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Effects of a Vegetated Stormwater-Detention Basin on Chemical Quality and Temperature of Runoff from a Small Residential Development in Monroe County, New York

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The vegetated stormwater-detention basin at a small residential development in Monroe County, N.Y. has been shown to be effective in reducing loads of certain chemical constituents to receiving waters. Loads of suspended solids, nitrogen, and phosphorus have been reduced by an average of 14 to 62 percent. The basin has little effect on the temperature of runoff between the inflow and the outflow; water temperatures at the outflow during summer storms averaged 0.5° C higher than those at the inflow.

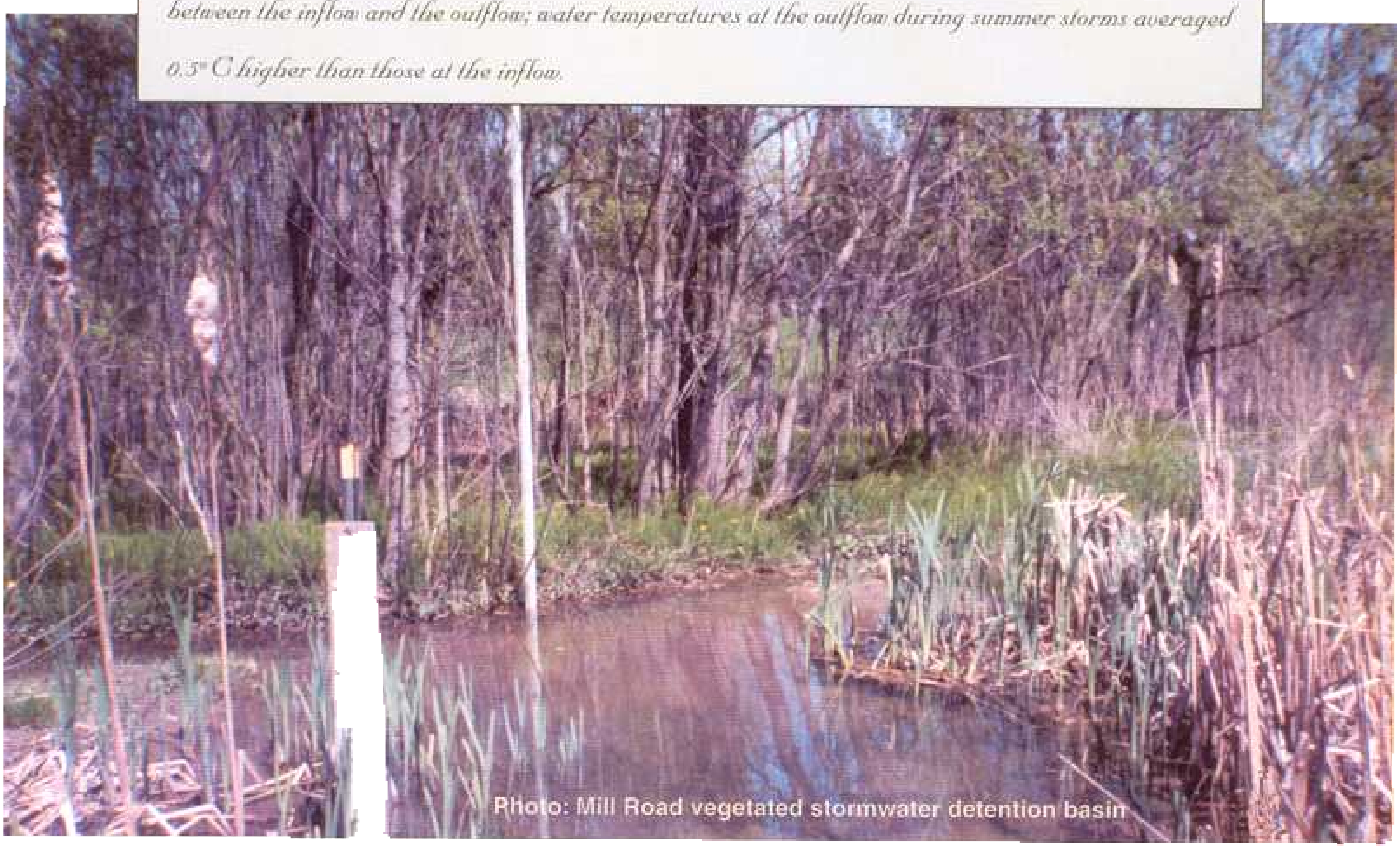

Photo: Mill Road vegetated stormwater detention basin

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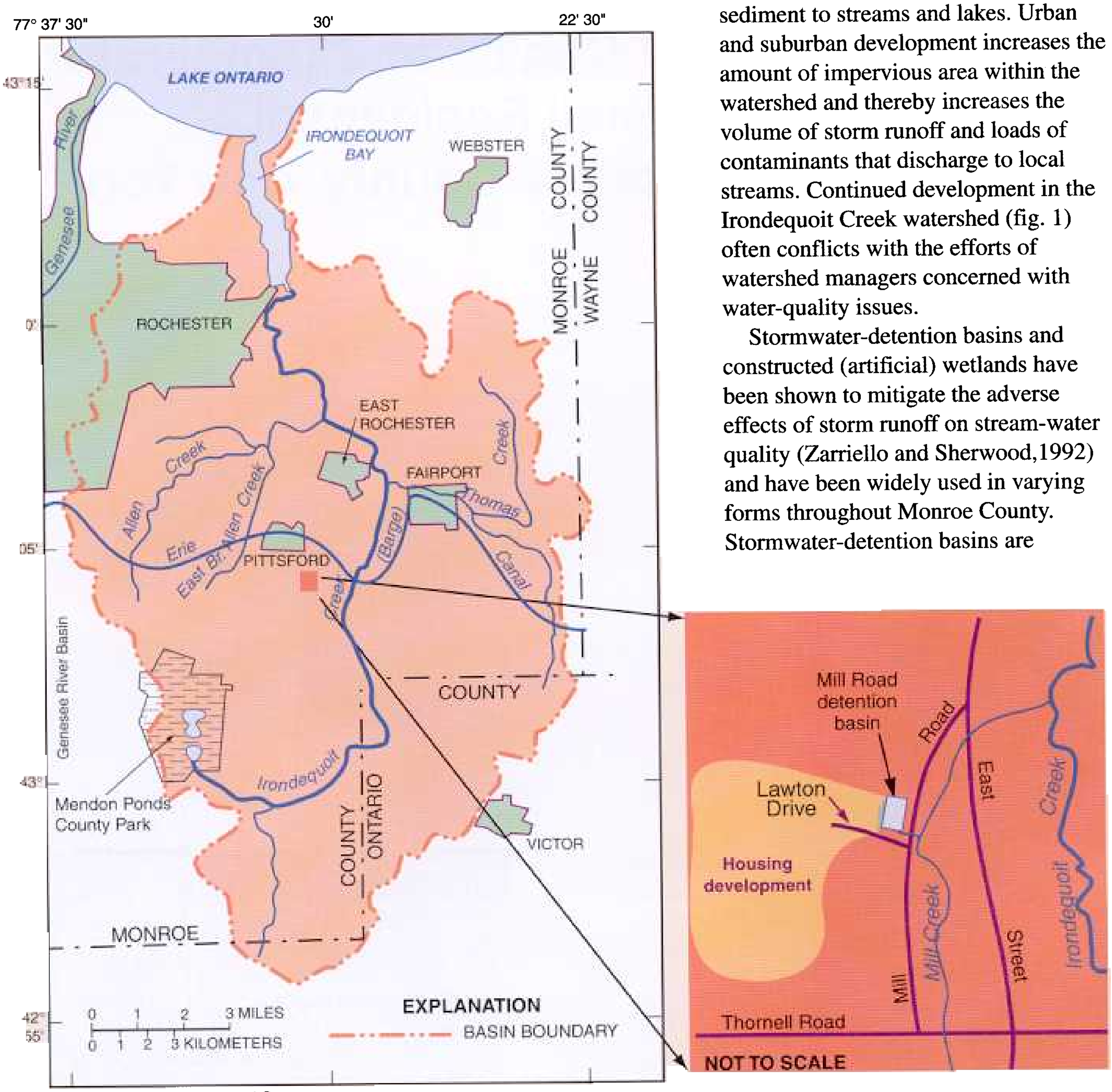
INTRODUCTION

Runoff from storm events can cause flooding and can transport contaminants such as lead, zinc, nutrients, and sediment to streams and lakes. Urban and suburban development increases the amount of impervious area within the watershed and thereby increases the volume of storm runoff and loads of contaminants that discharge to local streams. Continued development in the Irondequoit Creek watershed (fig. 1) often conflicts with the efforts of watershed managers concerned with water-quality issues.

