ANNUAL REPORT

JORDAN COVE URBAN WATERSHED SECTION 319
NATIONAL MONITORING PROGRAM PROJECT

prepared by

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RESULTS AND DISCUSSION

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EXECUTIVE SUMMARY

The Jordan Cove Urban Watershed study is in its eighth year. Construction is now complete in both watersheds; post-construction data is available only for the BMP watershed. Sampling and analysis continued as in other years with added sampling for the driveway study and the lawn nutrient study. Field equipment generally performed well, however, the flow meter at the control malfunctioned over two months and has been replaced. Lab equipment performed well and quality control was excellent.

BMP Watershed

The volume of stormwater runoff from the BMP Watershed decreased during the construction period and continued to decrease by >100% during the post-construction period. During construction, the concentrations of TSS, TP, NO_3, NH_3, and TKN increased. Following construction, only TSS, TP, and TKN concentrations increased. Concentration peaks were associated with turfgrass development. Exports generally declined in both construction and post-construction periods, except for TP which did not change. Cu and Zn concentrations increased during construction while Pb and Zn decreased following construction. Metals export declined following construction.

Traditional Watershed

The construction period ended just before this report was written, therefore, no post-construction results are yet available. During construction stormwater runoff from the traditional watershed increased. There was no increase in the concentrations of TSS, TP, NO_3, Cu, Pb, Zn and NH_3. TKN concentrations decreased. However, exports increased for all variables expect the metals. The erosion and sediment controls appeared to work at this site.

Driveway Runoff Study

Stormwater runoff and mass export of solids, nutrients, and metals was greater from the asphalt than the pavers than the crushed stone driveways. Concentrations of solids, nutrients and metals were lower in runoff from the paver driveways than the asphalt driveways. Concentrations of TP and Pb were lower in runoff from the crushed stone driveways than from the asphalt driveways.

Lawn Nutrient Study

NO_3-N desorbed from AEM strips, soil water NO_3-N concentrations and plant reflectance all indicate that the BMP lawns being monitored have lower values than the non-BMP lawns.

INTRODUCTION

Background

Long Island Sound is an impaired estuary due to low dissolved oxygen (hypoxia), toxic contaminants, pathogen contamination, floatable debris, and habitat degradation (LISS, 1994). Excessive nitrogen is believed to be responsible for hypoxia in the Sound. Nonpoint sources of pollution are estimated to be responsible for 21 % of in-basin human contributions of nitrogen to the Sound; the remaining nitrogen is supplied by point sources such as sewage treatment plants. Boundaries of the Sound transport 20 % of human-caused pollutant loading to the Sound.

Average toxic metal concentrations in Long Island Sound generally do not exceed New York or Connecticut standards except for mercury which exceeds standards occasionally in the East River (LISS, 1994). However, some sediments in western Long Island Sound have elevated concentrations of As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn with respect to the New York guidelines but not the Connecticut guidelines. Also, many urbanized harbors have sediments contaminated with metals. Some portions of Long Island Sound's sediments are higher than the NOAA national high values for PCB, DDT, and Chlordane (LISS, 1994). Urban runoff is believed to be the third major source of toxics following upstream sources (tributaries) and sewage treatment plants.

Pathogen contamination in Long Island Sound has been responsible for 1,440 beach-day closures from 1986 to 1990 (LISS, 1994). Also 73 % of the shellfish beds in New York and 35 % in Connecticut have been classified as "Restricted/Prohibited" due to pathogen contamination from both point and nonpoint sources. However, some closures are due to inadequate monitoring. Urban runoff, including CSO's are believed to be responsible for 47 % of the fecal coliform loading to Long Island Sound (LISS, 1994). Rivers, including upstream point and nonpoint sources add an additional 52 % of bacterial loading.

Floatable debris is found in the Sound, its bays and washed up on beaches. Most debris (74 %) are plastics. This debris is a threat to estuarine life. The floatable debris in the sound comes from stormwater discharges and CSOs, tributaries, and shoreline visitors and boaters. It is believed that 82 % of the debris is from storm sewers and CSOs (LISS, 1994).

Jordan Cove is a small estuary composed of a long (1.75 mi.) narrow (300 ft) neck feeding into an inner Cove (100 ac.) and then an outer Cove (390 ac.) before flowing into Long Island Sound. The inner cove is separated from the outer cove by a large sandbar. Fecal coliform bacteria sampling in the cove since 1990 has indicated that inner Jordan Cove has not met the bacteriological water quality criteria for an "Approved" shellfish growing area of a mean of 14 MPN/100 ml and <10 % of samples exceeding 43 MPN/100 ml. Inner cove samples have had a geometric mean ranging from 26 to 154 MPN/100 ml. Outer Jordan Cove also does not meet the criteria during wet weather conditions. Inner Jordan Cove is currently classified as "Restricted-Relay" for shellfish and outer Jordan Cove could be upgraded to a "Conditionally Approved" area.

Sediment sampling in Jordan Cove in 1994 indicated that certain portions of the Cove have high concentrations of arsenic (> 20 ppm) but no other metals exceed Connecticut guidelines. Water quality sampling in Jordan Cove in September, 1993 found dissolved oxygen concentrations ranged from 8.1 to 4.1 mg/l in bottom waters indicating, at least on a transient basis, depressed dissolved oxygen concentrations in portions of the Cove.

Jordan Brook has been sampled at eight locations since 1993 (EcoScience Laboratory, 1993). Additional sampling was conducted in 1978. Biological sampling of the eight sites was conducted in 1994. Fecal coliform abundance in Jordan Book appears to increase as it flows downstream. Sampling date averages have been 480, 84, and 48 FCU/100 ml. Total phosphorus concentrations average below 0.03 mg/l and nitrate concentrations are below 1 mg/l. The dissolved oxygen in the stream has ranged from 4.8 to 9 mg/l.

Biological sampling in Jordan Brook indicated that disturbance varies along the brook. The uppermost station is most natural and least disturbed. Two of the sites appear to be adversely influenced by siltation. The site below I-95 has an absence of mayflies and stoneflies (Jokinen and Colson, 1994).

The United States Environmental Protection Agency (USEPA) reports that nonpoint sources are responsible for a large portion of the remaining water quality impairments to our nation's waters (USEPA, 1998). Of the 72% of estuaries surveyed, 38% were designated impaired for one or more uses with nutrients being the largest pollutant. Inherent in the urbanization process is land under development. Construction and/or urban runoff was reported as sources of pollution at 14 of the 18 National Estuary sites, including Long Island Sound (USEPA, 1994a).

Project Description

The Jordan Cove Urban Watershed Section 319 National Monitoring Program Project is a ten year study designed to determine the water quantity and quality benefits through the development of an urban subdivision using pollution prevention BMPs. Stormwater runoff from three watersheds - control, traditional and best management practice (BMP) - is monitored as part of the study. The traditional watershed has been developed using 'traditional' subdivision requirements. The BMP watershed has been developed using a best management practice approach before, during, and after construction. The runoff from these two watersheds is compared to an existing control watershed. Ultimately, the goal will be to show that, by using a BMP approach, pre-development hydrologic conditions can be maintained during and after residential development.

The project is located within the Jordan Cove watershed in Waterford, Ct. (Figure 1). The existing control watershed exits at a stormwater pipe draining 43 lots ranging in size from 15,000 sq ft to 20,000 sq ft developed in 1988 (Figure 2). The traditional development is 18 units on 10.6 acres. The BMP portion of the subdivision is 12 units on 6.9 acres; both areas have approximately the same dwelling unit per unit area density (Figure 3). There is 26 % open space in the entire subdivision, mostly along the periphery. The past use of the property that is being development is a poultry farm in the area to be subdivided using traditional requirements; the BMP area was a closed out gravel pit.

A ten-year project is proposed to monitor three phases of the project. The first phase is the calibration period used for the paired watershed design. The second phase is the construction period. The third phase will be the long-term operations and management phase when both subdivisions will be completed.

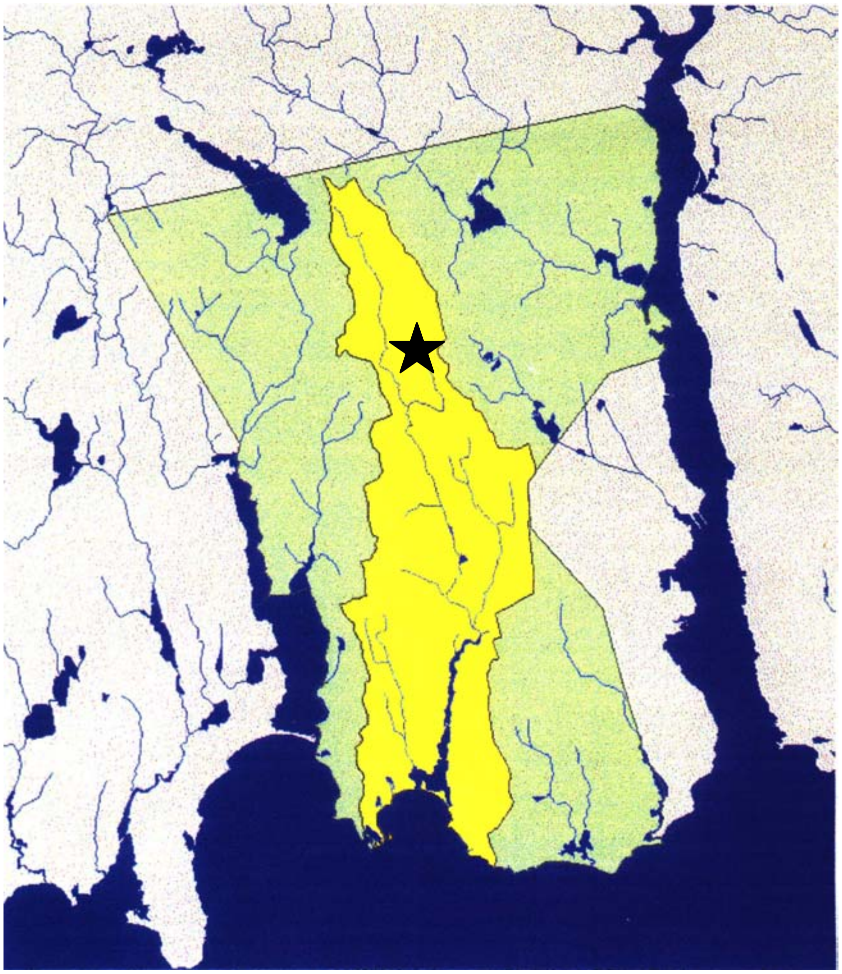

Figure 1. Jordan Cove Watershed showing location of project.

Figure 2. Control watershed subdivision showing monitoring location.

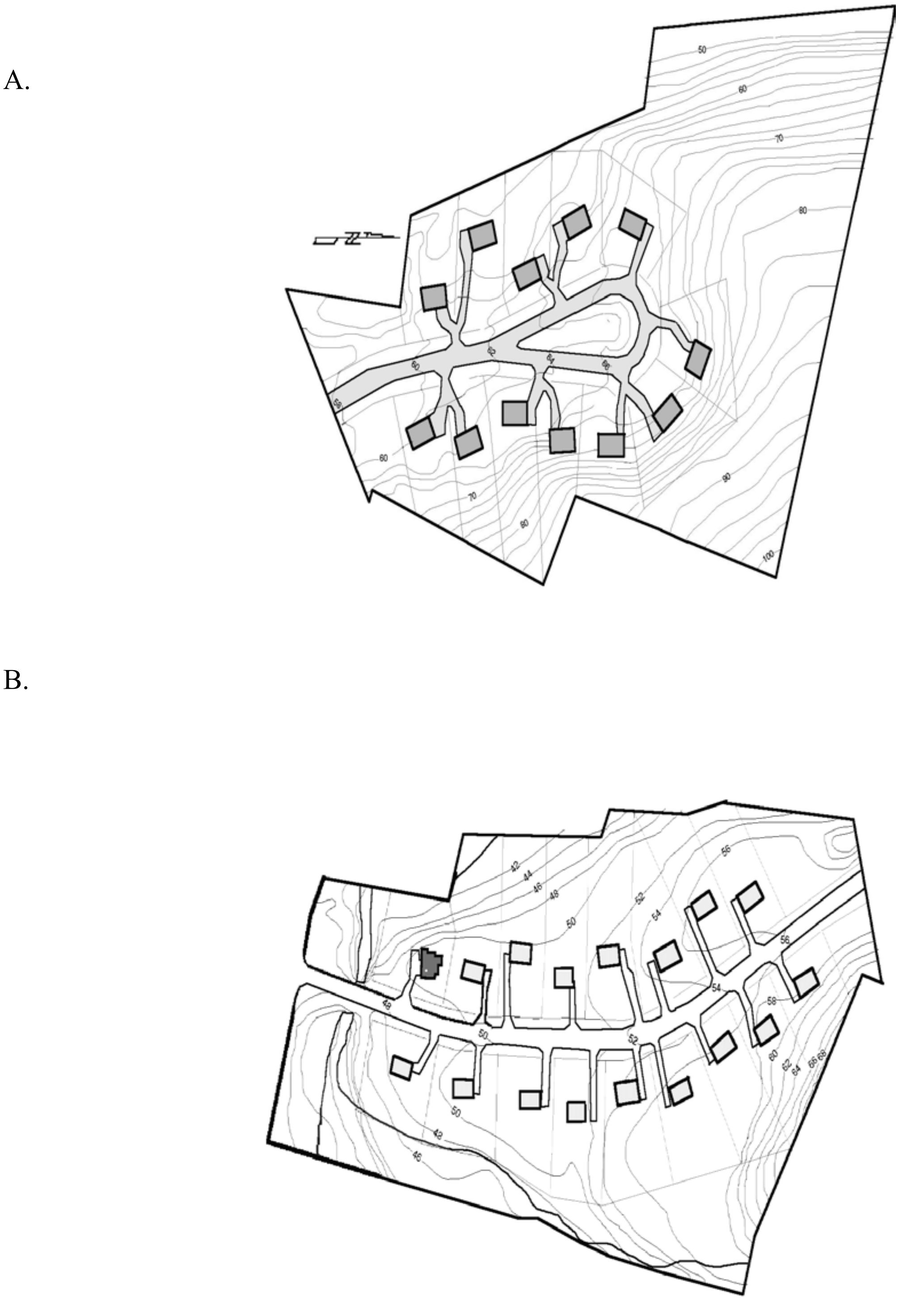

Figure 3. Jordan Cove subdivision showing area A (best management practices) and area B (traditional subdivision).

OBJECTIVES

The overall objective of the project is to demonstrate the water quantity and water quality benefits of developing urban residential subdivisions with BMP nonpoint source controls. There are a number of specific objectives related to the project:

1. To reduce the amount of runoff and sediment, bacteria, N, and P from residential developments during construction.
2. To reduce the amount of runoff and sediment, bacteria, N, and P exported from residential developments.
3. To demonstrate the use of residential nonpoint source controls for educational purposes.
4. To investigate the effectiveness of individual BMPs including alternative driveway pavement treatments, grassed swales, roof runoff rain gardens, landscaping, reduced site imperviousness, and general good housekeeping practices.

