CONSERVATION INNOVATION GRANTS
Final Report

Grantee Name: The Nature Conservancy
Project Title: Quantitative Comparison of the Effects of Controlled Drainage versus Constructed Wetlands on Water Quality at a Watershed Scale
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Project summary

Tile-drained farmlands in the Midwest have been identified as primary sources of nutrients to the Mississippi River and Gulf of Mexico. Thus, there is a real need to implement conservation practices that effectively reduce tile-drained nutrient exports from these agricultural watersheds. The objective of this project was to compare the ecological and economical benefits of wetlands versus a subirrigation-wetland system designed to intercept and retain tile drained water. Outreach was successful at permitting a 2-acre wetland and a subirrigation-wetland system to be installed on private farmland within Bray Creek, a 4000-ha agricultural subwatershed of the Mackinaw River, Illinois. We monitored throughout the watershed to measure any localized effects of these practices and also used a paired-watershed approach to determine if any measurable watershed changes in water quality or hydrology occurred during the study. No significant changes in water quality were observed at the watershed scale; however, because the constructed wetlands represent only 0.04% of total watershed area, we would not expect their installation to significantly improve water quality at a watershed scale. A comparison of the economic components of these two wetland systems remains to be completed due to initial construction problems in the wetlands at both sites that has complicated direct comparisons of relative benefits of wetland versus subirrigation practices. However, these problems have either been repaired or are in the process of being repaired and we will assess potential economical and ecological benefits of this type of practices in future years. Until we have better data from the subirrigation site, however, we intend to encourage simple wetland construction rather than subirrigation as a practical and economical way to reduce nutrient runoff from tile-drained farmlands.

This project has served as an important step towards implementing and measuring watershed-scale effectiveness of wetlands for reducing agricultural runoff from subsurface tiles. Over the next several years, we plan to establish new wetlands in targeted locations of Bray Creek based on a watershed model currently being developed. Monitoring stations that have been established throughout the paired watersheds as part of this project will enable us to assess changes in water quality and hydrology as wetland construction progresses. Establishment of monitoring stations throughout the two watersheds has provided insight into how local activities influence site-specific nutrient and suspended sediment concentrations that can be used to target future conservation efforts within the watershed. Another important aspect of this study has been the outreach and demonstration of these wetlands as a conservation practice to area landowners and farmers. These wetlands will continue to be used as demonstration sites to encourage farmers and landowners to consider these practices as we progress at testing watershed-scale effectiveness of wetlands in Bray Creek.

Introduction

A significant proportion of the nitrogen and phosphorus entering the Mississippi River comes from nonpoint sources in midwestern agricultural watersheds (Goolsby et al. 1999, Goolsby and Battaglin 2000, Dinnes et al. 2002) that subsequently contribute to hypoxia in the Gulf of Mexico (USEPA 1989, 1990, Alexander et al. 2008). Nitrate-nitrogen fluxes into the Mississippi River Basin are primarily transported from areas within five midwestern states that correspond closely to highest densities of tile drained farmland (Mitch and Day 2006, Sugg 2007). Illinois has the highest estimated total area of subsurface drainage than any other state in the basin (4.7 million ha, Sugg 2007) and contributes among the highest total nitrogen (16.8%) and phosphorus (12.9%) flux delivered to the Gulf of Mexico (Alexander et al. 2008). Still, conservation practices commonly used to control nutrient export are typically designed to intercept surface water runoff (e.g., field buffers, grass waterways) rather than the agricultural drainage entering watersheds through subterranean tiles.

Water management systems such as controlled drainage and constructed wetlands are two innovative conservation practices that have high potential for reducing export of nutrients from agricultural drainage tiles. Controlled drainage has been shown to reduce total drain outflow 79-94% and nitrates 62-96% compared to conventional subsurface drainage (Lalonde et al. 1996, Wesström et al. 2000). Several studies have shown that well-designed tile wetlands can effectively intercept and remove 46-80% of inflowing nitrates (Crumpton et al. 1993, Kovacic et al. 2000). Wetlands also slow drainage waters, which helps restore a more natural hydrology to the stream and reduces instream erosion. Although these studies present a compelling case for the efficiency of controlled drainage and wetlands for improving water quality at a particular site, the effects of these conservation practices at the watershed scale remains to be tested.

The objective of this project was to compare the ecological and economical benefits of wetlands versus controlled drainage. Early into the project, it was realized that the watershed slope was too steep for installation of traditional controlled drainage systems and we submitted a revision to USDA-NRCS to install a subirrigation-wetland system in place of the controlled drainage. This subirrigation system acts similar to controlled drainage in that it holds back tile water, but can be installed on steeper ground. This system has potential advantages both to the farmer (i.e., increased yields) and to water quality (i.e., lower nitrogen application, reduced tile runoff). Although we monitored throughout the watershed to measure any localized effects of these practices, we also used a paired-watershed approach to determine if any measurable watershed changes in water quality or hydrology occurred during the study.

Methods

Study sites

The Mackinaw River watershed covers portions of six counties across central Illinois and is the fourth largest tributary to the Illinois River system (Fig. 1A). Approximately 90% of the landuse in the 295,000-ha Mackinaw River watershed is agricultural, with row crop rotation for corn and soybean production accounting for 75% of all land cover (IDNR 1997). Subwatersheds in the headwater areas have been most heavily converted to agriculture with 80-93% of the land used for row crops. Approximately 58% of the total land area of the six counties through which the Mackinaw River runs has subsurface drainage systems (Sugg 2007) that remove excess water from the poorly drained soils and discharges it directly into adjacent streams. Our study was conducted in two adjacent 4000-ha watersheds near the headwaters of the Mackinaw River in McLean Co., Illinois (Fig. 1A). Bray Creek (N Lat. 40.54, W Long. 88.63) was selected as the treatment watershed and Frog Alley (N Lat. 40.54, W Long. 88.50) was selected as the reference watershed. Soils in both watersheds consisted of silt-loam mesic composition of Parr-Lisbon-Drummer association (USDA 1998) and total stream lengths were similar in Bray Creek (19.8 km) and Frog Alley (19.6 km). Landuse in both watersheds was extensively agricultural and the majority of stream length in each watershed was channelized with narrow stream buffers and very few trees. Channel maintenance in Bray Creek was primarily the responsibility of individual landowners; whereas, channelization and other channel maintenance was conducted in Frog Alley within the framework of an organized drainage district.

Wetland and controlled drainage construction

In the fall of 2004, mailings were sent to all residents in the Bray Creek watershed and to a select group of Frog Alley residents that provided results of previous research and described the new Conservation Innovation Grants project that was planned for these two subwatersheds. During this time, we surveyed Bray Creek subwatershed with McLean County Natural Resources Conservation Service (NRCS) and Soil and Water Conservation District (SWCD) to determine suitable sites for wetland and controlled drainage construction. Results of this survey revealed that the watershed slope was too steep for installation of traditional controlled drainage systems that require an <0.5% slope. We subsequently contracted with AGREM LLC (Colfax, Illinois, www.agrem.com) to install a modified controlled drainage system that included a wetland, retention pond, control gates, and pumping system for water management and subirrigation capacity. This modified system can be installed on steeper slopes (3-5%) than conventional controlled drainage systems and is designed to subirrigate croplands through drainage tiles during dry periods. Additionally, nitrogen fertilizer can be applied using the subirrigation system to reduce pre-planting application rate requirements. This subirrigation-wetland system acts similar to controlled drainage in that it holds back tile-drained waters and has additional potential advantages of increased agricultural yields and reduced nitrogen application to cropland.

