A Hydrologic and Water Quality Study of Cascade Creek, Erie, Pennsylvania

Final Report to

Erie-Western Pennsylvania Port Authority

Pennsylvania Growing Greener Program
Pennsylvania Department of Environmental Protection

Great Lakes Commission's Great Lakes Basin Program for Soil Erosion and Sedimentation Control

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A. Executive Summary

A detailed study of the hydrology, water and sediment quality of Cascade Creek, Erie, PA, was performed. It was found that the stream suffers from the typical problems associated with urbanization and non-point source pollution. The stream is characterized by an extremely flashy nature, i.e., the response of the stream to a storm event is rapid due a very short time of concentration and the direct connection of impervious surfaces to the stream bed. Similarly, the stream quickly returns to base flow.

Several methods were used to study the hydrology of the watershed. State-of-the-art software was employed for geographic information system-based computer modeling to estimate peak flows for typical return-interval storms, and a hydrodynamic computer model endorsed by the USEPA was used to model the watershed for prediction of sediment release and transport. Also, field reconnaissance was conducted to provide accurate input to the models, and to collect sediment and water samples along with *in situ* measurements of water quality. Samples were variously analyzed for heavy metal content, oil and grease, polycyclic aromatic hydrocarbons (PAHs), and typical water quality measures such as pH, dissolved oxygen, biochemical oxygen demand, and conductivity.

A number of locations along the stream system were identified as having unstable stream banks prone to mass wasting and rapid erosion. Typically, these were areas with steep denuded banks, and locations of storm drain culverts.

It was found that the peak flows at the mouth of the stream ranged from 1327 ft^3 s^{-1} for the two year storm event to 4606 ft^3 s^{-1} for the 100 year storm event. Using these peak flows, the capacity of the lower reach of the stream to convey this water during storm events was analyzed. It was suggested that the stream channel could be modified to accommodate the 25 year flood, and the volume of material to be removed was computed.

Sediments from the bed of Cascade Creek were found to be high in heavy metals and oil & grease compared to reference sites. Stream water at some locations was high in organic matter measured as biochemical oxygen demand, while dissolved oxygen, pH, and conductivity were all within acceptable ranges.

Computer modeling of the watershed predicted that approximately 1.2 million pounds of sediment are generated in the watershed and transported to the Bay each year by the stream. Certain regions of the watershed appear to generate a disproportionate amount of sediment due to a combination of land use, topography, and soil type.

A plan was developed for a reconstruction and restoration of the stream system within Frontier Park. This half-million dollar project would not only reduce stream bank erosion and protect valuable sports playing field areas from encroachment, but would also create a zone of increased aesthetic appeal and perceived value to the community.

Among the various urban stormwater best management practices discussed, those viewed as most likely to benefit the watershed are disconnection of downspouts on commercial and residential buildings, infiltration trenches and underground sand filters. These BMPs are recommended as the most practical and potentially efficacious techniques for reduction of runoff volume and improvement in water quality.

B. Problem Statement

Cascade Creek, an urban stream, drains about 6.5 mi^2 in the City of Erie and the Mill Creek Township (Figure 1). Sediment and associated pollutants are transported by the stream to Presque Isle Bay, a Great Lakes Area of Concern. Peak flows resulting from large storms cause flooding in the lower reaches. Scattered, uncoordinated efforts have failed to control the stream and reduce sediment/pollutant transport.

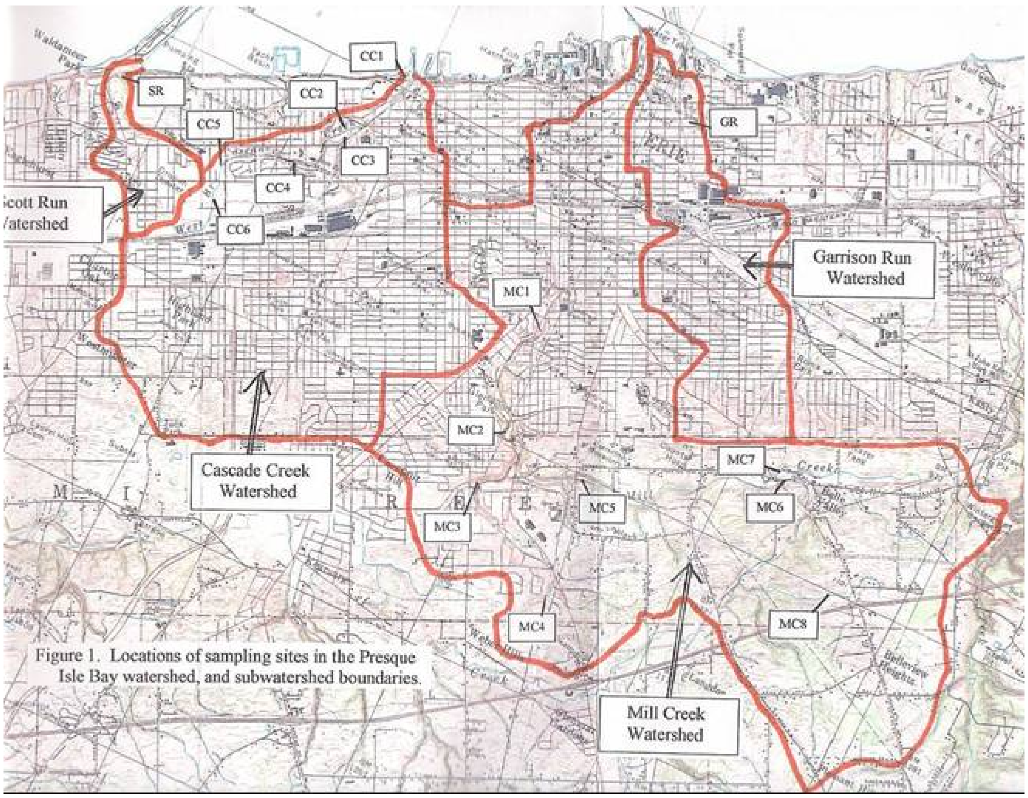


Figure 1. Watershed boundaries for Cascade Creek and other streams in Erie, PA, which drain into Presque Isle Bay.

C. Overall Project Goals

The goals of the project were to

1. Model the hydrology and sediment transport of the stream using state of the art computer software;
2. Identify flood prone areas and recommend channel modifications;
3. Develop recommendations to reduce stream channel degradation and to improve the health of the stream ecosystem using best management practices;
4. Educate stakeholders about how a healthy stream is an indicator of environmental quality and thus quality of life in the community.

D. Project Objectives

This report describes efforts to accomplish Goals #1 through 3. Goal #4 is beyond the scope of the current project as agreed to by the immediate funding source.

In order to accomplish the goals of the project as stated above, the following tasks were accomplished:

- peak flows were estimated for various return-interval storms using geographic information system (GIS) software and associated hydrologic computer models ;
- the generation and transport of sediment by the stream to Presque Isle Bay was modeled using state-of-the-art computer models;
- practical stormwater management practices were identified which would increase infiltration, reduce peak flows, and reduce the transport of sediments; and
- recommendations were developed for projects which might significantly reduce stream bank erosion and improve stream habitat for aquatic organisms.

Specifically, program activities included the following activities.

- the entire length of the stream system not enclosed in storm sewers was visually examined and documented photographically, including areas of unstable banks;
- monitoring and sample collection devices were installed at strategic locations in the watershed;
- hydrologic computer modeling was used to predict peak flows for various return-interval storms : 2, 5, 10, 25, 50, 100 yrs;
- stream sediments were analyzed for selected pollutants;
- GIS software was used to capture the topography, land use, soil types, and the stream network;
- estimated peak flows were used to design channel alterations to accommodate flow for various return-interval storm events;
- water quality computer modeling was used to predict sediment generation and transport under various land use scenarios.

E. Methods:

E.1 Monitoring & Sampling Equipment

An ISCO sampler was installed at mouth of Cascade Creek to record depth, pH, temperature, conductivity, rainfall. The sampler also collected samples during storm events. In addition to the main ISCO sampler, depth sensors (Global Water WL15 loggers) were installed on the Main and West Branches just above the confluence in Frontier Park of the two principle branches of the stream. The depth sensors recorded stream response to storm events. An example of the response of the stream to a storm event is provided in Figure 2.

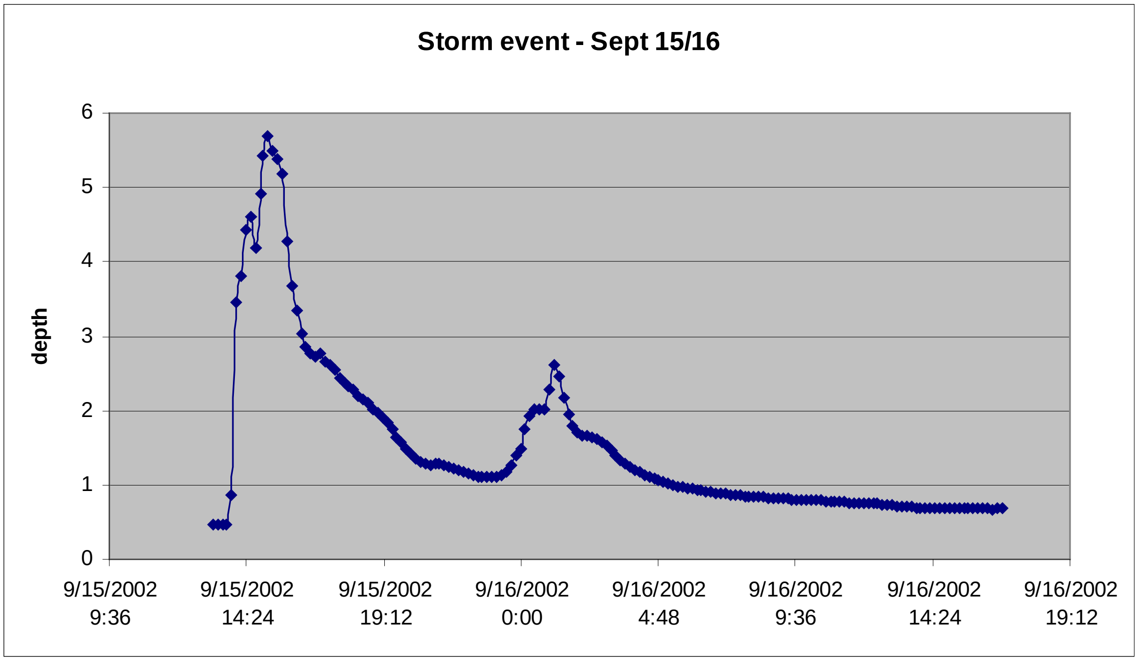


Figure 2. Stream response to a storm event on September 15, 2002.

E.2 Water Quality and Sediment Analysis

E.2.1. *In-Situ* Measurements

On-site measurements of pH, dissolved oxygen (DO) and temperature were made at each site using Accumet portable pH and DO meters. Specific conductivity was measured with a Corning 311 portable conductivity meter and recorded in mS/cm.

E.2.2. Water and Sediment Sample Collection Procedures

Three water and sediment samples were collected within each sample reach, one upstream, one downstream, and one in the middle of the sample reach. A duplicate was collected at each site from one of the three sample locations, chosen randomly. Sample bottles were pre-washed using Alconox and rinsed with tap water. The bottles were then placed in a 0.1 N nitric acid bath for 24 hours and rinsed with deionized water and acetone. Bottles used in BOD analysis were not rinsed in acetone.

Water samples were collected in 1 L plastic bottles (TSS and NPOC analysis) and in 250 mL small-neck plastic bottles (turbidity analysis). One additional 1 L plastic bottle was used to collect a sample for BOD_5 testing. All water samples were collected with the bottle mouth facing downstream and were filled to the top so as to avoid air headspace in the bottle.

Sediment samples were collected using a small garden shovel to scoop the sediment from the stream bed. The sediment was then passed through a #10 U.S Standard Testing Sieve (ASTM F-11) and transferred to the bottle with the shovel. The four samples collected at each site were placed in 250 mL wide-mouth plastic bottles for metals analysis. In addition, one sample was collected in a 250 mL wide-mouth glass bottle for oil & grease (HEM) analysis. The glass-bottle sample was a composite containing a mixture of sediment from the various spots along the sample reach. The sediment was mixed before it was transferred to the bottle.

E.2.3. Total Suspended Solids (TSS)

One-liter samples were filtered using a vacuum pump. Suspended solids were recovered using Whatman 934-AH glass fiber filters and placed in a drying oven at 105° C overnight. The increase in weight was recorded as TSS.

E.2.4. Dissolved Organic Carbon (DOC)

Dissolved organic carbon was measured for four samples per site using the filtrate from the suspended solids samples. Dissolved organic carbon was measured in the sample by the non-purgeable organic carbon (NPOC) method using a Shimadzu 5050A Total Carbon Analyzer. Each sample was acidified with phosphoric acid to convert carbonate and bicarbonate ions to carbonic acid. The sample was then sparged with oxygen for 10 minutes, stripping carbonic acid (as carbon dioxide) from the sample (this may also remove volatile organics). Before and after each sample batch, a standard of known carbon content as well as a deionized/distilled water blank were analyzed for quality control purposes.

E.2.5. 5 Day Biochemical Oxygen Demand (BOD_5)

The BOD_5 was determined at each site using the five-day test procedure as described by Standard Method 5210B (APHA et al., 1998). Initial and final DO concentrations were measured using a YSI 52 Dissolved Oxygen Meter. Samples were incubated in a Hach BOD Incubator 205 at 20° C in the dark for the test period. When necessary, samples were diluted 1:10 with dilution water prepared in accordance with Section 4.a. of the procedure. To insure quality control, a dilution water blank was run with each batch of diluted samples. A deionized water blank was run with all batches when the sample was not diluted.

E.2.6. Turbidity

Turbidity measurements were made on four samples per site. Readings were made using an Orbecco-Hellige Digital Direct-Reading Turbidimeter. Results were measured in nephalometric turbidity units (NTUs). The unit was zeroed and checked with a 40 NTU turbidity standard before every sample batch.

E.2.7. Acid Digestions for Metals Analysis

Acid digestions were performed on all plastic-bottle sediment samples. Samples (1-2 g wet wt) were digested with repeat additions of trace-metal grade nitric acid and 30% hydrogen peroxide according to EPA Method 3050B (EPA, 1990b). Hydrochloric acid (trace-metal grade) was added to the digestate and refluxed for 15 minutes. This is an optional step to increase the solubility of certain metals for later analysis (EPA 3050B, Section 2.3). The final digestate was diluted to 100mL using a volumetric flask. A duplicate and matrix spike (1.5 mg/L) of every tenth sample was digested for quality control purposes.

E.2.8. Moisture content

Approximately 10-g of sediment was placed in an aluminum weighing pan and its actual weight recorded. The sample was then dried at 105° C overnight in a drying oven. The sample was then cooled in a desiccator for at least 1 hour and weighed. The change in weight was then calculated. Two replicates from each bottle were measured and the average dry weight fraction was determined.

E.2.9. Metals Analysis by Flame Atomic Absorption (FLAA)

Final digestate from acid digestions were analyzed for metal content using FLAA spectroscopy. The analysis was performed for five metals: cadmium, copper, lead, nickel, and zinc using a Perkin Elmer AAnalyst 100 Atomic Absorption Spectrometer. Calibration and setup followed the procedure in the instrument User's Guide. The machine was optimized for each metal using a standard made at the characteristic concentration of that particular metal (the concentration at which the instrument detects an absorbance of 0.20 units). Once calibrated, the instrument was checked using a standard of known concentration every ten samples to ensure accuracy. Metals standards were prepared using 1mg/mL Fisher Scientific stock solutions of each metal.

E.2.10. Oil & Grease

Oil & grease was determined using the Hexane Extractable Material (HEM) in accordance with EPA Method 9071B, and was performed on one glass-bottle composite sample per site. The dry weight fraction was used to calculate the oil and grease concentration in mg/kg of dry sediment. A duplicate and matrix spike was extracted on every tenth sample. A method blank and a laboratory control sample were also extracted. Spiking solution was prepared according to Section 7.7 of the Method. Spiked samples and laboratory control samples contained 20mL of the 4000mg/L spiking solution.

E.3 Stream Channel Measurements

Cross-sections and longitudinal measurements of the stream channel were made using simple surveying equipment. Relative measurements only were made so as to document the current status of the stream within Frontier Park and downstream and for use in hydraulic calculations.

E.4 Hydrologic Modeling Using U.S.D.A. Soil Conservation Service (SCS) Technical Release 20 (TR-20)

Information was assembled in a format compatible with the proprietary software ArcView 3.2 (ESRI, Inc., Redlands, CA). ArcView is the engine used by the US EPA's BASINS system, which brings together government databases, GIS, and modeling into a common environment. BASINS is very useful for organizing and presenting environmental data, and for supplying input files to certain water quality models, including SWAT, which is a water quality model incorporated in BASINS. It models the generation, release, and transport of sediments and other pollutants on a watershed scale, and over long time periods. Output from SWAT was organized and presented graphically by use of GENSCN, also available from the USEPA.