The following quantitative treatment goals were developed consistent with the 6217 Coastal Zone guidance (EPA, 1993).

1. To implement BMPs on 100% of the lots in the BMP portion of the subdivision.

2. To maintain post-development peak runoff rate and volume at levels equal to predevelopment rates.

3. To maintain post-development loading of TSS at levels equal to predevelopment rates.

4. To retain sediment onsite during construction.

5. To reduce nitrogen export by 65%.

6. To reduce bacterial export by 85%.

7. To reduce phosphorus export by 40%.

PROJECT ORGANIZATION AND RESPONSIBILITY

Key personnel associated with the project are identified in Figure 4. John Clausen will serve as the person directly responsible to EPA for the quality and timely completion of the project. The project will be assisted by a University Research Technician II and by several graduate and undergraduate students. All water quality analysis has been conducted in the Department of Natural Resources Management and Engineering Water Quality Lab except for the metal analysis which was conducted by the Environmental Research Institute at the University of Connecticut.

A Project Advisory Committee has been established to provide a forum for continuing dialogue on the project. The Committee meets twice per year. The following agencies participate on the advisory committee:

Bruce Morton
Aqua Solutions

Stan Zaremba, Paul Stacey, Ernie Pizzuto, Eric Thomas
Connecticut Department of Environmental Protection

Chester Arnold, Karen Filchak
Cooperative Extension System

Mel Cote', Steve Winnett
Environmental Protection Agency

John Lombardi
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Tom Wagner, Hank Daniels, Maureen FitzGerald, Dave Martin
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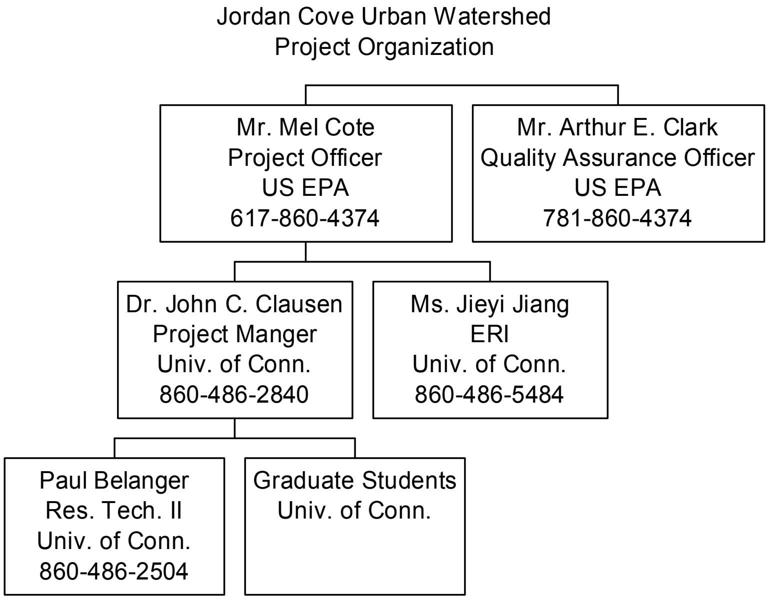

Figure 4. Jordan Cove Watershed project organizational chart.

METHODS

Study Design

The overall study design is the paired watershed approach (Clausen and Spooner, 1993). This approach uses two different time periods consisting of calibration and a treatment phases. During calibration, at least two watersheds similar in size and location, are monitored over time to determine a hydrologic relationship between them. During the calibration period no land use changes occur and regressions are developed between paired observations. Once a satisfactory relationship has been determined, treatment of one of the watersheds can begin whereupon changes over time can be monitored and new regressions can be developed. Changes between the periods are calculated based on a comparison of predicted values calculated from the regression equations and observed values during the treatment period. There are three watersheds in this study consisting of a control watershed and two treatment watersheds; traditional, and BMP.

The calibration period started at different dates depending on the site, and the treatment period start dates varied also (Table 1).

Project Schedule

Table 1. Jordan Cove Project Schedule.

Watershed	Calibration	Construction	Post-Construction
Control	11/95 -		
BMP	1/18/96 – 3/23/99	3/23/99 – 8/1/02	8/1/02 - present
Traditional	8/96 – 10/8/97	10/8/97 – 6/19/03	6/19/03 -

Study Area

The project is located in the town of Waterford, CT. The watersheds under study are located in the drainage basin contributing to a small estuary called Jordan Cove which in turn discharges into the Long Island Sound. The control site is a 5.63 ha. residential watershed containing 43 lots that have been developed for approximately 12 years (Figure 2). The traditional site is a subdivision containing 18 lots using ‘traditional’ regulations and construction practices (Figure 3B). Traditional house zoning was used, as was a curb and gutter stormwater collection system. A typical 8.5-m asphalt road was installed. Landscaping and turf is similar to other new subdivisions. Roof runoff is directed to lawn areas or onto driveways. Erosion and sediment controls used during construction were typical of other construction sites statewide. Impervious surface coverage is currently greater than 11%. The BMP watershed incorporates several pollution prevention measures as part of its design (Figure 3A). A main feature is the replacement of a traditional 8.5 m. asphalt road and curbs-and gutters, with a 6.1 m- wide concrete paver road and grassed bioretention swales. A bioretention cul-de-sac that allows for detention and infiltration of runoff was constructed in lieu of a conventional paved area. Individual bioretention gardens are incorporated into each lot to detain roof and lot runoff. Several alternative driveway surfaces are installed including asphalt, concrete pavers, and gravel. Houses were constructed in a cluster layout with reduced lawns, low-mow areas, and no-mow areas. Deed restrictions were developed to prevent certain activities during the study and ongoing education programs are used to instruct owners on good housekeeping practices. During construction additional BMPs have been used including locating and seeding stockpiles to prevent sediment loss, hay bales, silt fence, earthen berms and basement holes to retain stormwater onsite, and post-storm maintenance. Watershed areas for the traditional and BMP sites varied during land development.

The project is located in a climate that is influenced by both continental polar and maritime tropical air masses (Brumbach, 1965). Average annual precipitation is approximately 1,265 mm and distributed uniformly throughout the year. Hurricanes enter the state periodically. Soils on the sites are mapped as Canton and Charlton with an increasingly disturbed urban land classification associated with construction.

Waivers

Several waivers of the subdivision regulations for the Town of Waterford were obtained as part of the design of this study. These waivers included the reduction of road width from 8.5 to 6 m in the BMP watershed, reducing the curb height from 15 cm to no curb, and allowing paver blocks instead of asphalt. Also the cul-de-sac was modified to allow an oblique form vs a standard 15 m radius, that would have one-way traffic flow, and center depressed island as a bioretention area.

Deed Restrictions

Deed covenants were included in two documents as part of the subdivision. The first document is termed a “Declaration”. The declaration is needed to create a common planned community. The declaration also created the Glen Brook Green Association to oversee the common areas and administer the by-laws. The following are relevant sections of the declaration:

Sect 8.2 – Use and Occupancy Restriction for Specific Units

(a) Lots 10 through 21 inclusive are subject to an easement for the construction and maintenance of “Rain Gardens” with overflow connection to the grassed swale and/or detention basin as shown on said map.

(b) Lots 10 through 21 inclusive, and lots 22 through 28 inclusive are subject to an easement for the construction and maintenance of a drainage swale as shown on said map.

(g) All lots are part of a study site under Section 319 National Monitoring Program between the declarant, Federal, State and Local entities including but not limited to U.S. Environmental Protection Agency, Connecticut DEP, University of Connecticut and the Town of Waterford Conservation Commission and Planning and Zoning Commission, Grantees of Units 10 through 21 by the acceptance of a deed to said Unit agree to use their best efforts to cooperate with federal, state, and local officials to implement "best management practices" (BMP) and other storm water control techniques.

(h) The following covenants, easements and restrictions shall apply to Lots 10 through 21 for a period of time no later than ten (10) years from the date hereof (March 19, 1998):
    (1) No structures, fences, posts, mailboxes or other obstructions to water flow shall be placed in any swale or Rain Gardens located on said Lots 10 through 21.
    (2) No filling or alteration to the topography of any swales or Rain Gardens on said Lots 10 through 21 shall be allowed.
    (3) Driveways shall be maintained in original surfaces.
    (4) No impervious additions shall be permitted to any Unit building, including, patios, extension of driveways, provided however that "accessory buildings" as allowed by the Town of Waterford Zoning Regulations will be permitted upon approval by the Town of Waterford.
    (5) Units 10 through 21 are subject to the following BMP's: grass biotentention swale, bioretention gardens, area entitled "Conservation Zone", unit owners shall accept said units subject to the rules, regulations and restrictions as may be issued under the Section 319 National Monitoring Program for said areas.

(i) Plants located in any area of a Unit designated as "low mow area" and plants located in any Rain Garden shall not be disturbed, but in the event of replacement thereof only plants from the approved list attached to the landscaping plan of the subdivision map shall be allowed.

The Bylaws of Glen Brook Green Association, Inc. reaffirm the program in Section 3.11 below:

<u>Section 3.11 – National Monitoring Program</u>. All Unit owners acknowledge and recognize that for a period of ten (10) years from the date of the subdivision approval all lots are part of a study site under Section 319 National Monitoring Program between the Declarant, Federal, State, and Local entities including but not limited to U.S. Environmental Protection Agency, Connecticut DEP, University of Connecticut and the Town of Waterford Conservation Commission and Planning and Zoning Commission. All unit members agree to use their best efforts to cooperate with Federal, State and Local officials in their studies of the subdivision. Unit members will not take any action that will interfere with the restrictions and obligations of Units 10 through 21 to use their best efforts to cooperate with federal, state, and local officials to implement "best management practices" (BMP) and other storm water control techniques. Unit owners acknowledge that Association has the power to levy reasonable fines for any violation of this section (See Section 2.2 [k]). Unit owners agree not to amend these by-laws in any way that might affect the Section 319 National Monitoring Program unless the Town of Waterford consents in writing.

Monitoring Methods

Precipitation was recorded at the BMP site using a heated tipping bucket rain gauge. Air temperature was continuously monitored to allow separation of snowmelt periods from precipitation events. Stormwater flow was monitored continuously during storm events from the three watersheds using ISCO 4230 bubbler flowmeters. The control monitoring site has a combination rectangular/V-notch weir, installed in a 76 cm. stormwater pipe, discharging into a detention pond. The traditional monitoring site used a 38.1 cm. Palmer-Bowlus flume attached to a stormwater pipe located in a monitoring manhole. During calibration a 45.72 cm. H-flume was used to measure overland flow. A 45.72 cm. H-flume was used at the end of a grassed swale at the BMP monitoring site.

Samples were collected automatically by an ISCO sampler that has been programmed to collect a sample every 3000 cu ft of discharge. Collected samples were refrigerated in-situ. Three samples were taken at each flow interval; one is pre-acidified with sulfuric acid for nutrient preservation, the second is pre-acidified with nitric acid for metals analysis, and the third is not acidified. The third sample is intended for suspended sediment analysis. If flow was occurring during the field visit, a grab sample was taken for BOD and fecal coliform analysis.

Collected samples were immediately placed in a cooler with ice packs and transported to the water quality laboratory where they were stored in a refrigerator that has a constant temperature of 4^oC.

Each sample was dated and coded according to site, sample type, station number, and sample sequence. The actual sample containers were labeled only with a sample number for identification and whether the sample is acidified (A) and filtered (F).

Sample Analysis

Acidified composite stormwater samples were analyzed for nitrate+nitrite nitrogen (NO_3/NO_2-N), ammonia-nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) using a Lachat colorimetric flow injection system (USEPA, 1983). Non-acidified samples were analyzed for total suspended solids (TSS) using an approved EPA gravimetric method (APHA, 1989; USEPA, 1983). Acidified unfiltered samples were composited on a monthly basis and analyzed for copper (Cu), lead (Pb), and zinc (Zn) (USEPA, 1983). Grab samples were performed on site visits when stormflow was present and analyzed for fecal coliform bacteria and 5-day biochemical oxygen demand (USEPA, 1983). Sample volumes, preservation methods, and holding times are summarized in Table 2. Analytical methods are summarized in Table 3. Values for mass export (kg/ha/yr) were calculated by the multiplication of weekly cumulative flow and weekly sample concentration and subsequently divided by watershed area.

Maintenance

ISCO pump tubing was cleaned following the collection of 20 samples by removing the tube in place and replacing it with a cleaned tube. Cleaning includes pumping hot tap water through the tubing for at least two minutes, acid washing for two minutes, and rinsing with distilled water for two minutes. An equipment blank was collected every 20 samples by activating the ISCO sampler and running distilled water through the pump tubing into a bottle.

Table 2. Field sampling table for the Jordan Cove 319 Project.

Parameter	No/yr	Volume	Container	Preservation	Holding Time
Total suspended solids	156	200 ml	Plastic	Cool, 4^{o}C	7 days
Total phosphorus	156	50 ml	Plastic	Cool, 4^{o}C H_2SO_4 to pH<2	28 days
Total Kjeldahl-N	156	50 ml	Plastic	Cool, 4^{o}C H_2SO_4 to pH<2	28 days
Ammonia-N	156	12 ml	Plastic	Cool, 4^{o}C H_2SO_4 to pH<2	28 days
Nitrate+nitrite-N	156	12 ml	Plastic	Cool, 4^{o}C H_2SO_4 to pH<2	28 days
Fecal Coliform	156	100 ml	Plastic	Cool, 4^{o}C	6 hours
BOD	156	300 ml	Plastic	Cool, 4^{o}C	48 hours
Cu, Zn	156	100 ml	Plastic	Cool, 4^{o}C HNO_3 to pH<2	6 months
Pb	156	100 ml	Plastic	Cool, 4^{o}C HNO_3 to pH<2	6 months

Table 3. Laboratory Analysis Methods.

Parameter	Methodology	Detection Limit	EPA[1] Method	Standard Methods[2]
Residue, non-filterable	Gravimetric, dried at 103 - 105°C	4 mg/L	160.2	
Ammonia-N	Colorimetric automated	0.01 mg/L	350.1	
Total Kjeldahl-N	Colorimetric semi-automated	0.1 mg/L	351.2	
Nitrate-nitrite-N	Colorimetric, Cd reduction, automated	0.05 mg/L	353.2	
Total phosphorus	Colorimetric automated	0.005 mg/L	365.4	
Fecal Coliform	Membrane Filter	1 CU/100 mL		9222D
BOD$_5$	YSI probe	2 mg/L	405.1	5210B
Cu, Zn	Plasma emission spectroscopy	4 ug/L 10 ug/L	200.7	
Pb	Atomic absorption, furnace	1 ug/L	239.2	

[1] U.S. Environmental Protection Agency. 1983. Methods for chemical analysis of water and wastes. EPA-600/4-79-020. Environmental Monitoring and Support Laboratory, Cincinnati, OH.

