A HYDROLOGIC MONITORING PROGRAM FOR YELLOW CREEK WATERSHED

By

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ABSTRACT

Poland Village Council, in response to several recent flooding events that caused damage to properties, formed a committee called the Storm Water Abatement Team (SWAT) to study ways to reduce the future impact of storm water runoff in the Village and along Yellow Creek. There is little information about rates of runoff and flow dynamics of Yellow Creek and its tributaries available to evaluate flood reduction projects. To monitor flow rates, five gauging stations were established and stream cross-sectional area profiles for each were determined. For a wide range of flow conditions, the velocity of flow (ft/sec) and water depth (ft) were determined and the rate of flow calculated as the product of cross-sectional area and velocity. Then functional relationships between stage and flow rate were determined by constructing rating curves for the five gauging stations. Flow rates were also calculated by applying rating curve equations to citizens' monitoring data of stage at the gauging stations. Rainfall on the watershed was monitored by installing four rain gauges around the watershed. Two gauging stations were equipped with pressure sensors for continuous depth monitoring.

For the storm event on 27-28 October 2006, a detailed analysis of rainfall and streamflow hydrographs was performed to determine runoff coefficients. The runoff coefficient values obtained for the upper watershed were in the range of 0.19 to 0.24; runoff coefficients calculated for the lower watershed were in the range of 0.45 to 0.67.

Rainfall is fairly uniform around the watershed, but can differ from the average by 20% or more at some locations. Depth of flow estimates from pressure sensors did not agree with direct observations of stage in many cases; the source of error was not determined.

DEDICATION

This research study is dedicated to my late elder brother Vijayender Reddy Kallam, who had been an inspiration to me all of my life. It is also dedicated to my parents, Subba Reddy and Girija, who are a source of great strength and support to me.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my cordial gratefulness to my advisor Dr. Scott C. Martin who devoted immense time and effort in this research. I very much appreciate his great patience and tolerance and best of all his invaluable trust. It has been my pleasure to work with a farsighted advisor like Dr. Martin.

My special thanks to my committee members, Dr. Lauren A. Schroeder and Dr. Javed Alam, for their valuable time to serve on my committee. I would like to thank Aqua Ohio and Poland Village for providing funding to support this work. I would also like to thank Mr. John Bralich for providing me with maps of the watershed. My thanks to the School of Graduate Studies and Research at YSU for my Graduate Assistantship (GA) during this study. I would also like to thank department secretary Linda Adavasio, Justin Rogers of Mill Creek Metroparks, and Carl McMorran of Aqua Ohio, who provided their support during this research.

Finally, I like to thank my friends Vamsi Reddy, Rajesh Reddy, Prem Reddy, Rajesh, Ramana, Ramnath, Srinivas, and Sohini for their motivation and support.

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CHAPTER 1

INTRODUCTION

1.1 Description of Yellow Creek Watershed

Yellow Creek watershed (Figure 1.1) is located in northern Columbiana and southern Mahoning Counties of Ohio. Yellow Creek begins north of the Village of New Waterford in Unity Township, Columbiana County. The creek flows north through Beaver Township, Springfield Township, Poland Township, Poland Village and the City of Struthers before joining the Mahoning River in downtown Struthers. The watershed covers about 39.4 square miles (25,216 acres) which includes Pine, Hamilton, Burgess and Evans Lakes (AWARE, 2007a).

The Yellow Creek watershed has approximately 75 miles of streams. The main stem of Yellow Creek is 11.1 miles long, according to the Gazetteer of Ohio Streams (Krolcyzk *et al.*, 2001); however, according to the Mahoning County GIS, the main stem of Yellow Creek is 16.9 miles long. Burgess Run (5.9 miles) is the only major tributary which is named by the Gazetteer, but Drake's Run (2.4 miles), Beard Creek (0.7 miles), East Branch Yellow Creek (2.1 miles) and Turnpike Tributary are others which are recognized as being named locally. According to Mahoning County GIS, Yellow Creek has 69 unnamed tributaries, many of them first order streams (AWARE, 2007b).

