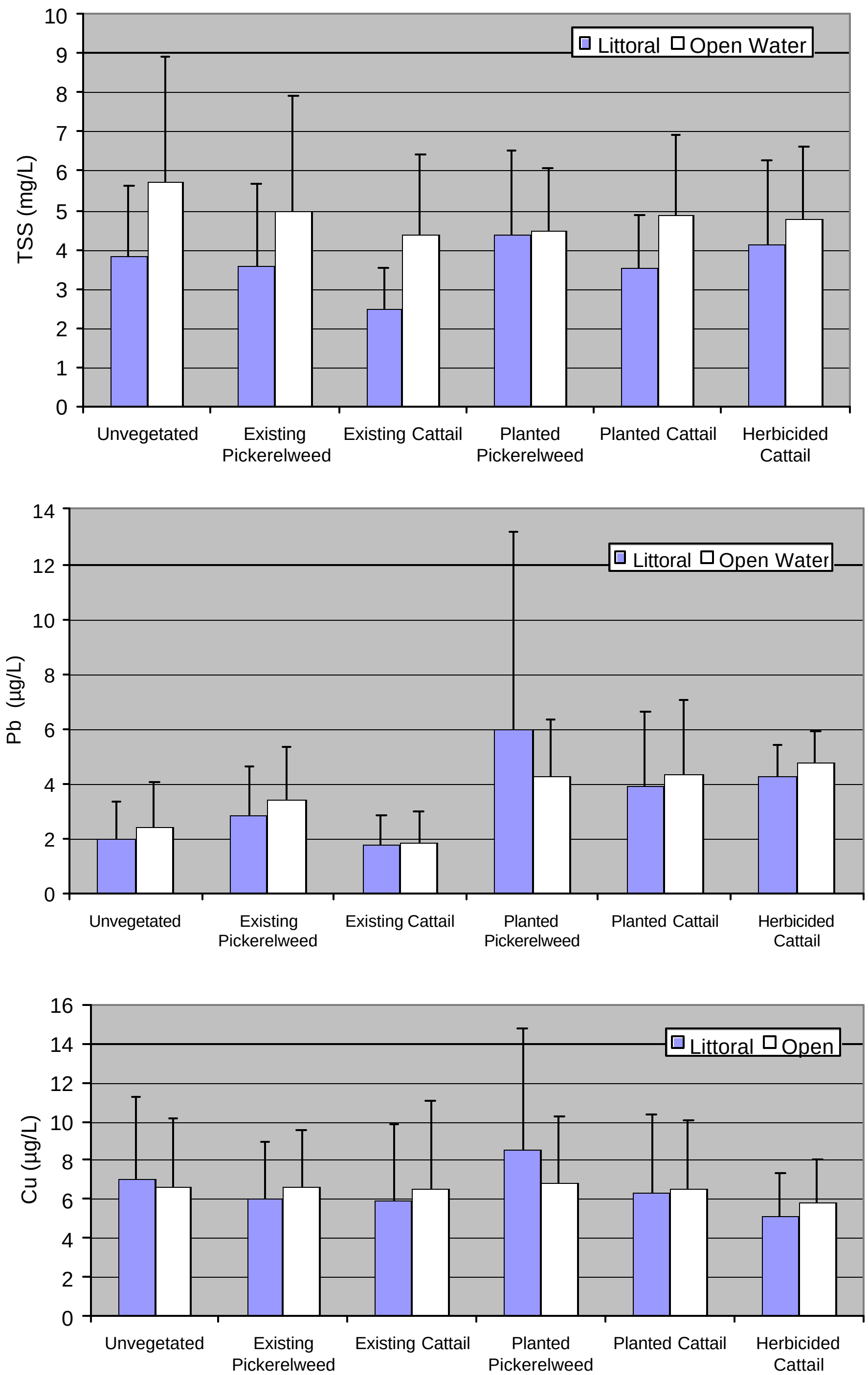


Figure 146. Average TSS, Cu and Pb inter-event concentrations (day 14) at littoral and open water locations during the study period. Error bars represent standard deviations calculated using values for individual compartments (n=2) and number of storm events (n = 9 for unvegetated and existing pickerelweed; n = 5 for existing cattail; n = 4 for herbicided cattail; n = 7 for planted pickerelweed and planted cattail).