BASINS does not contain a sophisticated hydraulic model for computing peak flow and hydrographs for individual storm events. Therefore, a different proprietary software know as WMS 6.1 (Scientific Software Group, Sandy, Utah) was used to prepare geographic, soil, and topographic information for transfer to TR-20, a hydraulic modeling program by the Natural Resources Conservation Service of the US Department of Agriculture. TR-20 was then used to estimate peak flow for various return-interval storm events. Although a relatively simple program, it is designed to model single storm events for heterogeneous watersheds (McCuen 1998). Hydrographs for each sub-basin are routed valley reaches and reservoirs. The combined hydrograph portrays peak flow at critical points in the watershed.

E.4.1. SCS Curve Number Technique

TR-20 determines rainfall runoff volumes through the SCS Curve Number technique. Each land cover and hydrologic soil group has unique qualities that determine how much infiltration of precipitation will occur, and from those values derive the amount of runoff that will be produced (Burian, 2002). The curve number is derived by pairing a particular land cover with a hydrologic soil group as shown in Table 1. (SCS, 1975).

Table 1. Example of TR-20 Curve Number Assignment.

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area 2/	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) 3/:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80

E.4.2. Rainfall/Runoff

The amount of runoff generated by a basin is estimated by the use of the SCS runoff equation. The runoff equation takes into consideration the amount of rainfall and the initial abstractive qualities of the land area which is reflected by specific curve numbers. It also determines the total abstractive qualities of the land surface. The total abstractive ability of the land surface subtracted from the total rainfall depth equals the total runoff depth from the basin.

Rainfall is distributed over a period of time. The distribution pattern of a storm varies from storm to storm and from region to region. The NRCS studied this phenomenon and developed four 24-hour synthetic rainfall distributions for various regions throughout the United States by studying National Weather Service and local rainfall information. Erie, PA is located within the Type II rainfall region which is characterized by the most intense short duration rainfalls. Figure 3 shows the distribution of rainfall types across the United States.

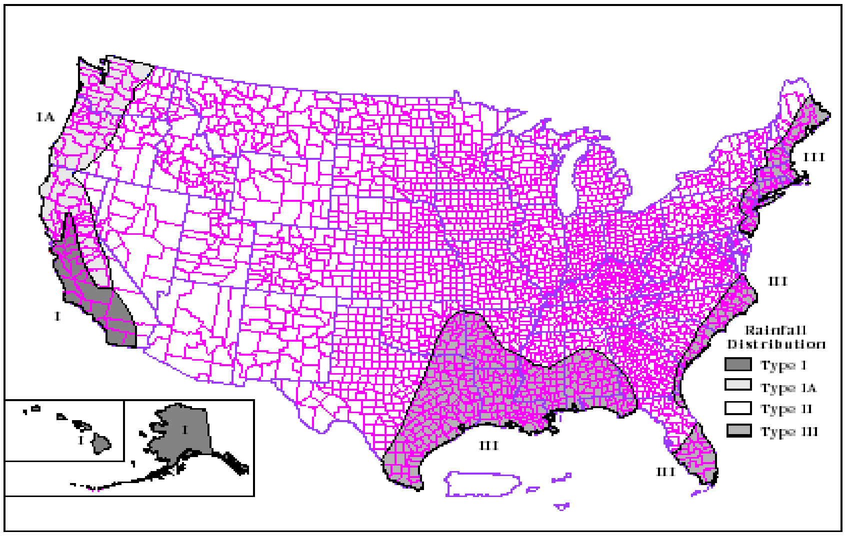


Figure 3. USDA NRCS Synthetic Rainfall Distribution Map

E.4.3. Return Interval Storm Modeling

The frequency with which a certain storm can be expected to occur is the reciprocal of the probability that the storm will be equaled or exceeded in a given year (Debo, 1995). In other words, the exceedence probability is inversely related to the interval at which the storm will return (Chen, 1995)

$$\mathbf{p = 1/T}$$

where p = exceedence probability and T = return interval

The NRCS has produced 24-hour rainfall maps for the significant return interval storms that are commonly used for modeling purposes. Return interval storm sizes for the Erie, PA are presented in Table 2.

Table 2. Return Interval Storm Precipitation Numbers for Erie, Pennsylvania

Return Interval (yrs)	*Precip. Depth (in)*
2 year	2.5
5 year	3.1
10 year	3.6
25 year	4.1
50 year	4.6
100 year	4.7

E.4.4. Geology of Cascade Creek Watershed, Erie, PA

Erie, PA is located in the northwestern reaches of the state and is bordered to the northwest by Lake Erie, creating 47 miles of shoreline. Most of this shoreline is made up of narrow beaches in front of 15 to 170 ft bluffs cut into Pleistocene and early Holocene glacial and lacustrine sediments atop Devonian shale bedrock. There is a narrow watershed along the Lake's shoreline which drains the small percentage of Pennsylvania which is part of the Great Lake's watershed, which flows to the Atlantic Ocean via the St. Lawrence river. These small streams have eroded overlying sediments down to the shale bedrock creating the majority of breaks in the nearly uniform bluff-face shoreline.

E.4.5. Hydrologic Soil Types

Soils are ranked into four major hydrologic categories for the purpose of hydrologic modeling in the SCS curve number method. The controlling factor for the soil types is their ability to transfer water through the porous regions of their matrix. The SCS has classified nearly 8,500 different soils into four hydrologic soil types based upon their hydrologic characteristics. These hydrologic categories are known as A, B, C, and D. Category A soils are sand, loamy sand or sandy loam types of soils. They have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission. Category B soils are silt loam or loam. They have a moderate infiltration rate when thoroughly wetted and consist chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Category C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure. Category D soils have the highest runoff potential and are clay loam, silty clay loam, sandy clay, silty clay or clay. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material. (USDA TR-55 manual).

E.4.6. Predominant Soil Types Within the Study Area

According to the soil survey of Erie County, Pennsylvania completed by the US Department of Agriculture, there are three major geologic soil groups found within the Cascade Creek Watershed: Conotton series, Erie series, and the Halsey series. Conotton series soils are deep, well-drained soils that are derived from acid shale bedrock and glacial sandstone and granite. Erie series soils consist of deep poorly drained soils in the upland areas whose parent material consists of bedrock and sandstone. The Halsey series is categorized as being a loamy deep, well drained soil common to this geographical area (USGS, 1968). All four hydrologic soil types are present in the Cascade Creek Watershed (Table 3).

Table 3. Cascade Watershed Hydrologic Soil Types By Area and Percentage of Total Area.

Hydrologic Soil Type	Area (mi2)	% of Total Area
Soil Group A	4.13	65.32
Soil Group B	0.67	10.65
Soil Group C	1.14	18.06
Soil Group D	0.38	5.97

E.4.7. Land Use Classification

E.4.7.1 Land Use Types

Land use describes how a tract of land is used, such as residential, commercial, or industrial. Land cover is closely related to land use in that it describes the state or physical appearance of a natural land surfaces such as bare soil, woods, or grasslands (Burian 2002). The land use and land cover classification describes the degree to which the ground's surface has become impermeable to water infiltration. The land use classification for a parcel of land is paired with a hydrologic soil type to determine the runoff potential of a tract of land through the SCS curve number method.

E.4.7.2 Predominant Land Uses Within the Study Area

The Cascade Creek Watershed is located in a highly urbanized area. Predominant land uses within the study area as classified by the SCS curve number method include 1/8 acre or less residential lots, ¼ acre residential lots, industrial, commercial, natural brush, light woods vegetation, and transportation usage. Table 4 presents land uses for the Cascade Watershed.

Table 4. Urbanized Watershed Land Use Defined By Area and Percentage of Total Area.

Land Use Type	Area (mi2)	% of Total Area
Industrial	1.38	21.28
Eighth Acre Residential	2.90	44.68
Half Acre Residential	0.28	4.26
Paved Open	0.28	4.26
Natural Cover	1.65	25.53

E.4.7.3 Land Use Comparison Between Local Government Entities

The Cascade Creek watershed is located within the jurisdictions of the City of Erie and the Millcreek Township (see Appendix for details). Land use within the City of Erie is mainly high density residential, and also includes areas zoned industrial which accommodate manufacturing facilities along the 12th Street corridor. The size of residential lots within Erie is mostly an eighth acre or less, but there is a small percentage of land which has quarter acre residential lots. Commercial land use is present within the City of Erie, but represents a small percentage of the total area and is mostly located along the southern Peach Street area and the 28th Street corridor.

The land use scheme changes when crossing the political boundary for Millcreek Township. Millcreek largely has been a suburban area for Erie, and there are more quarter acre residential lots in this area. Eighth acre residential lots are also present. The lack of commercial properties within western Erie allowed Millcreek to zone large areas commercial along the 12th and 26th Street corridors. Industrial areas are also found within the Millcreek portion of the watershed, mainly located along the Pittsburgh Avenue corridor.

E.4.8. Delineation and Digitizing the Water Conveyance Network

The Cascade Creek Watershed, approximately 6.5 square miles in area, is a small watershed requiring a high level of detail when delineating sub-basins in order to adequately simulate its response to precipitation events (Figure 4). The watershed was divided into three sub-basins. The three sub-basins represented the Main Branch, West Branch, and Lower Watershed areas of the Cascade basin.

Approximately 4 miles of Cascade Creek is in an open channel which drains to Presque Isle Bay. A small length of the Main Branch is located above ground, while a significant length of the West Branch and the stream from the confluence of the branches to the outlet is conveyed in an open channel. ArcView was employed to digitalize the open channel lengths of the creek utilizing digital orthographic photos. The orthographic photos were enlarged and arcs were created over the open channel portions of the stream and saved as shape files.

While TR 20 has the capability to make open channel flow hydraulic computations, it was not designed to be a storm sewer design tool. Since a large portion of the stream system is contained in storm sewers, sewer maps were obtained from the engineering offices of each locality. Storm sewer lines that drained into Cascade Creek were identified, and a precise watershed boundary was established. By comparing schematics to digital orthophotos, it was possible to represent the storm sewer lines as if they were stream segments The watershed basin and sub-basin boundaries were also created within ArcView. Circular connections within the sewer system were examined and resolved manually.

USGS digital elevation models (DEMs) are raster information coverages that describe the topography of a given area. Designed specifically for advanced observation purposes, each grid in the DEM dataset represents an area on the earth's surface which has a corresponding latitude, longitude, and elevation. The datasets are arranged to correspond with topographic quadrangles; therefore the four DEMs used for the study area were Erie North, Erie North OE, Erie South, and Swanville. They were obtained from USGS digital geographic data download internet website. The DEMs were then

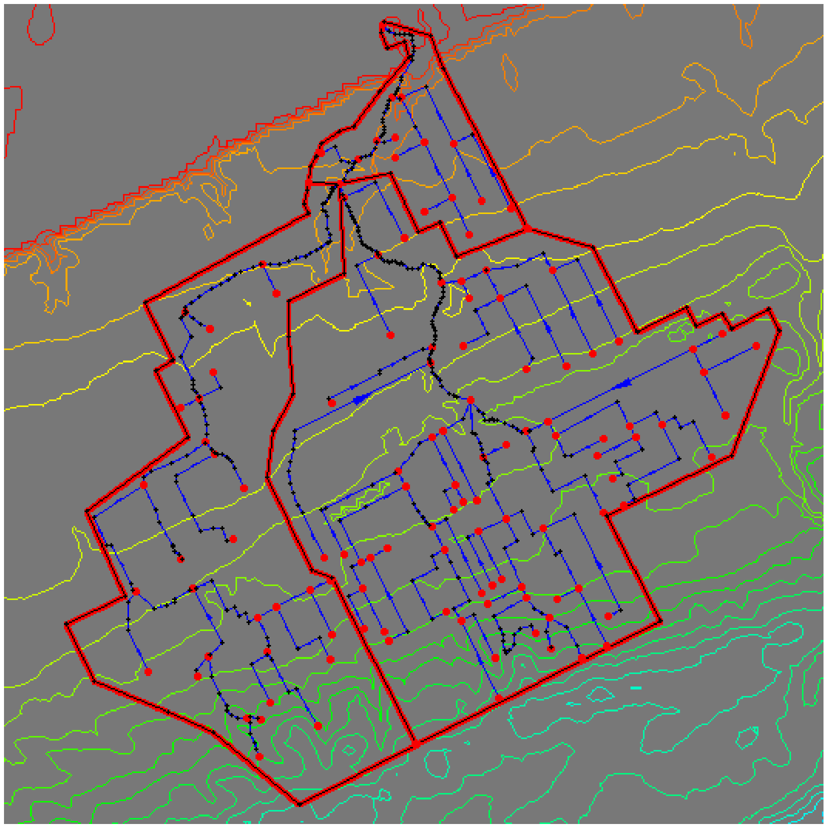


Figure 4. Watershed and sub-basin delineation for Cascade Creek within the WMS system.

imported into the WMS environment and were smoothed for greater resolution. NODATA grid cells were assigned values based upon the surrounding cell values.

The TOPographic ParameteriZation (TOPAZ) software package is included within the WMS software for the automated digital landscape analysis. The TOPAZ program was initiated analyzing each grid cell in the DEM datasets. The program utilizes the D-8 processing method to determine flow paths of water by identifying the steepest down slope flow path between each cell of a DEM and its eight neighboring cells (Ogden GIS Distributed Models I). The path is then identified as the path water would naturally flow during a storm event. TOPAZ also allows the user to enter threshold accumulation values which allow the program to identify where stream channels would occur based solely upon topographic data. The accumulation stream paths are represented by non-attribute arcs which are converted into stream attribute arcs. The TOPAZ program divided the Cascade catchment into three sub-basins, the Main Branch, West Branch , and Lower Watershed sub-basins. The catchment perimeter arcs were represented by non-attribute arcs which were converted into arcs identified as watershed boundaries. The boundary arcs are combined with the stream arc network to create a full drainage coverage.

E.4.9. Watershed Modeling System (WMS)

The GIS elements created in ArcView for the urbanized watershed modeling consisted of land use coverage, hydrologic soil type coverage, and stream and basin layers, as discussed previously. These files were saved as shape files (.shp) within ArcView and transported into WMS. The actual method for importation into WMS was unique for each file.

E.4.9.1 Time of Concentration for Areas in Storm Sewers

Time of concentration (ToC) is defined as the time required for a drop of water which falls on the most remote location in a watershed to reach the outlet (or point of study). Within WMS, the location farthest from the outlet of each sub-basin is assigned a point. The TOPAZ flow direction dataset is utilized to identify a path that runoff would travel from that point to the stream channel, then to the outlet of the basin. This distance is then separated into three types of flow: sheet, shallow concentrated, and channel.

The sheet flow section of the ToC arc is allowed to be no longer than 300 ft. and is given attributes so the program can determine the time required for water to move along that section based on the Velocity Method which considers slope and friction (represented by Manning's roughness coefficient). For highly urbanized areas with storm sewers, a Manning's roughness value of 0.014 was used for sheet flow and shallow concentrated flow. The shallow concentrated flow section occurs after water has traveled a short distance as a uniform sheet until it enters the storm sewer. In the storm sewer, flow is modeled as open channel flow using Manning's equation. The important parameters in Manning's equation are slope, roughness, hydraulic radius, and channel geometry. The hydraulic radius is a function of wetted perimeter and cross-sectional area, and is determined through a custom calculator within the WMS program. The Time Computation function then supplies the water travel times from the three arc sections and arrives at a ToC for the sub-basin.

All storm sewers were assumed to be circular, have a water depth of ¼ of the diameter of the pipe, and have a roughness coefficient of .014 unless a different shape or roughness was specifically known for a section.

E.4.9.2 Time of Concentration for Areas with Natural Stream Channels

Time computations for the natural portions of the sub-basins were conducted in a similar manner as in the urbanized watershed. In open channel sections of the stream, the stream dimensions were measured and averaged for each reach section that exhibited unique characteristics. Roughness coefficients were assigned by visually inspecting the open channel reaches and noting features of the channel's bed and bank according to Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplains (FHWA, 1984) From these observations a table was consulted and a proper coefficient value was assigned utilizing FHWA guide and Open Channel Hydraulics (Chow, 1959). Bankfull width and depth of open reaches were estimated by observing the scouring of the banks to determine a 2 year flood line.

F. Results

F.1 Curve Numbers, Infiltration, and Rainfall/Runoff

Runoff is directly related to the infiltration characteristics of sub-basins and the total watershed. Infiltration capacity of a basin is a function of the interaction of land use and hydrologic soil type which is reflected in a composite curve number for the basin. Table 5 presents the modeling results for the watershed by sub-basin and by natural cover verses urbanized areas. For simplicity, areas allocated to each category are not shown. Initial abstraction, i.e., the depth of rainfall which does not become runoff due to evaporation, interception, and infiltration, is also shown in Table 5 for the natural cover and urbanized portions of each sub-basin. These values assume a 24 hr storm. As can be seen, the difference in hydrologic response of the developed areas to that of the natural cover areas is dramatic.

Table 5. Curve numbers and initial abstraction natural cover and urbanized areas within the watershed.