A collaborative outreach effort between SWCD and The Nature Conservancy resulted in agreement with a landowner to allow installation of the subirrigation-wetland system on his farmland located along the mainstem of Bray Creek, approximately 3 miles upstream from the furthermost downstream monitoring station (Fig. 1B). AGREM LLC surveyed the proposed site in September 2005, using satellite real-time kinetic technology to produce a topography map with 5000 elevation points (Fig. 2A). New tile lines were installed on the contour of a 20-acre section within an 80-acre field on a one-tenth grade using a laser-guided tiling plow (www.agrem.com). Lateral tile lines (3-in diameter) were installed at a depth of 2-3 feet with 15-foot spacing. Control gates designed by AGREM LLC were installed along the perimeter of the 20-acre section to facilitate subirrigation (Fig. 2A). A 1-acre wetland (2-3 ft depth) and a 1-acre retention pond (5-6 ft depth) were constructed partially within an existing 100-ft stream buffer (Fig. 2B) and were eligible for enrollment in the USDA Conservation Reserve Program (CRP). CRP paid a 60% cost-share for wetland and retention pond construction and subsequent annual rental payments for any land removed from agricultural production. Main tile lines (6-in diameter) transported water from the laterals through control gates from 8 cropland acres to the wetland and from 12 cropland acres to the retention pond. Construction of the subirrigation-wetland system was completed in November 2005 at a total cost of approximately \$3000 acre^{-1}. We have encountered some construction flaws that have limited our capacity to use this site at its full capacity for subirrigation. After multiple attempts to correct the problem over the last few years, we have a capable contractor signed on to rebuild portions of the retention pond in summer 2009.

In response to the 2004 mailings, we were contacted by a landowner in the upper reaches of Bray Creek who was interested in constructed wetlands to intercept drainage tile runoff. In May 2005, a 6-acre area of this farmland was surveyed along an existing 50-foot wide grassed waterway by NRCS for the construction of 2.1 acres of wetland (Fig. 3A). The wetland consisted of three 0.7-acre cells with an average depth of 2 feet that were constructed to allow water to run consecutively from the first cell to the third cell and subsequently into Bray Creek through an AGREM control gate. The first cell, also fitted with an AGREM control gate, intercepted a 15-inch tile that drained approximately 200 acres of farmland. Wetland construction was completed in November 2005, funded by Ducks Unlimited at a total cost of approximately \$2700 $acre^{-1}$. However, because the same contractor was initially assigned to both projects, we encountered similar construction issues at this site that required a complete reconstruction of the wetland. Final construction was completed in September 2006 (Fig. 3B), funded by The Nature Conservancy at a total cost of \$3800 $acre^{-1}$. The reconstruction cost was higher than the initial construction cost due to the amount of work required to completely restructure the existing wetland, rather than start from flat ground. Overall, wetland construction at this site averaged \$3250 $acre^{-1}$. The 6-acre area was enrolled in CRP which paid a cost-share of 60% of the second construction and subsequent annual rental payments for any land taken out of agricultural production. Berms were seeded in October 2006 to prevent erosion, and the 4-acre buffer area around the wetland was seeded with native prairie seed in early spring 2007.

Monitoring stations

Downstream and upstream monitoring sites established within each watershed in 1999 were located approximately 1.6 km and 4.8 km upstream from the confluence of each stream and the Mackinaw River, respectively (Fig. 1B). These original monitoring stations were installed as part of a paired watershed study in which we evaluated whether Best Management Practices (BMPs) such as grassed waterways, stream buffers, and conservation tillage could induce watershed-scale (4,000 ha) changes in nutrients, suspended sediment concentrations or hydrology (Lemke et al., in review). In April 2005, installation of four new monitoring sites began in the two watersheds in locations upstream of the original monitoring stations. In Bray

Creek, one monitoring station was installed downstream from the new wetland site in the upper west branch and one downstream from the subirrigation-wetland site located on the mainstem of the creek (Fig. 1B). A third monitoring station was established on the east branch of Bray Creek to be used as a reference site for the west branch wetland site. One new monitoring station was installed on the mainstem of Frog Alley as a reference site for the new mainstem monitoring station in Bray Creek (Fig. 1B).

Monitoring

Water samples were collected biweekly at our original monitoring sites from 1999-2008 and at all new monitoring stations from March 2003 through December 2008. Samples were analyzed for nitrate-nitrogen (NO_3-N), total phosphorus (TP), dissolved reactive phosphorus (DRP) and total suspended solids (TSS) using standard methods (American Public Health Association 1998). Nitrate-nitrogen was analyzed using ion chromatography following EPA Method 300.0 and with a minimum detection limit of 0.25 mg/L as NO_3-N. Phosphorus analyses were conducted using a Perkin Elmer Lambda 35 dual beam spectrophotometer with a minimum detection level of 0.001 mg/L (DRP).

Water levels were recorded every 15 minutes at the four newest monitoring stations using ISCO automatic water samplers (Teledyne ISCO Inc., 6712 Compact Sampler, Lincoln, Nebraska) fitted with pressure transducers (Teledyne ISCO Inc., 720 Submerged Probe Module, Lincoln, Nebraska). Water levels were recorded every 15 minutes at the original downstream stations using Campbell data loggers (Campbell Scientific Inc., Model CR510, Logan, Utah) fitted with CS420-L pressure transducers (Druck Inc., Model PDCR 1830-8388, Houston, Texas) and were converted to discharge (Q) using discharge-rating curve equations. Storm event samples were collected at 45-minute intervals from all new monitoring stations and the longterm downstream stations using ISCO water samplers programmed to collect water during a rise of water levels. These samples were also analyzed for NO_3-N, TP, DRP, and TSS using methods previously described and the data are currently being analyzed.

Discharge rating curves were developed for the two most downstream monitoring stations to convert stream depth (m), width (m) and flow (m/s) to discharge (m^3/s), and were calibrated in the field using data collected during transect surveys conducted at a range of representative depths and flows for the watersheds. Discharge rating curve equations have been developed for the treatment (log treatment Q (m^3/s) = 0.4396 + 2.5198*log treatment stage (m), $R^2 = 0.89$, $P < 0.001$, n=24) and reference (log reference Q (m^3/s) = 0.4069 + 2.3926*log reference stage (m), $R^2 = 0.71$, $P < 0.001$, n=17) watersheds. Discharge rating curves are currently being developed for the four newest upstream monitoring stations using similar methods.

In partnership with Illinois Department of Natural Resources, we conducted biological surveys of fish (2005, 2007) and macroinvertebrates (2005) in both watersheds. The data from these surveys are currently being incorporated into longer term data analyses that relate water quality and hydrology to the health and biodiversity of fish, mussel, and invertebrate communities in these agricultural watersheds.

Data analyses

Biweekly nutrient and TSS data were analyzed using standard paired watershed methods described by Grabow et al. (1998) that are designed to decrease variability due to annual or seasonal effects (Stewart-Oaten et al. 1986, Grabow et al. 1998). Regression analyses were used to test for significant trends over time in the relationship between the treatment and reference watersheds for nutrient (NO_3-N, TP, and DRP) and TSS concentrations. In these analyses, biweekly concentrations of nutrients and TSS estimated for the reference watershed stations were subtracted from those of the corresponding treatment stations and fitted to a linear regression model. If nutrient or TSS concentrations decreased in the treatment watershed relative to the reference watershed then the difference between the biweekly samples of the two watersheds should become greater over time, resulting in a negative trend line. Discharge data and storm event data are currently being analyzed to determine annual nutrient loadings from each watershed. Analyses are also being conducted to determine relative changes in peak flow, low flow and base flow between treatment and reference stations.