[2] American Public Health Administration. 1989. Standard methods for the examination of water and wastewater. 17th Ed. APHA. Washington, D.C.

Driveway Study

Study Area

Study driveways were located in the BMP residential watershed. Precipitation during the study period was 14.8% below normal. There were 13 weeks with no precipitation, and therefore no runoff. There was an additional 6 weeks with less that 1 mm of precipitation. Of the six monitored driveways, there were two replicates each of asphalt, UNI group EcoStone ® interlocking concrete pavers, and crushed stone. Five of the driveways were shared and one was for a single home (Figure 5). Driveway watershed areas were calculated using as-built maps and field measurements. Total driveway area ranged from 7 m^2 to 650 m^2. The percent of land cover types in each driveway watershed varied and included driveway, lawn, and landscaped areas, roofs, and steps (Table 4).

Methods

The subdivision was under construction as the study began. Monitoring equipment was installed as each driveway was finished, resulting in unequal sampling periods at each site. The final site was completed in June 2002, providing 12 months during which all six sites were monitored and two years for some sites.

Driveway stormwater runoff was collected in a concrete trench drain (ABT® Inc. Troutman, NC) and volume was measured with a calibrated tipping bucket and mechanical counter. Approximately 0.0007 % of total flow was collected using a flow splitter into one bottle acidified with H_2SO_4 and another that was not acidified. A third bottle acidified with HNO_3 was added to asphalt 1 and paver 1 driveways for metals analysis. A portion of the H_2SO_4 acidified sample was used for metals analysis at the other four sites because there was not enough room for a third bottle. Samples were preserved in the field with ice packs replaced weekly. Precipitation was monitored on-site using a tipping bucket rain gauge. Onsite precipitation was used to calculate runoff coefficients, but rainfall departure from normal was calculated using precipitation measurements made at the Groton CT NCDC station (NOAA 2001, 2002). Acidified composite storm water samples were analyzed for nitrate-nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN) and total phosphorus (TP) with a Lachat flow injection analyzer (USEPA, 1983a). Un-acidified samples were analyzed gravimetrically for total residue (TSS) (USEPA, 1983a). Total copper, lead and zinc were determined on monthly composite unfiltered samples using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) methods 200.8 (USEPA, 1991).

Infiltration tests were performed on each driveway annually, using a single ring infiltrometer (Smith and Mullins, 1991). A Mariotte column (Bower, 1986) was used to maintain a constant ponding depth in the ring. Data presented is the average final infiltration rate of three tests per driveway in 2002 and two tests per driveway in 2003. A measured volume of stone from each crushed stone driveway was collected in the field, and then re-compacted to its original volume in the lab. Porosity was determined by adding a measured volume of water to the sample. A flowing infiltration test was also conducted in 2003. A metered perforated hose was placed on the driveway approximately 4.5 to 5 meters away from the trench drain. Infiltration was calculated as volume applied minus volume of runoff per unit time.

Driveway concentration, and runoff data were statistically analyzed using SAS version 8.0 software (SAS Institute, Inc. 2001). Data were found to be log-normally distributed, therefore, statistics were preformed on log-transformed data. Means presented are the anti-log of the transformed data. Repeated measures, analysis of variance was used to test for the overall difference among treatments. Seasons were used as the repeated measure. Two forms of runoff depth were analyzed: adjusted and unadjusted. Adjusted runoff depth included differences in watershed land cover. Two separate adjustments were :

a) Runoff depth * (proportion grass/roof), and
b) Runoff depth * proportion grass

These values were log-transformed and analyzed in the same manner as the unadjusted runoff depth data. To check and see if nutrient concentrations were possibly diluted by roof run-on, or concentrated by turf run-on, data were adjusted by watershed land area factors in a similar manner to depth adjustments.

Missing data due to equipment malfunctions, led to ignoring asphalt 2 and crushed stone 2 driveways in weekly pollutant export comparisons. Annual pollutant mass export was calculated from March 2002 – March 2003 for the asphalt 1, paver 1, and crushed stone driveways. Linear regressions were used to determine appropriate approximate values for missing volume data points. Average concentration values were used for missing concentration data. Linear regressions were preformed on logged data to determine if there was a relationship between rainfall and runoff depth for all driveways.

Table 4. Watershed characteristics for the six study driveway sites in Waterford, Ct.

Land Cover Type	Asphalt 1	Asphalt 2	Paver 1	Paver 2	Crushed Stone 1	Crushed Stone 2
Driveway (%)	56	100	22	100	53	37
Turf/landscaped (%)	0	0	63	0	27	13
Roof/steps (%)	44	0	15	0	21	50
Total area (m^2)	390	7	730	80	300	150
Slope (%)	3.3	3.2	4.4	4.7	2.6	4.5

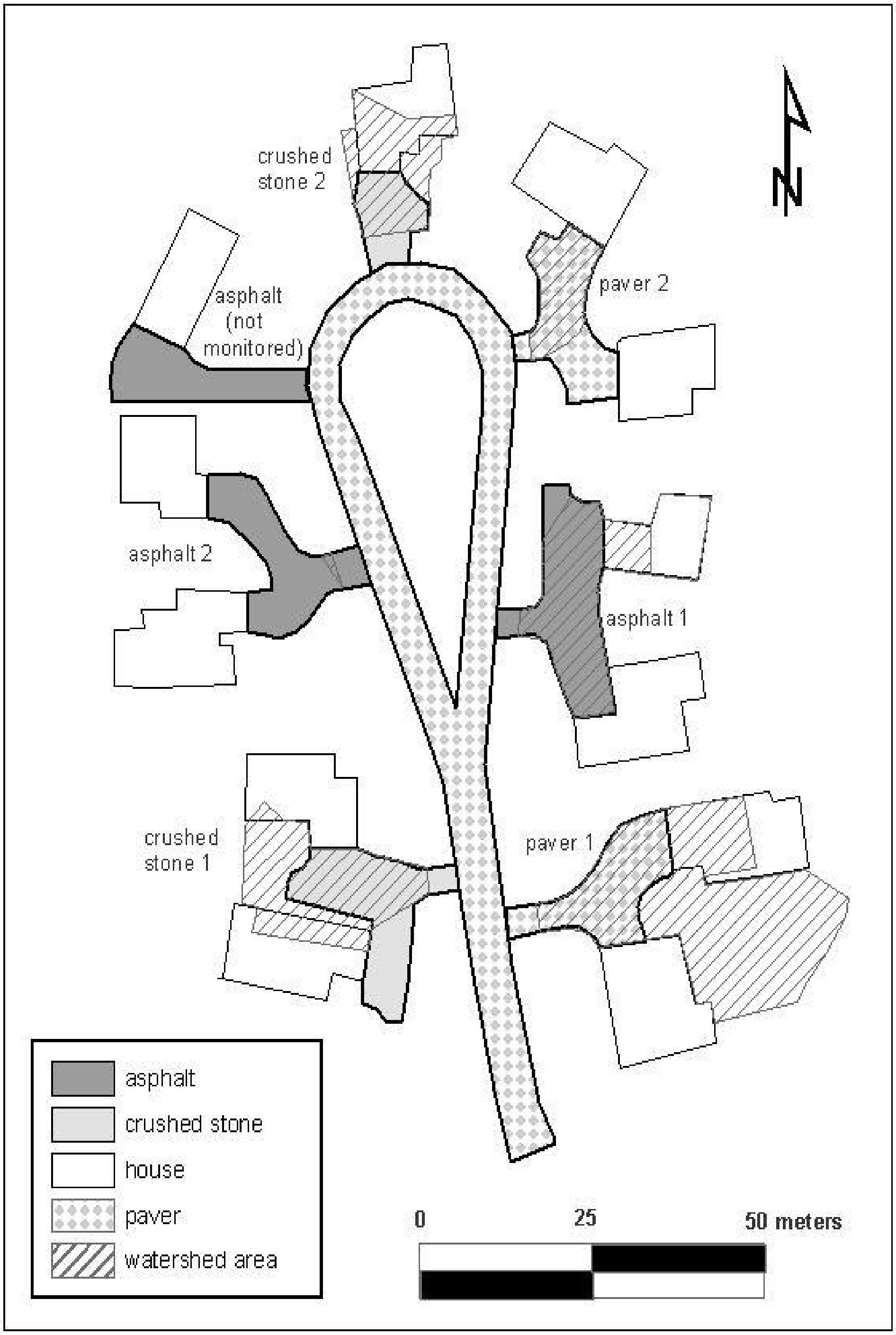

Figure 5. Project area site map including driveway type and watershed areas.

Lawn Nutrient Study

Throughout the control, BMP and traditional watersheds suction cup lysimeters (model 1905L06 slim tube sampler, Soilmoisture Equipment Corp, Goleta, CA), and anion exchange membranes (AEMs) were installed in lawns. Sites were chosen to represent a wide range of fertilizer applications. Water collected in suction cup lysimeters were collected following storm events. AEMs (type 204-U-386) were installed in the lawn surfaces and retrieved periodically and analyzed for NO_3-N. The AEMs were made from vinyl reinforcing fabric embedded with NH_4. Each AEM measured 6.25 X 2.5 cm. To install the strips, a vertical slit is made in the soil with a trowel, following by tamping in. AEM strips were prepared and analyzed for NO_3-N as described in Kopp and Guillard (2002). At sampling periods, spectral reflectance was measured which relates to the color of chlorophyll content of the lawn. This reflectance is used as a measure of lawn quality. Soil samples were also taken for nutrient analysis.

Household Survey

A 10-question survey was sent to each resident in the three watersheds each spring since 1999. A copy of the survey is given in the Appendix. The survey is intended to track information that might affect the study results. Questions focus on pets, lawn care, fertilizers, watering, leaf disposal, rain gutters, and car washing. This survey also gives us an opportunity to communicate study results. A gift is often offered to those who complete the questionnaire.

Statistical Analysis

All data were statistically analyzed using SAS version 8.0 software (SAS Institute, Inc., 1999). Analysis of variance (ANOVA) was used to test the significance of the regressions in each period. Analysis of covariance (ANCOVA) was used to test the differences between the two regression slopes and intercepts. Most water quality data were log-normally distributed, and therefore, means presented are anti-logs of log-transformed data.

RESULTS AND DISCUSSION

BMP Watershed

Runoff

Weekly flow is shown in Figure 7. Higher flow during calibration than during either construction or post construction periods is evident. During construction, mean weekly flow volume decreased 744 % based on the predicted value using the calibration regression equation and the control value observed during the treatment period (Table 5). The decrease in runoff can be attributed to landform changes that retained water onsite and allowed infiltration to occur after storm events. Specifically, an earthen berm was constructed upstream of the BMP monitoring station which pooled water and obstructed flow to the station for several months during the treatment phase. Additionally, excavations were performed for basements on all lots within a short period, resulting in 'detention basins' that held stormwater onsite. Lastly the fill needed to raise the elevation of the area allowed for higher infiltration than the native soil present before the treatment phase. During the first year of post-construction, flow decreased 106% as compared to the calibration period (Table 6).

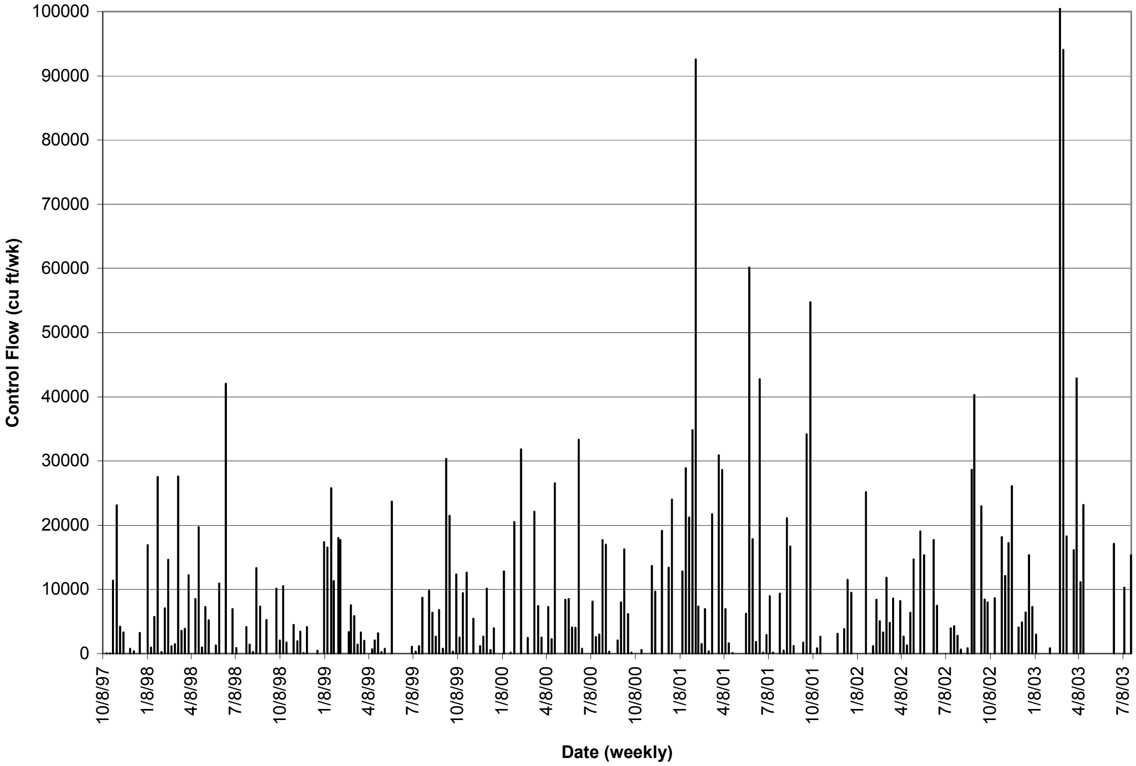

Figure 6. Control watershed weekly flow (Jordan Cove, Waterford, CT).

