Phosphorus Dynamics in Cranberry Systems; 310 report to MA DEP

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PHOSPHORUS DYNAMICS IN CRANBERRY PRODUCTION SYSTEMS: DEVELOPING THE INFORMATION REQUIRED FOR THE TMDL PROCESS FOR 303D WATER BODIES RECEIVING CRANBERRY BOG DISCHARGE

MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
INTERAGENCY SERVICE AGREEMENT NO. 01-12/319

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MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF RESOURCE PROTECTION

AND

US ENVIRONMENTAL PROTECTION AGENCY
REGION 1

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EXECUTIVE SUMMARY

Under the requirements of the Federal Clean Water Act, the Massachusetts DEP has been charged with the task of developing TMDL (total maximum daily load) reports for impaired water bodies on the state 303d list. Some of the water bodies on this list receive discharge water from cranberry production systems. Cranberry production is the major form of agriculture in S.E. Massachusetts. Although cranberry agriculture typically has a low fertilization rate compared to many crops, it generally discharges bog waters through surface water flow directly to streams, ponds or lakes and indirectly to coastal waters. For this reason, nutrient release by cranberry agriculture needs to be included in the development of TMDLs by the State of Massachusetts.

It has been estimated that Massachusetts cranberry production requires up to 10 acre-feet of water from all sources, although the most efficient beds may require half this amount. Water bodies associated with cranberry production in Massachusetts may have multiple uses and inputs including wildlife habitat, recreation, residential inputs (septic and surface runoff), and storm water discharge. Since cranberry production is dependent on a ready supply of clean water it is in the best interest of growers to minimally affect water quality. In addition, since water supplies are finite, the industry has made a significant effort at increasing water-use efficiency through the implementation of Best Management Practices (BMPs), such as laser leveling and tail-water recovery systems.

Fertilizing cranberries is a common and recommended practice. Research and grower experience has shown increased cranberry yields when appropriate amounts of fertilizer are added to producing beds. The primary nutrients added are nitrogen, phosphorus and potassium. Nitrogen is added exclusively in the ammonium form. Potassium is usually added as part of a blended fertilizer, typically as potassium sulfate. Potassium is thought to leach through the soil but is not known to cause significant environmental degradation. Phosphorus is also applied in blended fertilizers, usually as triple superphosphate, monoammonium phosphate, or diammonium phosphate.

In order to formulate TMDL standards for phosphorus, information that is extensive enough to allow generalization of the results to the predominant cranberry bog types in Massachusetts is needed. The information may also allow the recommendation of site-specific changes in practice that limit P export from cranberry systems while maintaining sustainable production of the crop (defined as >150 bbl/a for native selections and >200 bbl/a for hybrid cultivars).

The following research questions were posed:

- How much P enters and leaves cranberry bog systems on an annual basis (mass balance) and what activities contribute to nutrient releases? How does this compare to release from a natural freshwater wetland in the area?

- How does change in fertility practices (decreasing P rate) affect cranberry growth and productivity under the varied soil conditions? Can reductions in fertilization maintain cranberry production, while reducing phosphorus loss to receiving waters.

In this study, water and nutrient budgets were developed for three pairs of commercial cranberry bogs and the outcomes were compared to nutrient levels in a local vegetated wetland (Westport, MA) and to previously reported N and P levels in wetland settings. At some of the bog sites, fertilizer P inputs were reduced from 20-35% in the second and third years of the project and impact on nutrient budgets was determined. In addition, plot-scale research was conducted to examine the impact of reduced P fertilizer on cranberry productivity.

Findings

- Water input to the cranberry bog systems varied from 8-11 acre feet per season. Of this, 3.6-4.7 feet was from rainfall, the remainder of input was from groundwater upwelling (2 sites), irrigation and flooding. Water output was primarily from evapotranspiration (2.4 feet), infiltration, and surface discharge (primarily of floods).
- On a total budget basis, including fertilizer applications as inputs and crop and other biomass (leaves) removal as outputs, the bogs were generally net importers of total N and total P. The nutrients retained in the bog are constituents of the cranberry plants and microorganisms living in the bog or are retained within the bog soil and subsoil.
- When N and P of bog source waters was compared to that in discharge water, the bogs generally remained net importers of TN. However, TP in outgoing waters was greater than that in source water. Net TP fluvial output averaged 2.08 kg/ha/yr in 2002 (range 0.01 to 4.15); 1.66 kg/ha/yr in 2003 (range -0.63 to 3.62) and 1.22 kg/ha/yr in 2004 (range -1.24 to 4.30).
- The primary path of nutrient discharge from the bogs is through surface water. Cranberry bogs are constructed so that they have a perched water table and limited connection to the underlying groundwater. In addition, the saturated soils, high in Al and Fe, tend to retain P in the subsurface layers. If cranberry bogs contribute nutrients to groundwater, it would be primarily via surface discharge that infiltrates to groundwater off-bog.
- Flooding events were the primary source of TP output from the cranberry bogs. Particulate P became suspended in harvest floods due to agitation during crop removal and was discharged if the floods were released soon thereafter. Holding the flood for a finite period post-harvest decreased the TP load in the water, likely due to settling of particulates. Conversely, if the floods were retained on-bog for extended periods (~12 days), PO_4 concentration in the water increased, likely due to change in soil redox state due to soil anoxia. This phenomenon is also likely the source of P loading in the winter floods as well, since these floods tend to be held for longer periods.
- Cranberry bogs mimic natural wetlands in that they tend to retain nutrients during the spring and summer and discharge nutrients during fall and winter. This timing is helpful in mitigating the potential impact of the nutrient discharge since biological activity in receiving bodies is less during the fall and winter.
- Nutrient relationships of the cranberry bog were compared to those of other wetlands and other land uses. In comparison to the watershed in Westport, MA that was examined in the current study, TN output from the bogs was lower while TP output from the bogs was higher on a kg/ha basis. Organic matter and cations in the bog soil was lower than those in the wetland soils at Westport, while soil pH was similar. P in the bog soil was elevated in comparison to that in the Westport site, due to fertilizer applications to the bogs. In general, the bog TP output was intermediate in value compared to that in other wetlands

but somewhat higher than that from pristine wetlands. As is the case in other wetland systems, the capacity of a cranberry bog to retain nutrients may be limited when incoming loads are high. Gross TP export (kg/ha/yr) from the cranberry bogs was within the range of that for other reported agricultural land uses and the Westport study site but much greater than that for forested lands.
- When fertilizer P input was reduced (20-35%) at cranberry bog sites for two consecutive seasons, crop yield was not adversely affected at rates of 6.3 and 23 kg/ha at an organic soil site and a mineral soil site respectively. Likewise, in field plot studies, fertilizer P reductions were not associated with crop decline. After two seasons of reduced P, soil test P had declined compared to that of the control bogs but remained in the sufficient range. Plant tissue P was similar and in the sufficient range at all sites at the end of the two years of P reduction.
- Reducing P fertilizer on the cranberry sites did not immediately or consistently improve export water quality. However, after two seasons of P reduction, P concentrations at the site with 35% P reduction, and the lowest applied P rates, had harvest discharge water TP of 0.25 mg/L compared to 0.8 mg/L in the pre-reduction year.
- In plot-scale studies, cranberry yield was not related to applied P fertilizer. As P application rate increased to 22.4-33.6 kg/ha, soil and tissue P increased. However, at lower rates, soil and tissue P were in the sufficient range. Based on these plot studies, rates lower than 22.6 kg/ha (20 lb/acre) should be sufficient to support cranberry cultivation at least in the short term (1-3 years). Exactly how much reduction would be sustainable for longer periods remains unclear.

Recommendations

- Cranberry fertilizer applications just prior to flooding events should be avoided.
- Deposition of fertilizer into water that will exit the bog system should be avoided.
- Since flood discharges are the primary source of P release from the bog system, particular care should be taken in flood management:
    - ➢ Harvest floods should be retained on the bog for 1-3 days to allow particulate settling. Additional benefit may occur by the placement of physical barriers to particulate discharge (e.g. harvest booms place before the water exits the discharge flume) or the installation of tailwater recovery ponds.
    - ➢ Harvest flood retention for >10 days should be avoided if the discharge is to a nutrient-sensitive water body.
    - ➢ Tailwater recovery or discharge through holding ponds could reduce TP export from the bog system.
    - ➢ Winter flood withdrawal from beneath newly-formed ice should be the preferred practice in order to avoid anoxia injury to the cranberry plants and to minimize P movement from the soil into the flood water by minimizing the time that the flood remains on the bog.
- Fertilizer P rates should be no greater than 20 lb/a (22.4 kg/ha) on established cranberry beds. For native cultivars on organic soils, rates as low as 10-15 lb/a should be sufficient unless tissue tests show deficiency of P (<0.1% in plant tissue sampled in August). Fertility programs should be conservative but stable -- as a perennial plant cranberries often are responding to fertilizers applied in the previous year. To achieve lower P rates without inducing nitrogen deficiency, fertilizers with N:P_2O_5 ratios of 2:1 or 1:1 are

recommended. This would provide a ratio of N:P (actual) of 4:1 or 2:1. Examples of commercial products that fit this recommendation include 18-8-12 (approximately 4N:1P) or 15-15-15 (approximately 2N:1P).

- Despite the outcome of plot-scale research in this study, elimination of P fertilizer applications is not recommended based on previous studies (DeMoranville and Davenport, 1997; Greidanus and Dana, 1972; Eck, 1985) and on the poor availability of soil bound P during rapid plant growth and fruiting (summer). In addition, P rates greater than those recommended here may be necessary to replenish soil P stocks if soil or tissue test P results fall below the sufficient range.

PROJECT SUMMARY

Introduction

Under the requirements of the Federal Clean Water Act, the Massachusetts DEP has been charged with the task of developing TMDL (total maximum daily load) reports for impaired water bodies on the state 303d list. Some of the water bodies on this list receive discharge water from cranberry production systems. Nationally, water quality degradation of inland water bodies has been associated with phosphorus inputs. While phosphorus inputs stem from a variety of sources, nonpoint pollution from agriculture can be a major contributing factor to water degradation in some areas. Both animal agriculture and crop production can enhance nutrient inputs to surface waters (Sharpley, et. al., 1999). Cranberry production is the major form of agriculture in S.E. Massachusetts. Although cranberry agriculture typically has a low fertilization rate compared to many crops, it generally discharges bog waters through surface water flow directly to streams, ponds or lakes. Frequently this outflow of agricultural system water contains elevated levels of nitrogen and phosphorus, nutrients central to eutrophication of inland and coastal waters. For this reason, nutrient release by cranberry agriculture needs to be included in the development of TMDLs by the State of Massachusetts.

Cranberry is a wetland plant. Culture of this native plant is intimately associated with water. Water is used for frost protection, irrigation, pest management (to minimize the need for pesticides), harvest, and protection from desiccation and low-temperature injury during the winter. Historically, cranberry cultivation has been associated with wetlands, which provide suitable acidic soils and abundant surface water. Wetlands are extremely sensitive habitats for wildlife and play essential role in the hydrologic and nutrient cycles of watersheds, as a result cranberry culture has drawn intense scrutiny from the public, private advocacy groups and environmental agencies.

It has been estimated that Massachusetts cranberry production requires up to 10 acre-feet of water from all sources, although the most efficient beds may require half this amount. Water bodies associated with cranberry production in Massachusetts may have multiple uses and inputs including wildlife habitat, recreation, residential inputs (septic and surface runoff), and storm water discharge. Since cranberry production is dependent on a ready supply of clean water it is in the best interest of growers to minimally affect water quality. In addition, since water supplies are finite, the industry has made a significant effort at increasing water-use efficiency through the implementation of Best Management Practices (BMPs), such as laser leveling and tail-water recovery systems.

Fertilizing cranberries is a common and recommended practice. Research and grower experience has shown increased cranberry yields when appropriate amounts of fertilizer are added to producing beds. The primary nutrients added are nitrogen, phosphorus and potassium. Nitrogen is added exclusively in the ammonium form. Potassium is usually added as part of a blended fertilizer, typically as potassium sulfate. Potassium is thought to leach through the soil but is not known to cause significant environmental degradation. Phosphorus is also applied in blended fertilizers, usually as triple superphosphate, monoammonium phosphate, or diammonium phosphate.

Previous "grab sample" research in Wisconsin has shown that the concentration of soluble phosphorus in water exiting cranberry marshes is usually between 0.1 and 0.003 mg/l (WI DNR, unpublished data). The concentration of soluble phosphorus in these waters is usually below 0.1 mg/l. However, because of the large quantities of water discharged, the total phosphorus load may be significant.

The amount of fertilizer applied to cranberry beds is much smaller than would be applied to most agronomic crops. While potatoes or corn may receive 200 lb actual N/a, cranberries may receive 0 to 40 lb actual N/a per year (Hart et. al., 2000). The acidic soils common to cranberry culture tend to have high concentrations of iron, aluminum and magnesium. When phosphorus fertilizer (as ortho-phosphates) is added to the plantings it forms insoluble compounds with these naturally occurring metal cations and becomes unavailable to the plant. Therefore, cranberry growers make frequent applications of phosphorus fertilizer to keep some phosphate ions in the soil solution to support plant uptake. Previous research in Massachusetts (DeMoranville and Davenport 1997) has shown a yield increase with application of P fertilizers, but there was no observable increase in yield beyond 20 lb P/a. However, no information was available regarding response of cranberry productivity and plant growth to levels of P greater than 0 but less than 20 lb/a.

A great deal of literature exists regarding the movement and release of nutrients, including phosphorus, in natural wetland systems, both estuarine and fresh water (Johnston 1991, Nixon 1980, Howes *et al.* 1996). Existing data regarding fresh and salt water wetlands can be used as a point of comparison for the export of phosphorus and nitrogen from cranberry wetland systems. However, in this project a natural wetland in southeastern Massachusetts was examined to provide a benchmark for determining natural marsh export under local climate and geologic conditions.

There is very little available data documenting phosphorus dynamics related to cranberry agriculture. Current data consist mostly of single or occasional (non-systematic) grab samples. A report funded in part by the Lac Courte Oreilles tribe of Native Americans and the Lac Courte Oreilles Lake Owners Association suggested some phosphorus related water degradation associated with cranberry production on Musky Bay of Lac Courte Oreilles, WI (Barr Engineering, 1998). However, this study drew heavily on a limited number of grab samples. Mass balance calculations were not conducted to estimate total seasonal phosphorus dynamics. A study in Massachusetts, which included careful mass balance calculations, documented nitrogen and phosphorus release from established cranberry bogs to Buzzards Bay (Howes and Teal, 1995).

In that study, nitrogen losses were similar to those in surface water-dominated vegetated wetlands. Phosphorus output was shown to be minimal with the exception of certain seasonal occurrences, associated with the release of flood waters. As stated above, cranberry soil chemistry, particularly the high iron and aluminum associated with acidic soils, leads to extensive binding of phosphorus as iron and aluminum phosphates in the soil. However, it has been shown in rice (Shahandeh et al., 1994) that phosphorus can be released from such compounds when flooded soils become anaerobic. A similar phenomenon occurs in pond sediments during anaerobic events. It is likely that the spikes of P associated with flood release were related to change in aerobic state of the surficial soils during the flooded intervals.

Based upon present information, it is clear that:
- cranberry agriculture typically requires periodic phosphorus fertilizations;
- reducing fertilizer inputs represents a potential BMP for reducing phosphorus release, but the response of production to fertilization rates between 0-20 lb P/a is not known;
- cranberry agriculture releases phosphorus in discharge waters;
- generally the concentrations of phosphorus are low due to the natural sorption of ortho-phosphate by acidic soils;
- periodic release of phosphorus associated with flooding may represent much of the annual transport to receiving waters.

Project Objectives:

In order to formulate TMDL standards for phosphorus, information that is extensive enough to allow generalization of the results to the predominant cranberry bog types in Massachusetts is needed. The information may also allow the recommendation of site-specific changes in practice that limit P export from cranberry systems while maintaining sustainable production of the crop (defined as >150 bbl/a for native selections and >200 bbl/a for hybrid cultivars).

The following research questions were posed:

- How much P enters and leaves cranberry bog systems on an annual basis (mass balance)? How does this compare to release from a natural freshwater wetland in the area and literature values for other wetlands and other land use types?

- How does change in fertility practices (decreasing P rate) affect cranberry growth and productivity under the varied soil conditions? Can reductions in fertilization maintain cranberry production, while reducing phosphorus loss to receiving waters.

- Is flood release the major source for P (and N) export from cranberry systems or are other water management practices also a source? Is there a natural seasonal cycle in P release independent of flooding cycles?

Research objectives (from original proposal)

1. Determine P and N import and export from representative cranberry beds based on water events (any movement into or out of the system), including floods, irrigation and rain events. Determine extent of P (and N) input/output from cranberry systems on a seasonal basis. This is a survey study not a fully implemented mass-balance.

2. Determine N and P export from a natural freshwater wetland in southeastern Massachusetts.

3. Determine P and N export from cranberry beds where P fertilizer rate is reduced to less than 20 lb P/a. Compare to beds receiving 20 lb P/a or more. Collect yield data from these beds.

4. Determine the impact of reduction in P fertilization on cranberry sustainability.

Approach - experimental design

For Experiments 1-3 a Quality Assurance Plan was formulated prior to the initiation of sampling. Records of all fertilizers applied was maintained. See the Environmental Monitoring section.

Experiment 1 - Objectives 1 and 3. The study consisted of 3 pairs of non-flow through bogs, i.e. bogs where all water in and out was managed either by pumping or gravity flow. Two pairs consisted of organic soils and the third pair were mineral soil bogs. These types represent approximately 80% of Massachusetts cranberry bogs. In the first year of the study, all bogs were to receive at least 20 lb P/a in fertilizer applications. Bog selection was based on systems where water is *pumped*. This hydrologic control enhanced our ability to construct nutrient budgets for N and P using only grab sampling approaches coupled with metered flows and stage measurements. Table 1 contains a description of the bog sites, maps are shown in Appendix 1.

Table 1. Bog sites for nutrient budget study.

						Fertilizer P kg/ha	
Pair	**Bog name**	**Soil type**	**P regimen**	**Size (ha)**	**2002**	**2003**	**2004**
1	Eagle Holt	Organic	Reduced	25.62	20.0	16.1	6.3
1	Pierceville	Organic	Control	18.22	27.9	25.0	19.4
3	Benson's Pond	Organic	Reduced	9.71	22.4	18.1	19.6
3	White Springs	Organic	Control	3.08	22.4	20.6	18.8
2	Mikey/Kelseys	Mineral	Reduced	2.23	32.2	22.2	23.7
2	Ashleys	Mineral	Control	1.94	39.8	36.3	31.4

Beginning in May each year, and continuing for three years, water was sampled from the bogs (Table 2). Sampling was accomplished by collecting water during each event when water is moved onto or off of the bog. In addition, samples of pore water within the bog were collected, as were samples of source waters recharged from groundwater. Water samples were collected, for reference purposes, from standing flood waters over the surface of the bogs during flood events. Samples were analyzed for ammonium, TON, nitrate, total N (2003 and 2004 only), ortho-P, and total P (see Environmental Monitoring section).

Table 2. Description of water sampling stations for cranberry bog study.

Bog site	Sample site designation	Description	Associated events
Eagle Holt	EH1	Inlet from Blackmore Pond	Incoming harvest and winter floods
	BLK-2	Blackmore Pond	Irrigation, Frost, Chemigation 2002 and 2003
	EH1a	Sump filled from pond	Irrigation, Frost, Chemigation 2004
	EH2	Outlet to pond	Outgoing harvest and winter floods
	EH3	Outlet to rest of bog	Outgoing harvest and winter floods
	EH7a	Flooded Section K7	On bog water for flood graphs
	EH7b	Flooded section K6	On bog water for flood graphs
	EH7c	Flooded section K20	On bog water for flood graphs
	EH7e	Flooded section K9	On bog water for flood graphs
	EH7f	Flooded section K8	On bog water for flood graphs
	EH10	Inlet form K5	Incoming harvest flood from rest of bog
Pierceville	PV1	Inlet from Weweantic	Incoming harvest and winter floods
	PV1a	Irrigation pond for C2	Irrigation, frost, chemigation
	PV2	Discharge canal	Outgoing water
	PV3	Flooded bog samples	On bog water for flood graphs
	PV4	Irrigation pond for C1	Irrigation, frost, chemigation
	PV5	Irrigation pond for C3/4	Irrigation, frost, chemigation
Benson's Pond	BEN1	Groundwater fed water hole	Upwelling groundwater
	BEN2	Discharge canal	Outgoing harvest and winter floods
	BEN3	Irrigation pond*	Irrigation, frost, chemigation, surface discharge
	BEN4	Inlet from Weweantic	Incoming harvest and winter floods
	BEN5	Flooded bog samples	On bog water for flood graphs
White Springs	WS1	Inlet from Barret Pond	Incoming harvest and winter floods
	WS2	Discharge canal	Outgoing water
	WS3	Irrigation Pond	Irrigation, frost, chemigation, incoming groundwater
	WS4	Flooded bog samples	On bog water for flood graphs
Mikey/Kelsey	EH5	Water supply	All incoming water
	EH6	Discharge canal	Outgoing water
	EH8a	Flooded Mikeys	On bog water for flood graphs
	EH8b	Flooded Kelseys	On bog water for flood graphs
Ashleys	EH4	Water supply	All incoming water
	EH7d	Flooded bog samples	On bog water for flood graphs
	EH9	Discharge canal	Outgoing water

*fed from surface discharge

Periodically in spring and fall soil samples were collected randomly from each property and analyzed to characterize the phosphorus status of the soils on the test farms using the established soil test method Bray-1 (Bray and Kurtz, 1945). At this time research is underway at Washington State University and at the University of Wisconsin designed to identify a more diagnostic soil test for P in cranberry systems. As yet, such a method has not been discovered, although anion exchange membranes are promising. At present, the Bray test is the method of choice in cranberry nutrient planning.

Results of water quality sampling were used to approximate mass balance relationships as nutrient input/output budgets for N and P in the bog systems. Water volumes were estimated for all water movement events at the bog sites (see next section) and the volumes multiplied by appropriate sample nutrient concentrations to calculate kg of nutrient for each event. Nutrients in rainwater were assigned based on previous research (Hu et al., 1998). Nutrients in cranberry crop and removed biomass was estimated based on previous cranberry research (DeMoranville, 1992).

Flows were measured using an electromagnetic flow meter (Marsh McBirney, Inc.). Water depth was measured using logging pressure transducer water level monitors in water supplies and channels (Global Water Inc.) and with staff gauges (meter sticks) deployed in the bogs.

Water volume determinations

Incoming water for the bog sites consisted of rainfall, water applied through the irrigation system (frost, irrigation and chemigation events), flooding for harvest and winter protection, and groundwater upwelling (2 sites only). Since water upwelling was not measured directly, this volume was calculated as the difference between applied irrigation at these sites and that applied at a similar site that did not have incoming groundwater. Rainfall volume was assigned based on that recorded at the Cranberry Station in East Wareham, MA.

Outgoing water consisted of evapotranspiration (ET), flood discharge, and surface runoff or infiltration into the water table. ET for this region of the United Stated (based on USGS data) is 23 inches per year. The only published value (Hattendorf and Davenport, 1996) for cranberry ET of 7 to 17 mm/wk is considerably lower than 23 inches per year. However, that study was conducted in Washington at a location with lower temperature and sunshine than the Massachusetts cranberry region. A sphagnum bog in this region had an annual ET of ~40 inches (Hemond, 1980). During the summer months, Spartina growing in coastal Massachusetts had ET rates similar to those in the sphagnum bog (Howes et al., 1986). At a coastal cranberry bog, Howes and Teal (1995) calculated ET at 26.7 inches during the year of their study. In 1999 and 2000, B. Lampinen (personal communication) estimated ET for cranberry at the Cranberry Station bog. In the wetter year, ET averaged 0.82 inches per week, and in the drier year, 0.92 inches per week during the active growing season. Based on the monthly estimations at the sphagnum bog (Hemond, 1980), 75% of annual ET occurs from May through October. Extrapolating from Lampinen's summer data, annual ET for cranberry can be estimated at 29 inches per year. This value was used in the bog water budgets.

The assumption was made that the volume of water coming into the bogs must equal that leaving. In all cases, once flood discharge and ET were taken into account, there was remaining water that must be accounted for by surface runoff or infiltration.

Changes in water table depth at the bog sites were not measured. Therefore, the water to be assigned to surface discharge and/or infiltration was assigned based on certain assumptions. When surface runoff was observed at a site during much of a season, all remaining discharge volume was assigned to surface discharge. This is a simplification that leads to some overestimation of nutrient discharge since some (or most) of the nutrients in the water that infiltrates would be retained within the soil and subsoil of the bog, while those in surface discharge potentially move off site.

If surface discharge was not observed, infiltration was assumed to account for remaining discharge water. Since we did not sample the nutrient content of infiltrating water, and since there is evidence that much of these nutrients remain in the bog (Howes and Teal, 1995), no nutrient value was assigned to this water. This of course, leads to some degree of underestimation of total discharge.

In some cases, a portion of the discharge remainder volume was assigned to surface discharge based on flows observed during only part of the season. Attempts were made to estimate volume during observed surface runoff. However, generally, flow was extremely slow and consisted in a very shallow film of water in the channel. We were not able to obtain accurate estimations using a flow meter and the depth was too shallow for successful deployment of the pressure transducer depth monitors.

Discharge volume for flooding events was assumed to equal that of the incoming flood for that event and the entire volume was assigned to surface discharge. However, in the nutrient budget, assigning 100% to surface discharge may overestimate the nutrient discharge since for any portion of the flood that actually infiltrated, some portion of those nutrients would be retained in the bog soil. Saturated mineral and organic wetland soils such as those in cranberry beds, have some capacity to retain nutrients from subsurface flows (Phillips, 2001; Richardson, 1985). Based on observations at the Eagle Holt site where water level in the adjacent pond was monitored, close to 20% of the flood can infiltrate into the water table during the period of flooding if the water table is low prior to the flood event. This estimate is based on the increase in volume of the adjacent pond during the time that the 2002 harvest flood was maintained on the bog. However, following a wet summer (2003), no change in pond level was observed during the harvest flood. After the dry fall of 2003, some loss to groundwater was observed when the winter flood was applied (based on increased level in the adjacent pond). In early January 2004, the pond volume increased during the winter flood by the equivalent of 6% of the volume of the flood that was applied to the adjacent bog. Overall, in this study, flood infiltration appeared to be minimal except following prolonged drought conditions, such as at harvest in 2002.

The standard practice for winter flooding is to flood the bog in December or early January when weather conditions are such that the soil would freeze and the plants desiccate due to windy conditions (DeMoranville, 1998) . Generally, the flood is applied and retained until a surface layer of ice forms. Once the surface has frozen, the remaining water is removed from beneath the ice to avoid having anoxic water over the plants. In coastal Massachusetts conditions, the remaining ice generally thaws in mid-January. Additional water is then added to once again cover the plants. In this study, we estimated that 50% of the original volume was discharged and replaced during the mid-winter and that the final discharge would be equal to the entire original volume. In the late fall of 2002, growers collected rainwater on the bogs as part of the winter flood. This was necessary after the drought in the previous summer -- water supplies were low after harvest and growers feared not having enough stored water for the winter, thus they collected rainwater on the bogs through the late fall. Volume estimates for additional surface water for the initial winter flood that year are noted for each site (below).

Many of the estimates for volume of water applied using pumps were based on pump logs kept by the growers in which they recorded date and times that each pump was operated. We attempted to install volume monitors on the bog pumps but were not able to get the devices to operate properly. As an alternative, growers calibrated their pumps annually so that accurate estimates of volume were generally possible if the grower maintained accurate logs of minutes of pump operation.

Specific measurements and calculations for bog site water volumes are shown in Appendix 2.

Experiment 2 - Objective 2. [See also Appendix 3A]. This experiment was conducted in a natural freshwater wetland subwatershed in Southeastern Massachusetts. The site was chosen based on the assumption that it was roughly similar to cranberry wetlands, with water entering into the wetland predominantly from surface flow. Final site selection was accomplished after consultation between the project coordinators and wetlands specialists from MA DEP.

Water was collected using autosamplers (ISCO systems) that were placed to collect inlet and discharge waters in the wetland. Water flow was indirectly measured at each sampling station by a pressure transducer/data logger instrument. This instrumentation measured water level or stage, which was converted to flow volume based upon an empirically derived relationship between water level and flow volume. Flow volume was determined periodically by measuring flow velocities across the stream using an electromagnetic flow meter. The stage recorders were located adjacent to the autosamplers and programmed to record the water levels in the streams on a 15 minute basis.

The annual flux of nutrients into and out of the Westport River Wetland (WP) was estimated with flow and stage data and with nutrient data analyzed by SMAST. At the lower Westport site, continuous data were available from April 25, 2002 to October 30, 2002, from April 18, 2003 to July 7, 2003 and from April 9, 2004 to November 3, 2004. These stage data were used with measured instantaneous flow rates to predict continuous daily flows for the two years, April to April 2003-2004 and 2004-2005. In 2002, although stage data were recorded, there was insufficient accompanying flow data collected to allow prediction of continuous daily flows. Where stage data were not available during the 2003-2004 period, flows were interpolated from ratios of existing flow data at the upper and lower sites. Nutrient data from samples taken at both upper and lower sites were matched to corresponding flow data. Data from grab samples were matched to flow data from the same day. Data from samples taken by auto samplers over several days and composited were matched to flow data for the same interval of dates. On days where no samples had been taken, data were interpolated from existing data to yield predicted values. Daily flux estimates were made by multiplying predicted flows by existing or predicted nutrient concentrations. Daily fluxes were then added together to give the annual flux at the lower site. Because the predicted flows from stage data appeared significantly higher than expected for this geographic region, additional estimates of annual flux were calculated based on extrapolations from grab sample nutrients and instantaneous flow measurements. Nutrient fluxes out of the Westport watershed at the lower site ranged from 6 to 265 times the fluxes measured at the upper site (upper site was not at the top of the watershed).

Samples were analyzed for ammonium, nitrate, TON, ortho-P, and total P. Soil samples were collected randomly from the wetland and analyzed as in experiment 1. This study began in May 2002 (nutrient data only for 2002) and continued for three years. At the end of the study, cranberry discharge values were compared to those in the natural wetland.

Experiment 3 - Objectives 3 and 4. Using one bog from each of the paired sites in Experiment 1, the effect of reduced P fertilizer rate was examined (see Table 1 for rates). Water sampling continued as outlined under Experiment 1. Beginning in the second spring, one bog from each pair received a fertilizer regimen in which P rate was reduced. However, reduction was not achieved at one organic soil pair due to lack of grower cooperation. For one bog from each pair at the other organic soil pair and the mineral soil pair, fertilizer P use was reduced by 30-35% in both the second and third years of the study. Based on previous recommendations, the actual P rates applied at the mineral soil bogs was greater that that for the organic soil pairs.

Yield data for all bog pairs was collected and compared between bogs and to previous production history.

Experiment 4 - Objective 4. To further study the impact of reduced P rates on productivity, field plot research was conducted at 6 locations. Two protocols were followed (4 sites each). In the first, nitrogen, phosphorus, and potassium were applied separately with only P rate varying. In the second set of plots, P rate was varied by manipulating the use of commercial fertilizer products (a more commercially viable approach than individual element applications). Locations were chosen to reflect the range of soil types studied in objective 1. Protocols follow.

Phosphorus rate series. Field plots were established in a CRB design (4 locations, same cultivar, as blocks); 2x2 m plots; 5 replicates of each treatment in each block. At two locations, plots were treated for two years and at two other locations, plots were treated for three consecutive years. N was applied at 28 kg/ha (21-0-0 at 134 kg/ha) and K at 33.6 kg/ha (0-0-50 at 81 kg/ha) to all plots. Treatments were actual P rates of 0, 2.8, 5.6, 11.2, 16.8, 22.4, and 33.6 kg/ha (applied as 0-46-0). All fertilizer rates were divided equally into 3 applications and broadcast at roughneck stage, 75% bloom, and 2-3 weeks after 75% bloom.

N:P ratio series and phosphorus form. Field plots were established in a CRB design (4 locations, same cultivar, as blocks); 2x2 m plots; 5 replicates of each treatment in each block. The treatment protocol is shown in Table 3. N and K were applied as 21-0-0 and 0-0-50 respectively except for the 12-24-12 and 14-14-14 treatments. All granular materials were divided into 3 applications and broadcast at roughneck stage, 75% bloom, and 2-3 weeks after 75% bloom. Foliar P applications were made at early bloom, late bloom, and bud set stages.

Table 3. Fertilizer protocol for N:P ratio series field plot study. Rates are in kg per hectare of the actual elements. Fertilizers were applied in 3 evenly split applications each year.

	Rate (kg/ha)			
Treatment	**N rate**	**K rate**	**P rate**	**P form**
Untreated control	0	0	0	none
Zero P control	26	21	0	none
12-24-12	26	21	22.4	granular blend
14-14-14	26	21	11.2	granular blend
Granular 1N:1P	26	21	22.4	0-46-0 granular
Granular 2N:1P	26	21	11.2	0-46-0 granular
Granular 4N:1P	26	21	5.6	0-46-0 granular
Foliar 2N:1P	26	21	11.2	0-52-34 foliar, phosphoric acid
Foliar 5N:1P	26	21	5.6	0-52-34 foliar
Granular/Foliar 2N:1P	26	21	11.2	0-46-0, 0-52-34

The plot experiments continued for 4 seasons. Evaluations included: soil and tissue testing at years 1 and 3 and yield evaluation each season (a 30 x 30 cm area was hand harvested, the fruit was weighed, counted, and evaluated for field rot). Upright density evaluations originally planned were not carried out based on lack of utility for this metric as determined in other field studies that occurred during the course of this project. Yield evaluation data were analyzed using PROC GLM and PROC REG of PC SAS (SAS Institute, Cary, NC).

Contracted tasks summary

In order to accomplish the objectives and experimental plan for this study, certain tasks were established in the Scope of Services, on file with MA DEP.

A Quality Assurance Project Plan was prepared, was approved, and is on file at the Division of Watershed Management, Department of Environmental Protection, 627 Main Street, Worcester, MA 01608. See also the Environmental Monitoring Section. Bog and reference watershed sites were selected and approved by the DEP Project manager. The locations are described in Appendix 1.

The sites were monitored and sampled as described above and in Appendix 2 and seasonal data tables for nutrient and water budgets, soil analyses, and crop yields were prepared and are reported here (results section and Appendix 3 A-B, 4 and 5). A season or cranberry year was set as a 12 month period beginning in May. Field plots were established to study effect of P fertilizer rates on crop yield. The results are reported and discussed (results section and Appendix 6).

Results and discussion

Quality assurance sampling was conducted throughout this study and QA/QC goals were met (Appendix 7). While water field blanks did show detectable TP, in the range of 10 ppb, field samples were generally much higher in TP, indicating that there is no serious contamination issue. A full discussion of QA/QC sampling and outcomes is found in Appendix 7.

Bog sites

By May of 2002, all bog sites had been selected and monitoring protocols were in place. The 2002 season was designated as the baseline -- no P reductions were planned. In 2003 and 2004, P fertilization was reduced at one site from each pair, but at both sites at the Benson's/White Springs pair (Table 1). Water samples were collected at each site at approximately 3 week intervals or when events occurred that included water movement. Soil samples were collected at each bog site in the early spring of each year and in the Fall of 2003 and 2004. Table 4 shows average soil test P results for the bog sites (see Appendix 4 for the complete data set). These data highlight the variability problems with the use of the Bray test for cranberry soils. Despite two years of reduced P application, the Eagle Holt and Mikey/Kelsey sites show higher P at the end of the study compared to that in the initial year. However, within a sampling period (e.g. Fall 2004), the reduced bog soils did have lower Bray P compared to those of the companion control bogs.

Table 4. Average soil test P for bog sites.

					Soil test P (Bray) ppm		
Bog name	**Soil type**	**P regimen**	**Spring 2002**	**Spring 2003**	**Fall 2003**	**Spring 2004**	**Fall 2004**
Eagle Holt	Organic	Reduced	58.2	63.8	88.8	80.5	66.9
Pierceville	Organic	Control	50.5	57.3	87.3	80.3	92.0
Benson's Pond	Organic	Reduced	46.0	61.0	75.8	66.4	77.2
White Springs	Organic	Control	61.5	60.4	76.2	79.0	95.3
Mikey/Kelseys	Mineral	Reduced	60.0	78.3	103.0	82.0	79.8
Ashleys	Mineral	Control	68.8	71.5	118.8	70.5	98.5

Tables 5-13 show the water and nutrient budgets for the 3 paired sites for the 3 years of the study (2002-2004). Total inputs and outputs were compared. In addition, a comparison was made between the nutrient load in the incoming water vs. that in outgoing water (fluvial budget). The total annual water use at the bog sites varied from approximately 8 to >11 acre feet per season depending on site and year.

Table 5. Water and nutrient balance sheets for Organic Soil Bog Pair 1. Data for 2002 (year 1). No reduction in phosphorus fertilizer rate. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Data for TON and TN were not collected in 2002.

		Organic soil - Reduced 1 (Eagle Holt) 25.62 ha						Organic soil - Control 1 (Pierceville) 18.22 ha					
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TDN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TDN**
Inputs	Rainfall	366,256,851		7.79			281.69	260,430,029		5.54			200.29
	Irrigation	32,753,511	0.14	0.40	0.36	0.31	13.59	36,206,117	1.12	2.25	0.57	0.15	15.83
	Frost protection	58,381,629	0.26	0.73	0.66	0.57	21.52	31,742,393	0.78	3.34	0.44	0.16	14.10
	Pest management	2,183,700	0.02	0.03	0.01	0.01	1.06	3,039,802	0.16	0.26	0.16	0.01	1.97
	Harvest	58,937,022	1.29	2.96	2.30	1.54	25.14	115,982,857	4.66	7.61	2.12	2.65	55.31
	Winter protection	114,229,975	1.03	2.12	4.26	4.53	51.10	107,308,956	10.97	14.63	3.10	3.06	52.01
	Fertilizer			513.50			897.90			508.30			805.10
	total	**632,742,688**	**2.74**	**527.53**	**7.59**	**6.96**	**1292.00**	**554,710,154**	**17.69**	**541.93**	**6.39**	**6.03**	**1144.61**
Outputs	Evapotranspiration	188,691,574						134,170,738					
	Drainage/infiltration	229,280,945						143,593,125					
	Harvest	58,937,022	18.71	19.81	1.34	0.49	32.94	115,982,857	51.42	64.15	1.68	1.04	81.26
	Winter	155,768,148	13.41	27.36	2.78	0.18	20.41	160,963,434	20.92	29.63	3.48	3.35	80.79
	Plant material harvested			96.76			558.47			68.79			397.01
	total	**632,677,689**	**32.12**	**143.93**	**4.12**	**0.67**	**611.82**	**554,710,154**	**72.34**	**162.57**	**5.16**	**4.39**	**559.06**
	fluvial export load (kg/ha/yr)		**1.25**	**1.84**	**0.16**	**0.03**	**2.08**		**3.97**	**5.15**	**0.28**	**0.24**	**8.89**
	Net output (kg/ha/yr)												
	Total budget		***1.15***	***-14.97***	***-0.14***	***-0.25***	***-26.55***		***3.00***	***-20.82***	***-0.07***	***-0.09***	***-32.14***
	Fluvial budget		***1.15***	***1.29***	***-0.14***	***-0.25***	***-13.30***		***3.00***	***3.30***	***-0.07***	***-0.09***	***-9.74***
	kg fertilizer added per ha			***20.04***			***35.05***			***27.90***			***44.19***

Table 6. Water and nutrient balance sheets for Organic Soil Bog Pair 1. Data for 2003 (year 2). Phosphorus fertilizer was reduced at the Eagle Holt site. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Rainfall N and fertilizer N are included as TDN and TN. *Due to missing data, some nitrogen values are estimates.

		Organic soil - Reduced 1 (Eagle Holt) 25.62 ha								Organic soil - Control 1 (Pierceville) 18.22 ha							
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**
In	Rainfall	278,027,274		7.79				281.69	281.69	197,693,643		5.54				200.29	200.29
	Irrigation	37,144,237	0.25	1.86	0.56	0.12	11.00	9.99	11.69	28,265,508	1.52	6.05	0.86	0.33	29.95	20.55	31.14
	Frost protection	56,160,544	0.27	0.95	1.13	0.09	17.98	16.18	19.21	39,420,464	1.22	5.89	1.12	0.31	32.88	27.26	34.32
	Pest management	2,183,700	0.01	0.02	0.10	0.01	0.98	0.99	1.08	3,039,802	0.32	1.18	0.09	0.14	4.37	1.72	4.60
	Harvest	96,125,082	0.36	1.73	1.78	0.46	31.10	28.77	33.35	115,335,551	7.65	16.01	3.78	2.54	72.32	48.93	78.64
	Winter protection	162,815,282	0.49	3.22	4.67	1.12	88.91	86.15	94.70	98,318,595	3.58	4.38	2.81	6.87	48.10	51.12	57.78
	Fertilizer			412.50				935.20	935.20			454.90				663.70	663.70
	total	**632,456,119**	**1.38**	**428.07**	**8.24**	**1.80**	**149.97**	**1358.97**	**1376.92**	**482,073,563**	**14.29**	**493.95**	**8.66**	**10.19**	**187.62**	**1013.57**	**1070.47**
Out	Evapotranspiration	188,691,574								134,170,738							
	Drainage/infiltration	218,266,881	0.51	0.74	0.68	0.07	22.61	8.14	23.37	134,248,679	3.72	11.01	6.18	0.83	51.96	33.23	58.97
	Harvest*	96,125,082	34.35	46.15	4.57	0.37	85.77	59.85	89.44	115,335,551	53.53	69.14	2.58	1.08	126.68	89.82	130.34
	Winter*	129,352,583	17.66	34.95	13.33	1.25	139.71	109.15	143.35	98,318,594	18.20	24.90	5.50	2.90	80.90	60.50	89.20
	Plant material harvested			97.34					561.34			69.20					399.08
	total	**632,436,120**	**52.52**	**179.18**	**18.58**	**1.69**	**248.09**	**177.14**	**817.50**	**482,073,562**	**75.45**	**174.25**	**14.26**	**4.81**	**259.54**	**183.55**	**677.59**
	fluvial export load (kg/ha/yr)		**2.05**	**3.19**	**0.73**	**0.07**	**9.68**	**13.82**	**10.00**		**4.14**	**5.77**	**0.78**	**0.26**	**14.24**	**10.07**	**15.29**
	Net output (kg/ha/yr)																
	Total budget		***2.00***	***-9.71***	***0.40***	***0.00***	***3.83***	***-46.13***	***-21.84***		***3.36***	***-17.55***	***0.31***	***-0.30***	***3.95***	***-45.56***	***-21.56***
	Fluvial budget		***2.00***	***2.59***	***0.40***	***0.00***	***3.83***	***-9.63***	***-7.24***		***3.36***	***3.62***	***0.31***	***-0.30***	***3.95***	***-9.13***	***-7.04***
	kg fertilizer added per ha			***16.10***					***36.50***			***24.97***					***36.43***

Table 7. Water and nutrient balance sheets for Organic Soil Bog Pair 1. Data for 2004 (year 3). Phosphorus fertilizer was reduced for the second year at the Eagle Holt site. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Rainfall N and fertilizer N are included as TDN and TN.

		Organic soil - Reduced 1 (Eagle Holt) 25.62 ha								Organic soil - Control 1 (Pierceville) 18.22 ha							
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**
In	Rainfall	336,196,331		7.79				281.69	281.69	239,055,243		5.54				200.29	200.29
	Irrigation	33,114,943	0.16	1.03	0.66	0.13	13.20	10.89	13.99	36,206,117	1.25	5.14	1.45	0.10	44.32	27.82	45.87
	Frost protection	53,053,695	0.22	1.27	1.34	0.19	25.69	22.08	27.22	49,197,814	2.14	6.34	2.23	0.48	57.70	40.89	60.41
	Pest management	4,728,960	0.01	0.05	0.03	0.01	1.46	1.35	1.51	3,220,972	0.09	0.46	0.12	0.00	4.30	2.56	4.42
	Harvest	71,122,569	1.37	1.58	1.18	0.71	46.12	41.26	48.01	90,047,462	2.43	7.08	4.85	1.56	70.09	62.77	76.49
	Winter protection	238,922,572	0.55	4.22	2.06	7.72	102.37	95.23	112.14	156,719,983	6.18	11.33	8.98	7.95	95.80	98.65	112.74
	Fertilizer			162.30				849.20	849.20			352.50				741.80	741.80
	total	**737,139,070**	**2.31**	**178.24**	**5.27**	**8.76**	**188.84**	**1301.70**	**1333.76**	**574,447,590**	**12.09**	**388.39**	**17.63**	**10.09**	**272.21**	**1174.78**	**1242.02**
Out	Evapotranspiration	188,691,574								134,170,738							
	Drainage/infiltration	238,402,356								193,509,407							
	Harvest	71,122,569	13.54	19.57	0.89	0.53	58.08	45.36	59.51	90,047,462	58.61	64.87	2.51	1.03	106.66	83.56	110.20
	Winter	238,922,572	10.01	11.85	3.49	7.63	169.09	144.36	180.21	156,719,983	7.04	15.23	2.68	2.58	105.23	68.46	110.49
	Plant material harvested			112.55					637.43			84.71					476.62
	total	**737,139,071**	**23.55**	**143.97**	**4.38**	**8.16**	**227.17**	**189.72**	**877.15**	**574,447,590**	**65.65**	**164.81**	**5.19**	**3.61**	**211.89**	**152.02**	**697.31**
	fluvial export load (kg/ha/yr)		**0.92**	**1.23**	**0.17**	**0.32**	**8.87**	**7.41**	**9.36**		**3.60**	**4.40**	**0.28**	**0.20**	**11.63**	**8.34**	**12.11**
	Net output (kg/ha/yr)																
	total budget		***0.83***	***-1.34***	***-0.03***	***-0.02***	***1.50***	***-43.40***	***-17.82***		***2.94***	***-12.27***	***-0.68***	***-0.36***	***-3.31***	***-56.13***	***-29.90***
	fluvial budget		***0.83***	***0.60***	***-0.03***	***-0.02***	***1.50***	***-10.26***	***-9.56***		***2.94***	***2.43***	***-0.68***	***-5.18***	***-3.47***	***-15.42***	***-15.34***
	kg fertilizer added per ha			***6.33***					***33.15***			***19.35***					***40.71***

Table 8. Water and nutrient balance sheets for Organic Soil Bog Pair 3. Data for 2002 (year 1). No reduction in phosphorus fertilizer rate. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Data for TON and TN were not collected in 2002.

		Organic Soil Reduced Pair 3 - Benson's Pond 9.71 ha						Organic Soil Control Pair 3 - White Springs 3.08 ha					
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TDN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TDN**
Inputs	Rainfall	138,865,157		2.95			106.80	43,973,966		0.93			33.82
	Irrigation	13,018,574	0.09	0.85	2.02	1.16	8.81	4,125,951	0.01	0.07	0.05	0.04	0.76
	Groundwater upwelling	7,010,001	0.06	0.49	0.88	0.62	5.19	2,221,666	0.00	0.05	0.03	0.01	0.37
	Frost protection	18,897,929	0.10	1.60	1.38	0.55	12.16	5,989,284	0.01	0.25	0.04	0.03	1.00
	Pest management	1,679,816	0.01	0.09	0.24	0.14	0.84	532,381	0.00	0.01	0.02	0.01	0.14
	Harvest	53,878,398	1.79	2.88	1.31	10.63	32.04	12,655,503	0.38	0.91	0.06	0.10	4.50
	Winter protection	59266238	1.97	3.17	1.44	11.69	35.25	12,374,270	0.37	0.89	0.06	0.10	4.40
	Fertilizer			217.70			375.60			68.90			118.90
	total	**292,616,113**	**4.02**	**229.73**	**7.27**	**24.79**	**576.69**	**81,873,022**	**0.77**	**72.01**	**0.26**	**0.29**	**163.89**
Outputs	Evapotranspiration	71,541,829						22,654,912					
	Drainage/infiltration	86,378,289	0.70	4.79	21.14	11.46	74.27	29,688,602	3.36	11.86	2.18	0.22	24.16
	Harvest	53,878,398	16.87	25.14	1.83	32.12	77.74	12,655,503	2.49	2.78	0.28	0.23	0.36
	Winter	80,817,597	6.57	15.54	4.01	3.13	59.93	16,874,004	1.22	1.25	0.77	2.38	9.52
	Plant material harvested			39.63			226.44			9.72			57.57
	total	**292,616,113**	**24.14**	**85.10**	**26.98**	**46.71**	**438.38**	**81,873,021**	**7.07**	**25.61**	**3.23**	**2.83**	**91.61**
	fluvial export load (kg/ha/yr)		**2.49**	**4.68**	**2.78**	**4.81**	**21.83**		**2.30**	**5.16**	**1.05**	**0.92**	**11.05**
	Net output (kg/ha/yr)												
	Total budget		***2.07***	***-14.89***	***2.03***	***2.26***	***-14.24***		***2.05***	***-15.06***	***0.96***	***0.82***	***-23.47***
	Fluvial budget		***2.07***	***3.44***	***2.03***	***2.26***	***1.12***		***2.05***	***4.15***	***0.96***	***0.82***	***-3.56***
	kg fertilizer added per ha			***22.42***			***38.68***			***22.37***			***38.60***

Table 9. Water and nutrient balance sheets for Organic Soil Bog Pair 3. Data for 2003 (year 2). Phosphorus fertilizer was reduced at the Benson Pond site. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Rainfall N and fertilizer N are included as TDN and TN. *Due to missing data, some nitrogen values are estimates.

		Organic Soil Reduced Pair 3 - Benson's Pond 9.71 ha								Organic Soil Control Pair 3 - White Springs 3.08 ha							
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**
In	Rainfall	105,413,184		2.95				106.80	106.80	33,380,842		0.93				33.82	33.82
	Irrigation	10,498,850	0.25	0.82	0.77	0.29	7.88	7.15	8.94	3,327,380	0.06	0.23	0.09	0.01	0.72	0.65	0.82
	Groundwater in	6,999,233	0.18	0.65	2.34	0.55	6.81	7.05	9.70	2,218,253	0.04	0.12	0.06	0.01	0.55	0.51	0.62
	Frost protection	20,997,699	0.23	1.47	2.62	1.39	15.85	16.73	19.86	5,101,983	0.03	0.31	0.08	0.01	0.92	0.81	1.01
	Pest management	1,679,816	0.02	0.17	0.04	0.01	1.18	0.91	1.24	532,381	0.01	0.05	0.01	0.00	0.07	0.06	0.08
	Harvest	58,910,996	1.34	4.20	4.81	7.02	57.38	43.17	69.21	18,748,893	0.06	0.09	0.15	0.07	4.40	4.01	4.61
	Winter protection	80817597	1.84	5.76	6.59	9.63	78.72	59.23	94.95	16,874,004	0.03	0.08	0.18	0.12	5.17	4.88	5.46
	Fertilizer			175.30				408.20	408.20			63.40				129.30	129.30
	total	**285,317,375**	**3.86**	**191.32**	**17.17**	**18.89**	**167.82**	**649.24**	**718.90**	**80,183,736**	**0.23**	**65.21**	**0.57**	**0.22**	**11.83**	**174.04**	**175.72**
Out	Evapotranspiration	71,541,829								22,654,912							
	Drainage/infiltration	74,046,954	1.80	6.85	6.69	2.57	63.93	57.81	73.19	21,905,927	1.14	4.53	1.97	0.12	10.25	9.96	12.34
	Harvest	58,910,996	2.55	9.50	36.98	1.88	120.03	97.79	158.88	18,748,893	4.81	4.86	0.18	0.05	11.94	10.12	12.18
	Winter*	80,817,597	5.79	14.98	5.58	6.44	65.02	64.45	77.04	16,874,004	0.68	0.92	0.81	0.09	3.13	3.41	4.04
	Plant material harvested			37.12					213.92			13.07					74.29
	total	**285,317,375**	**10.14**	**68.45**	**49.25**	**10.89**	**248.98**	**220.05**	**523.03**	**80,183,736**	**6.63**	**23.38**	**2.96**	**0.26**	**25.32**	**23.49**	**102.85**
	fluvial export load (kg/ha/yr)		**1.04**	**3.23**	**5.07**	**1.12**	**25.64**	**22.66**	**31.83**		**2.15**	**3.35**	**0.96**	**0.08**	**8.22**	**7.63**	**9.27**
	Net output (kg/ha/yr)																
	Total budget		***0.65***	***-12.65***	***3.30***	***-0.82***	***8.36***	***-44.20***	***-20.17***		***2.08***	***-13.58***	***0.78***	***0.01***	***4.38***	***-48.88***	***-23.66***
	Fluvial budget		***0.65***	***1.58***	***3.30***	***-0.82***	***8.36***	***-2.16***	***-0.16***		***2.08***	***2.76***	***0.78***	***0.01***	***4.38***	***-6.90***	***-5.80***
	kg fertilizer added per ha			***18.05***					***42.04***			***20.58***					***41.98***

Table 10. Water and nutrient balance sheets for Organic Soil Bog Pair 3. Data for 2004 (year 3). Phosphorus fertilizer was not reduced in the second year at the Benson Pond site. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Rainfall N and fertilizer N are included as TDN and TN.