Land use figures from 1994 GIS data indicate that 56.9% of the Yellow Creek watershed is Agriculture, 17.9% is Residential, 14.6% is Forested, 3.3% is Commercial/Industrial/Urban and the remaining 7.3% is indicated as Other. A land use

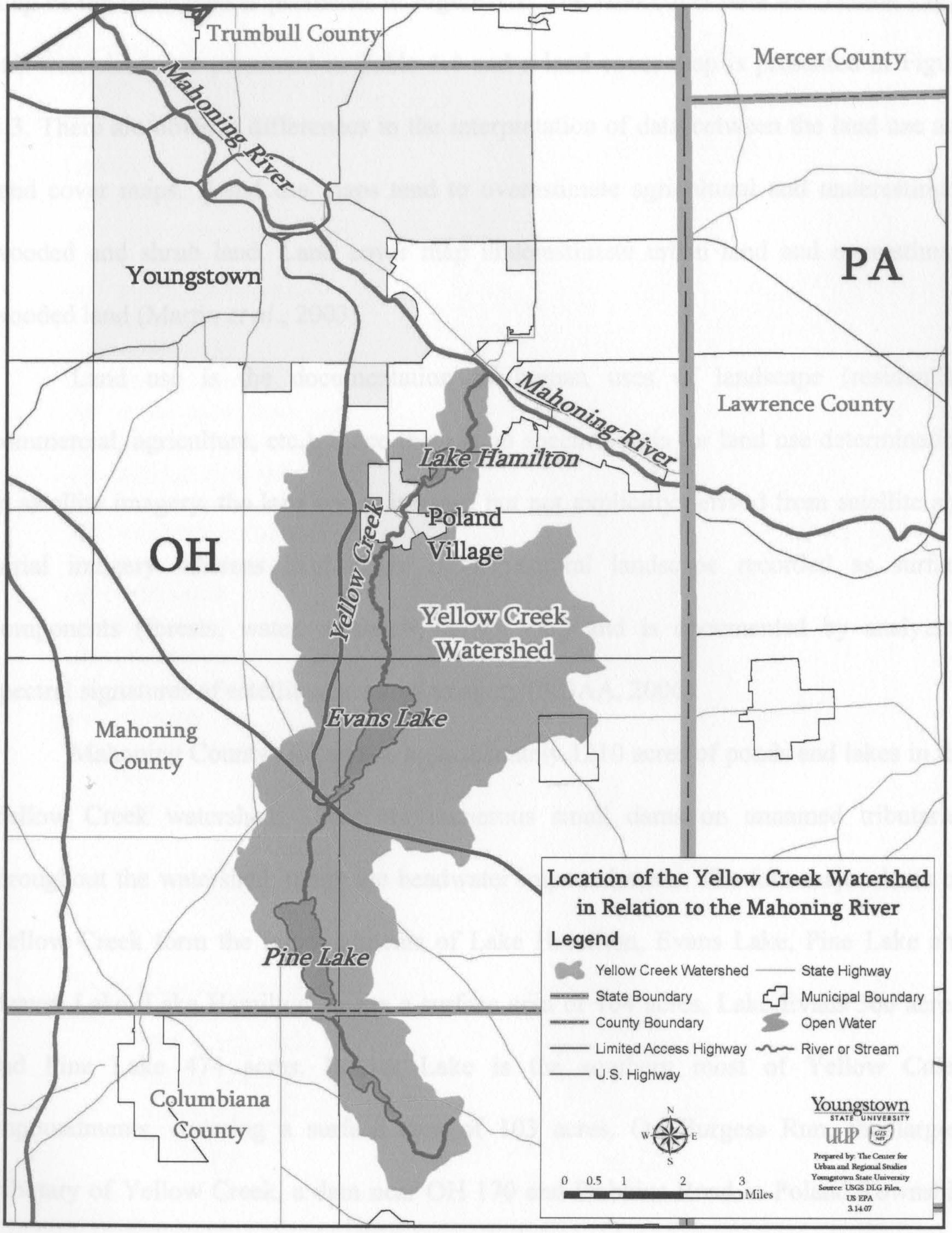

Figure 1.1 Location of Yellow Creek Watershed (map provided by YSU Center for Urban and Regional Studies).

map of the watershed is presented in Figure 1.2. The land cover data for Yellow Creek sub-watersheds are presented in Table 1.1 and a land cover map is presented in Figure 1.3. There are obvious differences in the interpretation of data between the land use and land cover maps. Land use maps tend to overestimate agricultural and underestimate wooded and shrub land. Land cover map underestimate urban land and overestimate wooded land (Martin *et al.*, 2003).