	Natural		Urbanized	
Basin	**Curve #**	**Initial Abstraction (in)**	**Curve #**	**Initial Abstraction (in)**
Main Branch	46	2.348	77	0.597
West Branch	41	2.878	74	0.703
Lower Watershed	66	1.03	84	0.381

The curve number relates rainfall depth to runoff depth, which can then be converted into runoff volume based on basin area. Table 6 presents the runoff in acre-feet for storm events corresponding to the standard return-intervals of interest.

Table 6. Runoff (acre-ft) for various return interval storms for each sub-basin.

Return Interval (yrs)	**2**	**5**	**10**	**25**	**50**	**100**
24 hr Rainfall (in)	**2.5**	**3.1**	**3.6**	**4.1**	**4.6**	**4.7**
Main Branch	149.3	234.5	315.8	404.9	500.4	520.2
West Branch	71.8	114.9	157.6	206.1	259.3	270.5
Lower Watershed	32.0	46.9	60.3	74.1	88.6	91.6
Total	253.1	396.3	533.7	685.1	848.3	882.3

F.2 Peak Flow

Water is routed through the stream system using travel time calculations. Time of concentration will differ for each sub-basin. Thus, peak flows for each sub-basin are not simply additive. Assuming the standard pattern of rainfall as depicted in the 24 hr Type II synthetic rainfall distribution, the peak flow can be predicted. Predicted peak flows for various return-interval storm events are presented in Table 7.

Table 7. Peak flow resulting from precipitation during various return-interval storms; flows are given in cfs; values are not additive due to time of concentration differences.

Return Interval (years)

Year Storm	2	5	10	25	50	100
West Branch	189	324	451	588	733	762
Main Branch	1062	1723	2328	2973	3643	3777
Confluence	1092	1781	2416	3095	3806	3951
Lower Watershed	246	359	457	555	659	680
Bay Outlet	1327	2125	2857	3632	4443	4606

F.3 Impact of BMPs on Runoff and Flow

As a modeling exercise, it was speculated that if extensive best management practices (BMPs) were employed at all commercial and industrial sites within the watershed, that the first half-inch of rainfall could be trapped and infiltrated into the ground. It is widely known by urban pollution experts that the first half-inch of runoff transports most of the urban pollution from the ground's surface. Significant runoff reduction would result (Table 8). Specific BMP recommendations will be presented later in this report.

Table 8. Runoff savings resulting from the employment of BMPs at all commercial and industrial sites in the watershed; assumption is that the first half-inch of runoff would be trapped and infiltrated.

Commercial and Industrial Land Use and Runoff

	Land Area	Runoff Savings ac/ft	Runoff Savings cf
West Branch	487 acres	20.29	883,840
Main Branch	505 acres	21.04	916,510

F.4 Sediment Transport During Storm Events

Over the time period from January, 2001, to August 3, 2001, water samples were collected during twelve storm events. For these twelve sampled events, 71,527 kg (157 tons) of suspended sediment was transported by the stream at our location near the mouth. This is roughly equivalent to over 200 m^3 of settled sediment, assuming a 35% solids content which is typical of upper-layer Bay sediments. We did not attempt to measure bed load, which consists of sand, gravel, cobbles, and boulders. It was apparent that a significant amount of material was transported by the stream during large events as bed load. Bed load is not important as a pollutant transport mechanism, but this material does make its way to Presque Isle Bay and contribute to the expansion of the Cascade Creek delta.

The sampler collected up to 24 samples automatically when the water level in the stream rose. The device was programmed to collect samples every 30 minutes; therefore, it was possible to track stream behavior over a maximum of 12 hours for a given event. Sample bottles were returned to the lab where each water sample was filtered and total suspended solids concentration (TSS) was determined. TSS ranged from less than 10 mg/L to about 2,000 mg/L. Since each sample represented a 30 minute interval, the concentration was multiplied by the average flow rate during that interval to compute the total mass of suspended sediment transported during that interval.

Figure 5 through Figure 9 are records of flow and (suspended) sediment transport during representative storms during the period. Notice that peak sediment loads corresponded to peak flow, and that sediment load often decreased more quickly than did flow after the peak had passed. When total sediment mass transported per event was

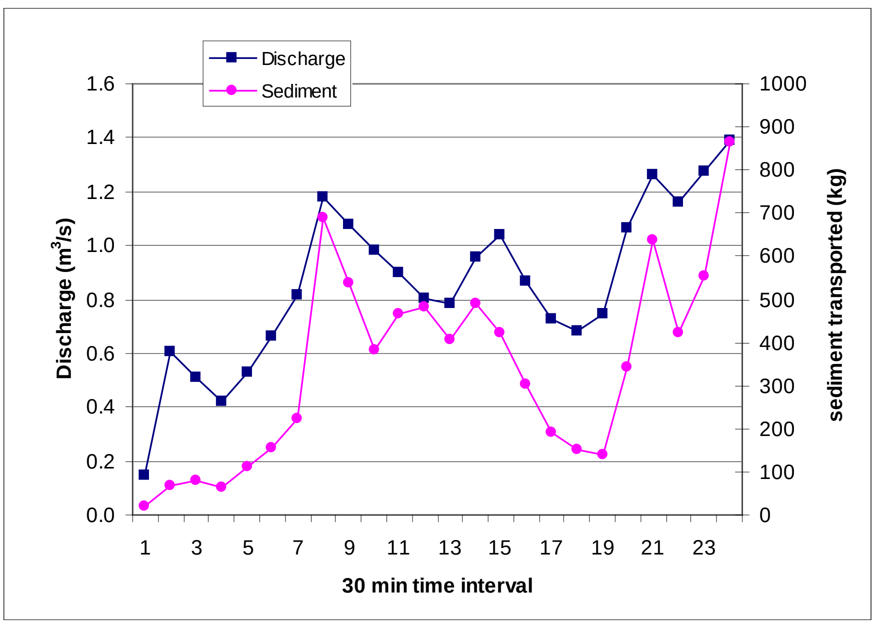


Figure 5. Mean discharge and mass of sediment transported during 30 minute sampling intervals during storm on February 14, 2001.

plotted verses total volume of water for the storm event (Figure 7), a clear relationship is demonstrated which is intuitively assumed: large events transport more sediment per cubic meter than do small events. Figure 8 illustrates the relationship between TSS and instantaneous discharge measurements. This relationship appears to be curvilinear, but the scatter in the data produces a high degree of variability. That variability is suppressed

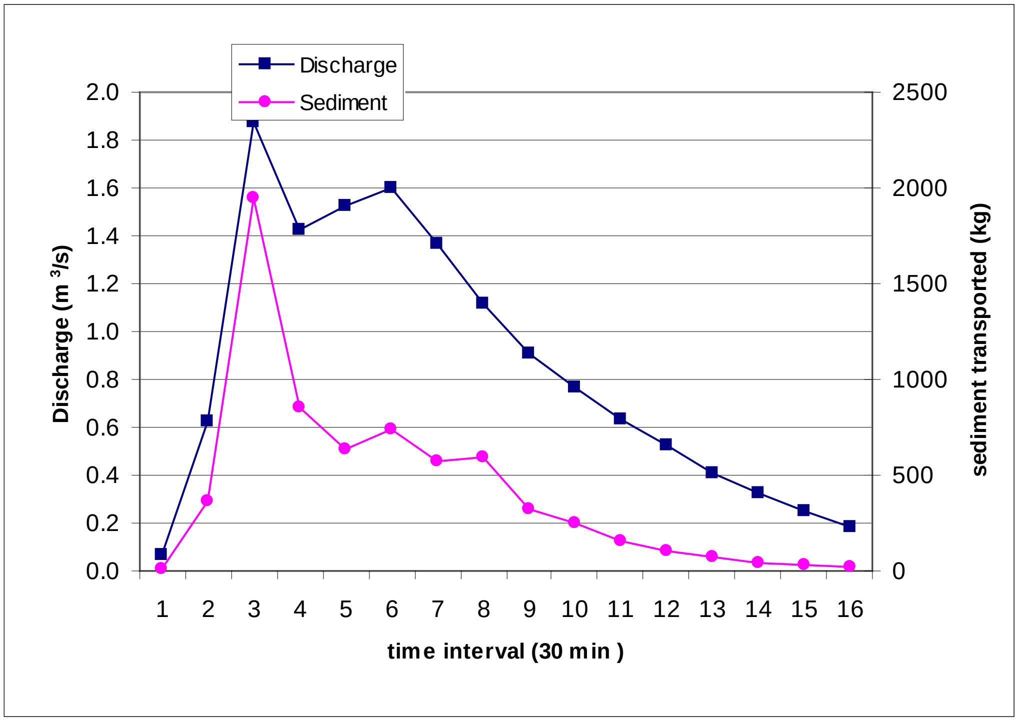


Figure 6. Mean discharge and mass of sediment transported during 30 minute sampling intervals for storm - May 24, 2001

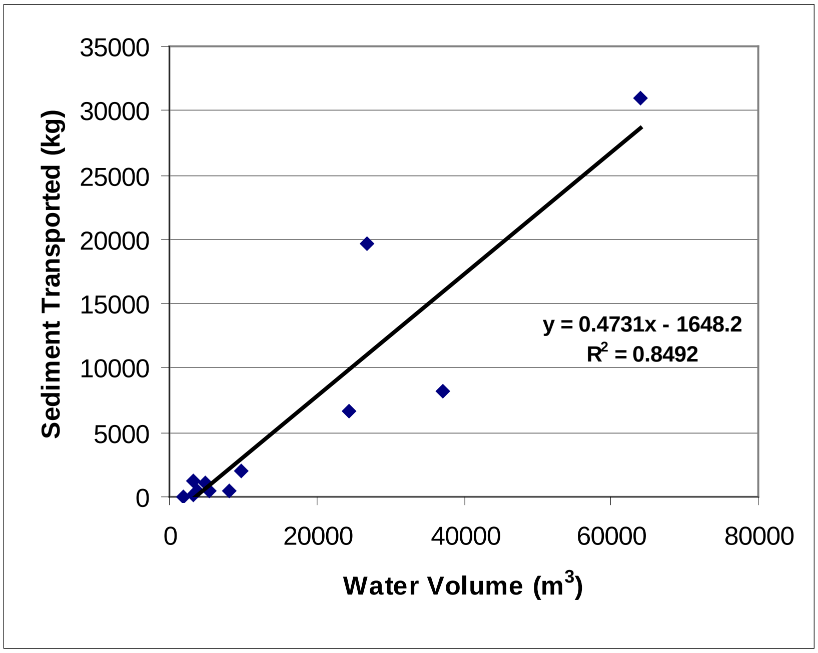


Figure 7. Sediment transported as a function of total volume for storm events on Cascade Creek.

somewhat when the mass of sediment transported per 30 minute interval is plotted verses instantaneous discharge (Figure 9). This plot shows a more pronounced non-linear relationship.

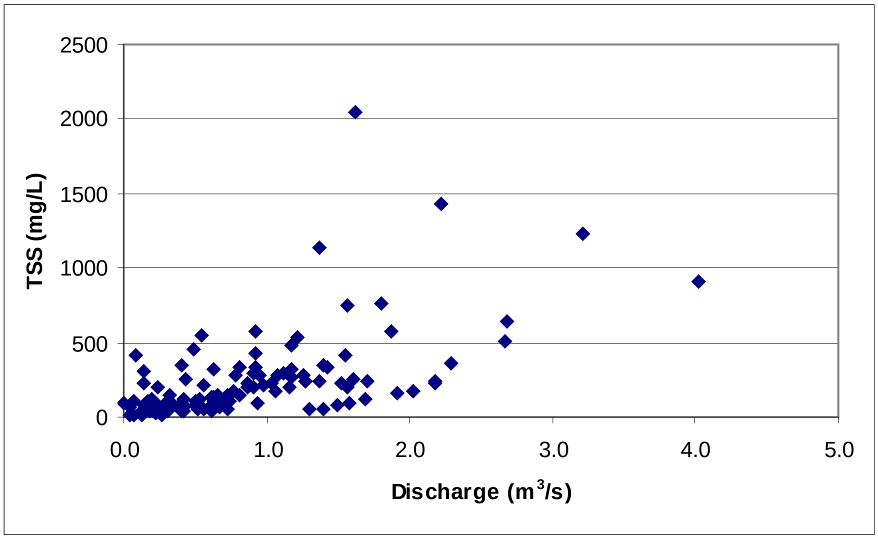


Figure 8. Total suspended solids concentration as a function of discharge during sampled storm events.

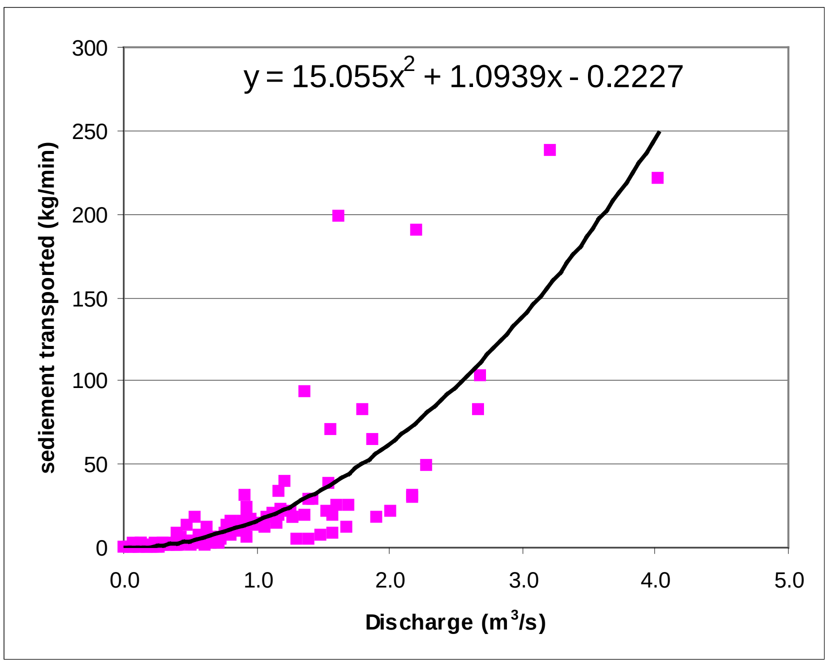


Figure 9. Sediment flux (kg/min) as a function of discharge during sampled storm events.

F.5 Description of the Stream System

A visual examination was conducted of the stream system, starting with the mouth and progressing upstream. References to left and right banks assume that the observer is facing upstream, and the terms “above” and “below” imply upstream and downstream, respectively. An extensive collection of photographs is included on a compact disk provided with this report. Figure 10 is a portion of a USGS topographic quadrangle map (Erie South 42080) which shows the lower reaches of the stream.

The lowest reach of the stream is that area below the walk bridge located near the entrance to the Niagara Pier gated condominium community. This is a delta area created as the stream emerges through the ancient bluff. The bluff to the east of the stream channel has been destroyed by land development activities, but the bluff to the west of the stream is intact and rises approximately 65 ft above the stream bed. The delta has been created by the deposition of sediments eroded from the watershed, and now extends approximately 1000 ft north of the bluff into Presque Isle Bay. This is an area of high instability, as the stream channel becomes clogged with debris and relocates itself frequently. The current channel flows along the right margin of the delta (near the developed peninsula known as Niagara Pier) and then becomes braided once reaching the elevation of the Bay (570 ft asl).

The stream channel above the delta is incised in bedrock as it runs alongside the Bayfront Highway for a distance of approximately 2100 ft until it runs under the highway. The stream bed elevation changes approximately 50 ft over this distance. There is significant potential for bank erosion on both sides of the stream. The west bank is steep for much of this stretch climbing to the top of the bluff, and there have been several episodes of mass wasting of the unconsolidated soil above bedrock into the stream. In one case, the stream was completely dammed and heavy equipment was required to clear the stream channel (Port Authority personal communication, 2003). On the east bank, grading for the highway has created a stable bank except where storm sewers empty into the stream channel. Frequently, rapid erosion has occurred around the sides of these culvert openings.

The reach of the stream located on the east side of the Bayfront Highway (portrayed in Figure 10 as an alternating dark and light heavy line angling northeast and then east along the waterfront) has been highly modified by the state highway department. The 6^{th} Street Bridge which crosses the Bayfront Highway and the stream was reconstructed in 1999. At that time, the banks of the stream were rebuilt of gabions, and the stream bed was constructed of rock mattresses. Above these structures, culvert openings for storm sewers emptying into the stream are frequently the foci of erosion.

Above the Bayfront Highway, the stream flows through Frontier Park, which exhibits the landform of an ancient floodplain. At the outside of meander bends, the southeastern bank is nearly vertical, rising about 15 feet above the stream bed with exposed fine grained unconsolidated clayey soil. The outside of meander bends on the northwestern bank is also steep but not so high, averaging only two to three feet. However, northwestern meander bends appear to be more rapidly growing out into the flat flood plain which occupies much of the central region of the park.

The stream’s two major branches join within Frontier Park: the Main Branch and the West Branch. The confluence is a site of major instability. Currently a concrete wall, which was constructed at least fifty years ago (as reported by local citizens who grew up

Figure 10. The lower reaches of Cascade Creek.

in this neighborhood), has partially collapsed into the stream channel due to undercutting of the stream bed. Water now flows behind a portion of the wall during storm events.