Stormwater-detention basins and constructed (artificial) wetlands have been shown to mitigate the adverse effects of storm runoff on stream-water quality (Zarriello and Sherwood,1992) and have been widely used in varying forms throughout Monroe County. Stormwater-detention basins are



Base from U.S. Geological Survey
State base map 1:500,000, 1974

Figure 1. Irondequoit Creek drainage basin and location of Brookside Meadows development and Mill Road artificial wetland, Monroe County, New York

catchments designed to attenuate peak flows and to promote the settling of suspended sediment and associated chemical constituents transported by runoff. Artificial or created wetlands are designed to be either permanently or intermittently wet, and can contain either a single hydrophilic (strong affinity for water) plant species such as cattails, or a diversity of plants including mosses, grasses, cattails, woody shrubs, and trees. Artificial wetlands provide the additional benefit of the uptake and removal of runoff-borne contaminants that can adversely affect receiving waters. The effectiveness of a detention basin or wetland in decreasing chemical and sediment loads depends on several factors, including the retention time during which suspended constituents can settle out, and the amount and type of vegetation, which not only retards flow through the basin and provides a substrate to which suspended constituents can adhere, but also takes up certain constituents directly and provides a setting for additional uptake by the associated microbial community. Detention basins are frequently converted to artificial or constructed wetlands either by planting vegetation within the detention basin or allowing it to grow naturally.