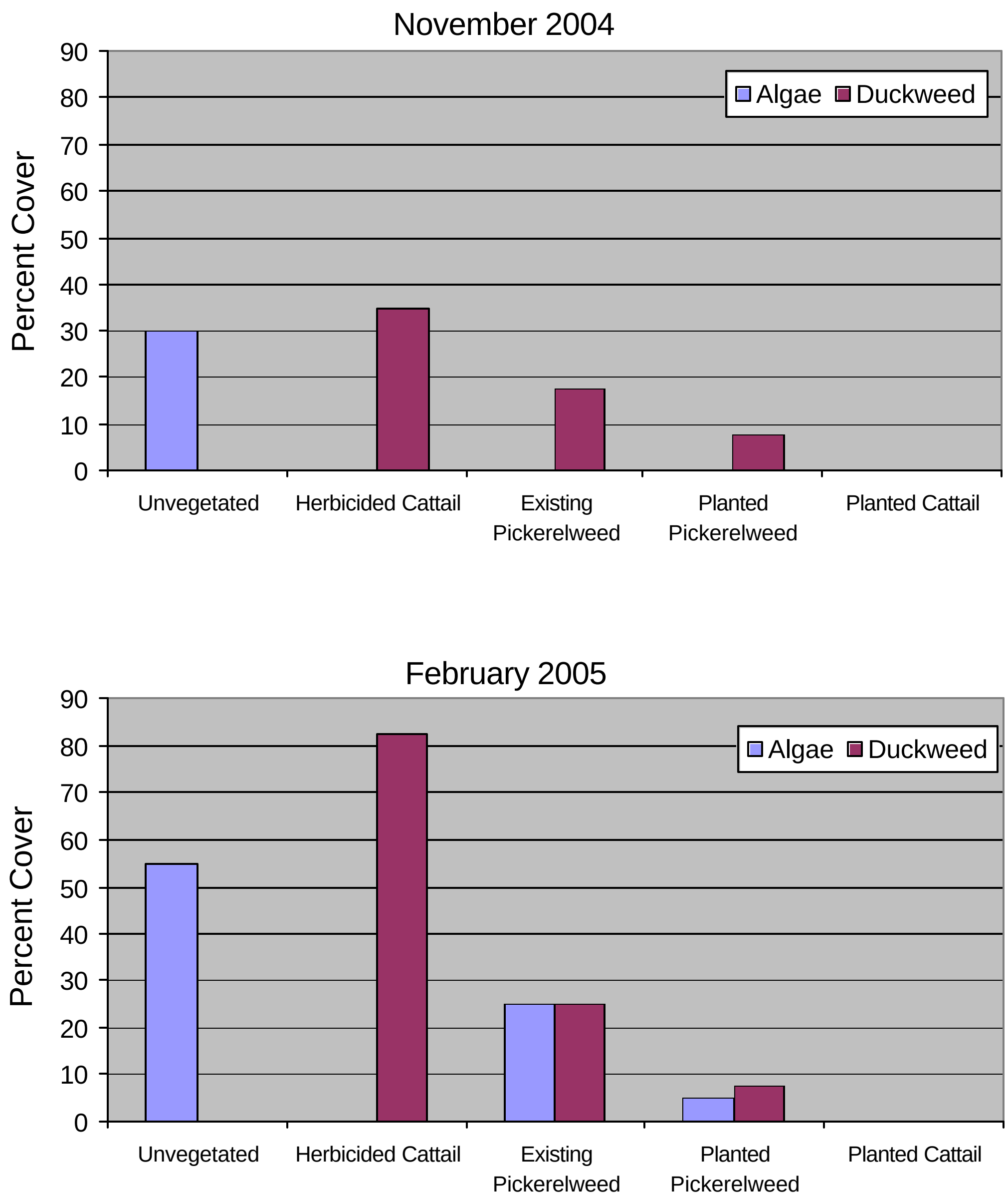


Figure 147. Percent cover of filamentous algae and duckweed in November 2004 and February 2005.