		Organic Soil Reduced Pair 3 - Benson's Pond 9.71 ha								Organic Soil Control Pair 3 - White Springs 3.08 ha							
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**
In	Rainfall	127,467,803		2.96				106.80	106.80	40,364,804		0.93				33.82	33.82
	Irrigation	5,459,402	0.03	0.17	0.19	0.05	3.28	2.61	3.51	1,730,238	0.01	0.01	0.08	0.00	0.54	0.54	0.62
	Groundwater in	14,760,605	0.54	2.24	1.42	0.88	13.97	9.12	16.28	4,678,050	0.02	0.06	0.10	0.01	1.54	1.44	1.65
	Frost protection	24,287,339	0.18	0.57	1.07	0.42	12.16	10.58	13.66	7,697,339	0.04	0.09	0.56	0.03	2.24	2.22	2.83
	Pest management	2,239,755	0.02	0.09	0.05	0.00	1.71	1.38	1.76	709,841	0.01	0.01	0.01	0.00	0.46	0.43	0.47
	Harvest	53,878,398	1.21	4.08	0.68	0.29	43.70	33.37	44.67	8,811,980	0.03	0.04	0.06	0.02	2.49	2.18	2.57
	Winter protection	80817597	1.00	3.46	6.57	8.40	23.64	32.13	38.62	16,874,004	0.06	0.07	0.09	0.06	4.95	4.34	5.10
	Fertilizer			190.00				287.60	287.60			57.80				93.10	93.10
	total	**308,910,899**	**2.98**	**203.57**	**9.98**	**10.04**	**98.46**	**483.59**	**512.90**	**80,866,256**	**0.17**	**59.01**	**0.90**	**0.12**	**12.22**	**138.07**	**140.16**
Out	Evapotranspiration	71,541,829								22,654,912							
	Drainage/infiltration	102,673,075	0.67	2.70	2.37	0.84	61.93	46.89	64.95	32,525,360	1.61	5.45	7.27	0.19	23.61	23.42	31.07
	Harvest	53,878,398	8.78	12.70	0.68	0.27	67.34	56.64	68.28	8,811,980	5.78	7.93	0.23	0.05	13.00	9.73	13.28
	Winter	80,817,597	2.99	8.17	3.87	0.85	68.72	60.00	73.44	16,874,004	0.51	1.07	0.08	0.04	4.30	3.01	4.41
	Plant material harvested			39.63					226.44			9.03					54.12
	total	**308,910,899**	**12.44**	**63.20**	**6.92**	**1.96**	**197.99**	**163.53**	**433.11**	**80,866,256**	**7.90**	**23.48**	**7.58**	**0.28**	**40.91**	**36.16**	**102.88**
	fluvial export load (kg/ha/yr)		**1.28**	**2.43**	**0.71**	**0.20**	**20.39**	**16.84**	**21.28**		**2.56**	**4.69**	**2.46**	**0.09**	**13.28**	**11.74**	**15.83**
	Net output (kg/ha/yr)																
	Total budget		***0.97***	***-14.46***	***-0.32***	***-0.83***	***10.25***	***-32.96***	***-8.22***		***2.51***	***-11.54***	***2.17***	***0.05***	***9.31***	***-33.09***	***-12.10***
	Fluvial budget		***0.97***	***1.03***	***-0.32***	***-0.83***	***10.25***	***-3.34***	***-1.92***		***2.51***	***4.30***	***2.17***	***0.05***	***9.31***	***-2.86***	***0.55***
	kg fertilizer added per ha			***19.57***					***29.62***			***18.77***					***30.23***

Table 11. Water and nutrient balance sheets for Mineral Soil Bog Pair. Data for 2002 (year 1). No reduction in phosphorus fertilizer rate. Net total included fertilizer inputs and removal in biomass. Export load is a calculation of the nutrients exported in the bog *water*. Net fluvial budget compares incoming and outgoing nutrients in water only. Data for TON and TN were not collected in 2002.

		Mineral Soil Reduced Pair 2 (Mikey/Kelseys) 2.23 ha						Mineral Soil Control Pair 2 (Ashleys) 1.94 ha					
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TDN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TDN**
Inputs	Rainfall	31,823,265		0.68			24.48	27,773,031		0.59			21.36
	Irrigation	6,392,170	0.06	0.45	0.10	0.02	2.98	6,465,611	0.04	0.36	0.12	0.03	4.74
	Frost protection	7,861,021	0.07	0.63	0.13	0.03	3.40	6,640,826	0.01	0.51	0.05	0.02	2.29
	Pest management	231,081	0.00	0.01	0.00	0.00	0.13	228,885	0.00	0.01	0.01	0.00	0.22
	Harvest	10,108,367	0.12	0.40	0.19	0.02	5.48	8,644,226	0.03	0.19	0.10	0.03	3.68
	Winter protection	9,328,191	0.11	0.37	0.17	0.02	5.05	9,443,522	0.03	0.20	0.10	0.03	4.02
	Fertilizer			71.80			151.50			77.20			118.40
	total	**65,744,094**	**0.36**	**74.34**	**0.59**	**0.09**	**193.02**	**59,196,102**	**0.11**	**79.06**	**0.38**	**0.11**	**154.71**
Outputs	Evapotranspiration	16,395,002						14,308,366					
	Drainage/infiltration	26,520,464						23,365,980					
	Harvest	10,108,367	0.51	0.81	0.49	0.10	5.77	8,644,226	0.38	0.59	0.29	0.05	2.53
	Winter	12,720,261	0.71	1.76	0.94	0.25	8.97	12,877,529	0.72	1.79	0.95	0.25	9.08
	Plant material harvested			11.00			61.50			6.21			36.69
	total	**65,744,095**	**1.22**	**13.57**	**1.43**	**0.35**	**76.24**	**59,196,101**	**1.10**	**8.59**	**1.24**	**0.30**	**48.30**
	fluvial export load (kg/ha/yr)		**0.55**	**1.15**	**0.64**	**0.16**	**6.61**		**0.57**	**1.23**	**0.64**	**0.15**	**5.98**
	Net output (kg/ha/yr)												
	Total budget		***0.39***	***-27.25***	***0.38***	***0.12***	***-52.37***		***0.51***	***-36.32***	***0.44***	***0.10***	***-54.85***
	Fluvial budget		***0.39***	***0.01***	***0.38***	***0.12***	***-12.01***		***0.51***	***0.27***	***0.44***	***0.10***	***-12.73***
	kg fertilizer added per ha			***32.20***			***67.94***			***39.79***			***61.03***

Table 12. Water and nutrient balance sheets for Mineral Soil Bog Pair. Data for 2003 (year 2). Phosphorus fertilizer was reduced at the Mikey/Kelseys site. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Rainfall N and fertilizer N are included as TDN and TN. *Due to missing data, some nitrogen values are estimates.

			Mineral Soil Reduced Pair 2 (Mikey/Kelseys) 2.23 ha								Mineral Soil Control Pair 2 (Ashleys) 1.94 ha						
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**
In	Rainfall	24,157,188		0.68				24.48	24.48	21,082,637		0.59				21.36	21.36
	Irrigation*	5,330,792	0.07	0.25	0.22	0.03	2.52	1.98	2.88	4,893,407	0.06	0.67	0.38	0.02	3.26	1.91	3.52
	Frost protection	4,859,069	0.01	0.11	0.05	0.03	1.93	1.57	2.01	7,996,773	0.04	0.53	0.15	0.04	5.37	2.63	5.56
	Pest management*	231,081	0.00	0.02	0.01	0.00	0.12	0.08	0.15	228,885	0.00	0.05	0.01	0.00	0.15	0.10	0.16
	Harvest*	10,718,940	0.39	1.11	0.39	0.04	5.60	5.50	6.38	8,881,055	0.09	0.92	0.27	0.04	7.77	3.37	8.07
	Winter protection*	12,007,926	0.44	1.24	0.43	0.04	6.27	6.16	7.15	12,877,529	0.13	1.33	0.39	0.05	11.27	4.88	11.71
	Fertilizer			49.40				84.10	84.10			70.50				87.5	87.50
	total	**57,304,996**	**0.91**	**52.81**	**1.10**	**0.14**	**16.44**	**123.87**	**127.15**	**55,960,285**	**0.32**	**74.59**	**1.20**	**0.15**	**27.82**	**121.75**	**137.88**
Out	Evapotranspiration	16,395,002								14,308,366							
	Drainage/infiltration	18,183,128								19893336							
	Harvest	10,718,940	1.04	2.67	0.16	0.04	10.00	6.77	10.21	8,881,055	0.16	1.08	0.38	0.15	5.63	5.52	7.81
	Winter*	12,007,926	0.67	0.88	0.24	1.12	11.41	8.47	12.47	12,877,529	0.72	1.79	0.95	0.25	8.75	9.08	11.71
	Plant material harvested			8.88					50.89			8.06					45.94
	total	**57,304,996**	**1.71**	**12.43**	**0.40**	**1.16**	**21.41**	**15.24**	**73.57**	**55,960,285**	**0.88**	**10.93**	**1.33**	**0.40**	**14.38**	**14.60**	**65.46**
	fluvial export load (kg/ha/yr)		**0.77**	**1.59**	**0.21**	**0.52**	**9.60**	**6.83**	**10.17**		**0.45**	**1.48**	**0.69**	**0.21**	**7.63**	**7.53**	**10.06**
	Net output (kg/ha/yr)																
	Total budget		***0.36***	***-18.11***	***-0.31***	***0.46***	***2.23***	***-48.71***	***-24.03***		***0.29***	***-32.81***	***0.07***	***0.13***	***-6.93***	***-55.23***	***-37.33***
	Fluvial budget		***0.36***	***0.06***	***-0.31***	***0.46***	***2.23***	***-11.00***	***-9.13***		***0.29***	***-0.63***	***0.07***	***0.13***	***-6.93***	***-10.13***	***-15.91***
	kg fertilizer added per ha			***22.15***					***37.71***			***36.34***					***45.10***

Table 13. Water and nutrient balance sheets for Mineral Soil Bog Pair. Data for 2004 (year 3). Phosphorus fertilizer was reduced for the second year at the Mikey/Kelseys site. Export load is a calculation of the nutrients exported in the bog *water*. Net total included fertilizer inputs and removal in biomass. Net fluvial budget compares incoming and outgoing nutrients in water only. Rainfall N and fertilizer N are included as TDN and TN.

		Mineral Soil Reduced Pair 2 (Mikey/Kelseys) 2.23 ha							Mineral Soil Control Pair 2 (Ashleys) 1.94 ha							
	Events	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**	**Volume (L)**	**kg PO4**	**kg TP**	**kg NH4**	**kg NO3**	**kg TON**	**kg TDN**	**kg TN**
In	Rainfall	29,211,372		0.68				24.48	24.48	25,493,561		0.59				21.36	21.36
	Irrigation	6,392,170	0.09	0.41	0.28	0.02	6.32	4.51	6.63	6,465,611	0.03	0.32	0.29	0.02	7.03	5.38	7.35
	Frost protection	7,847,181	0.09	0.43	0.26	0.06	6.19	5.25	6.51	6,828,670	0.04	0.34	0.17	0.02	4.80	3.14	4.98
	Pest management	256,579	0.01	0.02	0.01	0.00	0.23	0.15	0.24	375,687	0.00	0.02	0.01	0.00	0.47	0.38	0.48
	Harvest	14,789,423	0.97	2.43	0.34	0.15	19.41	15.34	19.91	11,604,578	0.09	1.05	0.06	0.00	6.94	4.93	7.00
	Winter protection	17,808,365	1.17	2.93	0.41	0.18	23.37	18.47	23.97	17,762,109	0.14	1.61	0.09	0.00	10.62	7.55	10.72
	Fertilizer			52.80				134.90	134.90			61.00				105.2	105.20
	total	**76,305,090**	**2.33**	**59.70**	**1.30**	**0.41**	**55.52**	**203.10**	**216.64**	**68,530,216**	**0.30**	**64.93**	**0.62**	**0.04**	**29.86**	**147.94**	**157.09**
Out	Evapotranspiration	16,395,002								14,308,366							
	Drainage/infiltration	27,312,300								24,855,163							
	Harvest	14,789,423	0.92	2.22	0.32	0.13	16.71	13.24	17.15	11,604,578	1.17	1.57	0.01	0.00	7.77	5.67	7.78
	Winter	17,808,365	1.44	1.92	0.48	1.88	6.16	7.10	8.53	17,762,109	1.21	2.72	0.17	0.56	12.36	10.43	13.10
	Plant material harvested			10.93					61.12			10.82					59.77
	total	**76,305,090**	**2.36**	**15.07**	**0.80**	**2.01**	**22.87**	**20.34**	**86.80**	**68,530,216**	**2.38**	**15.11**	**0.18**	**0.56**	**20.13**	**16.10**	**80.65**
	fluvial export load (kg/ha/yr)		**1.06**	**1.86**	**0.36**	**0.90**	**10.26**	**9.12**	**11.52**		**1.23**	**2.21**	**0.09**	**0.29**	**10.38**	**8.30**	**10.76**
	Net output (kg/ha/yr)																
	Total budget		***0.01***	***-20.01***	***-0.22***	***0.72***	***-14.64***	***-81.96***	***-58.22***		***1.07***	***-25.68***	***-0.23***	***0.27***	***-5.02***	***-67.96***	***-39.40***
	Fluvial budget		***0.01***	***-1.24***	***-0.22***	***0.72***	***-14.64***	***-21.46***	***-25.14***		***1.07***	***0.19***	***-0.23***	***0.27***	***-5.02***	***-13.73***	***-15.98***
	kg fertilizer added per ha			***23.68***					***60.49***			***31.44***					***54.23***

On a total budget basis in 2002 (Tables 5, 8, 11), all six bog sites showed a net negative output (i.e. storage in the bog) of total P and total dissolved N (since particulate N was not evaluated in 2002, there were no data for total N). However, when fertilizer inputs and biomass outputs are taken out of the equation, and only changes in fluvial water were examined, one of the six sites (Benson's Pond, Table 8) showed an output of 1.12 kg/ha of TDN and all sites showed TP output varying from 0.01 to 4.15 kg/ha TP. In 2003 (Tables 6, 9, 12), total N was analyzed with all bog sites showing net negative output of TN as well as TDN for both total and fluvial net budgets. In 2003, all sites again showed a negative output for TP on a total budget basis. However, 5 of the 6 sites showed net export of P in the fluvial budget, in amounts varying from 0.06 to 3.62 kg/ha TP, one site showed negative TP output (Table 12, Ashley's site). This can be accounted for by the fairly low net output in flood discharges at that site and fairly high TP in the irrigation water (input). In 2004 (Tables 7, 10, 13), all sites again showed net negative outputs for TN, TDN, and TP on a total budget basis. As was the case in 2003, one site had a small net output of 0.55 kg/ha/yr TN on a fluvial basis (Table 10, White Springs site). Similarly to 2003, 5 of the 6 sites had net TP fluvial output varying from 0.19 to 4.30 kg/ha/yr. One site (Table 13, Mikey/Kelseys site), had a negative fluvial output of 1.24 kg/ha/yr. In this case, negative output was due to retention of TP during flood events.

Overall, mean net fluvial TP output for the bog sites was 1.65 kg/ha/yr (range -1.24 to 4.30) while that for TN was -9.39 kg/ha/yr (range -25.14 to 0.55). The largest export was of TP was from the White Springs site. This site is a partial flow through bog with constantly upwelling groundwater that flows though the bog into its discharge canal. The mineral soil sites discharged the least TP. This is in agreement with reported data (Richardson, 1985) showing that mineral wetland soils have higher capacity to retain P when compared to peat wetland soils and that this capacity is related to Al and Fe in the soils. Cranberry bog soils are high in both Al and Fe. All sites in this study would be considered mineral wetland soils (<10% organic matter) based on the surface layers. However, only the sites designated as mineral soils have mineral subsoils, while the sites designated organic soil have peat underlayment.

In comparison to these study sites, at a cranberry site with constant streamflow, export of TN was 28.5 kg/ha and export of acid extractable phosphate was 12.3 kg/ha when disregarding inputs from fertilizer and outputs in biomass (Howes and Teal, 1995). In that study, when taking all input and export sources into account, the nitrogen balance was negative (-16.4 kg/ha) indicating storage of N or loss of gaseous N to the atmosphere. Based on a fertilizer P input of 32.3 kg/ha at the site, phosphorus balance would also have been negative if all inputs and outputs were included. Since a surface water steam in that bog flowed constantly, outputs from water sheeting across the beds following heavy rain and from direct deposition of aerially applied fertilizer in the bog stream contributed to the higher seasonal N output in that study. Further, due to the constant flow, the volume of water leaving this site was greater than that in our study bogs. In that study as in this, large exports of N and P were associated with flooding events. Since these events occur in the fall and winter, the cranberry bogs tend to act similarly to natural wetlands with nutrient uptake in the spring and summer followed by nutrient release in the fall and winter (Howes and Teal, 1995). In the Howes and Teal study, most N export from the bog was as NH_4 and particulates. The high NH_4 export in that study may relate to patterns of fertilizer use. In the study year, heavy rains followed summer fertilizer applications and a fall fertilizer application in September may have been too close to the harvest flood. In the current study, growers did not apply fertilizers after early August. In addition, streamflow through the bogs was limited or nonexistent for most of the bogs.

In a study of the Mill Brook Watershed on Nantucket (Howes and Millham, 1991), PO_4 concentration in water exiting a cranberry bog system was 0.042 mg/L, while further downstream approaching the harbor, TP was 0.092 mg/L. TDN left the bog at 0.99 mg/L but downstream water contained 0.71 mg/L TDN. In that system, the bog and the downstream wetland were both sources of PO_4 while the downstream wetland was a sink for TDN. TP concentrations in bog discharge in the current study ranged from less than 0.03 to ~1mg/L.

For pair 3, the organic soil pair of Benson's Pond and White Springs, surface discharge was observed on numerous occasions during the study. This water was sampled and was included in the budgets (Tables 8-10). However, all water not accounted for in other discharges was presumed to be surface discharge and this is not likely to be true. Some water presumably infiltrated into the bog subsoil. Since it is all water leaving the bog, one could argue that it doesn't matter where it went in terms of the budget. However, the nutrients in water infiltrating into the bog are highly unlikely to reach groundwater in their entirety. One would expect that some portion of the nutrient load would be buried in the bog subsoil or be retained in the peat. This is particularly true for P, which becomes tightly bound in acid soils such as the peat layers subtending the cranberry bogs.

Lowland cranberry bogs have elevated (perched) water tables, but minimal connection to groundwater (Rinta, 1990). Water trapped in the underlying peat layers moves very slowly. It is estimated that in natural bogs in New England, less than 1% of the water leaving may come from the peat zone (citation in Deubert and Caruso, 1989). Most organic soil cranberry bogs were constructed from natural bogs and have subsoils consisting of a barrier layer overlain by peat. Mineral soil cranberry bogs are man-made structures constructed to mimic the natural bog system, including a subsoil barrier layer. In a study of wetland meadows and fens in Western Europe (Venterink et al., 2002), nutrient input and output by groundwater flow were more or less negligible for nutrient availability for plant production. Howes and Teal (1995) outline the several arguments supporting the contention that for cranberry bogs of the organic soil type, exchanges through the groundwater pathway are minor for the flow-through bog they studied. They probed such a bog and found a layer of compacted peat with some clay underlying it. Their attempts to withdraw water from this layer via a pieziometer were not successful. They cite references to studies in which hydraulic measurements in similar layers of compacted organic sediments and peats were found to restrict vertical groundwater flows. Therefore, we can assume that the budgets for the Benson's/White Springs pair, in which all remainder water is assigned to surface discharge, overestimate nutrient discharge from the bog since for any portion that actually infiltrated nutrients would be retained within the bog rather than discharging. However, since we do not have an accurate estimation of how much of the water infiltrated vs. discharging through the surface pathway, we were not able to further refine the estimates.

In a study of a natural sphagnum bog, Hemond (1980, 1983) found that pore water in the underlying peat layer was relatively immobile and that export from the bog consisted primarily of surface runoff.

For the other organic soil pair (Eagle Holt/Pierceville), surface discharge (aside from floods) was seldom observed. When it was, a portion of the incoming water was assigned as surface discharge. The remaining unaccounted for incoming water was presumed to infiltrate. However, we had no way of measuring the nutrient content of infiltrating water and based on the arguments above, only a portion of its nutrients might reach groundwater. Regardless, one can presume that the budgets for this pair may somewhat underestimate nutrient discharge.

For the mineral soil pair (Mikey/Kelsey and Ashleys), surface discharge was never observed except during flood releases. While these are mineral soil bogs, they were constructed to mimic the historic bog type, including the perched water table and a barrier layer that allows the retention of floods over the bog. With this pair, since nutrient content of infiltrated water was not measured, the budget should be considered to somewhat underestimate output.

In an effort to determine influence of the bogs on groundwater nutrients, attempts were made to collect pore water in the peat underlying the bog using perforated pipes. As was the case in the previous cranberry study (Howes and Teal, 1995), we were only able to collect water from above the perched water table of the bogs. The organic soil bogs all have perched water tables above an underlying layer of peat while the mineral soil bogs were constructed with compacted soils forming a barrier layer above the water table. Howes and Teal (1995) examined nutrients in the pore water of upper soil layers (above the peat layer) and found that phosphate tended to be confined to the uppermost soil layers. Likely it became bound to soil particles by the time it migrated through the soil profile. Phosphorus fertilizer is readily sorped on cranberry soils (Davenport et al., 1997) and much less readily desorped if the soil is not flooded. Inorganic nitrogen was found in all layers, peaking during the summer fertilizer applications. Decline later in the season could be at least partially accounted for by plant uptake, microorganismal uptake, or soil binding (Howes and Teal, 1995). Additional evidence for retention of N and P by subsurface layers in wetland soils, such as those in a cranberry bog, comes from a laboratory study (Phillips, 2001) showing that saturated wetland soils are effective in removing nutrients from subsurface flows but less so at removing nutrients from surface flows. Therefore, even though we did observe some movement of water from flooded bogs into the groundwater after a prolonged droughty period (harvest 2002), it is our opinion that little TP or ammonium N move into groundwater by this route. While nitrate would be expected to move readily in the water column, nitrate levels in bog samples were consistently low and conversion of ammonium to nitrate is minimal in the acid bog soil (Davenport and DeMoranville, 2004).

To further examine the potential for nutrient movement into groundwater, the nutrient content of groundwater-fed surface bodies (small ponds) associated with the bogs was examined. Such bodies existed at the Benson's Pond, White Springs, and Eagle Holt sites. At the Benson's Pond site, the pond is within the bog and any leakage from the bog to the groundwater should contribute to the nutrient load in this pond. At the Eagle Holt site, groundwater flows beneath the bog towards Blackmore Pond. At the White Springs site, the groundwater-fed pond is upstream of the bog. Table 14 shows nutrient data for the three ponds. As expected, nutrients are highest in the irrigation pond at Benson's, likely due to the location of the pond within the bog perimeter such that it receives surface runoff in addition to groundwater inputs. A comparison of Blackmore Pond (downstream of the Eagle Holt bog) and the White Springs irrigation pond (upstream of the bog) is interesting. There appears to be little difference in P between the two bodies. While the nitrogen levels are higher in Blackmore Pond compared to the White Springs pond, there are >50 houses with septic systems surrounding Blackmore Pond, making it difficult to judge how much of the input comes from the bog. Further, that pond is also used for flooding of the bog, with some of the water being returned post-flood. This is an additional source of input from the bog.

Table 14. Nitrogen and phosphorus in groundwater fed ponds. Average of all collections within each year.

		Nutrients in water (mg/L)					
		PO4	TP	NH4	NO3	TDN	TN
Benson's Pond	**2002**	0.007	0.065	0.160	0.089	0.667	
	2003	0.023	0.082	0.272	0.073	0.888	1.239
	2004	0.031	0.141	0.080	0.043	0.623	1.118
Blackmore Pond	**2002**	0.004	0.012	0.010	0.008	0.404	
	2003	0.006	0.047	0.018	0.003	0.285	0.332
	2004	0.003	0.012	0.049	0.005	0.383	0.426
White Springs	**2002**	0.002	0.017	0.011	0.009	0.182	
	2003	0.012	0.056	0.025	0.003	0.176	0.224
	2004	0.005	0.006	0.029	0.002	0.245	0.293

In 2005, we collected samples at the White Springs site to compare the upwelling groundwater in the pond to that which upwells into the bog ditches (Table 15). TP and TN concentrations in the upgradient irrigation pond were greater than those in the water upwelling in the bog ditches at this May sampling date. This is likely due to the pond receiving a combination of groundwater and surface runoff. Surface runoff would have been substantial after the high snowfall winter and wet spring of 2004-2005. In contrast, the samples collected in the ditches, particularly at the upstream North end, were primarily groundwater. Moving towards the South end (downgradient), the bog samples increase in nutrient load, likely due to increased contribution from surface sheeting within the bog. A comparison of the irrigation pond to the water discharging from the bog showed that TP was similar in the two and that TN was greater in the bog discharge. Similarly to the irrigation pond, the bog discharge contains groundwater and surface sheeting inputs. The low nutrient load in the North end (upgradient) groundwater samples is indirect evidence that water moving between the water table and the bog surface does not pick up a large nutrient load. However, in this example, water is moving upward rather than toward the water table.

Table 15. Spring 2005 groundwater sampling.

		Nutrients in water (mg/L)					
		PO4	TP	NH4	NO3	TDN	TN
White Springs							
Pond	GW fed	0.048	0.216	0.072	0.012	0.305	0.537
North end Bog	GW upwelling	0.025	0.007	0.103	0.015	0.310	0.389
Center Bog	GW upwelling	0.016	0.041	0.039	0.010	0.208	0.249
South end Bog	GW upwelling	0.006	0.128	0.011	0.015	0.117	0.212
Outlet	Discharge	0.044	0.217	0.074	0.016	0.435	0.672

In addition to infiltration during the season, another avenue for bog water to potentially move into the groundwater is during flood events. During harvest floods at the Eagle Holt site, the level of the adjacent, downgradient pond was observed. In 2002, after a very dry summer in which area water tables were low, the pond level rose during the harvest flood. The volume change in the Pond, corrected for rainfall during the period, accounted for approximately 20% of the applied flood's volume indicating that at some times infiltration to groundwater may be significant. However, after the wet summer in 2003, the pond level did not change during the harvest flood of 2003. In 2004, during a wet fall, again there was no increase in Pond level while the harvest floods were held on the bog. Since infiltration during floods was variable at this site and not measured at all sites, all incoming flood volume was assumed to be surface discharged. This may be a source of nutrient export overestimation in some circumstances (e.g. 2002 harvest flood at Eagle Holt) since nutrient loading during infiltration is likely much less than that during surface discharge (see above)..

An examination of the data (Tables 5-13) shows that flood discharges were generally the source for the majority of P output from the bog systems. Howes and Teal (1995) also found that N and P discharge from cranberry bogs was primarily associated with flooding. Therefore, nutrient loads associated with flooding events were more closely examined (see also Figures in Appendix 3B). Figure 1 shows a typical harvest flood in which the water is only held briefly prior to discharge. Note that the water held on the bog just after harvest (days 1 and 2) has an increased nutrient load compared to the incoming water and that this load is somewhat reduced by the time of discharge on day 2.5 (Figure 1). This is likely due to particulates being churned into the water during harvest and settling back onto the bog prior to discharge.

Figure 1. Phosphorus content of water samples collected during the 2003 harvest at Pair 3 Reduced Bog (Mikey/Kelsey - Mineral soil). Flood release occurred on day 2.5.

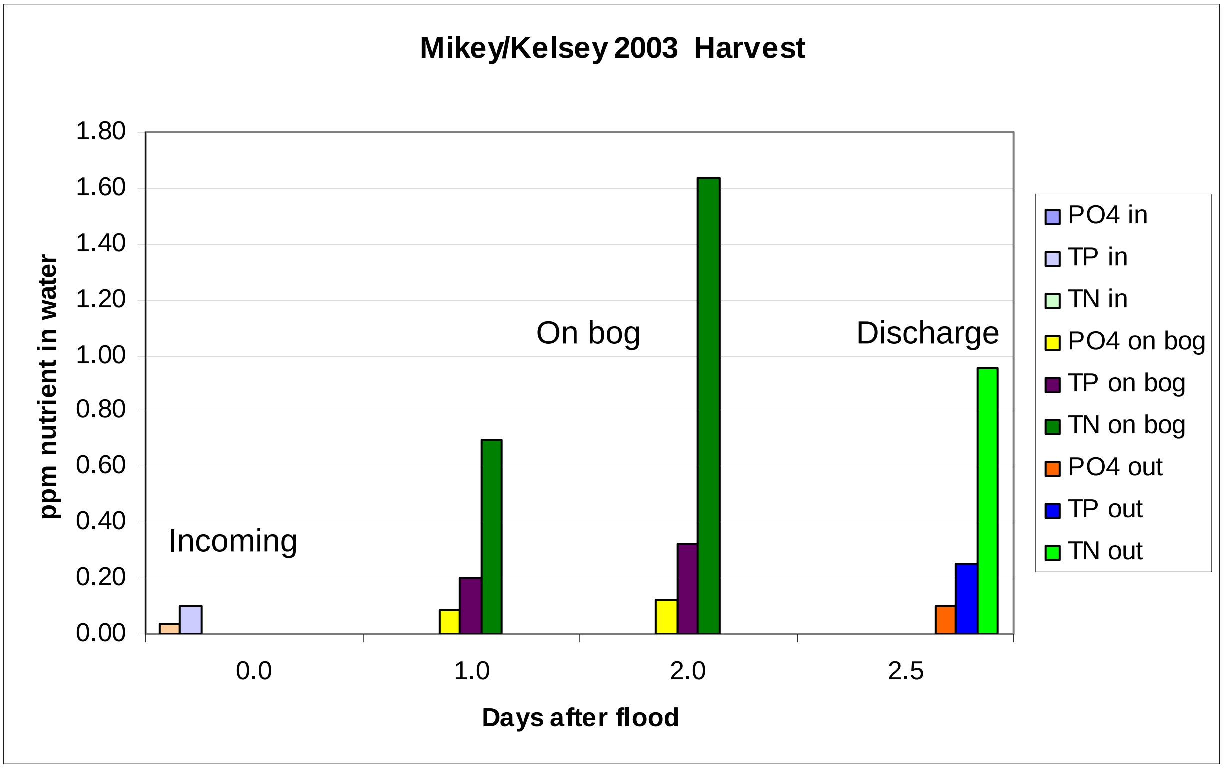


Figure 2 shows a 2002 harvest flood at the Eagle Holt site (Pair 1 reduced - organic soil). At this site, the grower was asked to hold the flood for an extended period and to then slowly release the flood. Beginning at day 12 of the flood, phosphate begins to increase in the water held over the vines, presumably due to anoxia in the bog **soil**. While slowly releasing the flood did lead to lowered P in the discharge water compared to that over the flooded vines, if the process goes on for too long, phosphate is released from the soil. In other words, gains due to particulate settling are offset by increased dissolved P.

In 2003, the slow release of harvest water was repeated at this site (Figure 3). In 2003, phosphorus was elevated during the harvest (day 1) due to agitation (particulate suspension and leaching from the plants). The phosphorus levels dropped by day 8, likely due to settling. However, phosphate movement into the flood water was increasing by the time the flood was released, likely due to changes in soil redox state (anoxia).

Figure 2. Phosphorus in harvest flood at Eagle Holt site (Organic reduced Pair 1) in 2002. Note that incoming water on day 1 was from an adjacent bog that was previously harvested. Flood release began on day 12.

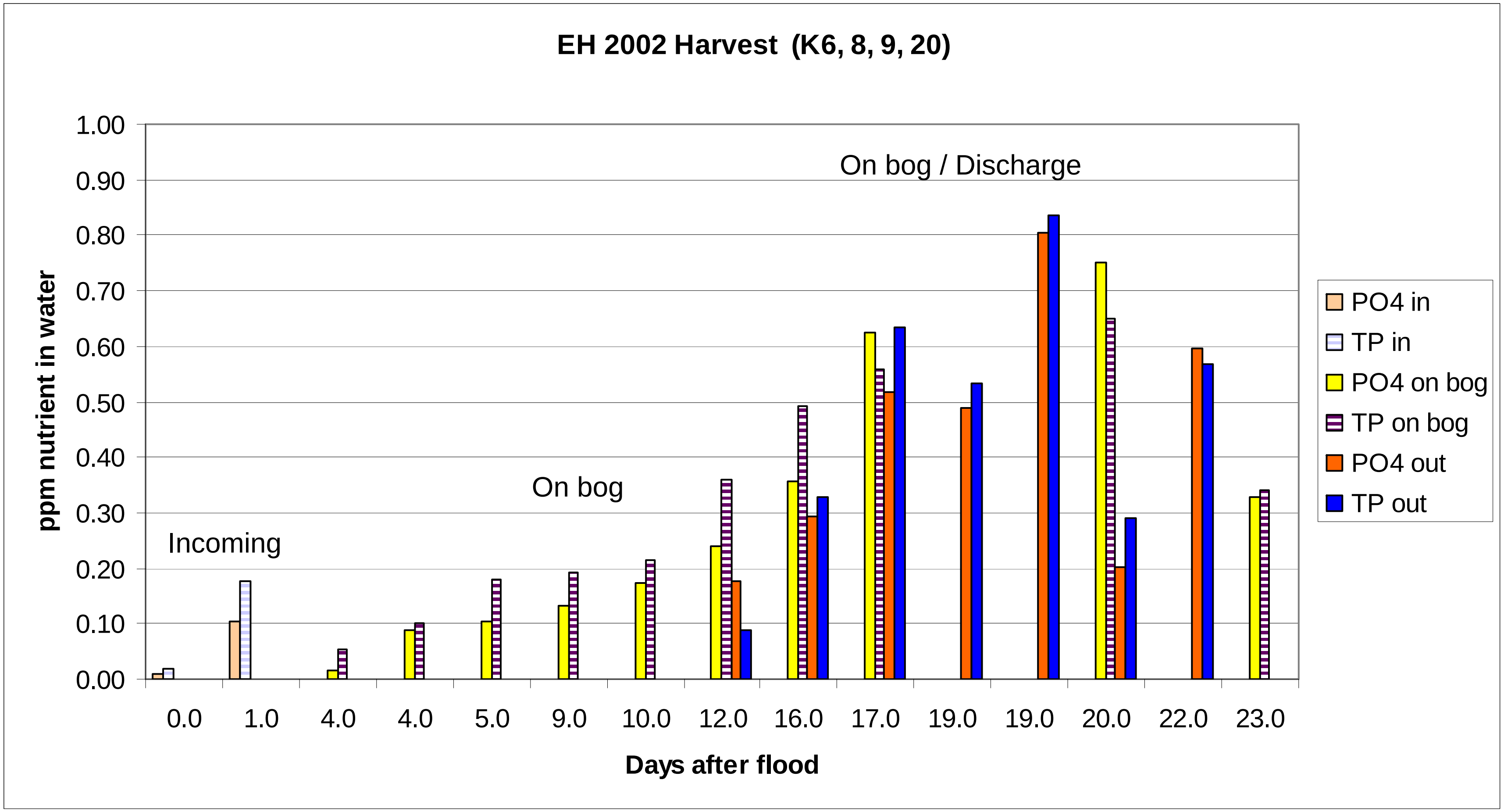
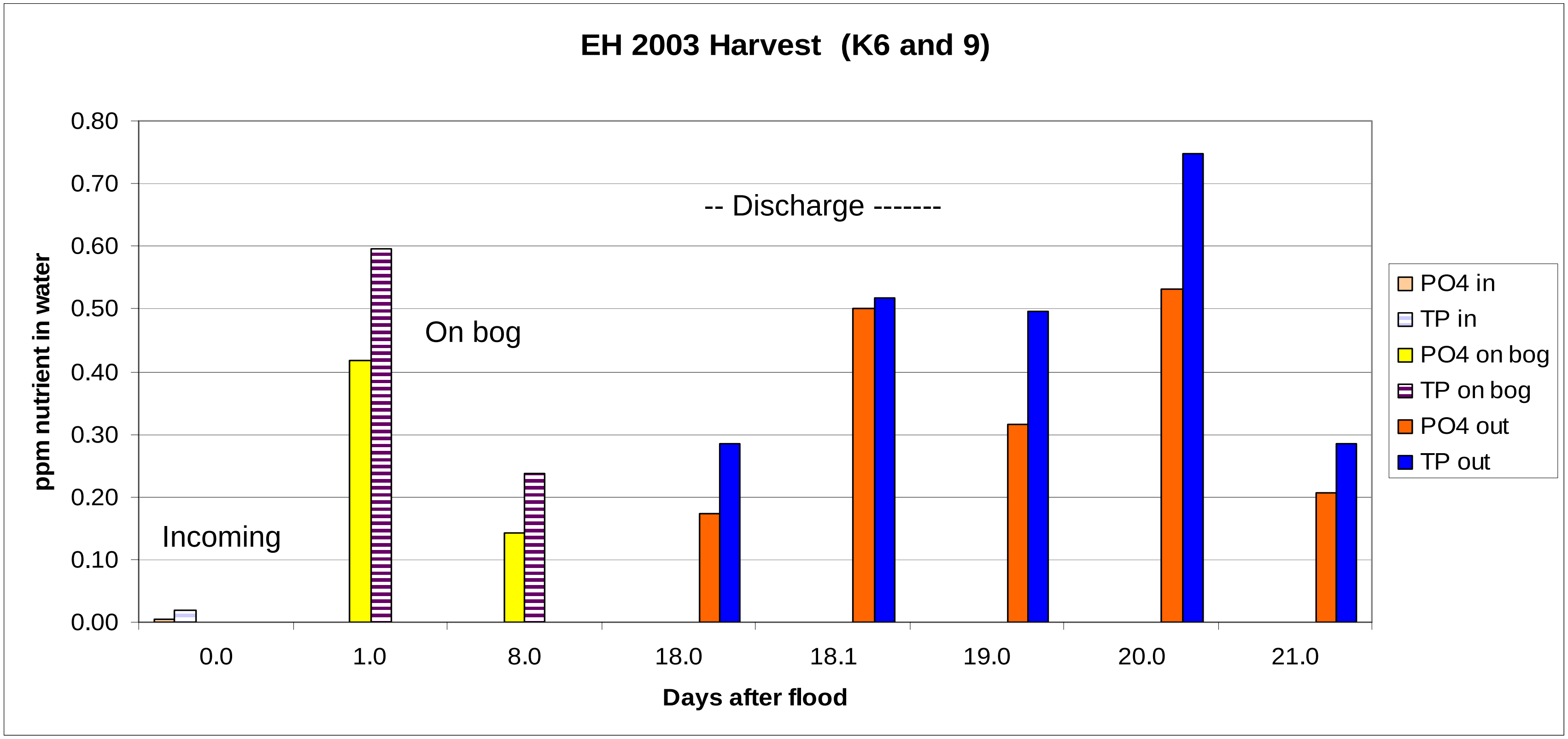
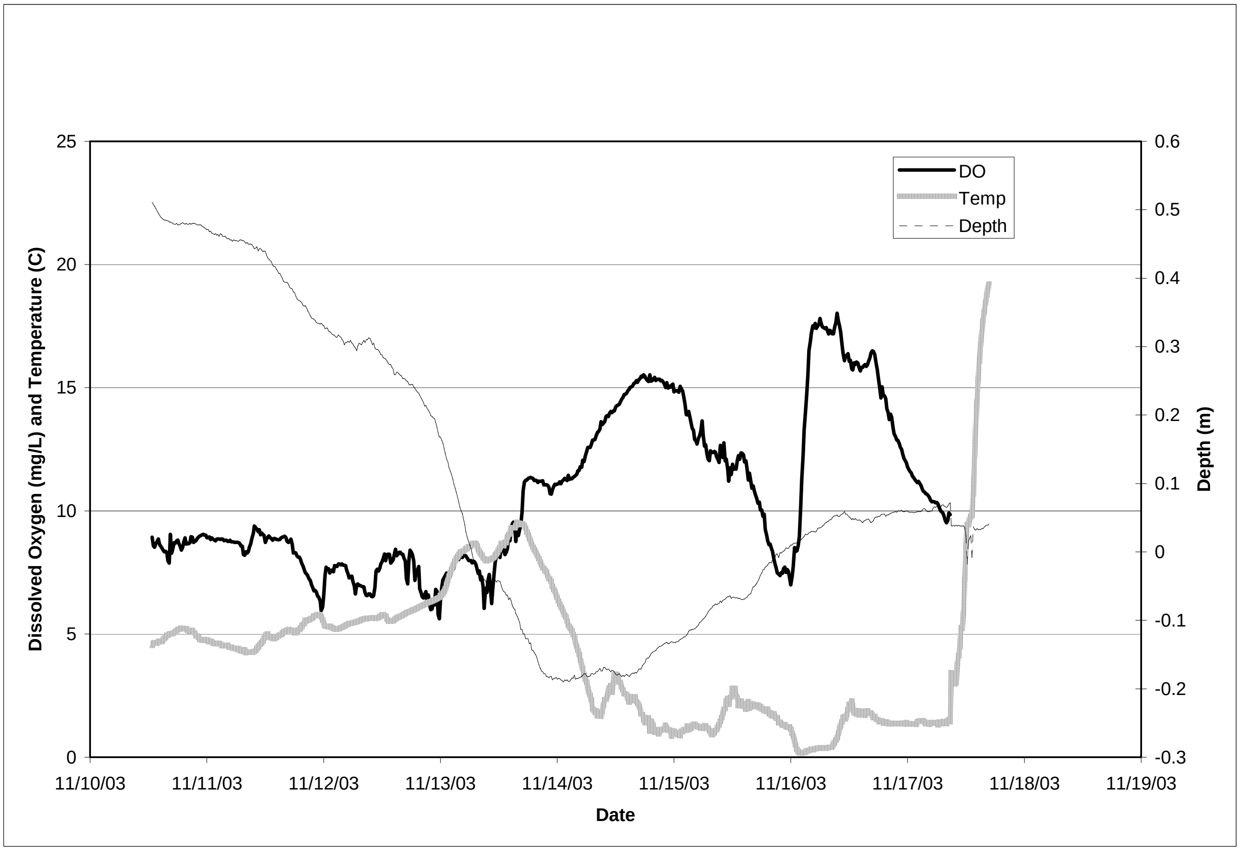


Figure 3. Nutrients in harvest flood at Eagle Holt site (Organic reduced Pair 1) in 2003. Flood release began on day 18.



A logging oxygen monitor in the flooded bog (Figure 4) showed a minimum oxygen content of 5.5 mg/L in the water near the soil surface for a short time early in the flood. Oxygen rose to >8 mg/L and remained at least that high during flood discharge. These data indicate that monitoring oxygenation in the flood water may not predict the timing of soil anoxia that leads to P flushing from the soil. Further, spot sampling of numerous harvest floods (Vanden Heuvel, personal communication), showed that oxygenation was generally in the range of 7-8 mg/L in the overlying water. Concentration in the soil porewater is unknown for those floods.

Figure 4. Dissolved oxygen in the flooded Eagle Holt Bog - harvest 2003.



Despite lack of oxygen depletion in the water of the flooded bogs, anoxia in the soil remains a likely cause of the release of dissolved phosphorus into the flood water during extended floods based on sorption/desorption studies (Davenport et al., 1997). To further test this hypothesis, soil cores were removed from commercial cranberry bogs receiving low or high phosphorus fertilization and from abandoned cranberry bogs (>30 years with no fertilizer added) (Schlezinger et al., 2003). The cores were flooded in the laboratory under controlled conditions with monitoring of soil oxygen levels. During the first 48 hours, oxygen was bubbled into the flood water. After this period, oxygen was allowed to deplete naturally. In the fertilized soils only, some P moved into the water during the initial flooding, in amounts correlating with fertilizer rates. At approximately day 10-12, all soils showed a flush of phosphorus into the flood water. Anoxic conditions had been reached in the soil by day 10. This mimics what we see in field situations, with some P moving into the initial flood and a second flush after extended flooding.

In a laboratory sorption/desorption study of wetland soil (Phillips, 2001), absorption or release of N and P depended mainly on the diffusion gradient between the soil and water if the soil was waterlogged. If the soil was enriched with N or P and the water was relatively clean, the wetland soil exported both nutrients. P was also exported as soil transitioned for dry to waterlogged conditions, similar to what happens when cranberry soil is flooded.

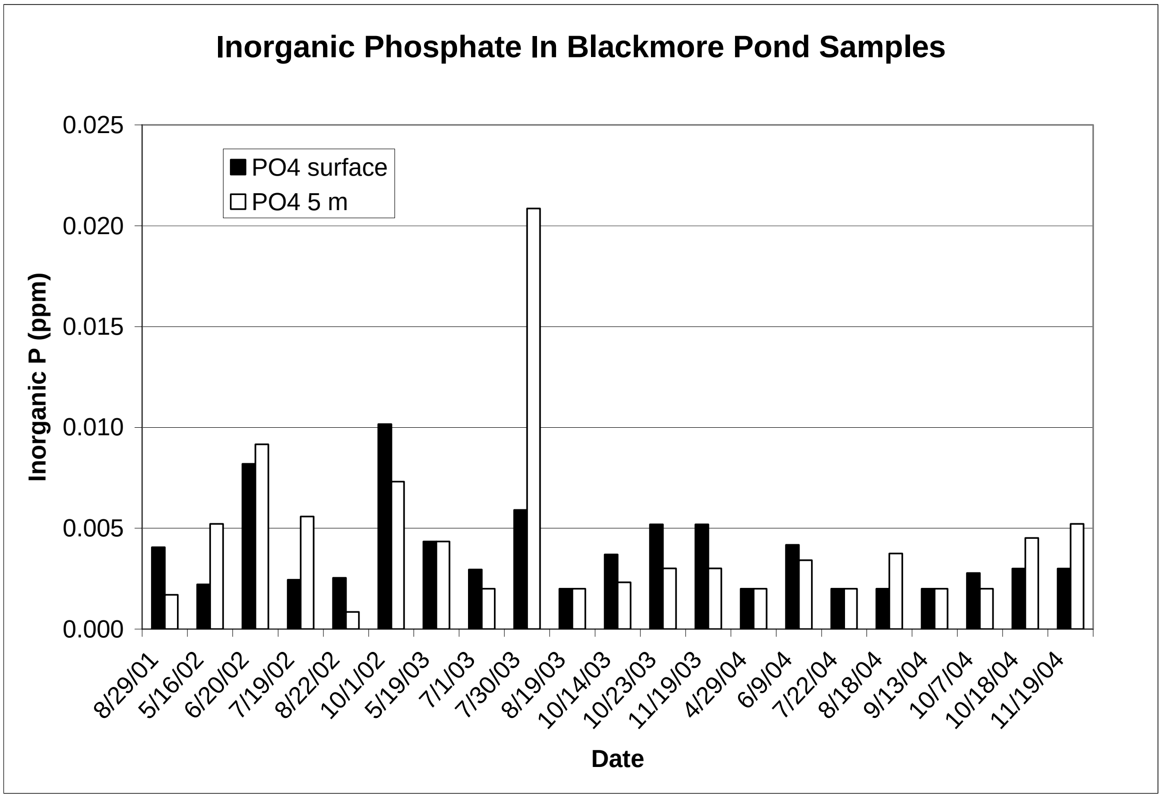
Total P concentrations in discharge flood water tended to be lowest at the mineral soil bogs (Figures in Appendix 3B), despite those being the bogs to receive the highest fertilizer P rates (Table 1). Total P in discharged harvest water for the mineral soil pair varied between 0.05 and 0.25 ppm and showed little response to fertilizer reduction during later years. Based on previous research (Davenport et al., 1997), in sandy soils of mineral bogs, one would expect more P availability throughout the season and less response to flooding compared to that in organic cranberry beds. As a result, the net export of TP from these bogs was the lowest (kg/ha) among the study sites.

In a comparison of a predominantly mineral bottomland hardwood swamp soil to that of a highly organic freshwater marsh (Masscheleyn et al., 1992), soil redox status was found to affect P release and assimilatory capacity. Iron in the swamp soil controlled the capacity of the soil to retain P based on its redox state. In anoxic (reducing) conditions, retention of P was impeded. In the freshwater marsh soil, P concentration in the water determined uptake regardless of redox state. Except under very oxidized conditions, this soil exported P unless concentrations in the incoming water were very high. In general, the mineral swamp soil had much greater capacity to remove nutrients from water. This is in agreement with the comparison of the organic and mineral soils pairs in this study.

For the surface water dominated organic pair (pair1), TP in harvest discharge varied from 0.2 to 0.8 mg/L with the higher concentrations associated with longer flood holding times. As the P rate was reduced each year on the Eagle Holt bog (from 20 to 15.1 to 6.3 kg/ha), TP concentration in the long harvest flood discharge declined in corresponding fashion from 0.8 mg/L (2002), to 0.6 mg/L (2003), to 0.25 mg/L (2004). At the companion control bog, TP in long harvest flood discharge remained between 0.6 and 0.8 ppm throughout the study.