Despite the documented water quality improvements provided by detention basins and artificial wetlands, the potential effect of these impoundments on streamwater temperature remains a concern because the sudden alteration of water temperature downstream from a basin in response to stormflows could affect the physical and chemical properties of the stream as well as the health of the resident fish and other aquatic organisms.

In 1994, the U. S. Geological Survey (USGS), in cooperation with the Monroe County Department of Health and the Town of Pittsford, began monitoring a diversely vegetated stormwater detention basin at a housing development (Brookside Meadows) in the Town of Pittsford (figs. 1, 2) to assess the effect of this basin on water quality downstream. The program entailed recording water temperature, collecting water samples for chemical analysis, and collecting flow data for use in calculating constituent loads at the inflow and outflow of the basin. This report describes the effectiveness of the vegetated detention basin in decreasing chemical loads entering the receiving stream, and the effects of the basin on the temperature of the outflow.

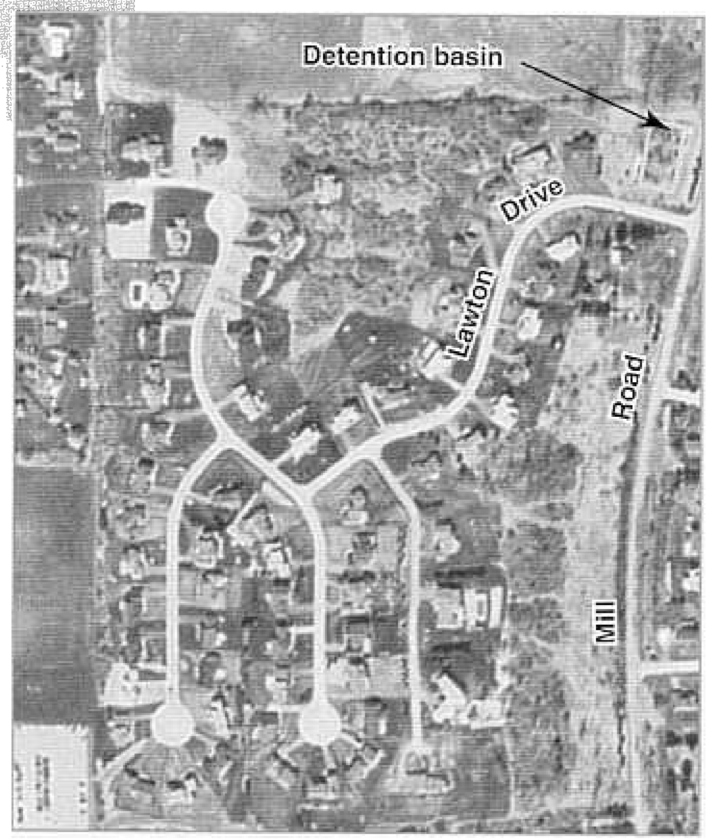


Figure 2. Aerial photo of Brookside Meadows residential development showing drainage area of the Mill Road artificial wetland (Courtesy of Monroe County Environmental Management Council, 2000)

BASIN DESCRIPTION AND HISTORY

The Mill Road artificial wetland is a small (0.6-acre) stormwater impoundment that was constructed in 1981 as a settling basin to retain stormflows and trap sediment caused by the construction of the Brookside Meadows residential development. Sediment was periodically removed from the basin during the period of construction (1981-90) but has not been removed since then, and sediment from disturbed soils and from impervious (paved) surfaces since construction was completed has accumulated to a thickness of about 2 feet above the original basin bottom. The growth of vegetation in the basin over the years has, in effect, turned the detention basin into an artificial wetland. Part of the basin is permanently wet and sustains emergent wetland vegetation (cattails and reeds); the rest of the basin is intermittently wet and contains a diversity of natural vegetation such as willows, grasses, and woody shrubs. The basin receives storm runoff from Brookside Meadows, a residential development with a steeply sloping (8 to 25 percent) drainage area of about 39 acres. Stormflows peak and recede quickly because the development is steeply sloped and contains large amounts (13.5 percent) of impervious surface area (roofs, streets, etc.). Because of the steep basin slope, runoff rates are highly correlated with rainfall intensity. Stormwater is retained in the detention basin because the outflow pipe (8 in. dia.) is smaller than the inflow pipe (30 in. dia.) (fig. 3). Runoff from the detention basin flows into Mill Creek Tributary, then into Mill Creek, and finally into Irondequoit Creek (fig. 1).