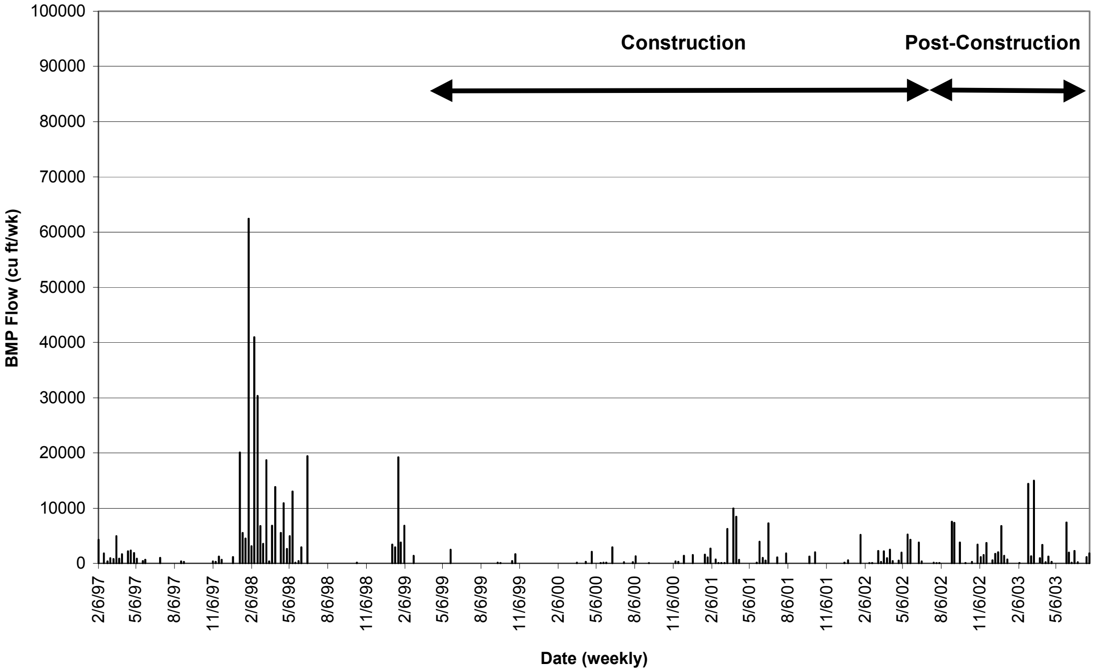

Figure 7. BMP watershed weekly flow (Jordan Cove, Waterford, CT).

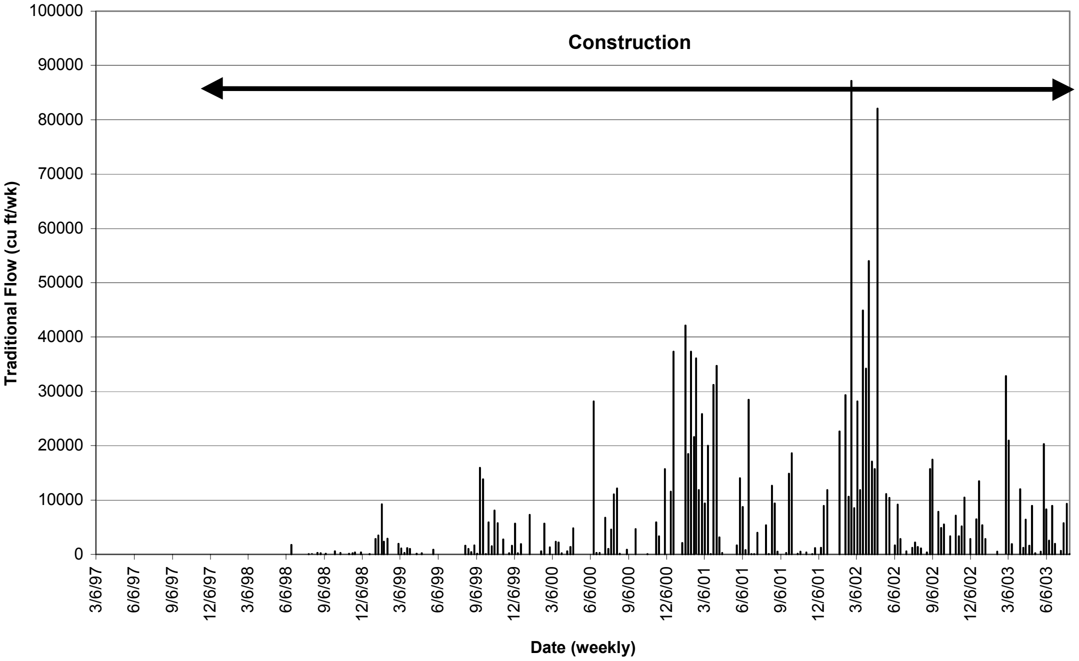

Figure 8. Traditional watershed weekly flow (Jordan Cove, Waterford, CT).

Sediment

Concentration. Using ANCOVA, TSS concentrations significantly increased ($P < 0.001$) 59% based on a difference in regression equation intercepts due to residential construction (Table 5). TSS concentrations in stormwater varied through the construction period (Figure 10). Peak TSS concentrations occurred during installation of the permanent monitoring station in March 2000 where slow re-growth of vegetation after seeding was observed. Additional peaks were observed in May 2000 when the swales were constructed. Vegetation was established by September 2000. The swales were reconstructed during the summer of 2001 (May 9th), resulting in higher TSS concentrations. Recent observations of TSS values at the BMP site have indicated a decline in concentrations.

Following construction, TSS concentrations have remained significantly higher than predevelopment concentrations (Table 6).

Export. During construction, sediment export did not increase significantly due to residential construction (Table 5). Following construction, TSS export declined significantly. This decrease following construction is likely due to the decrease in flow since concentrations increased somewhat.

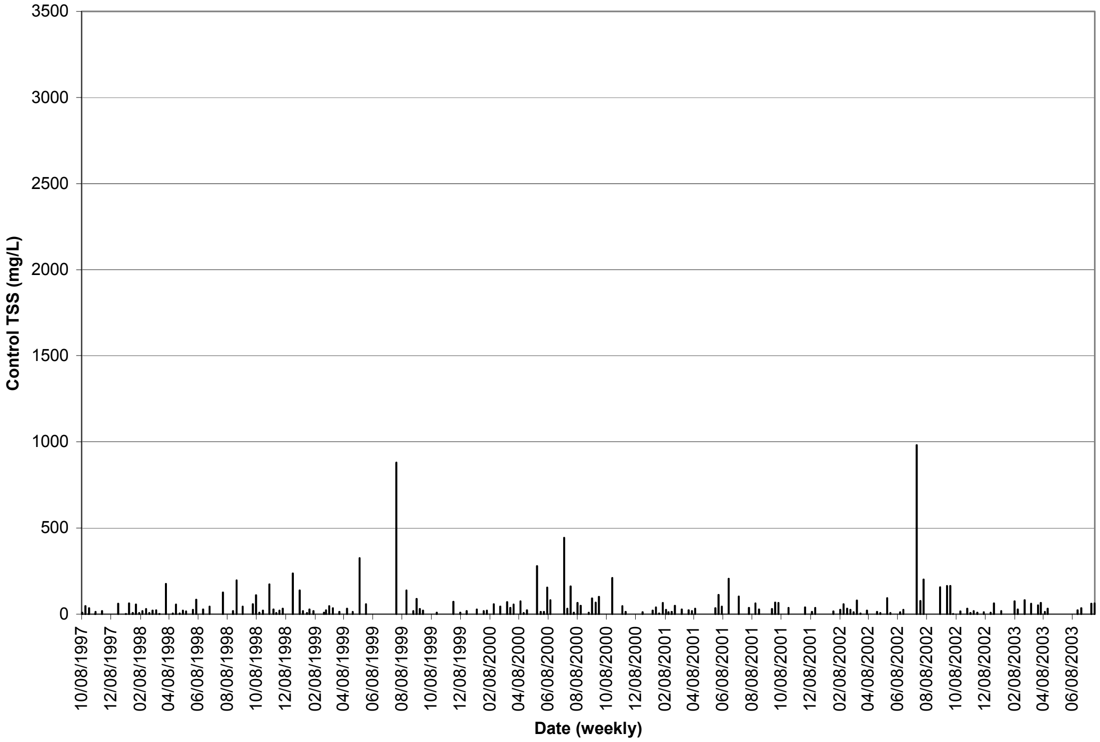

Figure 9. Control watershed TSS concentrations (Jordan Cove, Waterford, CT)

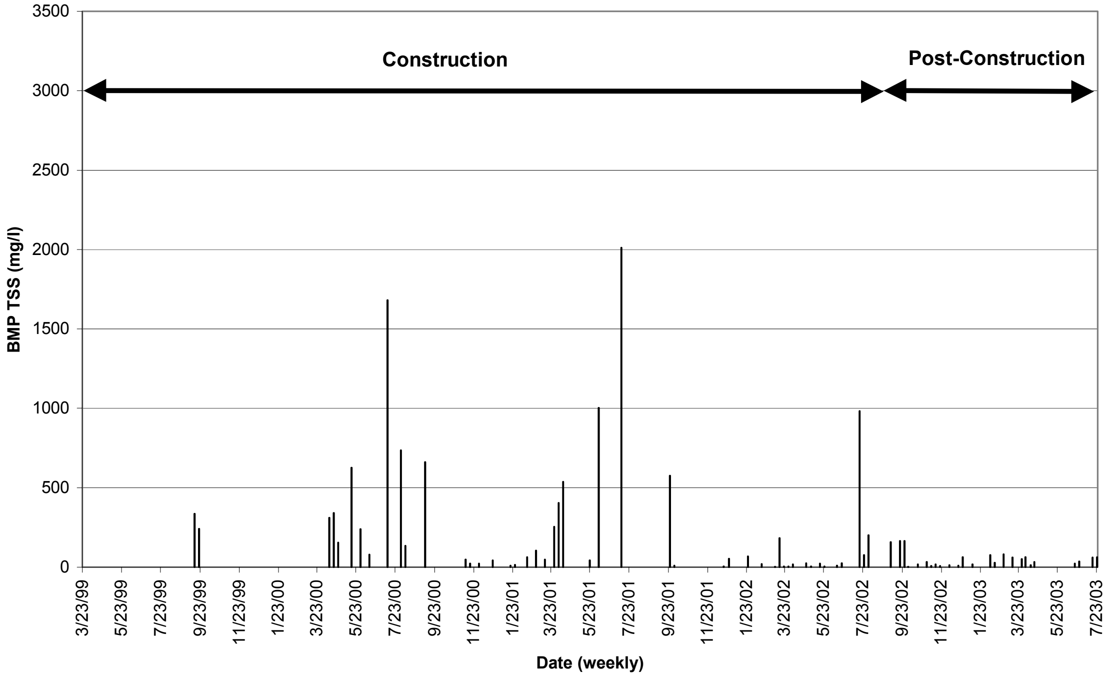

Figure 10. BMP watershed TSS concentrations (Jordan Cove-Waterford, CT)

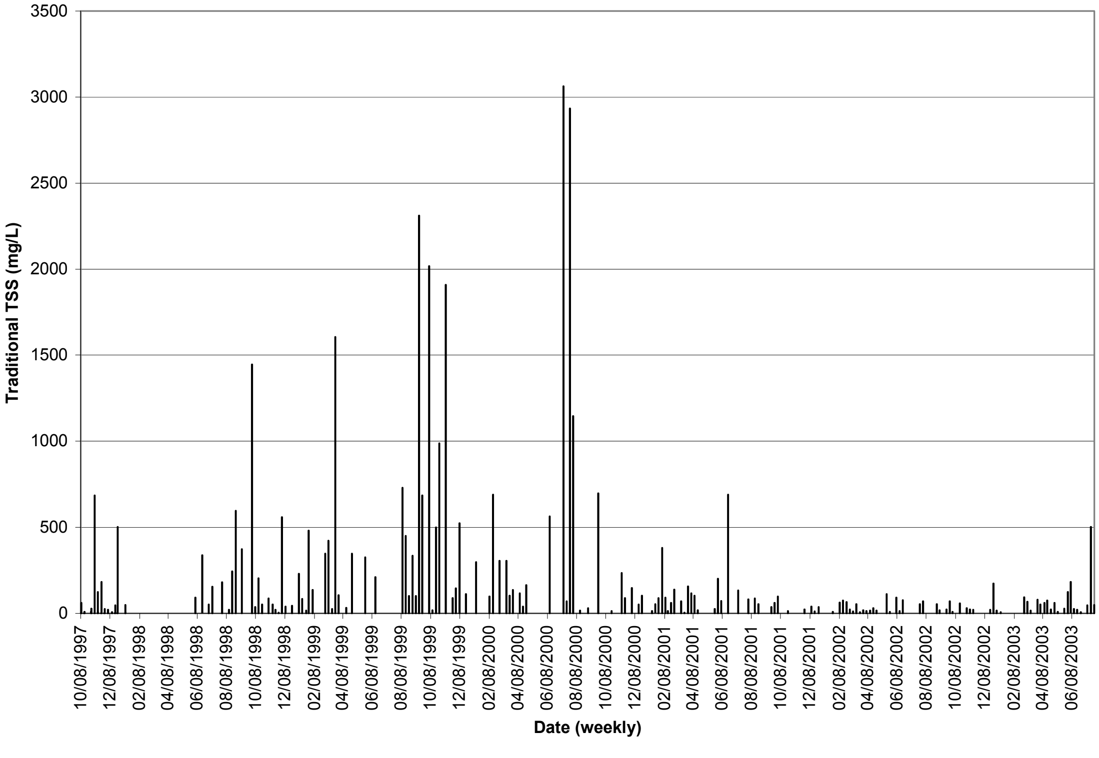

Figure 11. Traditional watershed TSS concentrations during the construction period (Jordan Cove-Waterford, CT)

Nitrogen

Concentration. During the construction period, the concentrations of NO_3-N, NH_3-N, and TKN all increased significantly in runoff from the BMP watershed (Table 5). The increase in NO_3-N concentrations is probably associated with fertilizer applications (Figure 13). During the first year of the post-construction period, NO_3-N, and NH_3-N concentrations did not increase, however, TKN concentrations remained higher (Table 6). The higher TKN concentrations were due to higher organic N.

Export. During construction, the export of NH_3-N and TKN decreased significantly (Table 5). This decrease was due to the flow decreases because concentrations had increased. Following construction, the export of NO_3-N, NH_3-N, and TKN all decreased significantly (Table 6). The flow decrease is responsible for these export decreases observed.