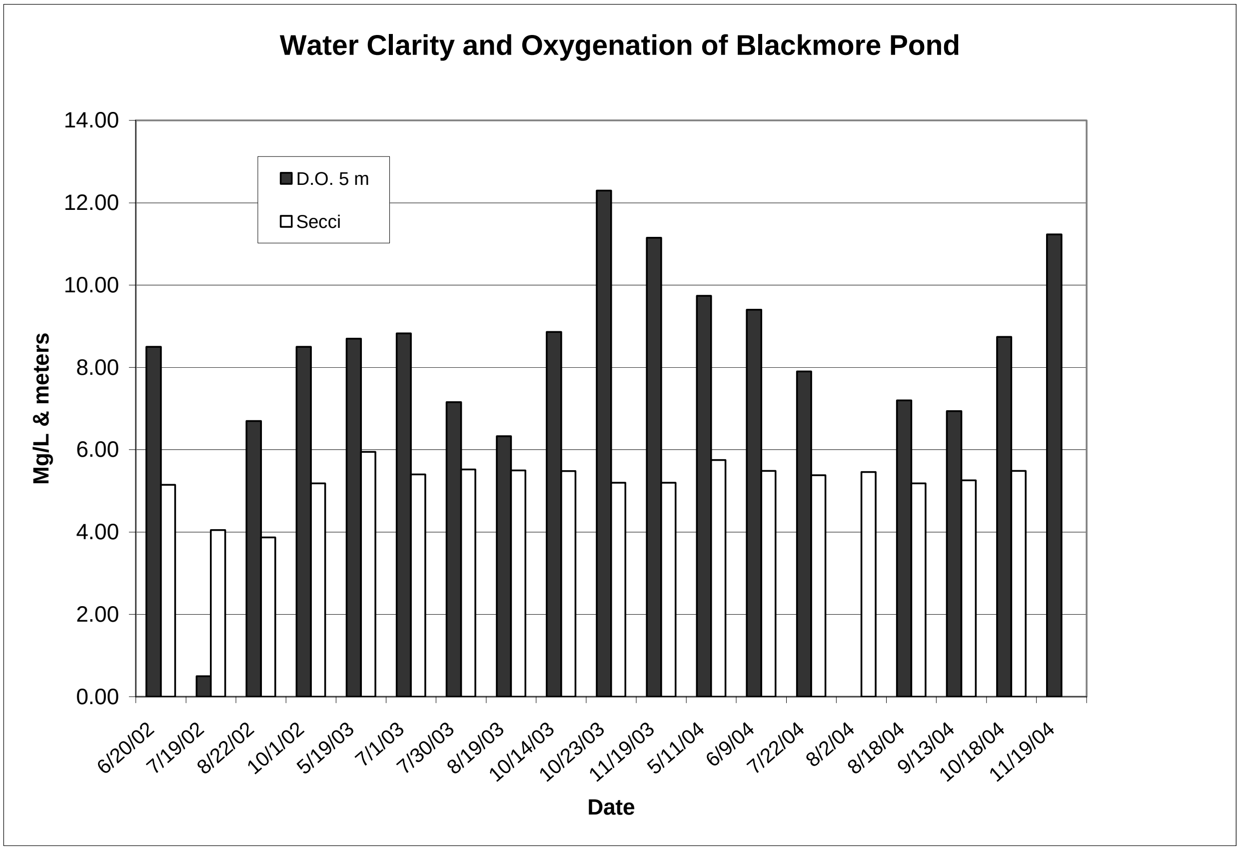
Water quality in Blackmore Pond, adjacent to and a water source for the Eagle Holt reduced organic soil site (pair 1) was studied as part of this project. Water from this pond is used as the water supply for the bog from September 15 through June 15 each year; water withdrawals during the summer months are not allowed. Figure 5 shows the PO_4 content of water samples collected from the Pond beginning in August of 2001. Samples were collected at 1 meter intervals from the deepest part of the pond starting at the surface and going down five meters. The pond is generally between 5 and 5.5 m deep.

Figure 5. Inorganic phosphorus in grab samples from Blackmore Pond.



In general, the pond retained good oxygenation throughout the study (Figure 6). An exception is a loss of oxygenation near the bottom sediments in July of 2002. Inorganic P levels in the Pond showed some periodicity (Figure 5), with increases occurring in the summers of 2002 and 2003 and during the harvest period (October - November). Summer increases in PO_4 can be attributed to concentration of nutrients due to evaporation or to release from sediments due to anoxia. However, dissolved oxygen monitoring (Figure 6) did not support this hypothesis. As was the case with harvest flood oxygen monitoring (Figure 4), oxygen in the water at vine level or in the deepest Pond water may not accurately predict oxygenation in the sediments.

Figure 6. Dissolved oxygen at 5 m in Blackmore Pond and depth at which a Secchi disk remained visible.



Total P (Figure 7) and total N (Figure 8) in the Pond water was also examined. Total P in the Pond was at its highest in 2003 and declined in 2004 following the first year of reduced P regimen at the bog. The spike in TP during the late summer of 2003 is somewhat mysterious, but is not primarily dissolved phosphate (compare to Figure 5). This is not a time when water was discharging fro the bog to the Pond. The two spikes in TP at 5 m in the summer of 2004 are likely due to sediment contamination in the sampling. As was the case for PO_4, TP levels rose slightly following discharge of harvest water to the Pond. In 2004, after two seasons of reduced P at the bog, the TP increase at harvest discharge was the least pronounced of the three years. In general, Pond TN remained between 0.3 and 0.5 ppm during the study years (Figure 8).

Figure 7. Total phosphorus in samples collected from Blackmore Pond.

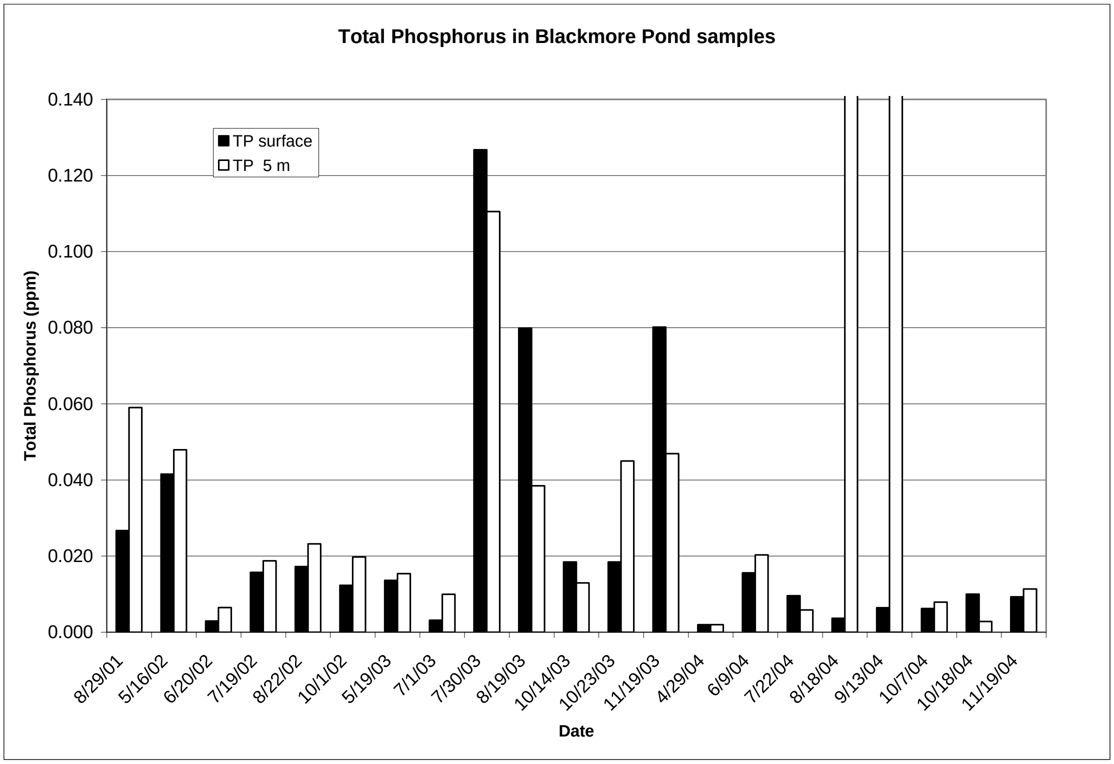
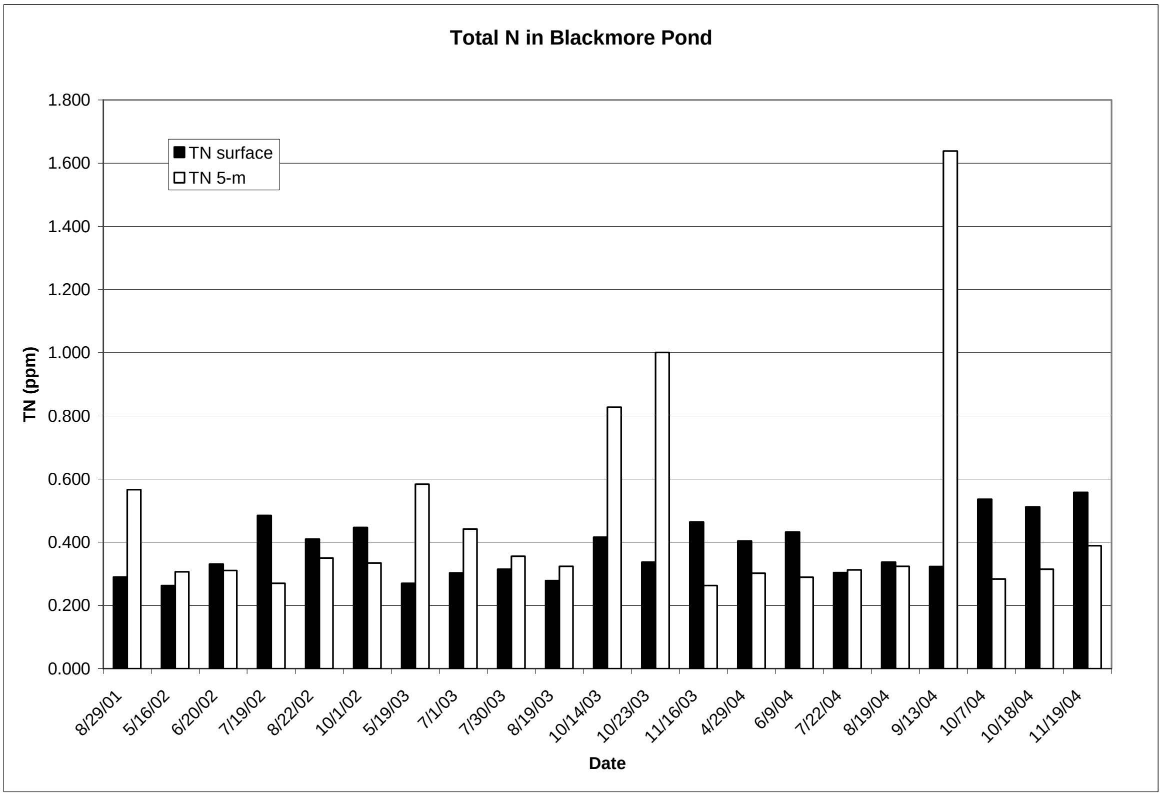


Figure 8. Nitrogen in samples collected from Blackmore Pond. Samples collected in 2001 and 2002 are for Total Dissolved N, remainder are TN.



At the Benson's Pond/White Springs organic bog pair, P fertilizer was not substantially changed between the bogs due to lack of grower cooperation and was ~22 kg/ha in 2002 and 18-19 kg/ha throughout the remainder of the study. At the White Springs bog, TP in discharge water was ~0.2 mg/L in 2002 and 2003 when the flood was maintained for less than 8 days. In 2004, the flood was held for >20 days and TP levels in discharge rose to 0.9 mg/L. At Benson's Pond, the flood was held for at least 20 days in all three years. Interestingly TP in discharge water ranged from 0.2 to 0.5 mg/L at that site, lower than that on other similarly fertilized organic soil sites (Eagle Holt 2002 and Pierceville all years).

Fertilizer P rates were successfully reduced by 30-35% at one bog in each of the other two pairs (Eagle Holt/Pierceville and Mikey-Kelsey/Ashleys). After one year of reduced P, total P output from the bogs was not affected (compare 2002 to 2003 in Tables 5 and 6 or 11 and 12). After two years of P reduction, TP output at the organic soil reduced P site was half that in 2002 (compare Tables 5 and 7), while TP output at the mineral soil reduced P site was negative. Reduction in P fertilizer use was associated with decreased P output in the bog water.

At the Benson's Pond/White Springs pair, differential fertilization was not achieved between the two bogs. However, the P fertilizer rate was reduced by ~20% at *both* bogs in 2003 and 2004 compared to that in 2002. In 2003, TP export from both bogs was less than that in 2002 (Table 8, 9). In 2004, TP output at Benson's Pond dropped further, but that at White Springs returned to 2002 levels.

Generally, some reduction in P export from the bogs was achieved with reduced fertilizer P inputs. At the site with the greatest reductions in fertilizer P (20 to 6 kg/ha), fluvial net TP export decreased from 1.29 to 0.60 kg/ha/yr. At the mineral soil reduced site (P fertilizer reduced from 32 to 23 kg/ha), fluvial net TP changed from 0.01 kg/ha/yr export to 1.24 kg/ha/yr retention in the bog.

Soil test P (Bray method) was little affected by the change in practice although the reduced P bogs had lower Bray P compared to the companion control beds in the final year (Table 4). At the end of two years of differential fertilization, all locations had tissue test P in the range of 0.12 to 0.13%, well within the standard recommended range (see Appendix 4 for complete data set).

Crops were compared for the bog pairs (Table 16 and Appendix 5). In order to account for the common biennial crop cycles seen on Massachusetts cranberry bogs, two year averages were compared (Table 16). For the comparison years, crops were low throughout the State in both 2002 and 2003 (one year during the pre-treatment period and the other within the reduced P period). Crop yields were generally unaffected by change in fertilizer practice at the organic soils bogs (Table 16 and Appendix 5). Both bogs in pair 1 showed increased yield in 2003-2004 compared to the previous two years. In fact, yields increased more at the reduced P bog of this pair than at the control bog. At the other organic soil pair (pair 3), yields were generally the same in both two year periods. For the mineral soil pair (pair 2), the outcome was somewhat different. Based on the two year averages, it would appear that the crop was greater at the bog receiving ~30 kg/ha P compared to that receiving ~20 kg/ha. However, the crop at the control bog was extremely low in 2002, leading to a lowered pre-treatment average for comparison purposes. If instead 2000-2001 is compared to 2003-2004 for the Ashley's bog, the increase in yield would be 6% instead of 50% and much less different from the 5% decline at the Mikey/Kelsey Bog (compare data in Appendix 5). These results support previous findings in plot-scale research, in which even extreme P fertilizer reductions do not affect yield for at least two seasons (Roper, personal communication and DeMoranville and Davenport, 1997). The P reductions at pairs 1 and 2 were achieved in 2004 through the use of an 18-8-12 material, new to the Massachusetts industry. Based on the successful outcome in this study, the use of this material is expanding throughout the industry in 2005. Long-term outcomes will continue to be of interest as recommendations for P rates of 10-15 lb/a for native cultivars on organic soils are implemented.

Table 16. Crop yield and fertilizer P applications at bog sites.

			Avg. Yield (bbl/a)		Fertilizer P kg/ha		
Bog name	Soil type	P regimen	2001-2002	2003-2004	2002	2003	2004
Eagle Holt	Organic	Reduced	111	146	20.0	16.1	6.3
Pierceville	Organic	Control	129	158	27.9	25.0	19.4
Benson's Pond	Organic	Reduced	131	133	22.4	18.1	19.6
White Springs	Organic	Control	108	101	22.4	20.6	18.8
Mikey/Kelseys	Mineral	Reduced	187	178	32.2	22.2	23.7
Ashleys	Mineral	Control	143	214	39.8	36.3	31.4

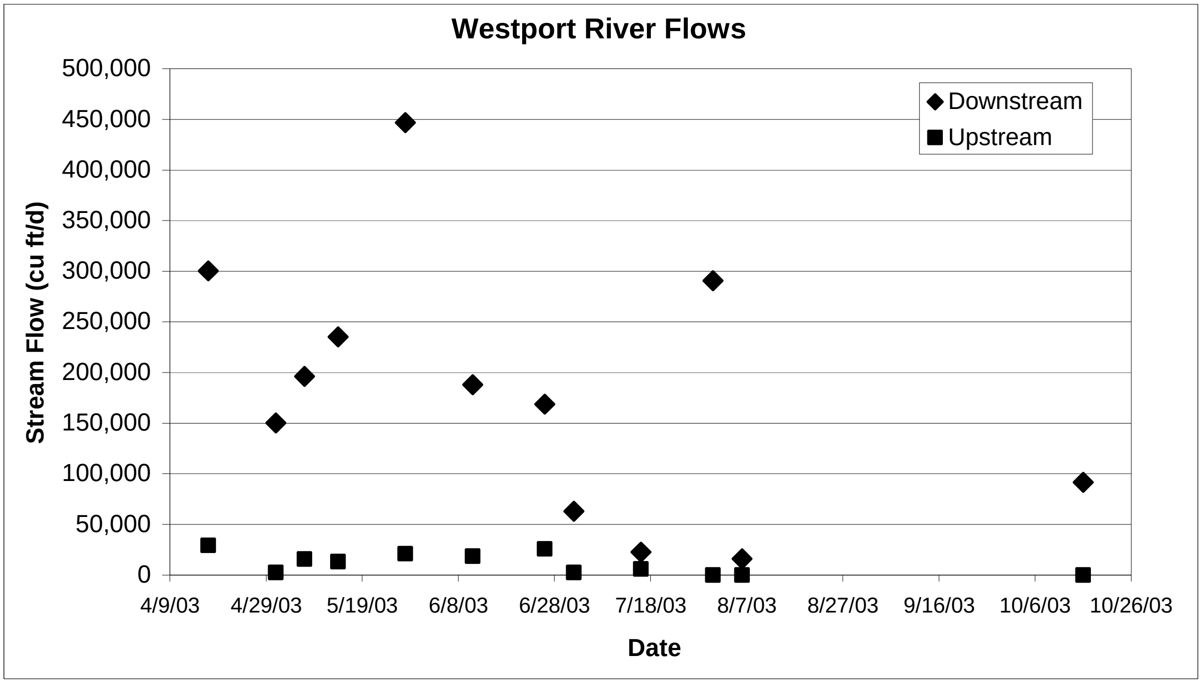
Wetland site - Westport

The purpose of investigating nutrient release/uptake by a reference natural wetland watershed was to provide a reference for interpreting parallel estimates for cranberry bogs. Since many bogs were constructed in wetland areas, net release/uptake by bogs should be evaluated relative to the land-use type, that might have occupied that acreage, should bog operations not have been undertaken. Land uses previous to cranberry cultivation on these lands include peatlands and forested wetlands as well as forested soils (more recent bog constructions).

In order to develop a defensible estimate of nitrogen and phosphorus release/uptake by a natural wetland system (or any system), it is necessary to quantify both the inputs and outputs of these nutrient species. The inputs would relate primarily to mass transport through inflowing surface and groundwaters, from the surrounding watershed, and from direct rainfall. The outputs would be primarily through transport via surface and groundwater outflows. For the purposes of creating a reference system to the cranberry bogs under study, it was agreed that the consumptive processes within the wetland (burial, denitrification, etc) need not be directly measured, but would be calculated from the inputs and outputs. The wetland site and sampling stations were selected with the idea that nutrient inputs and outputs would be quantified through sampling and the resulting budget estimates could be used for comparative purposes. The wetland selected was a 29.8 ha subwatershed within a 304.2 ha mixed use, primarily forested, watershed.

In 2001 and 2002, sampling was conducted at the Westport site. By the end of 2002, an error was discovered in the location of the upstream sampling location -- it was not at the correct location to sample the headwaters of the wetland. The upstream collection site was relocated prior to the beginning of 2003 sampling. Unfortunately, the 2003 data raised concerns over hydrologic conditions in the Westport wetland subwatershed that hinder data interpretation for net budgets. Based upon those data, it appears that the stream outflow at the downstream collection site is 4-22 times higher than the stream flow at the upgradient sampling site (Figure 8). In fact, for much of the summer of 2003 and fall of 2004, while there was water continuously flowing at the downstream sampling point, there was no flow at the upstream sampling location. The additional freshwater flowing out of the wetland is from direct groundwater inflow to the wetland, other surface water inflows from the remainder of the watershed, and rainfall directly to the wetland. While estimates of the volume and N and P input through precipitation inputs can be made, the surface water and groundwater volumes and nutrient concentrations are much more difficult to constrain.

Figure 8. Measured stream flow at the upstream and downstream stations to the Westport reference wetland site, 2003 season. Downstream flows range from about 4 to 21 times higher than upstream flows. On late summer/early fall dates with no data points, there was no flow.



Since the upstream sampling site at Westport did not capture most of the inflow to the lower site, precluding the calculation of a meaningful input/output net nutrient budget, the following discussion focuses on nutrient concentration in water draining from the watershed and gross nutrient export from the entire watershed based on data collected at the downstream sampling location.

From 2002 through early 2005, P and N levels in the water were assayed at the downstream sampling site -- TP was in the range of 0.017-0.037 mg/L and TN was in the range of 1.4-2.8 mg/L. These P loads are higher than those found in 'pristine' systems such as the Eel River (Plymouth, MA) and most Ponds on Cape Cod.

Gross watershed output was calculated based on stage/flow discharge relationships calculated for the downstream site (see Appendix 3A for data). An examination of that data showed that there were significant time gaps in the stage data leading to concerns about the 2004 data in particular. For this reason, additional estimates of annual flux were calculated based on extrapolations from grab sample nutrients and instantaneous flow measurements (see data tables in Appendix 3A).

Based on the entire watershed area (304.2 ha), the average gross export of nutrients from the Westport site (kg/ha/yr) was 0.14 for TP and 16.83 for TN using the flow-based calculations (Table 17 shows yearly data for both methods). The stage method required extensive estimations.

Table 17. Annual nutrient flux out of Westport study watershed based on extrapolation of data from grab samples and instantaneous flow measurements or stage data.

		Nutrients discharged (kg/ha/yr)						
Year	**Method**	**PO4**	**TP**	**NH4**	**NO3**	**TON**	**TDN**	**TN**
2003	flow	0.02	0.14	0.20	9.00	5.88	14.21	15.55
2003	stage	0.04	0.16	0.24	3.32	4.73	7.33	8.34
2004	flow	0.07	0.15	0.33	5.25	12.52	16.98	18.10
2004	stage	0.03	0.11	0.39	4.49	4.54	8.61	9.05

Average TP data in incoming and outgoing waters from the bog sites were compiled for comparison purposes (Table 18). At the Benson's Pond site, surface discharge during the season had significantly lower TP concentrations (0.056, 0.077, and 0.025 mg/L for the three years) compared to that in flood discharge (Table 18). While the TP in the seasonal surface discharge from Benson's Pond was similar to that in the Westport site water, flood discharge TP from bog sites is substantially higher in TP concentration compared to incoming bog waters or to the TP in the Westport samples. This comparison confirms that flood discharges are the events of concern for cranberry systems. TN in the bog discharge was generally less than that found in the downstream Westport samples.

Table 18. Average TP concentrations in waters of bog sites.

	All source water -- mean TP (mg/L)			**Flood discharges -- mean TP (mg/L)**		
	2002	2003	2004	2002	2003	2004
Eagle Holt	0.012	0.047	0.025	0.377	0.424	0.237
Pierceville	0.099	0.139	0.141	0.384	0.439	0.528
Benson's	0.065	0.077	0.079	0.291	0.158	0.165
White Springs	0.017	0.066	0.009	0.296	0.153	0.343
Mikey/Kelsey	0.074	0.045	0.094	0.100	0.170	0.118
Ashley's	0.060	0.108	0.066	0.109	0.127	0.147

TP and TN load of waters discharged from the cranberry bogs was calculated (Table 19). The numbers for gross discharge do not account for load in source water and are an estimation of the nutrients exiting the bogs only; net discharge subtracts incoming load. These data were compared to export data for the Westport site. At the Westport site, average downstream loads were 16.83 and 0.14 kg/ha/yr for TN and TP respectively. In comparison, average loads in cranberry discharge in this study were 13.96 and 2.91 kg/ha/yr for TN and TP respectively (see Table 19 also).

Table 19. Nutrient load in cranberry bog discharge water. Net discharge equals Gross discharge minus incoming load.

	TP (kg/ha/yr)			TN (kg/ha/yr)		
Gross discharge	2002	2003	2004	2002	2003	2004
Eagle Holt	1.84	3.19	1.23	---	10.00	9.36
Pierceville	5.15	5.57	4.40	---	15.29	12.11
Benson's	4.68	3.23	2.43	---	31.83	21.28
White Springs	5.16	3.35	4.69	---	9.27	15.83
Mikey/Kelsey	1.15	1.59	1.86	---	10.17	11.52
Ashley's	1.23	1.48	2.21	---	10.08	10.76
Net discharge						
Eagle Holt	1.29	2.59	0.60	---	-7.24	-9.56
Pierceville	3.30	3.62	2.43	---	-7.04	-15.34
Benson's	3.44	1.58	1.03	---	-0.16	-1.92
White Springs	4.15	2.76	4.30	---	-5.80	0.55
Mikey/Kelsey	0.01	0.06	-1.24	---	-9.13	-25.14
Ashley's	0.27	-0.63	0.19	---	-15.91	-15.98

Soil samples were collected from the Westport wetland subwatershed (Table in Appendix 4) for comparison to cranberry bog soils (Appendix 4 and Table 4). Organic matter in the bog soils was ~1-3%, while that at the natural wetland was generally 6-7%. As a result, the wetland soil held more K, Mg, and Ca, likely due to cation exchange sites on the organic particles. The soil pH of the wetland soil was very acidic (pH~4), similar to that in older cranberry beds. The soil pH was similar at the upstream and downstream ends of the wetland but organic matter and cations were greater in the downstream soil compared to that in the upstream soil. Soil P was similar in the upstream and downstream Westport soils but significantly lower (~10 ppm) than that in the cranberry bogs (Table 4). This is not surprising, since the bogs have received fertilizer P inputs over a period of years.

The Westport site is a reference forested watershed (92 percent forested of which 16 percent is classified as forested wetland) while the remainder is mostly scattered homes and open land and only 1 percent roads or other impervious type areas. Table 20 shows published gross export figures for various land uses. In comparison to other forested and wetland sites the Westport watershed discharge (kg/ha/yr) is within the <0.01 to 0.88 range for TP but substantially higher than the 0.5 to ~6.0 range for TN (Table 20, middle section).

While many commercial bogs were once natural wetlands (peatlands), in some cases low relief forests have been converted to bogs by logging, leveling and application of dikes etc and Westport is not unlike such areas in the bog study site.

Comparisons or conclusions about net or gross nutrient export from the wetlands area within the Westport watershed can not be made directly to other wetlands or bogs. However, considering only the gross export from the entire Westport watershed of 304 ha, it is clear that TP export is lower than the *average* gross or net export from the bogs. This is to be expected given the fertilizer applications and large inputs of source water the bogs receive. Notably, TN export from the Westport watershed was greater than the gross export from the cranberry bog sites, while net TN export from the bogs was negative (N was retained).

Westport is only one site and should not be overemphasized. In addition, we compared the average bog nutrient export (Tables 5-13; 19) to other literature values of wetland nutrient budgets as well as those for other land uses (Table 20). While wetlands are generally considered to be improvers of water quality, primarily due to their ability to accrete sediments, their capacity to retain nutrients may change over time and with continued loading may reverse so that they become nutrient exporters (Johnston, 1991; Erwin et al., 1997; Richardson, 1985; Peverly, 1982). In laboratory studies, saturated wetland soils discharged N and P to nutrient-poor surface water and only acted as nutrient sinks when the water source had high concentrations of N and P (Phillips, 2001).

Table 20. Export coefficients (gross discharge) for various land uses.

Land use	TP (kg/ha/yr)	TN (kg/ha/yr)	Reference
Wetlands (Beaver pond, swamps)	0.6 to 0.68	3.67 to 13.44	Devito et al., 1989
Freshwater wetland (peat soil)	0.41	---	Richardson, 1985
Wetland (Natty Pond Brook, MA)	0.42 to 0.47	3.3 to 7.2	Surballe, 1992
Alluvial cypress swamp	3.4	---	cited in Richardson, 1985
High reach tidal marsh (MD)	5.9	56	Jordan and Correll, 1991
Kettle pond wetland (MA)	---	2.94	Hemond, 1983
Mixed watershed with forest/wetland	0.14 to 0.15	15.55 to 18.10	Westport, this study
Forest/wetland (NC/VA)	0.09 to 0.21	0.69 to 3.8	Dodd et al., 1992 (cited in Lin, 2004)
Forest land (26 samples)	0.19 to 0.83; mean 0.236	1.38 to 6.26; mean 2.86	Reckhow et al., 1980
Forest (mineral soil)	0.24		Richardson, 1985
Forest	0.007 to 0.88	1.0 to 6.3	Loehr et al, 1989 (cited in Lin, 2004)
Forest (Wisconsin)	0.112	3.72	Clesceri et al, 1986 (cited in Lin, 2004)
Idle land	0.05 to 0.25	0.5 to 6.0	Loehr et al, 1989 (cited in Lin, 2004)
Mixed land use (Wisconsin)	0.176	4.07	Clesceri et al, 1986 (cited in Lin, 2004)
Mixed forest (56%)/ agric. (19%)	0.13	2.46	Dai et al., 2005
Row crops (26 samples)	0.26 to 18.6; mean 4.46	2.1 to 79.6; mean 16.09	Reckhow et al., 1980
Non-row crops (13 samples)	0.10 to 2.90; mean 1.08	0.97 to 7.82; mean 5.19	Reckhow et al., 1980
Mixed agriculture (20 samples)	0.08 to 3.25; mean 1.13	2.82 to 41.50; mean 16.53	Reckhow et al., 1980
Rural cropland	0.06 to 2.9	2.1 to 79.6	Loehr et al, 1989 (cited in Lin, 2004)
Agriculture (NC/VA)	0.55 to 2.03	5.0 to 14.3	Dodd et al., 1992 (cited in Lin, 2004)
Urban (23 samples)	0.19 to 6.23; mean 1.91	1.48 to 38.47; mean 9.97	Reckhow et al., 1980
Residential	0.77 to 2.2	5.0 to 7.3	Loehr et al, 1989 (cited in Lin, 2004)
Developed land (NC/VA)	0.45 to 1.5	5.0 to 9.72	Dodd et al., 1992 (cited in Lin, 2004)
Cranberry bogs - flow through	9.9	23	Howes and Teal, 1995
Cranberry bog - organic soil, contained	1.23 to 5.57	9.36 to 15.29	this study
Cranberry bog - organic soil, partial flow through	2.43 to 5.16	9.27 to 31.83	this study
Cranberry bog - mineral soil, contained	1.15 to 2.21	10.06 to 11.52	this study

Studies of natural wetlands (wetlands without a known upstream source, but rather a relatively unpolluted upstream source of water) have found wetlands to be a moderate source of phosphorus and nitrogen (upper portion of Table 20). On a net and gross discharge basis, the cranberry bogs in this study fell within the range of values for TP discharge in the wetland studies (0.42 to >3 kg/ha/yr, Table 20) but was greater than that in a pristine MA wetland (Surballe, 1992; Natty Pond Brook -- 0.42 to 0.47 kg/ha/yr TP).

On a gross output basis, discharge from the cranberry bogs of TN was greater than that for TN discharge in wetlands. However, on a net output basis, the cranberry bogs in this study generally acted as sinks for TN. A study of restored wetlands in the Iowa Great Lakes Watershed (van der Valk and Crumpton, 2004) showed that such wetlands could remove TN from water flowing through them, but effects on TP were less clear.

TN loss from a natural sphagnum bog in Massachusetts was calculated at 2.94 kg/ha/yr (Hemond, 1983). Of that, approximately 2 kg/ha was in the form of NH_4. Interestingly, about 80% of incoming N in that system was retained in the bog. That bog, similar to many organic soil cranberry bogs, is a kettle hole type; nutrient poor and isolated from surrounding surface and groundwater. However, in the case of cranberry bogs, a surface water connection is established to allow for irrigation and flooding practices.

The natural sphagnum bog (Hemond, 1983) was also similar to cranberry bogs in its nitrogen cycle properties. Nitrate was very low in the pore water despite its deposition from rain. Study of the bog soil showed that any added nitrate was rapidly converted to NH_4. In cranberry bogs, fertilizers are applied as NH_4 and it has been shown that if the soil is maintained at low pH (the standard practice), conversion to nitrate is negligible due to low populations of nitrifying bacteria (Davenport and DeMoranville, 2004). In both the cranberry bog and the sphagnum bog the primary nitrogen processes are mineralization, demineralization, and some denitrification.

Comparing nutrient export of the bogs to export coefficients for agricultural land uses shows that cranberries tend to fall within the reported ranges for TN and TP export (references in Table 20).

Concentrations of TP in cranberry discharge water were compared to published values. In this study TP in cranberry flood discharge averaged 0.1 to 0.5 mg/L in comparison to 0.53 mg/L TP in a previous study (Howes and Teal, 1995) but higher than the ~0.1 mg/l reported for cranberries in WI (WI DNR, unpublished data). In comparison, the mean TP concentrations the discharges from subwatersheds within a rural Vermont watershed that includes farmland were 0.2 to 0.55 mg/L (Windhausen et al, 2004) and discharge TP concentration from restored wetlands in Iowa was 0.108 mg/L (van der Valk and Crumpton, 2004). TP concentrations in water leaving the Westport study watershed were much lower at 0.017 to 0.037 mg/L.

In summary, cranberry bogs appear to function similarly to other wetlands, having some capacity to retain nitrogen and to a lesser extent phosphorus. As is the case in other wetland systems, their capacity to retain nutrients may be limited when incoming loads are high. Phosphorus losses from the bog systems appear to be primarily during flood discharges, likely due to change in soil redox state during prolonged anoxia. Gross TP export (kg/ha/yr) from the cranberry bogs was within the range of that for other reported agricultural land uses, somewhat higher than that from pristine wetlands (but similar to some values reported), and much greater than that for forested lands.

Fertilizer field plots

Field plots were established to assess the impact of reduced P fertilizer on cranberry production. In the first set of plots, N and K were held constant while P rate was varied from 0 to 33.6 kg/ha. Yield data are shown in Table 24. Statistical analysis of the data (PROC GLM) showed that while yield varied significantly among locations and years, P rate differences were not significant and did not interact significantly with location or year. A Dunnett's test of the entire data set comparing means for all other rates to those for the untreated control showed no significant difference between 0 and all other P rates. When locations and years were examined separately, the Dunnett's test for the second year at Location 4 showed significantly lower yield with 2.8, 16.8, or 22.4 kg/ha P compared to the 0 rate. However, the 5.6, 11.2, and 33.6 kg/ha rates were not significantly different from 0 (Table 21). Regression analysis of the data set did not reveal any significant linear or quadratic relationship between P rate and yield. Regression analysis of each location for each year did reveal a weak but significant negative relationship between yield and P rate for year 1 at Location 1. However, the r^2 value (0.12) indicates that the relationship does not account for the majority of yield variation. In summary, after up to three years of treatments, there was no predictable relationship between P rate and crop yield. In a previous study in Massachusetts, yield separations between 0 and 22.4 kg/ha P rates were apparent at year 3 (DeMoranville and Davenport, 1997). In Wisconsin (Greidanus and Dana, 1972), on peat soil, P deficiency was induced at 0 or 11 kg/ha P but not at 33 kg/ha P. In a six year study in New Jersey (Eck, 1985), cranberry yield was unaffected in the first year of differential P fertilization (rates of 0, 5, 10, 20, 40, and 80 kg/ha) but in subsequent years, optimum yield was associated with rates of 20-40 kg/ha P.

Table 21. Plot yields -- years 2000-2004. P rate series. Values are the mean of 5 replicates.

	Yield (bbl/a)							
	Location 1		Location 2			Location3		
P rate (kg/ha)	***2000*****	***2001***	***2000***	***2001***	***2002***	***2000***	***2001***	***2002***
0	169	147	239	163	79	344	113	222
2.8	132	79	212	146	94	304	93	219
5.6	119	112	263	94	56	326	80	183
11.2	96	80	230	187	93	274	91	244
16.8	97	107	247	150	93	307	95	191
22.4	113	70	278	123	118	343	68	224
33.6	90	80	253	125	69	339	81	193

** Yield = 139 - 1.92 * P rate. (p=0.0237; r^2=0.12)

	Yield (bbl/a)	
	Location 4	
P rate (kg/ha)	***2003***	***2004***
0	61	254
2.6	78	165*
5.6	72	174
11.2	72	171
16.8	72	147*
22.4	74	166*
33.6	76	176

*Significantly different from 0 kg/ha by Dunnett's test; alpha set at 0.05.

In the current study, no tissue P deficiency or yield reduction was achieved after 3 years of P fertilizer reduction. Certainly, there is no indication in these data that rates above 22 kg/ha (20 lb/a) are justified. Soil and tissue P analyses were conducted during the study (Tables A6-3, A6-4 in Appendix 6). In general, P was higher in soil and tissue after three years, regardless of P rate treatment. Since tissue P remained adequate in the no P added plots, it is not surprising that yield was unaffected. Conversely, tissue P in the fertilized plots remained well within the standard range (0.10-0.20%), well below that level at which toxicity would be expected. Soil P levels were generally at the high end of the normal range (20-60 ppm) or greater, and in the excess range (>80 ppm) after two years of 33.6 kg/ha P applications at Location 4. High soil P levels have been associated with zinc (Zn) deficiencies in crops grown on soils low in available zinc (Marschner, 1986). However, these are likely due to reactions between P and Zn in the soil leading to decreased Zn uptake by the plants rather than any competition within the plant. The plants analyzed in this study all had Zn within or above the normal range (15-30 ppm) for cranberry regardless of soil P levels. A correlation analysis of soil P levels and tissue P and Zn levels showed only weak relationships -- both tissue parameters were negatively correlated with soil P levels (Pearson coefficients of -0.484 ($p<0.001$)and -0.515 ($p<0.001$) for tissue P and Zn, respectively).

A second plot study was established in which differential P application was accomplished by manipulating applications of various commercial fertilizer products. The treatments were applied at two locations for four consecutive years and at two others for two years only. The crop yield results for those plots are shown in Table 22.

Table 22. Plot yields -- years 2000-2004. N:P ratio variation. Values are the mean of 5 replicates.

			Yield (bbl/a)					
			Location 1		Location 2			
N:P ratio	P form	P rate (kg/ha)	***2000***	***2001***	***2000***	***2001***	***2002***	***2003***
no N or P	none	0	301	86	147*	238	258	317
1:0	none	0	248	93	***278***	283	***202***	258
1:1	blend	22.4	270	134	196	350	221	258
2:1	blend	11.2	320	113	165*	280	195	274
1:1	TSP	22.4	246	106	165*	270	204	301
2:1	TSP	11.2	270	123	177	270	202	237
4:1	TSP	5.6	274	115	138*	344	224	278
2:1	foliar	11.2	261	129	194	303	207	240
5:1	foliar	5.6	256	124	191	318	272	197
2:1	TSP/foliar	11.2	229	169	174*	255	295*	270

			Yield (bbl/a)				
			Location 3			Location 4	
N:P ratio	P form	P rate (kg/ha)	***2001***	***2002***	***2003***	***2003***	***2004***
no N or P	none	0	73	165*	227	141	28*
1:0	none	0	101	***296***	218	183	***105***
1:1	blend	22.4	95	271	278	167	83
2:1	blend	11.2	103	251	276	181	141
1:1	TSP	22.4	106	253	271	157	116
2:1	TSP	11.2	83	276	213	136	134
4:1	TSP	5.6	136	319	278	215	129
2:1	foliar	11.2	119	216	204	128	85
5:1	foliar	5.6	96	276	220	144	95
2:1	TSP/foliar	11.2	99	259	88	184	100

*Different from 0 P control (second row) by Dunnett's test, alpha set at 0.05.
No significant regression relationships between P rate and yield.

Crop yields among the treatments were different at some locations in some years. At location 1, there were no treatment differences in the two years studied. At locations 3 and 4, only the unfertilized controls (no N or P applied) differed from the 0 kg/ha P plots after two years of treatment. At location 2, there were differences in some years among the treatments. However, only in year 1 were some P treated plots lower yielding than those without P, with no clear regression relationship between amount of P added and yield. As was the case with the P rate series plots, soil P levels were within or above the normal range in all treatments (Table A6-5, Appendix 6). In this study, only plots receiving 22.4 kg/ha P had significantly greater soil P when compared to the 0 kg/ha treatment plots. Similarly, tissue P was generally greater in plots receiving 22.4 kg/ha compared to those receiving no P (Table A6-6, Appendix 6). Tissue P and Zn levels in plots from this study were generally within or just above the standard range. In contract to the other plot study, correlation analysis showed a weak *positive* correlation between soil P and tissue P or Zn (Pearson coefficients of 0.344 (p<0.0001)and 0.18 (p=0.0165) for tissue P and Zn, respectively).

In both field plot studies, there was indication that rates below 22.4 kg/ha were sufficient to sustain cranberry yield at least in the short term (up to 4 years) and that rates of 22.4 kg/ha or higher increased soil and tissue P in cranberries that were already in the sufficient range. This is in agreement with studies conducted recently in Wisconsin, where plots on both an organic soil and a mineral soil bed were treated for up to four years with differential rates of P fertilizer. In that study no significant yield differences were observed despite lower tissue P in the lower rate treatments (Roper, personal communication). As in that study, tissue P in these plots, while somewhat affected by treatment, remained in the sufficient range.

Taken together with the crop results for the bog water quality sites, the results of the field plots support a recommendation that fertilizer P applications to cranberry bogs should not exceed 20 lb/acre/yr (22 kg/ha) if soil and tissue P are in the sufficient range. This level of added P should support production of all cultivars on all soil types. However, native cultivars on organic soil types should be sustainable with the addition of lower P rates (10-15 lb/acre). Conversely, newer cultivars that yield in the 300 bbl/acre range may require higher rates. An examination of a native cultivar bog (DeMoranville, 1992) showed that the plant biomass, not including fruit, contains ~27 kg/ha P. Since each year, the bog turns over ~50% of the root biomass and ~33% of the aboveground structures, as well as producing a crop, it is foreseeable that over time, soil supplies of P would decline with the implementation of these P fertilizer recommendations. In such situations, higher P rates would be warranted periodically to replenish soil stocks.

Conclusions and Recommendations

In this study, water and nutrient budgets were developed for three pairs of commercial cranberry bogs and the outcomes were compared to nutrient levels in a local vegetated wetland and to previously reported N and P levels in wetland, forest and agricultural settings. At some of the bog sites, fertilizer P inputs were reduced from 20-35% in the second and third years of the project and impact on nutrient budgets was determined. In addition, plot-scale research was conducted to examine the impact of reduced P fertilizer on cranberry productivity.

Conclusions

- Water input to the cranberry bog systems varied from 8-11 acre feet per season. Of this, 3.6-4.7 feet was from rainfall, the remainder of input was from groundwater upwelling (2 sites), irrigation and flooding. Water output was primarily from evapotranspiration (2.4 feet), infiltration, and surface discharge (primarily of floods).
- On a total budget basis, including fertilizer applications as inputs and crop and other biomass (leaves) removal as outputs, the bogs were generally net importers of total N and total P. The nutrients retained in the bog are constituents of the cranberry plants and microorganisms living in the bog or are retained within the bog soil and subsoil.
- When N and P of bog source waters was compared to that in discharge water, the bogs generally remained net importers of TN. However, TP in outgoing waters was greater than that in source water. Net TP fluvial output averaged 2.08 kg/ha/yr in 2002 (range 0.01 to 4.15); 1.66 kg/ha/yr in 2003 (range -0.63 to 3.62) and 1.22 kg/ha/yr in 2004 (range -1.24 to 4.30).
- The primary path of nutrient discharge from the bogs is through surface water. Cranberry bogs are constructed so that they have a perched water table and limited connection to the underlying groundwater. In addition, the saturated soils, high in Al and Fe, tend to retain

P in the subsurface layers. If cranberry bogs contribute nutrients to groundwater, it would be primarily via surface discharge that infiltrates to groundwater off-bog.

- Flooding events were the primary source of TP output from the cranberry bogs. Particulate P became suspended in harvest floods due to agitation during crop removal and was discharged if the floods were released soon thereafter. Holding the flood for a finite period post-harvest decreased the TP load in the water, likely due to settling of particulates. Conversely, if the floods were retained on-bog for extended periods (~12 days), PO_4 concentration in the water increased, likely due to change in soil redox state due to soil anoxia. This phenomenon is also likely the source of P loading in the winter floods as well, since these floods tend to be held for longer periods.
- Cranberry bogs mimic natural wetlands in that they tend to retain nutrients during the spring and summer and discharge nutrients during fall and winter. This timing is helpful in mitigating the potential impact of the nutrient discharge since biological activity in receiving bodies is less during the fall and winter.
- Nutrient relationships of the cranberry bog were compared to those of other wetlands and other land uses. In comparison to the watershed in Westport, MA that was examined in the current study, TN output from the bogs was lower while TP output from the bogs was higher on a kg/ha basis. Organic matter and cations in the bog soil was lower than those in the wetland soils at Westport, while soil pH was similar. P in the bog soil was elevated in comparison to that in the Westport site, due to fertilizer applications to the bogs. In general, the bog TP output was intermediate in value compared to that in other wetlands but somewhat higher than that from pristine wetlands. As is the case in other wetland systems, the capacity of a cranberry bog to retain nutrients may be limited when incoming loads are high. Gross TP export (kg/ha/yr) from the cranberry bogs was within the range of that for other reported agricultural land uses and the Westport study site but much greater than that for forested lands.
- When fertilizer P input was reduced (20-35%) at cranberry bog sites for two consecutive seasons, crop yield was not adversely affected at rates of 6.3 and 23 kg/ha at an organic soil site and a mineral soil site respectively. Likewise, in field plot studies, fertilizer P reductions were not associated with crop decline. After two seasons of reduced P, soil test P had declined compared to that of the control bogs but remained in the sufficient range. Plant tissue P was similar and in the sufficient range at all sites at the end of the two years of P reduction.
- Reducing P fertilizer on the cranberry sites did not immediately or consistently improve export water quality. However, after two seasons of P reduction, P concentrations at the site with 35% P reduction, and the lowest applied P rates, had harvest discharge water TP of 0.25 mg/L compared to 0.8 mg/L in the pre-reduction year. When a model of P retention by wetlands was tested in the Florida Everglades (Richardson et al, 1997), output water TP was reduced below 0.05 mg/L only when input TP was limited to 1 $g/m^2/yr$ [10 kg/ha/yr]. The authors found that when modeling P storage capacity of wetland soil, storage was proportional to loading but output increased exponentially after a loading threshold was reached. In the Everglades system, that threshold was 1 $g/m^2/yr$. Based on this study, the threshold may be considerably higher for cranberry wetlands.
- In plot-scale studies, cranberry yield was not related to applied P fertilizer. As P application rate increased to 22.4-33.6 kg/ha, soil and tissue P increased. However, at lower rates, soil and tissue P were in the sufficient range. Based on these plot studies,

rates lower than 22.6 kg/ha (20 lb/acre) should be sufficient to support cranberry cultivation at least in the short term (1-3 years). Exactly how much reduction would be sustainable for longer periods remains unclear.

Recommendations

- Cranberry fertilizer applications just prior to flooding events should be avoided.
- Deposition of fertilizer into water that will exit the bog system should be avoided.
- Since flood discharges are the primary source of P release from the bog system, particular care should be taken in flood management:
    - ➢ Harvest floods should be retained on the bog for 1-3 days to allow particulate settling. Additional benefit may occur by the placement of physical barriers to particulate discharge (e.g. harvest booms place before the water exits the discharge flume) or the installation of tailwater recovery ponds.
    - ➢ Harvest flood retention for >10 days should be avoided if the discharge is to a nutrient-sensitive water body.
    - ➢ Tailwater recovery or discharge through holding ponds could reduce TP export from the bog system.
    - ➢ Winter flood withdrawal from beneath newly-formed ice should be the preferred practice in order to avoid anoxia injury to the cranberry plants and to minimize P movement from the soil into the flood water by minimizing the time that the flood remains on the bog.
- Fertilizer P rates should be no greater than 20 lb/a (22.4 kg/ha) on established cranberry beds. For native cultivars on organic soils, rates as low as 10-15 lb/a should be sufficient unless tissue tests show deficiency of P (<0.1% in plant tissue sampled in August). Fertility programs should be conservative but stable -- as a perennial plant cranberries often are responding to fertilizers applied in the previous year. To achieve lower P rates without inducing nitrogen deficiency, fertilizers with N:P_2O_5 ratios of 2:1 or 1:1 are recommended. This would provide a ratio of N:P (actual) of 4:1 or 2:1. Examples of commercial products that fit this recommendation include 18-8-12 (approximately 4N:1P) or 15-15-15 (approximately 2N:1P).
- Despite the outcome of plot-scale research in this study, elimination of P fertilizer applications is not recommended based on previous studies (DeMoranville and Davenport, 1997; Greidanus and Dana, 1972; Eck, 1985) and on the poor availability of soil bound P during rapid plant growth and fruiting (summer). In addition, P rates greater than those recommended here may be necessary to replenish soil P stocks if soil or tissue test P results fall below the sufficient range.

PROJECT BUDGET

Expense Item	**Grant**	**UMASS match**
1. Salary[1]		
Project leader 7% FTE		$25,575
Technician	$123,389	
Hourly labor ($7.5/hr)		$5,000
Subtotal salary	**$123,389**	**$30,575**
2. Consultants/Subcontracts		
UMass Dartmouth summer worker	$2,500	
Subtotal cons/sub	**$2,500**	
3. Equipment/supplies		
Equipment (recorders, monitors)	$11,880	
Misc. supplies	$1,361	
Subtotal equip/supp	**$13,241**	
4. Analytical		
Water samples (bogs - SMAST)	$57,400	
Wetland (SMAST)	$9,360	
Soils and tissue samples	$1,628	
Subtotal analytical	**$68,388**	
5. Indirect charges	**$19,679**	
6. IC differential		**$94,510**
TOTAL	**$227,197**	**$125,085**

[1] Salary includes benefits (fringe)

ENVIRONMENTAL MONITORING

A full copy of the project QAPP is on file at the Division of Watershed Management, Department of Environmental Protection, 627 Main Street, Worcester MA, 01608. For a discussion of quality assurance outcomes, see Appendix 7.

Data Quality Objectives

The data quality objective for all parameters was to limit overall error to 20 percent or less. This level of accuracy is sufficient to model N and P loading in this system. The project provides data of known accuracy and precision for water samples within specified holding times. The specific types of data quality objectives are:

Accuracy: Accuracy is determined by how close to the true or expected value the reported values are. Accuracy objectives for each of the analyses are shown in Table A1 Accuracy of water sample chemistry was measured by analysis of spiked samples at the SMAST laboratory.

Soil and tissue analyses were carried out at Midwest laboratories, Inc. a commercial laboratory that provides QA/QC and GLP (Good Laboratory Practices - standards used by EPA in pesticide registration and other programs) assurance. Accuracy was measured by analysis of standard reference materials (SRMs). Analysis of SRMs was performed at a frequency of one per analytical batch.

Accuracy of flow measurements (manual flow data and depth recordings) was determined by comparison to a similar flow-meter instrument and by manual determination of depth and flow rate (timing a floating object for specified distance).

Precision: Precision is determined by how field duplicate samples or lab duplicate samples agree with each other. Precision objectives for each analysis are shown in Table A1. Every 20th soil or tissue sample and every 10th water sample or at least 1 per sample series (if less than 10 are run) were split to create lab duplicates prior to analysis. Precision was analyzed as relative percent difference of duplicate samples:

RPD= (sample-duplicate)/((sample+duplicate)/2)*100

In addition, field blanks and field duplicates were collected, analyzed, and compared. Locations of field duplicate collection was varied from one sampling round to the next. For soil and tissue samples, split samples (division of single, well-mixed sample) substituted for field duplicates.