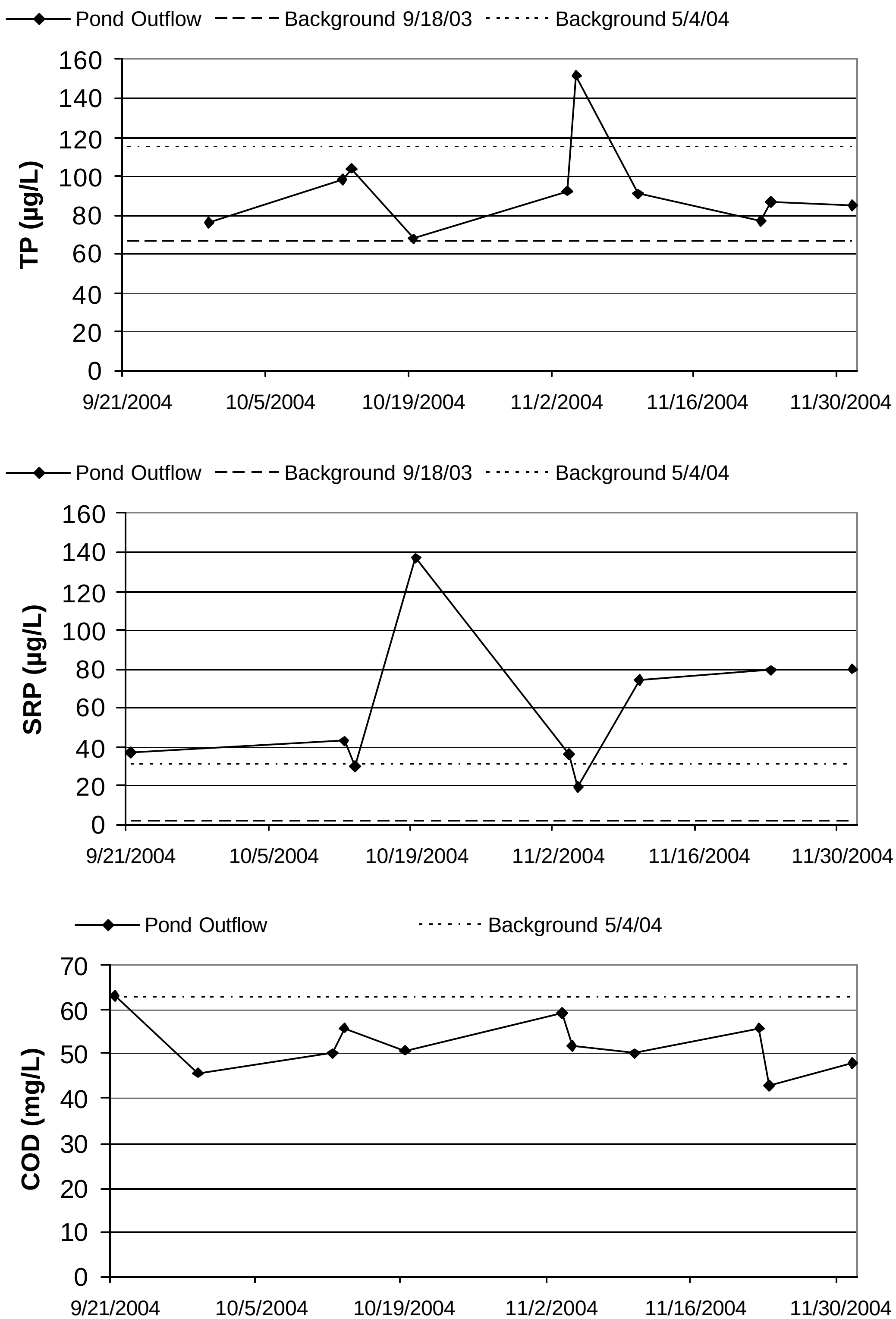


Figure 148. Detention pond TP, SRP and COD outflow concentrations from September through November 2004. Also included are background concentrations (collected from pond water column) in September 2003 and May 2004.