Both branches of the stream pass under 8th street at the southern margin of the park (Figure 12). A seven-foot diameter culvert accommodates the Main Branch which flows essentially due north at this point, and a six-foot culvert conveys the West Branch under 8th Street at the southwestern corner of the park. Although the Main Branch is the larger of the two branches, it is generally not indicated on topographic maps because just south of 12th Street it is completely contained within a storm sewer system.

The short reach of the Main Branch just south of 8th Street has been the site of recent land development. A convenience store was constructed during 2002, and the land adjoining the eastern bank of the steam was denuded of vegetation. A grant was obtained from the Pennsylvania Growing Greener program to protect the stream bank along the development using state-of-the-art engineering techniques. The technique chosen by the design firm was gabion baskets along the lower bank with seeded sloping soil above. Within a year of being constructed, a 10 year storm event occurred in September, 2002, resulting in more water than could be conveyed by the culvert under 8th Street. The new stream bank was destroyed and considerable soil was washed downstream (). As of the date of this report, the embankment has not been reconstructed.

Figure 11. Eroded stream bank just south of 8th Street on the Main Branch of Cascade Creek.

The area between 8th Street and 12th Street through which the Main Branch flows is dominated by a major interchange on Interstate Highway 79, and its termination as an interstate highway. The stream briefly appears just south of 12th Street, but is completely contained in storm sewers from this point south (upstream) to its southern boundary along Grandview Road and Upper Peach Street.

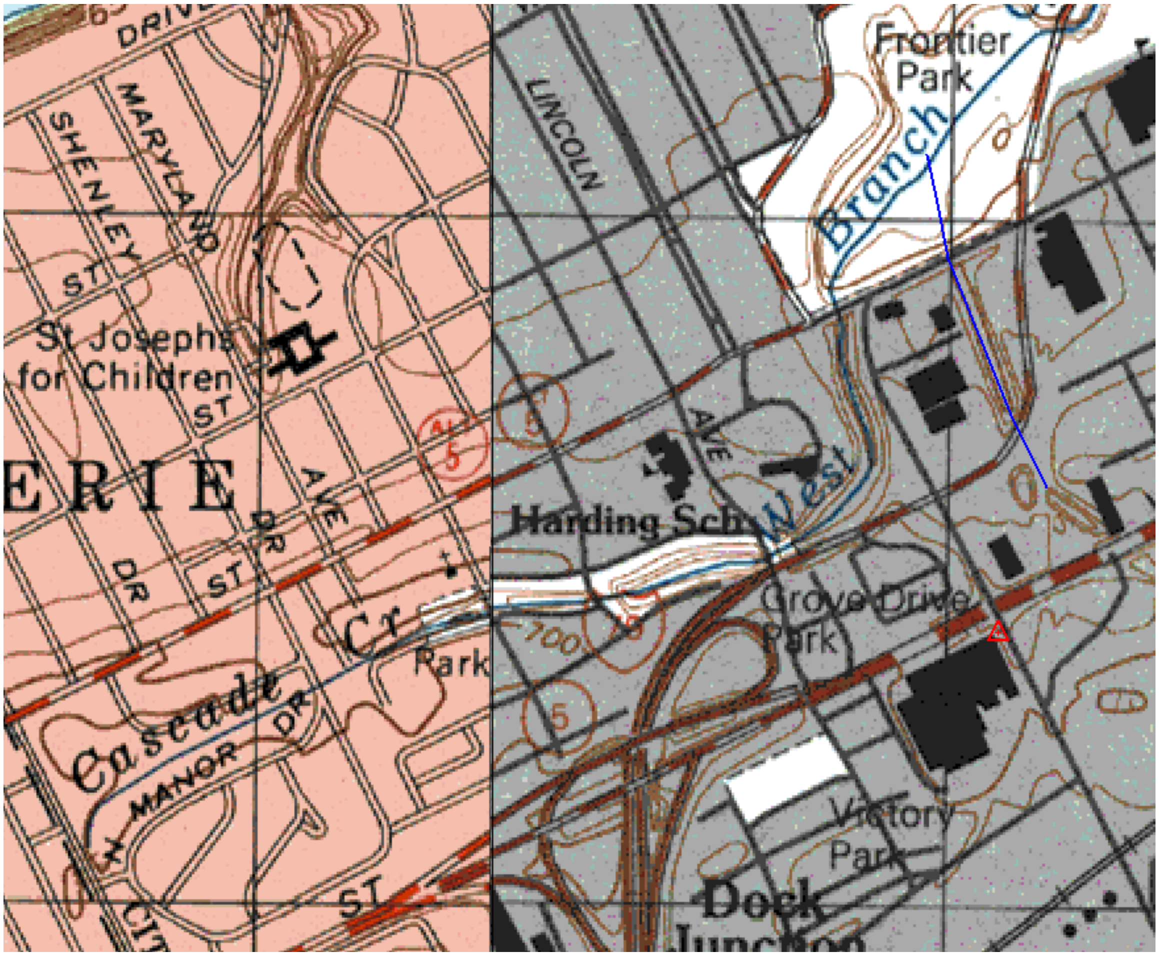


Figure 12. Cascade Creek just upstream from Frontier Park. (this is a composite of two USGS topographic maps printed at different times using different shading to indicate urban areas).

The West Branch stream channel upstream from Frontier Park is located in a residential neighborhood and is characterized by a series of deep ravines (Figure 12). These ravines are densely vegetated and do not appear to be experiencing rapid erosion. At Pittsburgh Avenue (which serves here as the City of Erie and the Millcreek Township boundary), shown at the lower left-hand corner of Figure 12, the stream channel is a concrete lined drainage ditch while it parallels Pittsburgh Avenue and is contiguous to the large paved parking lot of the West Erie Plaza. There are no observable stormwater retention devices or other BMPs along the stream channel in this location.

The channel makes a series of ninety-degree turns to accommodate streets and commercial properties as it approaches its headwaters behind the area known as the Yorktown Shopping Center commercial area. This is a relatively flat wetlands area located alongside the major railroad corridor which is a major feature of the Erie landscape. In addition to the channel shown in Figure 13, a considerable area of the upper watershed is in storm sewers which empty into the stream at several locations within Millcreek Township and is conveyed under the railroad tracks from the south. This upper region of the watershed is relatively flat, and thus stream bank erosion does not appear to be an issue. However, this area is heavily industrial and commercial in nature, and is likely the source of urban non-point source pollution which is carried downstream by sediment particles. Millcreek Township has aggressive stormwater management requirements for new development, but much of the property in this portion of the watershed is grandfathered from these requirements. There are few observable BMPs for stormwater management and non-point source pollution control.

Figure 13. Upper reaches and headwaters of the West Branch of Cascade Creek.

F.6 Water and Sediment Quality Findings

F.6.1. *In-situ* Water Quality Measurements

Water quality measurements were made at various locations along the stream during base flow (Figure 14). It was found that specific conductivity ranged from 0.8 to 3.42 mS/cm, with a mean of 1.41 mS/cm; dissolved oxygen (DO) varied from 8.8 to 11.0 mg/L; pH was relatively constant at about 8.0; total suspended solids (TSS) during base flow was low with an average of 4 mg/L of suspended solids; and turbidity ranged from 1.3 to 6.7 nephalometric turbidity units (NTUs), with a mean of 3.88 NTUs.

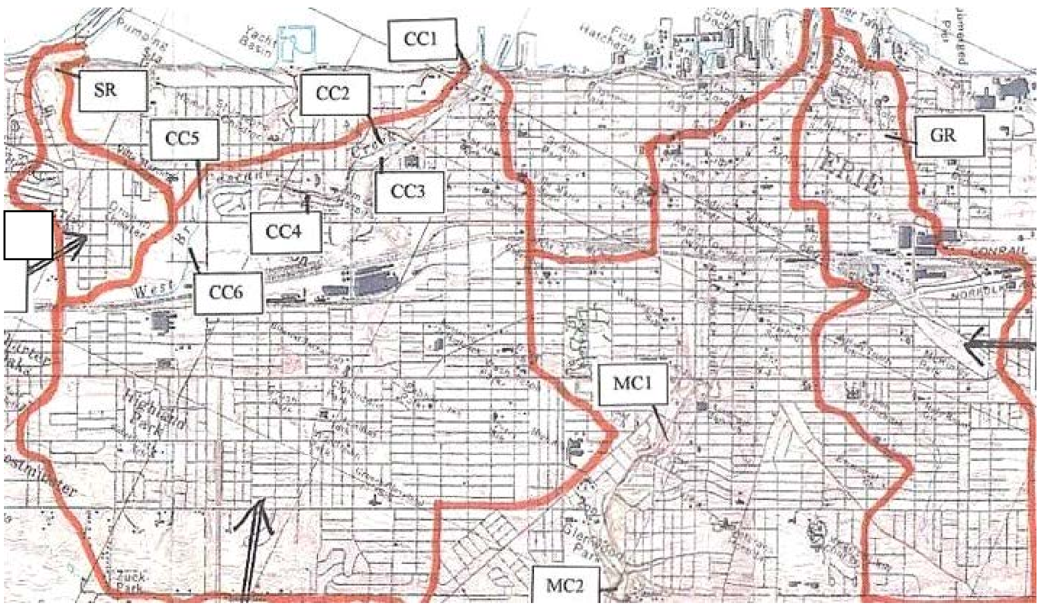


Figure 14. Locations for water and sediment quality measurements.

F.6.2. Laboratory Analysis of Water and Sediment Quality

Samples of water were retrieved for laboratory analysis of 5-Day biochemical oxygen demand (BOD5) and total organic carbon (TOC), and fine-grained bottom sediments were collected for measurement of oil and grease, polycyclic aromatic hydrocarbons, and selected heavy metals.

F.6.2.1 Biochemical Oxygen Demand (BOD_5)

BOD_5 is an indirect measure of the amount of organic pollution in a water sample. A value of 10 mg/L or less is considered to be relatively unpolluted. Samples from Cascade Creek ranged from very low values to as high as about 22 mg/L (Figure 15). High values were also found for samples from highly polluted nearby locations (outside of the watershed) such as Garrision Run (GR), Scott Run (SR), and the Myrtle Street Sewer outfall (MSS).

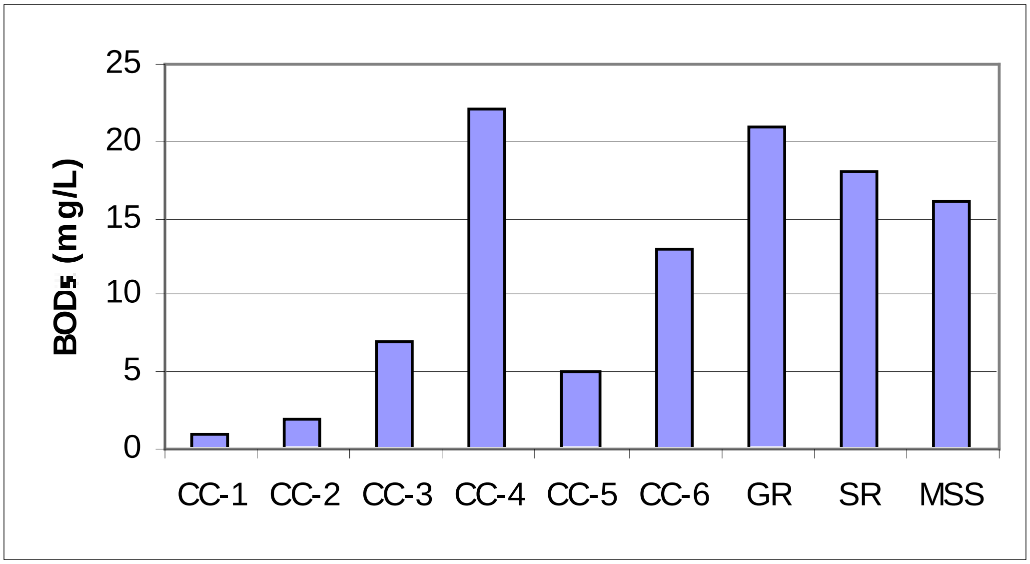


Figure 15. BOD_5 measurements for Cascade Creek and nearby locations.

F.6.2.2 Oil & Grease

Oil and grease is a catch-all surrogate for high molecular weight organic pollution which is common in urban settings. The USEPA set a value of 2,000 mg/kg as indicative of a highly polluted sediment. Values for Cascade Creek and nearby locations were all above this level (Figure 16).

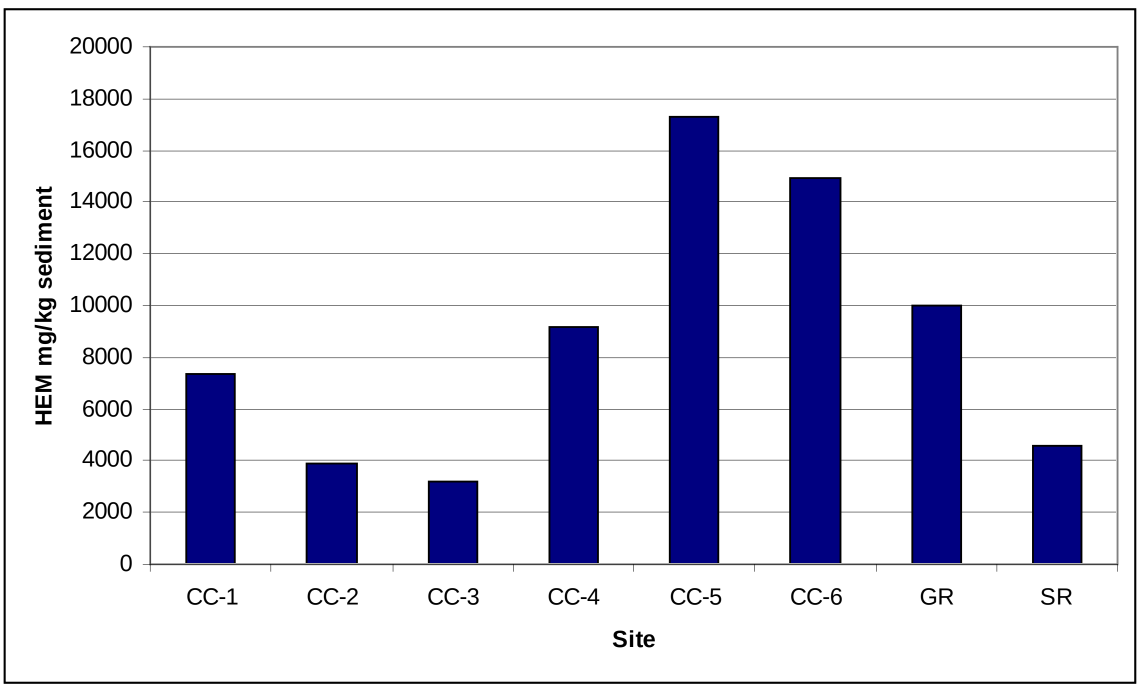


Figure 16. Oil and grease in sediments from Cascade Creek and nearby locations; measured as hexane extractable material.

F.6.2.3 PAHs in Cascade Creek Sediments

A limited number of samples were analyzed for polycyclic aromatic hydrocarbons (PAHs). It should be cautioned that the sediments collected were from the bottom of the streams. Thus, the samples were of coarser material than that usually associated with PAHs. Therefore, these results (Figure 17) may not be representative of actual contamination of the finer particles transported by the stream which do not ever settle until reaching the mouth of the streams.

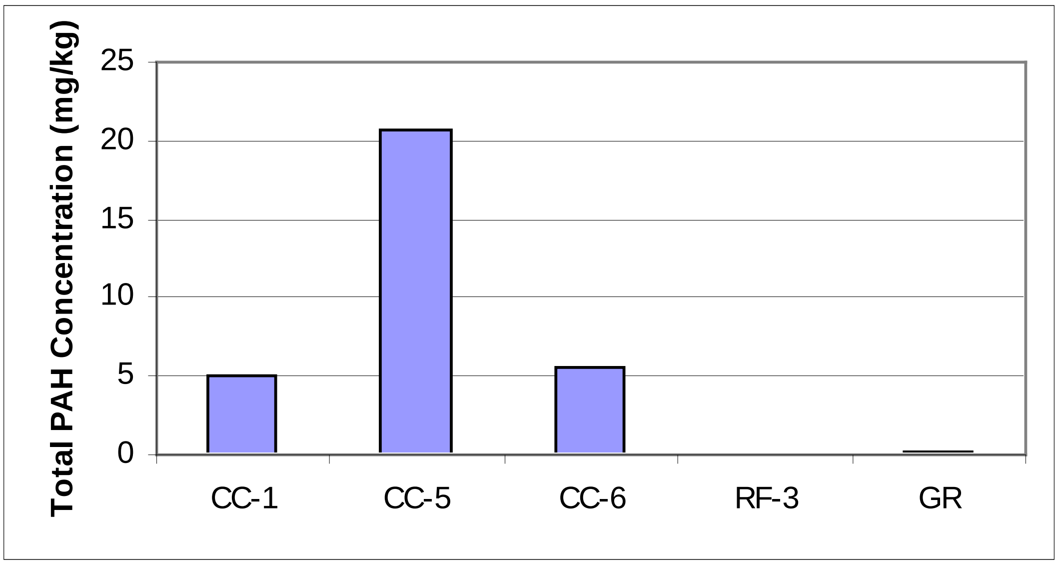


Figure 17. PAHs in sediment samples from Cascade Creek and other areas.