Precision of flow measurements will be determined by taking duplicate measurements of flow and stream width and depth. Once a flow rating curve has been developed, its predictive value will be compared to manual field measurements of flow.

Detection Limits: Detection limits must be reported so that the lowest level of detection for each analysis is known. By comparing a result to the specified detection limit it can be reliably determined if the analyte is present. Detection limit objectives for each analysis are shown in Table A1.

Holding Times: Each analysis must be completed on each sample within the specified holding time. This holding time starts from the time of sampling and may vary depending on the type of analysis. Holding times are listed in Table A2.

Comparability: Comparability refers to the extent to which the data from this study is comparable to other studies conducted in the past or from other areas. Because the sampling is based on a limited number of sites (a single site for the natural wetland), rather than from a statistically based random sample we can not use our data to make statistical estimates of the population of unsampled locations. We will, however, be using standard methods to determine all chemical measurements. Further, we will compare our results to those in the published literature, particularly that regarding nutrient content in natural wetlands.

Table A1 Data Quality Objectives.

Goals for minimum analytical detection limits, accuracy and relative precision of duplicates.

Parameter	Units	MDL[1]	Accuracy[2]	Precision[3] (RPD)	Expected Range
Ammonium in water	mg/l	0.004	80%-120% of matrix spike	<20% RPD	0.014-0.700
Nitrate+nitrite in water	mg/l	0.004	80%-120% of matrix spike	<20% RPD	0.014-0.700
TON in water (total organic N)	mg/l	0.014	80%-120% of matrix spike	<20% RPD	0.030-1.400
ortho-P in water	mg/l	0.003	80%-120% of matrix spike	<20% RPD	0.031-0.775
Total P in water	mg/L	0.006	80%-120% of matrix spike	<20% RPD	0.050-0.900
Flow measurements	$m^3\ hr^{-1}$	n.a.[4]	1% of meter full scale	<20% RPD[4]	0-540
Crop yield	bbl/acre (bbl=100lb)	1 lb	------	------	150-250 bbl/acre
Soil analyses (total available P)	ug/g dry matter[5]	1 ug/g	90%-110% of SRM	<20% RPD	20-80 ug/g
Plant tissue analyses (total P)	% dry matter[5]	0.01%	75%-125% of SRM	<20% RPD	0.1-0.2%

[1] Method Detection Limit. [2] For explanation of accuracy see text. [3] Relative Percent Difference of duplicate field samples, see also section B.5. [4] Based upon other field studies, the actual value is placement dependent (depth, width of stream, etc.). [5] Percent solids analysis to be performed on all samples.

Table A2 Preservation and holding times for water samples

Parameter	Container	Sample volume	Preservative	Holding Time
Ammonium	HDPE (acid leached)*	60 ml	H_2SO_4 if ISCO** 4^oC if Grab	28 days 24 hrs
Nitrate+Nitrite	HDPE (acid leached)*	60 ml	H_2SO_4 if ISCO Frozen if Grab	28 days 28 days
TON (total organic N)	HDPE (acid leached)*	60 ml	H_2SO_4 if ISCO Frozen if Grab	28 days 28 days
ortho-P***	HDPE (acid leached)*	60 ml	H_2SO_4 if ISCO 4^oC if Grab	28 days 48 hrs
Total P	HDPE (acid leached)*	60 ml	H_2SO_4	28 days
Color	Plastic	1 L		
Plant samples	Plastic bag	~250 ml	frozen	2 months
Soil samples	Plastic bag	~600 ml	air dried	2 months

*   High Density Polyethylene leached in 10% HCl.
** ISCO samples are preserved to pH 2, grab samples are held on blue ice and run immediately or frozen immediately upon return to the laboratory
***For ISCO samples preserved with H_2SO_4, ortho-P is referred to as acid extractable P. The relationship between acid-extractable P and unpreserved ortho-P will be determined and reported as well.

LESSONS LEARNED

This project presented many challenges for the research team. Most difficult were defining a site for the natural wetland study and modeling water movement in the bog systems. QAPP development was a longer process than anticipated and this along with inexperience on the part of the data collection team and the difficulties in selecting a wetland site delayed the start of the project. As a result, the end date for the project was less than 2 months beyond the final data collection date for the bog sites, presenting a significant challenge.

Meeting project timelines was a significant challenge in this project. Even more of a challenge was working with commercial farmers to collect a rigorous data set. After several nights without sleep during frost season, notifying us so that we could sample or filling out a log book tended to fall to low priority for the growers. Water discharge during the season was often difficult to quantify since surface flow, if it existed at all, was often so slow and shallow as to preclude successful use of instrumentation for quantification. Despite the challenges, we feel that we have succeeded in describing and quantifying N and P movement in the bog systems.

The wetland site remains problematic for the reasons outlined in the project summary and in the data reports from SMAST. Finding a wetland in Southeastern Massachusetts that receives no input form urbanization and/or agriculture was well near impossible. As a result, the wetland studied had much greater nutrient loads downstream compared to upstream along with significantly greater water output, indicating that we have not defined inputs completely. Unfortunately, doing so would be well beyond the scope of this project.

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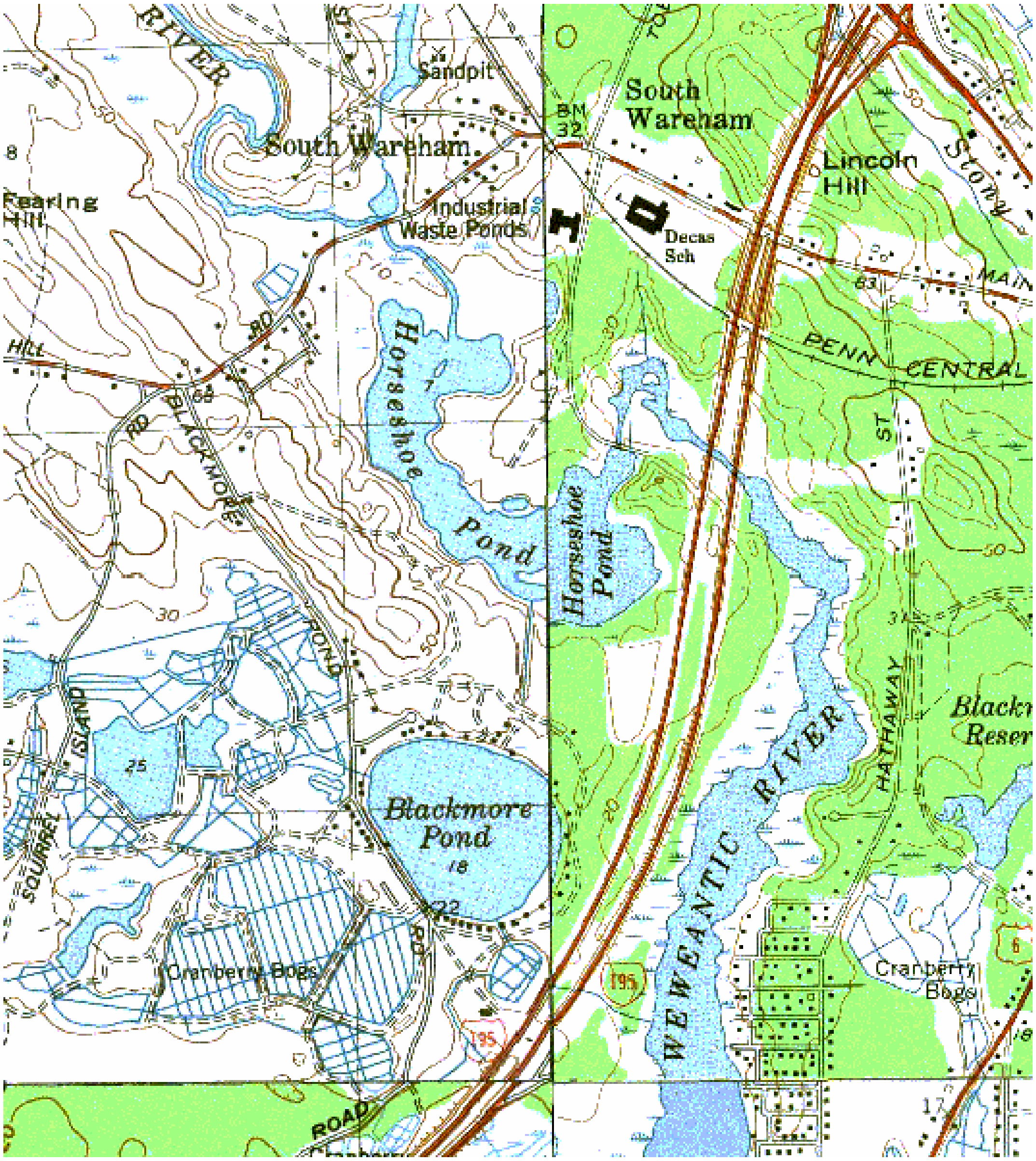
APPENDIX 1.
Site descriptions.

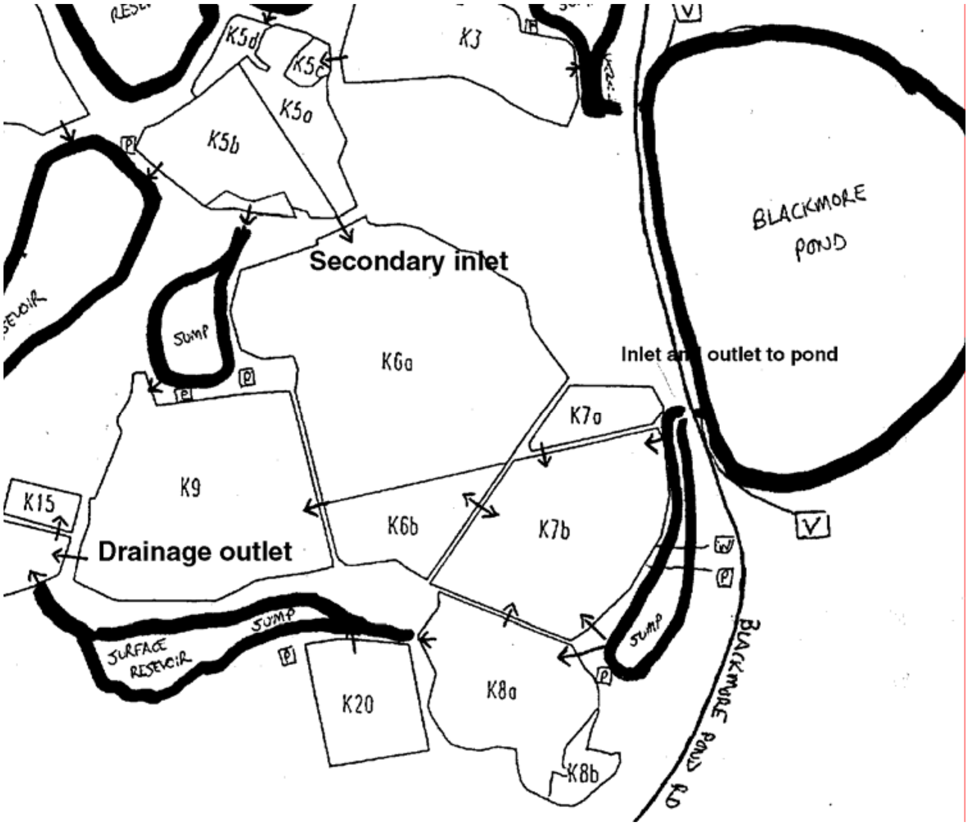
Bog sites:

Site 1: organic soil pair - Blackmore Pond (reduced P) and Pierceville (control) Bogs. The bogs are owned by the Beaton family. Contact person is Matt Beaton. The two bogs are approximately 3 miles apart. Management and soil type are similar.

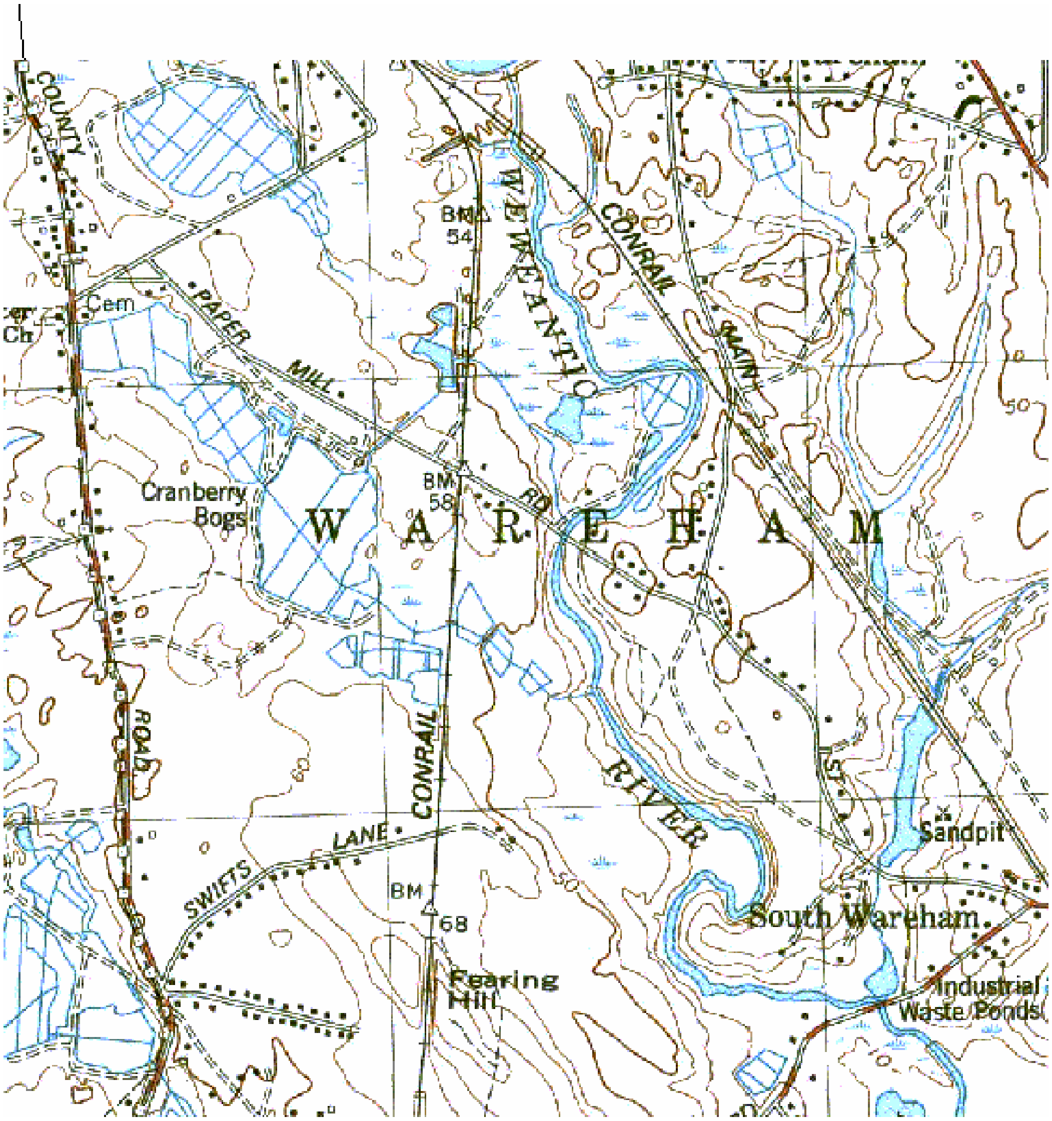
The Blackmore Pond bogs are located adjacent to Blackmore Pond in Wareham, MA. Bog location is marked (label - Cranberry bogs) on the USGS quad excerpt below (Quad 265830-265834 on MASS GIS); collection points are marked on the grower map (next page).



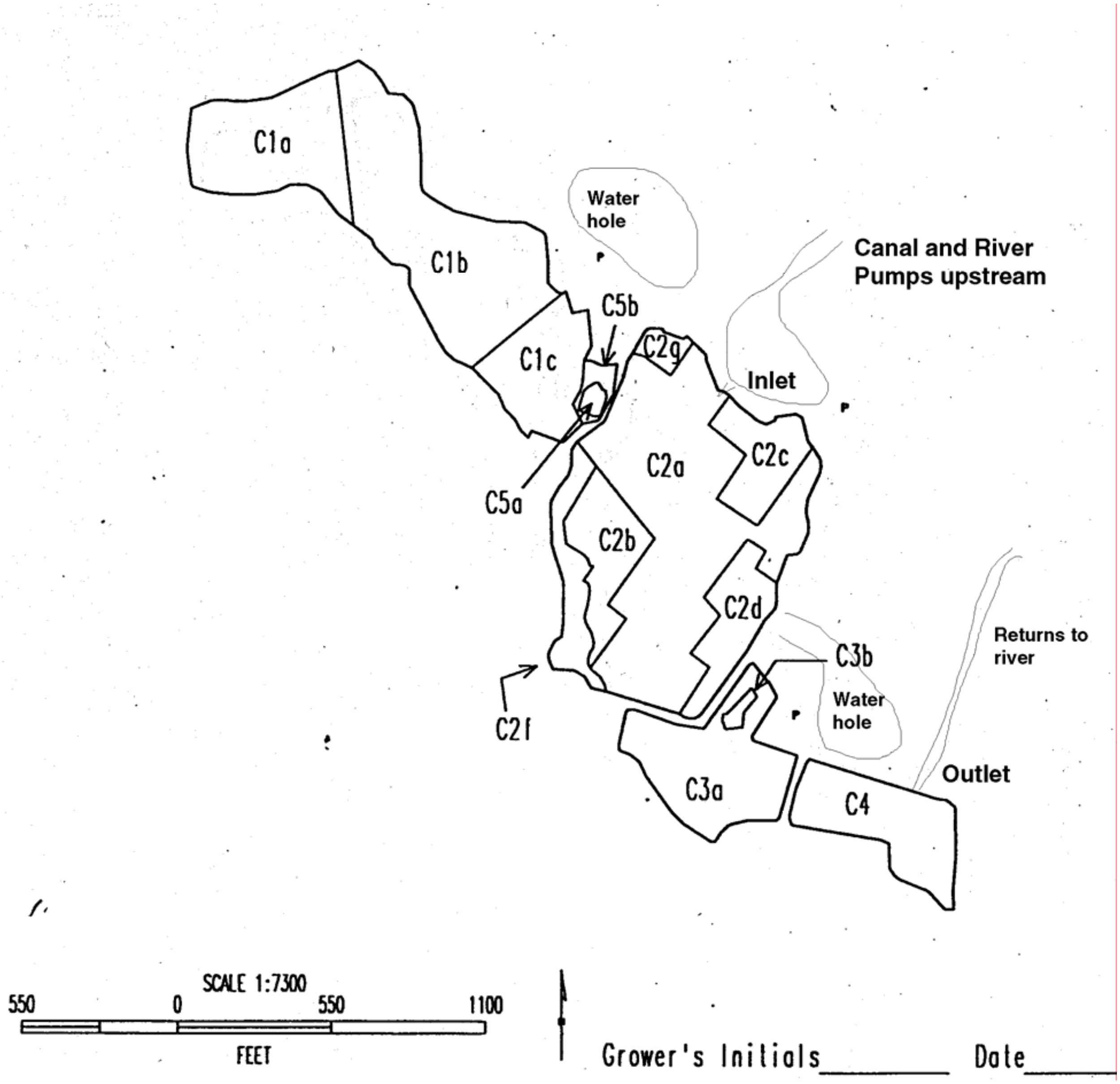
This was the bog within the pair to receive reduced fertilizer in 2003 and 2004. The sections included in the study are marked K6a and b, K7a and b, K8 a and b, K9, and K20 and account for approximately 63 acres. Water enters the system from Blackmore Pond (near K7a) - pump, from the secondary inlet at K6 (gravity), and from irrigation pumps (marked P) adjacent to K9, K7b, K8a, and K20. Water leaves the system to Blackmore Pond (pump or gravity) or from the K9 flume (gravity, summer months). All inlets, outlets and pumps market on the map were monitored. Additional arrows are internal water movements within the bogs (water originated from labeled inlets).



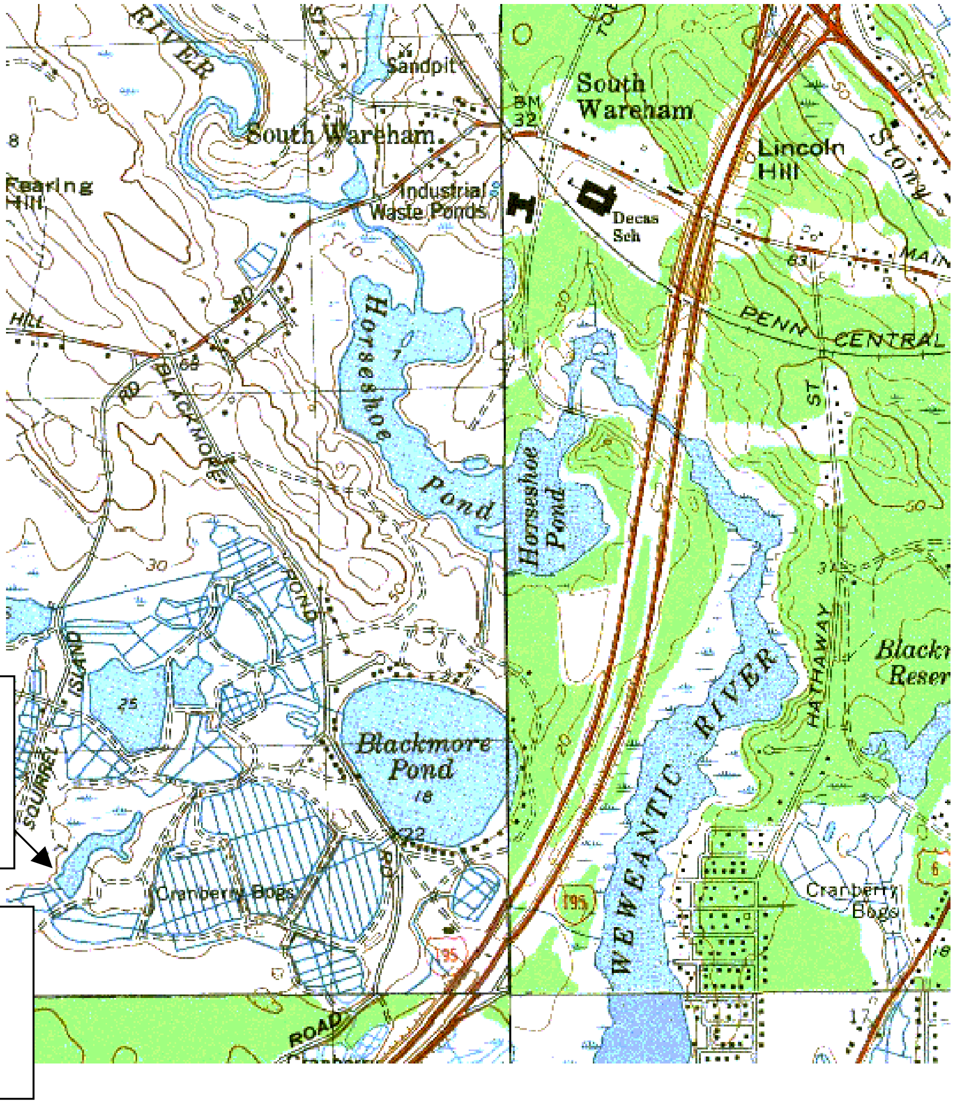
The Pierceville Bogs are located off Paper Mill Road in Wareham. Bog location is marked (label - Cranberry bogs) on the USGS quad excerpt below (Quad 261834-265834 on MASS GIS); collection points are marked on the grower map (following page).



This bog system, consisting of 45 acres received full fertilizer rates throughout the study. All sections shown on the map were included in the study. Water is pumped from the Weweantic into a canal and then into the water hole marked inlet, and exits at a flume (gravity outlet) to return to the river downstream. Irrigation from the 3 pumps marked P. All pumps (inlet, irrigation) and the gravity outlet were monitored.



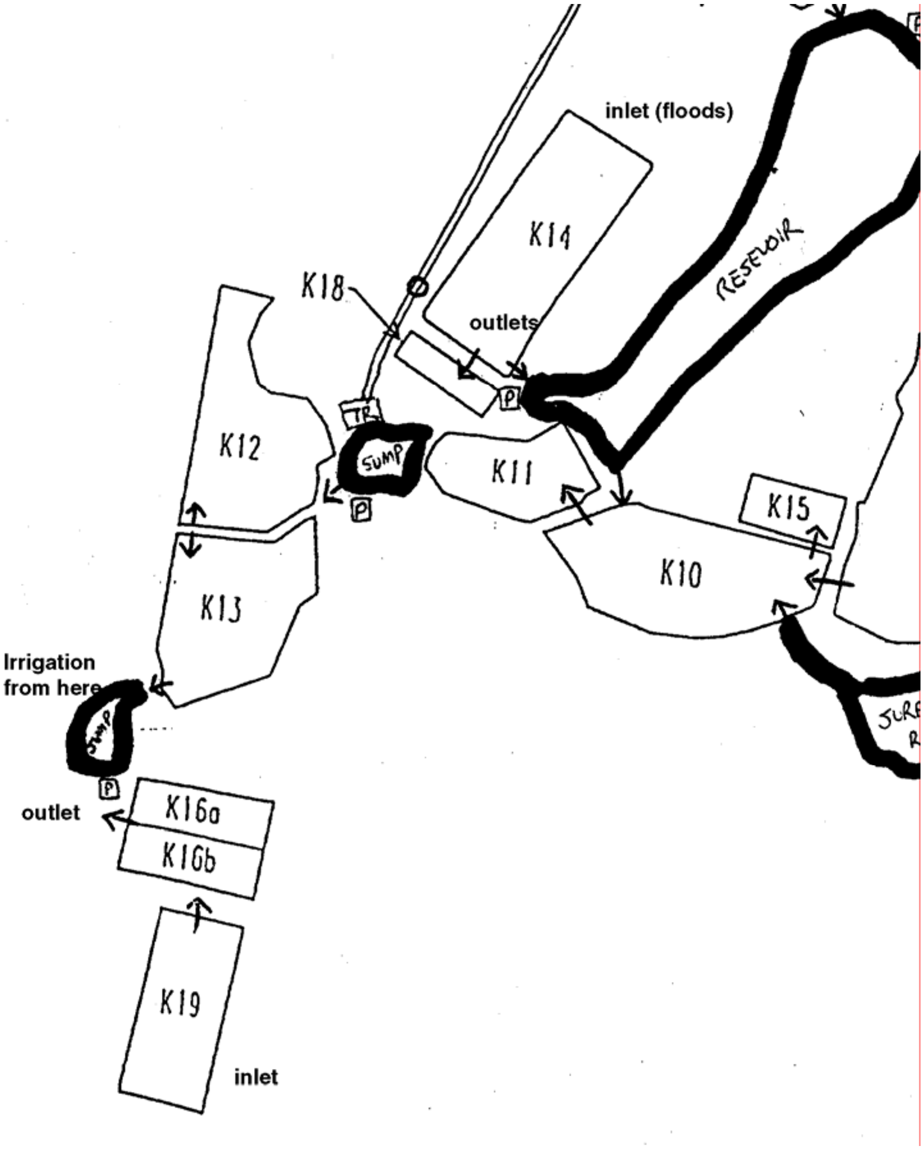
Site 2: Mineral soil pair - Ashley's Bog (Control) and Kelsey's/Mikey's (Reduced P) Bog at Eagle Holt are adjacent to the Blackmore Pond Bogs (marked new construction on USGS quad 265830-265834 on MASS GIS below). Collection points are marked on the grower map on the next page.



Reservoir shown on next map

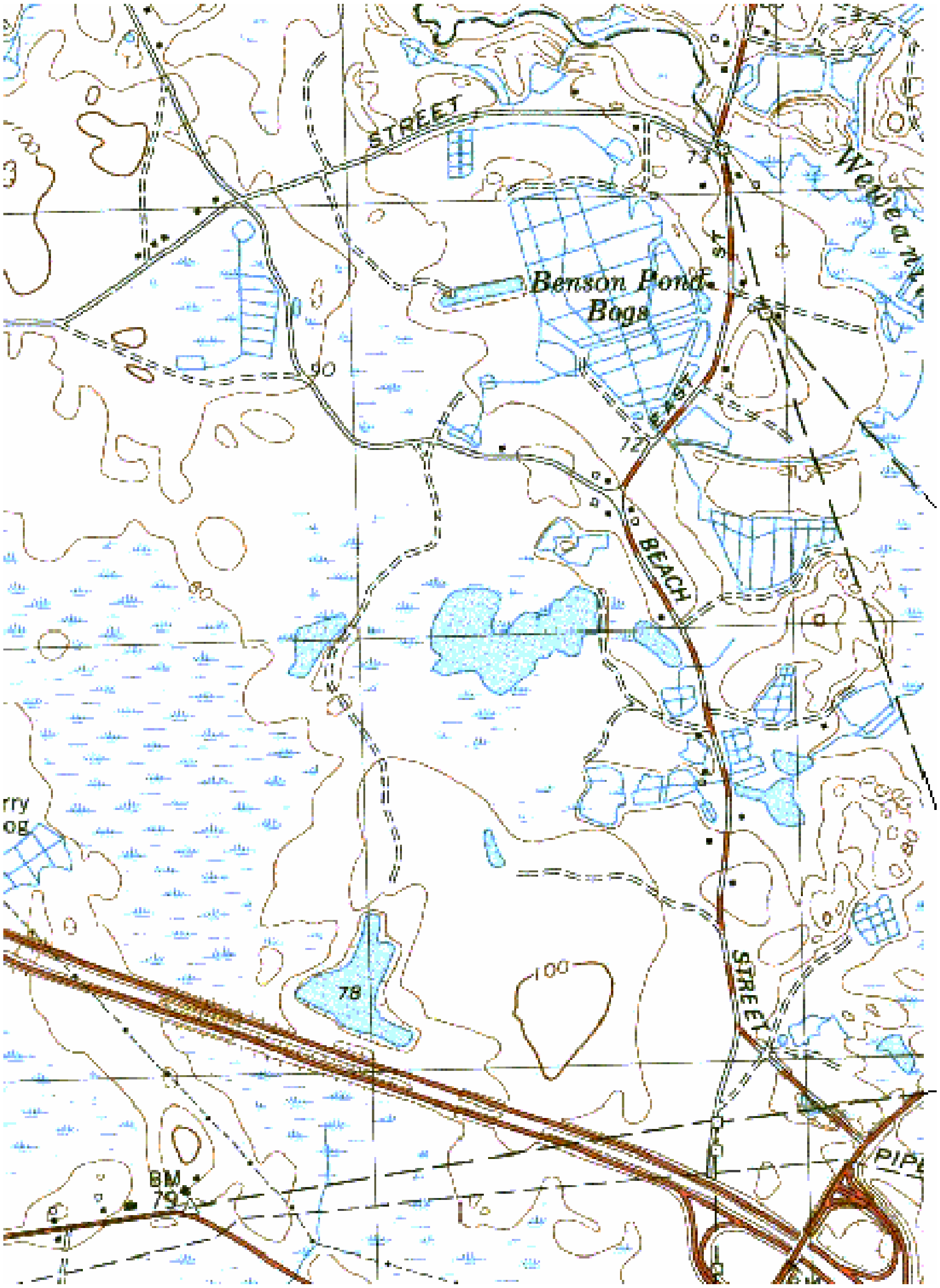
Bogs are new construction here

Ashley's Bog (K14, 4.17 acres) and Kelsey's/Mikey's Bog (K19 and K16, total 5.46 acres)
The bogs are owned by the Beaton family. Contact person is Matt Beaton. The two bogs are less than 1/4 mile apart, just west of the Blackmore Bogs in Wareham, MA. Management and soil type are similar. K16/19 received reduced fertilizer in 2003 and 2004. Both bogs with collection points are shown in the grower diagram below. K14 receives irrigation water from the adjacent reservoir (pump marked). K19 and 16 receive flood water from the irrigation sump via an underground line emptying into K19 as marked (inlet). Outlets and K14 inlet are gravity.

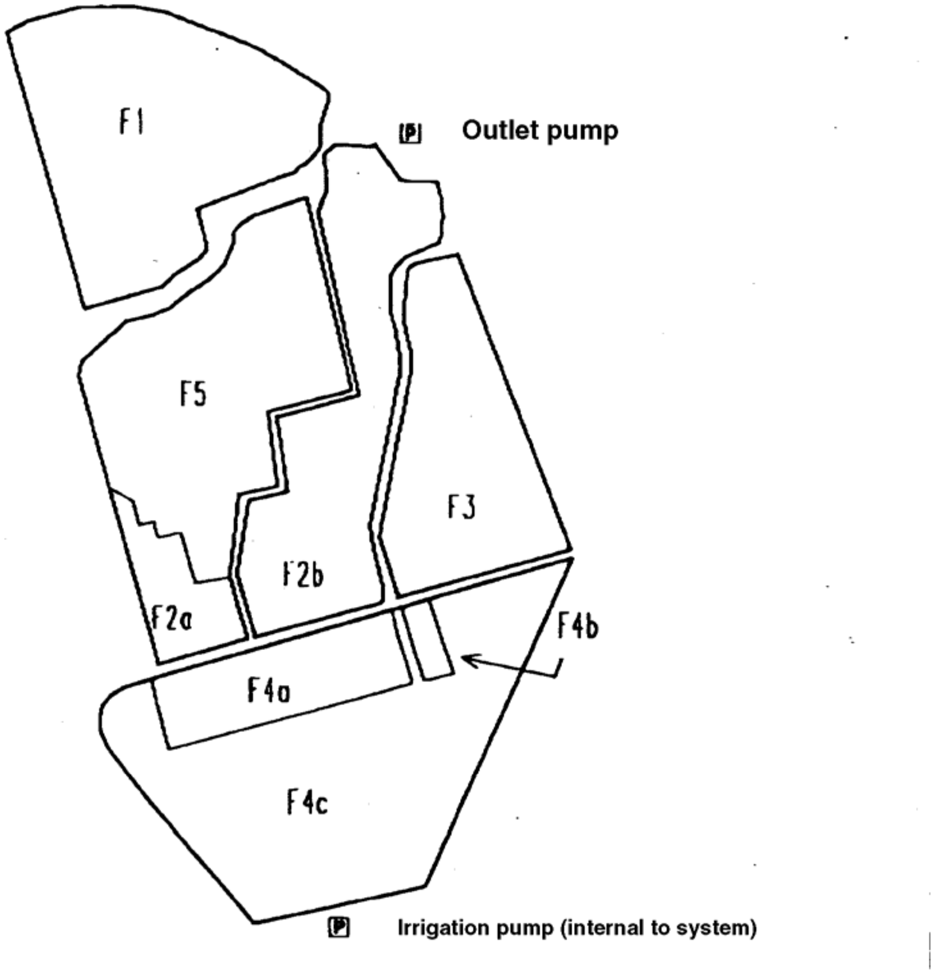


Site 3: organic soil pair- Benson's Pond (reduced P) and White Springs Bogs. The bogs are owned by Kirby Gilmore (contact). The two bogs are approximately 3 miles apart, with similar management and water flow design. Benson's Pond received reduced P in 2003, both properties received low P in 2004.

Benson's Pond Bogs are located on East Street in Middleboro, MA (near the South Carver border) directly north of Exit 2 of Route 495. Bog location is marked on the USGS excerpt below (the bog intersects quads 261842 and 261838 on MASS GIS); collection points are marked on the grower map (following page).

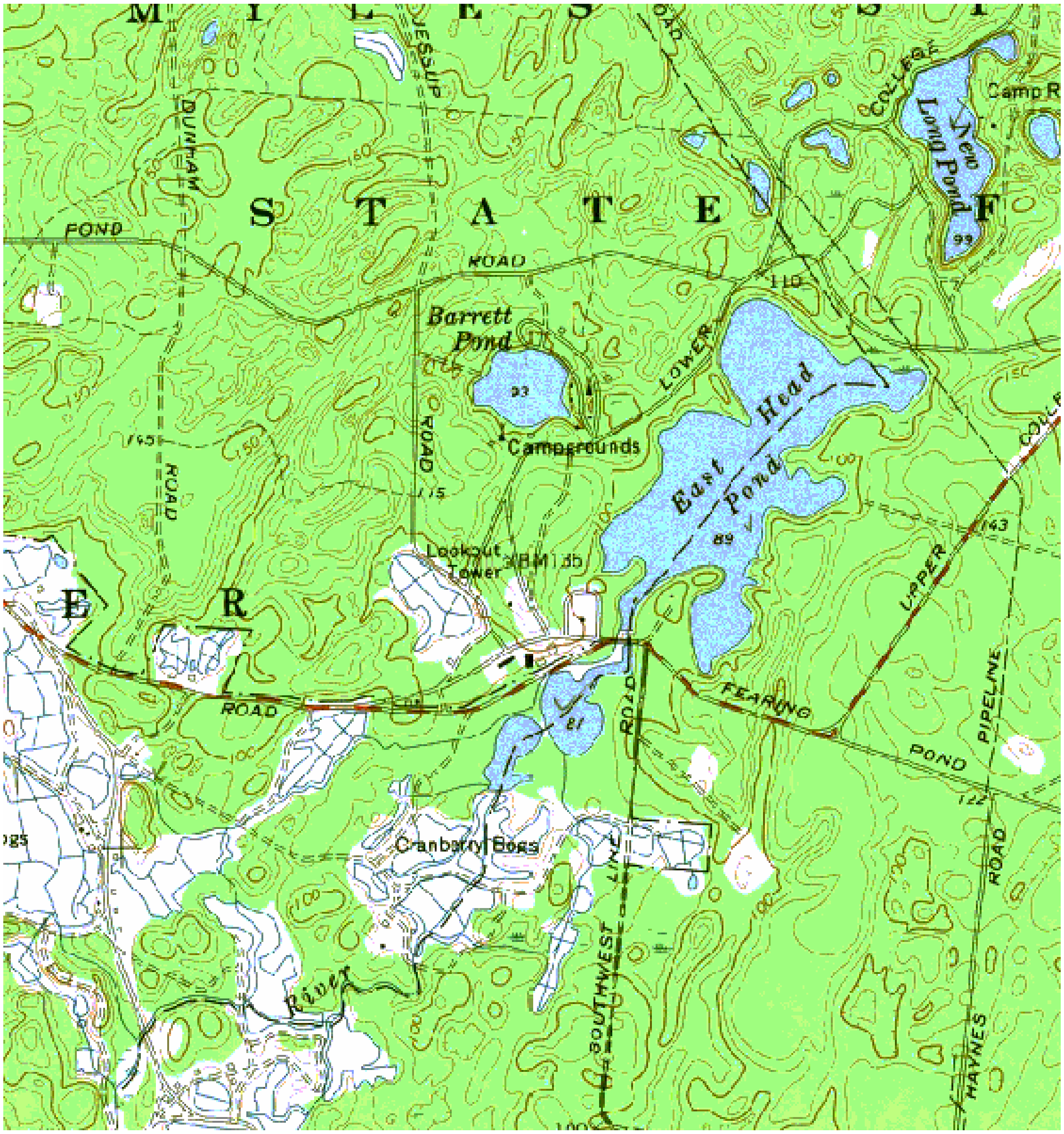


Benson's Pond System (19.69 acres).

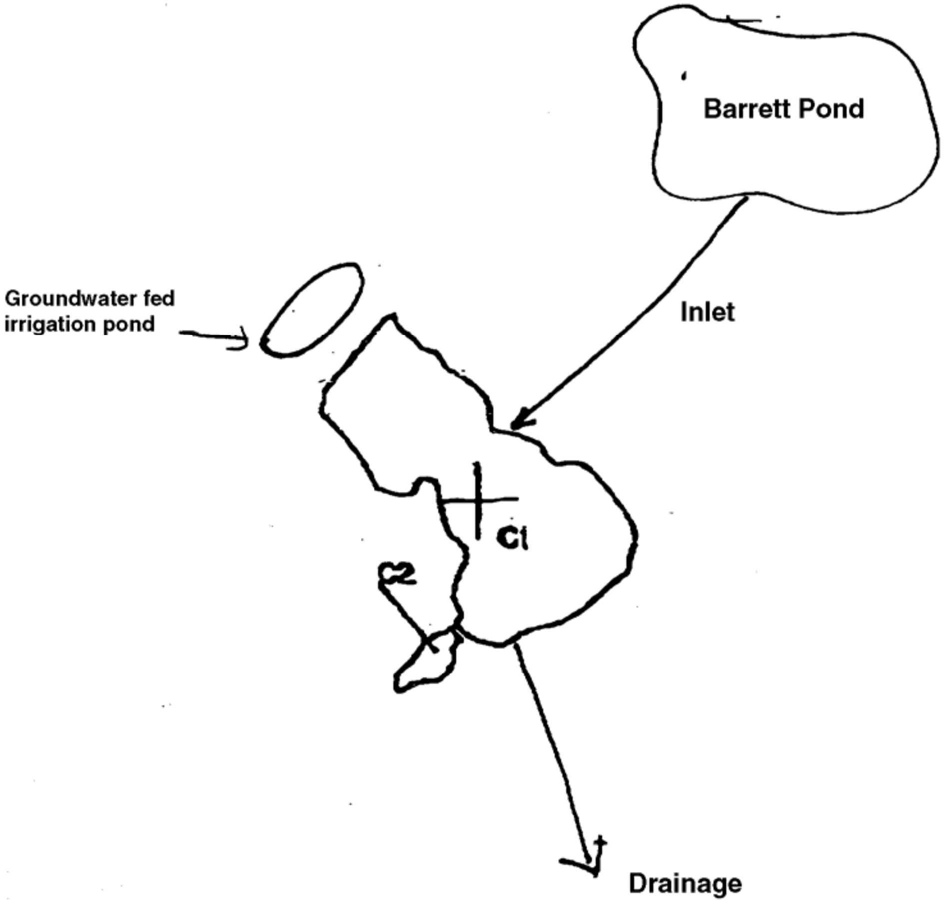


P **Lift pump here used to flood from the Weweantic**

White Springs Bog is off Cranberry Road, just North of the ranger station in Miles Standish Reservation in Carver, MA. Bog location is marked (adjacent to the words 'lookout tower') on the USGS excerpt below (quad 269842 on MASS GIS); collection points are marked on the grower map (following page)..



White Springs (7.57 acres).



Description and map of natural wetland site

The natural vegetated wetland site is located in Westport, MA adjacent to Route 88. Upstream water was collected adjacent to Route 88, south of Hix Bridge Road, where the wetland stream intersects the road. Downstream water was collected on the property of Russ and Suze Craig. Locations are marked on the USGS quad below (Quad 237810 on MASS GIS).

APPENDIX 2.

Specific measurements and calculations for bog site water volumes

Eagle Holt (Organic Reduced 1):
Pump logs were initiated in late summer of 2002. Logs consisted of clipboards placed in each pumphouse on which the grower recorded dates and times of pumping events. Prior to log placement, frost management and irrigation events were not recorded. Spring frost pumping in 2002 was estimated from records of frost events (Cape Cod Cranberry Growers Association frost warning service). Irrigation in 2002 was estimated to be similar to that in 2004 based on weather conditions in the two summers. Chemigation was estimated to be similar to that in 2003 based on similar pest pressures in the two years (2004 insect pressure was significantly greater that in the two previous years). Dates and times of other frost, chemigation, and irrigation events for the remainder of the project were gathered from the logs. Volumes were then calculated based on the pump calibration data (gal/min) provided by the grower.

Generally, except for a brief period in 2003, this site had no observed surface water discharge except during flood releases.

Harvest and winter floods, unless noted, consisted of water pumped from Blackmore Pond via a lift pump. This pump is rated for a maximum of 20,000 gal/min. Data was collected for the number of minutes of pumping (log). However, the actual volume pumped via the lift pump depends on the head of water in the pond. This changes during events and from year to year. For this reason, estimation of volume for these flood events using the pump log were extremely high, since the pump seldom worked to capacity. For example for the 2002 harvest flood of section K6 and K9, minutes pumped multiplied by 20,000 gal/min would estimate a flood with a depth of 2.2 feet. The observed depth during this event was actually 0.77 feet. Even presuming some infiltration due to the previously dry summer, the estimate from the pump log is very high. Furthermore, some water contributing to the flood came from an adjacent section (as much as 25% came from this source). So the pump was certainly moving much less than the rated 20,000 gal/min. For this reason, we used the depth of flood, based on readings from staff gauges placed in the bogs, to estimate volume for flood events at this site.

This approach was validated during the harvest of 2003. During this period, a pressure transducer in Blackmore Pond (water supply for the bog) was used to record change in Pond depth. Based on Pond bathymetry and change in depth of the pond, we calculated the volume of water pumped out of the pond and onto the bog for two harvest events. In the first event, water removed from the pond was estimated at 4.79 million gallons and water on the bog based on staff gauge estimations was 5.05 million gallons. Using pump data for this event gave an estimate of >13 million gallons. For the second event, volume loss from the pond was 4.30 million gallons and the on-bog volume was estimated at 6.7 million gallons, while the pump data estimated almost 16 million gallons.

For the winter flood in the 2002 bog year, 40% of the initial flood was estimated to be rainwater collected in the late fall.

Pierceville (Organic Control 1):
Pump logs were installed at this site in the early fall of 2002. From that time forward, logs were used to estimate frost, chemigation, and irrigation water. Frost events for spring 2002 were estimated as for the Eagle Holt site. Irrigation was estimated to be similar to that in 2004 based on weather conditions in the two summers. Chemigation was estimated to be similar to that in 2003 based on similar pest pressures in the two years (2004 insect pressure was significantly greater that in the two previous years).

Generally, except for a brief period in 2003, this site had no observed surface water discharge except during flood releases.

For flooding events at this site, pump data was used to estimate volume. Flood water for this site is pumped from the Weweantic river at 3,800 gal/min. The grower at this site kept excellent logs. When volume estimates from pump data were compared to those based on staff gauge readings in the bogs, the values were similar.

For the winter flood in the 2002 bog year, 50% of the initial flood was estimated to be rainwater collected in the late fall. This estimate was based on a comparison to pump data for winter floods in other years.

Benson's Pond (Organic Reduced 3):
The grower at this site kept poor pump logs, failing to record frost and chemigation events. Frost event times were estimated using data from the Pierceville site (geographically closest). Chemigation was estimated based on an average time of 40 minutes per event and an estimate of 6 sprays in 2002 and 2003 and 8 sprays in 2004 (higher pest pressure). Since irrigation was significantly less than at the Pierceville site which was close enough to receive similar rainfall and which has similar soil type, it was assumed that the difference in volume was due to upwelling groundwater at the Benson's Pond site. This is a site that receives upwelling groundwater, which must be pumped out of the bog periodically during the year. Groundwater contribution to the water balance was estimated as the difference between irrigation at this site and the Pierceville site. One of the irrigation ponds at the bog is fed by this upwelling groundwater - it was sampled to determine the nutrient content of the incoming groundwater for the nutrient budget.

Water is pumped onto this site for floods. However, the grower failed to complete the log for the flood pump. Therefore, flood volumes were estimated from staff gauge data. For the winter flood in the 2002 bog year, 40% of the initial flood was estimated to be rainwater collected in the late fall.

All data collection at this site and the companion control (White Springs) was confounded by poor cooperation from the grower - in addition to keeping poor logs, he often failed to communicate regarding flooding events. This led to poor timing of sample collections around several events and the necessity to estimate flood volumes and pumping volumes based on the data we did have. Further, appreciable P reduction was not achieved due to lack of cooperation in following the fertilizer protocols designed for the project and communicated to the grower.

White Springs (Organic Control 3):
Since this site was managed virtually identically to the Benson's Pond site, and since, like that site, this bog received upwelling groundwater, many of the assumptions made for the Benson's site were also made for this site. However, the pump logs were somewhat better kept at this site, particularly for frost events. Missing data for frost and chemigation was estimated as for the Benson's site. Irrigation records were more complete and as for the Benson's site, groundwater input was estimated from a comparison to the Pierceville site. The irrigation pond at this site is fed by the same groundwater that wells up into the bog -- water from the pond was used to estimate nutrients in the incoming groundwater. Water left this site as surface discharge (gravity flow) during the season. However, while constant, the flow rate could not be estimated due to shallowness of the water in the outlet pipe -- often little more than a film of water.

Water is pumped onto this site for floods. The grower failed to complete the log for the flood pump for all events - start and end dates are recorded but there was no indication that pumping was not continuous. If volume is estimated by extrapolating the entire period when pumping occurred (based on the logged dates) along with the pump capacity or the measured flow though the inlet channel, the flood would have been approximately 5 feet deep -- far greater than what was measured with staff gauges. Therefore, flood volumes were estimated from staff gauge data. For the winter flood in the 2002 bog year, 40% of the initial flood was estimated to be rainwater collected in the late fall.

Mikeys/Kelseys (Mineral Reduced 2):
Pump logs were installed at this site in the early fall of 2002. From that time forward, logs were used to estimate frost, chemigation, and irrigation water. Frost events for spring 2002 were estimated as for the Eagle Holt site. Irrigation in 2002 was estimated to be similar to that in 2004 based on weather conditions in the two summers. Chemigation in 2002 was estimated to be similar to that in 2003 based on similar pest pressures in the two years (2004 insect pressure was significantly greater that in the two previous years).

There is no evidence that groundwater enters this bog during the season and no surface outflow was observed except during flood releases.

Water is pumped from a surface reservoir for floods, additional water for floods comes from a tailwater recovery system. The pump log data (which were only completed for some flood events) estimated flood volume that was significantly lower than that calculated based on staff gauge readings. Since there was no volume estimate for the tailwater system, staff gauge data was used to estimate flood volumes. For the events where outflow was estimated using flow meter data, the outflow volume corresponded well (within 10%) with the on-bog volume calculated based on the staff gauges. For the winter flood in the 2002 bog year, 40% of the initial flood was estimated to be rainwater collected in the late fall.

Ashley's (Mineral Control 2):
Pump logs were installed at this site in the early fall of 2002. From that time forward, logs were used to estimate frost, chemigation, and irrigation water. Frost events for spring 2002 were estimated as for the Eagle Holt site. Irrigation in 2002 was estimated to be similar to that in 2004 based on weather conditions in the two summers. Chemigation in 2002 was estimated to be

similar to that in 2003 based on similar pest pressures in the two years (2004 insect pressure was significantly greater that in the two previous years).

There is no evidence that groundwater enters this bog during the season and no surface outflow was observed except during flood releases.

Water is pumped from a surface reservoir for floods. The pump log was not completed for flooding events. Therefore, staff gauge data was used to estimate flood volumes. For the winter flood in the 2002 bog year, 40% of the initial flood was estimated to be rainwater collected in the late fall.

By compiling this data N and P losses were estimated from cranberry beds of the organic and mineral soil types. These data were compared to published data regarding P and N releases from natural wetlands.

APPENDIX 3.
Wetland and bog data reports/tables

As described in the approach section, all bog sites and the natural site were monitored for nutrient and water inputs and outputs for three years. All sites were monitored in year one (pretreatment). Monitoring continued during years 2 and 3 as the low P fertilizer treatment was applied to 3 of the bogs beginning in year 2 and continuing through year 3. The following sections, Appendix 3A-B, contain the data reports for the wetland site (3A) and the bog sites (3B).