Results

Nitrate concentrations varied with season at all sites, with maximum levels generally occurring April through June and minimum levels during August and September (Fig. 4). With the exception of several dates in fall 2004 at the downstream monitoring station in Frog Alley when NO_3-N concentrations reached 29.4 mg N L^{-1} (Fig. 4A), biweekly ranges were similar among downstream (<1 to 20.4 mg N L^{-1}, Fig. 4A), midstream (<1 to 19.8 mg N L^{-1}, Fig. 4B) and upstream sites (<1 to 22.4 mg N L^{-1}, Fig. 4C). Patterns of TP and TSS tended to be event-driven rather than seasonal. Biweekly concentrations for total phosphorus ranged from <0.01 to 0.59 mg P L^{-1} at downstream stations (Fig. 5A), <0.01 to 0.95 mg P L^{-1} at midstream stations (Fig. 5B), and <0.01 to 0.56 mg P L^{-1} at midstream stations (Fig. 5C). Biweekly concentrations for total suspended sediment concentrations ranged from 0 to 168 mg DM L^{-1} at downstream stations (Fig. 6A), 0.5 to 104 mg DM L^{-1} at midstream stations (Fig. 6B), and 0.1 to 110 mg DM L^{-1} at upstream stations (Fig. 6C).

Regression analyses did not reveal any significant changes between the two watersheds for biweekly nitrate concentrations during this study at the downstream (R^2=0.009, *df*=218, *p*=0.16) (Fig. 7A), midstream (R^2=0.0002, *df*=95, *p*=0.88) (Fig. 7B) or upstream sites (R^2=0.009, *df*=91, *p*=0.36) (Fig. 7C). There also were no significant reductions in TP concentrations in the treatment downstream (R^2=0.001, *df*=130, *p*=0.70) (Fig. 8A) and upstream (R^2=0.02, *df*=90, *p*=0.15) (Fig. 8C) sites relative to the reference sites. In contrast, regression analysis did show a significant reduction in TP for biweekly water samples collected from the reference watershed at the midstream sites relative to the treatment (R^2=0.11, *df*=92, *p*=0.001), although the regression coefficient was very low (Fig. 7B). No significant reductions in TSS concentrations were observed between the two watersheds at the downstream (R^2=0.013, *df*=210, *p*=0.10) (Fig. 8A) and upstream sites (R^2=0.02, *df*=97, *p*=0.15) (Fig. 8C); however, regression analysis revealed a significant reduction in TSS for biweekly water samples collected from the reference watershed at the midstream sites relative to the treatment (R^2=0.13, *df*=97, *p*=0.0002) (Fig. 8B).

Discussion

Outreach was successful at implementing two wetland-based projects on private farmlands in the treatment watershed (Bray Creek) within a reasonable amount of time following funding of the project. However, our analyses showed no significant watershed-scale improvements in water quality in terms of nitrate concentrations, total phosphorus, or suspended solids. Research in Illinois and Iowa suggests that it may take a wetland to watershed area of 2-3% to remove significant amounts of NO_3-N from agricultural watersheds (Crumpton et al. 2008). Similarly, cumulative 2-year data from an ongoing study between the Conservancy and University of Illinois suggest that a wetland to watershed ratio of 3-9% can reduce exports of

NO_3-N by 18-43% and orthophosphate by 43-56%. Because the wetlands constructed in Bray Creek represent only 0.04% of the total watershed area, we would not expect their installation to significantly improve water quality at a watershed scale. As of yet, there are no studies that have shown water quality improvements at the scale of Bray Creek (4000 ha) as a result of best management practices (BMPs). Previous research in these watersheds has shown that BMPs are needed that intercept tile drainage in order to address nutrient runoff concerns (Lemke et al., in review). It is yet unknown what it will really take to impact water quality at these larger scales; however, this project has served as an important step towards implementing and measuring watershed-scale effectiveness of wetlands for reducing agricultural runoff from subsurface tiles.

We currently have funding to continue wetland research in our paired watershed sites through 2011. Longterm monitoring data from our paired watersheds are being incorporated into a hydrologic watershed model by the Illinois State Water Survey to predict where wetlands will be most effective in the watershed at reducing nutrient runoff. Proper placement of wetlands is an important component of programs that work to effectively reduce annual nitrate exports (Crumpton et al., 2008). Over the next 2-3 years we will establish wetlands in locations predicted by the watershed model, beginning in the headwaters of Bray Creek. Monitoring stations that have been established throughout the paired watersheds during this project will enable us to assess changes in water quality and hydrology as wetland construction progresses.

Establishment of monitoring stations throughout the two watersheds has also provided insight into how local activities influence site-specific nutrient and sediment concentrations. Nitrate concentrations and dynamics were remarkably similar among all sites within each watershed, and suggest homogenous input distributions and watershed-scale influences on concentrations. In contrast, total phosphorus (TP) and suspended sediment concentrations (TSS) were much more variable and site-specific. In the fall of 2005, dredging at the midstream station in Frog Alley (reference watershed) resulted in extremely high TP (Fig. 5B) and TSS (Fig. 6B) concentrations relative to the midstream station in Bray Creek (treatment watershed) and downstream stations in both watersheds. Localized increases were also observed in TP and TSS concentrations at the upstream sites. These patterns may indicate precipitation events that disproportionally increased discharge at the narrower, smaller upstream sites relative to the wider-banked, larger downstream sites. These sites likely receive greater surface and tile runoff relative to their size due to higher slopes of the moraine than the downstream sites. Further analyses of discharge and precipitation data will provide important information on how storm events influence water quality relative to stream site location and can be used to target future conservation efforts within the watershed.

Another important aspect of this study has been the outreach and demonstration of wetlands as a conservation practice to area landowners and farmers. Previous outreach efforts in these two watersheds resulted in higher implementation of several more traditional BMPs (i.e., grassed waterways, stream buffers), although farmers were not interested in wetlands as a conservation investment (Lemke et al., in review). However, an important aspect of outreach and implementation of any new conservation practice is demonstrating its practicality and economical aspects on the ground. Previous survey results from farmers and landowners in the Mackinaw River watershed revealed that visual demonstrations of new practices were their preferred outlets for learning about new conservation applications (TNC, unpublished data). A prime example of this approach occurred in the treatment watershed when a private landowner worked with Land Improvement Contractors of America during 2007 to install a 2-3 acre wetland on his land near the downstream monitoring station in Bray Creek. Approximately 10-12 acres of wetlands have been installed at a Demonstration Farm in Lexington, Illinois, that are also used to show how these and other conservation practices function on working farmlands. These wetlands will be used as demonstration sites to encourage farmers and landowners to consider these practices as we continue to test watershed-scale effectiveness of wetlands in Bray Creek.

A comparison of the economic components of these two wetland systems remains to be completed. Inadequate construction of the wetlands at both sites hindered some factors of the project and complicates making direct comparisons of the relative benefits of wetland versus subirrigation practices. Although the costs of each project were similar on a per acre basis ($3000-$3250), the total cost of the subirrigation project was $60,000 versus and average of $19,500 for the upstream wetland project. Reconstruction of the upstream wetland site was completed in 2006, thus this site has been functioning properly for approximately 3 years. Because the retention pond has not yet been properly repaired, we have been unable to determine the economic benefits of subirrigation for potential yield increases during dry years. Subirrigation potentially offers some real advantages in terms of yield increases, reduced nitrogen application and reduced nutrient runoff and may be an effective practice in certain situations and locations. Reconstruction of the retention pond is scheduled for summer 2009 and we will assess potential economical and ecological benefits of this type of practices in future years. Until we have better data from the subirrigation site, however, we intend to encourage simple wetland construction rather than subirrigation as a practical and economical way to reduce nutrient runoff from tile-drained farmlands.