Land use is the documentation of human uses of landscape (residential, commercial, agriculture, etc.). Since there is no spectral basis for land use determination in satellite imagery, the land use is inferred but not explicitly derived from satellite and aerial imagery whereas land cover is the natural landscape recorded as surface components (forests, water, wetlands, urban, etc.) and is documented by analyzing spectral signatures of satellite and aerial imagery (NOAA, 2006).

Mahoning County GIS shows approximately 1210 acres of ponds and lakes in the Yellow Creek watershed. There are numerous small dams on unnamed tributaries throughout the watershed; many are headwater impoundments. The four major dams on Yellow Creek form the impoundments of Lake Hamilton, Evans Lake, Pine Lake and Beaver Lake. Lake Hamilton covers a surface area of 104 acres, Lake Evans 566 acres, and Pine Lake 474 acres. Beaver Lake is the southern most of Yellow Creek impoundments, covering a surface area of 103 acres. On Burgess Run, the largest tributary of Yellow Creek, a dam near OH 170 and Dobbins Road in Poland Township forms the 20 acre impoundment known as Burgess Lake and also there is a small concrete dam approximately 10 feet high on Burgess Run in Springfield Township near Arrel Road (AWARE, 2007b).

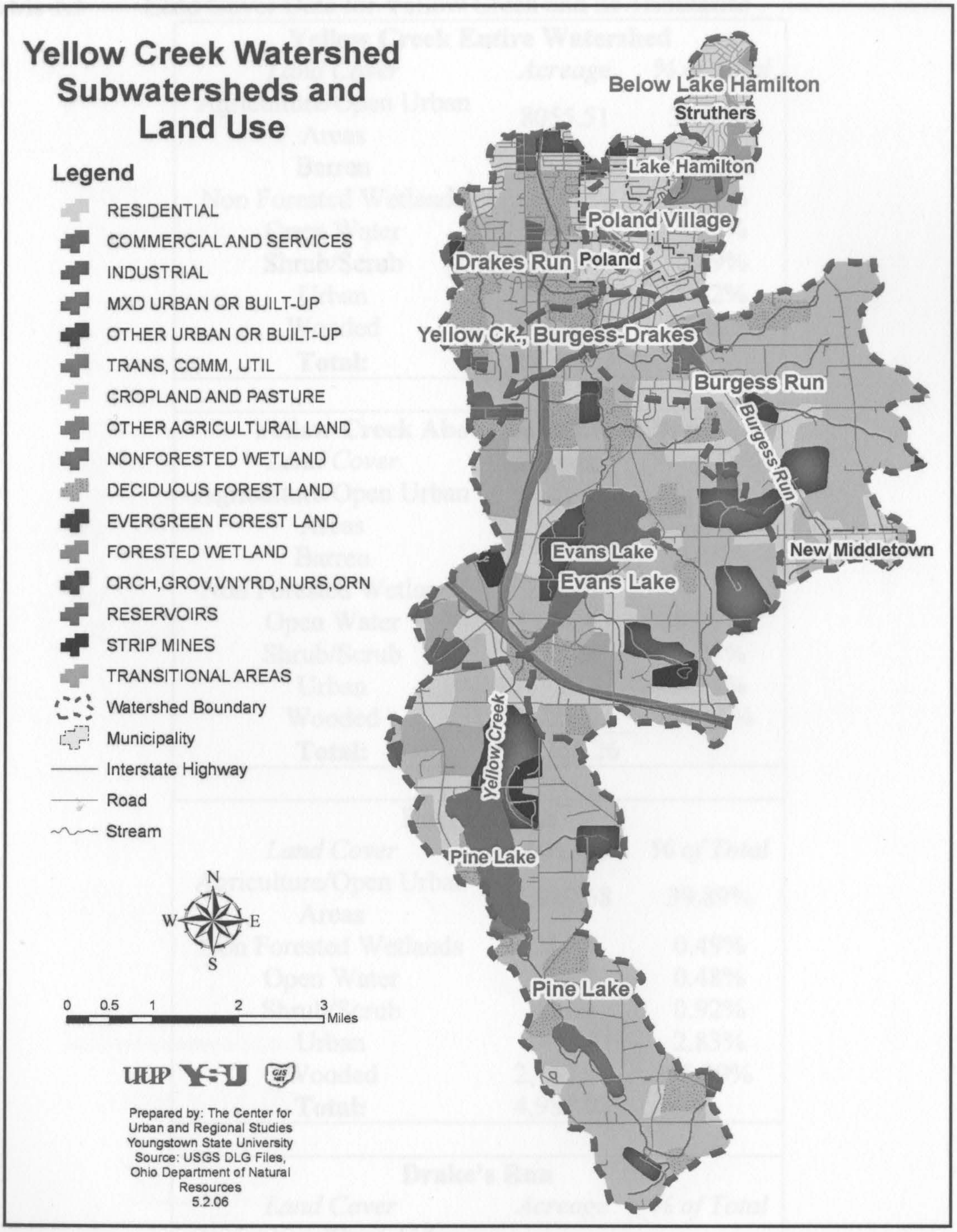

Figure 1.2 Yellow Creek Watershed Land Use, 2006 (map provided by YSU Center for Urban and Regional Studies).

Table 1.1 Land Cover Data for Yellow Creek and its Tributaries

Yellow Creek Entire Watershed		
Land Cover	*Acreage*	*% of Total*
Agriculture/Open Urban Areas	8055.51	30.97%
Barren	6.18	0.023%
Non Forested Wetlands	314.79	1.21%
Open Water	1209.9	4.65%
Shrub/Scrub	232.27	0.89%
Urban	1772.49	6.82%
Wooded	14411.49	55.42%
Total:	26002.63	

Yellow Creek Above Lake Evans Dam		
Land Cover	*Acreage*	*% of Total*
Agriculture/Open Urban Areas	4791.04	38.74%
Barren	6.18	0.05%
Non Forested Wetlands	211.01	1.71%
Open Water	1,086.43	8.79%
Shrub/Scrub	155.09	1.25%
Urban	390.13	3.15%
Wooded	5,726.38	46.31%
Total:	12,366.26	

Burgess Run		
Land Cover	*Acreage*	*% of Total*
Agriculture/Open Urban Areas	1,989.68	39.89%
Non Forested Wetlands	24.49	0.49%
Open Water	23.78	0.48%
Shrub/Scrub	45.69	0.92%
Urban	141.33	2.83%
Wooded	2,762.96	55.39%
Total:	4,987.93	

Drake's Run		
Land Cover	*Acreage*	*% of Total*
Agriculture/Open Urban Areas	266.27	18.19%
Non Forested Wetlands	5.09	0.35%
Shrub/Scrub	5.10	0.35%
Urban	331.32	22.64%
Wooded	855.85	58.47%
Total:	1,463.63	