A. Outflow pipe and manhole

B. Detail of inflow pipe

C. Inflow pipe

Figure 3. Photographs showing inflow (B, C) to Mill Road artificial wetland, and outflow pipe (A).

DATA COLLECTION

Instrumentation was installed at the inlet and the outlet of the basin in 1995 to collect water samples, measure flow, monitor water temperature, and record the amounts of precipitation and the water levels in the basin. All data were stored on a data logger, which also governs the operation of the water samplers. The data are then used to estimate loads of chemical constituents into and out of the basin; these load values in turn are used to assess the effectiveness of the basin in reducing chemical loads.

Water samples are collected by flow-activated automatic samplers at the inflow and outflow of the basin and analyzed for concentrations of chemical constituents such as nutrients (species of nitrogen and phosphorus), suspended and dissolved solids, common ions (chloride and sulfate), and lead and zinc. The volume of flow into and out of the basin is measured and used to calculate chemical loads. A typical inflow and outflow hydrograph for a moderately high flow event is depicted in figure 4. Thermistors recorded water temperatures at the inflow and outflow to assess the basin's effects on the temperature of runoff flowing into the receiving stream.

EFFECT OF DETENTION BASIN ON CONSTITUENT LOADS

Fourteen high flow events between January 1996 and September 1999 were selected as representative events at this site. These events were selected because they represent seasonal variation, have varying flow conditions, and had adequate sample coverage. Constituent loads were estimated from the calculated inflow and outflow volumes for each storm, multiplied by the mean constituent concentrations for the storm. Inflow and outflow volumes were calculated from the beginning to the end of each 5-minute logging interval.

The inflow volumes of the 14 high flow events ranged from 11,600 cubic feet to 141,000 cubic feet with a mean of 40,400 cubic feet. Outflow volumes ranged from 10,400 cubic feet to 125,300 cubic feet, with a mean of 36,900 cubic feet, and averaged about 9.5 percent less than inflow volumes. The lower flow volumes at the outflow are at least partially accounted for by infiltration to ground water on the southeast side of the basin. While amounts of loss to ground water have not been quantified, soil cores and an injection test indicate that soils there are conducive to infiltration.

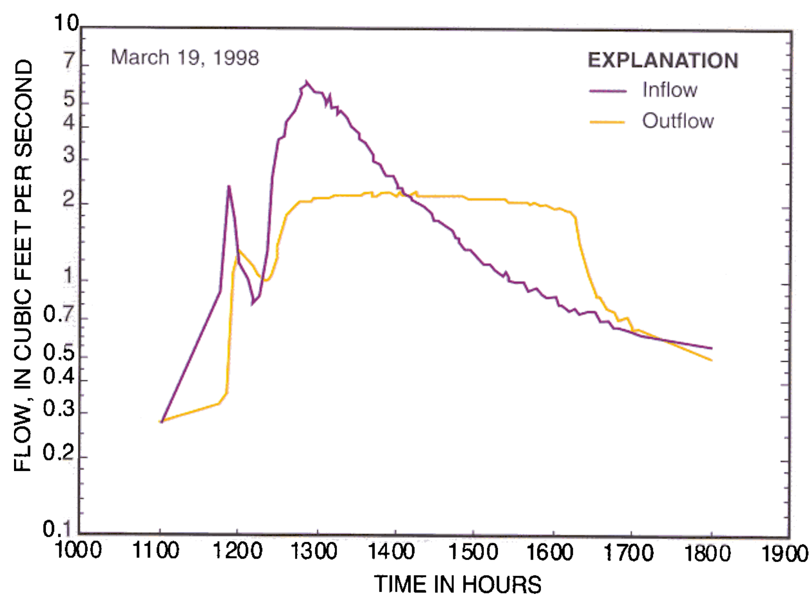


Figure 4. Typical inflow and outflow hydrograph for the Mill Road detention basin in response to a moderately high flow

REMOVAL EFFICIENCY

Mean loads of most constituents were higher at the inflow than at the outflow (table 1). Removal efficiencies defined as ((*load in* - *load out*) ÷ *load in*) x 100 generally were greatest for those constituents associated with particulate transport—suspended solids (62 percent), ammonia + organic nitrogen (19.1 percent), and total phosphorus (38 percent). Positive removal efficiencies indicate a reduction in load within the basin, either through settling or through uptake by plants. Negative efficiencies indicate an increase in load at the outflow, generally through resuspension or dissolution of constituents deposited in the wetland by previous storms. A statistical test (Wilcoxon signed-rank test) was used to evaluate whether differences between the inflow loads and the outflow loads were statistically significant at the 95-percent confidence level ($\alpha = 0.05$). If tests do show a statistical significance, that means there is a 95-percent chance that an actual reduction in loads occured at the outflow, rather than an apparent reduction resulting from a chance arrangement of data.