Next steps

Although the primary objective of our research is to document and measure watershed-scale changes in water quality, we are also interested in measuring how well individual wetlands reduce nutrients within the watershed. We are currently working with researchers at University of Illinois to calibrate control gates and install monitoring equipment at the subirrigation and the upstream wetland systems in order to measure nutrient inputs and outputs at these wetland sites. We are also developing rating curves at all monitoring stations in order to calculate discharge and subsequent transport of nutrients at these sites. Macroinvertebrate samples from both watersheds are being processed and analyzed. Over the next several years, we will train a team of stakeholders to assist with targeted landowner outreach for wetland construction to test and calibrate the watershed hydrologic model that is currently being developed by the Illinois State Water Survey.

Acknowledgements

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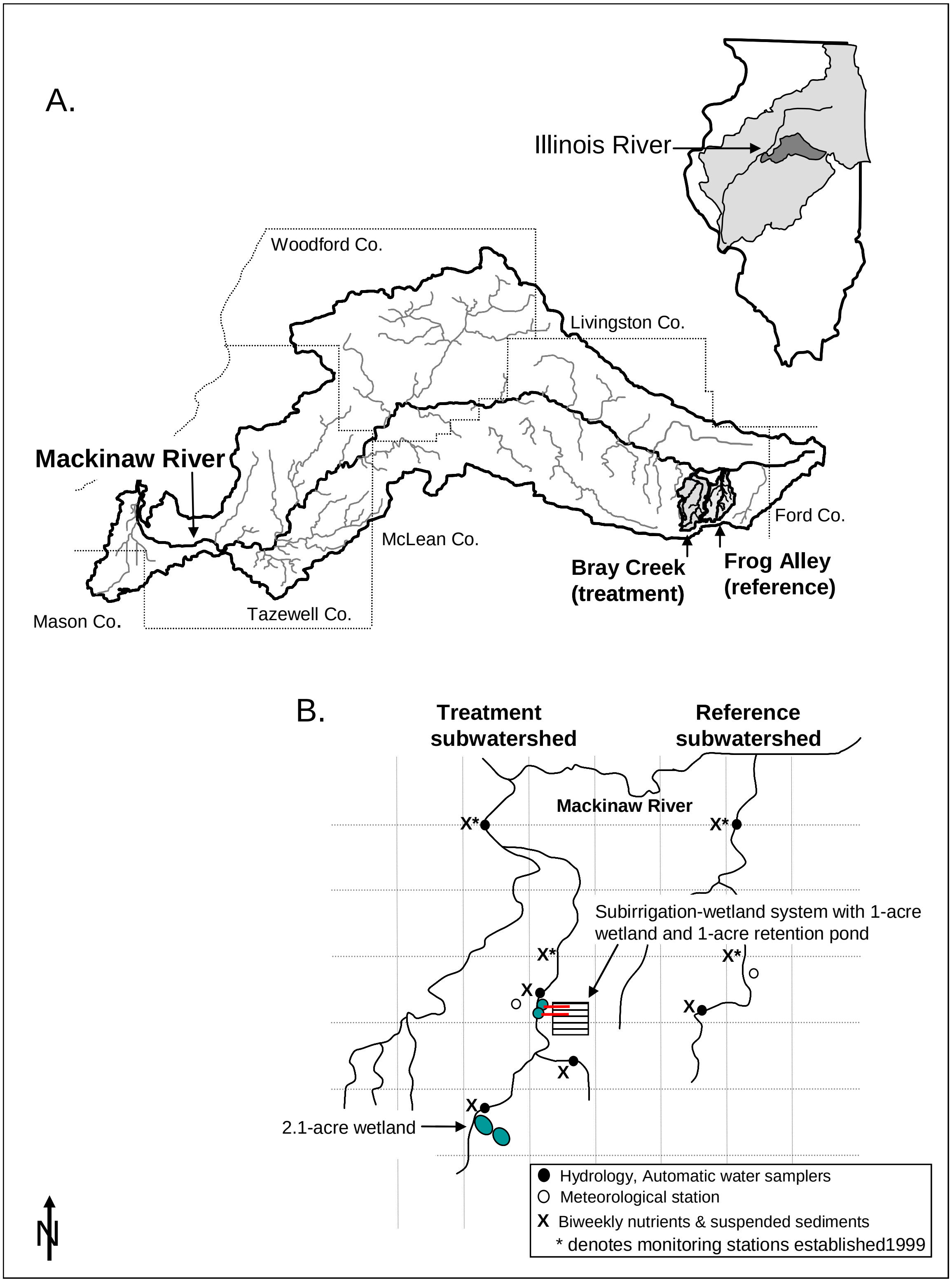

Figure 1. Location of the paired-watershed study within the Mackinaw River watershed, Illinois (A) and detailed locations of monitoring stations within the two paired watersheds (B).