Source: USGS DLG files, Ohio Department of Natural Resources, 2007

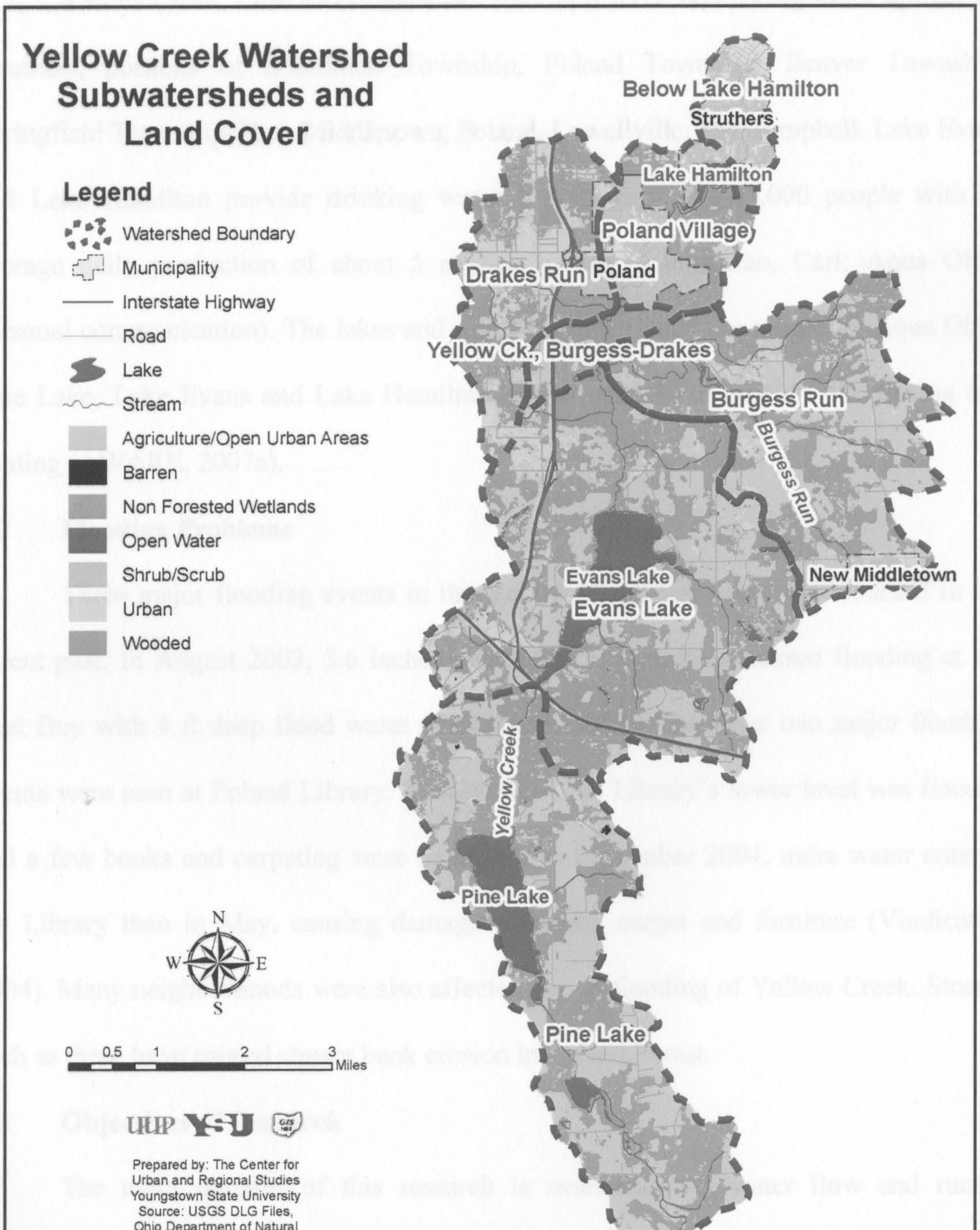

Figure 1.3 Yellow Creek Watershed Land Cover, 2007 (map provided by YSU Center for Urban and Regional Studies).

Yellow Creek, Lake Evans and Lake Hamilton serve as drinking water sources for Struthers, portions of Boardman Township, Poland Township, Beaver Township, Springfield Township, New Middletown, Poland, Lowellville, and Campbell. Lake Evans and Lake Hamilton provide drinking water for about 50,000-55,000 people with an average daily production of about 5 million gallons (McMorran, Carl; Aqua Ohio, personal communication). The lakes and water treatment plant are owned by Aqua Ohio. Pine Lake, Lake Evans and Lake Hamilton are all used for recreation like fishing and boating (AWARE, 2007a).