F.6.2.4 Sediment-associated Heavy Metals

Samples were collected from fine bottom sediments and analyzed for the following heavy metals: cadmium, copper, nickel, lead, zinc. Detailed results are available in the Appendix.

For this discussion, the values have been summarized and organized based on the toxicity of each of these metals. One designated toxicity value for heavy metals is the lowest effect level (LEL) (Persaud et al., 1993), which is the level at which an adverse effect is observed for aquatic organisms. A toxicity unit (TU) ratio was calculated by dividing the measured metal concentration by its LEL. A value of 1.0 means that the measured value equals the LEL for that metal. Then, the TUs for the measured metals were averaged for the Cascade Creek sites and for other locations, including a number of non-urban reference sites. As can be seen in Table 9, the Cascade Creek sites, Myrtle Street Sewer, and Garrison Run are high compared to reference sites.

Table 9. Ranking of average toxicity unit ratios based on LEL values for selected heavy metals for Cascade Creek and reference sites.

Rank	Site	Average LEL Equivalents
1	CC-6	4.9
2	CC-5	4.7
3	MSS	4.5
4	GR	3.6
5	CC-3	2.9
6	CC-2	2.4
7	CC-1	2.2
8	CC-4	1.4
9	RF-3	1.4
10	SR	1.4
11	RF-1	1.0
12	RF-2	1.0
13	RF-4	0.7
14	RF-7	0.6
15	RF-6	0.5
16	RF-5	0.3

F.7 Soil & Water Assessment Tool (SWAT) Computer Modeling

F.7.1. Model Preparation

SWAT is a complex sophisticated hydrodynamic and water quality modeling tool which is driven by input from the BASINS GIS system. Forcing functions are long term climatic data for the specific area of study. Hydrologic soil group, land use, topography all contribute to the calculation of flow and sediment yield. Figure 18 is an illustration of a GIS window used to generate input to the model. The watershed was then sub-divided by the model in order to organize calculations (Figure 19). Because the model is designed to deal only with natural stream channels, main trunk lines for storm sewers were input as if they were natural channels with slopes corresponding to the natural topography.

Once the model was constructed and calibrated using observations of actual flow and sediment transport, it was possible to simulate long time periods of flow and sediment transport using randomly generated weather. A ten-year simulation run time was chosen as sufficiently long to adequately described the behavior of the watershed. Yearly averages were then computed by the model for inclusion in the results below.

It was also possible to reclassify land use to simulate the hydrology of the watershed and the sediment yield under hypothetical scenarios. One hypothetical scenario selected was the theoretical prehistoric past in which there was no impervious surface due to land development. All land uses were reclassified to be “forest”. Other factors remained unchanged. The model was then run for a 10-year simulation to estimate pre-historic hydrology and sediment generation.

The other hypothetical scenario simulated was a future in which all of the land surface had been developed and with a high degree of impervious surface. This is unlikely ever to be the case, but represents an extreme possibility.

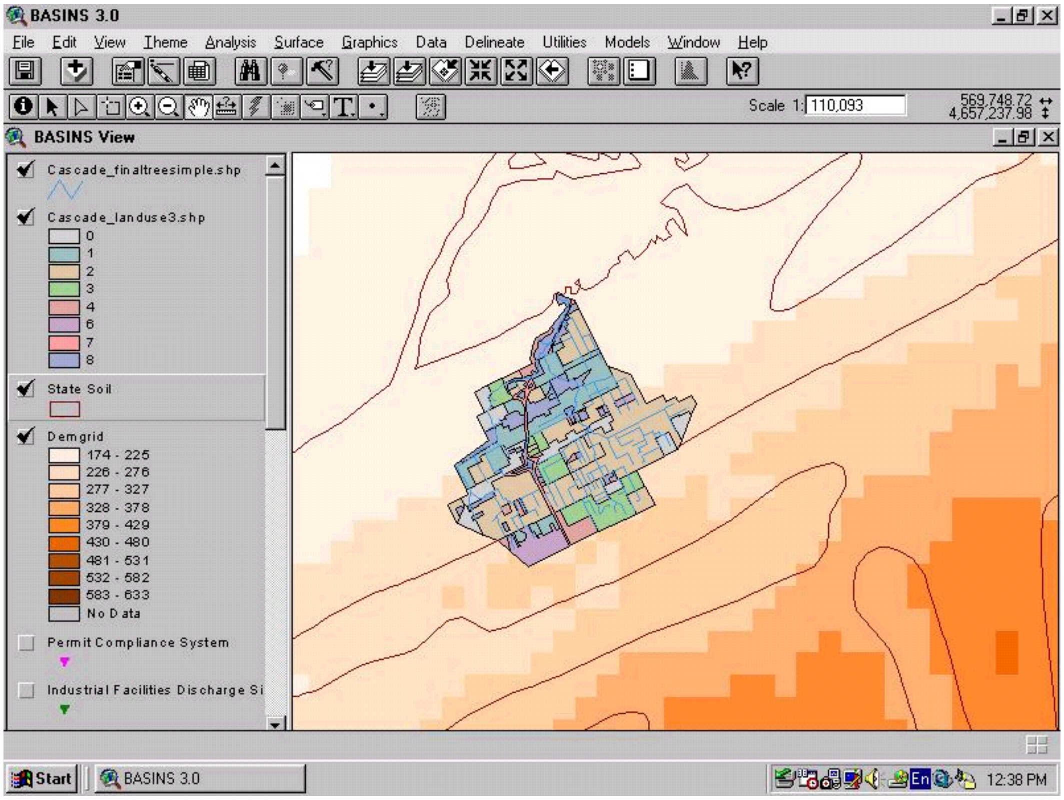


Figure 18. Illustration of GIS window used to generate SWAT output.

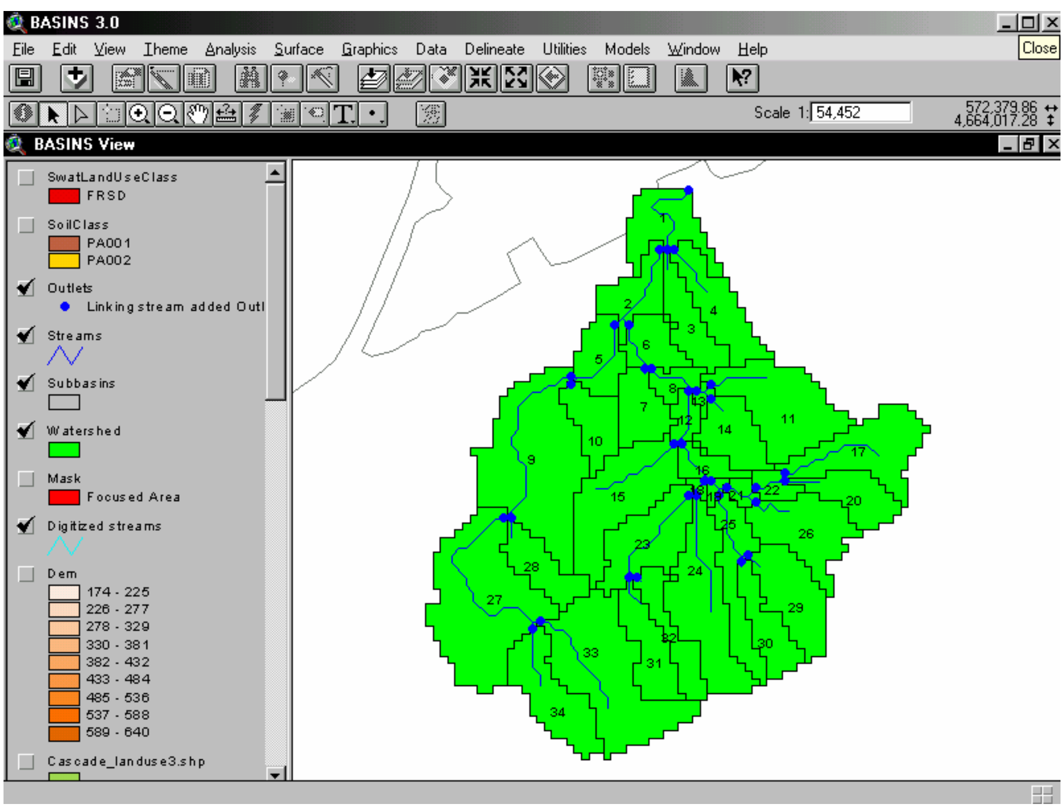


Figure 19. Cascade Creek watershed divided by SWAT into sub-basins.

F.7.2. SWAT Results

F.7.2.1 Average Annual Values

Results of the 10-year simulations for the three scenarios studied are presented in Table 10. In addition to the land use changes specified above, it was assumed that the climatic factors as well as topography and stream channel characteristics remained unchanged. As can be seen below, surface runoff increased with increasing impervious surface, while evapotranspiration decreased due to the loss of vegetation. Increased surface runoff implies that infiltration decreased. The consequences of decreased infiltration include a lower water table, decreased base flow in streams (such that smaller tributaries may become dry at times of year with lower rainfall).

Decreased base flow has a dramatic impact on aquatic organisms. Not only does the volume of habitat available become diminished, but the temperatures usually go up. A completely urban area usually has fewer trees to provide shade for the stream bed. Consider for example that portion of the West Branch which runs alongside the West Erie Plaza … there is no suitable habitat for anything other than bacteria. Higher temperatures may not be suitable for many organisms, and some organisms may be able to survive briefly but not complete their life cycle. For example, trout species cannot survive in warm waters. Higher temperatures also lead to lower dissolved oxygen (DO) levels (oxygen is not as soluble in warm water as it is in cooler water), and low DO may lead to poorer habitat conditions. Compounding the DO problem is the occurrence of organic pollution, measured as BOD. It was noted above that high BOD values were measured in the most polluted and urban sampling sites in the city and township. High BOD leads to growth of bacteria which consume what little oxygen is present, creating even more unacceptable conditions for higher life forms.

Table 10. Hydrologic output values from the SWAT model for the Cascade Creek watershed; values are reported in mm of depth of water.

	mm of Water		
	Prehistoric Past (100% Forest)	**Present Day**	**Hypothetical Future** (100% Developed)
Precipitation	926	926	926
Snow Fall	226	226	226
Snow Melt	220	220	220
Sublimation	4	4	4
Surface Runoff Flow	233	266	295
Lateral Soil Flow	8.5	8.7	4.3
Revaporation	3	0.01	1.9
Total Water Yield	238	274	297
Evapotranspiration	661	626	610
Transmission Losses	3.14	0.02	1.97

Erosion is a natural process which has occurred all throughout the history of the earth. Our goal is to slow erosion and prevent human activity from accelerating it above its natural rate. Natural surfaces such as fields, forests, and lawns are subject to more erosion than are surfaces covered in asphalt and concrete, but it is an outdated mode of thinking that the solution to urban problems is to cover all surfaces in sight with concrete. There was a time when civil engineers operated under that philosophy, but there is now an awareness within that profession that important structures such as roads, bridges, buildings, and stream banks can be protected while preserving infiltration and controlling erosion through natural engineering techniques.

The SWAT estimated sediment yield varied as the watershed became more or less impervious (Table 11). In both hypothetical scenarios, the sediment yield decreased compared to current conditions. As would be expected, "forest" land cover has a low erosion rate compared to a mixed use. SWAT estimated that under current conditions, 0.342 metric tons of sediment are generated per hectare of surface area. Since the watershed is 1,678 hectares (6.48 mi^2), the sediment generated by the watershed under current conditions is approximately 574 metric tons (1,262,527 lb) per year, which is about 355,000 lb more than under prehistoric conditions. Thus, Cascade Creek is exporting to Presque Isle Bay about 28,400 ft^3 every year (assuming a typical moisture content of 35% for surface sediments).

Table 11. Sediment loading to the stream system from the watershed under three scenarios.

	Tonnes per Hectare		
	Prehistoric Past (100% Forest)	**Present Day**	**Hypothetical Future** (100% Developed)
Sediment Loading	0.246	0.342	0.328

The fully urbanized scenario would generate less sediment mass, but those sediments would more highly polluted than sediments from natural areas. Studies have shown that urban runoff typically contains a wide range of pollutants, and for many pollutants is more concentrated than is sewage (Table 12). As is seen below, urban runoff may be as highly polluted as sewage for most parameters.

Table 12. Pollution in runoff generated from various sources source: Novotny and Olem, 1994.

Type of Wastewater	BOD_5 (mg/l)	Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Lead (mg/l)	Total Coliforms (MPN/100 ml)
Urban storm-water[a]	10–250 (30)	3–11,000 (650)	3–10	0.2–1.7 (0.6)	0.03–3.1 (0.3)	10^3–10^8
Construction site runoff[b]	NA	10,000–40,000	NA	NA	NA	NA
Combined sewer overflows[a]	60–200	100–1100	3–24	1–11	(0.4)	10^5–10^7
Light industrial area[c]	8–12	45–375	0.2–1.1	NA	0.02–1.1	10
Roof runoff[c]	3–8	12–216	0.5–4	NA	0.005–0.03	10^2
Typical untreated sewage[d]	(160)	(235)	(35)	(10)	NA	10^7–10^9
Typical POWT effluent[d]	(20)	(20)	(30)	(10)	NA	10^4–10^6

Note: ( ) = mean; NA = not available; POWT = Publicly owned treatment works with secondary (biological) treatment.
[a] Novotny and Chesters (1981) and Lager and Smith (1974).
[b] Unpublished research by Wisconsin Water Resources Center.
[c] Ellis (1986).
[d] Novotny, et al. (1989).

F.7.2.2 Average Annual Sediment Yield by Sub-basin

The SWAT model was also helpful in identifying which sub-basins generated the most sediment. The combination of soil type, land use, and topography play a role in determining sediment yield and delivery to the stream system. Figure 20 presents the present day simulation of sediment yield by each sub-basin per year. As can be seen, sub-basins 24, 25, 26, 27, 33 contributed most of the sediments to the stream. These are typically residential areas with greater slope, resulting in greater erosion potential. These areas are served by storm sewers and there are no natural stream channels.

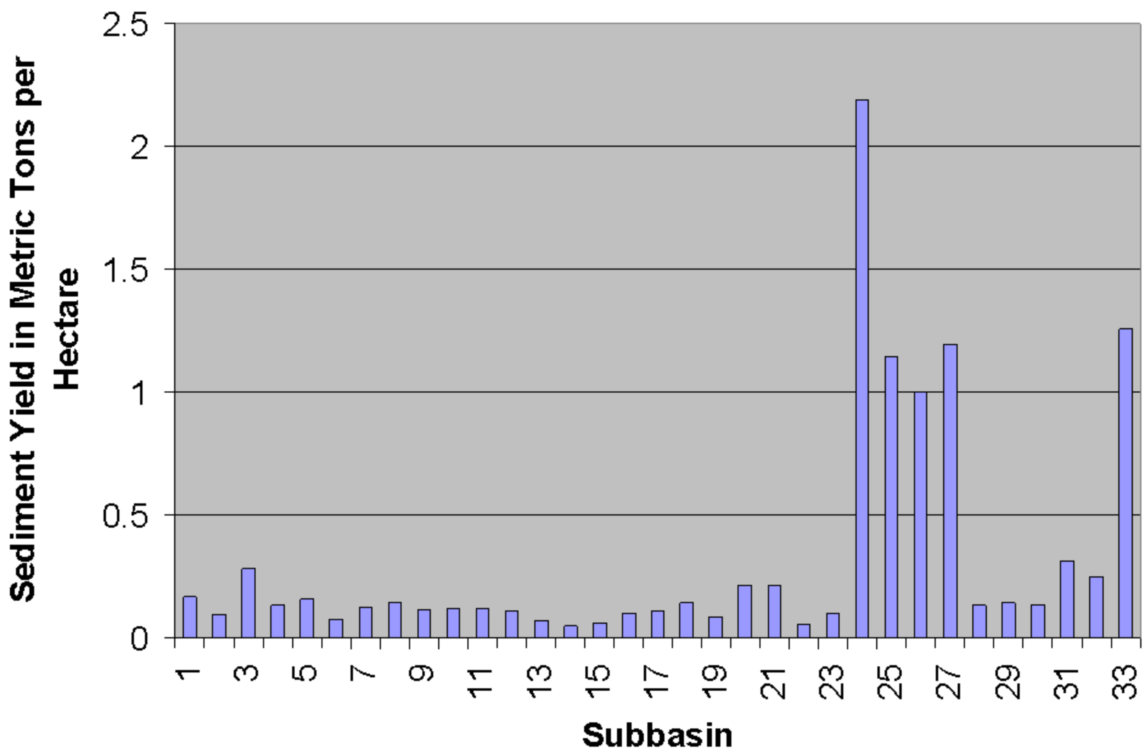


Figure 20. Sediment yield by sub-basin for the Cascade Creek watershed.