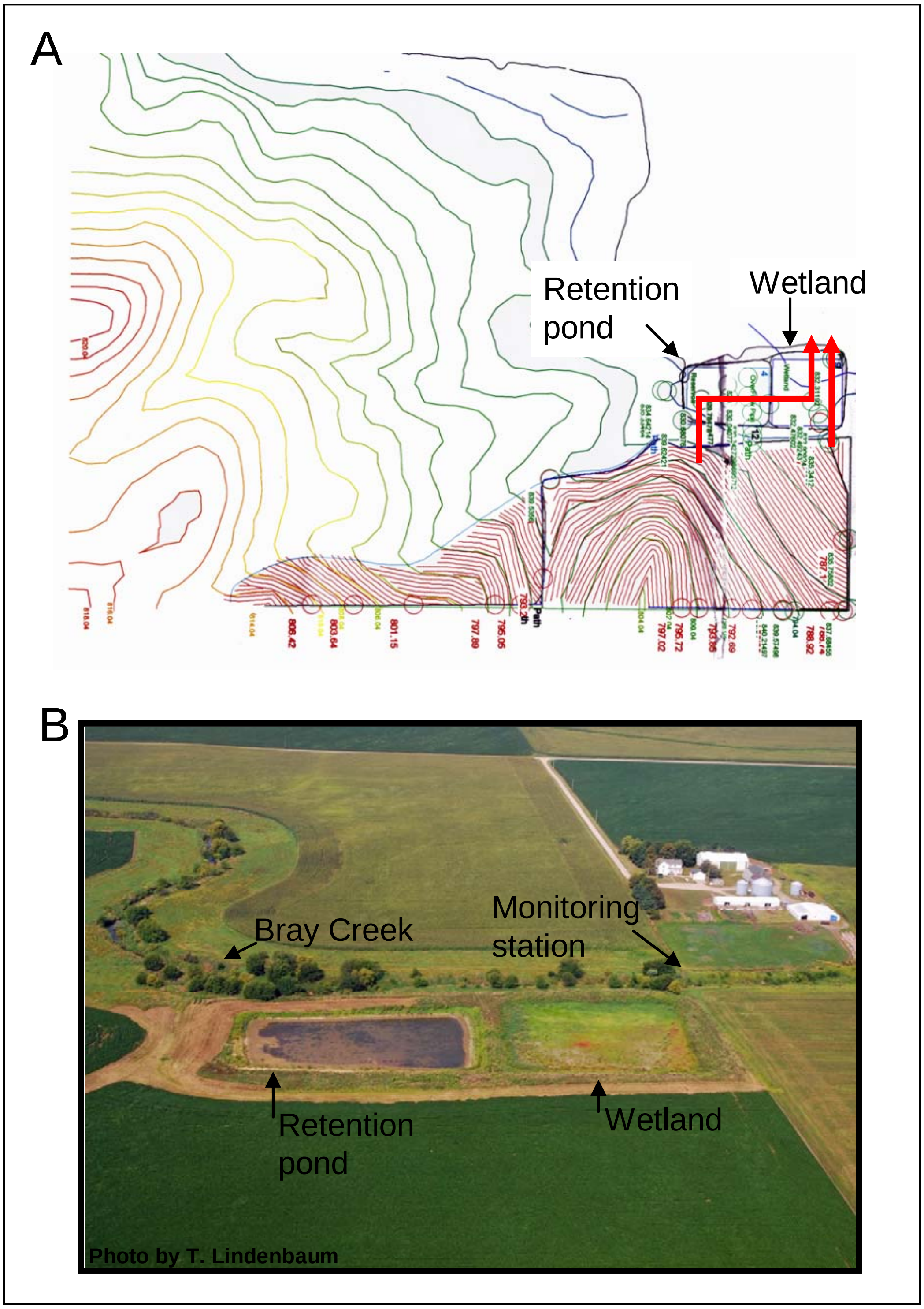

Figure 2. Detailed map showing the subirrigation-wetland system with topography, new tiles (red lines), control gates (open circles), retention pond, and wetland. Red arrows indicate water flow direction through pond and wetland to Bray Creek (A). Aerial view of subirrigation site, photographed August 2008 (B).

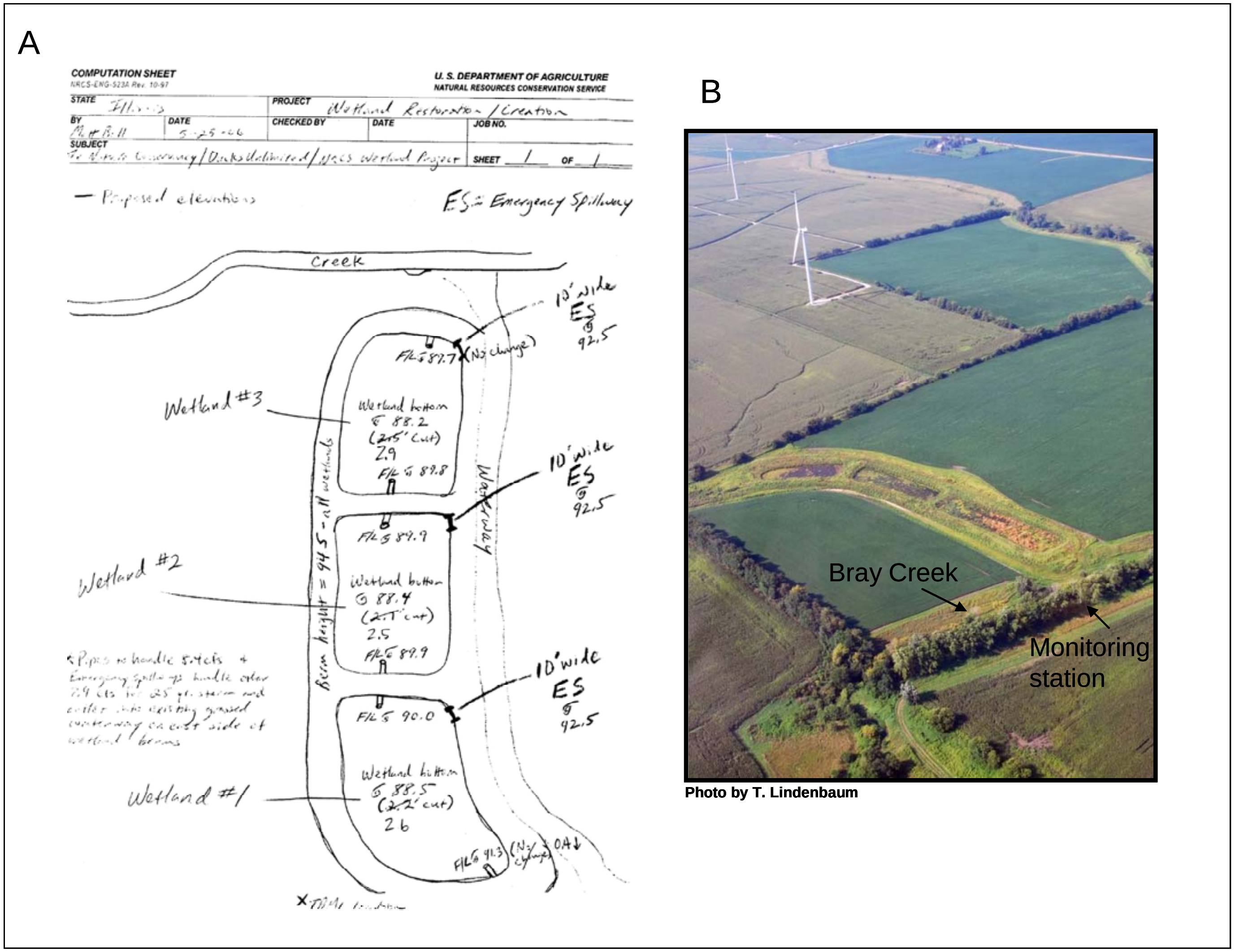

Figure 3. Detailed map showing the upstream wetland site design (A) and aerial view (B) photographed August 2008.