APPENDIX 3A.
Data report - wetland

************** Draft Technical Memorandum, revised by DeMoranville************

To: Carolyn DeMoranville, Director Cranberry Station
From: Brian Howes & David White, Coastal Systems Program SMAST-UMD
Date: July 7, 2005
RE: Westport Natural Wetland Sampling Revised

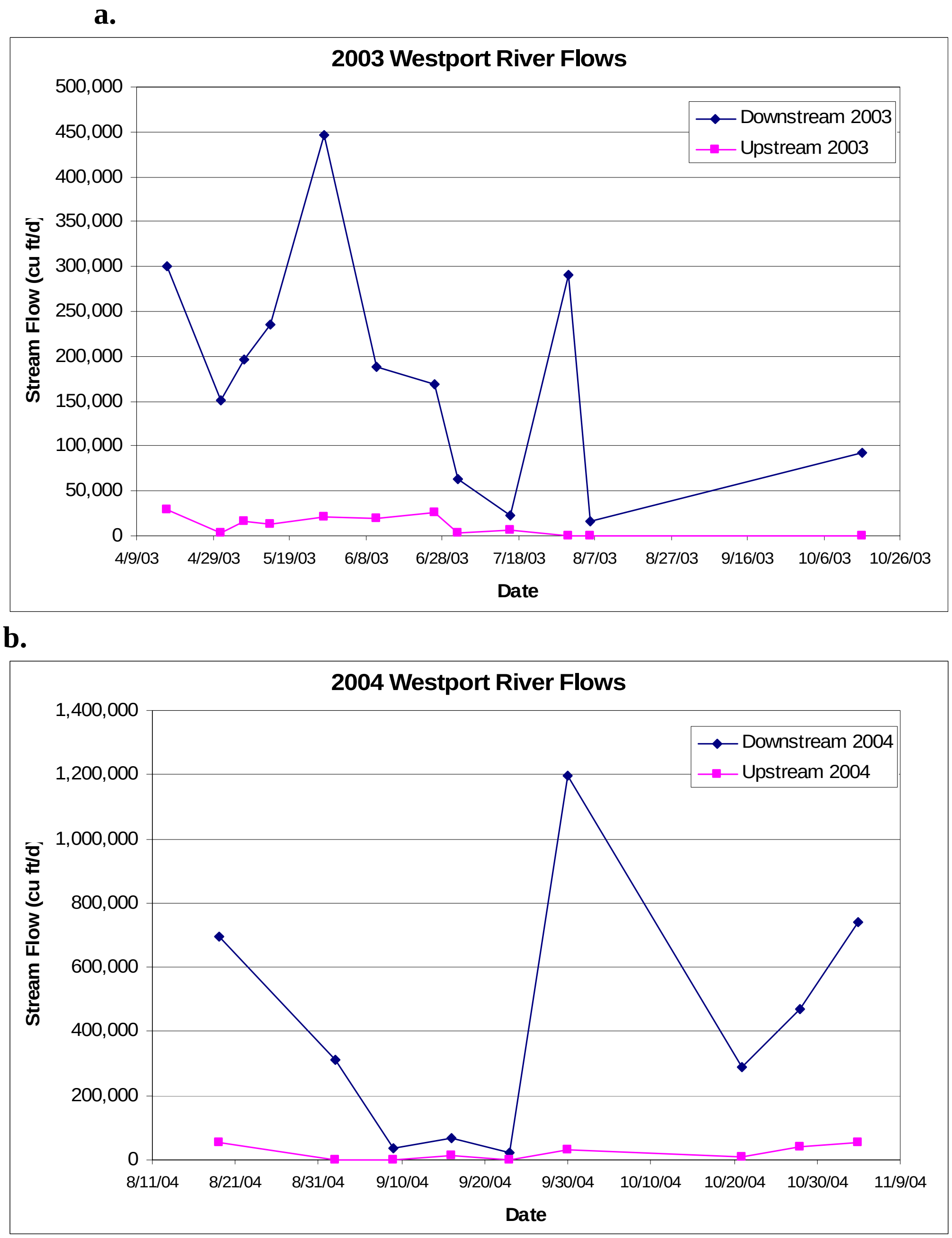
****

The Bog Phosphorus Loss Project has sampled both cranberry bogs and a natural freshwater wetland system. This Technical Memorandum relates to the natural freshwater wetland portion of the study, as the cranberry bog work-up is being handled separately. The freshwater wetland portion of the project has focused on a flow-through wetland system in Westport, MA from July 2001 through May 2005.

The purpose of investigating nutrient release/uptake by a natural wetland was to provide a reference for interpreting parallel estimates for cranberry bogs. Since many bogs are frequently constructed in wetland areas, net release/uptake by bogs should be evaluated relative to the land-use type, which would occupy that acreage, should bog operations not have been undertaken. In order to develop a defensible estimate of nitrogen and phosphorus release/uptake by a natural wetland system (or any system), it is necessary to quantify both the inputs and outputs of these nutrient species. The inputs would relate primarily to mass transport through inflowing surface and groundwaters, from the surrounding watershed, and from direct rainfall. The outputs would be primarily through transport via surface and groundwater outflows. For the purposes of creating a reference system to the cranberry bogs under study, we (the CES team and DEP) decided that the consumptive processes within the wetland (burial, denitrification, etc) need not be directly measured, but would be calculated from the inputs and outputs. The wetland site was selected with the idea that it should have quantifiable nutrient inputs and outputs, and the focus was to use these data to determine the net release/uptake of nutrients for comparison to the cranberry bog data sets. The concept was that the outflowing stream from the wetland is the sole pathway for export from the wetland and that the difference between the input and output is solely the result of wetland function.

As noted in multiple correspondences and summarized in a March 9, 2003 Technical Memorandum, the wetland site presented problems relative to calculating a mass release or uptake of nutrients, primarily relating to the “ability to produce an accurate water balance” and “concerns over watershed nutrient inputs”. The fundamental issue remains: “…the concern over watershed nutrient inputs not accounted for in the upgradient sampling station. The concern is that this lack of accountability will confound our ability to determine the net uptake or loss of phosphorus and nitrogen from this system for comparison to the cranberry bog systems under investigation.” Unfortunately, the data collection over the past 3 years has underscored our concerns over hydrologic conditions in the Westport wetland that hinder data interpretation. Based upon the most recent data, it appears that the stream outflow from the wetland is 4-59 times higher than the stream flow at the upgradient site in 2003 and 4-39 times higher in 2004 (Figure 1). The additional freshwater flowing out of the wetland is from direct groundwater inflow to the wetland, other surface water inflows and rainfall directly to the wetland. While estimates of the volume and N & P input through precipitation inputs can be made, the surface water and groundwater volumes and nutrient concentrations are much more difficult to constrain. Part of the problem is the very different N&P levels typical of surface versus groundwater and the absence of any watershed or groundwater information. The real issue is that errors in estimating these unmeasured inputs are magnified in any estimated nutrient release/uptake by the freshwater wetland.

Figure 1. Measured stream flow at the upstream and downstream stations to the Westport reference wetland site: a. 2003 and b. 2004. Downstream flows range from about 4 to 59 times higher than upstream flows in 2003 and from 4 to 39 times higher in 2004. On late summer/early fall dates with no data points, there was no flow.



Annual Nutrient Flux Estimated from Measured Stream Flows

Nutrient flux estimates using measured stream flows were calculated by multiplying flow rate in m^3/sec by the concentration, in mg/L, of the nutrient from samples taken on the same day. The result was then upscaled to g/day. The average daily flux of all days where flux was measured was calculated and upscaled to an estimate of annual flux. Results are presented below.

N&P Fluxes:

The system appears to show a large daily and annual export of DIN and TN in both 2003 and 2004, but the inflowing stream only accounts for about 1-3% of the outflow in 2003 and from 1-4% in 2004. Export of PO4 and TP are smaller but inflows represent only about 5-12% of export in 2003 and 7-10% in 2004 (Tables 1, 2, 5). Annual exports (total and per hectare) of N and P in 2003 are smaller but still comparable to those in 2004, which is to be expected because water export estimates for 2004 are more than twice those for 2003 (Tables 3 and 4).

The present difficulty in evaluating the role the natural wetland as a net source or sink of N & P, stems from the inability to determine the source of the additional dissolved inorganic nitrogen (DIN), total nitrogen (TN), ortho-phosphorus (PO4) and total phosphorus (TP) (Figure 2, 3, 4, 5) seen in the outflow versus inflow stream. It is not possible to quantify how much of the net nutrient release relates to wetland processes versus watershed inputs, as the sampling program captured only 6% of the freshwater inflow in 2003 and 5% in 2004. If direct rainfall is added, this number increases to 16%-22% of the potential water balance in 2003 and 9%-12% in 2004. The ranges are based upon an evapotranspiration loss of rain of ~40% and a 0% evapotranspiration loss (i.e.100% of rain goes to outflow), respectively. The individual inflows and outflows and calculated net import/export are presented in Tables 1-2 and Tables 3-5, respectively. In 2003 the stream inflow of water, and each nitrogen and phosphorus species accounts for between 0%-30% of that measured at the stream outflow site, except for several dates in the summer where downstream flows were relatively low and influxes accounted for 30%-97% of the outflows. In 2004 the stream inflow of water, and each nitrogen and phosphorus species accounts for between 0%-23% of that measured at the stream outflow site, except for several dates in late summer where upstream and downstream flows were zero or relatively low and influxes accounted for 0.4%-76% of the outflows, and in 2 instances influxes were 2-3 times outfluxes. Since the “missing” water volume is similar in magnitude to the “missing” nutrient masses in most instances and the larger watershed dynamics with respect to water and nutrient contributions to the wetalnd portion studied were not quantified, we did not know how to sufficiently constrain the data to make a useful estimate of release/uptake by the wetland system.

While we cannot make a quantitative estimate of wetland contribution to the measured nutrient outflow from the Westport wetland system, we did confirm that atmospheric deposition is insufficient to account for the observed N & P fluxes. Based upon a wetland area of 29.8 hectares determined from GIS (DeMoranville personal communication) and atmospheric deposition rates of 30.5 mg P/m^2/yr and 1090 mg N/m^2/y, we estimate a total input of 9.1 kg P and 330 kg N per wetland per annum. Adding these estimates of direct atmospheric deposition to the measured inflow masses, accounts for only 27% and 15% of the total P and N in the outflow waters in 2003 and 26% and 10% of the total P and N in the outflow waters in 2004. Therefore, we conclude that the “missing” P & N in the outflow results from either a wetland in non-steady state or inputs from an unidentified watershed source or both in concert. Given this uncertainty, we will confine ourselves to a discussion of the nutrient export from the watershed as measured at the downstream collection site.

Figure 2. Measured dissolved inorganic nitrogen in downstream (outflowing) and upstream (inflowing) surface waters to the Westport natural freshwater wetland system: a. 2003 and b. 2004.

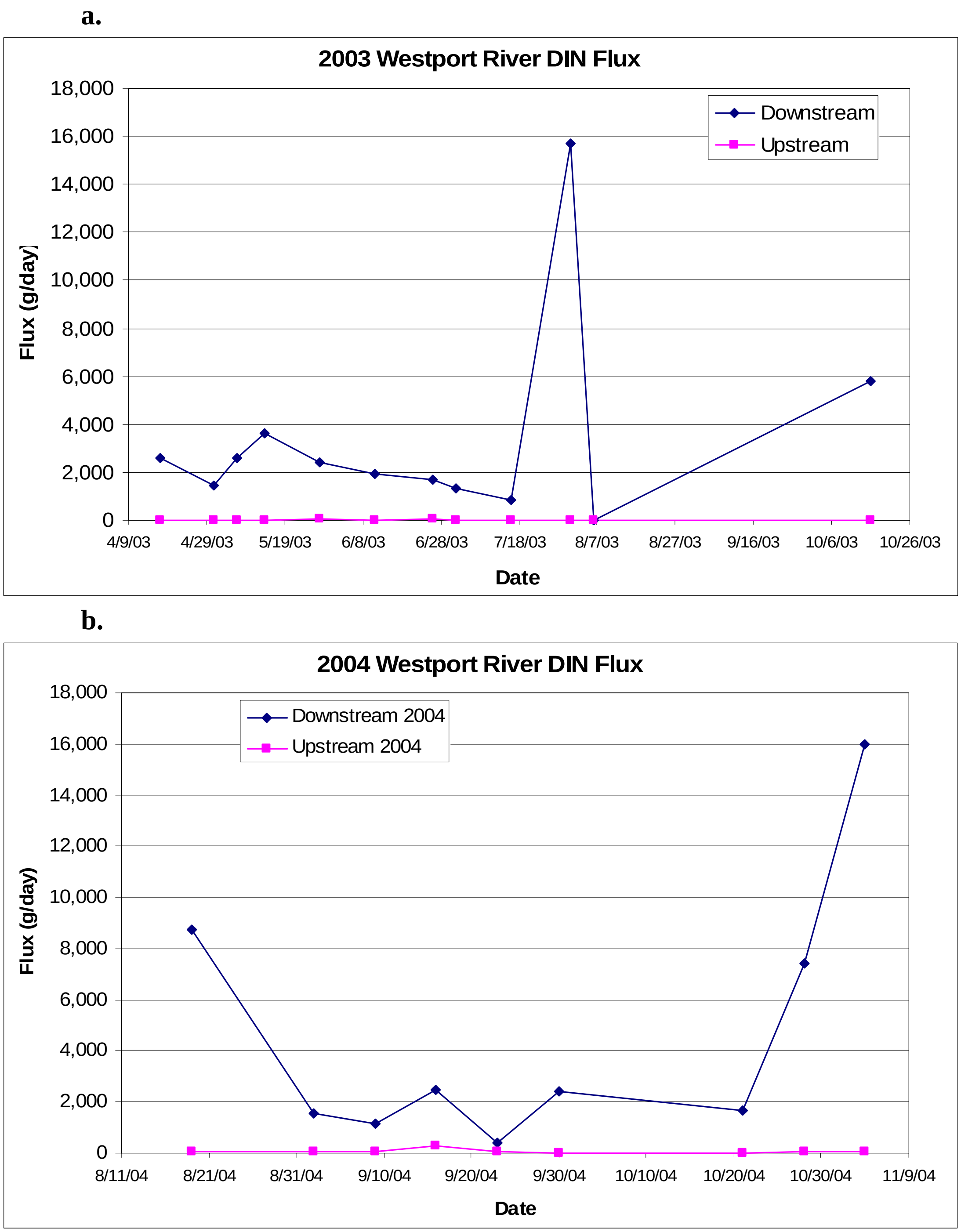
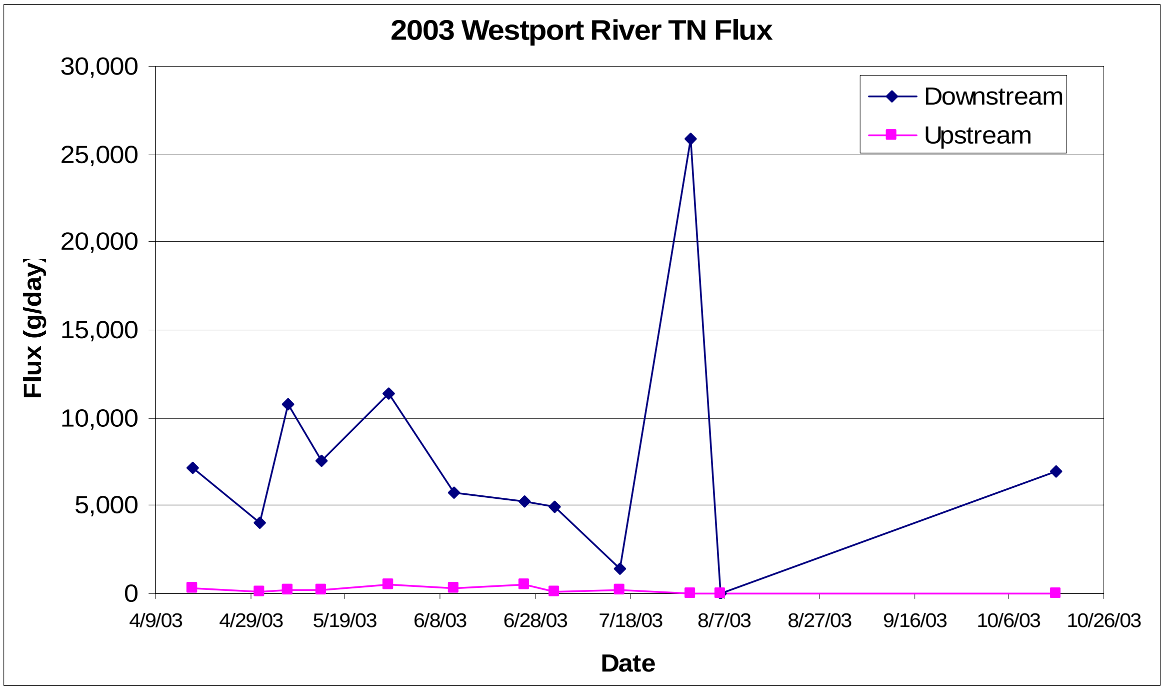


Figure 3. Measured total nitrogen in downstream (outflowing) and upstream (inflowing) surface waters to the Westport natural freshwater wetland system: a. 2003 and b. 2004.

a.



b.

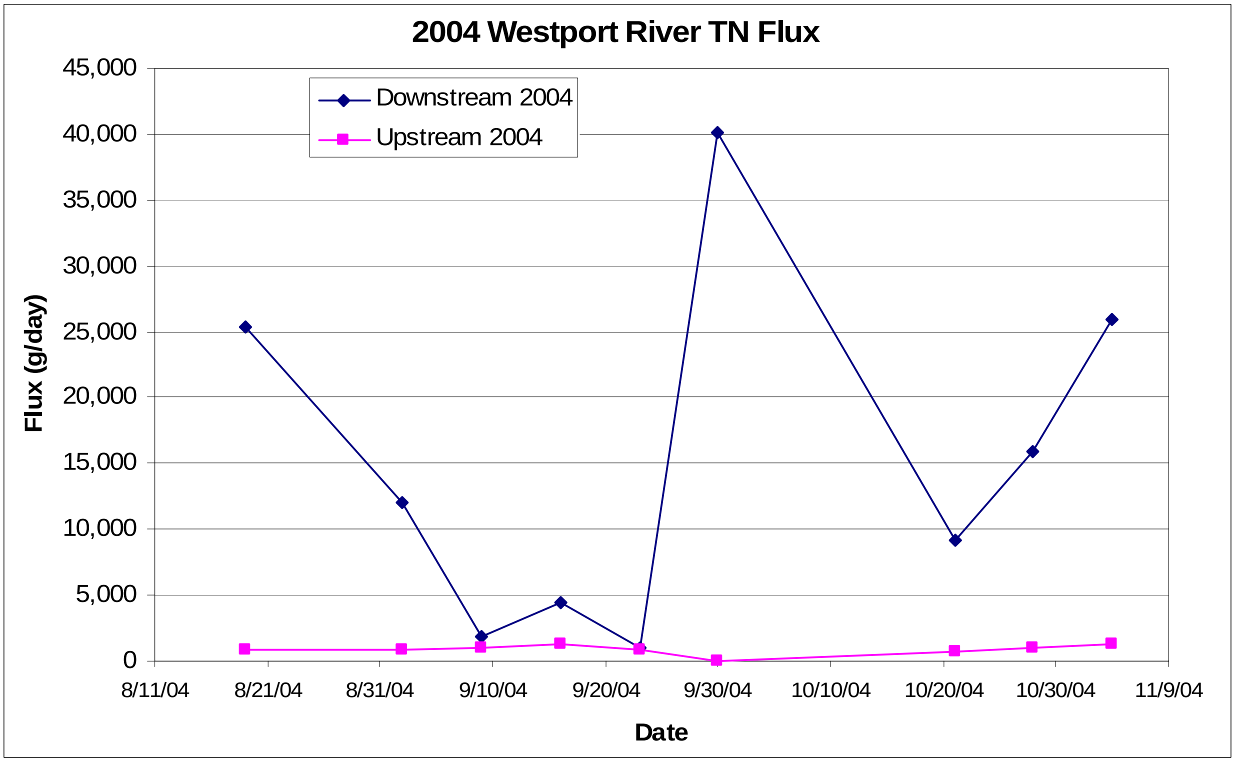
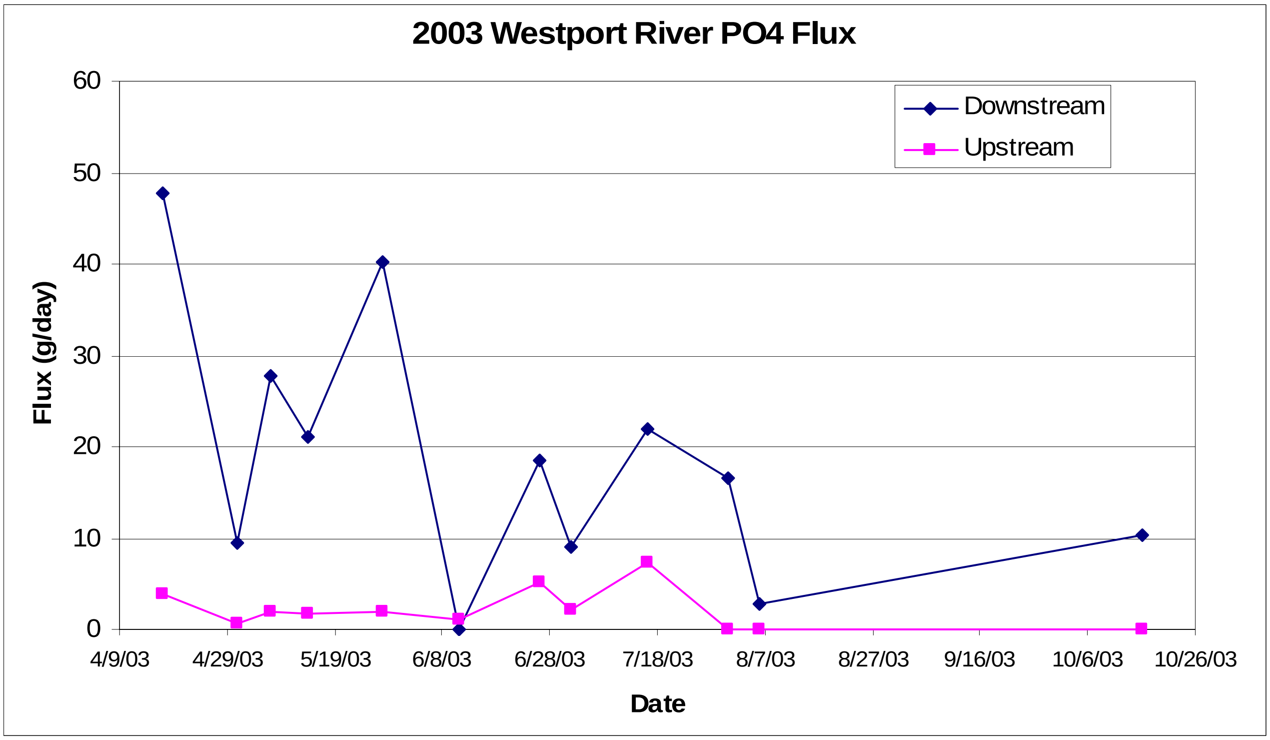


Figure 4. Measured ortho-phosphate in downstream (outflowing) and upstream (inflowing) surface waters to the Westport natural freshwater wetland system: a. 2003 and b. 2004.

a.



b.

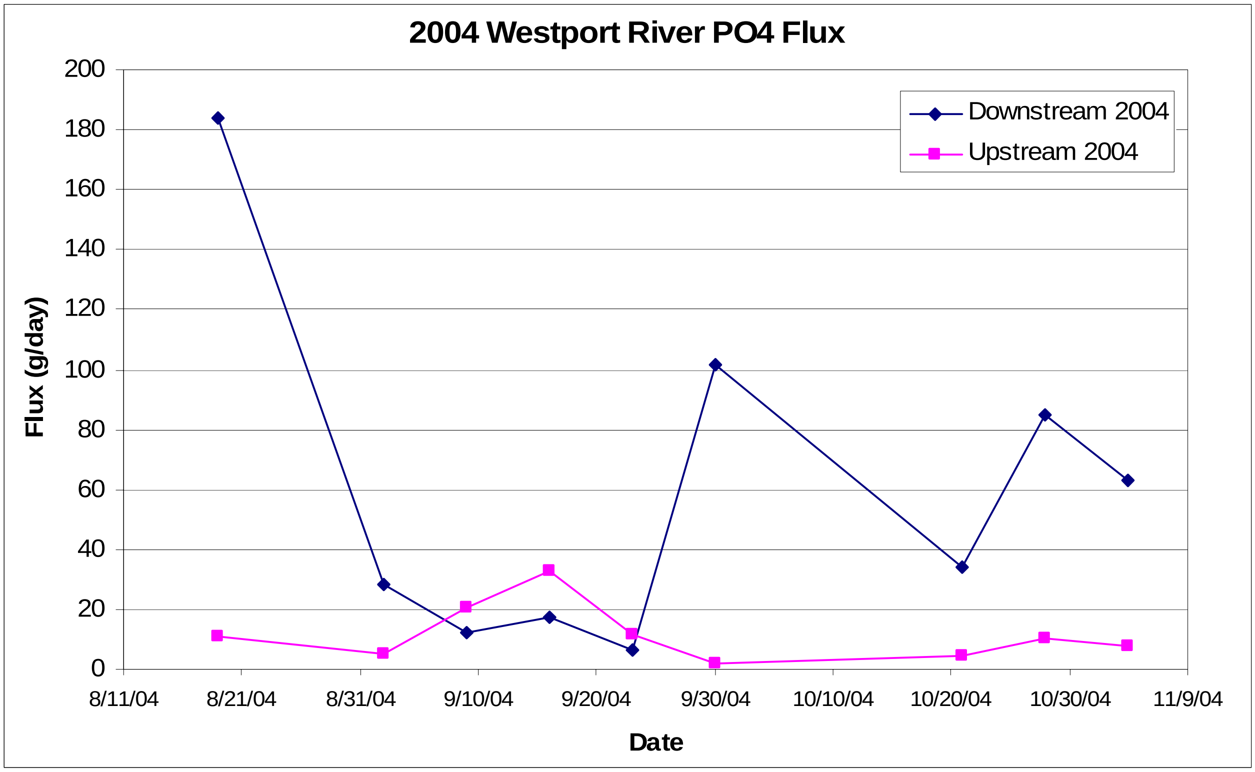
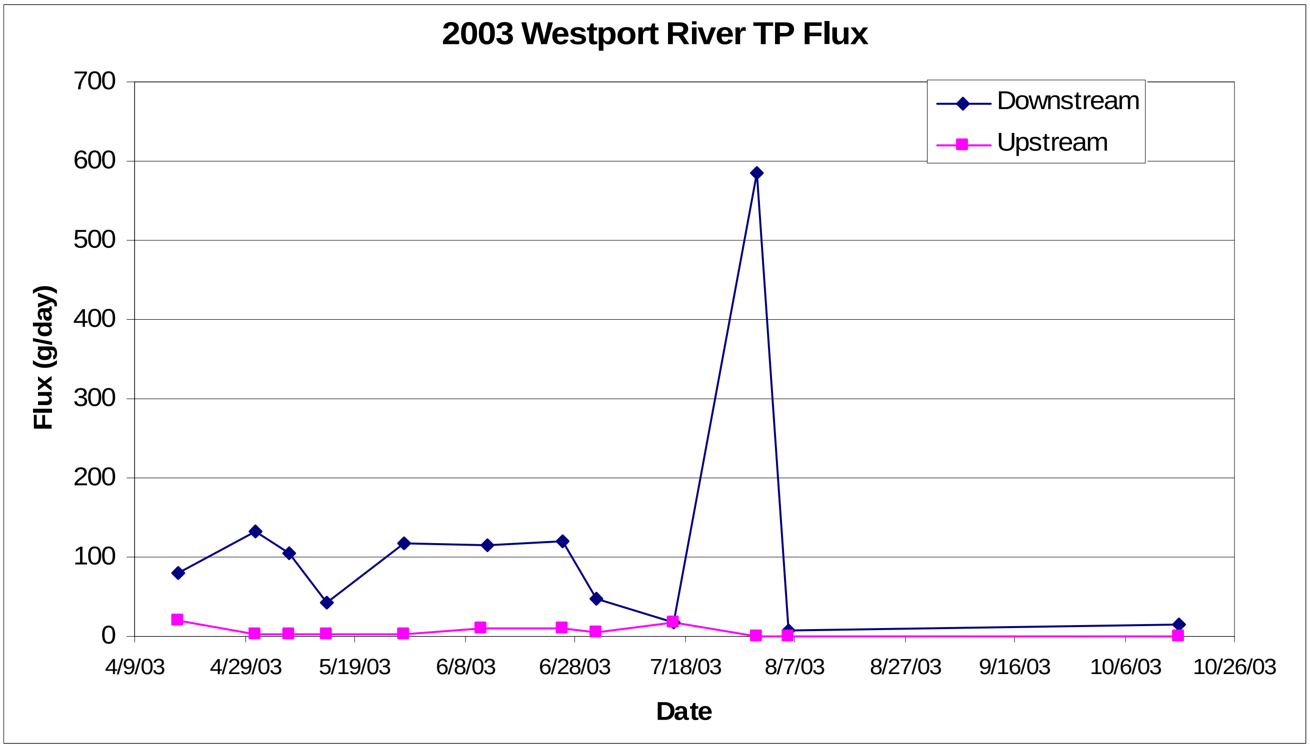


Figure 5. Measured Total Phosphorus in downstream (outflowing) and upstream (inflowing) surface waters to the Westport natural freshwater wetland system: a. 2003 and b. 2004.

a.



b.

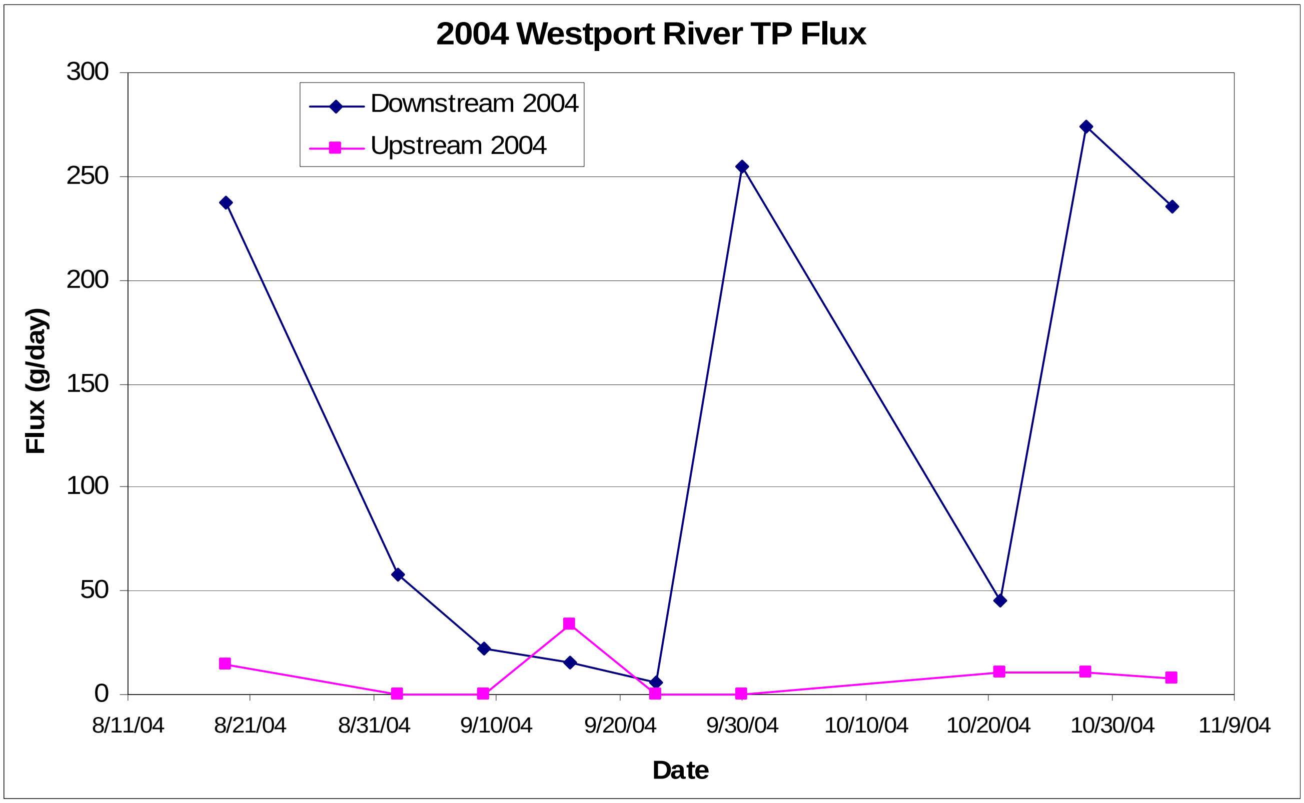


Table 1. Nitrogen and phosphorus mass flux rates into the Westport natural wetland system measured at the upgradient stream site: a. 2003 and b. 2004.

a.

	Westport Up Stream 2003 Flux g N or P/day								
Date	**Q cu ft/d**	**PO4**	**TP**	**NH4**	**NOx**	**DIN**	**DON**	**PON**	**TN**
4/17/2003	29,153	4.0	20.5	3.4	11.4	14.8	300.0	27.4	342.2
5/1/2003	2,566	0.7	1.4	1.0	1.4	2.5	51.4	11.1	65.0
5/7/2003	15,725	1.9	2.8	18.3	6.3	24.6	192.2	11.8	228.5
5/14/2003	13,323	1.8	2.3	21.8	3.2	24.9	169.8	12.0	207.3
5/28/2003	21,146	1.9	3.7	25.9	6.5	32.4	327.5	107.2	467.1
6/12/2003	18,722	1.1	9.9	0.0	6.6	6.9	266.8	37.3	309.4
6/26/2003	25,920	5.2	9.0	40.1	12.0	52.1	431.0	49.6	532.6
7/2/2003	2,661	2.1	5.9	2.2	1.5	3.7	53.5	6.8	64.0
7/16/2003	5,853	7.3	17.4	15.2	2.4	17.7	192.6	34.8	245.1
7/31/2003	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8/6/2003	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10/16/2003	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	**11,256**	**2.16**	**6.07**	**10.66**	**4.28**	**14.96**	**165.39**	**24.82**	**205.09**

Flux is derived by multiplying the measured flow (Q) and the nutrient concentration

Note: there was no flow at the upstream site on July 31, August 6 and October 16, 2003

b.

	Westport Up Stream 2004 Flux g N or P/day								
Date	**Q cu ft/d**	**PO4**	**TP**	**NH4**	**NOx**	**DIN**	**DON**	**PON**	**TN**
8/19/2004	52,285	15.1	14.9	85.9	22.0	107.9	1,066.7	50.7	1,225.4
9/2/2004	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9/9/2004	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9/16/2004	15,769	13.5	33.7	112.4	9.3	121.6	394.8	19.8	536.3
9/23/2004	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9/30/2004	30,393	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10/21/2004	10,917	1.3	10.3	4.5	2.8	7.3	192.7	6.3	206.3
10/28/2004	40,929	11.2	10.8	22.2	12.2	34.4	973.7	84.9	1,093.0
11/4/2004	53,817	11.0	7.4	40.2	9.4	49.6	1,452.9	292.6	1,795.1
Average	**22,679**	**5.8**	**8.6**	**29.5**	**6.2**	**35.6**	**453.4**	**50.5**	**539.6**

Table 2. Nitrogen and phosphorus mass flux rates out of the Westport natural wetland system measured at the downgradient stream site: a. 2003 and b. 2004.

a.

	Westport Down Stream 2003 Flux g N or P/day								
Date	**Q cu ft/d**	**PO4**	**TP**	**NH4**	**NOx**	**DIN**	**DON**	**PON**	**TN**
4/17/2003	300,326	47.8	79.1	30.0	2,586.1	2,616.1	4,438.3	125.2	7,179.5
5/1/2003	150,301	9.5	131.9	98.5	1,325.0	1,423.6	2,462.2	99.2	3,985.0
5/7/2003	196,301	27.8	105.6	127.8	2,473.6	2,595.9	3,357.4	127.8	10,783.7
5/14/2003	235,302	21.0	41.3	255.9	3,396.2	3,652.2	3,691.3	173.3	7,515.5
5/28/2003	446,645	40.1	117.6	276.5	2,142.8	2,419.3	8,572.1	392.1	11,382.8
6/12/2003	188,045	0.0	115.5	87.1	1,827.4	1,914.5	3,391.6	431.6	5,737.7
6/26/2003	168,805	18.6	119.5	314.1	1,398.2	1,712.3	3,344.9	170.0	5,227.3
7/2/2003	62,830	9.0	48.0	46.9	1,303.6	1,350.5	1,141.6	2,432.8	4,924.9
7/16/2003	22,550	22.0	17.9	31.2	843.3	874.5	488.5	15.4	1,378.4
7/31/2003	290,714	16.5	584.5	222.3	1,5501.1	15,723.3	5,505.6	4,627.3	25,856.3
8/6/2003	16,074	2.7	7.3	25.0	ND	ND	ND	16.8	ND
10/16/2003	91,745	10.4	15.6	454.6	5,341.4	5,796.0	1,072.9	36.4	6,905.3
Average	**180,803**	**18.8**	**115.3**	**164.2**	**3,467.2**	**3,643.5**	**3,406.0**	**720.7**	**8,261.5**
Out/In	**16**	**9**	**19**	**15**	**810**	**244**	**21**	**29**	**40**

b.

	Westport Down Stream 2004 Flux g N or P/day								
Date	**Q cu ft/d**	**PO4**	**TP**	**NH4**	**NOx**	**DIN**	**DON**	**PON**	**TN**
8/19/2004	694,298	183.9	237.7	867.3	7,862.9	8,730.2	16,052.5	520.3	25,302.9
9/2/2004	313,052	28.0	57.9	368.9	1,210.0	1,579.0	9,825.3	600.0	12,004.3
9/9/2004	38,262	11.9	22.5	25.8	1,141.4	1,167.1	693.0	71.7	1,931.8
9/16/2004	67,492	17.6	15.1	37.2	2,414.9	2,452.1	1,337.6	582.9	4,372.6
9/23/2004	23,342	6.7	6.1	8.9	383.2	392.1	561.5	20.7	974.3
9/30/2004	1,198,628	101.8	254.3	397.0	2,036.9	2,434.0	32,729.6	5031.3	40,194.8
10/21/2004	290,259	33.9	45.8	138.8	1,540.7	1,679.5	7,392.9	159.2	9,231.5
10/28/2004	470,280	85.1	273.6	388.1	7,024.3	7,412.4	8,131.1	297.6	15,841.1
11/4/2004	742,476	63.1	235.3	255.7	15,758.0	16,013.7	8,780.3	1085.9	25,880.0
Average	**426,454**	**59.1**	**127.6**	**276.4**	**4374.7**	**4651.1**	**9,500.4**	**929.9**	**15,081.5**
Out/In	**19**	**10**	**15**	**9**	**707**	**130**	**21**	**18**	**28**

Table 3. Annual Total Export of Nutrients from the watershed and natural wetland system based on flow data and nutrient concentrations normalized to an entire year.

Year	Q cu ft	Westport Wetland Annual Nutrient Export Kg							
		PO4	**TP**	**NH4**	**NOx**	**DIN**	**DON**	**PON**	**TN**
2003	65,993,199	6.9	42.1	59.9	1,265.5	1,329.9	1,243.2	263.0	3,015.4
2004	155,655,821	21.6	46.6	100.9	1,596.8	1,697.7	3,467.7	339.4	5,504.7

Table 4. Annual Total Export of Nutrients (from Table 3) per Hectare from the watershed and natural wetland system based on a watershed area of 304.2 ha.

Year	Westport Wetland Annual Nutrient Export Kg/ha							
	PO4	**TP**	**NH4**	**NOx**	**DIN**	**DON**	**PON**	**TN**
2003	0.02	0.14	0.20	4.16	4.37	4.09	0.86	9.91
2004	0.07	0.15	0.33	5.25	5.58	11.40	1.12	18.10

Table 5. Net losses of nitrogen and phosphorus from the watershed and natural wetland system measured as the difference between the input at the upgradient stream site and the outflow at the downgradient stream site: a. 2003 and b. 2004.

a.

2003	Net Flow Q cu ft/day	Westport Wetland: Net Export grams N or P/day							
		PO4	**TP**	**NH4**	**NO3 NO2**	**DIN**	**DON**	**PON**	**TN**
4/17/2003	271,173	44	59	27	2,575	2,601	4,139	98	6,838
5/1/2003	147,735	9	131	98	1,324	1,421	2,411	88	3,920
5/7/2003	180,576	9	103	110	2,467	2,571	3,165	116	10,556
5/14/2003	221,979	19	39	234	3,393	3,627	3,522	161	7,309
5/28/2003	425,498	38	114	251	2,136	2,387	8,245	285	10,916
6/11/2003	169,323	2	106	87	1,821	1,908	3,125	394	5,429
6/26/2003	142,885	13	110	274	1,386	1,660	2,914	120	4,695
7/2/2003	60,169	7	42	45	1,302	1,347	1,088	2,426	4,861
7/16/2003	16,698	15	0	16	841	857	296	-19	1,133
7/31/2003	290,714	355	585	222	15,502	15,724	5,506	4,628	25,858
8/6/03	16,074	3	7	25	51,892	51,917	12,675	17	64,608
10/16/03	91,745	29	16	455	5,342	5,796	1,073	36	6,906

Net Flow showed net outflow from the system, with outflow 4-21 times measured inflow volumes.

b.

2004	Net Flow **Q cu ft/d**	**PO4**	**TP**	**NH4**	**NOX**	**DIN**	**DON**	**PON**	**TN**
8/19/2004	642,013	169	223	781	7,841	8,622	14,986	470	24,078
9/2/2004	313,052	28	58	369	1,210	1,579	9,825	600	12,004
9/9/2004	38,262	12	23	26	1,141	1,167	693	72	1,932
9/16/2004	51,724	4	-19	-75	2,406	2,331	948	563	3,836
9/23/2004	23,342	7	6	9	383	392	562	21	974
9/30/2004	1,168,236	102	254	397	2,037	2,434	32,730	5,031	40,195
10/21/2004	279,342	33	36	134	1,538	1,672	7,200	153	9,025
10/28/2004	429,351	74	263	366	7,012	7,378	7,157	213	14,748
11/4/2004	688,659	52	228	216	15,749	15,964	7,327	793	24,085

Net Flow showed net outflow from the system, with outflow 4-39 times measured inflow volumes

Annual Nutrient Flux Estimated from Stage Data

The annual flux of nutrients into and out of the Westport River Wetland (WP) was also estimated with flow and stage data provided by CES and with nutrient data collected by CES and analyzed by SMAST. Continuous stage data were available at the upper Westport site from April 18, 2003 to March 3, 2004 and from June 18 to November 4, 2004. Flow data were interpolated from March 4, 2004 – June 18, 2004. At the lower Westport site, continuous data were available from April 18, 2003 to July 7, 2003 and from April 8, 2004 to November 3, 2004. From July 7, 2003 till April 18, 2004, measured staff gauge readings were used and data were interpolated to estimate flows during this period. These stage data were used with measured instantaneous flow rates (see Tables 1 and 2) to predict continuous daily flows for the 2003 (April 18, 2003 to April 17, 2004) and 2004 (partial: April 18, 2004 to November 3, 2005) growing years. Where stage data were not available during this period, flows were interpolated from ratios of existing flow data at the upper and lower sites. Nutrient data from samples taken at both upper and lower sites were matched to corresponding flow data. Data from grab samples were matched to flow data from the same day. Data from samples taken by auto samplers over several days and composited were matched to flow data for the same interval of dates. On days where no samples had been taken, data were interpolated from existing data to yield predicted values. Daily flux estimates were made by multiplying predicted flows by existing or predicted nutrient concentrations. Daily fluxes were then added together to give the annual flux at both the upper and lower sites (Table 6). Since stage data were not available for the entire year, annual flux was estimated by upscaling the total outflux for each year to a full 12 months (WP-D out protracted). Nutrient fluxes out of the Westport wetland at the lower site range from 5 to 206 times the fluxes into the wetland at the upper site in 2003 and from 4 to 754 times in 2004.

The total annual flux and the flux per hectare calculated from the stage data (Tables 6 and 7) are generally very comparable to those calculated from flow data only (Tables 3 and 4). Given the two different approaches used to estimate fluxes, the results are reasonable. Given the large degree of interpretation required for the incomplete stage data set, the values reported in the final report are based on flow data (Tables 3 and 4).

Table 6. Annual nutrient flux into and out of Westport River wetland based on stage data: a. 2003 and b. 2004.

a.

Estimated Cumulative Nutrient Flux 4/18/2003 to 4/17/2004

	Nutrient Flux in Kg N or P							
	PO4	**TP**	**NH4**	**NO3**	**DIN**	**DON**	**PON**	**TN**
WP-U (in)	2.2	4.9	9.2	4.9	14.1	105.8	38.7	157.9
WP-D (out)*	5.3	21.8	33.5	462.5	485.1	536.9	122.8	1163.2
WP-D (out) protracted	11.6	47.5	73.2	1,009.1	1,058.4	1,171.5	268.0	2,537.9
Out/In	5.3	9.6	8.0	205.5	75.0	11.1	6.9	16.1

*** No Stage Data from 10/23/03 - 4/8/04**

b.

Estimated Cumulative Nutrient Flux 4/18/2004 to 11/3/2004

	Nutrient Flux in Kg N or P							
	PO4	**TP**	**NH4**	**NO3**	**DIN**	**DON**	**PON**	**TN**
WP-U (in)	2.5	6.8	13.7	1.8	15.5	68.5	33.9	118.0
WP-D (out)*	6.0	18.9	69.0	797.0	865.6	661.2	143.3	1,606.6
WP-D (out) protracted	10.3	32.4	118.3	1,366.3	1,483.9	1,133.5	245.7	2,754.1
Out/In	4.1	4.8	8.6	753.5	95.5	16.5	7.3	23.3

***No Stage Data after 11/4/04**

Table 7. Annual nutrient export (from Table 6) per hectare of watershed area.

Estimated Cumulative Nutrient Flux per Hectare of Watershed Area

	Nutrient Flux in Kg N or P/ha							
	PO4	**TP**	**NH4**	**NO3**	**DIN**	**DON**	**PON**	**TN**
2003	0.04	0.16	0.24	3.32	3.48	3.85	0.88	8.34
2004	0.03	0.11	0.39	4.49	4.88	3.73	0.81	9.05

Status: Given the uncertainties in the water balance, the utility of more rigorous analysis of the time-series data is unclear. It is possible that a detailed site survey, watershed delineation and watershed analysis and additional stream flux measurements on yet unidentified streams might allow further refinement of the data. However, there is no certainty that this is will be the case. The large net nitrate+nitrite flux may indicate the inflow of watershed nitrogen through groundwater inflows to the wetland. Nitrate is the predominant form of nitrogen in groundwater in this region. The likelihood of significant watershed N inputs is supported by observations of the field team which suggest an animal agricultural enterprise in the watershed. Wetlands typically release reduced forms of nitrogen, ammonium and organic nitrogen, which may also indicate that groundwater is the predominant source of this nitrogen. In addition, the wetland does seem to release organic forms and ammonium, but without knowing the levels of these species entering the system, we cannot realistically speculate as the role of the wetland as in the net mass release or uptake of nitrogen or phosphorus. For example, the unaccounted for inputs may be such that when compared to the outflow a conclusion of net uptake may be supported, or be sufficiently low compared to the outputs and result in a conclusion of net release. Since there are multiple potential sources and transport mechanisms and these generally occur in combination, it is difficult to constrain the input values in a fashion sufficient to support management decisions relative to cranberry agriculture.

References

Hu, H., H. Chen, N.P. Nikolaidis, D.R. Miller and X. Yang. 1998. Estimation of nutrient atmospheric deposition to Long Island Sound. Water, Air and Soil Pollution 105: 521-538.

E.C. Jordan Inc. 1987. Installation Restoration Program Ashumet Pond Trophic State and Eutrophication Control Assessment. Final Report: Task 1-4. Installation Restoration Program, Massachusetts Military Reservation. Prepared for HAZWRAP, Oak Ridge, TN.

United Nation Environment Programme, Division of Technology, Industry and Economics. 2000. Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication.

APPENDIX 3B.
Data report - bogs

Data was collected at the 6 bog sites beginning in May. The bog year was assigned as May 15 through the following May 14 for each year, e.g. the 2002 bog year was May 15, 2002 through May 14, 2003. The project technician kept logs of sample collections and observations at the bogs. A copy of his log is provided on CD. In addition, the following files are submitted on CD:

File name	**Description**
Water budgets.xls	Summary data
Water Budgets - In.xls	Details of water inputs
2002 nutrient budgets.xls	Details of nutrient ins and outs, calculation information
2003 nutrient budgets.xls	Details of nutrient ins and outs, calculation information
2004 nutrient budgets.xls	Details of nutrient ins and outs, calculation information
fert records.xls	Details of fertilizers applied to bog sites
soil table 2002-2004.xls	Soil and tissue analysis results for bog sites
2002 flood graphs.xls	graphic representation of nutrients during flood events
2003 flood graphs.xls	graphic representation of nutrients during flood events
2004 flood graphs.xls	graphic representation of nutrients during flood events
Yield fert 2000-2004.xls	Fertilizer summary and yield information
2002 bog samples SMAST.xls	Data file from lab - analytical results
2003 bog samples SMAST.xls	Data file from lab - analytical results
2004 bog samples SMAST.xls	Data file from lab - analytical results
2005 bog samples SMAST.xls	Data file from lab - analytical results
Blackmore graphs.xls	Data and graphs for water analyses of Blackmore Pond

The results for the individual sites are shown in the tables below and the summary findings are in the body of the report. The figures below show nutrient relationships during harvest and winter floods (additional data beyond that in the body of the report).

Figure 3B-1. Pierceville early harvest 2002. Organic soil pair 1, control bog Sections C3 and C4. Discharge began on Day 3.

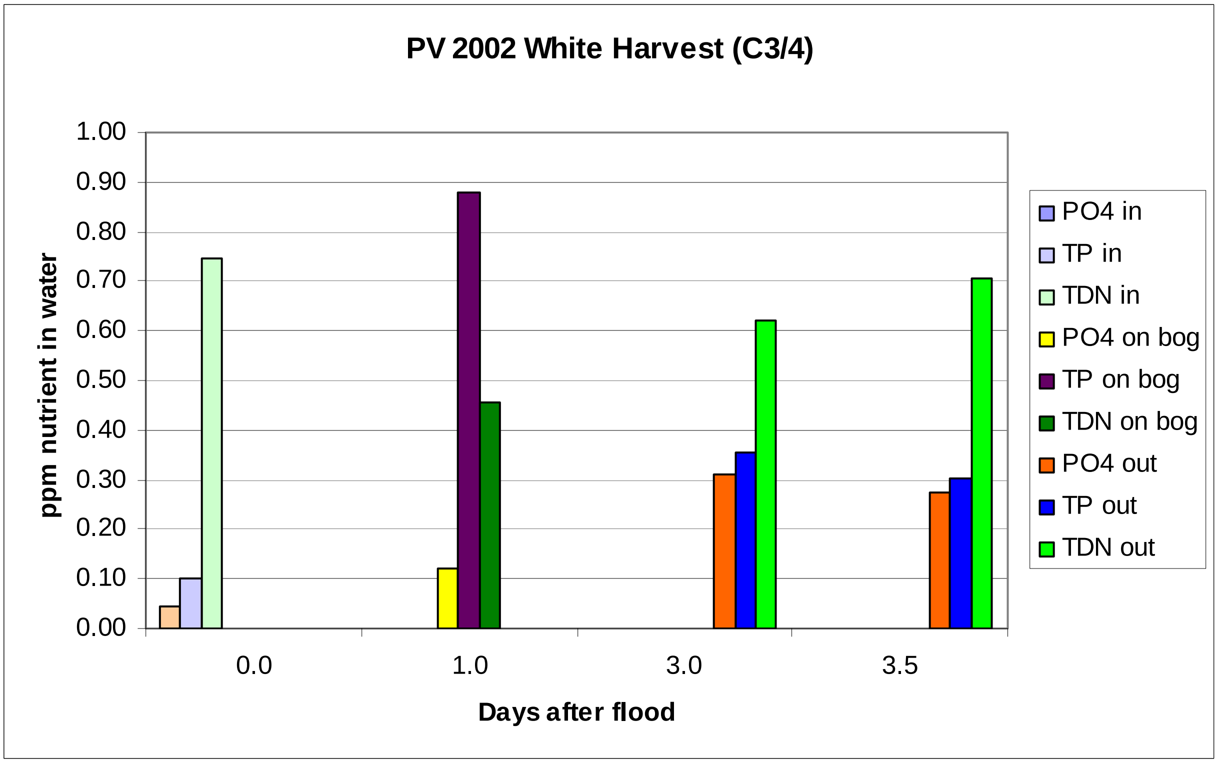


Figure 3B-2. Pierceville harvest 2002. Organic soil pair 1, control bog Sections C1 and C2. Discharge began on Day 12.3.