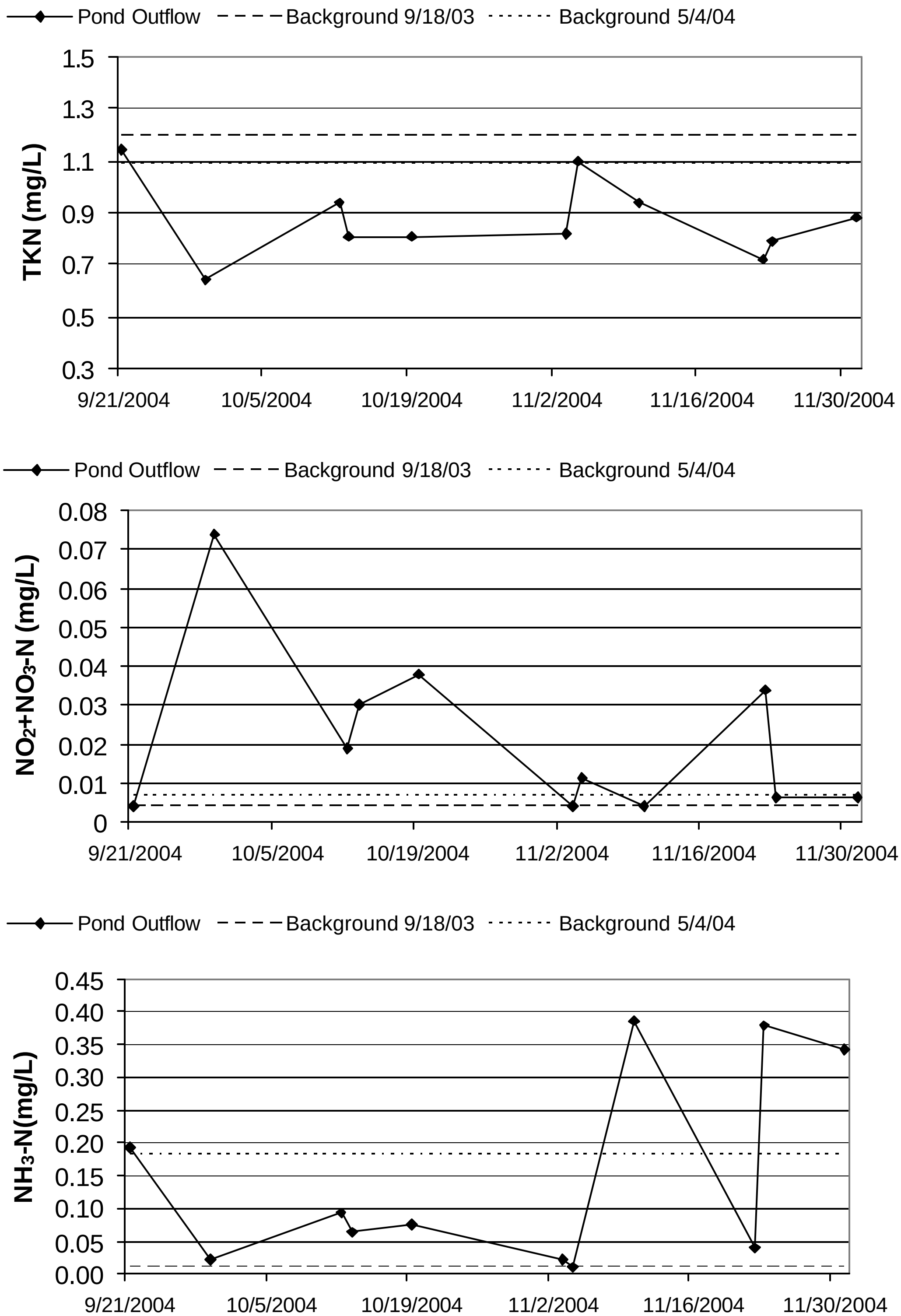


Figure 149. Detention pond TKN, NO_2 + NO_3-N and NH_3-N outflow concentrations from September through November 2004. Also included are background concentrations (collected from pond water column) in September 2003 and May 2004.