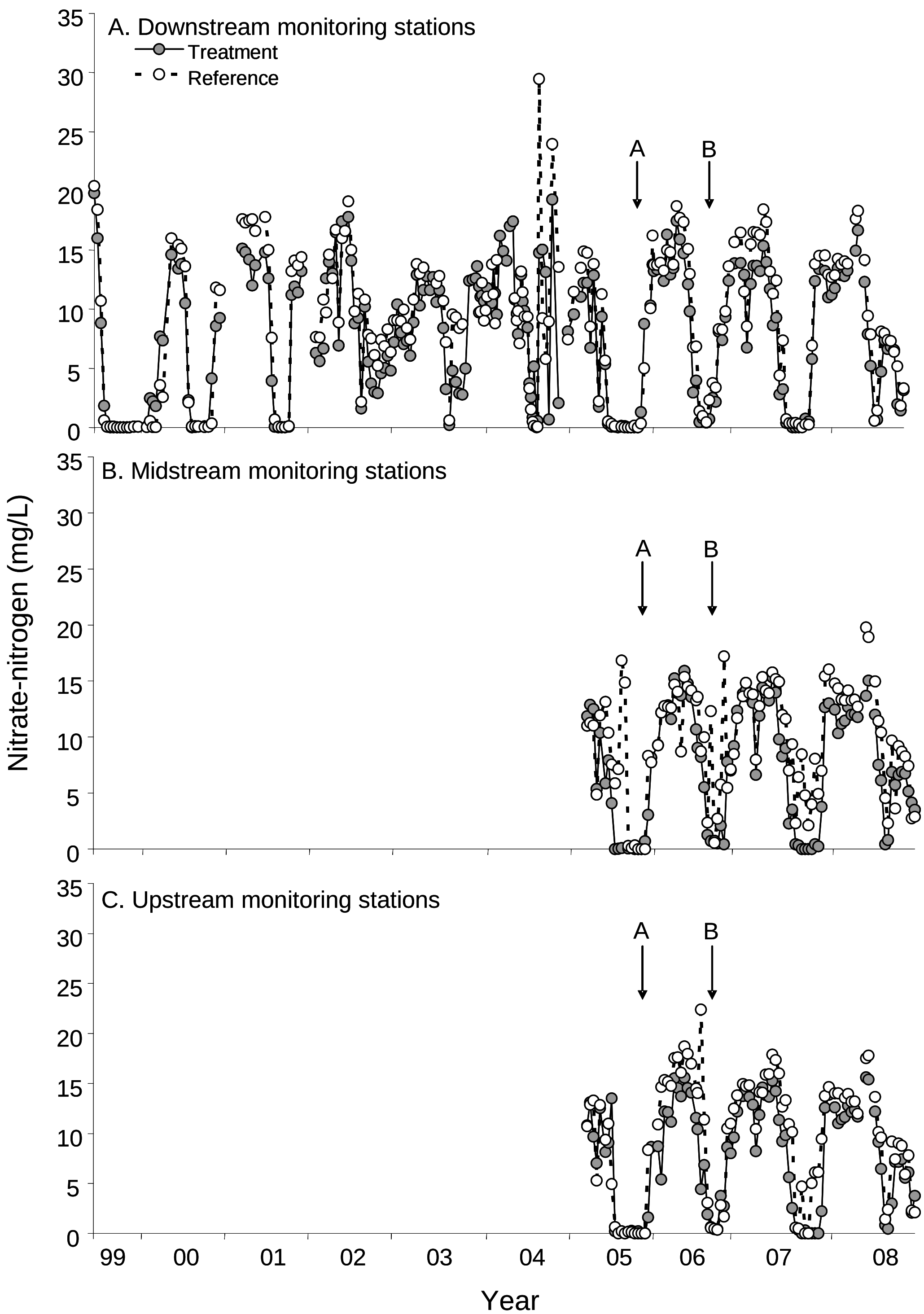

Figure 4. Nutrient concentrations for nitrate-nitrogen collected from the downstream (A), midstream (B) and upstream (C) stations in the treatment and reference watersheds. Concentrations are based on bi-weekly samples collected June 1999-December 2008 (downstream) and March 2005-December 2008 (midstream, upstream sites). Arrows indicate installation of the subirrigation (A) and upstream wetland sites (B).

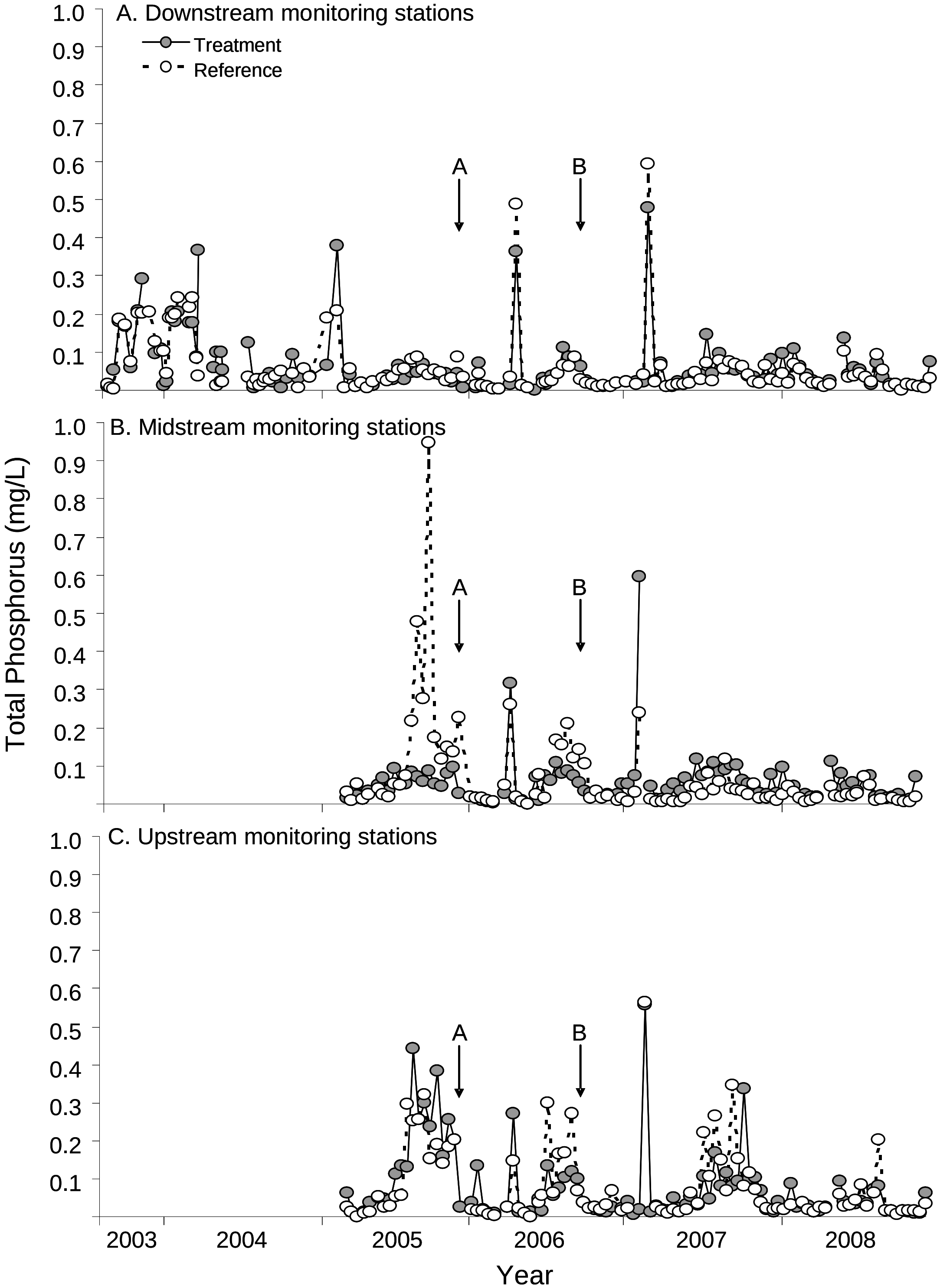

Figure 5. Nutrient concentrations for total phosphorus collected from the downstream (A), midstream (B) and upstream (C) stations in the treatment and reference watersheds. Concentrations are based on bi-weekly samples collected August 2003-December 2008 (downstream) and March 2005-December 2008 (midstream, upstream). Arrows indicate installation of the subirrigation (A) and upstream wetland sites (B).