Removal efficiencies are computed in relation to the inflow loads; therefore, large absolute values must be considered in relation to the constituent mass that is entering the basin. Overall removal efficiencies (table 1) for each constituent are based on average of the loads for all 14 events, whereas average removal efficiencies (table 2) are the average of the individual event removal efficiencies. Overall removal efficiencies can be misleading; for example, the data indicate a positive overall removal efficiency for dissolved chloride, even though only two individual events showed a positive removal efficiency, whereas 11 events showed a negative removal efficiency and resulted in a negative average removal efficiency. This indicates that loads of dissolved chloride at the outflow are likely to be higher than those at inflow. Large input loads of chloride tended to result in positive removal efficiencies while small input loads tended to produce negative removal efficiencies (fig. 5). Other constituents whose inflow loads appeared to be positively correlated with removal efficiency were total suspended solids, nitrite + nitrate, dissolved sulfate, and dissolved solids. Constituents with positive overall removal efficiencies, but negative removal efficiencies for individual flows, were suspended solids, ammonia + organic nitrogen, orthophosphate, total organic carbon, and total zinc (table 2).

One important benefit of artificial or created wetlands is the removal of phosphorus from stormwater. While

Table 1. Average Inflow volume and outflow volume and constituent loads at the inflow and outflow of the Mill Road detention basin for fourteen high flow events 1996-99.

[Volume is cubic feet, constituent loads are in pounds. Red type indicates difference between inflow and outflow load is statistically significant at α = 0.05]

Constituent or property	Average load in	Average load out	Overall removal efficiency[1]
Volume	**40,400**	**36,900**	--
Suspended solids	**250**	**95.5**	**61.8**
Ammonia, as N	**0.27**	**0.20**	**25.9**
Ammonia + organic nitrogen, as N	2.25	1.82	19.1
Nitrite + nitrate, as N	2.66	2.50	6.0
Phosphorus, total as P	**0.52**	**0.32**	**38.5**
Orthophosphate, as P	**0.14**	**0.12**	**14.3**
Total organic carbon	**17.9**	**15.0**	**16.2**
Chloride, dissolved	82.1	71.2	13.3
Sulfate, dissolved	48.5	48.6	-0.21
Zinc, dissolved	**10.6**	**18.0**	**-69.8**
Zinc, total	**174**	**124**	**28.7**
Dissolved solids	**167**	**381**	**-128**

These removal efficiencies are based on the average inflow and outflow load phosphorus is not the sole cause of eutrophication (aging process of water bodies), it is frequently the key element required by freshwater plants and usually is present in the least amount relative to need. Therefore, an increase in phosphorus allows plants to make use of other nutrients already present in the water and thereby promotes plant and algal growth. Generally, of all the elements required for plant growth in water, phophorus is the most easily controlled. The vegetated detention basin at Mill road produced a statistically significant reduction in total phosphorus load (about 35 percent) and in orthophosphate load (about 15 percent) in stormflows during 1995-99. These removal efficiencies for phosphorus are similar those noted under the maximum water-retention configuration of another detention basin within the Irondequoit Creek Basin (Zarriello and Sherwood, 1992).

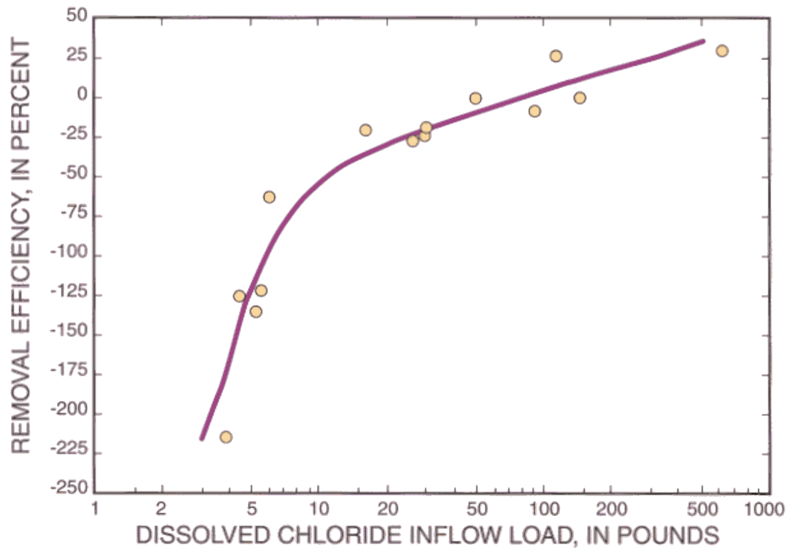


Figure 5. Graph showing relationship between dissolved chloride removal efficiency and chloride load at the detention basin inflow (Location is shown in fig. 1).