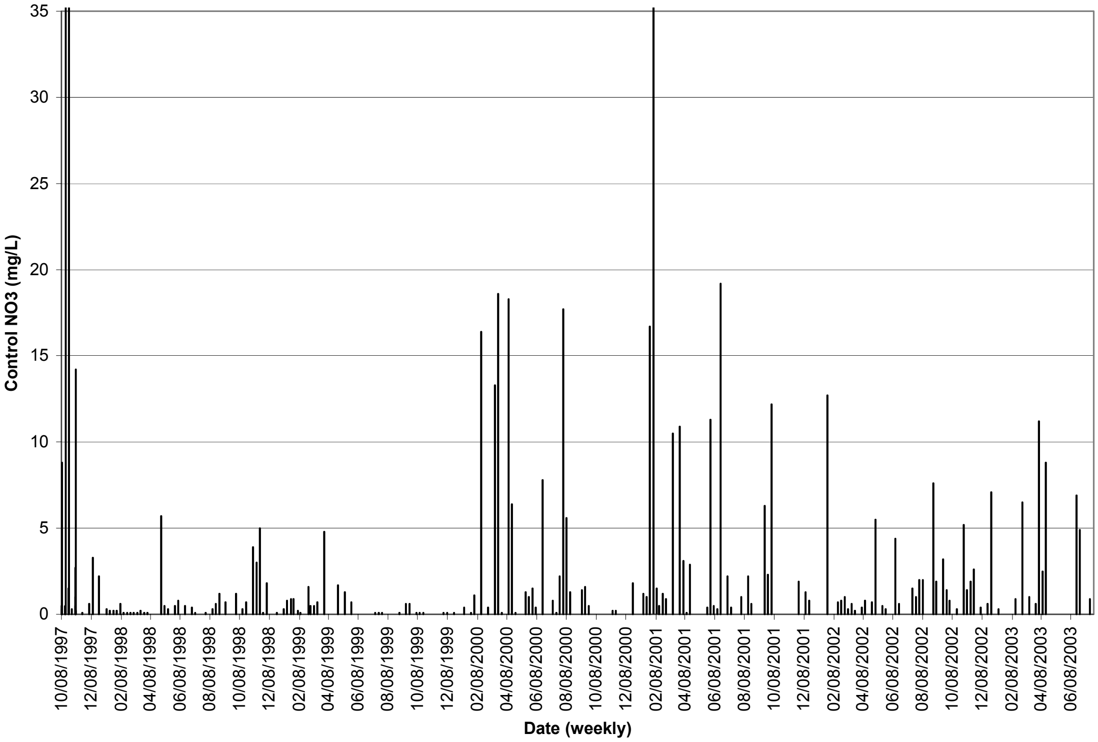

Figure 12. Control watershed NO_3-N concentrations (Jordan Cove-Waterford, CT)

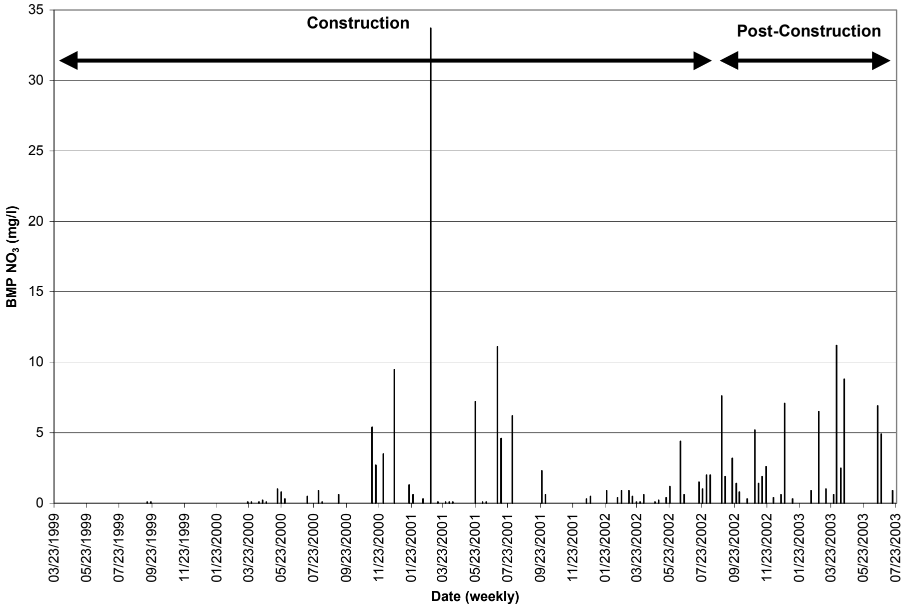

Figure 13. BMP watershed NO_3-N concentrations (Jordan Cove-Waterford, CT)

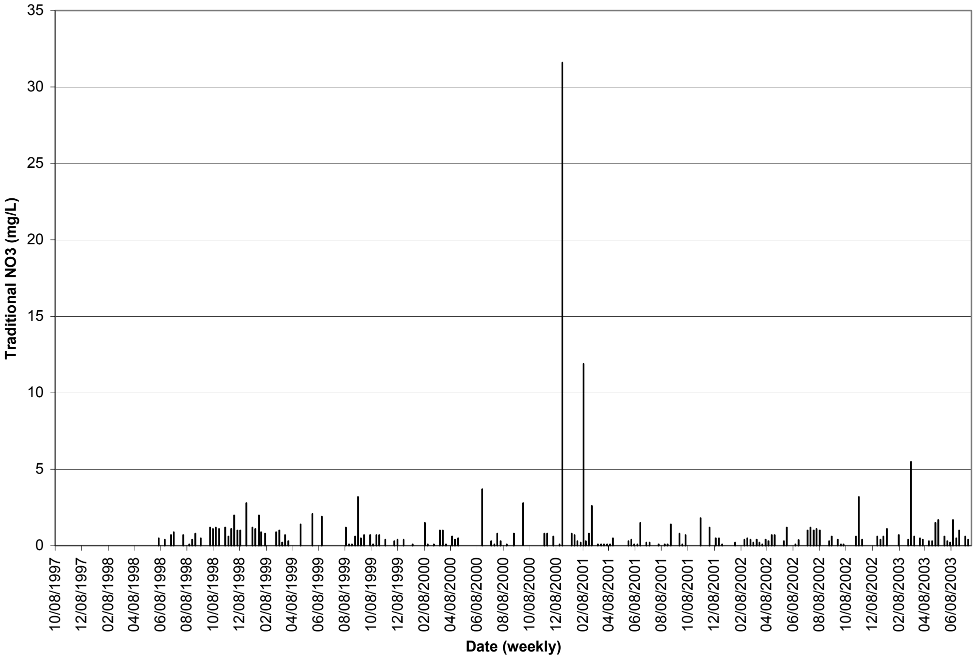

Figure 14. Traditional watershed NO_3-N concentrations (Jordan Cove-Waterford, CT)

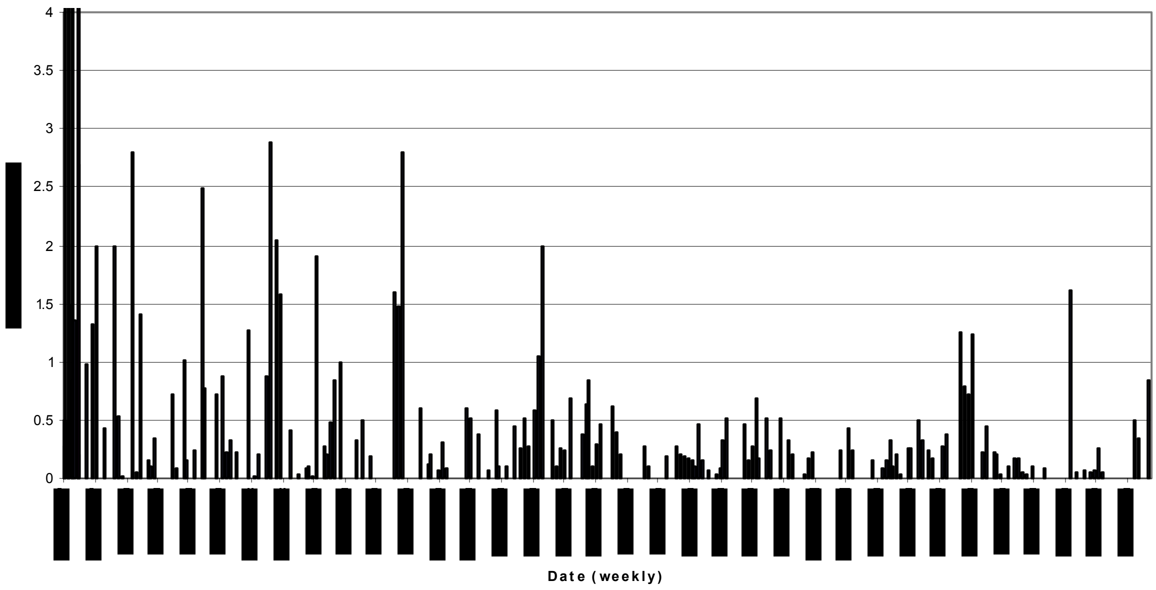

Figure 15. Control watershed NH_3-N concentrations (Jordan Cove-Waterford, CT).

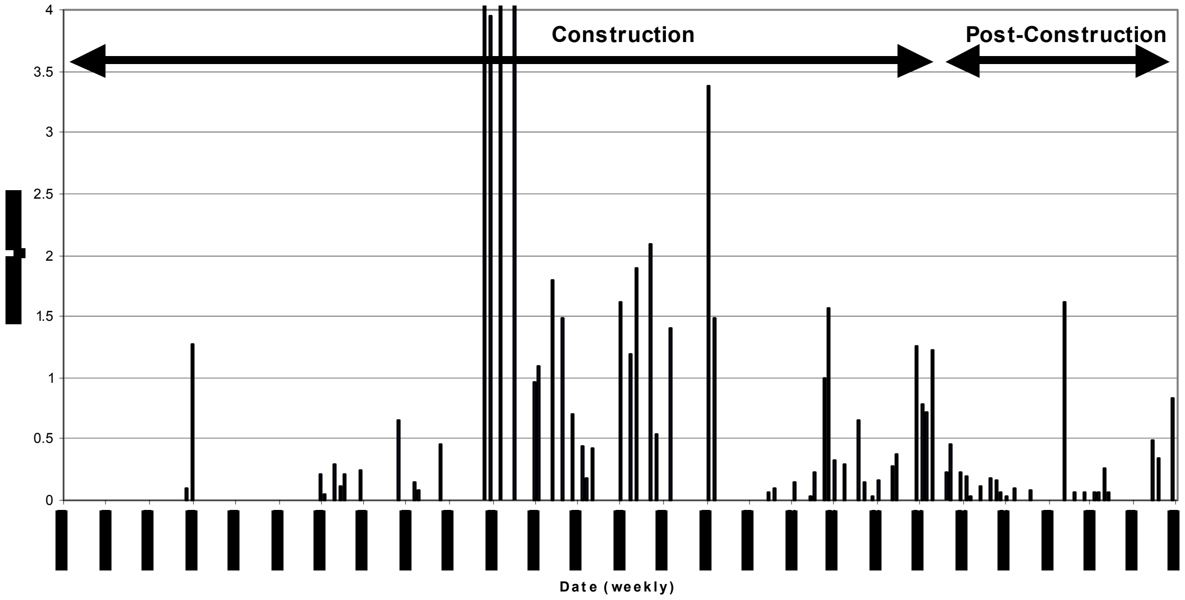

Figure 16. BMP watershed NH_3-N concentrations (Jordan Cove-Waterford, CT).

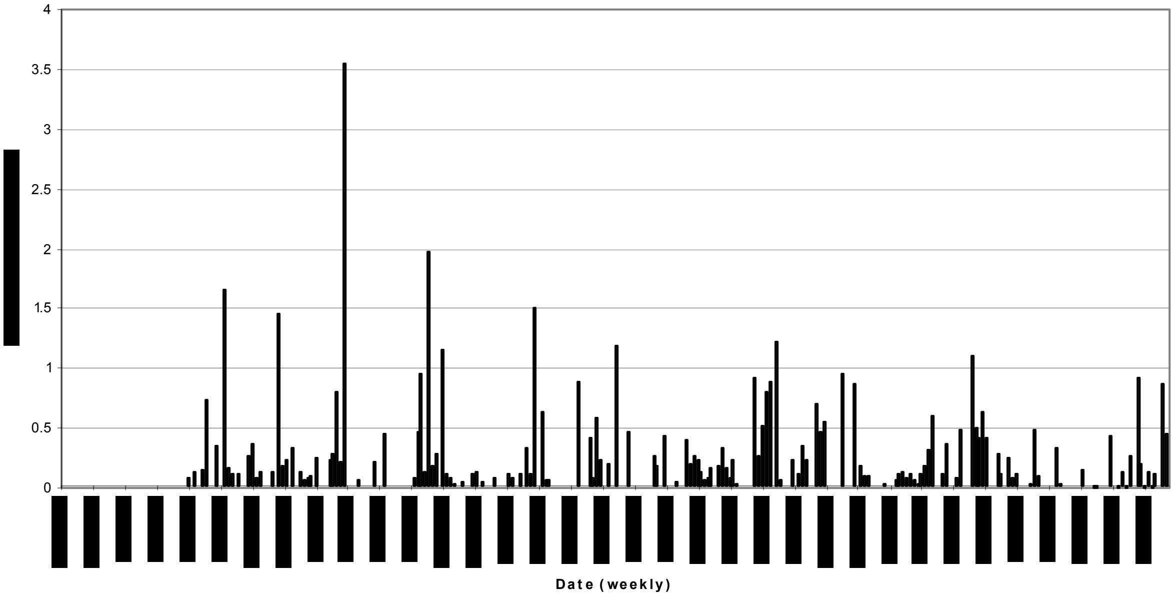

Figure 17. Traditional watershed NH_3-N concentrations (Jordan Cove-Waterford, CT).

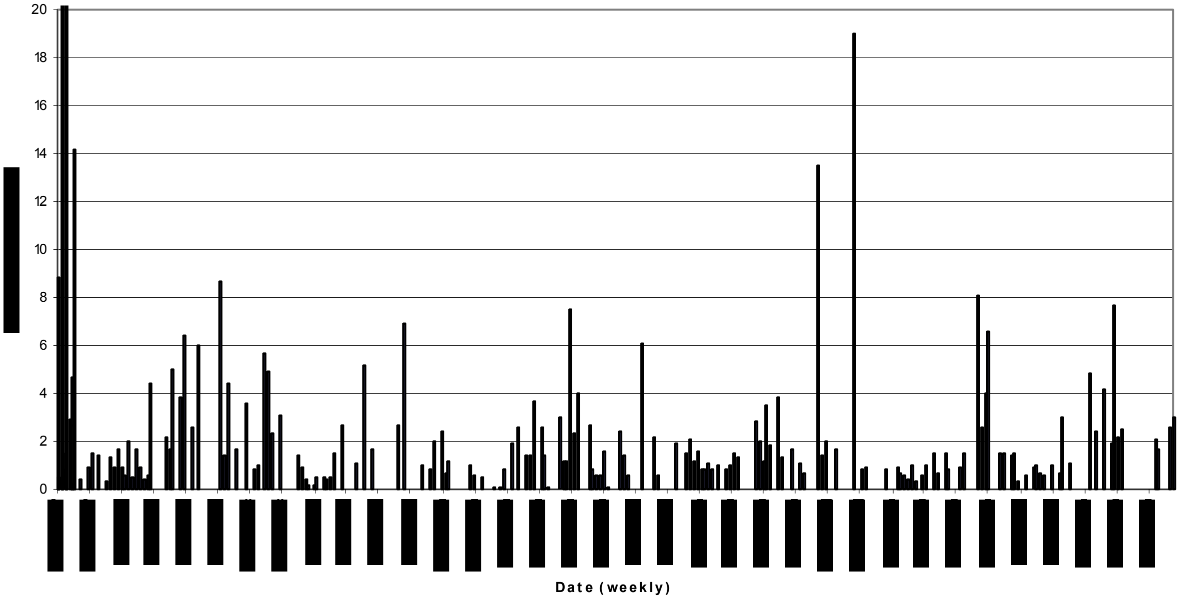

Figure 18. Control watershed TKN concentrations (Jordan Cove-Waterford, CT).