F.8 Flood Control Modifications to the Lower Reach

F.8.1. Analysis of the Lower Reach

Of particular concern are occasional episodes of flooding along the lower reach of the stream, between the Niagara Point Bridge and the Walk Bridge where the stream emerges from its bedrock cut channel into its delta at Presque Isle Bay. In order to recommend channel modifications to accommodate flows from various return-interval storm events, it was necessary to calculate those peak flows. Data was presented previously in this report for those values. For convenience, the design flows for the various sized storms is presented again in Table 13.

Table 13. Design peak flow values for determining lower reach channel modifications.

Return Interval	Peak Flow (cfs)	Return Interval	Peak Flow (cfs)
2 yr	1327	25	3632
5 yr	2125	50	4443
10 yr	2857	100	4606

A survey of the lower reach was conducted to determine elevation of the stream bed and ground surface, and cross sections at important locations. Bank elevation, bed elevation, cross-sectional area, and slope at each cross-section were then used to compute current flow capacity of the channel at bank-full stage. Manning's equation was used to calculate the flow capacity of the channel under present and potential future conditions of cross-sectional area, bed slope, and hydraulic radius, using a roughness factor of 0.04. Certain design considerations were adopted which restricted the potential channel modifications. They included the following factors.

- The geometry and bed elevation were modified at each cross-section, and flow capacity was re-computed so as to accommodate each of the design events.
- The channel shape was retained when possible, and a deep thalweg was retained in the new cross-sections.
- Bed elevations at upper end and lower end were essentially maintained.
- Maximum channel width of 40 ft was limited by the Bayfront highway and the existing bike path.
- The old abandoned bridge located 540 ft below the Niagara Point bridge must be removed under all scenarios.
- The Visitor Center building must be removed to accommodate greater than the 10-Year flow.
- Since the 50-year and 100-year flows were so close in value, the 50-year flow level was omitted from further computations.

F.8.2. Longitudinal profile and alternative bed levels

The slope of the ground and the slope of the stream bed at the upper and lower ends of the study reach limited the deepening of the channel. Profiles to accommodate each of the design flows are presented in Figure 21.

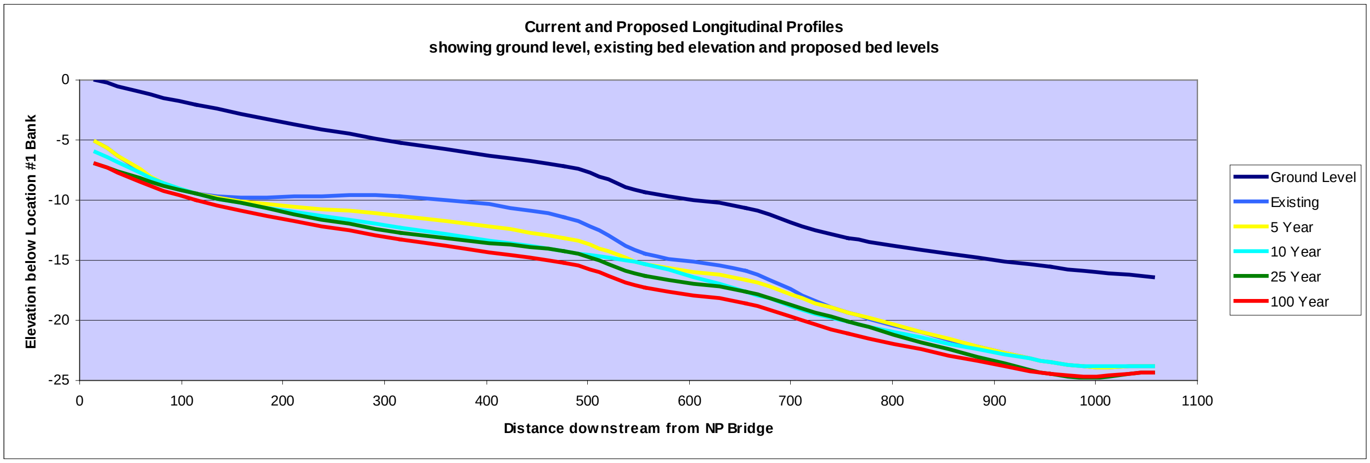


Figure 21. Existing and proposed profiles of the stream channel in the lower reach.

F.8.3. Channel width and alternative widths

The width of the channel is limited to the west by a steep bank, and to the east by a bike path and the Bayfront Highway. This limitation resulted in a maximum width for the channel of about 40 ft along most of the lower reach (Figure 22). In the figure, the upper margin is portrayed as being straight; that is not true, but for convenience to present the necessary modifications, it is presented here as such.

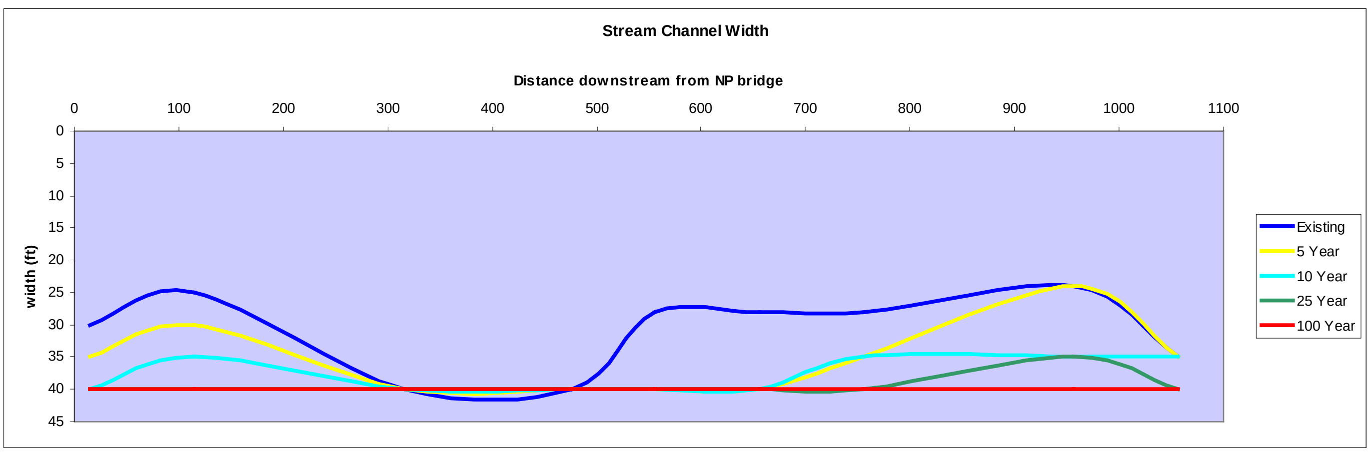


Figure 22. Existing and proposed channel width along the lower reach; note: the upper boundary (the east bank) is not truly straight, but is presented here in schematic nature only.

F.8.4. Existing and proposed cross sections

By an iterative process, cross-sections at each station were developed which are capable of transporting the various design flows. Those cross sections are presented below in Figure 23.

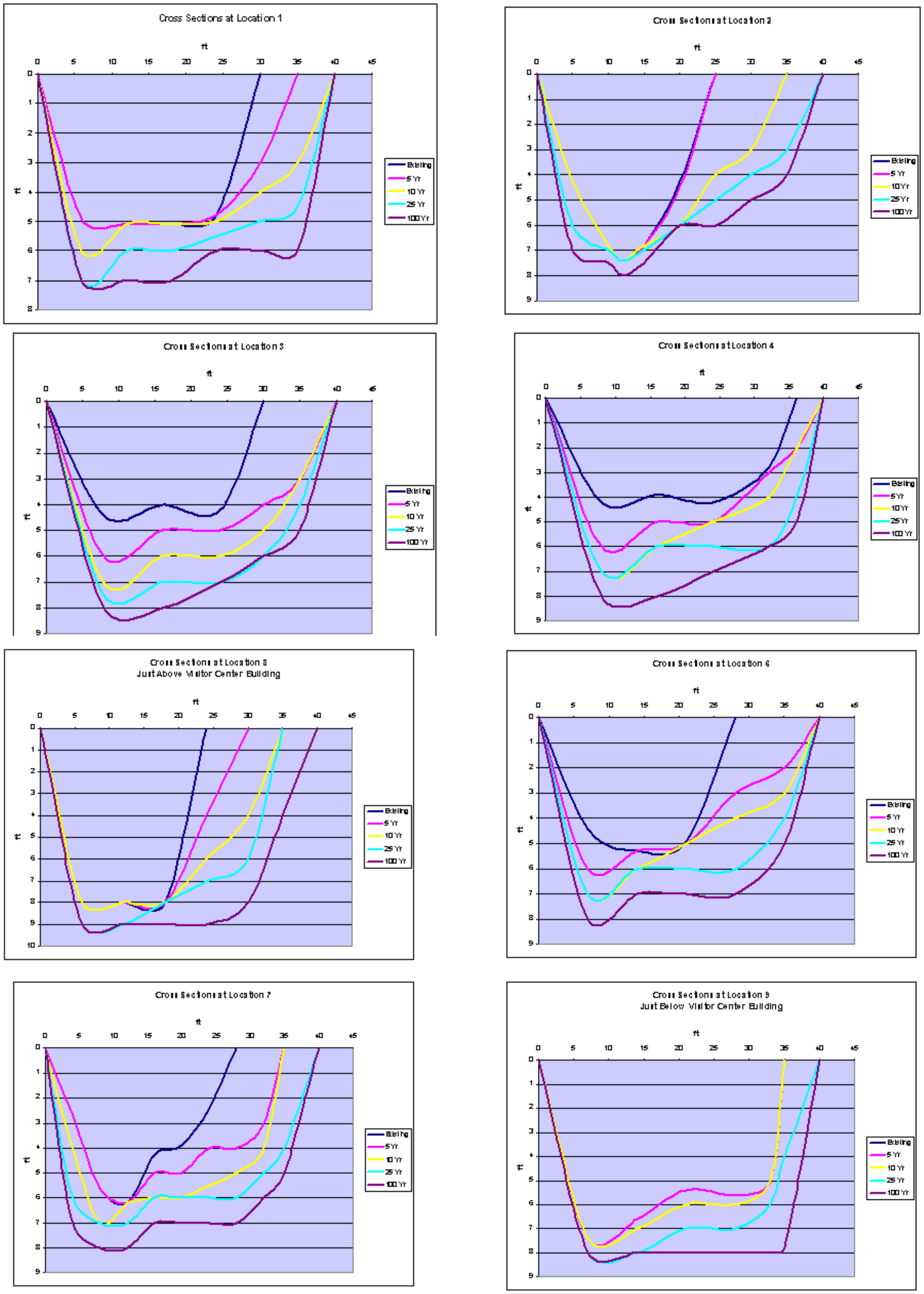


Figure 23. Existing and proposed cross sections of lower reach to accommodate design flows.

F.8.5. Volume of bedrock to be excavated

The lower reach of Cascade Creek is cut into shale bedrock. Essentially all of th material which might be removed in order to enlarge the channel would thus be rock. By calculating the increased volume of the stream channel needed to accommodate various flows, it is possible to calculate the amount of bedrock which would be excavated under each scenario (Table 14).

Table 14. Volume of channel and volume of bedrock to be excavated to accommodate flood waters under various scenarios.

Volume of Channel (yd3)				
Existing	5 Year	10 Year	25 Year	100 Year
4,420	5,619	6,853	8,089	9,431

Volume to be Excavated (yd3)				
Existing	5 Year	10 Year	25 Year	100 Year
na	1,199	2,433	3,669	5,011

F.9 Stream Bank Stabilization and Riparian Zone Restoration in Frontier Park

Extreme flow events, unstable banks, and loss of riparian buffer have resulted in excessive erosion and rapid migration of the stream within Frontier Park. Prior efforts to stabilize banks and reduce erosion have met with limited success within the Park. A plan was developed by Environmental Design Group, Inc., Akron, OH, to employ the techniques of Natural Stream Channel Design to restore the creek within the limits of the park. That report is included in the Appendix of this report. The estimated cost to restore the stream within the Park is $410,000. This is viewed as a highly desirable project by the current authors, and hopefully will be the subject of further efforts on the part of the City and the citizens of Erie.

G. Best Management Practices for Urban Areas

The goals of urban BMPs are to increase infiltration and minimize the transport of urban pollutants into the stream system. It is widely believed that the first ½ inch of rainfall in any storm event transports most of the surface pollution (the so-called "first flush"). For Erie, those storms up to 0.63" of rainfall (over 24 hr) constitute 60% of the annual rainfall (Penn DOT).

Guidance for the selection and use of best management practices for urban stormwater has been developed by various federal and state agencies. Recently, the Pennsylvania Association of Conservation Districts (PADC) has published a document entitled Pennsylvania Handbook of Best Management Practices for Developing Areas. The introduction to that document states that "it summarizes state-of-the-art site planning and BMP alternatives from the Northeast United States and other areas, and tailors them to Pennsylvania conditions." Many of the recommendations related to BMPs are obtained or derived from this document.

The PADC advocates that the selection of BMPs grow out of a five part philosophy:

1. Break up large impervious areas
2. Apply BMPs near the source of runoff
3. Evaluate needs for treating runoff
4. Satisfy the groundwater recharge objectives
5. Satisfy the runoff peak attenuation objectives

Since the watershed incorporates portions of the City of Erie and the Mill Creek Township, it would be necessary for the governments of those two localities to adopt certain policies. To some degree, these policies are already in place in each locality.

Of particular concern in the PADC guidance are so-called sensitive areas, i.e., stream corridors, wetlands, steep slopes and highly erodible soils, and Karst bedrock. Because the underlying bedrock in our area is shale, we do not have to be concerned with Karst bedrock, but there are important considerations within the Cascade Creek drainage related to the other factors.

G.1 Preventing Runoff from Small Storms

While it is difficult and expensive to retro-fit an already developed urban area, there are a number of land development and planning practices which can make a difference. These include:

- Using Permeable Paving Materials
- Reducing the Hydraulic Connectivity of Impervious Surfaces
- Routing Residential Roof Runoff Over Lawns
- Routing Commercial Downspouts Into Infiltration Trenches (currently, commercial downspouts <u>must</u> be connected to the storm sewer system)
- Reducing the Use of Storm Sewers
- Encouraging or Requiring the Use of Infiltration Trenches at All Industrial and Commercial Properties

G.2 Examples of Urban BMPs include

- Detention & retention basins
- Constructed wetlands, infiltration basins
- Infiltration trenches, dry wells
- Porous pavement
- Grassed swales
- Vegetated filter strips
- Below ground filters
- Proper disposal of household wastes including motor oil & antifreeze
- Proper use of fertilizers & pesticides
- Disconnecting downspouts from sanitary and storm sewers

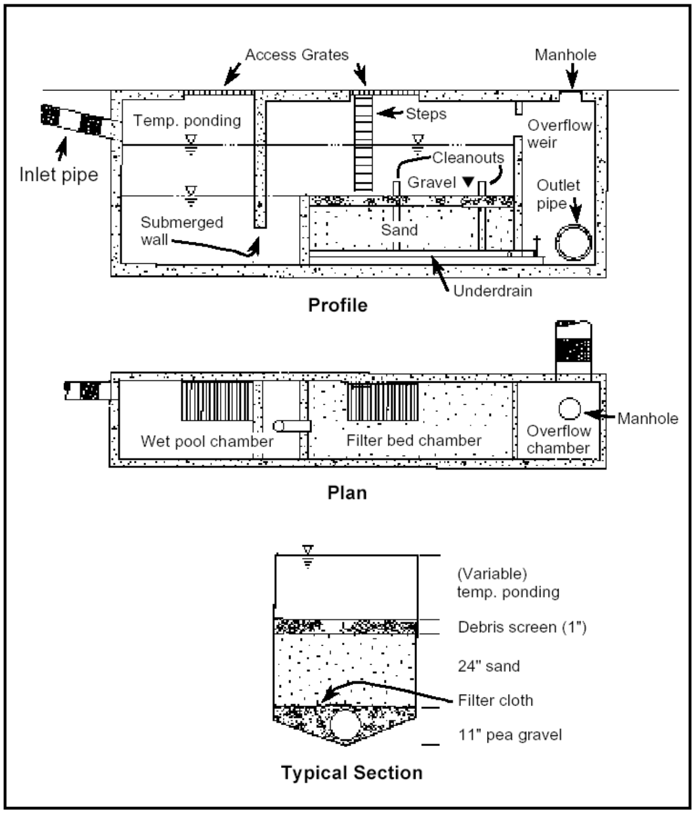
Performance of BMPs varies (Table 15), as do the capital and operating costs. The City of Erie and the Township of Millcreek both have stormwater detention requirements for new developments, but existing land use is grandfathered and not required to retrofit their property. Nonetheless, there may be some mechanism for funding and encouraging the use of these BMPs to control stormwater.

Table 15. Typical performance of urban BMPs.