Table 2. Removal efficiencies for selected constituents for each of the fourteen high-flow events at the Mill Road detention basin.
[all values are percent; diss, dissolved; Location is shown in fig. 1]

Date	Max storm disch	Total susp-ended solids	Am-monia	Ammonia + organic nitrogen	Nitrite + nitrate	Total phos-phorus	Ortho-phos-phate	Total organic carbon	Dis-solved chlo-ride	Dis-solved sulfate	Dis-solved zinc	Total zinc	Dis-solved solids
Jan. 18, 1996	2.1	-103	28.6	-15.5	11.4	2.50	22.2	--	30.1	21.9	--		
Apr. 30, 1996	4.4	11.4	41.7	4.42	-1.87	52.0	37.5	-1.86	-23.6	-24.0	--	-27.0	-30.5
May 11, 1996	2.9	64.1	48.4	34.4	0.94	43.7	22.9	16.7	0.00	0.67	--	27.6	--
Jul. 3, 1996	4.6	46.6	44.8	-4.92	-28.6	0.00	33.3	--	-135	-46.1	--		
Sep. 13, 1996	4.8	50.9	16.7	-17.1	9.39	10.5	5.88	-4.38	-20.4	--	--	39.4	-7.69
Dec. 13, 1996	2.8	71.3	44.4	14.1	-1.69	32.9	16.0	18.0	25.9	-10.8	--	22.6	--
May 19, 1997 (1)	2.2	63.6	15.4	0.00	-41.7	63.6	50.0	16.7	-125	--	34.7	29.8	-63.8
May 19, 1997 (2)	6.9	80.9	2.27	-5.92	7.51	47.2	12.5	15.8	-19.0	--	-88.0	38.8	-30.3
Aug. 16, 1997	7.8	71.2	25.9	11.1	-55.7	47.8	20.0	-27.0	-215	--	-29.6	42.1	--
Mar. 8, 1998	3.5	60.6	28.6	26.7	4.31	0.00	20.0	10.9	-0.80	-12.2	-101	-47.1	-12.2
Mar. 19, 1998	6.0	72.1	64.3	67.7	8.62	54.6	20.0	41.0	-9.54	-0.63	-230	62.0	-66.5
Aug. 20, 1999	8.4	70.1	47.4	25.9	3.45	32.1	-14.3	4.55	-63.3	-104	-21.8	52.9	8.00
Sep. 7, 1999	1.9	83.9	66.7	29.2	-13.2	50.0	-25.0	47.5	-122	-17.2	-66.7	42.2	-59.1
Sep. 16, 1999	2.0	82.0	56.4	19.5	32.9	27.6	6.25	4.76	-27.0	-10.8	-110	37.4	--
Average		**47.7**		**13.5**	**2.5**	**33.2**	**16.2**	**11.9**	**-50.3**	**-20.3**	**-76.5**	**26.7**	**-32.8**

EFFECT OF DETENTION BASIN ON WATER TEMPERATURE

Artifically induced water-temperature changes in streams, caused by the release of water from upstream impoundments, may adversely affect downstream aquatic ecosystems. Sudden temperature changes in open waters, especially during the summer, may affect periphyton, benthic invertebrates, and fish in addition to causing shifts in algal predominance.

Nineteen precipitation events over a 5-year period (1995-99) were examined to determine the effect of the Mill Road detention basin on the temperature of water leaving the basin. Four of the events occured during the fall, three during the winter, four during the spring, and eight during the summer. Inflows and outflows are plotted by season in figure 6.

Several factors, either individually or in combination, can affect the temperature of runoff as it passes through the vegetated detention basin; among these are the temperature of the impervious surfaces on which the rain falls, the intensity of precipitation, the air temperature during the storm, the water-retention time in the basin, and the amount and stage of the foliage development on vegetation within the basin.

Stormflow entering the basin during cold months generally produces an initial spike (increase) in water temperature within the basin, but this decreases rapidly as the flow increases. As flow from the event subsides, temperatures return to pre-event levels. Outflow temperatures responded similarly, but generally take longer to return to prestorm levels. Outflow temperatures from fall though spring were typically 1 to 3 °C (2 to 5 °F) cooler than inflow temperatures.

Summer is the period of greatest concern over the thermal effect of detention basin discharges on receiving waters. The duration of the eight summer storms selected for analysis ranged from 6 to 40 hours. Typically, inflow temperatures during these storms exceeded outflow temperatures until the recession, and thereafter decreased more rapidly than outflow temperatures (fig. 7). This is because the temperature of runoff entering the basin is initially increased by contact with warm or hot impervious surfaces and, thus, caused a sharp initial increase in temperatures at the inflow. When the impervious surfaces begin to cool, and precipitation intensity decreased, the water temperature at the basin inflow also begins to decrease. The highest temperatures at the inflow generally occured shortly after the peak flow. The temperature pattern at the outflow was similar—a sharp initial increase as the runoff reached the outflow, followed by a temperature peak which occured longer after the outflow peak than it had at the inflow peak. Maximum outflow temperatures were usually slightly lower than maximum inflow temperatures (table 3), whereas mean outflow temperatures were essentially the same as, or slightly higher than mean inflow temperatures. A maximum instantaneous outflow temperature of 24.1°C (75 °F) was noted during the July 8, 1998 storm. Maximum inflow and outflow temperatures tended to be similar among summer storms, and in five of the eight storms, maximum temperatures at the outflow were slightly lower than those at the inflow.