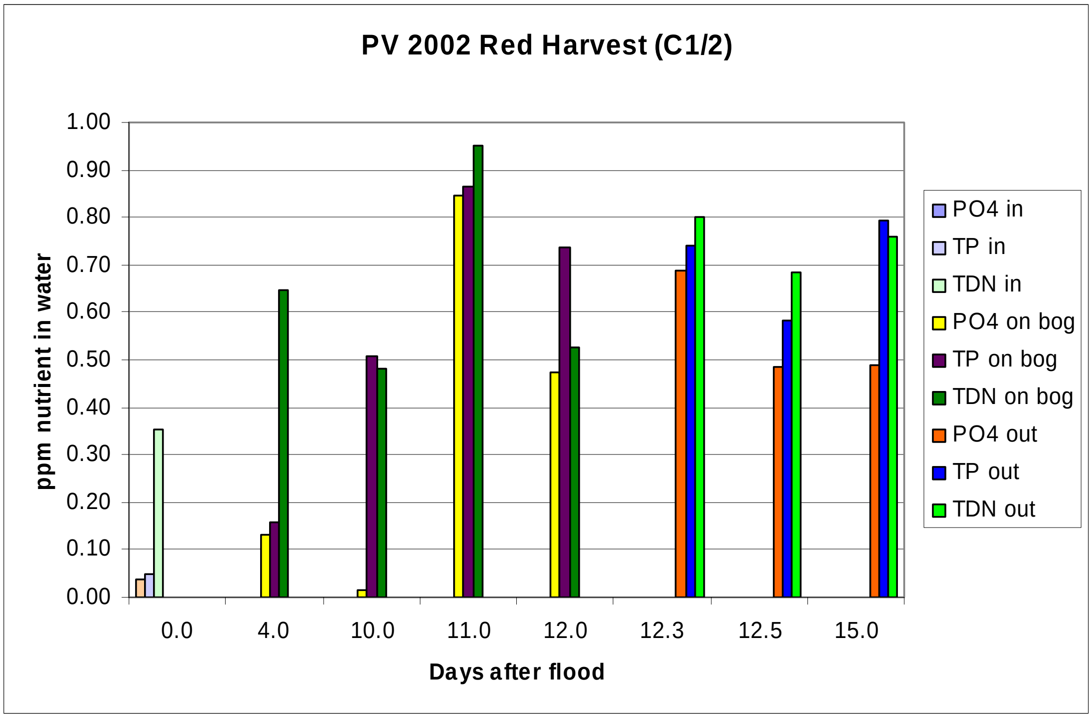


Figure 3B-3. Eagle Holt harvest 2002. Organic soil pair 1, reduced bog Section K7. Discharge began on Day 4.

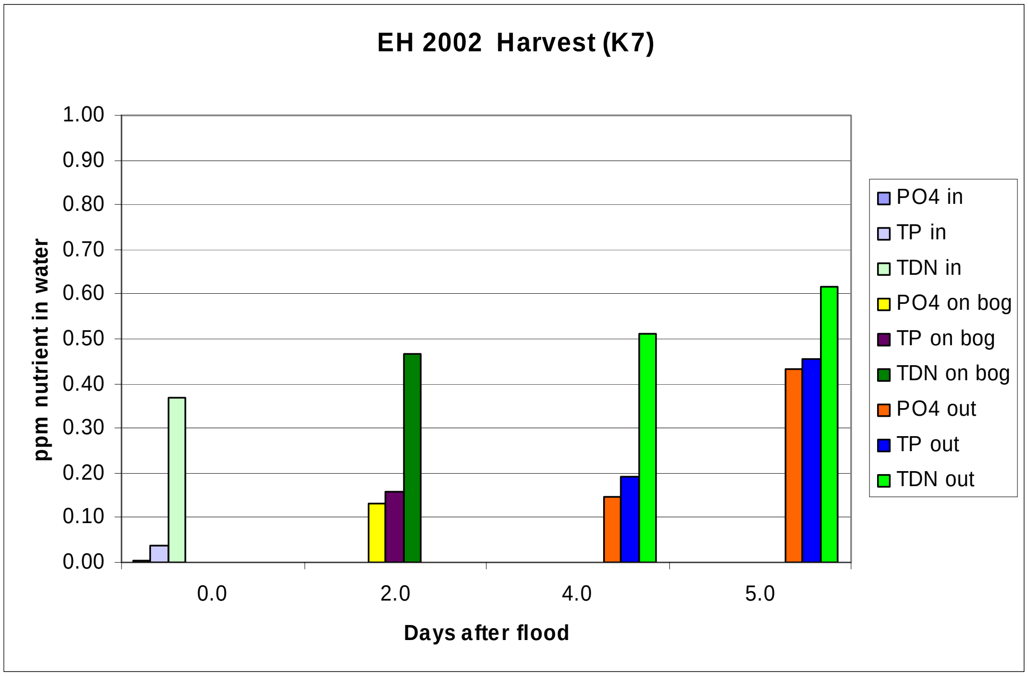


Figure 3B-4. White Springs harvest 2002. Organic soil pair 3, control bog.

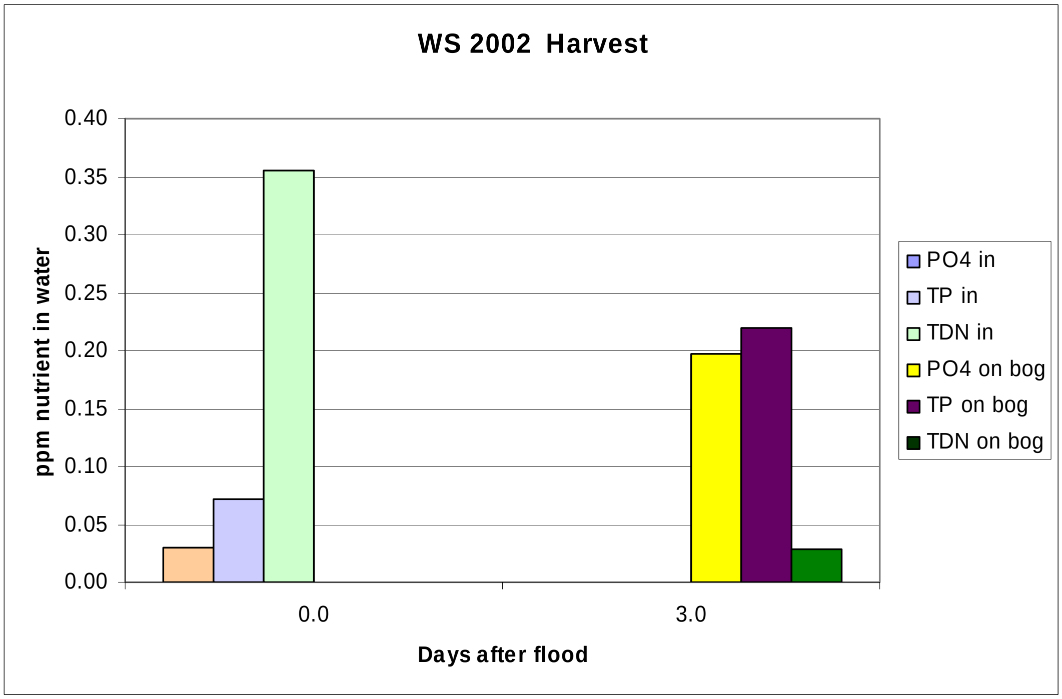


Figure 3B-5. Benson's Pond harvest 2002. Organic soil pair 3, reduced bog. Discharge began on Day 21.

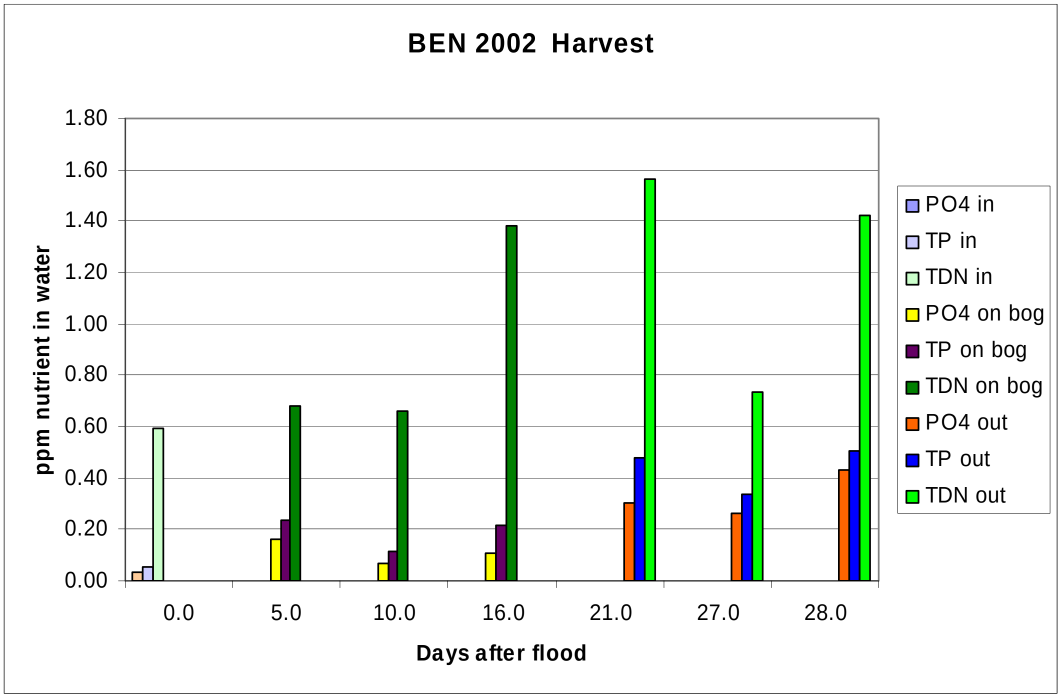


Figure 3B-6. Ashley's Bog harvest 2002. Mineral soil pair 2, control bog. Discharge was on Day 5.

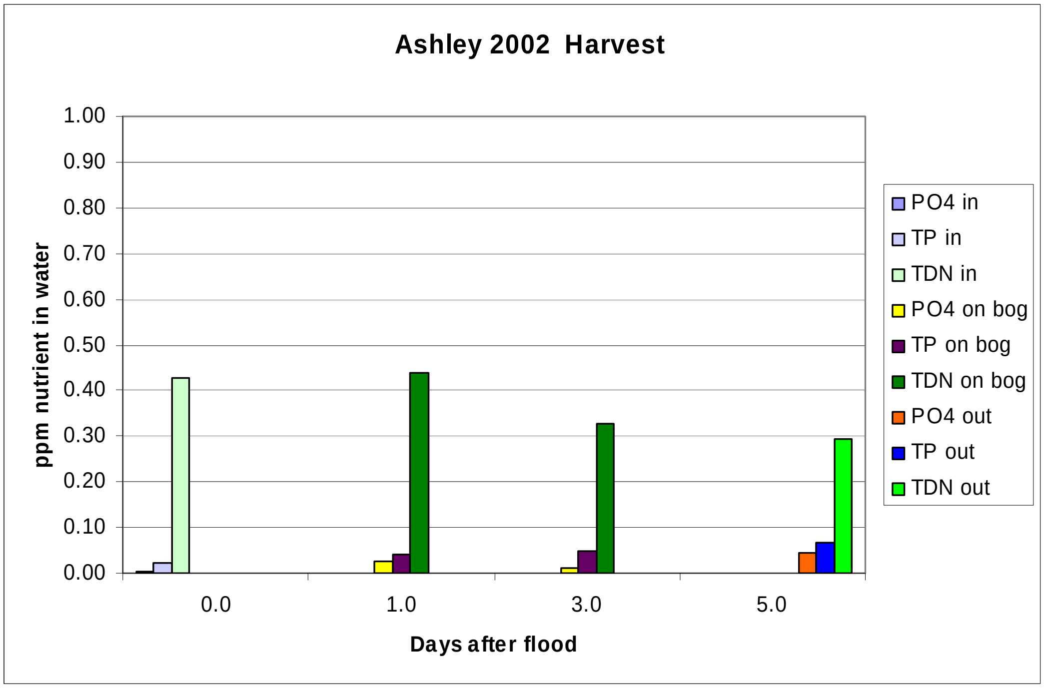


Figure 3B-7. Mikeys/Kelseys Bog harvest 2002. Mineral soil pair 2, reduced bog. Discharge began on Day 6.

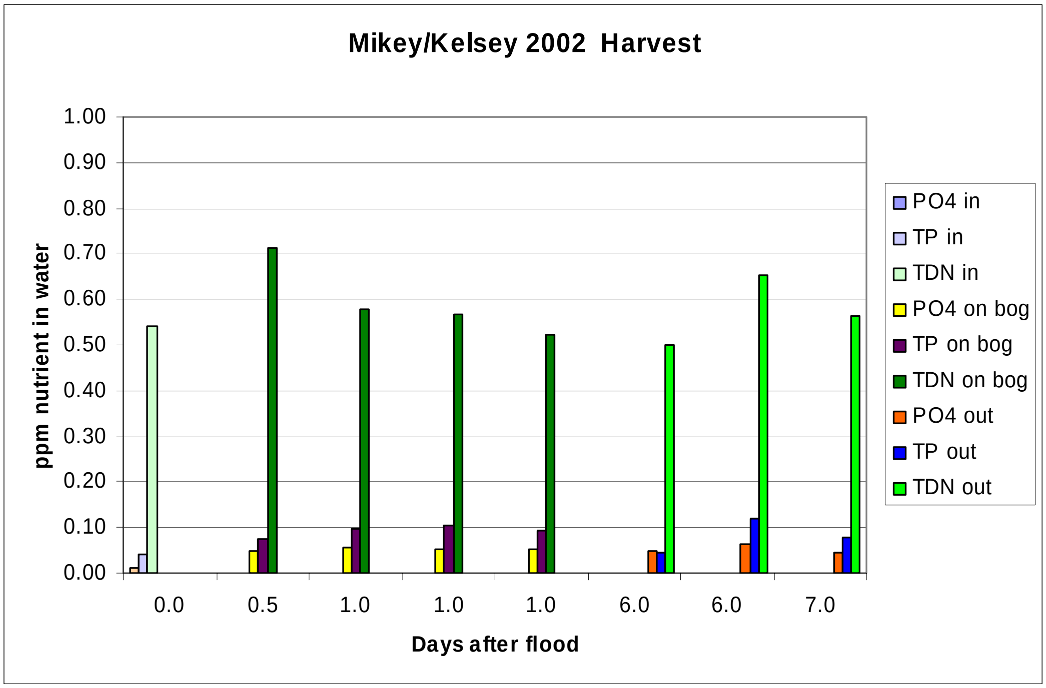


Figure 3B-8. Pierceville early harvest 2003. Organic soil pair 1, control bog Sections C3 and C4. Discharge began on Day 3.

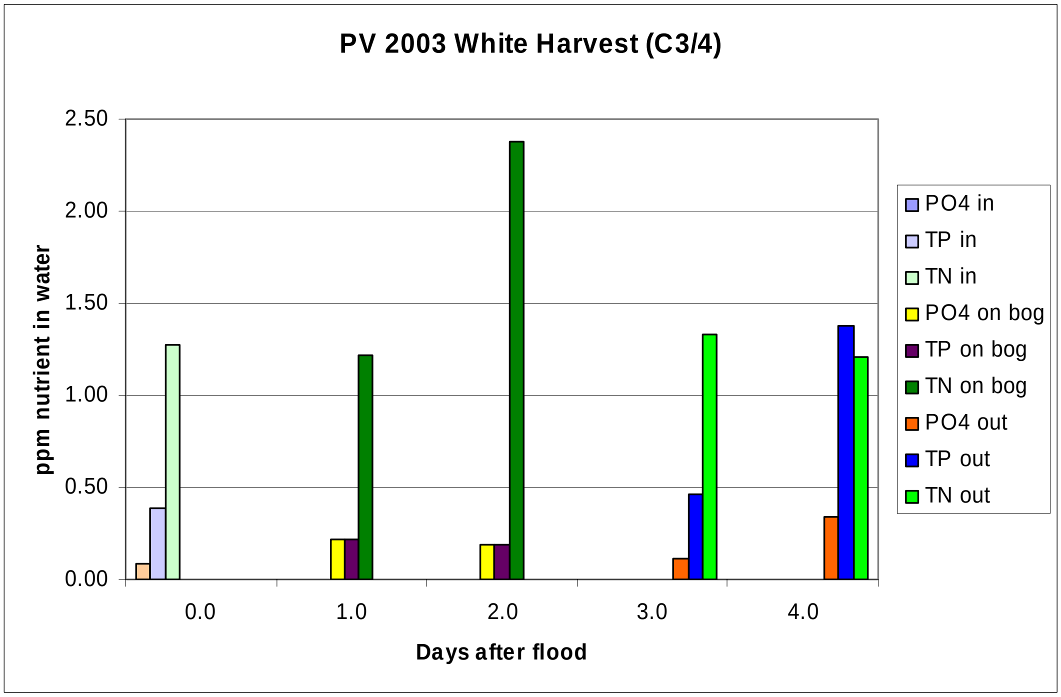


Figure 3B-9. Pierceville harvest 2003. Organic soil pair 1, control bog Sections C1 and C2. Discharge began on Day 12.

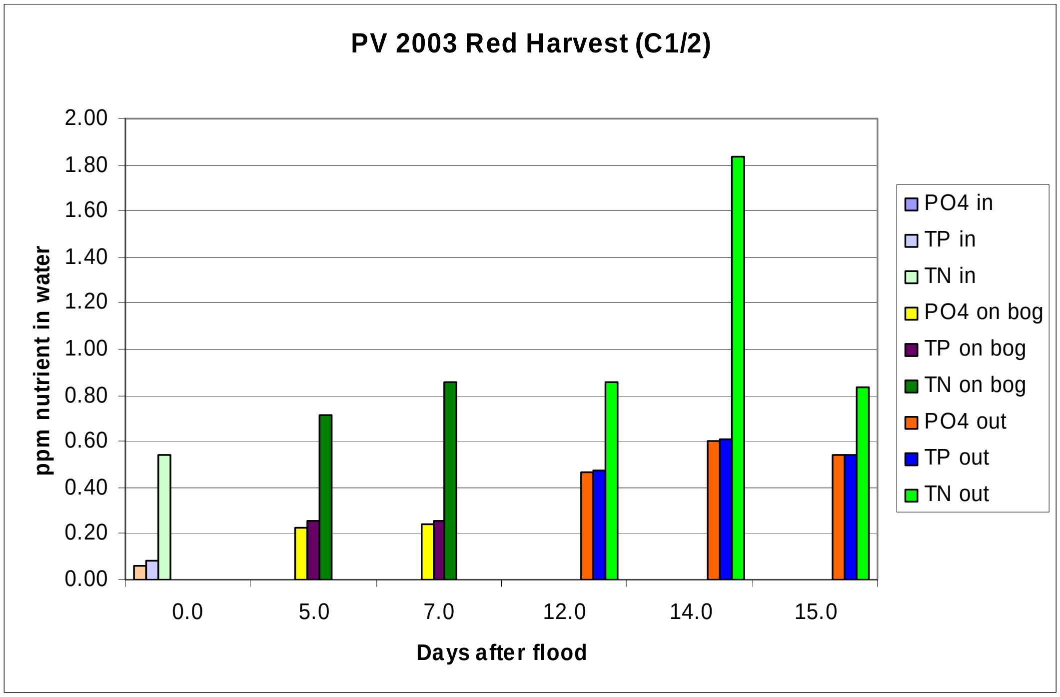


Figure 3B-10. Eagle Holt harvest 2003. Organic soil pair 1, reduced bog Sections K7 and K8. Discharge began on Day 14.

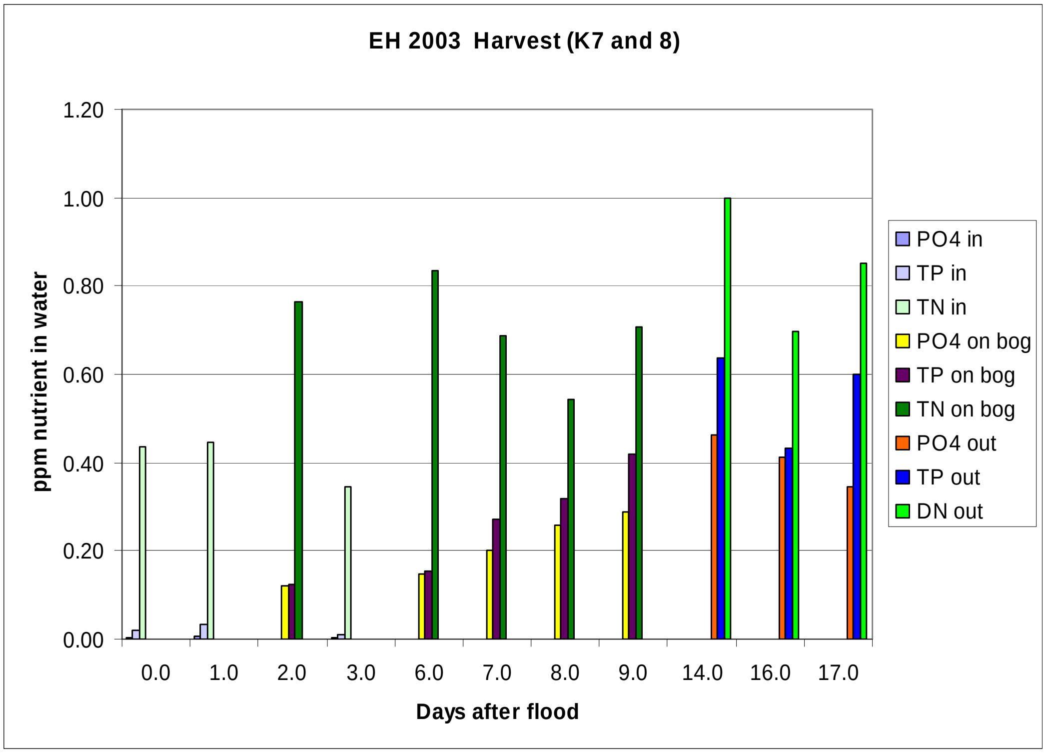


Figure 3B-11. White Springs harvest 2003. Organic soil pair 3, control bog. Discharge was on Day 8.

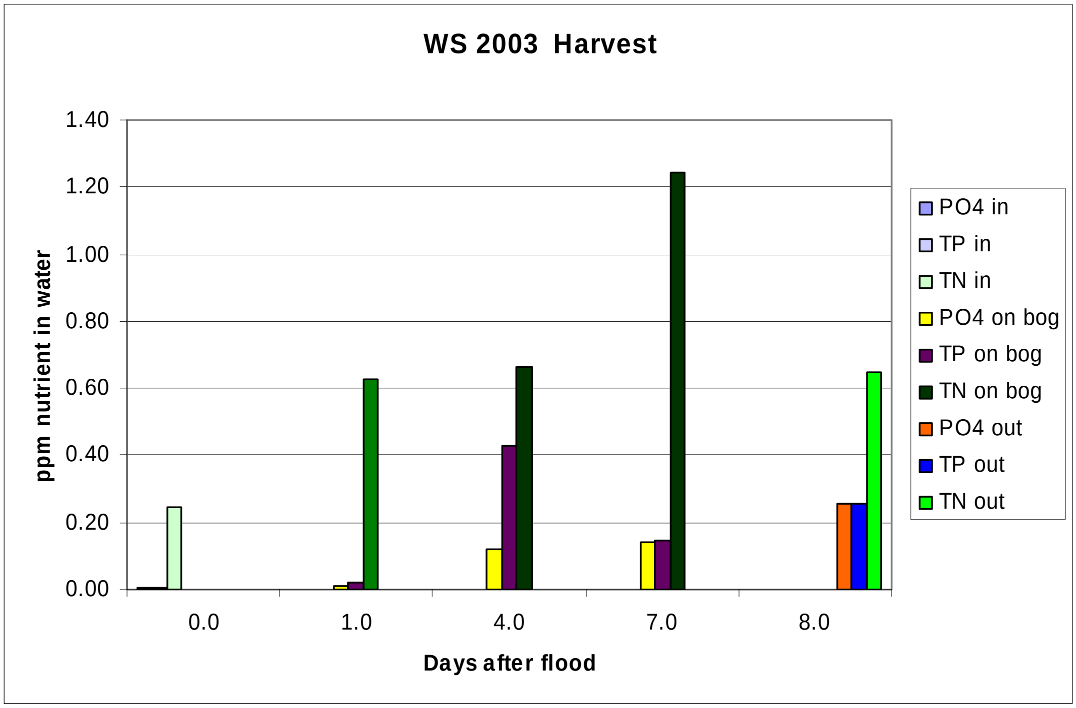


Figure 3B-12. Benson's Pond harvest 2003. Organic soil pair 3, reduced bog. Discharge was on Day 21.

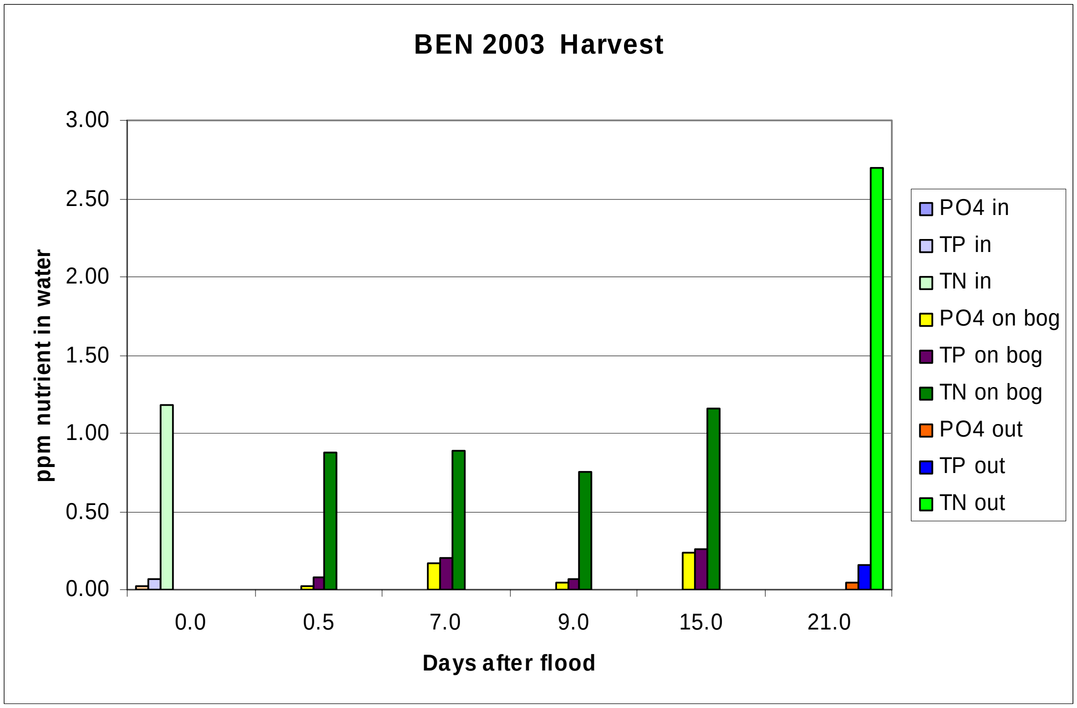


Figure 3B-13. Ashley's Bog harvest 2003. Mineral soil pair 2, control bog.

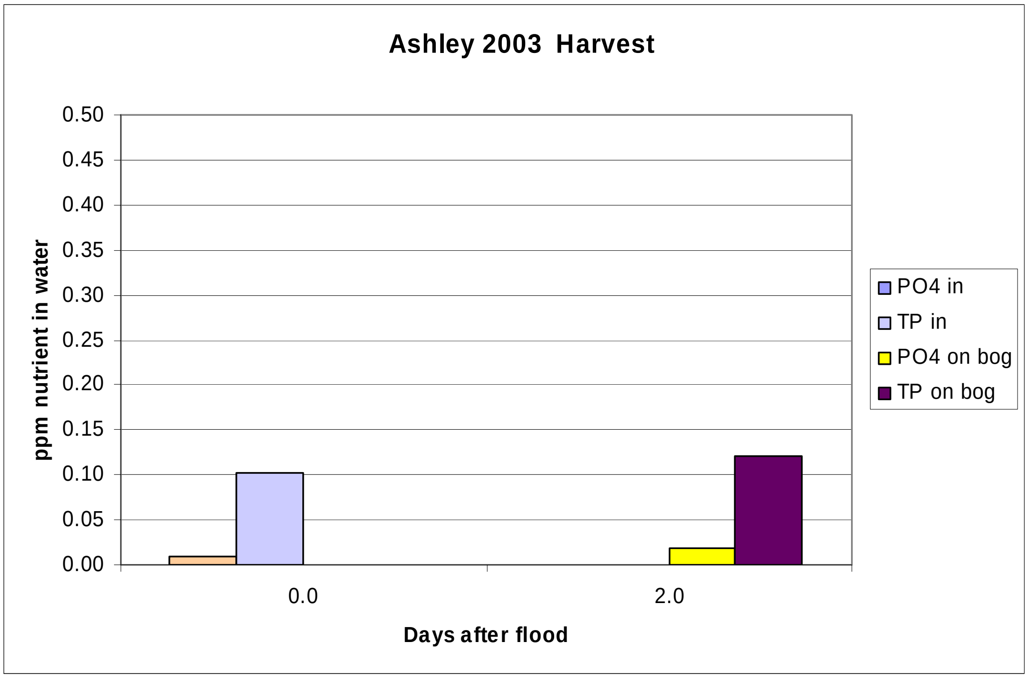


Figure 3B-14. Pierceville harvest 2004. Organic soil pair 1, control bog. Day 13-14 discharge after harvest of Sections C1 and C2. Remaining water moved to C3 and C4 for harvest and then was discharged at day 24-25.

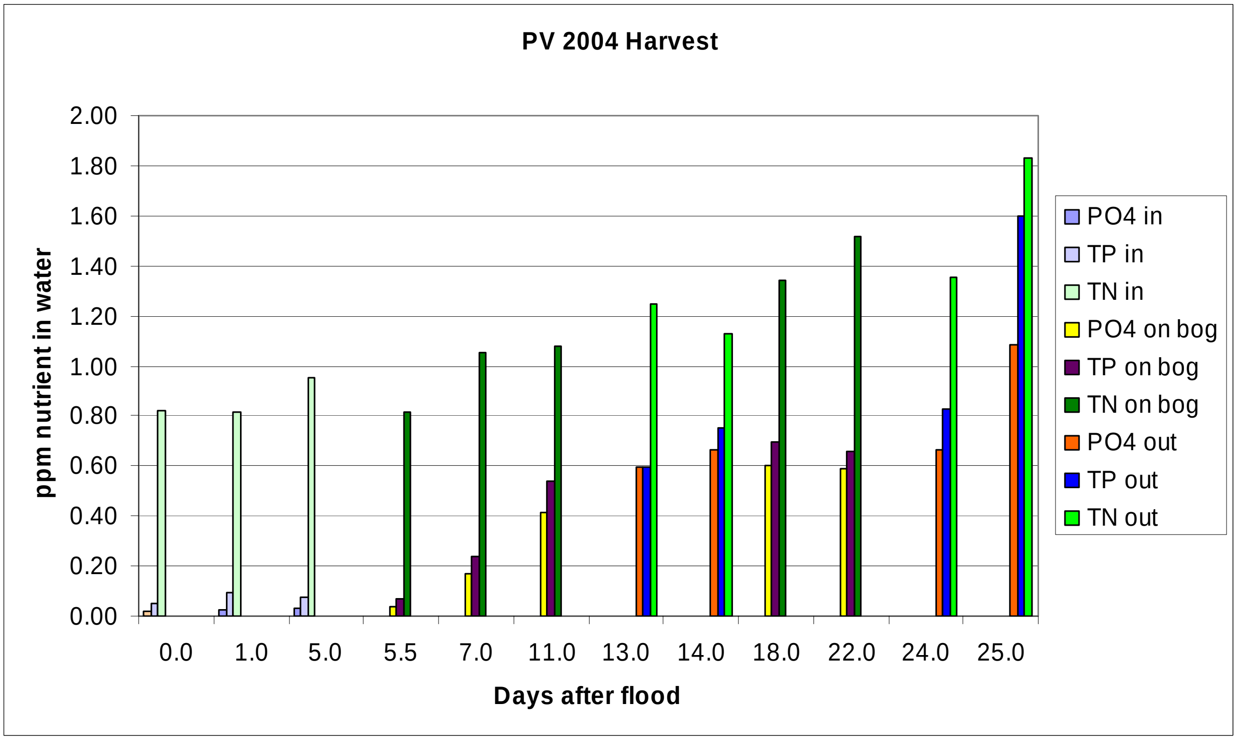


Figure 3B-15. Eagle Holt harvest 2004. Organic soil pair 1, reduced bog Sections K7 and K8. Some water was discharged on Day 13. At Day 17 water remaining on the bog was sampled.

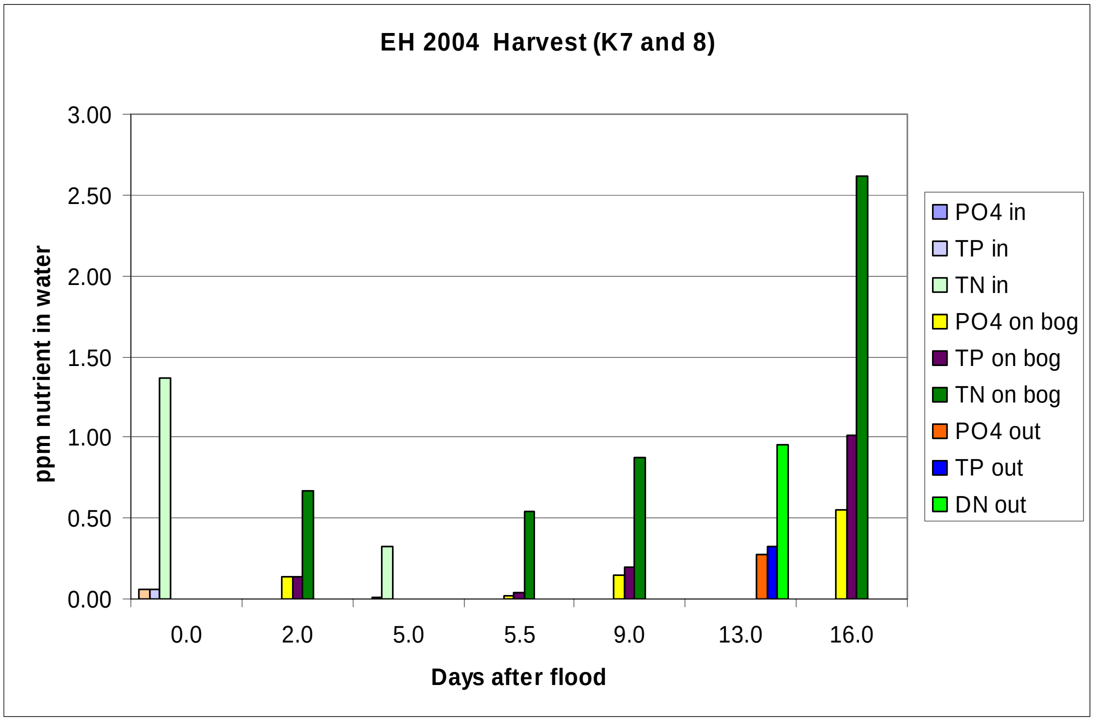


Figure 3B-16. Eagle Holt harvest 2004. Organic soil pair 1, reduced bog Sections K6, 9, and 20. Discharge began on Day 10.

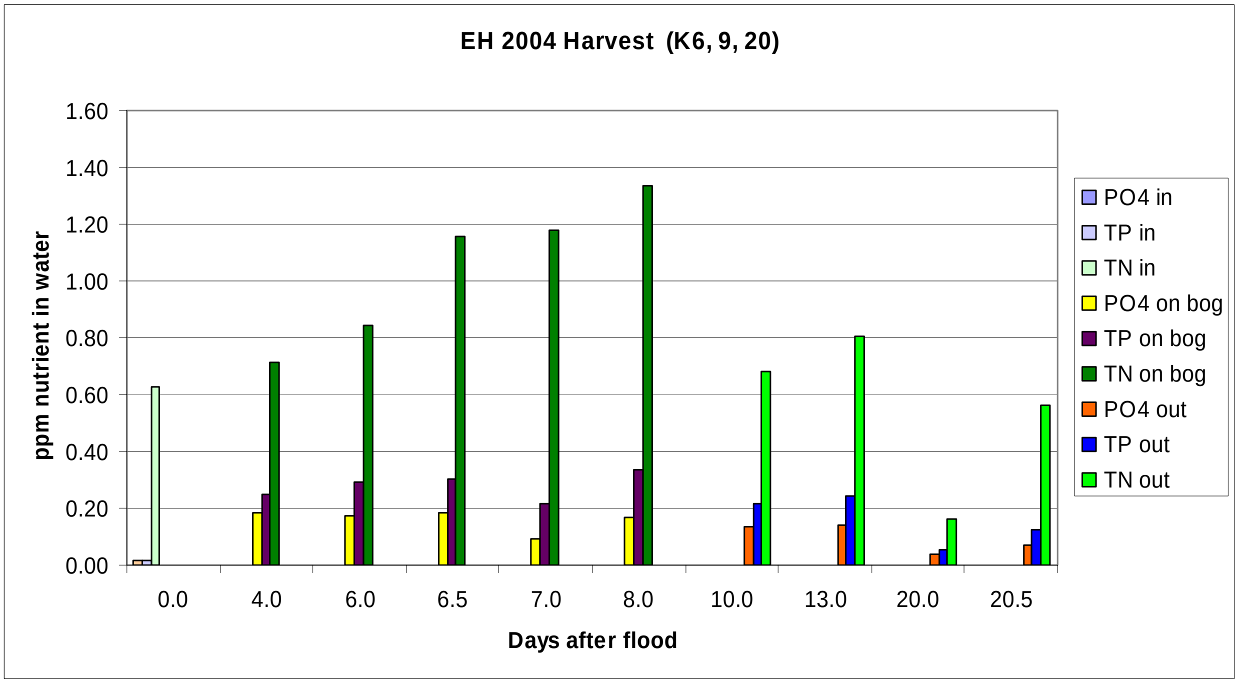


Figure 3B-17. White Springs harvest 2004. Organic soil pair 3, control bog.

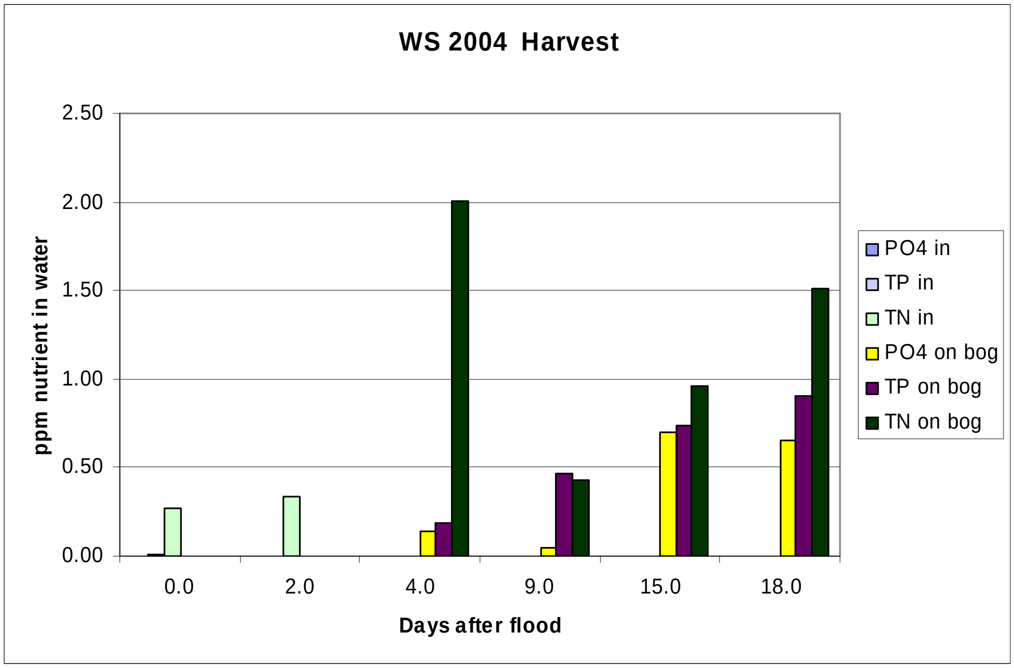


Figure 3B-18. Benson's Pond harvest 2004. Organic soil pair 3, reduced bog. Discharge began on Day 26.

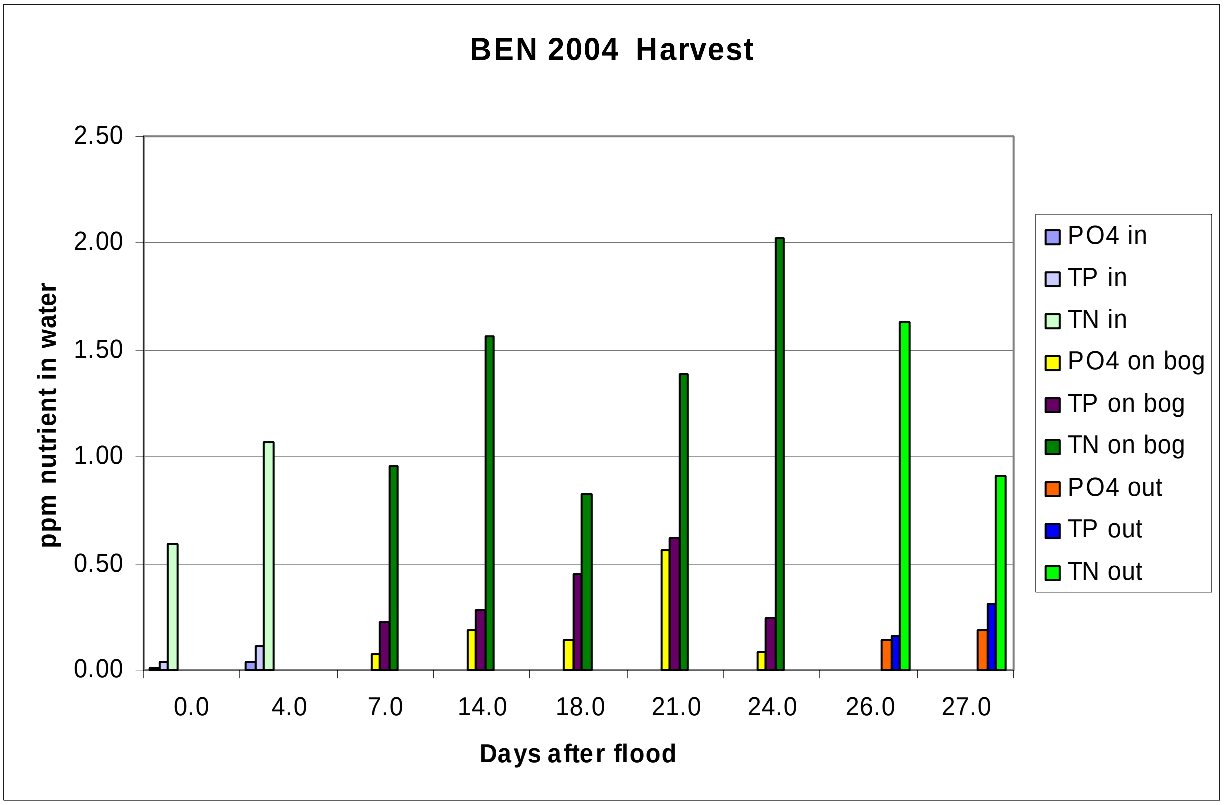


Figure 3B-19. Ashley's Bog harvest 2004. Mineral soil pair 2, control bog.

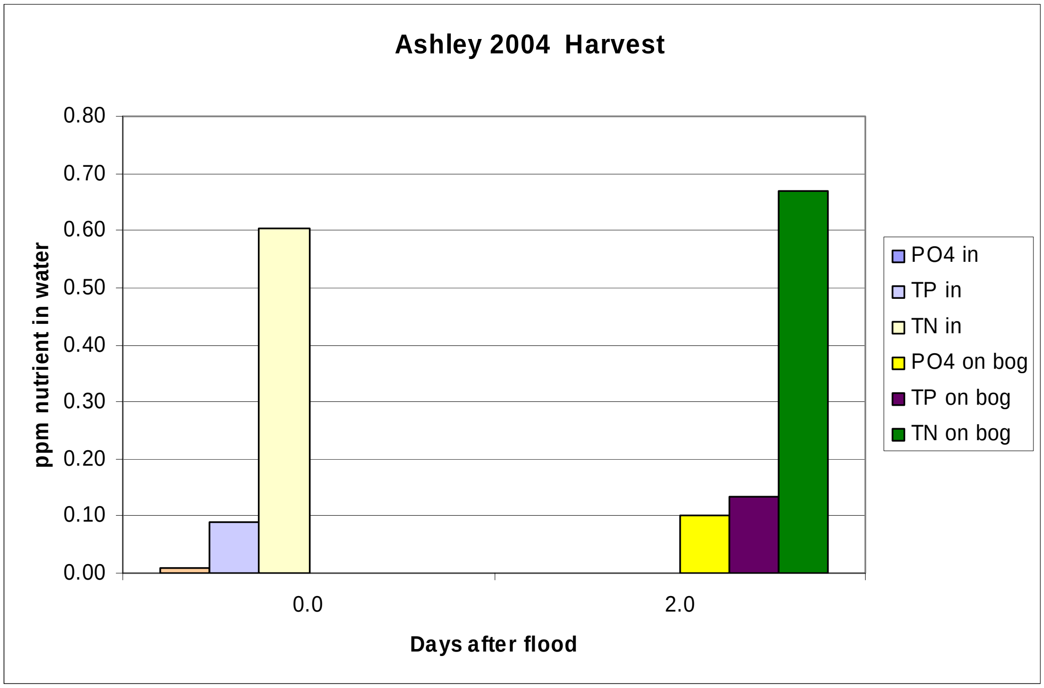


Figure 3B-20. Mikey/Kelseys Bog harvest 2004. Mineral soil pair 2, reduced bog. Some water was discharged on Day 1, remainder was discharged beginning on Day 5.5.

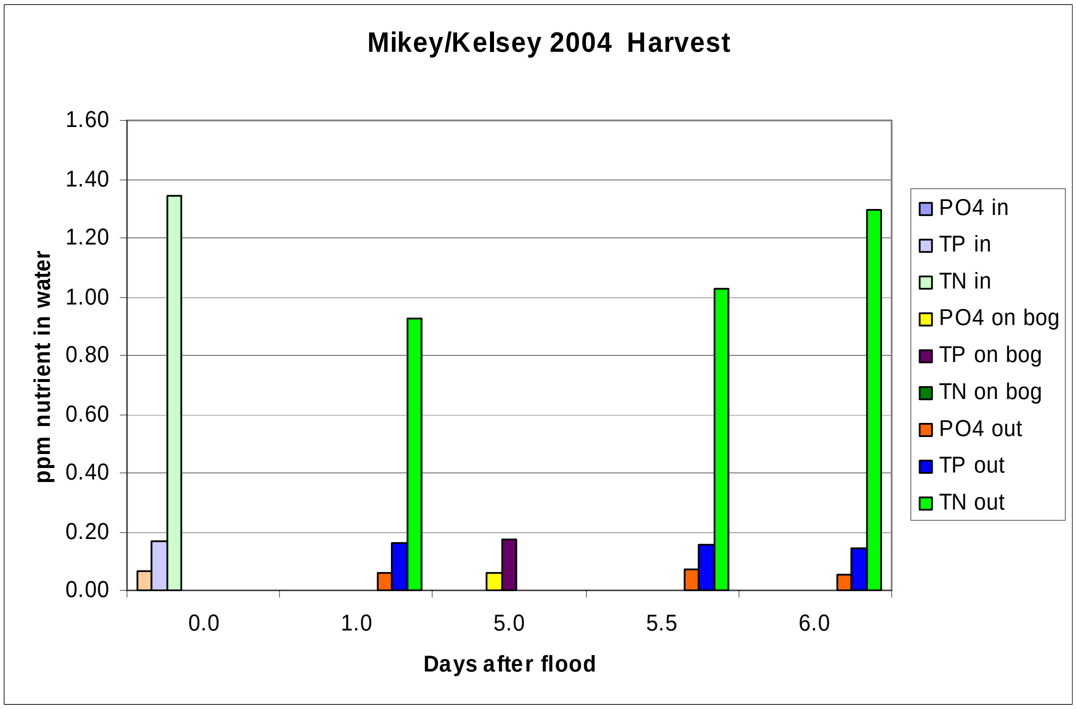


Figure 3B-21. Winter floods at Pierceville 2002. Organic soil pair 1, control bog.