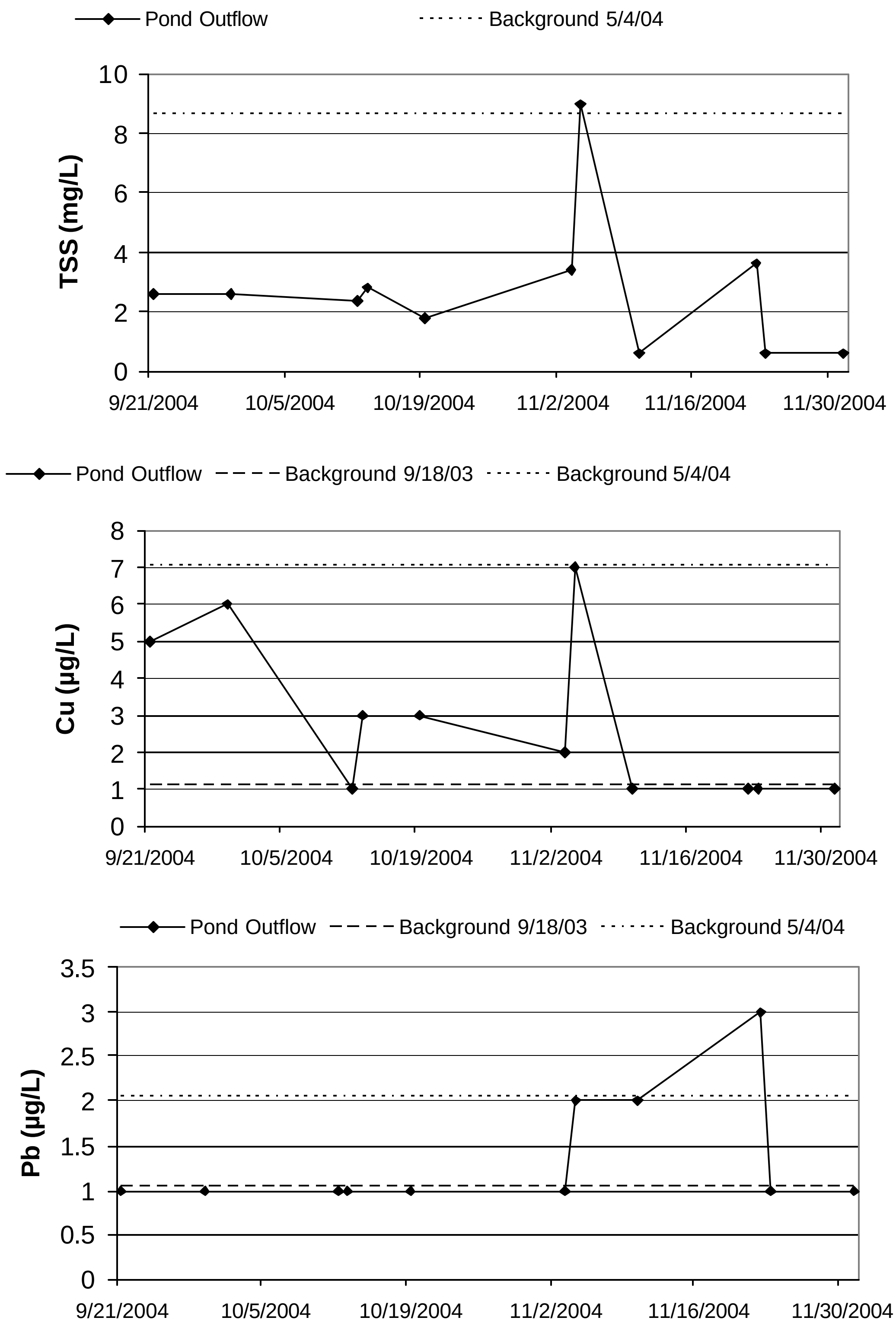


Figure 150. Detention pond TSS, Cu and Pb outflow concentrations from September through November 2004. Also included are background concentrations (collected from pond water column) in September 2003 and May 2004.