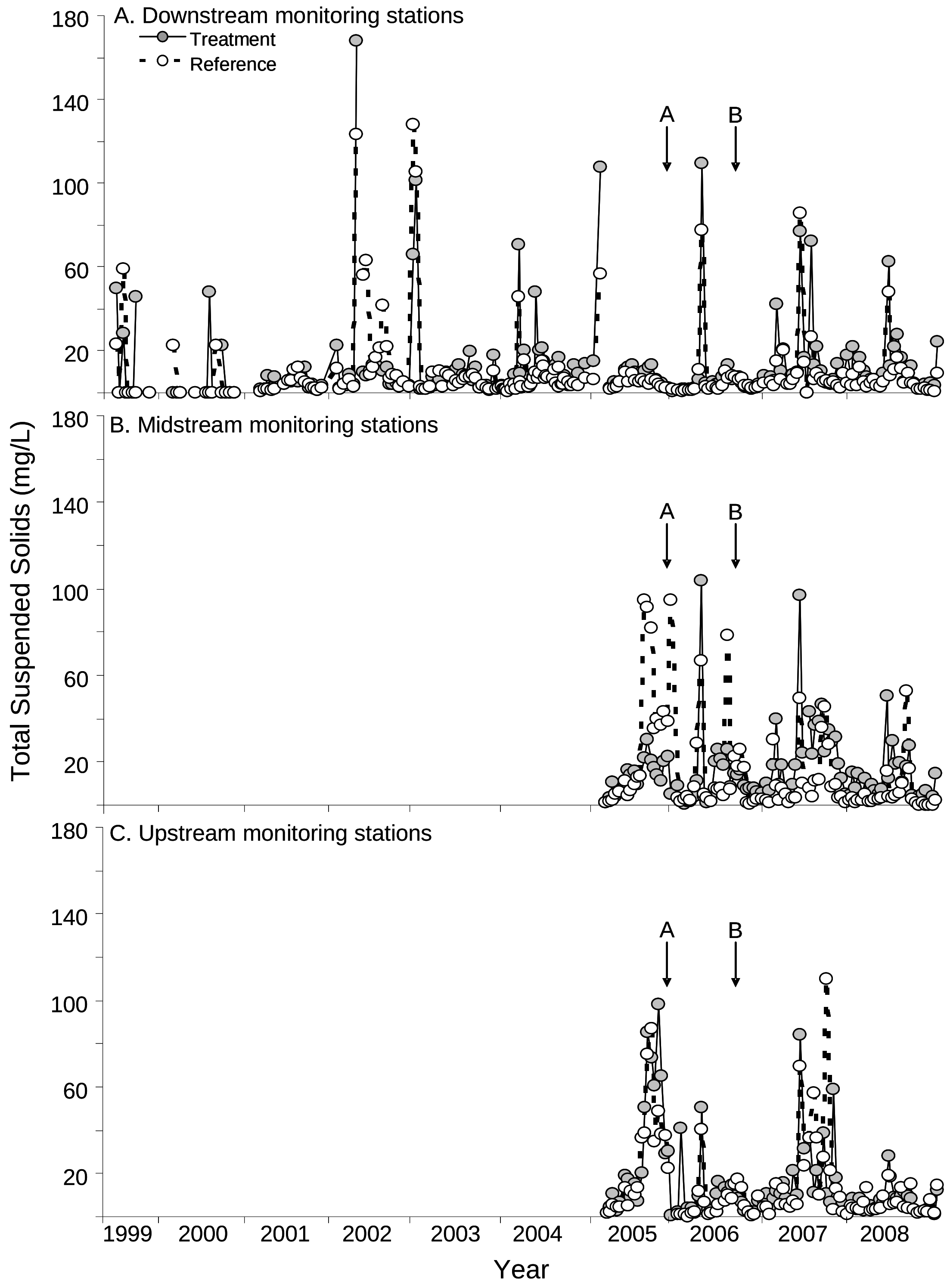

Figure 6. Nutrient concentrations for total suspended sediments collected from the downstream (A), midstream (B) and upstream (C) stations in the treatment and reference watersheds. Concentrations are based on bi-weekly samples collected June 1999-December 2008 (downstream) and March 2005-December 2008 (midstream, upstream). Arrows indicate installation of the subirrigation (A) and upstream wetland sites (B).

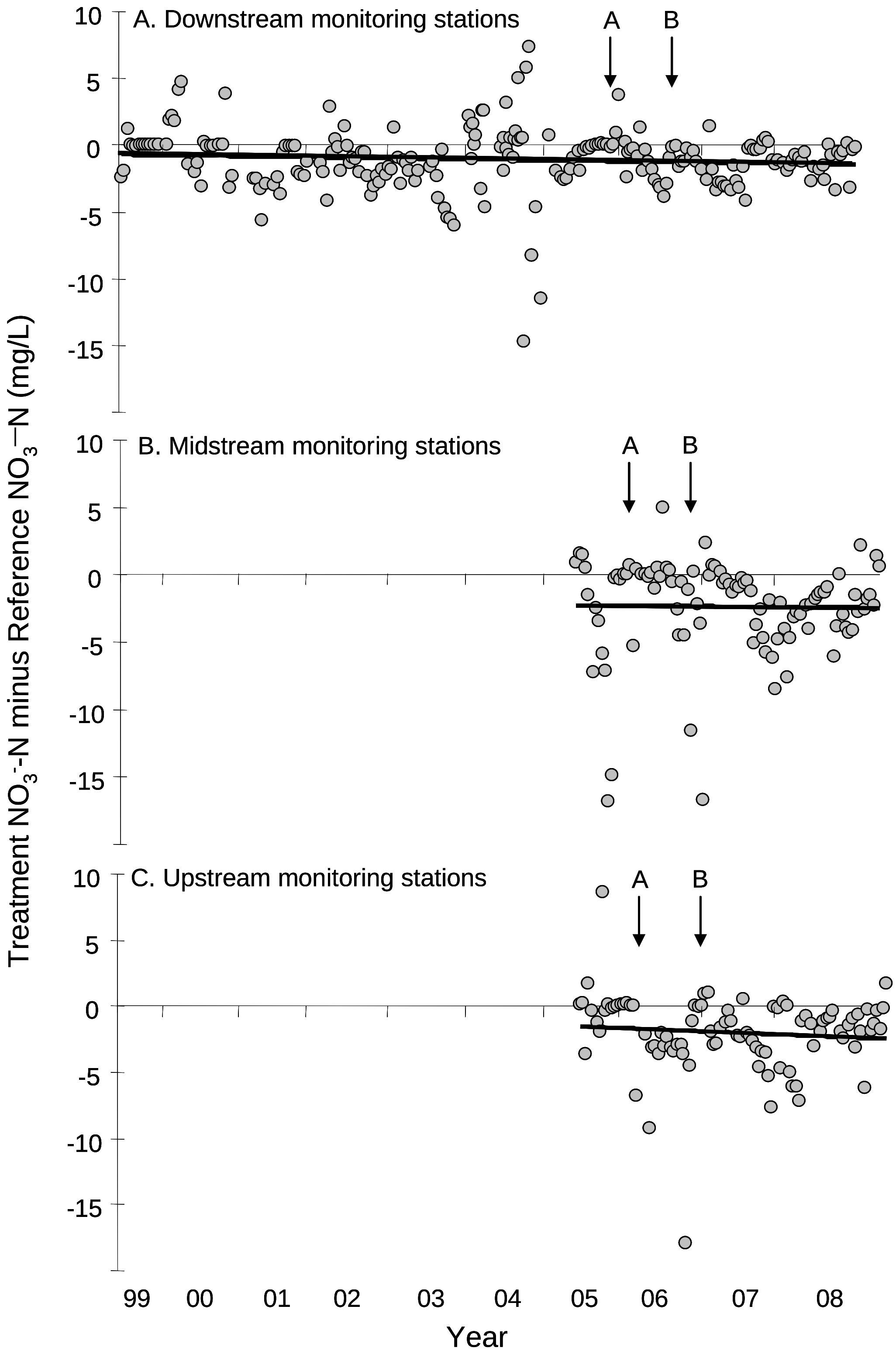

Figure 7. Differences between nitrate-nitrogen concentrations at downstream (A), midstream (B), and upstream (C) stations in water samples collected biweekly from the treatment watershed versus the reference watershed. Arrows indicate installation of the subirrigation (A) and upstream wetland sites (B).