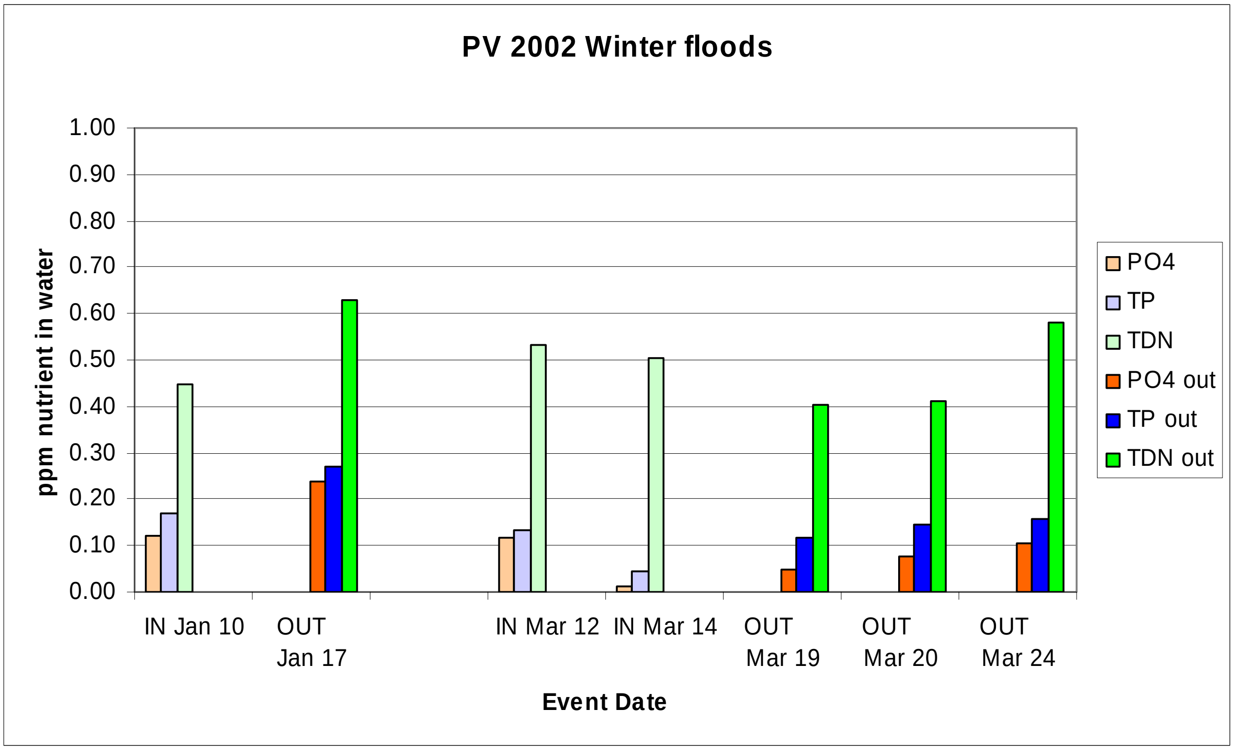


Figure 3B-22. Winter floods at Eagle Holt 2002. Organic soil pair 1, reduced bog.

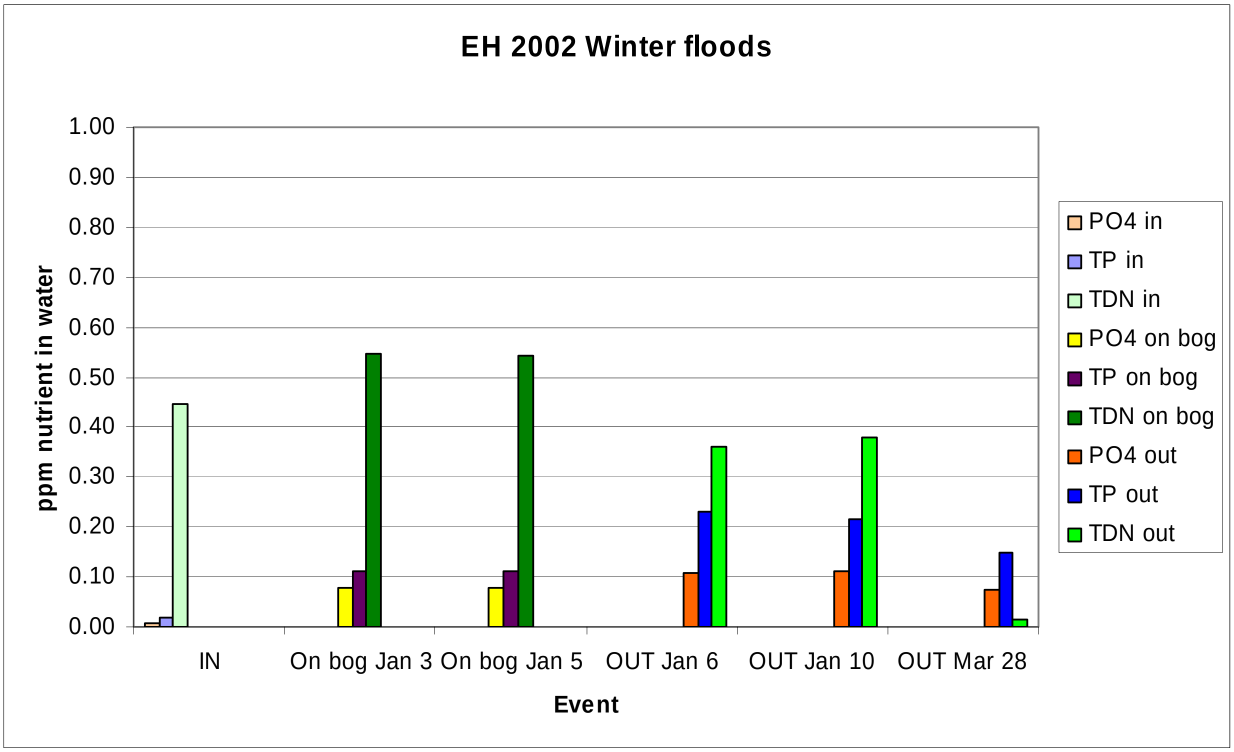


Figure 3B-23. Winter floods at White Springs 2002. Organic soil pair 3, control bog.

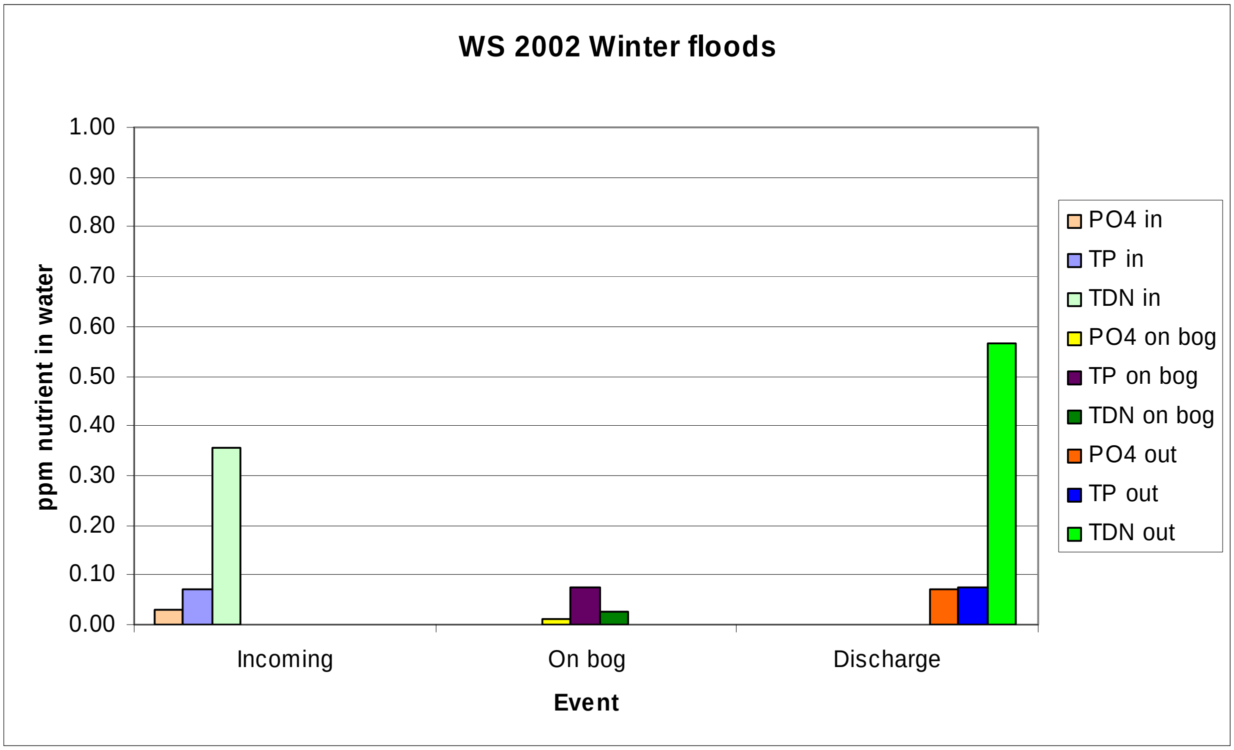


Figure 3B-24. Winter floods at Benson's Pond 2002. Organic soil pair 3, reduced bog.

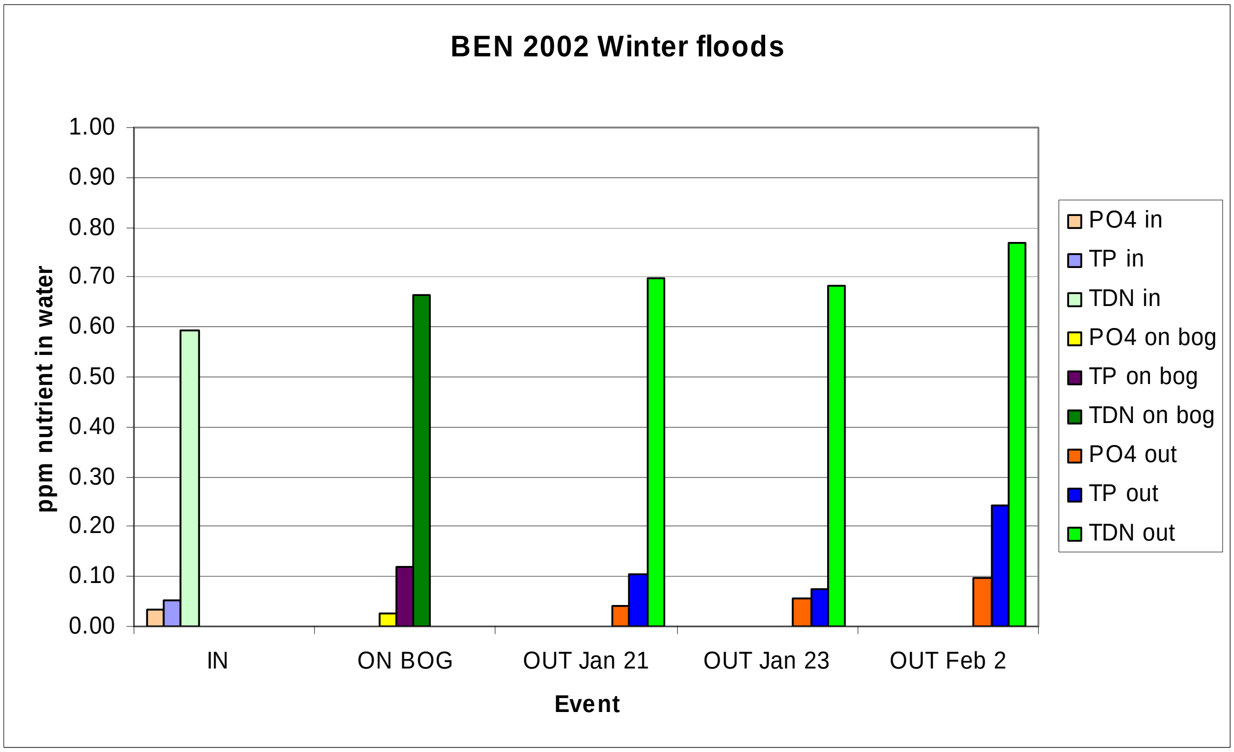


Figure 3B-25. Winter floods at Mikey/Kelseys Bog 2002. Mineral soil pair 2, reduced bog.

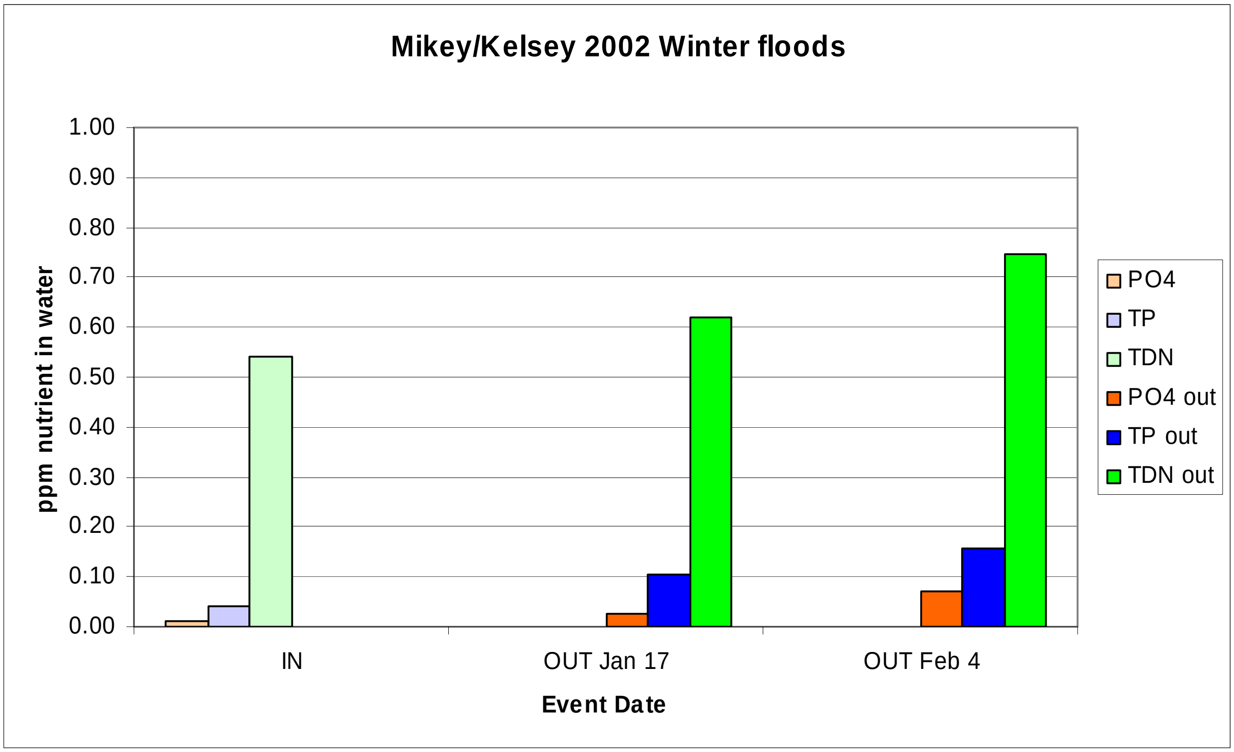


Figure 3B-26. Winter floods at Pierceville 2003. Organic soil pair 1, control bog.

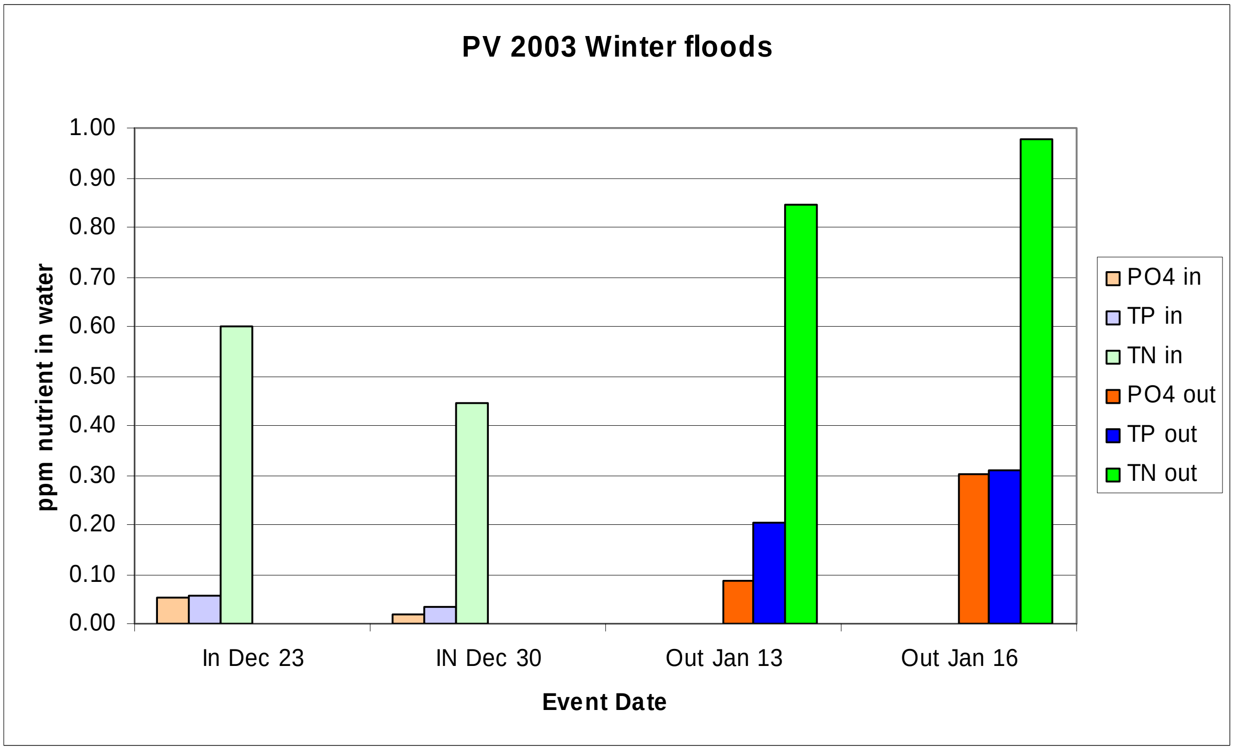


Figure 3B-27. Winter floods at Eagle Holt 2003. Organic soil pair 1, reduced bog.

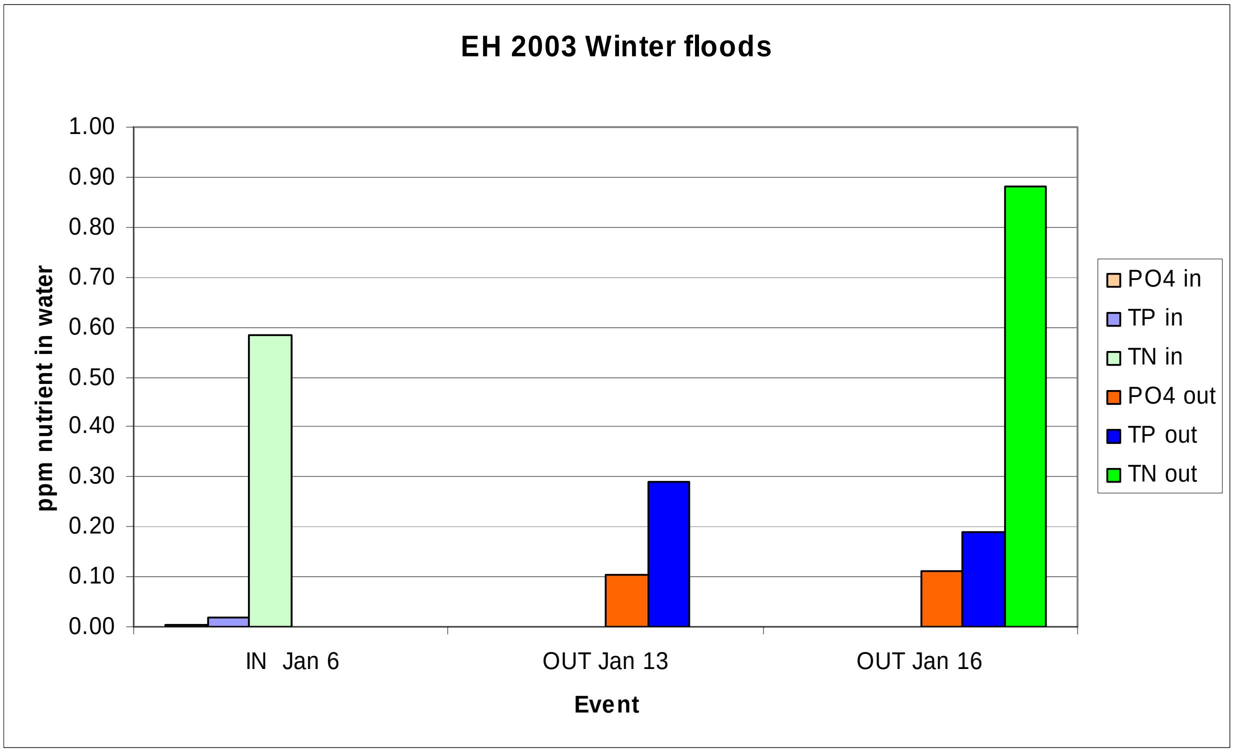


Figure 3B-28. Winter floods at White Springs 2003. Organic soil pair 3, control bog.

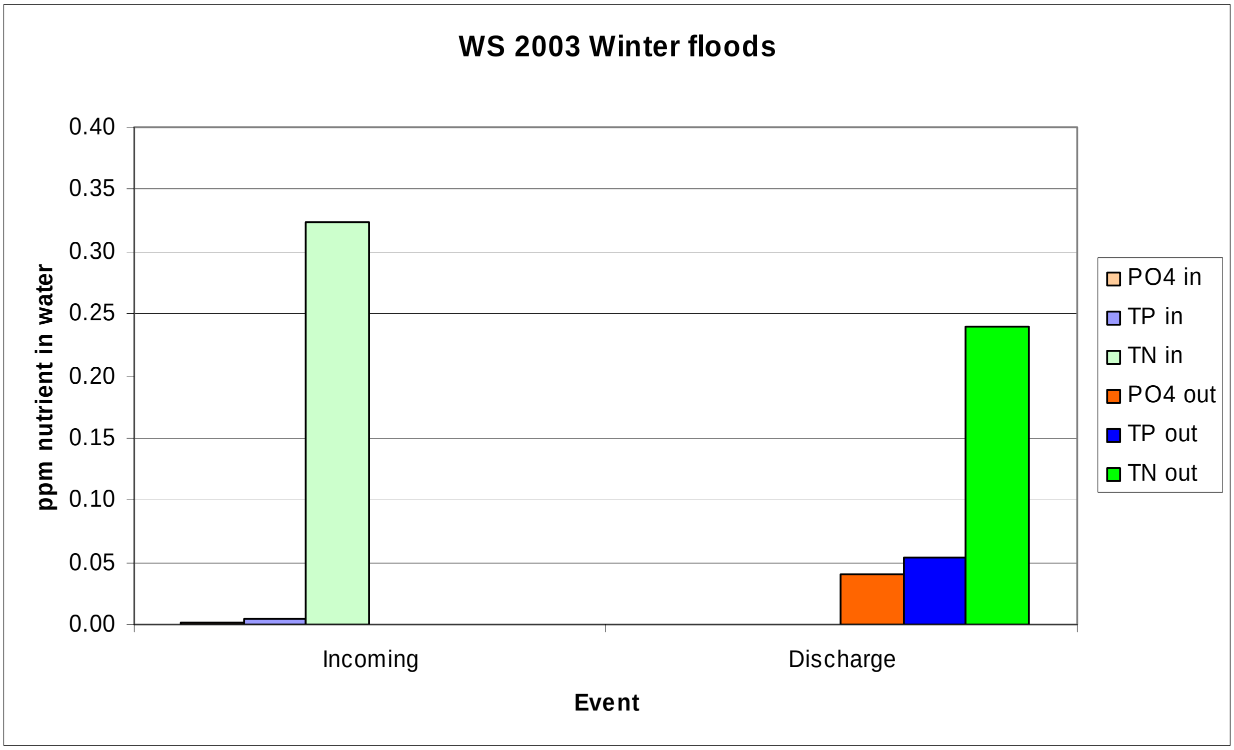


Figure 3B-29. Winter floods at Benson's Pond 2003. Organic soil pair 3, reduced bog.

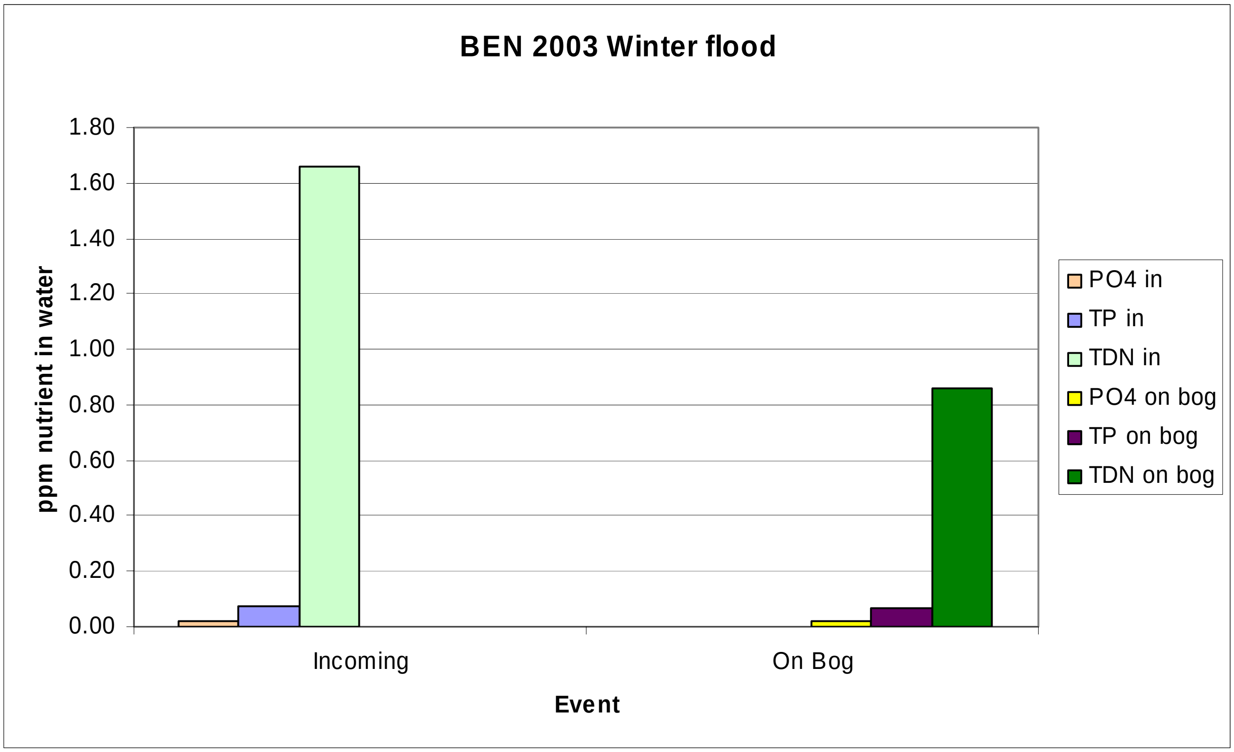


Figure 3B-30. Winter floods at Pierceville 2004. Organic soil pair 1, control bog.

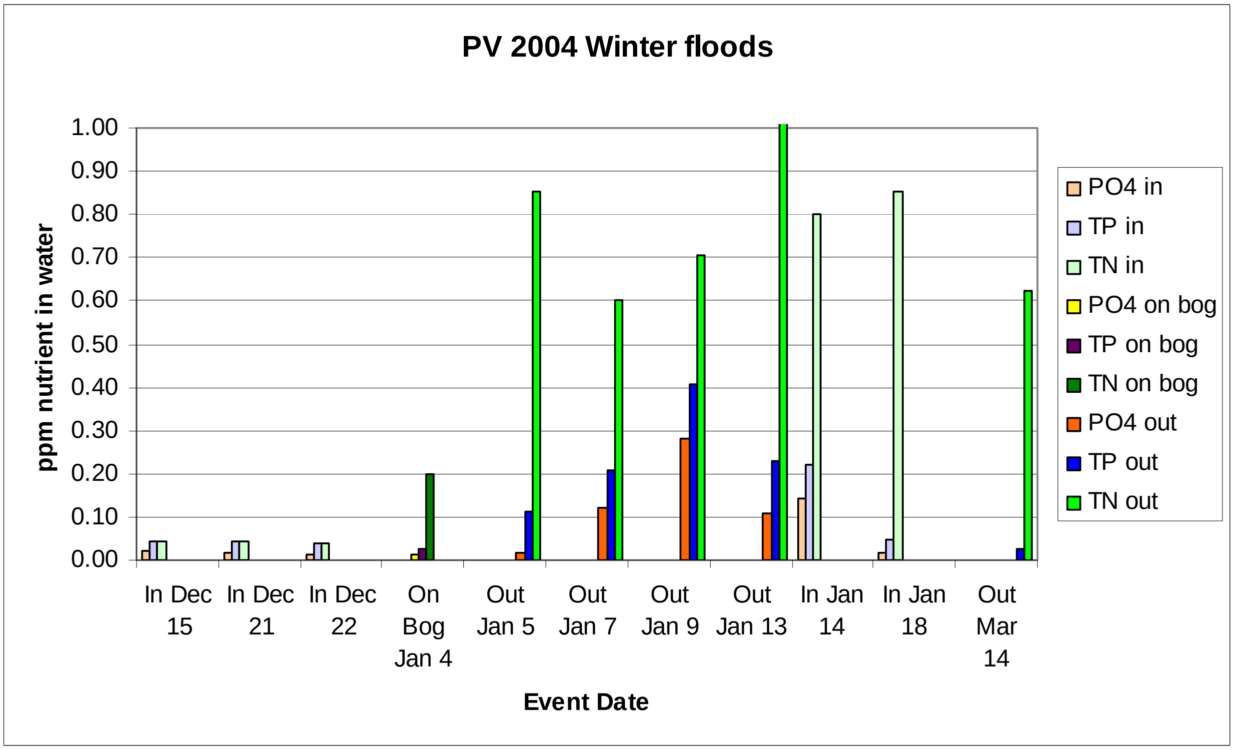


Figure 3B-31. Winter floods at Eagle Holt 2004. Organic soil pair 1, reduced bog.

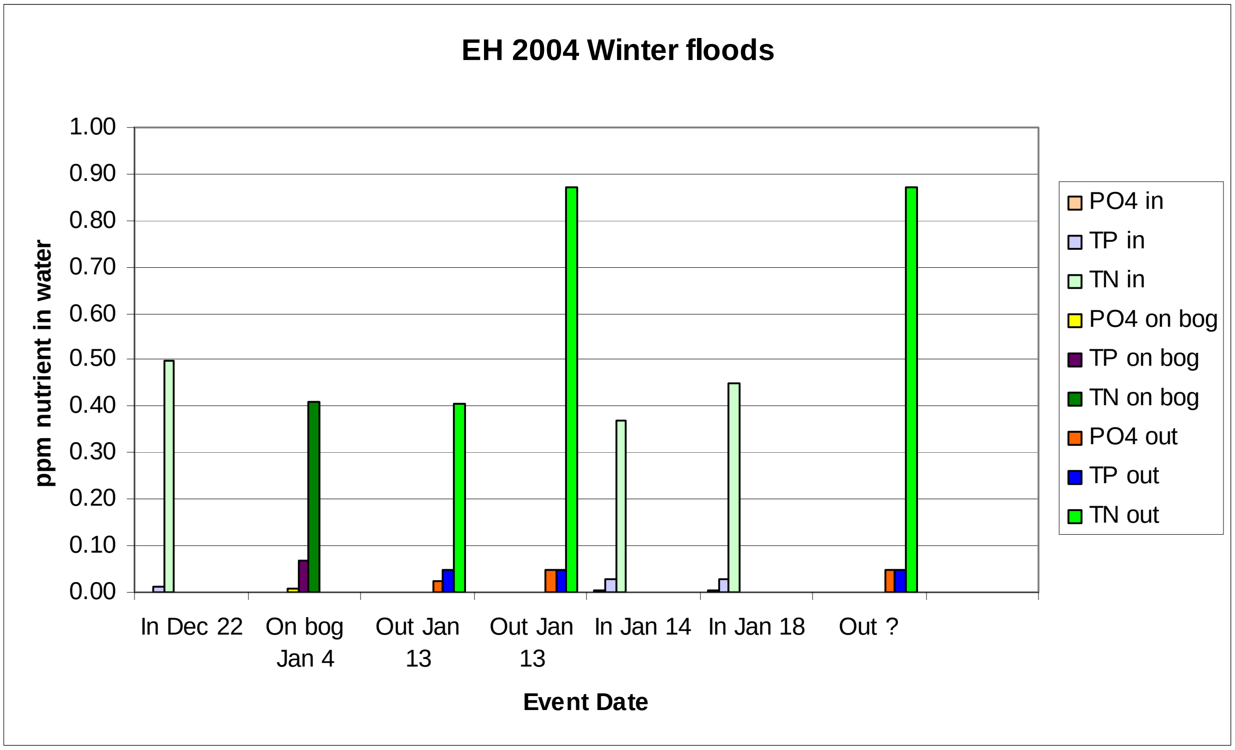


Figure 3B-32. Winter floods at Benson's Pond 2004. Organic soil pair 3, reduced bog.

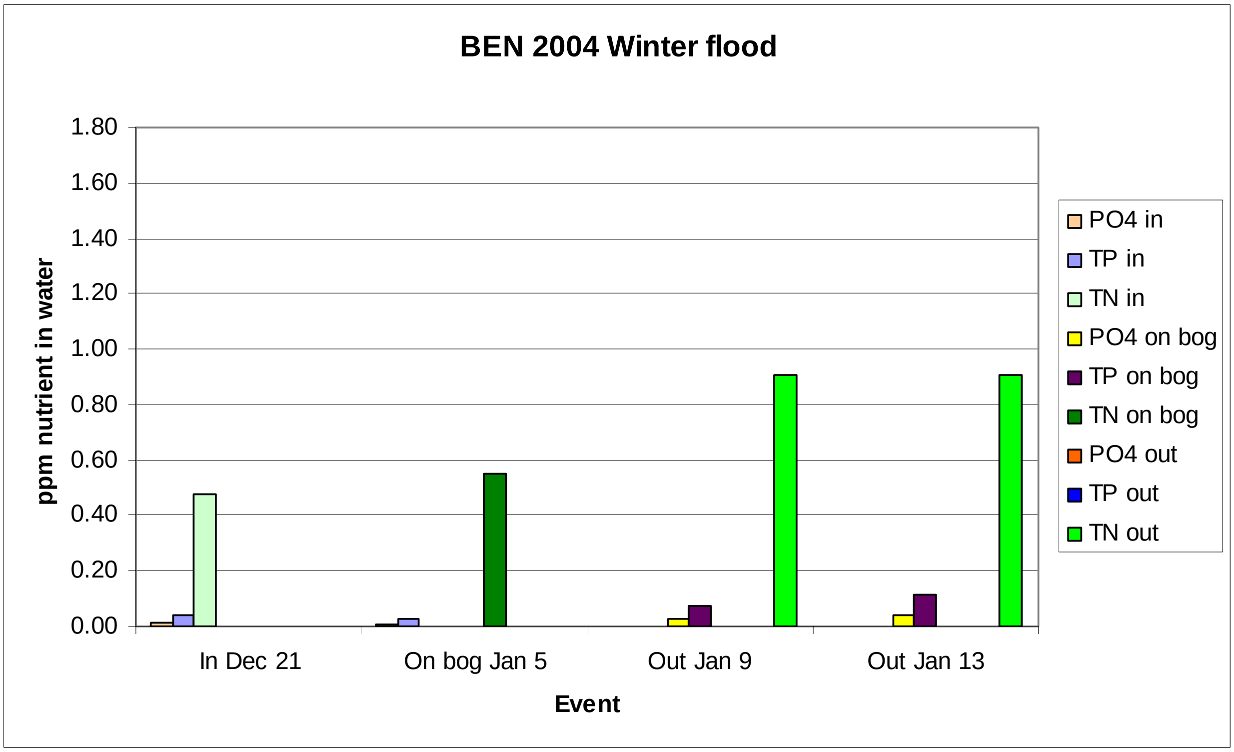


Figure 3B-33. Winter floods at Ashleys Bog 2004. Mineral soil pair 2, control bog.

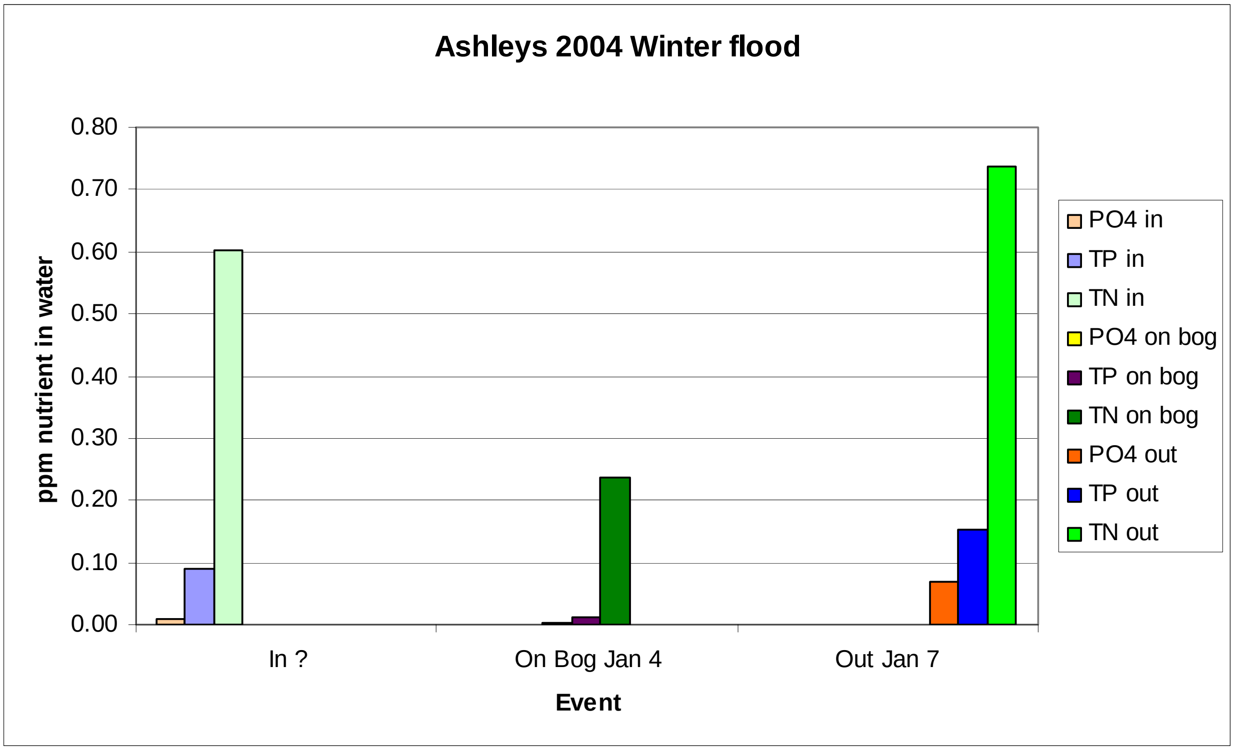
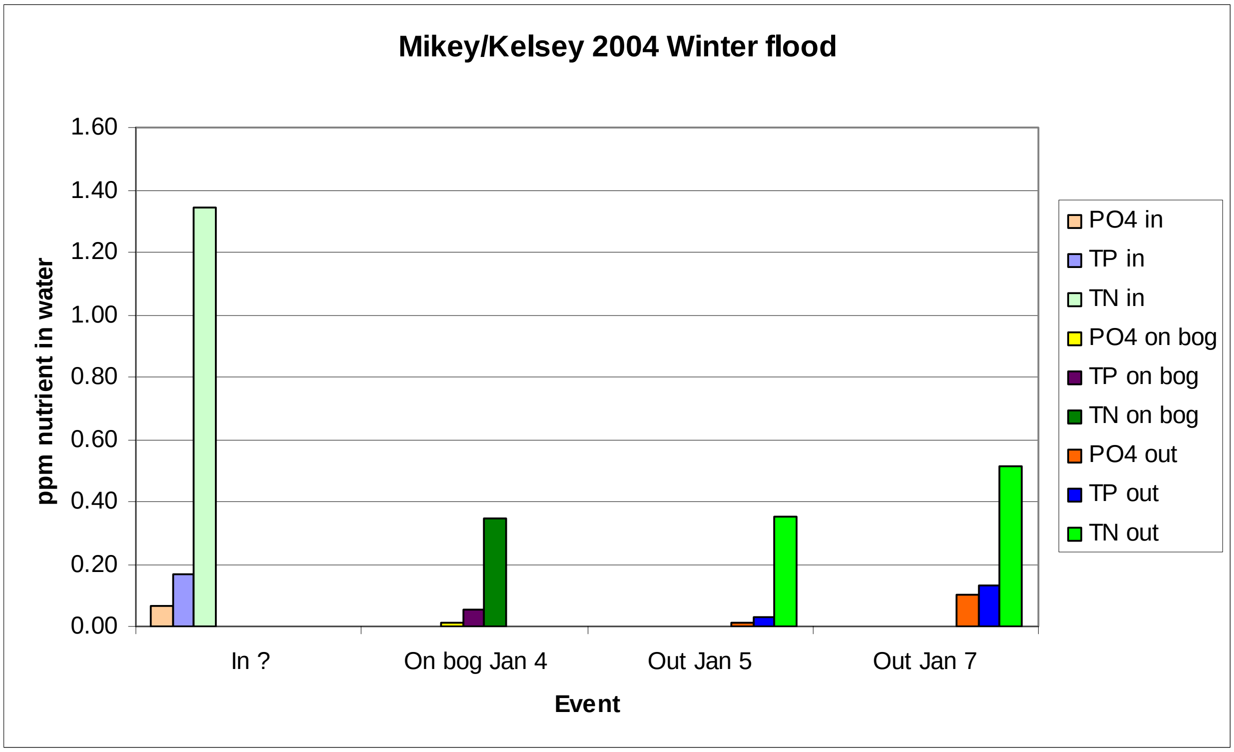


Figure 3B-34. Winter floods at Mikey/Kelseys Bog 2004. Mineral soil pair 2, reduced bog.



APPENDIX 4.
Soil and plant nutrients at field sites

Phosphorus project soil analysis data
Samples collected April 17-18 2002

ID	Location	organic matter percent	Bray P ppm	K ppm	Mg ppm	Ca ppm	soil pH
I Organic Control (PV)	C1b	2.7	66	76	25	68	4.4
I Organic Control (PV)	C2a north	2.6	43	58	21	62	4.2
I Organic Control (PV)	C2a south	2.8	44	97	27	72	4.4
I Organic Control (PV)	C4	2.3	49	61	22	71	4.2
I Organic Reduced (EH)	K8a center	2.4	73	81	26	59	4.2
I Organic Reduced (EH)	K7b north	2.5	47	76	28	82	4.3
I Organic Reduced (EH)	K7b south	2.7	74	85	30	78	4.3
I Organic Reduced (EH)	K9 south	2.7	62	72	27	87	4.4
I Organic Reduced (EH)	K9 north	2.7	68	82	28	82	4.4
I Organic Reduced (EH)	K20 center	0.7	25	44	12	45	4.7
II Mineral Reduced (Kelseys)	West	1.2	45	49	14	50	4.6
II Mineral Reduced (Kelseys)	East	1.1	63	58	17	50	4.6
II Mineral Reduced (Mikeys)	South	1.9	87	51	28	83	4.6
II Mineral Reduced (Mikeys)	North	1.2	45	55	21	69	4.7
II Mineral Control (Ashleys)	South	0.8	62	38	13	51	4.9
II Mineral Control (Ashleys)	West	1.4	79	55	20	74	4.4
II Mineral Control (Ashleys)	Center	1.6	103	59	21	77	4.5
II Mineral Control (Ashleys)	East	1.6	31	69	19	65	4.5
III Organic Reduced (BEN)	F1 north	2.8	63	50	24	99	4.5
III Organic Reduced (BEN)	F1 center	2.6	57	69	25	104	4.4
III Organic Reduced (BEN)	F4c west	3.5	53	63	32	124	4.3
III Organic Reduced (BEN)	F4c east	2.5	42	80	25	104	4.4
III Organic Reduced (BEN)	F5 north	1.3	37	70	15	72	4.6
III Organic Reduced (BEN)	F5 center	0.9	24	74	16	96	4.7
III Organic Control (WS)	Shed south	2.8	42	58	24	57	4.0
III Organic Control (WS)	Shed north	4.1	76	88	31	71	4.5
III Organic Control (WS)	Pump north	3.2	76	64	32	103	4.2
III Organic Control (WS)	Pump south	2.5	52	64	22	49	4.1

Phosphorus project soil analysis data
Samples collected May 16-20, 2003

ID	Location	organic matter percent	Bray P ppm	K ppm	Mg ppm	Ca ppm	soil pH
I Organic Control (PV)	C1b	1.6	66	16	27	86	4.7
I Organic Control (PV)	C2a north	1.7	58	40	23	94	4.8
I Organic Control (PV)	C2A south	2.0	47	37	24	87	4.8
I Organic Control (PV)	C4	1.4	59	27	20	68	4.7
I Organic Control (PV)	C1a	2.0	39	51	42	189	4.8
I Organic Control (PV)	C2c	3.0	63	28	27	115	4.8
I Organic Control (PV)	C3a-b	2.2	69	37	34	137	4.7
I Organic Reduced (EH)	K9 NW	1.8	72	20	23	81	4.8
I Organic Reduced (EH)	K9 center	2.8	72	46	28	89	4.9
I Organic Reduced (EH)	K9 SE	2.2	69	33	24	96	4.8
I Organic Reduced (EH)	K6 NW	2.0	64	23	25	92	4.9
I Organic Reduced (EH)	K6 N	2.2	65	31	29	129	4.8
I Organic Reduced (EH)	K6 S	2.5	75	40	26	94	4.8
I Organic Reduced (EH)	K6 E	2.2	81	27	27	86	4.9
I Organic Reduced (EH)	K7b N	2.1	40	22	23	82	4.7
I Organic Reduced (EH)	K7b N cent.	1.7	57	25	26	95	4.8
I Organic Reduced (EH)	K7b S cent.	2.2	55	46	22	76	4.5
I Organic Reduced (EH)	K7b S	2.1	40	35	26	92	4.7
I Organic Reduced (EH)	K8a	1.3	77	35	21	69	4.7
I Organic Reduced (EH)	K20	0.9	63	12	15	65	4.8
II Mineral Red. (Kelseys)	K19 W	1.6	77	27	25	188	5.7
II Mineral Red. (Kelseys)	K19 E	1.2	72	19	22	106	5.7
II Mineral Reduced (Mikeys)	K16 S	0.9	84	26	19	76	5.2
II Mineral Reduced (Mikeys)	K16 N	1.3	80	36	27	93	5.1
II Mineral Control (Ashleys)	K14 S	1.2	58	23	19	77	5.2
II Mineral Control (Ashleys)	K14 W	1.5	79	53	25	93	4.9
II Mineral Control (Ashleys)	K14 center	1.9	79	62	23	80	4.8
II Mineral Control (Ashleys)	K14 E	1.5	70	34	25	94	4.9
III Organic Reduced (BEN)	F1 N	2.0	56	27	26	128	4.7
III Organic Reduced (BEN)	F1 center	1.8	59	32	21	91	4.9
III Organic Reduced (BEN)	F5 N	1.7	56	57	40	83	4.3
III Organic Reduced (BEN)	F5 center	1.7	73	31	33	174	4.6
III Organic Reduced (BEN)	F2b	1.6	57	50	34	304	5.2
III Organic Reduced (BEN)	F3	1.7	56	32	27	141	4.9
III Organic Reduced (BEN)	F4c E	1.8	61	25	22	104	4.8
III Organic Reduced (BEN)	F4c W	1.6	70	44	30	167	4.9

III Organic Control (WS)	Shed N	2.3	54	18	20	75	4.8
III Organic Control (WS)	Shed S	1.7	65	21	22	72	4.8
III Organic Control (WS)	Center	1.7	55	37	20	71	4.7
III Organic Control (WS)	Pump N	2.2	65	32	22	71	4.7
III Organic Control (WS)	Pump S	1.5	63	27	20	72	4.7

Phosphorus project soil analysis data
Samples collected November 18 2003

ID	Location	organic matter percent	Bray P ppm	K ppm	Mg ppm	Ca ppm	soil pH
I Organic Control (PV)	C1b	1.4	112	26	22	83	4.7
I Organic Control (PV)	C2a north	2.4	53	45	28	101	4.5
I Organic Control (PV)	C2A south	2.7	76	50	31	101	4.5
I Organic Control (PV)	C4	2.4	63	52	34	118	4.4
I Organic Control (PV)	C1a	2.3	79	53	33	109	4.5
I Organic Control (PV)	C2c	2.8	102	79	40	133	4.5
I Organic Control (PV)	C3a-b	2.8	126	51	35	118	4.5
I Organic Reduced (EH)	K9 NW	1.9	100	65	40	180	4.5
I Organic Reduced (EH)	K9 center	2	95	62	37	142	4.5
I Organic Reduced (EH)	K9 SE	2.2	87	55	35	139	4.5
I Organic Reduced (EH)	K6 NW	3.8	85	61	46	166	4.6
I Organic Reduced (EH)	K6 N	3.9	108	67	44	138	4.7
I Organic Reduced (EH)	K6 S	2.7	91	34	29	106	4.6
I Organic Reduced (EH)	K6 E	4.5	85	59	46	159	4.5
I Organic Reduced (EH)	K7b N	2.9	77	53	38	136	4.6
I Organic Reduced (EH)	K7b N cent.	3.3	69	53	35	107	4.6
I Organic Reduced (EH)	K7b S cent.	3.5	63	64	39	123	4.5
I Organic Reduced (EH)	K7b S	3.4	102	45	37	123	4.6
I Organic Reduced (EH)	K8a	2.9	119	41	30	97	4.5
I Organic Reduced (EH)	K20	1.3	73	24	22	96	4.8
II Mineral Reduced (Kelseys)	W	1.5	68	64	50	238	5.2
II Mineral Reduced (Kelseys)	E	1.6	122	42	31	172	5
II Mineral Reduced (Mikeys)	S	1.1	94	36	34	156	5.2
II Mineral Reduced (Mikeys)	N	1.4	128	41	29	105	4.9
II Mineral Control (Ashleys)	S	1.5	91	31	37	101	4.9
II Mineral Control (Ashleys)	W	2.4	115	47	32	112	4.6
II Mineral Control (Ashleys)	Center	2.7	126	53	34	103	4.5
II Mineral Control (Ashleys)	E	3	143	63	41	139	4.6
III Organic Reduced (BEN)	F1 N	2.5	59	43	31	125	4.5
III Organic Reduced (BEN)	F1 center	1.8	85	25	25	228	5
III Organic Reduced (BEN)	F5 N	2.1	45	26	23	121	4.8

III Organic Reduced (BEN)	F5 center	2.3	84	27	24	107	4.5
III Organic Reduced (BEN)	F2b	2.5	66	41	29	114	4.3
III Organic Reduced (BEN)	F3	2.2	83	34	25	100	4.6
III Organic Reduced (BEN)	F4c east	2.5	93	32	25	113	4.4
III Organic Reduced (BEN)	F4c west	2.5	91	32	29	133	5
III Organic Control (WS)	Shed S	2.8	78	51	46	260	4.5
III Organic Control (WS)	Shed N	3.8	81	35	31	84	4.4
III Organic Control (WS)	Center	3.5	75	47	27	89	4.3
III Organic Control (WS)	Pump N	3.3	61	42	31	91	4.2
III Organic Control (WS)	Pump S	3.3	86	54	33	94	4.2