Conclusions and Recommendations

Conclusions

The principal objective of this effort was to evaluate potential water quality benefits in a wet detention pond due to the presence of emergent macrophyte vegetation in the littoral zone. We constructed an experimental facility, comprised of ten compartments, in a 1 ha wet detention pond. Each compartment contained both a shallow littoral zone and a deep, open water region. The compartments were subjected to nine simulated storm events over eight months, during which time we added comparable volumes of "spiked" pond waters to each compartment over a 9-hour period. Water quality in existing and planted pickerelweed and cattail compartments was compared with that in compartments with an unvegetated littoral zone during both storm event and inter-event periods.

Those contaminants exhibiting highest removal rates during the study, based on mean concentration reductions during the inter-event periods in the littoral region of unvegetated compartments, were NO_2 + NO_3-N (98%), Pb (93%), SRP (89%), Cu (88%) and NH_3-N (87%). Moderate removal rates were observed for TP (63%) and TKN (37%), while relatively poor removal was documented for TSS (27%) and COD (10%). Percentage removal rates in compartments with vegetated littoral zones were comparable.

During inter-event periods, water quality often improved more rapidly and to a greater extent in the shallow littoral region than in the deeper open water region of the compartments. This difference was statistically significant for TP and NH_3-N in unvegetated and pickerelweed compartments. Contaminant removal effectiveness within littoral and open water regions, however, was not consistently influenced by presence of either cattail or pickerelweed, whether in existing stands or newly planted.

Presence of vegetation had little long-term effect on contaminant removal rates, although we did observe some short-term differences between treatments. Herbiciding of cattails resulted in a short-term increase in littoral and open water TP and SRP concentrations, but little or no effect on TSS, COD, N or metals concentrations. Additionally, while few water chemistry differences were noted, we did observe in the final months of the study that unvegetated compartments

developed a higher standing crop of filamentous algae than vegetated compartments. Similarly, at this time the herbicided cattail exhibited the highest cover of floating duckweed among treatments.

Contaminant removal effectiveness probably was related to the chemical form and concentration of the constituent in the inflow waters. Native COD and organic N in the pond waters were relatively recalcitrant, whereas the spiked aliquots of COD (fructose) and N (NO_2 + NO_3-N, NH_3-N) were readily removed within the compartments. Inflow TSS concentrations to the compartments were typically 10 mg/L or less, much lower than the average TSS levels found in central Florida urban runoff. These low inflow TSS levels probably explain the low percentage removal rates for this constituent. Additionally, due to low TSS levels, most of the contaminants were provided to the compartments in a dissolved form. This study therefore provides an extensive data record on removal of dissolved nutrients and metals under low TSS conditions, information that should prove useful for wet detention pond performance modeling and design purposes.

Data from this study do not support the hypothesis that littoral zone emergent vegetation, either existing or newly-planted, enhances pollutant reduction in a wet detention pond. This observation holds for pickerelweed and cattail, the two vegetation types evaluated in this study. There remain several factors, however, that should be investigated to more thoroughly define the role of emergent macrophytes in removing pollutants in wet detention ponds. For example, soils play a strong role, at times as great as that of vegetation, in controlling contaminant cycling in aquatic systems. The interaction between soil physical/chemical characteristics and macrophyte vegetation on pond contaminant removal performance therefore warrants investigation. Additionally, it should be noted that due to the low TSS levels in the simulated runoff, the present study does not represent a definitive evaluation of effects of vegetation on littoral zone effectiveness. Pollutant removal performance of the various treatments (e.g. littoral vs. open water; vegetated vs. non-vegetated compartments) might differ with high inflow particulate concentrations, a situation where sedimentation, rather than biological treatment, is the dominant contaminant removal process for the bulk of the inflow pollutants.

Recommendations

Our experimental facility proved flexible and effective for evaluating different treatments under replicated conditions. The findings from this exploratory study suggest several additional investigations that may lead to improved wet detention pond design and management approaches. Investigations based on individual topics listed below, or combinations of selected topics, should further define littoral zone and macrophyte vegetation effects on detention pond water quality.

Alternative contaminant types

Both vegetated and unvegetated compartments could be utilized to evaluate removal of other types of stormwater runoff contaminants. For example, pollutant removal effectiveness of the vegetated and unvegetated compartments could be evaluated under high TSS loadings, rather than the low TSS conditions utilized in the present study. Additional investigation would be required to successfully address the practical constraints to particle spiking noted in the Methods section of this report.