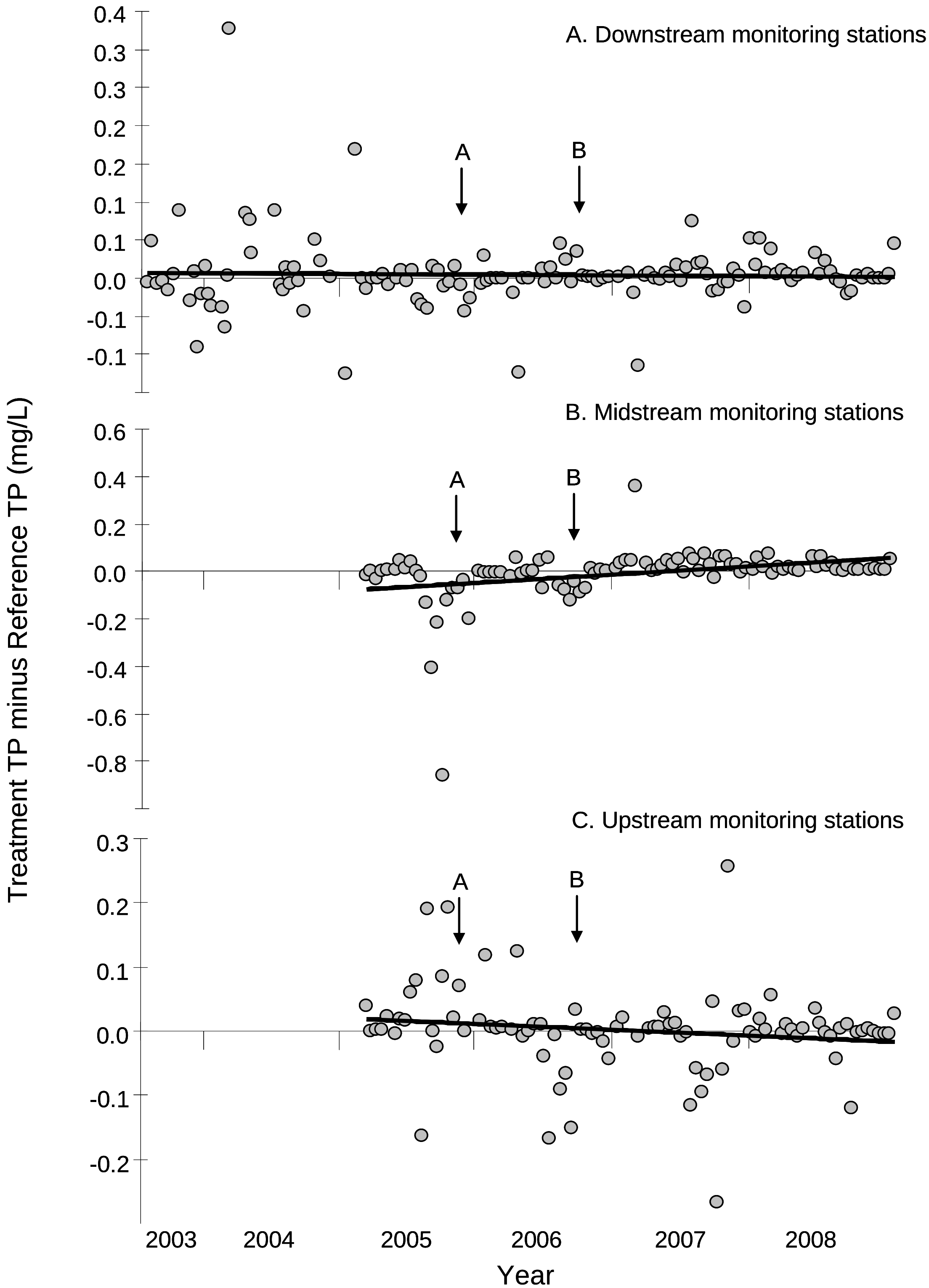

Figure 8. Differences between total phosphorus concentrations at downstream (A), midstream (B), and upstream (C) stations in water samples collected biweekly from the treatment watershed versus the reference watershed. Arrows indicate installation of the subirrigation (A) and upstream wetland sites (B).

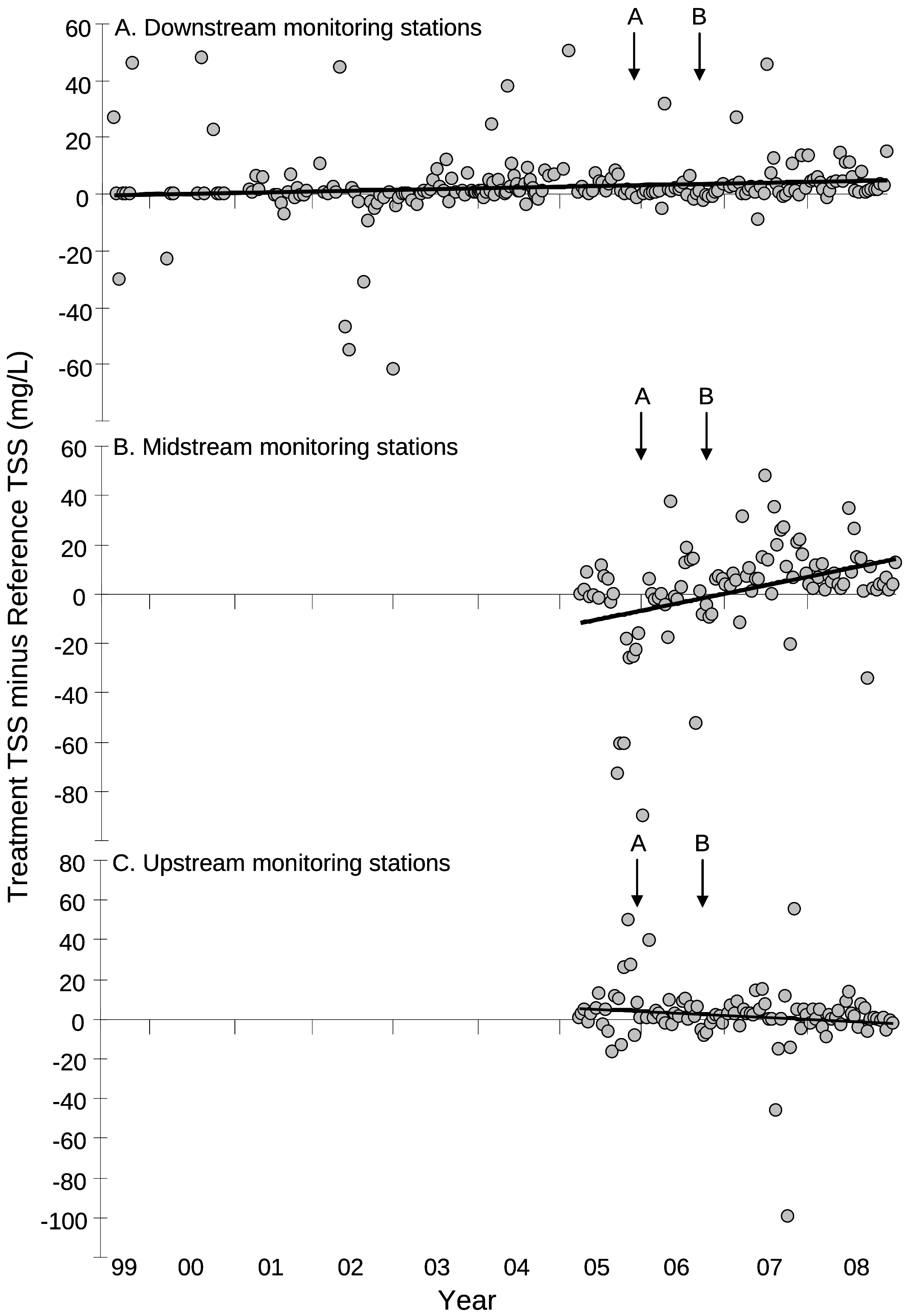

Figure 9. Differences between total phosphorus concentrations at downstream (A), midstream (B), and upstream (C) stations in water samples collected biweekly from the treatment watershed versus the reference watershed. Arrows indicate installation of the subirrigation (A) and upstream wetland sites (B).