BMP Type	Typical Pollutant Removal (percent)				
	Suspended Solids	Nitrogen	Phosphorus	Pathogens	Metals
Dry Detention Basins	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Retention Basins	50 - 80	30 - 65	30 - 65	< 30	50 - 80
Constructed Wetlands	50 - 80	< 30	15 - 45	< 30	50 - 80
Infiltration Basins	50 - 80	50 - 80	50 - 80	65 - 100	50 - 80
Infiltration Trenches/ Dry Wells	50 - 80	50 - 80	15 - 45	65 - 100	50 - 80
Porous Pavement	65 - 100	65 - 100	30 - 65	65 - 100	65 - 100
Grassed Swales	30 - 65	15 - 45	15 - 45	< 30	15 - 45
Vegetated Filter Strips	50 - 80	50 - 80	50 - 80	< 30	30 - 65
Surface Sand Filters	50 - 80	< 30	50 - 80	< 30	50 - 80
Other Media Filters	65 - 100	15 - 45	< 30	< 30	50 - 80

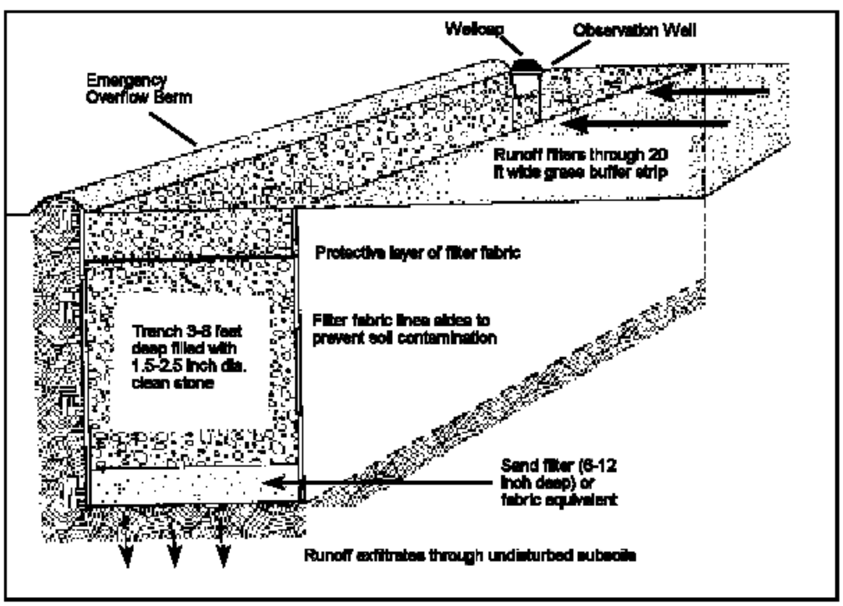
Source: Adapted from US EPA, 1993c.

Of particular interest in this highly developed watershed are underground sand filters (Figure 24) and infiltration trenches (Figure 25). These structures are intended to accept the first ½ inch of rainfall which flushes the greatest amount of sediment and pollution from impervious surfaces. The clever implementation of these underground structures would not result in the loss of utility or parking spaces, and would thus not impose an on-going economic loss on the property owner. A desirable, though ambitious goal would be to assist, encourage, and facilitate the installation of infiltration structures by all owners of commercial property with impervious surfaces in excess of some minimum area. Since impervious surface includes roof tops as well as parking lots, roads, and sidewalks, a reasonable threshold size might be 1 acre. Since these devices do accumulate sediments, there would be an on-going maintenance expense. Studies of urban BMPs have estimated maintenance expenses (Table 16).



Source: Claytor and Schueler, 1996.

Figure 24. Underground sand filter for the capture and treatment of stormwater runoff.



Source: Schueler et al, 1992.

Figure 25. Infiltration trench for the capture and treatment of stormwater runoff.

Table 16. Typical maintenance costs for urban BMPs.

BMP	Annual Maintenance Cost (% of Construction Cost)	Source(s)
Retention Basins and Constructed Wetlands	3%-6%	Wiegand et al, 1986 Schueler, 1987 SWRPC, 1991
Detention Basins[1]	<1%	Livingston et al, 1997; Brown and Schueler, 1997b
Constructed Wetlands[1]	2%	Livingston et al, 1997; Brown and Schueler, 1997b
Infiltration Trench	5%-20%	Schueler, 1987 SWRPC, 1991
Infiltration Basin[1]	1%-3%	Livingston et al, 1997; SWRPC, 1991
	5%-10%	Wiegand et al, 1986; Schueler, 1987; SWRPC, 1991
Sand Filters[1]	11%-13%	Livingston et al, 1997; Brown and Schueler, 1997b
Swales	5%-7%	SWRPC, 1991
Bioretention	5%-7%	(Assumes the same as swales)
Filter strips	$320/acre (maintained)	SWRPC, 1991

1. Livingston et al (1997) reported maintenance costs from the maintenance budgets of several cities, and percentages were derived from costs in other studies

H. Final Thoughts and Recommendations

While this study has produced a large quantity of data and other information, it remains for community decision makers to decide what to do. They are left to consider what actions, if any, are appropriate to improve the environmental quality of the City of Erie and Millcreek Township. Some might ask what the hydrology and sediment transport of a small stream has to do with general environmental quality and quality of life in a community. And why should any actions be taken now. After all, the current conditions have come about slowly, and we have grown accustomed to them. They seem "normal" and acceptable to most persons if only because most people cannot imagine it any other way.

For example, a great credit to the City of Erie and its civic leaders is the transformation of the city's waterfront. Prior to the construction of the Bayfront Highway, the urban waterfront was occupied almost exclusively by industrial activity at a busy commercial port. As those activities lost their economic vitality, visionary civic leaders imagined an Erie which had never before existed. The result of that vision is our current waterfront which has become a center for enjoyment by the citizenry and home to renewed economic activity, and is the future of Erie.

A stream can be thought of as the bloodstream of an organism. Just as the waste products of cellular metabolism make their way into the blood stream before elimination from the body, so do the waste products of the community find their way into the neighborhood streams. And just as we conduct various blood tests to assess bodily health, so too can we look at the health of our urban streams to assess the general environmental quality of our communities. There is no doubt that the quality of life we humans experience is linked directly to the quality of the environment we inhabit. If one is ever in doubt of that, just plan a trip to a slum.

So, improving stream quality is not just good for stream creatures, such as fish and frogs, salamanders and otters, but it is also good for us in our neighborhoods. We cannot make a significant change in our urban streams without making a change in the way we and our neighbors behave.

But, this is an engineering and scientific study, and we offer the following list of recommendations.

- Organize and execute an on-going educational program in cooperation with existing environmental groups, to inform and train the public in how their activities affect their environment;
- GIS-based computer modeling can be used to assess impacts of major changes in land use within the watershed, but is not appropriate for small incremental analysis of individual land use planning;
- If it is considered necessary to modify the lower reach of Cascade Creek, use the 25 Yr storm event for sizing channel modifications;
- Encourage the use of Best Management Practices at the source of the runoff: parking lots, industrial areas, residential areas, to minimize the "first flush" effect;
- Disconnect residential and commercial downspouts from the storm sewer system;
- Restore Cascade Creek within Frontier Park using Natural Stream Channel Design principles.

I. References Cited

APHA, AWWA, WEF, 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition . American Public Health Association, Washington, DC.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Callender, E., and K. C. Rice. 2000. "The Urban Environmental Gradient: Anthropogenic Influences on the Spatial and Temporal Distributions of Lead and Zinc in Sediments. Environmental Science and Technology. 34(2): 232-238.

EPA, 1977. Guidelines for the Pollutional Classification of Great Lakes Harbor Sediments. Region V, April.

EPA. 1990a. Managing Contaminated Sediments. USEPA, Sediment Oversight Technical Committee. EPA 506/6-90/002.

EPA, 1990b. Test methods for evaluating solid waste: physical/chemical methods. 3rd Edition. SW-846.U.S. Environmental Protection Agency, Washington, DC.

EPA, 1996a. Nonpoint Source Pollution: The Nation's Largest Water Quality Problem. Fact Sheet on Nonpoint Source Pollution. EPA841-F-96-004A.

EPA, 1996b. Managing Urban Runoff. Fact Sheet on Nonpoint Source Pollution. EPA841-F-96-004G.

GLNPO, 2000. Presque Isle Bay Area of Concern. Great Lakes National Program Office, EPA Region V, Chicago.

Fischenich, J. C., R. B. Stoir, and T. Stanko. 2001. Assessing Urban Watersheds: The Case of Big Creek, GA. The Journal for Surface Water Quality Professionals. Forester Communications, Inc.

Long, E. R. and L. G. Morgan, 1990. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National States and Trends Program. National Oceanic Atmospheric Administration (NOAA) Technical Memorandum No. 5, OMA52, NOAA National Ocean Service, Seattle, Washington.

Nerbonne, B. A., and B. Vondracek. 2001. Effects of Local Land Use on Physical Habitat, Benthic Macroinvertabrates, and Fish in the Whitewater River, MN. Environmental Management. 28: 87-99.

NYDEC, 1999. Technical Guidelines for Contaminated Sediments. New York State Department of Environmental Conservation.

Novotny, V., and H. Olem. 1994. Water Quality: Prevention, Identification, and Mangement of Diffuse Pollution. International Thomson Publishing, Inc.

Persaud, D., R. Jaagumagi, and A. Hayton, 1992. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. Ontario Ministry of the Environment, Queen's Printer for Ontario.

Potomac-Hudson, 1991. Presque Isle Bay Ecosystem Study: Background Report. Potomac-Hudson Engineering, Inc.

USGS., 2001. Selected Findings and Current Perspectives on Urban and Agricultural Water Quality by the National Water-Quality Assessment Program. United States Geological Survey News Release.

Zhou, C.Y. et al. 1997. Soil, Lead and other Metal Levels in Industrial, Residential and Nature Reserve Areas in Singapore. Environmental Monitoring and Assessment. 44:605-615.

J. APPENDIX

J.1 Quality Assurance Review by Hill Engineering, Inc.

J.2 Sediment Associated Metals Information

J.3 Report by Environmental Design Group on analysis and development of Cascade Creek within Frontier Park using Natural Stream Channel Restoration Techniques

J.4 SWAT Simulation Input and Output Files

HILL ENGINEERING, INC.
8 GIBSON STREET NORTH EAST, PENNSYLVANIA 16428
(814) 725-8659 FAX: (814) 725-3867

July 18, 2003

Mr. Harry R. (Rick) Diz, PhD
Associate Professor and Chair
Department of Environmental Science and Engineering
Gannon University
109 University Square
Erie, PA 16541-0001

Reference: Cascade Creek Study

Dear Mr. Diz:

I have completed my review of the documents provided by you relative to your study of the Cascade Creek Watershed. My comments are contained herein.

Documents Reviewed

1. Draft Masters Thesis by Timothy J. Bruno titled "Hydrologic Modeling of Cascade Creek Watershed, Erie, PA" May, 2003, including the following supporting attachments:

    a. Urbanized Watershed Schematic Plan
    b. TR-20 Routing Schematic
    c. Arc Travel Time Computations
    d. TR-20 input and output data for 2, 5, 10, 25, 50 and 100 year return period events
    e. Cascade Modeling Data Comparison, TR-20/TR-55

2. Cascade Creek Measurements and Current Flow Capacity-Niagara Point Access Bridge to Foot Bridge – Area of Flooding Concern.

Comments

1. With respect to Mr. Bruno's draft Masters Thesis and related documents, it is my opinion that the modeling techniques and procedures are reasonable and consistent with accepted engineering standards. This opinion is limited to the overall approach and methods, and does not extend to specific input data selection and output results.

2. With respect to the Cascade Creek Measurements and Current Flow Capacity calculations, it is my opinion that the calculation methodology is reasonable and consistent with accepted engineering standards. This opinion is limited to the overall approach and does not extend to specific input data selection and output results.

3. It is my understanding that the results are not intended to be used directly as a basis for design of construction improvements within the watershed, but may serve as a starting point for more detailed analyses.

I appreciate the opportunity to be of service on this project. Please do not hesitate to contact me if you have any questions.

Very truly yours,

HILL ENGINEERING, INC.

Clayton J. Falls, P.E.

J.5 Sediment-Associated Heavy Metals

For the purpose of this study, the sediment criteria risk levels determined by the State of New York (NYDEC,1999) will be employed since the USEPA has not yet adopted guidance for contaminated sediments. NYDEC (1999) used the results from two studies to determine low-effect (LEL) and severe effect levels (SEL). The LEL is the lower of either the Persaud et al. (1992) LEL or the Long and Morgan (1990) Effect-Range Low. Similarly, the lower value of the two studies was used to determine the SEL. The LEL implies a contaminant level such that the majority of benthic organisms would be able to conduct a complete life cycle. As stated by Persaud et al. (1992), the SEL suggest the likelihood of pronounced disturbance of the sediment dwelling community. The NYDEC considers an area where the LEL is exceeded to be contaminated (NYDEC, 1999). All metals results are presented based on mean values for all samples analyzed at a given site, and reported as mg metal per kg dry sediment.

The copper concentration in sediments at CC-5 was the only site in the study to exceed the SEL (110 mg/L), and thus was considered to be severely contaminated with copper. The rest of the Cascade Creek sites had copper concentrations that fell above the LEL (16 mg/L) but below the SEL.

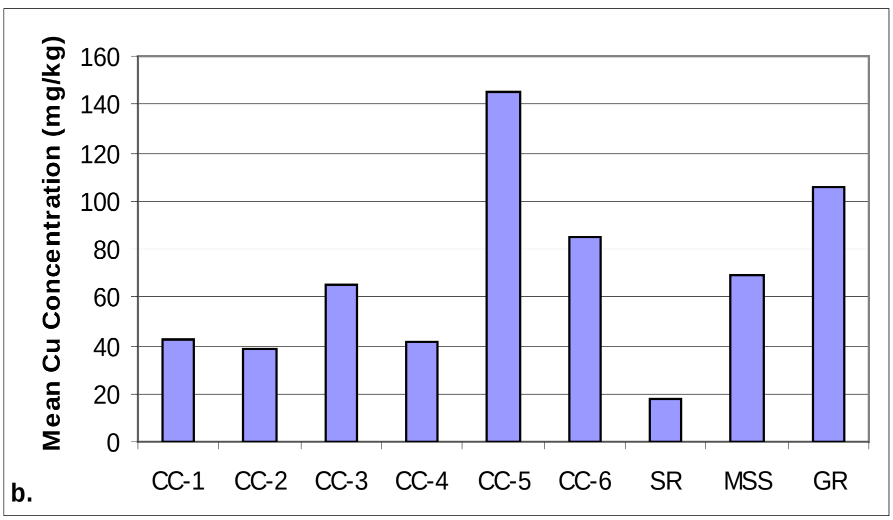


Figure 26. Mean copper concentrations at Cascade Creek, Scott Run, Myrtle St. Sewer, Garrison Run sites.

The LEL and SEL for lead in sediment are 31 and 110 mg/kg, respectively. The Cascade Creek sites were all above the LEL. CC-5 and CC-6 stand out as having the highest concentrations along Cascade Creek. CC-5 exceeded the SEL with a concentration of 130 mg/kg and CC-6 had a concentration of 101 mg/kg. GR and MSS were also severely impacted by lead contamination with levels above the SEL at 125 and 154 mg/kg, respectively. The mean sediment concentration of lead at Scott Run was below the LEL.

c.

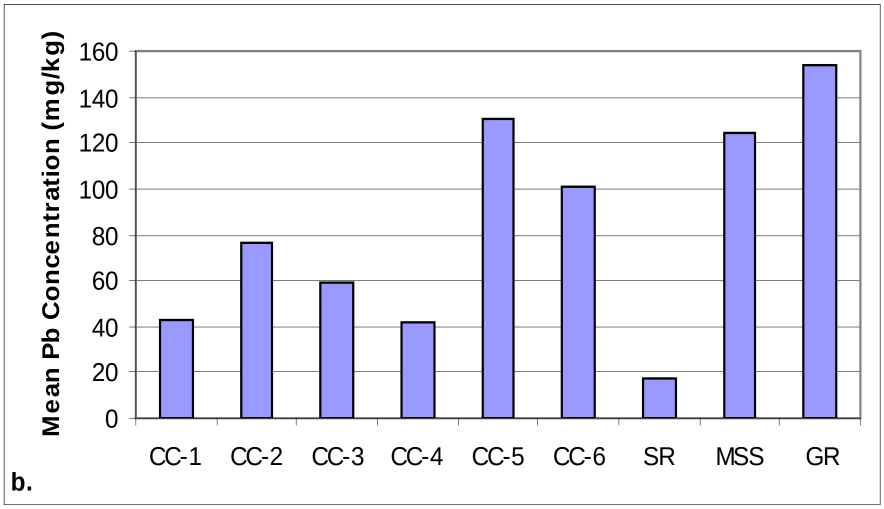


Figure 27. Mean lead concentrations at Cascade Creek, Scott Run, Myrtle St. Sewer, and Garrison Run.

The LEL and SEL for nickel in sediment are 16 and 50 mg/kg. Except for CC-4, all of the Cascade Creek sites exceeded the SEL. CC-6 (at 191 mg/kg), was almost four times higher than the SEL. MSS had an even higher nickel concentration at 194 mg/kg. Reference sites exhibited uniformly low nickel concentrations.