Additionally, there are other constituents whose fate may be worth evaluating in vegetated and unvegetated littoral regions, such as microbiological parameters (e.g., fecal coliforms) or potentially toxic constituents (polynuclear aromatic hydrocarbons).

Alternative contaminant concentrations and loadings

In the present study, certain contaminants (e.g. NO_2 + NO_3-N, SRP, Pb, Cu) exhibited almost complete removal in both vegetated and unvegetated treatments. It is possible that there is a concentration or loading threshold for these constituents, above which vegetation treatment differences might become apparent. For such parameters, it would be useful to simultaneously test a range of spiking concentrations in different compartments, for example at levels 1X, 2X and 5X of those evaluated herein.

Long-term evaluation to capture effects of season and cumulative loadings

We began to detect biological differences (i.e., algae proliferation) during the latter part of this study, either due to cumulative nutrient loadings or seasonal effects. A study of longer

duration, such as two to three years, likely would provide more definitive results on the effects of littoral vegetation type on water chemistry and pond aesthetics.

A greater littoral zone percentage

The ratio of littoral zone to open water in the present study was 20%, which is representative for many of the ponds that we have inspected in central Florida. Because we did detect some water quality benefits of the littoral zone over the open water region, it is possible that a greater littoral fraction, such as 30 – 50%, would provide more definitive results.

Alternative vegetation types

One means of deploying more macrophyte biomass in a pond without expanding the shallow littoral is to utilize submerged aquatic vegetation (SAV), which can thrive in deeper water than emergent macrophytes. SAV can have pronounced effects on the water column microenvironment (e.g., pH and DO), which in turn can influence removal of constituents such as P and metals. A second vegetation type that should be considered is floating vegetation, such as *Hydrocotyle spp*. Floating macrophytes could either be allowed to spread throughout the compartments unchecked, or could be contained within a barrier in a managed "floating wetland" configuration.

Alternative soil types

As noted above, our evaluation was performed in a pond representing one soil type. For a follow-on effort, the soils in this pond could be characterized with respect to physical and chemical attributes. Vegetated and unvegetated compartments could then be deployed and evaluated in a separate pond that contains markedly different soils (e.g., with respect to particle size fraction, organic matter content, etc.)

Modifications to monitoring plan

Our findings demonstrate that macro- and micro-algae in the compartments can play a critical role in nutrient cycling, which in turn can affect water column chemical attributes. Therefore, for all future efforts we should closely track algal components (chlorophyll *a* and secchi depth for phytoplankton; percentage cover, standing crop and elemental composition for filamentous algae) throughout the study. For any long-term effort, it also would be useful to characterize

compartment sediments and macrophyte tissues at the beginning and end of the study. The above information would enable us to better define the long-term fate and cycling of pollutants in vegetated and unvegetated systems.

Literature Cited

Barr Engineering. 2001. Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates. Prepared for Metropolitan Council. St. Paul, MN.

Bingham, D.R. 1994. Wetlands for stormwater treatment. Pp. 243-262 In Kent, D. M. (ed.) Applied Wetlands Science and Technology. Lewis Publishers / CRC Press, Boca Raton, Florida. 436 pp.

Center for Watershed Protection. No date. Stormwater management fact sheet: Wet pond. www.stormwatercenter.net. Ellicot City, Maryland.

City of Houston, Harris County, and Harris County Flood Control District. 2001. Storm Water Quality Management Guidance Manual.

DeBusk, T.A., R.B. Laughlin, and L.N. Schwartz. 1996. Retention and compartmentalization of lead and cadmium in wetland microcosms. Water Resources 30(11):2707-2716.

England, G. 2001. The use of ponds for BMPs. Stormwater 2(5) July / August.

Fisher, M.M. and K.R. Reddy. 2001. Phosphorus flux from wetlands soils affected by long-term nutrient loading. Journal of Environmental Quality, 30:261-271.

Florida Department of Environmental Regulation, 1988. The Florida Development Manual: A Guide to Sound Land and Water Management.