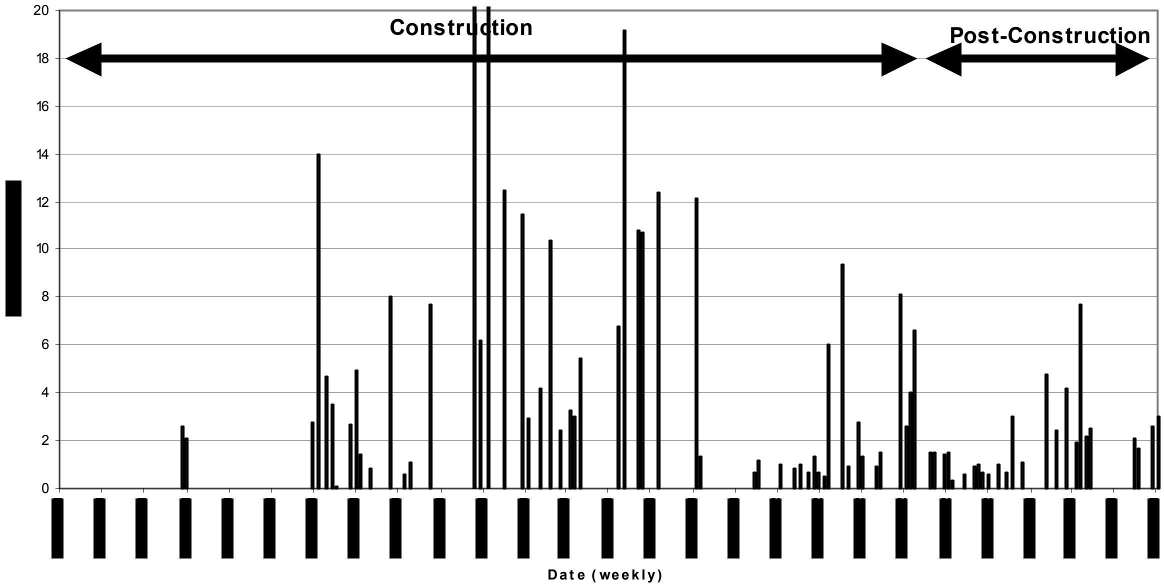

Figure 19. BMP watershed TKN concentrations (Jordan Cove-Waterford, CT).

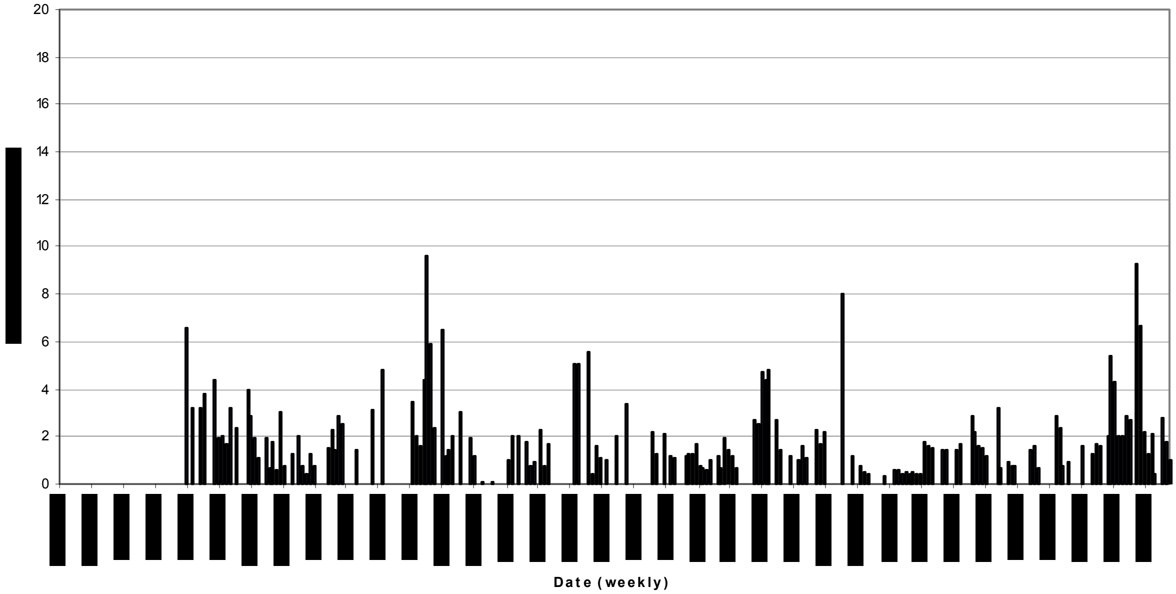

Figure 20. Traditional watershed TKN concentrations (Jordan Cove-Waterford, CT).

Total Phosphorus

Concentration. The concentration of TP increased significantly both during construction and following construction (Tables 5 and 6). The increases during construction are particularly noticeable (Figures 21-23).

Export. TP export did not change during either the construction period or the first year of the post-construction period.

Metals

Concentration. The concentrations of both Cu and Pb increased in stormwater during construction but Zn concentrations did not increase (Table 5). Following the construction period, the concentrations of Pb and Zn decreased and Cu concentrations did not change (Table 6).

Export. There was no change in the export of metals during construction at the BMP site (Table 5). The export of Cu, Pb, and Zn decreased following construction, because of both flow and concentration decreases (Table 6).

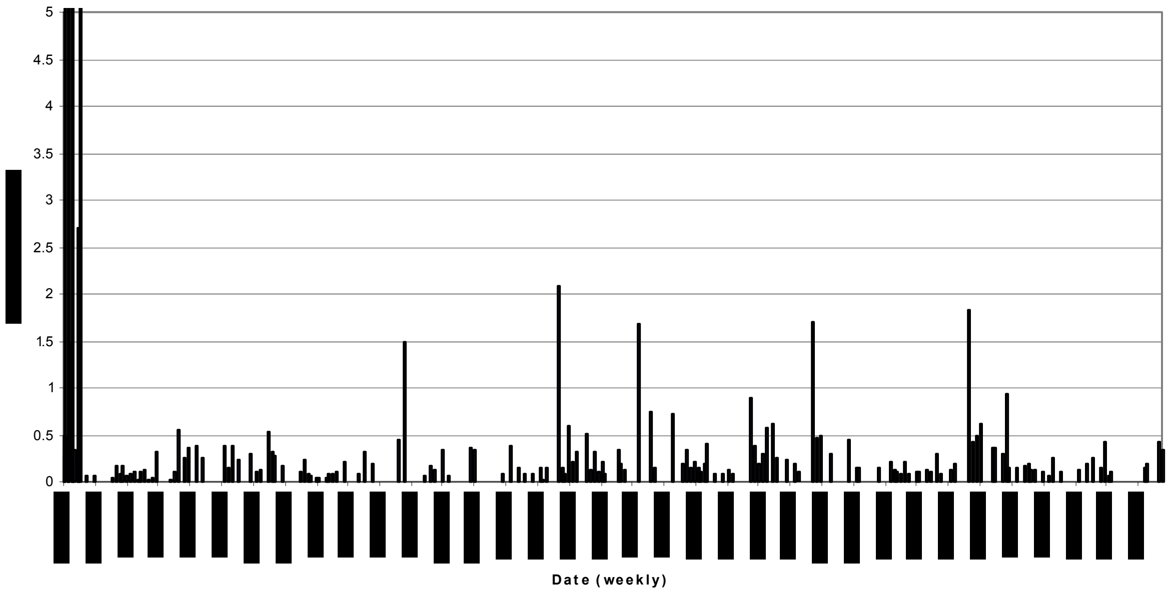

Figure 21. Control watershed TP concentrations (Jordan Cove-Waterford, CT).

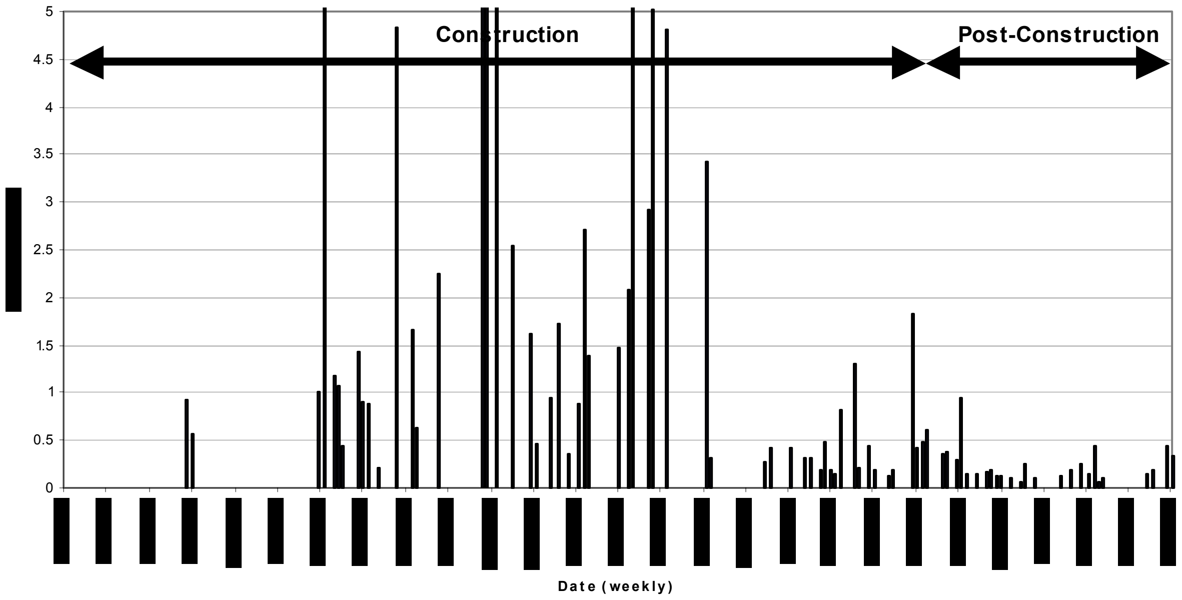

Figure 22. BMP watershed TP concentrations (Jordan Cove-Waterford, CT).

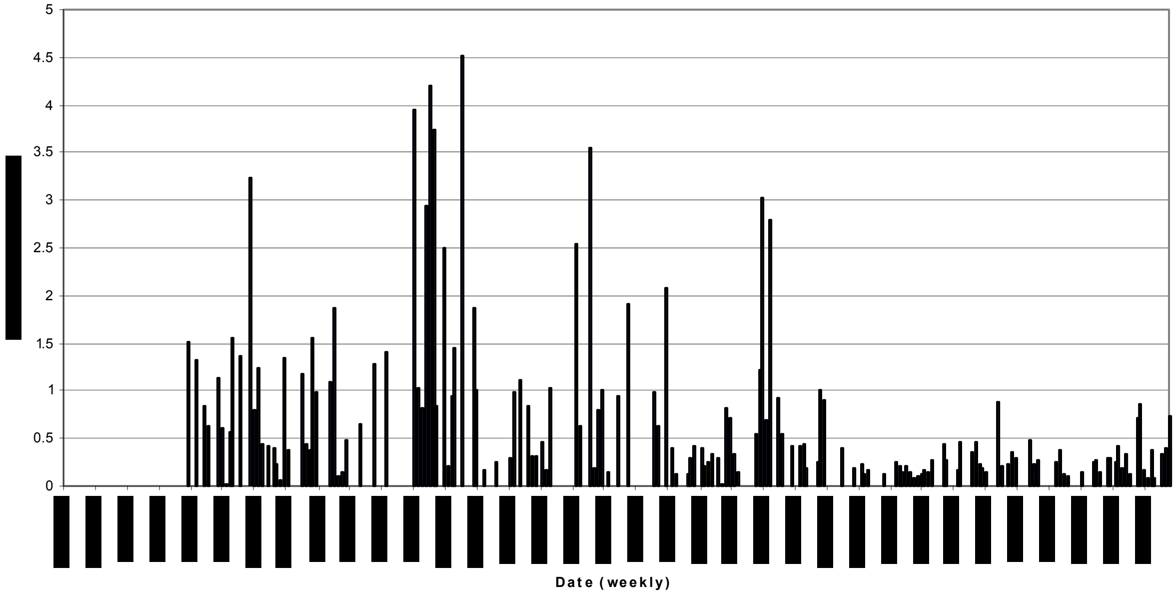

Figure 23. Traditional watershed TP concentrations (Jordan Cove-Waterford, CT).

Traditional Watershed

Runoff

Flow volume increased significantly during construction by over 99% (Table 7) during construction in the traditional watershed (Figure 8). The major cause of the increase in flow volume was the creation of the asphalt roadway during construction that was directly connected to a curb and gutter stormwater collection system.

Sediment

Concentration. There was no change in the concentration of TSS during construction in the traditional watershed (Table 7, Figure 11). This finding indicates that erosion and sediment controls were adequate during construction.

Export. The export of TSS increased over 99% significantly during construction primarily because runoff increased (Table 7).

Nitrogen and Phosphorus

Concentration. The concentration of NO_3-N (Figure 14), NH_3-N (Figure 17), and TP (Figure 23) did not change during construction (Table 7). The concentration of TKN decreased significantly during construction (Figure 20). There is no apparent explanation for this decrease but it would represent a decrease in organic – N concentrations.

Export. The export of NO_3-N, NH_3 , TKN and TP all increased significantly during construction, primarily due to the increase in flow (Table 4).

Metals

Concentration. The concentration of Cu, Pb, and Zn did not change during construction in the traditional watershed (Table 7).

Export. The export of metals increased significantly during construction in the traditional watershed. These increases were associated with the increase in flow (Table 7).

Table 5. BMP watershed results for the construction period (3/23/99-8/1/02).