Phosphorus project soil analysis data
Samples collected May 2004

ID	Location	organic matter percent	Bray P ppm	K ppm	Mg ppm	Ca ppm	soil pH
I Organic Control (PV)	C1b	2.4	60	63	34	110	4.3
I Organic Control (PV)	C2a north	1.9	72	41	31	93	4.6
I Organic Control (PV)	C2A south	1.7	85	37	29	86	4.5
I Organic Control (PV)	C4	2.2	66	60	29	94	4.4
I Organic Control (PV)	C1a	3.4	72	59	40	137	4.5
I Organic Control (PV)	C2c	2.1	92	56	29	86	4.6
I Organic Control (PV)	C3a-b	2.4	115	80	38	125	4.7
I Organic Reduced (EH)	K9 NW	2.4	92	66	39	133	4.6
I Organic Reduced (EH)	K9 center	2.3	95	69	30	110	4.6
I Organic Reduced (EH)	K9 SE	1.9	82	50	26	94	4.6
I Organic Reduced (EH)	K6 NW	3.1	83	62	39	120	4.7
I Organic Reduced (EH)	K6 N	3	82	51	34	119	4.5
I Organic Reduced (EH)	K6 S	3.2	55	59	36	109	4.4
I Organic Reduced (EH)	K6 E	2.5	70	63	33	109	4.5
I Organic Reduced (EH)	K7b N	1.8	110	31	25	98	4.5
I Organic Reduced (EH)	K7b N cent.	2	75	48	30	104	4.5
I Organic Reduced (EH)	K7b S cent.	2.1	74	51	31	103	4.5
I Organic Reduced (EH)	K7b S	2.5	78	43	33	107	4.3
I Organic Reduced (EH)	K8a	2.3	94	42	31	85	4.3
I Organic Reduced (EH)	K20	0.6	57	35	17	64	4.7
II Mineral Reduced (Kelseys)	W	1.7	86	75	59	265	4.9
II Mineral Reduced (Kelseys)	E	1.8	73	42	37	126	4.6
II Mineral Reduced (Mikeys)	S	1	80	56	35	124	5.3
II Mineral Reduced (Mikeys)	N	1.5	89	55	37	116	5
II Mineral Control (Ashleys)	S	0.9	68	27	25	92	4.9

II Mineral Control (Ashleys)	W	2.9	59	70	48	161	4.5
II Mineral Control (Ashleys)	Center	2.6	74	78	41	124	4.6
II Mineral Control (Ashleys)	E	2.4	81	95	44	148	4.6
III Organic Reduced (BEN)	F1 N	1.5	80	38	60	210	4.8
III Organic Reduced (BEN)	F1 center	2.1	59	45	29	133	4.6
III Organic Reduced (BEN)	F5 N	1.3	46	27	22	90	4.8
III Organic Reduced (BEN)	F5 center	1.3	51	31	22	95	4.7
III Organic Reduced (BEN)	F2b	2.1	62	39	28	110	4.7
III Organic Reduced (BEN)	F3	1.9	76	42	27	113	4.5
III Organic Reduced (BEN)	F4c east	2.1	89	42	32	137	4.5
III Organic Reduced (BEN)	F4c west	2.3	68	50	37	162	4.6
III Organic Control (WS)	Shed S	1.6	62	33	21	72	4.5
III Organic Control (WS)	Shed N	2.4	79	53	26	77	4.6
III Organic Control (WS)	Center	2.6	85	72	36	122	4.3
III Organic Control (WS)	Pump N	2.3	83	39	26	74	4.3
III Organic Control (WS)	Pump S	2.2	86	39	30	90	4.5

Phosphorus project soil analysis data
Samples collected Nov 2004

ID	Location	organic matter percent	Bray P ppm	K ppm	Mg ppm	Ca ppm	soil pH
I Organic Control (PV)	C1b	3	75	68	48	187	4.4
I Organic Control (PV)	C2a north	2.3	85	62	34	125	4.4
I Organic Control (PV)	C2A south	3.9	118	75	36	139	4.3
I Organic Control (PV)	C4	3.4	74	86	39	145	4.4
I Organic Control (PV)	C1a	3.6	63	97	48	116	4.5
I Organic Control (PV)	C2c	3.8	116	78	38	112	4.2
I Organic Control (PV)	C3a-b	3.2	113	59	39	177	4.2
I Organic Reduced (EH)	K9 N	2.8	98	58	31	120	4.4
I Organic Reduced (EH)	K9 center	3.6	63	67	56	283	4.3
I Organic Reduced (EH)	K9 S	3.2	82	87	44	143	4.3
I Organic Reduced (EH)	K6 W	3.9	65	71	50	219	4.6
I Organic Reduced (EH)	K6 N cent.	3.9	68	70	32	125	4.5
I Organic Reduced (EH)	K6 S	3.8	72	75	46	178	4.1
I Organic Reduced (EH)	K2 E	4.6	73	72	59	278	4.3
I Organic Reduced (EH)	K7b N	4.6	26	80	49	211	4.3
I Organic Reduced (EH)	K7b N cent.	3.8	42	78	42	175	4.5
I Organic Reduced (EH)	K7b S cent.	3.4	60	73	35	142	4.3
I Organic Reduced (EH)	K7b S	4	40	62	34	120	4.3
I Organic Reduced (EH)	K8	4.7	105	71	45	121	4.2
I Organic Reduced (EH)	K20	0.8	76	31	17	74	4.8
II Mineral Reduced (Kelseys)	W	1.9	97	60	30	125	4.7
II Mineral Reduced (Kelseys)	E	1.6	71	60	27	104	4.7
II Mineral Reduced (Mikeys)	S	1.2	71	47	31	133	5
II Mineral Reduced (Mikeys)	N	1.9	80	78	32	130	4.7
II Mineral Control (Ashleys)	S	1.8	74	54	29	107	4.8
II Mineral Control (Ashleys)	W	2.7	93	67	28	106	4.7
II Mineral Control (Ashleys)	Center	2.5	109	60	29	116	4.7
II Mineral Control (Ashleys)	E	3	118	76	32	122	4.6
III Organic Reduced (BEN)	F1 N	3.7	73	54	24	120	4.5
III Organic Reduced (BEN)	F1 center	3.3	75	54	22	106	4.7
III Organic Reduced (BEN)	F5 N	2.6	75	35	24	132	4.4
III Organic Reduced (BEN)	F5 center	3.9	70	55	29	132	4.6
III Organic Reduced (BEN)	F4c E	4.1	78	68	36	175	4.9
III Organic Reduced (BEN)	F4c W	2.9	92	52	31	152	4.7
III Organic Control (WS)	Shed S	4.1	81	54	27	106	4.5
III Organic Control (WS)	Shed N	3.4	86	49	24	91	4.6
III Organic Control (WS)	Pump N	4.3	110	72	26	85	4.3
III Organic Control (WS)	Pump S	4.5	104	60	33	100	4.4

Phosphorus Project Samples collected August 2004
Plant tissue analysis

Location	Section	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Fe (ppm)	Mn (ppm)	B (ppm)	Cu (ppm)	Zn (ppm)
I Organic Control (PV)	C2a	1.03	0.11	0.52	0.19	0.70	72	179	32	120	27
I Organic Control (PV)	C4	1.33	0.16	0.50	0.25	1.03	96	515	50	5	46
I Organic Control (PV)	C1b	1.00	0.12	0.55	0.20	0.78	92	206	47	5	22
I Organic Reduced (EH)	K6a	1.10	0.11	0.53	0.20	0.73	40	292	23	90	26
I Organic Reduced (EH)	K6b	1.16	0.13	0.51	0.23	0.83	67	505	31	6	25
I Organic Reduced (EH)	K7b	0.90	0.11	0.46	0.20	0.90	83	411	31	5	30
I Organic Reduced (EH)	K8a	1.26	0.17	0.68	0.21	0.64	51	255	27	6	29
I Organic Reduced (EH)	K9	1.43	0.15	0.62	0.18	0.67	74	422	27	5	31
I Organic Reduced (EH)	K20	1.09	0.12	0.46	0.26	0.64	143	455	51	5	24
II Mineral Reduced (Kelseys)	K19	1.42	0.15	0.50	0.26	0.79	183	515	37	4	36
II Mineral Reduced (Mikeys)	K16	1.23	0.13	0.46	0.22	0.86	257	460	43	4	28
II Mineral Control (Ashleys)	K14	1.15	0.15	0.40	0.25	0.92	150	478	42	6	39
III Organic Reduced (BEN)	F1	0.89	0.11	0.49	0.20	0.72	63	517	25	4	15
III Organic Reduced (BEN)	F4e	1.05	0.13	0.54	0.20	0.61	50	218	24	5	19
III Organic Reduced (BEN)	F5	0.96	0.11	0.45	0.21	0.81	119	818	31	3	20
III Organic Control (WS)	C1	1.03	0.12	0.50	0.19	0.57	37	155	23	4	19

Soil analyses
Westport wetland site
Spring 2005

Sample	organic matter percent	Bray P ppm	K ppm	Mg ppm	Ca ppm	soil pH
WPD-1	10.6	17	175	135	439	3.9
WPD-2	6.7	8	93	41	124	4
WPD-3	7.4	10	81	54	167	4.1
WPD-4	7.2	6	93	37	95	4.1
WPU-1	6.7	9	81	49	119	4
WPU-2	6.8	11	76	36	82	4
WPU-3	7.6	13	118	96	403	4.1
WPU-4	6.4	11	63	33	92	4.2

QC data Field duplicates/blanks

WPD-4	7.2	6	93	37	95	4.1
WPD-4 DUP	7.4	7	104	36	93	4.1
WPU-1	6.7	9	81	49	119	4
WPU-1 DUP	6.5	11	82	50	121	4

APPENDIX 5.
Yield at bog sites

				Yield (bbl/a)			
		Acres	**2000**	**2001**	**2002**	**2003**	**2004**
Pair 1 Pierceville	org- control	45.0	175	141	117	119	195
Eagle Holt	org -reduced	63.3	155	104	117	119	172
Pair 2 Ashleys	Min-control	4.8	182	220	65	150	277
KelseyMikeys	Min-reduced	5.5	267	153	221	136	218
Pair 3 White Spring	org-control	7.6	205	154	62	159	42
Benson Pond	org-reduced	24.0	127	117	144	121	144

Bog site yield analysis. Yield in bbl/a.

	5 year average (2000-2004)	2 years pre change (2001-2002)	2 years of reduced P (2003-2004)	% change from pre-reduction*
#1 Control	149	129	158	+22
#1 Reduced	133	111	146	+32
#2 Control	179	143	214	+50
#2 Reduced	199	187	178	-5
* *#3Control	124	108	101	-6
* *#3 Reduced	131	131	133	+2

*Compare the 2 reduced years (2003-2004) to the 2 previous years.

**Note that this pair had virtually no differential in P applied (both reduced 20% in 2003 and 2004).

Summary - yield and fertilizer use at bog sites.

Location	Year	Size (acres)	Yield (bbl/a)	N (lb/a)	P (lb/a)
#1 Control	2000	45.0	175		
Pierceville	2001		141	32.1	29.3
Organic soil	2002		117	34.8	19.3
	2003		119	32.9	22.9
	2004		195	36.3	17.3
#1 Reduced P	2000	63.3	155		
Eagle Holt	2001		104	17.7	12.5
Organic soil	2002		117	30.8	18.0
	2003		119	32.6	14.6
	2004		172	29.6	5.7
#2 Control	2000	4.8	182		
Ashley's	2001		220	36.3	31.7
Mineral soil	2002		65	45.6	28.4
	2003		150	40.0	32.8
	2004		277	47.0	27.9
#2 Reduced P	2000	5.5	267		
Mikey/Kelsey	2001		153	60.4	27.8
Mineral soil	2002		221	60.8	29.3
	2003		138	33.9	20.3
	2004		218	54.4	21.3
#3 Control	2000	7.6	205		
White Springs	2001		154	19.0	8.3
Organic soil	2002		62	42.5	20.3
	2003		159	37.5	18.7
	2004		42**	27.0	11.8
#3 Reduced P	2000	24.0	127		
Bensons Pond	2001		117	19.0	8.3
Organic soil	2002		144	42.5	20.3
	2003		121	37.5	16.4
	2004		144	27.0	11.8

**severe winterkill followed by fireworm infestation

APPENDIX 6.
Cranberry field experiments with phosphorus rate -- data tables.

Plot locations were established and fertilizers applied according to the schedule in the approach section. Yield and analytical data are shown below. As some locations were lost due to grower interference, others were added (see data tables).

Table A6-1. Plot yields -- years 2000-2004. P rate series. Data are means of 5 replicates.

	Yield (bbl/a)							
	Location 1		Location 2			Location3		
P rate (kg/ha)	***2000*****	***2001***	***2000***	***2001***	***2002***	***2000***	***2001***	***2002***
0	169	147	239	163	79	344	113	222
2.8	132	79	212	146	94	304	93	219
5.6	119	112	263	94	56	326	80	183
11.2	96	80	230	187	93	274	91	244
16.8	97	107	247	150	93	307	95	191
22.4	113	70	278	123	118	343	68	224
33.6	90	80	253	125	69	339	81	193

** Yield = 139 - 1.92 * P rate. (p=0.0237; r^2=0.12)

	Yield (bbl/a)	
	Location 4	
P rate (kg/ha)	***2003***	***2004***
0	61	254
2.6	78	165*
5.6	72	174
11.2	72	171
16.8	72	147*
22.4	74	166*
33.6	76	176

*Significantly different from 0 kg/ha by Dunnett's test; alpha set at 0.05.

Table A6-2. Plot yields -- years 2000-2004. N:P ratio variation. Data are means of 5 replicates.

			Yield (bbl/a)					
			Location 1		Location 2			
N:P ratio	P form	P rate (kg/ha)	***2000***	***2001***	***2000***	***2001***	***2002***	***2003***
no N or P	none	0	301	86	147*	238	258	317
1:0	none	0	248	93	***278***	283	***202***	258
1:1	blend	22.4	270	134	196	350	221	258
2:1	blend	11.2	320	113	165*	280	195	274
1:1	TSP	22.4	246	106	165*	270	204	301
2:1	TSP	11.2	270	123	177	270	202	237
4:1	TSP	5.6	274	115	138*	344	224	278
2:1	foliar	11.2	261	129	194	303	207	240
5:1	foliar	5.6	256	124	191	318	272	197
2:1	TSP/foliar	11.2	229	169	174*	255	295*	270

			Yield (bbl/a)				
			Location 3			Location 4	
N:P ratio	P form	P rate (kg/ha)	***2001***	***2002***	***2003***	***2003***	***2004***
no N or P	none	0	73	165*	227	141	28*
1:0	none	0	101	***296***	218	183	***105***
1:1	blend	22.4	95	271	278	167	83
2:1	blend	11.2	103	251	276	181	141
1:1	TSP	22.4	106	253	271	157	116
2:1	TSP	11.2	83	276	213	136	134
4:1	TSP	5.6	136	319	278	215	129
2:1	foliar	11.2	119	216	204	128	85
5:1	foliar	5.6	96	276	220	144	95
2:1	TSP/foliar	11.2	99	259	88	184	100

*Different from 0 P control (second row) by Dunnett's test, alpha set at 0.05.
No significant regression relationships.

Table A6-3. Soil tests. P rate series. Data are means of 3 replicates.

	Soil test - Bray P (ppm)						
	Location 1	Location 2		Location 3		Location 4	All Locations
P rate (kg/ha)	***Year 1***	***Year 1***	***Year 3***	***Year 1***	***Year 3***	***Year 2***	***mean***
0	59	31	62	31	49	68	50
2.8	61	34	62	51	50	70	55
5.6	56	38	66	39	50	77	54
11.2	63	32	83	46	65	75	61
16.8	61	53	73	39	46	82	59
22.4	51	37	71	46	58	78	57
33.6	66	42	69	48	65	98	65

Years and Locations combined (no interaction with treatment). Soil test P = 53.8 + 0.33 * P rate (p=0.0384, r2 = 0.03).

Table A6-4. Tissue tests.   P rate series. Data are means of 3 replicates.

	Tissue test						
	Location 1	Location 2			Location 3		
P rate (kg/ha)	***Year 1 - P (%)***	***Year 1 - P (%)***	***Year 3 - P (%)***	***Year 3 (Zn ppm)***	***Year 1 - P (%)***	***Year 3 - P (%)***	***Year 3 (Zn ppm)***
0	0.10	0.12	0.16	32	0.13	0.16	30
2.8	0.11	0.11	0.15	29	0.14	0.16	35
5.6	0.11	0.11	0.17	27	0.12	0.16	33
11.2	0.11	0.11	0.15	30	0.15	0.18	35
16.8	0.12	0.12	0.13	29	0.15	0.17	32
22.4	0.12	0.12	0.17	30	0.15	0.17	32
33.6	0.13	0.14	0.16	28	0.16	0.16	30

	Tissue test			
	Location 4			
P rate (kg/ha)	***Year 1 - P (%)***	***Year 1 (Zn ppm)***	***Year 2 - P (%)***	***Year 2 (Zn ppm)***
0	0.10	29	0.12	22
2.8	0.11	31	0.11	19
5.6	0.10	29	0.11	19
11.2	0.10	29	0.11	21
16.8	0.12	34	0.12	20
22.4	0.11	38	0.13	20
33.6	0.11	34	0.13	20

Years and Locations combined (no interaction with treatment). Tissue P = 0.128 + 0.0006 * P rate; *p*=0.0096, r2 = 0.05.

Table A6-5. Soil tests. N:P ratio variation. Data are means of 3 replicates.

			Soil test - Bray P (ppm)			
			Location 1	Location 2		
N:P ratio	P form	P rate (kg/ha)	***Year 1***	***Year 1***	***Year 3***	***Year 4***
no N or P	none	0	29	66	82	71
1:0	none	0	29	61	57	78
1:1	blend	22.4	29	60	97	77
2:1	blend	11.2	30	72	93	58
1:1	TSP	22.4	36	72	80	59
2:1	TSP	11.2	34	54	79	61
4:1	TSP	5.6	28	64	75	62
2:1	foliar	11.2	33	67	80	83
5:1	foliar	5.6	31	64	84	74
2:1	TSP/foliar	11.2	34	65	88	69

			Soil test - Bray P (ppm)				
			Location 3			Location 4	**All locations**
N:P ratio	P form	P rate (kg/ha)	***Year 1***	***Year 2***	***Year 3***	***Year 2***	***mean***
no N or P	none	0	73	73	47	117	70
1:0	none	0	65	79	59	112	***68***
1:1	blend	22.4	61	98	55	128	76*
2:1	blend	11.2	61	83	44	119	70
1:1	TSP	22.4	72	96	51	144	76*
2:1	TSP	11.2	65	78	49	135	69
4:1	TSP	5.6	56	72	55	110	65
2:1	foliar	11.2	56	70	50	117	70
5:1	foliar	5.6	57	72	48	103	67
2:1	TSP/foliar	11.2	62	83	53	125	72

Years and Locations combined (no interaction with treatment).

*Different from 0 P control (second row) by Dunnett's test, alpha set at 0.05.

Table A6-6. Tissue tests. N:P ratio variation. Data are means of 3 replicates.

			Tissue test					
			Location 1	Location 2				
N:P ratio	P form	P rate (kg/ha)	***Year 1 - P (%)***	***Year 1 - P (%)***	***Year 3 - P (%)***	***Year 3 - Zn (ppm)***	***Year 4 - P (%)***	***Year 4 - Zn (ppm)***
no N or P	none	0	0.14	0.21	0.19	38	0.15	33
1:0	none	0	0.14	0.18	***0.17***	33	***0.15***	34
1:1	blend	22.4	0.13	0.21	0.21*	37	0.17*	36
2:1	blend	11.2	0.15	0.19	0.20	38	0.16	35
1:1	TSP	22.4	0.15	0.20	0.21*	42	0.17*	36
2:1	TSP	11.2	0.15	0.20	0.19	34	0.16	35
4:1	TSP	5.6	0.13	0.18	0.19	37	0.15	37
2:1	foliar	11.2	0.15	0.18	0.17	35	0.16	35
5:1	foliar	5.6	0.14	0.20	0.18	34	0.16	32
2:1	TSP/foliar	11.2	0.12	0.20	0.19	34	0.16	33

			Tissue test					
			Location 3					
N:P ratio	P form	P rate (kg/ha)	***Year 1 - P (%)***	***Year 1 - Zn (ppm)***	***Year 2 - P (%)***	***Year 2 - Zn (ppm)***	***Year 3 - P (%)***	***Year 3 - Zn (ppm)***
no N or P	none	0	0.10	23	0.12	31	0.12	31
1:0	none	0	***0.09***	21	***0.12***	28	***0.10***	22
1:1	blend	22.4	0.10*	20	0.16*	30	0.13*	24
2:1	blend	11.2	0.11	19	0.14	27	0.11	24
1:1	TSP	22.4	0.10	21	0.14	29	0.11	25
2:1	TSP	11.2	0.10	21	0.12	24	0.11	27
4:1	TSP	5.6	0.09	23	0.12	28	0.11	21
2:1	foliar	11.2	0.10	22	0.11	29	0.11	24
5:1	foliar	5.6	0.10	21	0.13	27	0.11	23
2:1	TSP/foliar	11.2	0.11	21	0.14	25	0.11	22

*Different from 0 P control (second row) by Dunnett's test, alpha set at 0.05.

Table A6-6. Tissue tests, continued. N:P ratio variation. Data are means of 3 replicates.

			Tissue test			
			Location 4			
N:P ratio	P form	P rate (kg/ha)	***Year 1 - P (%)***	***Year 1 - Zn (ppm)***	***Year 2 - P (%)***	***Year 2 - Zn (ppm)***
no N or P	none	0	0.15	35	0.15	26
1:0	none	0	***0.14***	31	***0.12***	25
1:1	blend	22.4	0.17*	32	0.17*	28
2:1	blend	11.2	0.16*	32	0.15*	27
1:1	TSP	22.4	0.17*	42	0.15*	28
2:1	TSP	11.2	0.14	32	0.13	28
4:1	TSP	5.6	0.15	33	0.13	24
2:1	foliar	11.2	0.15	30	0.14	29
5:1	foliar	5.6	0.15	29	0.13	24
2:1	TSP/foliar	11.2	0.14	32	0.15	29

*Different from 0 P control (second row) by Dunnett's test, alpha set at 0.05.

APPENDIX 7.
Quality assurance plan, reporting

A Quality Assurance Project Plan was prepared and approved by DEP and EPA. A copy of this plan is on file at the Division of Watershed Management, Department of Environmental Protection, 627 Main Street, Worcester MA, 01608.

Below is a Technical Memorandum from the Project QC Director regarding QA/QC results through 2004:

************************* Technical Memorandum ********************************

To: Carolyn DeMoranville, Director Cranberry Experiment Station.
From: David White, Coastal Systems Program SMAST
Brian Howes, Coastal Systems Program SMAST
Date: February 14, 2005
RE: QA/QC results for DEP Cranberry Bog N/P Project

The Coastal Systems Analytical Facility (SMAST) has been supporting the Cranberry Experiment Station (CES) effort to determine the net flux of nitrogen and phosphorus from cranberry bogs and a natural wetland systems in Westport, MA. The project has operated under a Quality Assurance Project Plan (QAPP), with sampling by CES staff and chemical analysis by SMAST. Data review and synthesis has been lead by the Project Leader, Dr. DeMoranville, with support from SMAST Staff, Drs. White and Howes.

As part of the analytical activity, we have reviewed relevant aspects of the QAPP for comparison to the resultant field and laboratory program. The results of this QA/QC review are presented below:

1. Holding Times - Holding times are critical for sample integrity. Cross checks of Chain of Custody forms indicate that all samples were transported to the SMAST Facility within specified holding times and arrived in appropriate containers.

2. Preservatives applied - Where indicated in the QAPP, preservatives were added to the appropriate samples prior to storage.

3. COC maintained - All chain of Custody forms have been maintained in a binder dedicated to the project, with updates conducted with the arrival of each new sample series.

4. Blanks - All analytical runs for each analyte include a “laboratory blank”, consisting of MilliQ water. The results of these blanks represent the level of “contamination” within the reagents, glassware and dilution water used in the assays. In all cases the laboratory blank was small relative to the signal and was accounted for in the reported results.

“Field blanks” were sent to the SMAST Facility by the CES field team with field samples. These field blanks consisted of MilliQ water added to sample bottles and transported to the field site and then to SMAST for analysis. The MilliQ water was treated a sample in the field, i.e. filtered or unfiltered, as appropriate (Table 1).

Table 1. Results of analysis of field blanks.

Date	uM PO4	uM TP	uM NH4	uM NO3	uM TDN
3/11/2002		0.6			
4/25/2002	<0.1	0.1	0.2	<0.05	3.33
6/24/2002	<0.1	<0.1	0.5	0.13	5.69
8/19/2002	0.1	0.1	1.8	0.34	14.88
10/23/2002	0.6	0.7	0.9	0.27	9.02
11/21/2002		0.5		0.36	4.25
5/7/2003	0.1	0.1	4.4	0.18	13.02
7/22/2003	<0.1		9.5		
10/3/2003	<0.1		0.5	0.08	4.23
6/4/2004	<0.1	0.2	2.0	0.17	18.42
08/18/04	0.1	0.1	1.8	0.10	9.21
Mean	**0.1**	**0.3**	**2.4**	**0.2**	**9.1**
MDL	0.1	0.1	0.1	0.05	0.05

In general the field blanks were low for the inorganic assays, but elevated for the organic assays. However the ammonium levels were highly variable and sometimes elevated. Relative to ammonium and organic nutrients the most likely explanation stems from the storage of the MilliQ, used in the field blanks, at CES for various periods as it was used and replenished from the SMAST system. It is a common occurrence that ammonium will increase in distilled water held in the laboratory environment and even in the vessels associated with stills. The high organic levels may result from microbial growth in translucent bottles held in the laboratory over extended periods. These explanations are supported by the fact that MilliQ assayed in the laboratory, filtered and unfiltered is at background levels. MilliQ held in sample bottles set up in the laboratory show similarly low levels.

5. Analytical Duplicates - Duplicate assays were run on more than 10% of the delivered samples. All laboratory duplicates were within the 20% RPD limit specified within the QAPP . This is not surprising, as it is required for data acceptance at the time of assay. If samples ever fail to meet this criterion, they are re-analyzed.

6. Field Duplicates - True field duplicates are sampled collected as a split, i.e. sample water is collected simultaneously from the same parcel of water. The duplicates collected in the present effort were collected at the same location, but sequentially (2 separate samples collected at the same site within a short time of each other). Therefore, differences between the replicates, includes both analytical, sampling and some spatial/temporal variation. Even so, the replicate field sample data generally fell within the ±20% RPD specified in the QAPP at levels > 1 uM (Tables 2 and 3).

Table 2. "Duplicate" field samples*. RPD of duplicate samples taken at CES sites 2002-2004. Low/High indicates values were less/greater than 1.0 uM, as the detection limit is approached the RPD increases (as expected).

Date		uM PO4		uM TP		uM NH4		uM NO3		uM TDN
3/11/2002	High	**0.90%**	High	**0.70%**	Low	**30.40%**	Low	**10.20%**	High	**0.10%**
6/24/2002	Low	**2.30%**	Low	**3.40%**	Low	**78.30%**	Low	**24.30%**	High	**5.00%**
8/19/2002	Low	**3.40%**	Low	**45.00%**	Low	**3.60%**	Low	**34.50%**	High	**40.60%**
10/23/2002	High	**11.80%**	High	**8.50%**	Low	**13.20%**	High	**0.60%**	High	**9.60%**
11/8/2002	High	**3.50%**	High	**2.90%**	High	**5.80%**	High	**9.00%**	High	**8.50%**
4/25/2002	Low	**0.00%**	Low	**1.80%**	Low	**27.10%**	High	**5.80%**	High	**14.30%**
11/21/2002	NA	**ND**	Low	**36.80%**	NA	**ND**	High	**2.20%**	High	**4.70%**
5/7/2003	Low	**24.80%**	Low	**7.70%**	High	**16.60%**	High	**0.30%**	High	**2.50%**
7/22/2003	Low	**47.70%**	Low	**69.20%**	Low	**47.40%**	Low	**29.70%**	High	**18.90%**
10/3/2003	Low	**31.90%**	Low	**0.80%**	High	**5.00%**	Low	**54.70%**	High	**3.50%**
6/4/2004	High	**11.60%**	High	**ND**	High	**12.30%**	Low	**6.00%**	High	**41.10%**
8/18/2004	Low	**49.40%**	Low	**5.30%**	Low	**72.50%**	Low	**0%**	High	**62.80%**

* Field "duplicates" were not "true", but were sequential samples from the same site.

Table 3. Average absolute differences and RPD of field duplicate samples taken at CES sites 2002-2004. Low/High indicates values were less/greater than 1.0 uM, as the detection limit is approached the RPD increases (as expected).

	uM PO4		uM TP		uM NH4		uM NO3		uM TDN	
	ABS DIFF	RPD	ABS DIFF	RPD	ABS DIFF	RPD	ABS DIFF	RPD	ABS DIFF	RPD
Low Ave. (<1 uM)	0.06	22.8%	0.5	21.3%	0.8	38.9%	0.2	22.8%	ND	ND
High Ave. (>1 uM)	0.27	7.0%	0.2	4.0%	0.8	10.0%	0.6	3.6%	8.1	17.6%

Below is a Technical Memorandum from the Project QC Director regarding QA/QC results for 2005:
****************************** Technical Memorandum********************************
To: Carolyn DeMoranville, Director Cranberry Experiment Station.
From: David White, Coastal Systems Program SMAST
Brian Howes, Coastal Systems Program SMAST
Date: July 11, 2005
RE: 2005 QA/QC results for DEP Cranberry Bog N/P Project
****

The Coastal Systems Analytical Facility (SMAST) has been supporting the Cranberry Experiment Station (CES) effort to determine the net flux of nitrogen and phosphorus from cranberry bogs and a natural wetland systems in Westport, MA. The project has operated under a Quality Assurance Project Plan (QAPP), with sampling by CES staff and chemical analysis by SMAST. Data review and synthesis has been lead by the Project Leader, Dr. DeMoranville, with support from SMAST Staff, Drs. White and Howes.

As part of the analytical activity, we have reviewed relevant aspects of the QAPP for comparison to the resultant field and laboratory program. Overall the limits specified in the QAPP appear to have been generally met and therefore the dataset should move to the next level of data analysis and synthesis. Limitations primarily were related to the number of field duplicates conducted and apparent problems with the conduct of the field blanks. The specific results of this QA/QC review are presented below:

1. Holding Times - Holding times are critical for sample integrity. Cross checks of Chain of Custody forms indicate that all samples were transported to the SMAST Facility within specified holding times and arrived in appropriate containers.

2. Preservatives applied - Where indicated in the QAPP, preservatives were added to the appropriate samples prior to storage.

3. COC maintained - All chain of Custody forms have been maintained in a binder dedicated to the project, with updates conducted with the arrival of each new sample series.

4. Blanks - All analytical runs for each analyte include a “laboratory blank”, consisting of MilliQ water. The results of these blanks represent the level of “contamination” within the reagents, glassware and dilution water used in the assays. In all cases the laboratory blank was small relative to the signal and was accounted for in the reported results.

“Field blanks” were sent to the SMAST Facility by the CES field team with field samples. These field blanks consisted of acid washed bottles sent to SMAST where reagent grade MilliQ water was added. The MilliQ water was treated as a sample and analyzed as appropriate (Table 1).

Table 1. Results of Analysis of Field Blanks

Date	uM PO4	uM TP	uM NH4	uM NO3	uM TDN
2/24/2005	<0.1	NS	<0.1	0.09	4.09
4/20/2005	<0.1	NS	<0.1	0.05	8.81
2/24/2005	<0.1	NS	<0.1	0.08	3.65
4/20/2005	<0.1	NS	<0.1	0.05	3.49
4/20/2005	<0.1	NS	<0.1	<0.05	1.50
5/12/2005	<0.1	NS	<0.1	0.05	1.54
5/12/2005	<0.1	NS	<0.1	0.05	2.70
5/12/2005	<0.1	NS	<0.1	0.08	4.12
5/12/2005	<0.1	NS	<0.1	<0.05	0.97
2/17/2005	<0.1	NS	<0.1	0.08	2.58
3/4/2005	<0.1	NS	<0.1	0.25	3.93
Mean	**0.1**	**ND**	**0.1**	**0.07**	**3.40**
MDL	**0.1**	**0.1**	**0.1**	**0.05**	**0.05**

Field blanks were low or below detection for the inorganic assays, but elevated for TDN. The most likely explanation for high TDN field blanks is that the digestion tubes were not pre-digested before being run due to the fact that TDN concentrations are high from the bog samples and blank values are 10% or less on average of sample values.

5. Analytical Duplicates - Duplicate assays were run on more than 10% of the delivered samples. All laboratory duplicates were within the 20% RPD limit specified within the QAPP. This is not surprising, as it is required for data acceptance at the time of assay. If samples ever fail to meet this criterion, they are re-analyzed.

6. Field Duplicates - True field duplicates are samples collected as a split, i.e. sample water is collected simultaneously from the same parcel of water. The duplicates collected in the present effort were collected at the same location, but as 2 separate samples collected at the same site within a short time of each other or at the same time but in different containers. Therefore, differences between the replicates, includes both analytical, sampling and some spatial/temporal variation. Even so, the replicate field sample data generally fell within the ±20% RPD specified in the QAPP for each analyte wihen concentrations were > 1 uM (Tables 2 and 3). This is typically the case for environmental samples, given that as one approaches the detection limit, small absolute differences between sample become larger and larger percent differences. The results of the ammonium analysis are an excellent example of this effect. An average absolute difference of 0.39 uM resulted in an RPD of 32.3% in the samples less than 1 uM, whereas at concentrations >1 uM, an average absolute difference of 0.74 uM resulted in only a 15.2% RPD.

Table 2. RPD of duplicate samples taken at CES sites 2002-2004. Low/High indicates values were less/greater than 1.0 uM.

Date		uM PO4		uM TP		uM NH4		uM NO3		uM TDN		mg/L POC		mg/L PON		(ug/L) CHl-a		(ug/L) Phaeo
4/20/2005	LOW	**0.0%**	HIGH	**1.2%**	HIGH	**1.2%**	HIGH	**0.6%**	HIGH	**14.6%**	HIGH	**3.2%**	HIGH	**0.8%**				
4/20/2005	LOW	**42.9%**	HIGH	**0.9%**	HIGH	**3.3%**	HIGH	**0.1%**	HIGH	**19.1%**	HIGH	**0.6%**	HIGH	**5.4%**				
5/11/2005	LOW	**13.7%**	HIGH	**0.1%**	HIGH	**5.3%**	HIGH	**3.0%**	HIGH	**6.5%**	HIGH	**0.1%**	HIGH	**0.6%**				
4/20/2005	LOW	**14.3%**	HIGH	**2.3%**	HIGH	**9.2%**	LOW	**5.8%**	HIGH	**9.4%**	HIGH	**1.2%**	HIGH	**1.1%**				
4/20/2005	LOW	**14.3%**	HIGH	**4.6%**	LOW	**43.5%**	LOW	**16.0%**	HIGH	**20.1%**	HIGH	**8.5%**	HIGH	**9.4%**				
5/11/2005	LOW	**4.3%**	LOW	**3.6%**	LOW	**25.9%**	LOW	**23.8%**	HIGH	**28.2%**	HIGH	**4.2%**	HIGH	**7.3%**				
4/20/2005	LOW	**0.0%**	HIGH	**2.6%**	LOW	**11.5%**	LOW	**0.5%**	HIGH	**8.1%**	HIGH	**27.2%**	HIGH	**25.9%**				
4/20/2005	LOW	**0.0%**	HIGH	**0.4%**	LOW	**15.0%**	LOW	**0.7%**	HIGH	**10.1%**	HIGH	**20.6%**	HIGH	**21.1%**				
4/20/2005	LOW	**14.3%**	HIGH	**0.3%**	LOW	**34.3%**	LOW	**5.6%**	HIGH	**6.1%**	HIGH	**12.7%**	HIGH	**11.6%**				
4/20/2005	LOW	**0.0%**	HIGH	**21.1%**	LOW	**15.0%**	LOW	**1.9%**	HIGH	**40.2%**	HIGH	**19.4%**	HIGH	**22.0%**				
5/11/2005	LOW	**0.0%**	HIGH	**10.4%**	LOW	**12.1%**	LOW	**15.7%**	HIGH	**1.1%**	HIGH	**4.3%**	HIGH	**5.8%**				
4/20/2005	LOW	**20.0%**	HIGH	**15.2%**	LOW	**7.9%**	LOW	**10.2%**	HIGH	**23.2%**	HIGH	**1.6%**	HIGH	**0.1%**				
4/20/2005	LOW	**20.0%**	HIGH	**7.0%**	LOW	**18.0%**	LOW	**14.9%**	HIGH	**4.3%**	HIGH	**0.9%**	HIGH	**3.4%**				
4/20/2005	LOW	**11.1%**	HIGH	**8.4%**	LOW	**28.7%**	LOW	**19.7%**	HIGH	**6.1%**	HIGH	**4.6%**	HIGH	**5.5%**				
5/11/2005	LOW	**16.7%**	HIGH	**13.1%**	HIGH	**40.9%**	HIGH	**12.0%**	HIGH	**15.3%**	HIGH	**8.2%**	HIGH	**7.8%**				
4/13/2005	LOW	**0.0%**	LOW	**35.3%**	LOW	**66.4%**	LOW	**2.1%**	HIGH	**26.8%**	HIGH	**31.3%**	HIGH	**24.5%**				
4/13/2005	LOW	**0.0%**	LOW	**14.6%**	LOW	**29.5%**	LOW	**5.3%**	HIGH	**25.6%**	HIGH	**1.1%**	HIGH	**6.3%**				
4/13/2005	LOW	**0.0%**	LOW	**12.3%**	LOW	**52.0%**	LOW	**32.5%**	HIGH	**26.4%**	HIGH	**16.1%**	HIGH	**13.0%**				
4/13/2005	LOW	**0.0%**	LOW	**16.6%**	LOW	**66.4%**	LOW	**42.9%**	HIGH	**39.3%**	HIGH	**19.3%**	HIGH	**14.9%**				
5/11/2005	LOW	**14.3%**	HIGH	**3.8%**	LOW	**12.5%**	LOW	**2.8%**	HIGH	**9.6%**	ND		ND					
4/13/2005	LOW	**0.0%**	LOW	**1.2%**	LOW	**66.0%**	LOW	**3.4%**	HIGH	**9.4%**	HIGH	**7.0%**	HIGH	**4.1%**				
4/13/2005	HIGH	**2.5%**	HIGH	**1.2%**	LOW	**9.5%**	LOW	**2.5%**	HIGH	**1.9%**	HIGH	**10.3%**	HIGH	**12.2%**				
5/11/2005	HIGH	**1.8%**	HIGH	**0.1%**	LOW	**3.3%**	LOW	**0.0%**	HIGH	**1.1%**	HIGH	**0.0%**	HIGH	**2.1%**				
4/13/2005	LOW	**6.6%**	HIGH	**6.0%**	HIGH	**23.2%**	HIGH	**15.8%**	HIGH	**17.3%**	HIGH	**40.0%**	HIGH	**38.1%**				
5/11/2005	HIGH	**10.7%**	HIGH	**0.8%**	HIGH	**21.2%**	HIGH	**0.7%**	HIGH	**12.6%**	HIGH	**0.0%**	HIGH	**0.0%**				
4/13/2005	LOW	**20.0%**	LOW	**7.7%**	LOW	**34.5%**	LOW	**14.0%**	HIGH	**12.1%**	ND		ND					
5/11/2005	LOW	**14.4%**	HIGH	**0.6%**	LOW	**41.2%**	LOW	**46.8%**	HIGH	**25.5%**	HIGH	**12.8%**	HIGH	**15.3%**				
2/11/2005	LOW	**6.7%**	LOW	**12.9%**	HIGH	**20.5%**	HIGH	**1.9%**	HIGH	**4.7%**	ND		ND		LOW	**41.7%**	LOW	**40.0%**
2/17/2005	LOW	**0.0%**	HIGH	**19.5%**	HIGH	**22.5%**	HIGH	**11.1%**	HIGH	**9.5%**	HIGH	**16.3%**	HIGH	**18.0%**	HIGH	**5.4%**	HIGH	**17.8%**
2/11/2005	LOW	**0.0%**	LOW	**2.6%**	LOW	**81.5%**	HIGH	**10.1%**	HIGH	**38.6%**	HIGH	**5.1%**	HIGH	**3.2%**	LOW	**41.2%**	LOW	**61.7%**
2/17/2005	LOW	**0.0%**	LOW	**5.0%**	HIGH	**19.1%**	LOW	**3.4%**	HIGH	**3.3%**	HIGH	**25.6%**	HIGH	**32.6%**	HIGH	**0.4%**	LOW	**85.5%**
2/24/2005	LOW	**0.0%**	LOW	**0.0%**	LOW	**16.3%**	LOW	**4.9%**	HIGH	**7.1%**	HIGH	**63.2%**	HIGH	**63.6%**	HIGH	**7.6%**	LOW	**94.8%**

4/20/2005	LOW	**7.1%**	HIGH	**2.8%**	LOW	**28.1%**	LOW	**29.7%**	HIGH	**50.7%**	HIGH	**43.2%**	HIGH	**42.6%**
4/20/2005	HIGH	**2.6%**	HIGH	**20.1%**	LOW	**6.1%**	LOW	**5.2%**	HIGH	**8.8%**	HIGH	**23.1%**	HIGH	**21.2%**
5/11/2005	HIGH	**5.2%**	HIGH	**0.3%**	HIGH	**1.3%**	LOW	**13.2%**	HIGH	**17.6%**	HIGH	**4.7%**	HIGH	**1.0%**
4/20/2005	LOW	**0.0%**	LOW	**5.6%**	LOW	**43.5%**	LOW	**59.4%**	HIGH	**36.5%**	HIGH	**45.0%**	HIGH	**26.2%**
4/20/2005	LOW	**0.0%**	LOW	**21.3%**	LOW	**58.9%**	LOW	**56.2%**	HIGH	**73.8%**	HIGH	**21.9%**	HIGH	**14.6%**
5/11/2005	LOW	**27.3%**	LOW	**20.3%**	LOW	**9.3%**	LOW	**5.8%**	HIGH	**2.2%**	HIGH	**1.5%**	HIGH	**1.4%**

Table 3. Average absolute differences and RPD of duplicate samples taken at CES sites 2002-2004. Low/High indicates values were less/greater than 1.0 uM.

	uM PO4		**uM TP**		**uM NH4**		**uM NO3**		**uM TDN**		**mg/L POC**		**mg/L PON**		**ug/L CHl-a**		**ug/L Phaeo**	
	ABS DIFF	**RPD**	**ABS DIFF**	**RPD**	**ABS DIFF**	**RPD**	**ABS DIFF**	**RPD**	**ABS DIFF**	**RPD**	**ABS DIFF**	**RPD**	**ABS DIFF**	**RPD**	**ABS DIFF**	**RPD**	**ABS DIFF**	**RPD**
Low Ave. (<1 uM)	0.04	8.1%	0.15	11.4%	0.39	32.3%	0.12	15.3%	ND	ND	ND	ND	ND	ND	0.92	41.5%	0.68	70.5%
High Ave. (>1 uM)	0.11	4.5%	0.34	6.0%	0.74	15.2%	2.17	6.1%	12.63	17.7%	148.96	14.4%	11.71	13.8%	0.19	4.5%	1.20	17.8%

In addition to QA/QC conducted at the SMAST laboratory, QC/QA was conducted for soil samples collected from the bog sites and analyzed at Midwest Laboratories, Inc. The following are QC samples associated with field collections of soil samples. A purchased soil sample with guaranteed analysis (Plant and Soil Analysis Council) was used as a standard reference (SRM).

QC data Spring 2002	**Sample**	**OM**	**Bray P**	**K**	**Mg**	**Ca**	**pH**
I Organic Control (PV)	C1b	2.7	66	76	25	68	4.4
I Organic Control (PV)	C1b duplic.	2.1	53	82	24	75	4.5
QC data Spring 2003							
II Mineral Red. (Kelseys)	K19 E	1.2	72	19	22	106	5.7
II Mineral Red. (Kelseys)	K19 E dup	0.8	68	12	19	81	5.1
I Organic Reduced (EH)	K6 S	2.5	75	40	26	94	4.8
I Organic Reduced (EH)	K6 S (dup)	2.7	65	49	32	118	4.6
III Organic Reduced (BEN)	F4c E	1.8	61	25	22	104	4.8
III Organic Reduced (BEN)	F4c E (dup)	2.4	61	25	27	127	4.9
I Organic Control (PV)	C4	1.4	59	27	20	68	4.7
I Organic Control (PV)	C4 (dup)	2.8	76	44	32	101	4.3
Purchased standard soil	analysis	3.00	44	446	338	1463	5.3
Purchased std. (dup)	duplicate	3.00	43	445	308	1432	5.3
Purchased std. – stated analysis and SD	analysis	2.98	39	344	344	1835	5.5
	SD	0.69	6	81	81	503	0.2
		all within 1 SD except for K					
QC data Fall 2003	Field dups						
II Mineral Reduced (Kelseys)	E	1.6	122	42	31	172	5
II Mineral Reduced (Kelseys)	E dup	1.9	122	38	27	135	4.9
I Organic Reduced (EH)	K6	2.7	91	34	29	106	4.6
I Organic Reduced (EH)	K6 dup	3	119	43	32	111	4.5
I Organic Control (PV)	C1b	1.4	112	26	22	83	4.7
I Organic Control (PV)	C1b dup	1.4	111	27	23	89	4.6
III Organic Reduced (BEN)	F3	2.2	83	34	25	100	4.6
III Organic Reduced (BEN)	F3 dup	2.9	87	35	26	102	4.7
III Organic Control (WS)	Shed S	2.8	78	51	46	260	4.5
III Organic Control (WS)	Shed S dup	3	82	31	27	112	4.8

QC data Spring 2004

		OM	Bray P	K	Ca	Mg	pH
II Mineral Reduced (Kelseys)	E	1.8	73	42	37	126	4.6
II Mineral Reduced (Kelseys)	E dup	2	75	61	37	132	4.6
II Mineral Control (Ashleys)	Center	2.6	74	78	41	124	4.6
II Mineral Control (Ashleys)	Center dup	2.7	75	75	43	124	4.6
I Organic Reduced (E Holt)	K6	3.2	55	59	36	109	4.4
I Organic Reduced (E Holt)	K6 dup	2.2	55	59	35	98	4.3
I Organic Control (PVL)	C1b	2.4	60	63	34	110	4.3
I Organic Control (PVL)	C1b dup	2	66	77	32	100	4.5
III Organic Reduced (Benson)	F3	1.9	76	42	27	113	4.5
III Organic Reduced (Benson)	F3 dup	2	74	33	26	110	4.5
III Organic Control (WS)	Pump N	2.3	83	39	26	74	4.3
III Organic Control (WS)	Pump N dup	2	80	24	28	87	4.2
Purchased standard soil	analysis	2.9	46	455	342	1488	5.3
Purchased std.	duplicate	2.8	44	455	361	1543	5.1
Purchased std. stated	analysis	2.98	39	344	344	1835	5.5
	SD	0.69	6	81	81	503	0.2

QC data Fall 2004

I Organic Control (PVL)	C1b	3	75	68	48	187	4.4
I Organic Control (PVL)	C1b dup	3.8	91	74	37	135	4.3
II Mineral Reduced (Kelseys)	E	1.6	71	60	27	104	4.7
II Mineral Reduced (Kelseys)	E dup	2.2	80	67	38	126	4.6
II Mineral Control (Ashleys)	W	2.7	93	67	28	106	4.7
II Mineral Control (Ashleys)	W dup	2.1	89	61	28	106	4.7
I Organic Reduced (EH)	K6 S	3.8	72	75	46	178	4.1
I Organic Reduced (EH)	K6 S dup	4	87	73	53	206	4
III Organic Reduced (BEN)	F4c E dup	4.1	78	68	36	175	4.9
III Organic Reduced (BEN)	F4c E dup	3.4	100	56	31	152	4.8
III Organic Control (WS)	Shed N	3.4	86	49	24	91	4.6
III Organic Control (WS)	Shed N dup	4.1	91	61	28	93	4.7
Purchased standard soil	analysis	2.5	46	436	319	1593	5.5
Purchased std. stated	stated	2.98	39	344	344	1835	5.5
Purchased std.	SD	0.69	6	81	81	503	0.2

Standard reference samples were analyzed in three of the sample batches. P analyses for the SRM were within 20% of the stated P content in all cases. Deviation in P analysis from duplicate field samples was high in the initial sampling (Spring 2002) and in some of the Spring 2003 samples (>20%). In order to determine if variability was due to duplication methodology, we undertook a duplication study in the summer of 2003. Samples were prepared in two ways -- 1) several cores were taken and placed in a plastic bag, the bag was agitated, and two samples were removed and re-bagged (method previously used); or 2) several cores were taken and placed in a plastic bag, the soil was removed and air dried, then passed through a soil sieve and mixed; two samples were then re-bagged from the mixed soil. The second method resulted in a more homogeneous sample, so that aliquots from the sample gave somewhat less variability between duplicate samples for most analytes (although not for P). Consequently, samples collected beginning with the Fall of 2003 were brought back to the lab, air dried, sieved and mixed prior to sending them to the analytical laboratory. Average deviation among field duplicates for P analysis was <20% for these subsequent samples (tables above).

Phosphorus project soil analysis data
Samples collected Aug 6, 2003
Test new method of field dups

Mix split - old method - sample collected, hand mixed in bag, split
Dry, sieve split - new method - sample collected, air dried,
forced through soil sieve, mixed and split

QC data

ID	Location	Method	organic matter percent	Bray P ppm	K ppm	Mg ppm	Ca ppm	soil pH
I Organic Control (PV)	C1b	Mix split a	3.5	99	54	34	125	4.7
I Organic Control (PV)	C1b	Mix split b	4.2	99	62	40	131	4.7
I Organic Control (PV)	C1b	Dry, sieve split a	3.3	88	61	33	113	4.7
I Organic Control (PV)	C1b	Dry, sieve split b	3.5	109	65	57	231	4.8
I Organic Reduced (EH)	K6	Mix split a	1.9	95	44	31	117	4.8
I Organic Reduced (EH)	K6	Mix split b	2.2	113	41	32	136	4.7
I Organic Reduced (EH)	K6	Dry, sieve split a	2.7	105	57	37	128	4.7
I Organic Reduced (EH)	K6	Dry, sieve split b	2.1	96	53	34	120	4.7
II Mineral Reduced (Mikeys)	S	Mix split a	1.4	83	35	23	99	5.2
II Mineral Reduced (Mikeys)	S	Mix split b	1.1	94	38	22	90	5.3
II Mineral Reduced (Mikeys)	S	Dry, sieve split a	1	73	41	42	200	5.4
II Mineral Reduced (Mikeys)	S	Dry, sieve split b	1	62	40	39	191	5.2
II Mineral Control (Ashleys)	Main piece	Mix split a	1.7	129	69	32	129	5.2
II Mineral Control (Ashleys)	Main piece	Mix split b	1.6	119	71	39	159	4.9

II Mineral Control (Ashleys)	Main piece	Dry, sieve split a	1.6	138	72	39	147	4.8
II Mineral Control (Ashleys)	Main piece	Dry, sieve split b	1.7	136	74	41	156	4.9
III Organic Reduced (BEN)	F5	Mix split a	0.9	59	28	20	98	5
III Organic Reduced (BEN)	F5	Mix split b	0.9	60	21	18	90	5
III Organic Reduced (BEN)	F5	Dry, sieve split a	0.7	64	25	19	95	4.7
III Organic Reduced (BEN)	F5	Dry, sieve split b	0.8	62	23	18	85	4.9
III Organic Control (WS)	Shed S	Mix split a	3.2	75	52	76	553	5.2
III Organic Control (WS)	Shed S	Mix split b	2.6	83	37	31	157	4.7
III Organic Control (WS)	Shed S	Dry, sieve split a	3.5	101	43	30	116	4.6
III Organic Control (WS)	Shed S	Dry, sieve split b	2.8	88	41	29	115	4.7

Dry, sieve method seems to give better reproducibility for most analytes
We used this method from this point on for all samples to ensure that the sample is homogeneous when submitted to the lab.