In general, mean water temperatures for the eight summer storms were 0.5° C (0.9° F) higher at the outflow than at the inflow. Mean outflow temperatures ranged from 17.1 to 20.9°C (63 to 70° F). The greatest difference between mean water temperature at the outflow and that at the inflow was 1.9° C (3.4° F) during the storm of August 20, 1999. Thus, the basin appears to have little effect on the temperature of runoff and, thus, should have little affect on receiving waters during the summer.

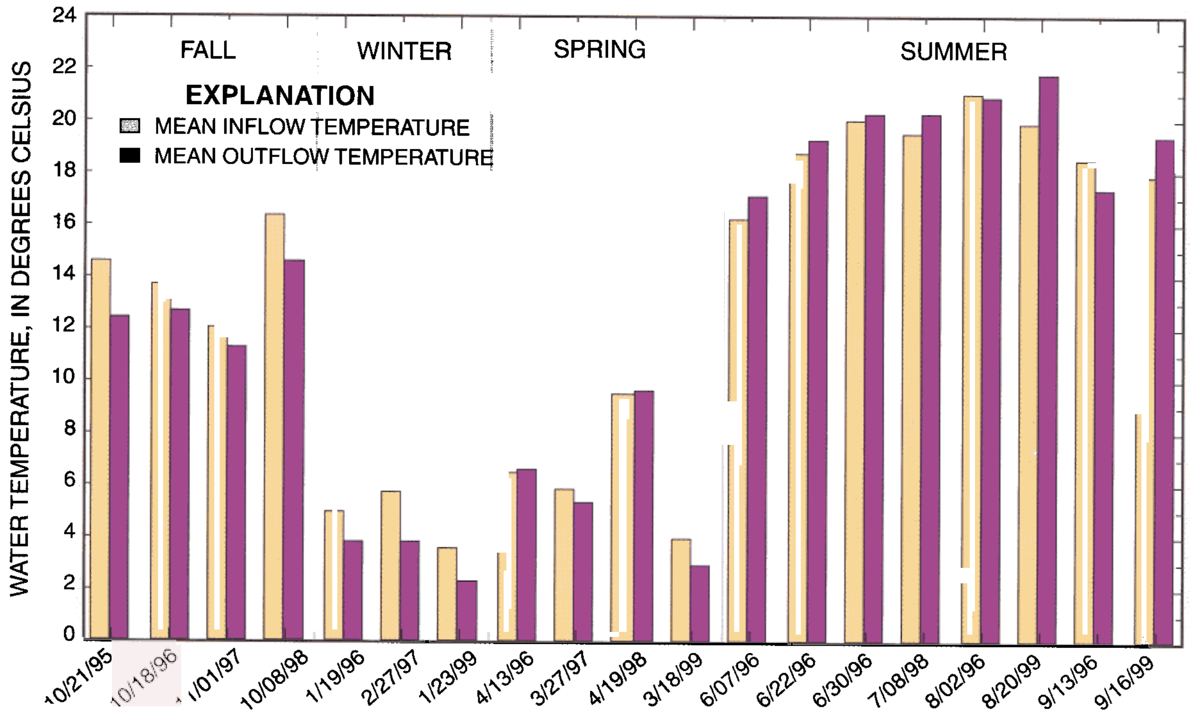


Figure 6. Average inflow and outflow temperatures at the Mill Road vegetated detention basin for selected storms, by season, 1995-99. (Location is shown in fig. 1).