	Calibration		Treatment Period			
				BMP		
	Control	BMP	Control	Observed	Predicted	% Change
Observations	94	116	66	97		
	(m^3/week)					
Flow	123.33	22.46	139.33	2.86	24.16	-744***
	(mg/L)					
TSS	22	2	22	6	2.5	59***
NO_3-N	0.5	0.4	1.1	1.1	0.4	64***
NH_3	0.16	0.11	0.35	0.96	0.15	84***
TKN	1.2	0.9	1.3	2.2	0.9	59***
TP	0.133	0.084	0.210	1.561	0.083	95***
BOD	2	1	2	2	2	0
	(No. fcu/100 ml)					
FC	14	2	3	2	11	-450$^{\text{N.S.}}$
	(ug/L)					
Cu	10	8	13	30	8	73**
Pb	6	3	6	10	4	62.5**
Zn	66	88	58	117	86	26.5$^{\text{N.S.}}$
	(g/week)					
TSS	583	59	840	88	67	24$^{\text{N.S.}}$
NO_3-N	49	26	168	16	25	-52$^{\text{N.S.}}$
NH_3	7	16	42	5	15	-175*
TKN	67	31	174	24	32	-30*
TP	12	5	30	12	5	58$^{\text{N.S.}}$
	(g/ha/mo)					
Cu	1.06	1.64	1.99	1.48	1.67	-13$^{\text{N.S.}}$
Pb	0.62	0.24	0.93	0.59	0.31	46.8$^{\text{N.S.}}$
Zn	7.13	3.01	8.70	0.82	4.26	-418$^{\text{N.S.}}$

Table 6. BMP watershed results for the post-construction period (8/2/02-7/24/03).

	Calibration		Treatment Period			
				BMP		
	Control	BMP	Control	Observed	Predicted	% Change
Observations	126	120	30	34	--	
	(m^3/week)					
Flow	98.78	19.51	241.72	15.67	32.48	-107*
	(mg/L)					
TSS	22	2	26	6	2.6	59***
NO_3-N	0.5	0.4	1.8	0.4	0.4	13$^{n.s.}$
NH_3-N	0.16	0.11	0.12	0.07	0.10	-43$^{n.s.}$
TKN	1.2	0.9	1.8	1.8	1.0	44*
TP	0.133	0.084	0.212	0.502	0.084	83***
	(ug/L)					
Observations	33	33	8	8		
Cu	10	8	24	5	9	-86$^{N.S.}$
Pb	6	3	6	1	4	-177**
Zn	66	88	48	11	90	-627**
	(g/week)					
TSS	3,673	355	811,849215		517	-140***
NO_3-N	58	24	764	8	19	-148*
NH_3	24	5	36	1	8	-1294***
TKN	167	91	599	37	132	-262**
TP	17	4	75	12	5	58$^{N.S.}$
	(g/ha/mo)					
Cu	1.06	1.64	2.83	0.33	1.68	-412**
Pb	0.62	0.24	1.70	0.89	0.45	-409*
Zn	7.13	3.01	12.46	0.72	7.95	-999*

Table 7. Traditional watershed results for the construction period (10/8/97 – 6/12/03).

	Calibration		Treatment Period			
				Traditional		
	Control	Traditional	Control	Observed	Predicted	% Change
Observations	75	15	155	135		
			(m^3/week)			
Flow	113.85	0.10	128.40	20.73	2.28	99.6***
			(mg/L)			
TSS	31	132	32	78	125	-60$^{\text{N.S.}}$
NO_3-N	0.9	0.3	0.8	0.5	0.3	40$^{\text{N.S.}}$
NH_3	0.15	0.08	0.25	0.19	0.16	19$^{\text{N.S.}}$
TKN	1.3	4.0	1.4	1.6	4.2	-167***
TP	0.159	1.009	0.153	0.5463	0.872	-88*
BOD	2	30	90	73		
			(No. fcu/100 ml)			
FC	48	10	13	10		
Observations	20	7	65	55		
			(ug/L)			
Cu	8	8	13	17	12	28$^{\text{N.S.}}$
Pb	6	11	6	8	10	-30$^{\text{N.S.}}$
Zn	58	65	61	75	86	-16$^{\text{N..S.}}$
			(g/week)			
TSS	3,678	30	6,279	5,050	18	99.7***
NO_3-N	63.48	0.07	157.61	30.02	0.08	99.7***
NH_3	18.15	0.24	46.51	10.55	0.27	97.4***
TKN	149.60	0.91	267.19	89.64	0.65	99.3***
TP	19.28	0.33	30.13	29.52	0.16	99.5***
			(g/ha/mo)			
Cu	0.81	0.02	1.71	3.54	0.02	99.5***
Pb	0.60	0.04	0.73	1.52	0.04	97.7***
Zn	5.76	0.21	7.93	15.15	0.20	98.7***

Driveway study

Runoff Depth

Stormwater runoff depth was significantly different among all driveway types (Table 8), with the order of decreasing runoff being asphalt > paver > crushed stone. These results were consistent with findings from other paver research (Pratt et al. 1995). Booth and Leavitt (1999) observed runoff from turfstone as < 1% of total rainfall, which is much less than what was observed for the pavers used in this study. The runoff depth, adjusted for land cover, did not change the significance of the results obtained. There were no seasonal statistical differences for runoff depth from the repeated measures analysis.

Table 8. Mean weekly pollutant concentration in stormwater runoff from asphalt, paver and crushed stone driveways, Waterford, CT

	Asphalt	Paver	Crushed Stone
Variable		(mm)	
Depth	1.8 a	0.5 b	0.04 c
		concentration (mg/l)	
TSS	47.8 a	15.8 b	33.7 a
NO_3-N	0.6 a	0.2 b	0.3 ab
NH_3-N	0.18 a	0.05 b	0.11 a
TKN	8.0 a	0.7 b	1.6 ab
TP	0.244 a	0.162 b	0.155 b
		Concentration (ug/l)	
Cu	18 a	6 b	16 a
Pb	6 a	2 b	3 b
Zn	87 a	25 b	57 ab

Within each variable, means followed by the same letter are not significantly different at α=0.05

Infiltration test results generally supported the runoff depth findings (Table 9). Flowing infiltration tests were similar to single ring tests. However, the crushed stone driveway flowing infiltration results were lower than the single ring infiltration (Table 9). The portion of the driveway closest to the trench drain where the flowing infiltration tests were conducted was compacted compared to the remaining driveway area. Compaction would naturally lower infiltration rates. Table 10 is a compilation of infiltration rates for different soil types and land covers. Infiltration rates measured in this study for paver and crushed stone driveways fall into the rapid infiltration category.

James and Thompson (1997) reported that while runoff from asphalt surfaces equaled 100% of the rainfall, paver runoff only equaled 38-61% of the total rainfall. Clogged pavers have been reported to infiltrate only 1.2 mm/hr when they have become clogged (Kresin et al. 1997). That

Table 9. Average infiltration rates from asphalt, paver, and crushed stone driveways

Test and Year	Asphalt	Paver	Crushed Stone
		cm/hr	
Single ring infiltrometer test 2002	0	19.6	18.5
Single ring infiltrometer test 2003	0	15.3	12.7
Flowing infiltration test 2003	0	20.7	6

Table 10. Comparison of infiltration rates

Category	Infiltration	Reference
	Cm/hr	
Very rapid	>25	Novotny, 2003
Rapid	12.5 – 25.0	“ “
Moderately rapid	6.3 – 12.5	“ “
Moderate	2.0 – 6.3	“ “
Moderately slow	0.5 – 2.0	“ “
Slow	0.12 – 0.5	“ “
Very slow	<0.12	“ “
Non-compacted Sandy soil	38.1	USEPA, 1999
Compacted sandy soils	7.62	“ “
Non-compacted Dry clay	22.4	“ “
All other clay soils	1.8	“ “
Undisturbed forest floor	6.0	Chow, 1964
Oak Hickory forest	7.6	“ “
Unimproved pasture	2.4	“ “

rate is twenty times less than the infiltration rates measured in this study (Table 9).

Pratt et al. (1995) observed that the concrete paver blocks, different from the type used in this study, could absorb the first four to five mm of rainfall within the first minutes of a precipitation event. During this driveway study, it was observed that during the first few minutes of a precipitation event, puddles would begin to form on the asphalt driveways while the pavers would absorb the moisture. During light rainfall events, puddles would not form on paver driveways for up to 30 minutes. The flowing infiltration tests also demonstrated the difference in response time of the driveway types. On the asphalt driveway it took one minute for the flow to discharge. For the crushed stone and paver driveways discharge didn't occur for 20 minutes after application of water.

Figure 24 shows the weekly runoff response to rainfall. The slopes of the regression equations show that asphalt runoff was greater than paver runoff, which was greater than crushed stone runoff (Figure 24). R^2 value for paver (F=38.0, $p<0.0001$) and crushed stone driveways (F=34.5 $p<0.0001$) may be lower than the asphalt R^2 (F= 158.7, $p<0.0001$) due to variable infiltration amounts. As Rushton (2001) observed, for watersheds with pervious areas, rainfall intensity may play an important role in predicting stormwater runoff depth.

Table 11. Comparison of Runoff Coefficients between driveway study and other permeable pavement research

Pavement type	Runoff Coefficient*	Reference
	%	
Asphalt	40	This study
Paver	24	This study
Crushed Stone	5	This study
Permeable Concrete block	41	Pratt et al. 1995
Asphalt	100	James and Thompson 1997
Paver with 7.6 cm base	38	James and Thompson 1997
Paver with 10.2 cm base	61	James and Thompson 1997
Asphalt, no swale	54	Rushton 2001
Pervious paving with swale	15	Rushton 2001

* Runoff Coefficient = average (runoff depth / rainfall depth)

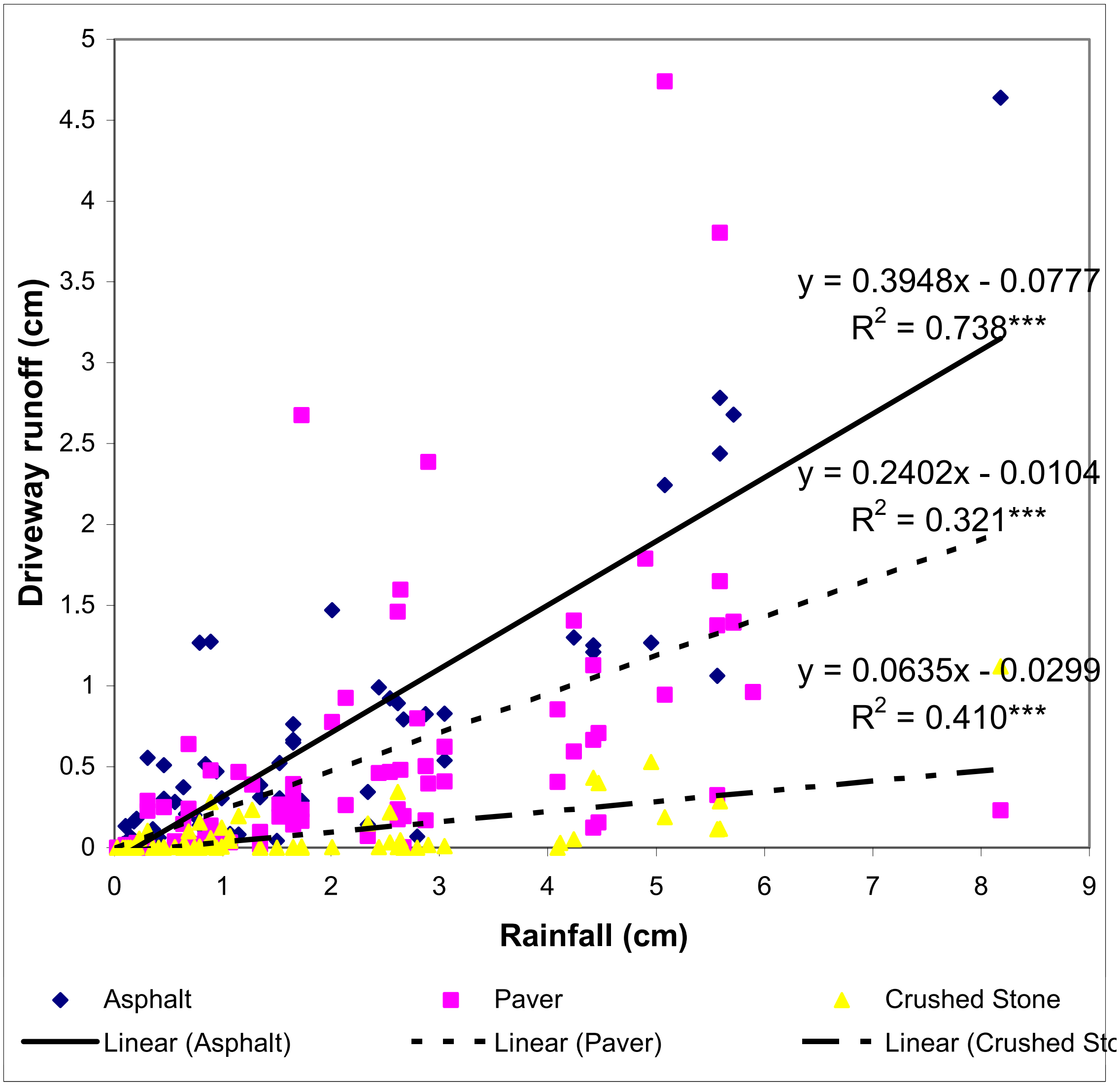

Figure 24. Rainfall runoff regressions. *** Indicates significance at p<0.0001.

Concentration

Runoff from paver driveways contained significantly lower concentrations of measured variables than the asphalt driveways (Table 8). Concentrations in crushed stone runoff were significantly lower than asphalt runoff but not different from paver runoff for TP and Pb. NO_3-N, TKN, and Zn concentrations in crushed stone runoff were not different from either asphalt or paver runoff. TSS, NH_3-N, and Cu, concentrations in crushed stone runoff were not significantly different from that found in asphalt runoff, but higher than that in paver runoff. Though there was not an overall statistical difference between crushed stone and asphalt TKN runoff concentrations, asphalt had a statistically higher TKN concentration than crushed stone in the summer. It was not possible to determine pollutant runoff contributions from the different source areas within each watershed due to the nature of the sampling. Instead, adjustments used to modify depth data were also applied to concentration data to determine if watershed land cover had an effect on runoff pollutant concentration. Adjusted concentration data did not produce any differences in results than the unadjusted data. Data truncated to the final 12 months, to exclude the period when only three driveways were being monitored, did not show any changes in findings.

TSS concentrations observed in this study were lower than the 100 mg/l reported for urban runoff in the NURP study (USEPA 1983b), and the 300 mg/l for asphalt driveways reported by Bannerman et al. (1993). Seasonal results from the repeated measures analysis showed paver TSS concentrations were significantly lower in the fall (4.0 mg/l) than any other season (25.2 mg/l). Crushed stone TSS concentrations in runoff averaged 23.3 mg/l in winter, spring and fall, but were significantly higher in the summer, averaging 111.0 mg/l. These seasonal differences may be due to high TSS in runoff from the crushed stone 2 driveway during the summer of 2002. Erosion in the crushed stone 2 watershed area was high because of poorly established grass on sloped areas that drained onto the driveway.