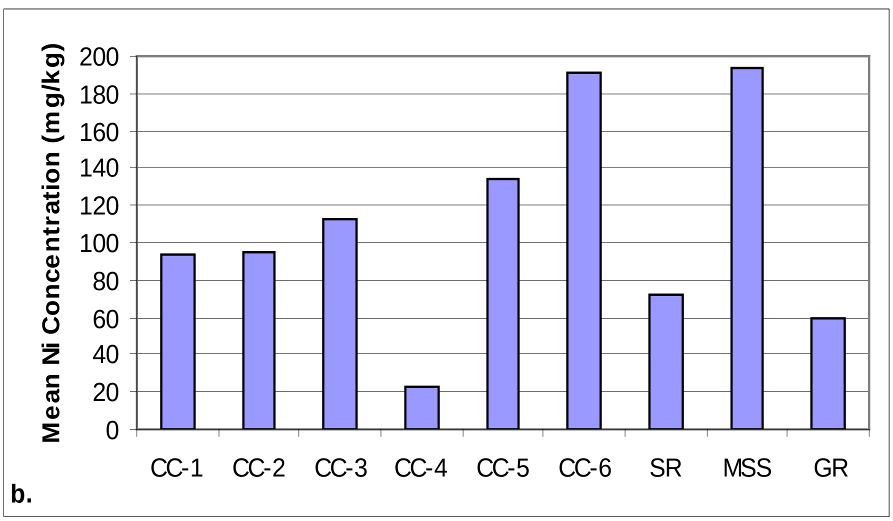


Figure 28. Mean nickel concentrations at Cascade Creek, Scott Run, Myrtle St. Sewer, and Garrison Run,.

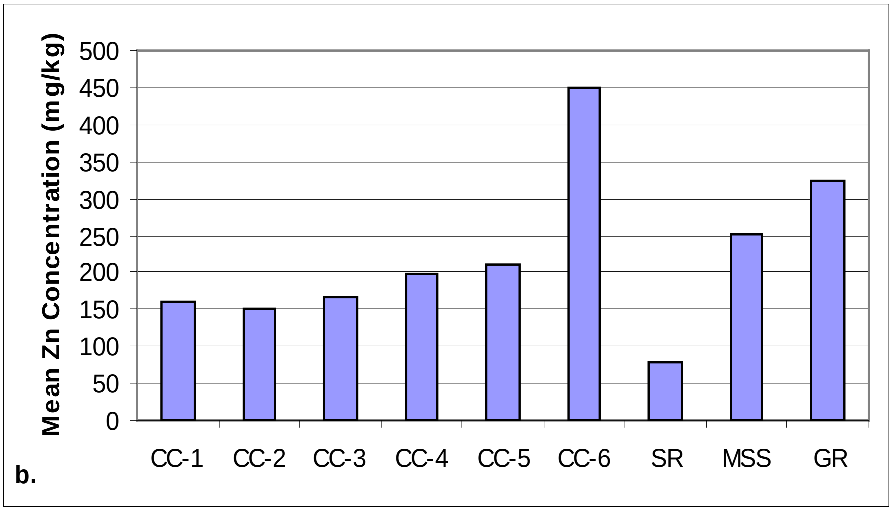


Figure 29. Mean zinc concentrations at Cascade Creek, Scott Run, Myrtle St. Sewer, and Garrison Run..

The LEL for zinc in sediment is 120 mg/kg, and the SEL is 270 mg/kg (NYDEC, 1999). All Cascade Creek sites exceeded the LEL and were considered to be moderately contaminated. CC-6, with a value of 450 mg/kg, exceeded the SEL and its sediment was considered to be severely impacted. SR was the only study site to have a concentration below the LEL. MSS concentration was just below the SEL but GR exceeded the SEL with a value of 325 mg/kg.

Zinc concentrations at the reference sites were all below the LEL of 120 mg/kg with the exception of RF-2, which had a concentration of 124 mg/kg.

EDG
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450 GRANT STREET
AKRON, OHIO 44311-1183
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LETTER OF TRANSMITTAL

TO: Gannon University
Dept. of Envir. Science & Eng.
GU Box 4117, 109 University Sq.
Erie, PA 16541-0001

DATE: 1-10-3 **JOB #:** 584501
ATTN: Dr Harry R. Diz, PhD
RE: Cascade Creek

WE ARE SENDING YOU [ ] ATTACHED [ ] SHOP DRAWINGS [ ] PRINTS
[ ] PARTIAL PAY REQUEST [ ] CHANGE ORDER [ ] SPECIFICATIONS
[ ] COPY OF LETTER [ ] REPORT [ ] ORIGINAL DRAWINGS
[ ] UNDER SEPARATE COVER VIA ____________, THE FOLLOWING

COPIES	DATE	NO.	DESCRIPTION
1			Revised Report

THESE ARE TRANSMITTED AS CHECKED BELOW:
[ ] FOR APPROVAL [ ] FOR REVIEW & COMMENT [ ] REVISE & RESUBMIT
[✓] FOR YOUR USE [ ] CONFORMS TO DESIGN CONCEPT
[ ] UNACCEPTABLE [ ] AS REQUESTED [ ] REVIEWED AS NOTED
[ ] COMMENTS ATTACHED [ ] ____________

REMARKS: Provided is an updated report based on the revised flows.

cc:

SIGNED: [signature]

E:corp\forms\edg\trans.frm

CASCADE CREEK
CHANNEL ANALYSIS

Prepared
for

Gannon University
Department of Environmental
Science & Engineering
109 University Square
Erie, PA 16541-001

Prepared by:

Environmental Design Group, Inc.
450 Grant Street
Akron, Ohio 44311

Cascade Creek Channel Analysis

A channel analysis was performed on Cascade Creek along the West Branch and Main Branch to Bayfront Highway. Data collected by the Department of Environmental Science and Engineering from Gannon University was used to evaluate the channel. This information included 2, 5, 10, 25, 50 and 100 year flows, channel cross section data for five locations on the West Branch and four locations on the Main Branch, channel slopes and photographs at each of the cross sections. This data was used to evaluate the channel to determine if natural channel techniques would be an effective method to reduce channel erosion and enhance existing aquatic and wildlife habitat areas within the channel.

In order to identify the appropriate natural channel techniques to implement within a channel it is important to determine channel flows and corresponding velocities. This was accomplished by entering the data into the Haestad Methods FlowMaster software. The cross section data, horizontal distances and corresponding elevations were used to define the channel geometry at each cross section. The photographs identifying each cross section location were used to develop representative Manning's n-values for the channel and overbanks. Channel slopes developed from field data provided by the University were also utilized in the evaluation. With this data available the Manning's equation within the FlowMaster software was used to calculate the depth of flow, velocity and Froude number within the channel at each cross section location for the various storm events

West Branch

The weighted Manning's n-value calculated for each cross section is shown in Table 1.0. The weighted n-value was calculated based on n-values entered into FlowMaster for the left and right overbanks and channel bottom. Also shown in Table 1.0 is the channel slope used to evaluate the cross section. This slope was obtained from the data provided by The University.

TABLE 1.0
West Branch
Weighted n-values & Channel Slope

Cross Section	N-values	Channel Slope (ft/ft)
1	.04	.0272
2	.085	.0272
3	.08	.0086
4	.049	.0086
5	.04	.0086

As shown in the photographs the channel bottoms appeared to be primarily gravel with cobblestone and some larger rock. The overbanks were generally vegetated with areas of exposed soil in several of the outside meander banks.

The Manning's n-value combined with the cross section data, flows and channel slope provided the information necessary to determine channel flow depth and velocities at each of the cross sections. The output generated using the FlowMaster software is provided in Appendix A. Table

2.0 shows the calculated depth of flow and velocity for each cross section evaluated along the West Branch.

TABLE 2.0
West Branch
Depth of Flow & Velocities

Cross Section	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s
1	1.4	6.32	1.8	7.3	2.1	8.0	2.45	8.52	2.74	9.	2.8	9.14
2	3.9	4.7	4.9	5.68	5.67	6.31	6.41	6.82	7.16	7.29	7.31	7.38
3	5.12	2.97	6.41	3.39	7.43	3.68	8.36	3.93	9.23	4.2	9.41	4.25
4	4.36	3.76	5.57	3.98	6.51	4.21	7.34	4.46	8.13	4.73	8.29	4.78
5	3.12	4.83	3.52	4.83	3.82	5.26	4.07	5.66	4.32	6.06	4.37	6.14

In general the FlowMaster analysis showed the creek to overtop its bank on the west side (field side) at cross sections 2, 3, 4 and 5, during all storm events except for the 2-year. This connection to the existing floodplain on the west side helps to control velocities and erosion along the west bank. Natural channel improvements are generally designed utilizing bankfull flow conditions (flows generated by the more frequent storm events). The velocities generated by the 2-year storm event are acceptable for natural channel design. The natural channel design techniques presented also take into consideration the higher velocities generated by the less frequent storms. Natural channel design stabilization techniques can be implemented that will provide bank protection during the less frequent storms that generate somewhat larger velocities. Although the flows within the west branch range from 220 cfs to 814 cfs, the connection to the floodplain on the west bank helps to control velocities. The velocities and floodplain connection indicate natural channel design techniques could be utilized to stabilize the embankments.

Main Branch

The weighted Manning's n-value calculated for each cross section is shown in Table 3.0. The weighted n-value was calculated based on n-values entered into FlowMaster for the left and right overbanks and channel bottom. Also shown in Table 3.0 is the channel slope used to evaluate the cross section. This slope was obtained from the data provided by The University.

TABLE 3.0
Main Branch
Weighted n-values & Channel Slope

Cross Section	N-values	Channel Slope (ft/ft)
6	.089	.0154
7	.064	.0045
8	.047	.0089
9	.046	.0013

The photographs showed the Main Branch channel bottom to be similar to the West Branch. The Main Branch appeared to be primarily gravel with cobblestone and some larger rock. The overbanks were generally vegetated with areas of exposed soil where erosion was occurring.

The Manning's n-value combined with the cross section data, flows and channel slope provided the information necessary to determine channel flow depth and velocities at each of the cross sections. The output generated using the FlowMaster software is provided in Appendix A. Table 4.0 shows the calculated depth of flow and velocity for each cross section evaluated along the Main Branch.

TABLE 4.0
Main Branch
Depth of Flow & Velocities

Cross Section	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s	Flow Depth ft.	Vel. ft/s
6	6.55	7.84	8.09	7.63	9.08	7.82	10	8.13	10.85	8.48	10.91	8.5
7	5.57	2.99	6.76	3.43	7.68	3.76	8.55	4.05	9.39	4.33	9.43	4.34
8	6.15	6.78	7.67	7.76	8.85	8.5	10	9.12	11.16	9.66	11.22	9.68
9	9.03	3.58	11.51	4.19	13.46	4.63	15.3	5.02	23.95	3.68	24.10	3.69

The flows within the Main Branch correspond to 945 cfs, 1504 cfs, 2010 cfs, 2535 cfs, 3085 cfs and 3115 cfs for the 2, 5, 10, 25, 50 and 100 year storm events respectively. These flows were used to evaluate each of the cross sections within Table 3.0. The velocities ranged from 3 ft/s to almost 10 ft/s.

As experienced in the West Branch the Main Branch also overtopped its banks. However, the FlowMaster analysis indicated both the west and east banks experienced overtopping. Once again, this indicates a connection to the floodplain. Although the output generated by the FlowMaster analysis indicates the water levels at the cross sections to range from 5 ft to almost 24 ft, in reality the flow will utilize the existing floodplain resulting in lower velocities and depth of water. As Table 3.0 indicates higher velocities are generated within the Main Branch of Cascade Creek. However, appropriate natural channel design techniques could be implemented to protect and stabilize these embankments from the flows and velocities generated during the less frequent storm events.

Based on the data provided the analysis of the cross sections within Cascade Creek indicates natural channel technique improvements could be an effective option towards stabilizing existing channel banks within the Main Branch.

Cascade Creek Concept

Review of the site and analysis of the data provided, indicate Cascade Creek's alignment to be suitable for natural channel design improvements. These reviews indicate a series of meanders within the reach and riffle pool areas and point bars at several locations within the study reach. Erosion along many of the outside meanders also exists. This is attributed partly to the weakness of established riparian vegetation. Based on the velocities determined at each of the cross sections, and our review, natural channel design techniques are proposed to improve channel erosion and enhance aquatic and wildlife habitats within the area.

Natural channel design improvements proposed within Cascade Creek include; installing root wads along the outside meanders to reduce erosion, live branch layering to stabilize straight channel riffle banks, improvements and widening of the riparian corridor, armoring of subdrainage outfalls and enhancements to the existing plunge pools at the outfall locations. In order to preserve the channel and vegetation established once the design is implemented, designated trails and fishing areas have also been identified.

West Branch Improvements

Proposed improvements to the West Branch involve formalizing the existing plunge pool. The enhancements would include enlarging the existing pool and increasing the depth to at least three feet. The toe of the pool banks would be lined with rock protection. The pool would provide an area for energy dissipation, acting to reduce velocities prior to the flow progressing downstream where the velocities could and have been damaging to the downstream channel banks.

As shown on the concept plan root wads have been proposed at the outside meander locations to stabilize the banks. These are supported by tree plantings behind the root wads. This is supplemented in straight channel and riffle sections with live branch layering to develop root mass protection. Channel flow is naturally directed to the outside meander. The root wads will reinforce the banks, providing the protection necessary to deflect the flow away from the embankment, reducing erosion that would otherwise occur. The live branch layering, once established, will provide a strong root mass system stabilizing the banks

The concept also includes creating a riparian corridor within a minimum 25-foot area beyond the channel banks. Improvements to this area would involve significant revegetation of the riparian corridor with trees and shrubs. The drainage outfalls from the play field are proposed to be armored with rock to prevent scour at these locations.

Establishment of the riparian corridor coupled with the natural channel design techniques should provide the bank erosion protection while simultaneously encouraging plant and animal life to inhabit the creek.

Main Branch

Natural channel designs techniques similar to those proposed for the West Branch are also proposed for the Main Branch.

Enlargement of the existing plunge pool is proposed in the form of regraded banks to a lesser slope and the creation of wetland margins on the pool sides flanking the outfall. Outside meander locations have been identified for root wad installation. Channel flow is naturally directed to the outside meander. The root wads will reinforce the banks, providing the protection necessary to deflect the flow away from the embankment, reducing erosion that would otherwise occur. Live branch layering is also proposed along straight channel and riffle banks. The live branch layering, once established, will provide a strong root mass system stabilizing the banks.

Improvements to the Main Branch would also include establishing a connection to the existing wetland area on the northwest side of the channel. A backwater channel connection is proposed to increase flow into the wetland area. A weir would be constructed at a height that will allow flow to enter the wetland area during storm events. Riparian corridor widening is also proposed for the Main Branch by reinforcement of existing vegetation to a minimum 25-foot width.

Confluence

At the location where the Main and West Branch converge a concrete wall exists which was intended to protect the embankment from damaging flows and velocities. Currently the flow from the Main Branch is conveyed directly into the concrete wall and deflected downstream. The wall is being undermined by those flows and is collapsing. The proposed improvement to the confluence involves modifying the existing radius on the east bank, providing a larger radius more in keeping with the anticipated flows. With the flow redirected, removal and replacement of the concrete wall with root wads is proposed. The root wad mass must be sized appropriately to protect the existing embankment. The root wad should provide the bank reinforcement necessary to protect the embankment during periods of high flows and velocities. The root wads will also provide habitat locations for plant and animal life. Reinforcement of the root wads with tree plantings is proposed to form an eventual root mass behind the root wads.

Recreational Access

Considering the use of the stream for public access fishing, the concept calls for improvements to these access points and connecting trails to reduce the impact on the natural channel improvements. Well defined trails are proposed that connect with the existing walks. These are connected to defined fishing access points at the inside meanders of the stream. These locations are the least affected by disturbance of the vegetation. Access locations are proposed to be identified through a post and rope system of fencing. In addition a fishing pier is proposed at the plunge pool on the Main Branch of the creek over the existing outfall. Since the shoreline is a favorable location for fishing, the pier will provide a controlled access point while preventing disturbance to the shoreline banks.

<u>Conclusion & Recommendations</u>

As reported the existing alignment of Cascade Creek already includes many of the characteristics of a healthy channel. The characteristics include the presence of meander patterns, riffle pool sequence and point bars. Significant erosion has occurred within the channel reach studied and as pointed out primarily results from the lack of vegetation along the banks. Natural channel design techniques have been proposed and are recommended to stabilize the channel and increase the presence of plant and animal life within the creek. Provided following is a summary list of the recommended techniques and improvements propose for Cascade Creek.

- Expand the Plunge Pool in both the West and Main Branch
- Install Root Wads along the outside meander locations
- Live branch layering along straight channel and riffle pool banks

- Creation of a riparian corridor (at least 25' wide)
- Backwater channel connection to the existing wetland area during storm events
- Modification to the sharp radius at the confluence, and removal of the existing concrete wall
- Removal of the concrete wall
- Establishment of designated access areas to the channel and a fishing pier over the Main Branch outfall
- Establishment of trails to preserve and protect the riparian corridor

Implementation of the above improvements should provide the bank protection and stabilization required during periods of high velocities. In addition the natural channel design improvements should provide an environment that encourages plant and animal life to inhabit.

SWAT Simulation Input and Output Files for One Scenario