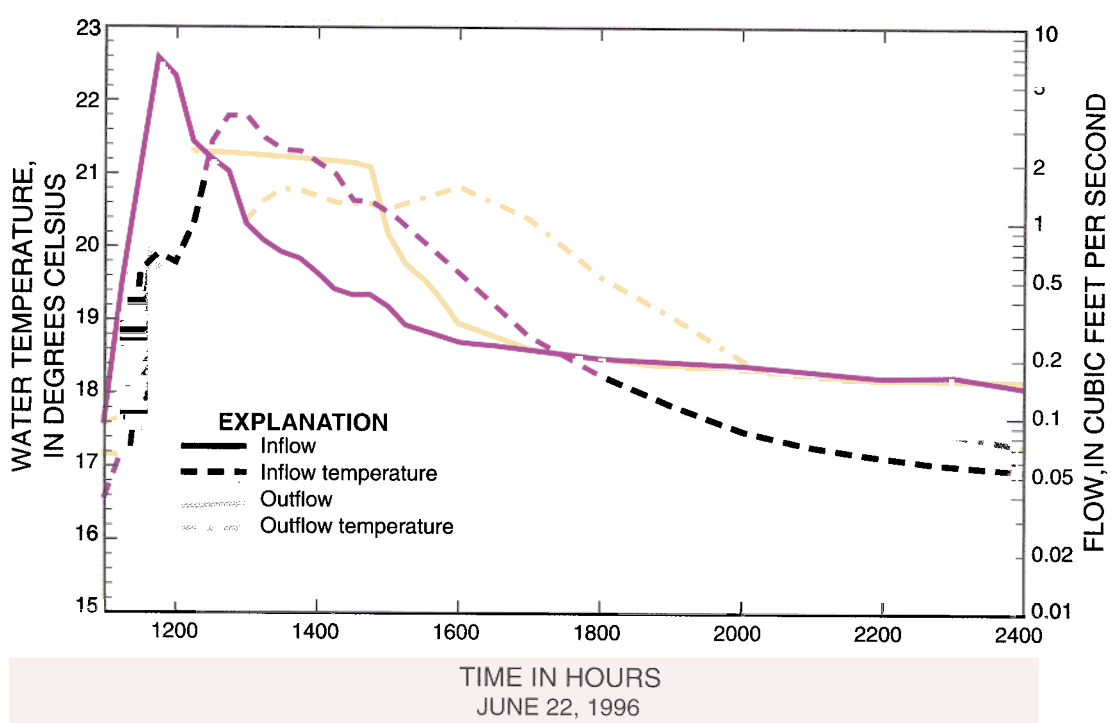


Figure 7. Graph showing inflow and outflow hydrograph, and inflow and outflow temperature at Mill Road vegetated detention basin during a representative stormflow event. (Location is shown

Table 3. Maximum, minimum, and average inflow and outflow temperatures with event duration and flow volume at the Mill Road detention basin for selected events during 1995-99. [Temperature values are degrees celsius]

Event	Duration (hours)	Flow volume (cubic feet)	Maximum inflow temperature	Maximum outflow temperature	Average inflow temperature	Average outflow temperature
06/07/96	24	37,000	21.0	20.4	16.2	17.1
06/22/96	13	30,400	21.8	20.8	18.7	19.2
06/30/96	35	62,200	21.5	21.3	20.0	20.2
08/02/96	6	23,300	24.1	22.5	21.0	20.9
09/13/96	12	56,900	19.9	18.7	18.5	17.3
07/08/98	40	259,000	23.0	24.1	19.5	20.3
08/20/99	12	34,600	21.0	23.2	19.9	21.8
09/16/99	17	43,000	19.8	20.5	17.8	19.4
Average	**19.9**	**68,300**	**21.5**	**21.4**	**19.0**	**19.5**

SUMMARY AND CONCLUSIONS

This study was undertaken in 1995 to assess the effectiveness of a naturally vegetated stormwater-detention basin in decreasing the amounts of contaminants carried by storm runoff from a residential development into an adjacent stream.

The basin decreased the average loads of all constituents except dissolved sulfate, dissolved zinc, and dissolved solids. The average load of chloride was greater at the inflow (82.1 lbs) than at the outflow (71.2 lbs), which indicates a net removal that can be attributed to a single high flow during January 1996, in which the inflow load greatly exceeded the outflow load. The loads of all other dissolved constituents were greater at the outflow than at the inflow, indicating resupension or dissolution of constituents deposited in the basin by previous storms. Overall removal efficiencies ranged from +62 percent for suspended solids to -128 percent for dissolved solids. The vegetated detention basin was effective in removing total phosphorus (38-percent removal efficiency) and orthophosphate (14-percent removal efficiency). These results suggest that the basin is effective in decreasing loads of suspended constituents and of constituents that are adsorbed to suspended particles, but is not effective in removing dissolved constituents.

Water temperatures at the outflow during fall and winter averaged about 1.4° C (2.5 ° F) lower than at the inflow, whereas spring water temperatures at the outflow were about the same as at the inflow. The thermal effect of the detention basin on receiving waters during summer storms was minimal; average maximum inflow and outflow temperatures were essentially equal. The average outflow temperature for all eight summer storms exceeded the inflow temperature by 0.5° C (0.9° F).

The results of this study indicate that vegetated detention basins can provide an effective means of decreasing the loads of certain suspended constituents in suburban runoff without adversely affecting the temperature of the receiving water body.

REFERENCE CITED

Zarriello, P.J., and Sherwood, D. A., 1992, Effects of stormwater detention on the chemical quality of runoff from a small residential development Monroe County, New York: U.S. Geological Survey Water-Resources Investigations Report 92-4003, 57 p.

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