Grace, K.A. 2003. Phosphorus Removal and Soil Stability within Emergent and Submerged vegetation Communities in Treatment Wetlands. MS Thesis, Department of Soil and Water Science, University of Florida, Gainesville, FL.

Hammer, D.A. (ed.). 1988. Constructed wetlands for wastewater treatment: Municipal, industrial, and agricultural. Lewis Publishers, Chelsea Michigan. 831 pp.

Harper, H.H. 1994. Stormwater loading rate parameters for central and south Florida. Environmental Research & Design, Inc. Orlando, Florida.

Harper, H.H. 2002. Significance of littoral zone vegetation and pond depth on wet detention pond performance. Proceedings of the Seventh Biennial Stormwater Research and Watershed Management Conference. SWFWMD and FDEP. P. 59.

Heaney, J.P., R. Pitt, and R. Field. 1999. Innovative urban wet-weather flow management system. EPA/600R-99/029. National Risk Management Research Laboratory, Office of Research and Development, Cincinnati, OH.

Johengen, T.H. and P.A. LaRock. 1993. Quantifying nutrient removal processes within a constructed wetland designed to treat urban stormwater runoff. Ecological Engineering 2:347-366.

Kadlec, R.H. and R.L. Knight. 1995. Treatment Wetlands. Lewis Publishers, Boca Raton, Florida. 893 pp.

Kent, D.M. 1994. Applied Wetlands Science and Technology. Lewis Publishers, Boca Raton, Florida. 436 pp.

Kent, D.M., M.A. Langston, T.A. DeBusk, and S. Davidson. 1997. Stormwater pollutant removal in live and artificial emergent plant mesocosms. Proceedings of the Fifth Biennial Stormwater Research Conference. SWFWMD. Pp. 22-31.

Lorenz, J.S. and D.D. Biesboer. 1987. Nitrification, denitrification and ammonia diffusion in a cattail marsh. In: K.R. Reddy and W.H. Smith. Aquatic Plants for Water Treatment and Resource Recovery. Magnolia Publishing, Orlando, FL.

Maryland Department of the Environment. 2000. Maryland Stormwater Design Manual: Volumes I & II. Prepared by Center for Watershed Protection. Baltimore, MD.

Moshiri, G.A. (ed.). 1993. Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, Florida. 632 pp.

Richardson, C.J. and S. S. Qian. 1999. Long-term phosphorus assimilative capacity in freshwater wetlands: a new paradigm for sustaining ecosystem structure and function. Environmental Science and Technology 33(10): 1545-1551.

Rushton, B. 1997. Processes that affect stormwater pollution. Proceedings of the Fifth Biennial Stormwater Research Conference. SWFWMD. Pp. 43-53.

St. Johns River Water Management District. 2003. Environmental Resource Permits: Regulation of Stormwater Management Systems. Chapter 40C-42, F.A.C. Palatka, FL.

Stoker, Y.E. 1997. Effectiveness of the Bayside Bridge stormwater collection and detention system, Pinellas County, Florida. Proceedings of the Fifth Biennial Stormwater Research Conference. SWFWMD. P. 73.

Strecker, E.W., M.M. Quigley, B. Urbonas, and J. Jones. 2004. Analyses of the expanded EPA/ASCE international BMP database and potential implications for BMP design. In Sehlke, G., D.F. Hayes, and D.K. Stearns (eds.) Critical Transitions in Water and Environmental Resources Management. Proceedings of the 2004 World Water and Environmental Resources Congress. Salt Lake City, Utah.

U.S. Environmental Protection Agency. 1999a. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012. Office of Water, Washington, D.C.

U.S. Environmental Protection Agency. 1999b. Storm water technology fact sheet: Wet detention ponds. EPA 832-F-99-048. Office of Water, Washington, D.C.

U.S. Environmental Protection Agency. 2002. Considerations in the Design of Treatment Best Management Practices (BMPs) to Improve Water Quality. EPA/600/R-03/103. National Risk Management Research Laboratory, Office of Research and Development, Cincinnati, OH.

Walker, W.W. Jr. 1987. Phosphorus removal by urban runoff detention basins. Lake and Reservoir Management, 3:314-326.