Bannerman et al. (1993) reported 1.16 mg/l TP in asphalt driveway runoff which is higher than the 0.24 mg/l reported in this study for asphalt driveways. This study's results were similar to Rushton's (2001) findings of 0.11 mg/l TP in asphalt runoff and the EMC of 0.62 mg/l TP in residential runoff reported from the NURP study (USEPA 1983b) for residential watersheds. Driveway's are a critical source area for phosphorus; finding paver runoff to have significantly lower TP runoff concentrations is important for controlling this pollutant. Paver runoff concentrations of both NO_3-N NH_3-N (Table 8) were comparable to those reported by Rushton (2001) of 0.15 mg/l and 0.11 mg/l respectively. This study's asphalt NO_3-N runoff concentration was higher than Rushton's (2001) finding of 0.27 mg/l, but the 0.13 mg/l of NH_3-N in Rushton's (2001) study was similar to this study's results (Table 8).

Metals runoff concentrations were similar to what has been reported in other studies for asphalt and paver driveways (Table 12). Overall, Pb concentrations reported in this study were lower than runoff concentrations reported in other studies (Table 12). Runoff from asphalt and crushed stone driveways had Cu concentrations above all aquatic toxicity thresholds (Table 12). Paver driveway runoff Cu concentrations were greater than saltwater aquatic toxicity limits. Pb concentrations were lower than aquatic toxicity thresholds for all driveway materials. Booth et al. (1999) reported copper concentrations in stormwater infiltrated through Eco-stone pavers to be higher than concentrations measured in runoff in this study. Runoff Pb and Zn concentrations were higher in this study than infiltrated water concentrations reported by Booth et al. (1999)

Table 12 Summary of previous research of concentration results of Cu, Pb and Zn in runoff from various surfaces compared to human consumption and aquatic health guidelines.

Source	Cu	Pb	Zn	Reference
		ug/l		
Pervious asphalt	11.2	20.7	158	Legret and Colandini, 1999
Asphalt driveway	17	17	107	Bannerman et al. 1993
Asphalt parking lot	10.3	4.1	44.8	Rushton 2001
Pervious pavement with swale	3.4	1.25	18.6	Rushton 2001
Grasspave ^{1}	21.4	0.00	2.5	Booth and Leavitt 1999
Gravel Pave ^{1}	1.9	0.41	2.0	Booth and Leavitt 1999
Turfstone ^{1}	1.4	0.00	0.0	Booth and Leavitt 1999
UNI Eco-Stone ^{1}	14.3	0.62	7.9	Booth and Leavitt 1999
Toxicity to freshwater aquatic life (acute/chronic)	13/9.0	65/2.5	120/120	USEPA 1999a
Toxicity to saltwater aquatic life (acute/chronic)	4.8 /3.1	210 / 8.1	90 / 81	USEPA 1999a
Human Consumption	1300	0 (at tap)	9100	USEPA 1999a

1) subsurface only

Export

Mass export for this study was calculated as kg/ha/yr. Most other studies report export as mass per storm event or mass per multiple storm events. Comparison of non-uniform export data is difficult. Mass export for all variables from asphalt driveways was greater than mass export from paver driveways, which in turn was greater than the export from crushed stone driveways (Table 13). James and Thompson (1997) reported TSS, NO_3, NH_3, TKN, Cu, Pb, Zn export in runoff was greater from an asphalt parking lot than from an Eco-stone paver parking lot in Guelph, Canada. Using the full study data set, repeated measures analysis showed that crushed stone driveways had significantly higher NO_3-N and TKN export in the winter (0.56, 1.46 kg/ha/yr) than in the spring (0.004, 0.01 kg/ha/yr). Paver driveways had significantly greater export of TP in the fall than in the winter and summer (0.05, 0.02 kg/ha/yr). Fall stormwater runoff may be higher in phosphorus in the fall due to increased organic matter decomposition. There is no explanation for why this increase in phosphorus concentration was only observed in paver driveway runoff and not in asphalt or crushed stone runoff.

Table 13. Annual pollutant export from asphalt, paver, and crushed stone driveways, Waterford, CT

	Asphalt	Paver	Crushed Stone
		Kg/ha/yr	
TSS	230.1	23.1	9.6
NO_3-N	1.78	1.25	0.15
NH_3-N	0.65	0.12	0.03
TKN	13.06	1.08	0.47
TP	0.81	0.25	0.04

Lawn Nutrient Study

Box plots comparing NO_3-N desorbed from AEM strips, soil water NO_3-N concentrations and plant reflectance all indicate that the BMP lawns being monitored have lower values than the non-BMP lawns (Figure 25).

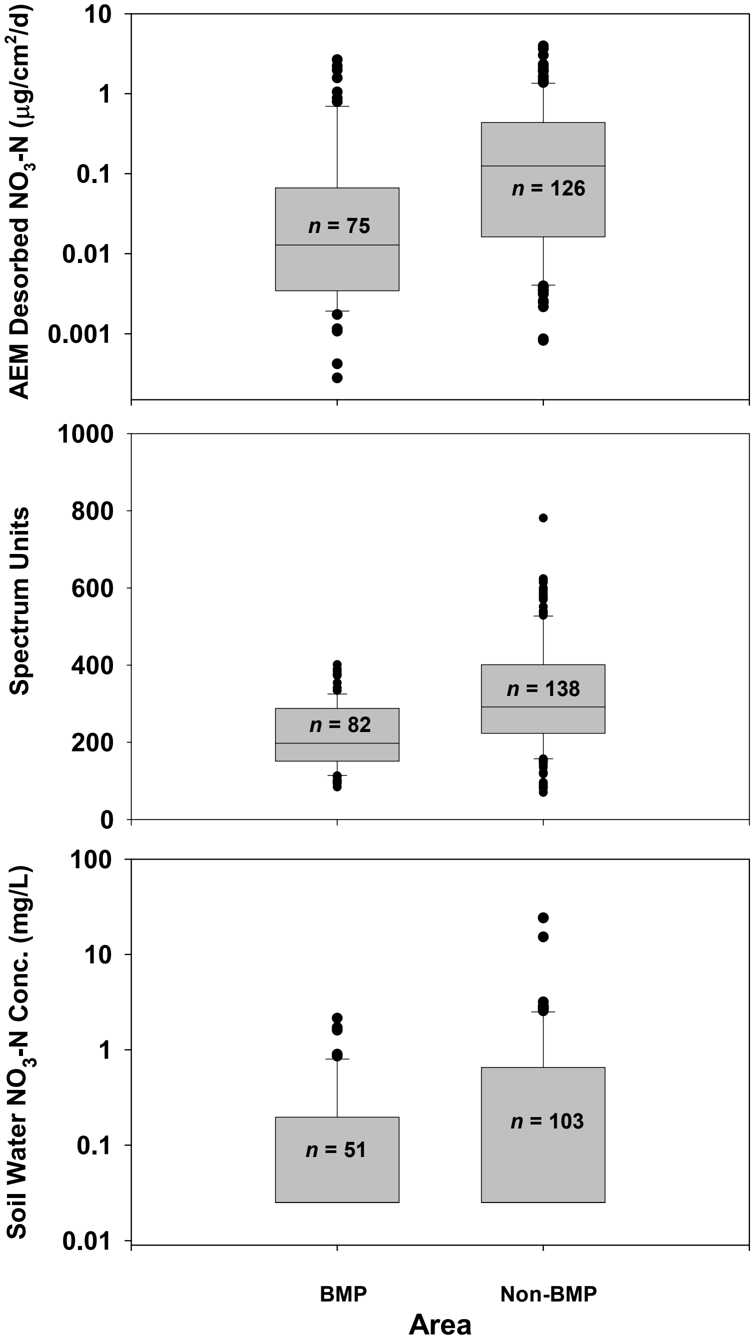

Figure 25. Comparison of the BMP and non-BMP areas for Anion Exchange Membrance desorbed NO_3-N, turf greenness, and soil water NO_3-N concentrations.Wiskers are 10 and 90th percentiles.

Household Survey

There were no significant differences in responses to the questions across years for any watershed. This generally means that residents are not changing their behavior during the study period. This is an especially important assumption for control watershed residents. Response rates for 2003 were 54, 54, and 58% for the control, traditional, and BMP watersheds, respectively. There are not major differences among watersheds. BMP residents do their own lawn care, use more mulching mowers, apply less fertilizers, and water less than residents in the other watersheds (Table 14).

Table 14. Survey results for 2003 by watershed.

Pets	**Control**	**BMP**	**Traditional**
Cat	7.7 %	0 %	0 %
Dog	15.4 %	8.3 %	7.7 %
Waste handling			
Compost	**2 %**		
Inside	**18 %**		**18 %**
Outside	**13 %**	**50 %**	**27 %**
Trash	**67 %**	**50 %**	**55 %**
Lawn Care			
Self	**84 %**	**100 %**	**71 %**
Professional service	**16 %**		**29 %**
Lawn Clippings			
Left on lawn	**29 %**	**17 %**	**22 %**
Compost/garden	**29 %**	**33 %**	**11 %**
Mulch mower	**43 %**	**71 %**	**44 %**
Bag - trash	**0 %**	**0 %**	**0 %**
Other			**22 %**
Fertilize lawn			
Yes	**90 %**	**14 %**	**100 %**
No	**10 %**	**86 %**	**0 %**
Fertilize # of times/yr			
1-2	**47 %**	**33 %**	**14 %**
3-4	**35 %**	**67 %**	**71 %**
>4	**6 %**		**14 %**
Unknown	**12 %**		
How decide fertilizer?			
Bag instructions	**48 %**	**44 %**	**62 %**
Calibrated spreader	**14 %**	**33 %**	**12 %**
Past experience	**5 %**	**11 %**	**0 %**
Professional service	**33 %**	**0 %**	**25 %**
Soil test	**0 %**	**11 %**	**0 %**
Lawn watering method			
Auto sprinkler	**4 %**	**0 %**	**25 %**
Hand hose	**16 %**	**12 %**	**0 %**
Manual sprinkler	**48 %**	**50 %**	**50 %**
Nature	**32 %**	**38 %**	**25 %**
Leaf disposal			
Bag/curb	**45 %**	**25 %**	**17 %**
Compost	**14 %**	**38 %**	**0 %**
Mulch/lawn	**14 %**	**38 %**	**33 %**
Professional service	**14 %**	**0 %**	**17 %**
Put in street	**5 %**	**0 %**	**0 %**
Other	**5 %**	**0 %**	**0 %**
Rain gutters dump			
Driveway	**30 %**	**33 %**	**14 %**
Foundation drain	**4 %**	**0 %**	**0 %**
Lawn	**67 %**	**67 %**	**86 %**
Car wash/year			
0	**6 %**	**20 %**	**12 %**
1-4	**38 %**	**60 %**	**38 %**
5-10	**6 %**	**0 %**	**25 %**
11- 20	**38 %**	**20 %**	**0 %**
>20	**12 %**	**0 %**	**25 %**
Where wash car			
Driveway	**94 %**	**100 %**	**94 %**
Lawn	**6 %**	**0 %**	**6 %**

CONCLUSIONS

Residential construction has had significant impacts on runoff quality and quantity. Typical hydrologic alterations due to construction activities, such as increased runoff volume, were not found in the BMP watershed. On the contrary, a two-order magnitude reduction of stormwater runoff was observed. This reduction can be attributed to both, excavation of all basements in a relatively short time and proper location of earthen berms, to retain and infiltrate stormwater onsite. Deceases in runoff continued in the BMP watershed during the first year of the post-construction period. During the construction phase in the traditional watershed, runoff volume increased by a magnitude of two.

Concentrations of TSS, NO_3-N, NH_3, TKN and TP significantly increased in stormwater runoff at the BMP site during construction. In contrast, TSS, NO_3-N, NH_3, and TP concentrations did not change, and TKN concentrations experienced a significant reduction, during construction in the traditional watershed. Single activities contributed to concentration spikes, and are important. These events included TSS increases during unstabilized soil conditions in the swales and N and P increases following fertilization. Following the construction period at the BMP watershed, TSS, TP, and TKN remained higher.

The mass export of sediment, some nutrients, and metals did not change in stormwater runoff from the BMP watershed during construction and decreased following construction. In contrast the mass export of sediment nutrients and metals all increased in stormwater runoff from the traditional watershed during construction. These increases were associated with higher discharge from the traditional watershed during construction.

Relation to treatment goals

1. To implement BMPs on 100% of the lots in the BMP portion of the subdivision. – **goal met**.

2. To maintain post-development peak runoff rate and volume at levels equal to predevelopment rates. **– volume goal met**.

3. To maintain post-development loading of TSS at levels equal to predevelopment rates **– goal met.**

4. To retain sediment onsite during construction. – **goal met on a mass basis but not a concentration basis.**

5. To reduce nitrogen export by 65% - **goal met.**

6. To reduce bacterial export by 85%. **– no change in fecal coliform bacteria**

7. To reduce phosphorus export by 40%. – **goal met**

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JORDAN COVE WATERSHED HOUSEHOLD 10-POINT SURVEY

1. How many pets/what types do you have that go outside? ____________________
1a. How do you handle disposal of pet wastes?
___ Waste is handled inside ___ Waste is left to decompose outside
___ Waste is composted ___ Waste picked up & thrown out with trash
___ Other ____

2. Who takes care of your lawn?
___ Myself/members of family ___ Non-professional paid help (student)
___ Professional lawn care service ___ Other ___________________________

3. When your lawn gets cut, what happens to the clippings?
___Left on lawn ___mulched with mower
___ Added to compost or garden ___ Bagged and put in trash
___ Other (please specify) ____

4. Do you fertilize your lawn? ___ Yes ___ No (Go to question 5)

4a. How many times each season do your fertilize your lawn/how much do you apply?

Spring (March-May)	__________ times	__________ pounds
Summer (June-August)	__________ times	__________ pounds
Fall (Sept.-Nov.)	__________ times	__________ pounds
Winter (Dec.-Feb.)	__________ times	__________ pounds

4b. How do you decide how much fertilizer to use?
___ Professional service takes care of fertilizing. ___ Based on soil test
___ Follow the instructions on the bag ___ Based on past experience
___ Use calibrated spreader

5. What lawn watering method do you use?
___ I let nature take its course ___ I water by hand with a hose
___ I use a manual sprinkler with I turn on/off and move myself
___ I have an installed sprinkler in lawn set on ___manual or ___ automatic

6. How do you dispose of leaves in the fall/spring?
___A professional service removes them ___ Pile on my property
___ Mulch them and leave on lawn ___ Add to compost
___ Bag and put at curb ___ Put into street
___ Other (please specify) ____

7. Where do your rain gutters run to?
___ flow on lawn ___ flow on driveway
___ connected to foundation drain ___ other (please specify) ___________________________

8. How often do you wash your car at home? (please specify) ___________________________

9. Where do you wash your car at home? (please specify) ___________________________

10. ___ I would like to receive more information about the Jordan Cove project.

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