1.2 Flooding Problems

Three major flooding events in the Yellow Creek watershed are recorded in the recent past. In August 2003, 3.6 inches of rainfall in Boardman caused flooding at the Best Buy with 4 ft deep flood water (Vindicator, 2003). The other two major flooding events were seen at Poland Library. In May 2004, the Library's lower level was flooded and a few books and carpeting were damaged. In September 2004, more water entered the Library than in May, causing damage to books, carpet and furniture (Vindicator, 2004). Many neighborhoods were also affected due to flooding of Yellow Creek. Storms such as these have caused stream bank erosion in Poland Forest.

1.3 Objectives of Research

The main purpose of this research is assessment of water flow and runoff dynamics for Yellow Creek above the Route 170 Bridge. A monitoring study was begun to obtain data that can be used to evaluate proposed flood reduction projects.

The objectives of the project were:

1. Establishment of gauging stations on Yellow Creek and its tributaries;

2. Collection of flow measurements under a range of hydrologic conditions, including storm events;
3. Development of preliminary rating curves to relate water depth to flow at the gauging locations;
4. Installation and monitoring of rain gauges throughout the watershed; and
5. Installation and monitoring of in-stream pressure sensors for continuous depth measurements.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Hydrology:

Hydrology can be defined as a multidisciplinary subject that deals with the occurrence, movement, distribution and quality of water throughout the earth. Water on earth exists in a space called the hydrosphere, which extends about 15 km up into the atmosphere and about 1 km down into the lithosphere, the crust of the earth. Water circulates in the hydrosphere through the maze of paths constituting the hydrologic cycle (Chow *et al.*, 1988). The hydrologic cycle is a continuous process in which water is evaporated from oceans, moves inland as moist air masses, and produces precipitation. The precipitation that falls on land flows into lakes, rivers, or aquifers. The water in lakes, rivers and aquifers then either evaporates back to the atmosphere or eventually flows back to the ocean, completing a cycle.

Precipitation is a major component of the hydrologic cycle. Precipitation that reaches the surface of earth can occur in many different forms, including snow, hail, sleet, and rain. In most locations, the majority of precipitation falls as rain, and the word "precipitation" is used interchangeably with "rainfall". Important rainfall characteristics include the total amount (depth) over some period, the intensity, and the distribution over time and space. The spatial distribution of rainfall is shown by isohyetal maps, whereas the temporal distribution of rainfall is shown by hyetographs. Determination of rainfall events is very important in any hydrologic design projects and the most common approach is to use a design storm or intensity-duration-frequency (IDF) curves. IDF curves are presented as a graph, with duration plotted on the horizontal axis, intensity on vertical axis, and a series of curves, one for each design return period or frequency. The frequency is usually expressed in terms of return period, T, which is the average length of time between precipitation events that equal or exceed the design magnitude. The partial duration based point precipitation frequency estimate curves (similar to IDF curves) for the Youngstown area are shown in Figure 2.1 (NOAA, 2007).

The intensity, I, is defined as the time rate of precipitation, that is, depth per unit time (mm/hr or in/hr). The average intensity is expressed as (Chow *et al.*, 1988):

$$I = P / T_d \qquad \text{(Eq 2.1)}$$

Where,

P is the rainfall depth in mm or inches, and

T_d is the duration, usually in hours.

Two types of rainfall data are commonly required in urban hydrology: 1) "raw" point precipitation data; i.e., actual hyetographs and 2) processed data, usually in the form of frequency information. Processed data include many varieties of statistical summaries, but the most common type of processed data used in urban hydrology is in the form of intensity-duration-frequency (IDF) curves. Computerized point precipitation data are available from the National Weather Service, the U.S. Army Corps of Engineers, the U.S. Geological Survey, or USGS (Bedient and Huber, 1992), and the National Oceanic and Atmospheric Administration (NOAA).

After rainfall, hydrologists are concerned about runoff, which can be defined as the part of rainfall water that appears in uncontrolled surface streams, drains or sewers. Direct (or surface) runoff and base (ground-water) runoff are two different types of

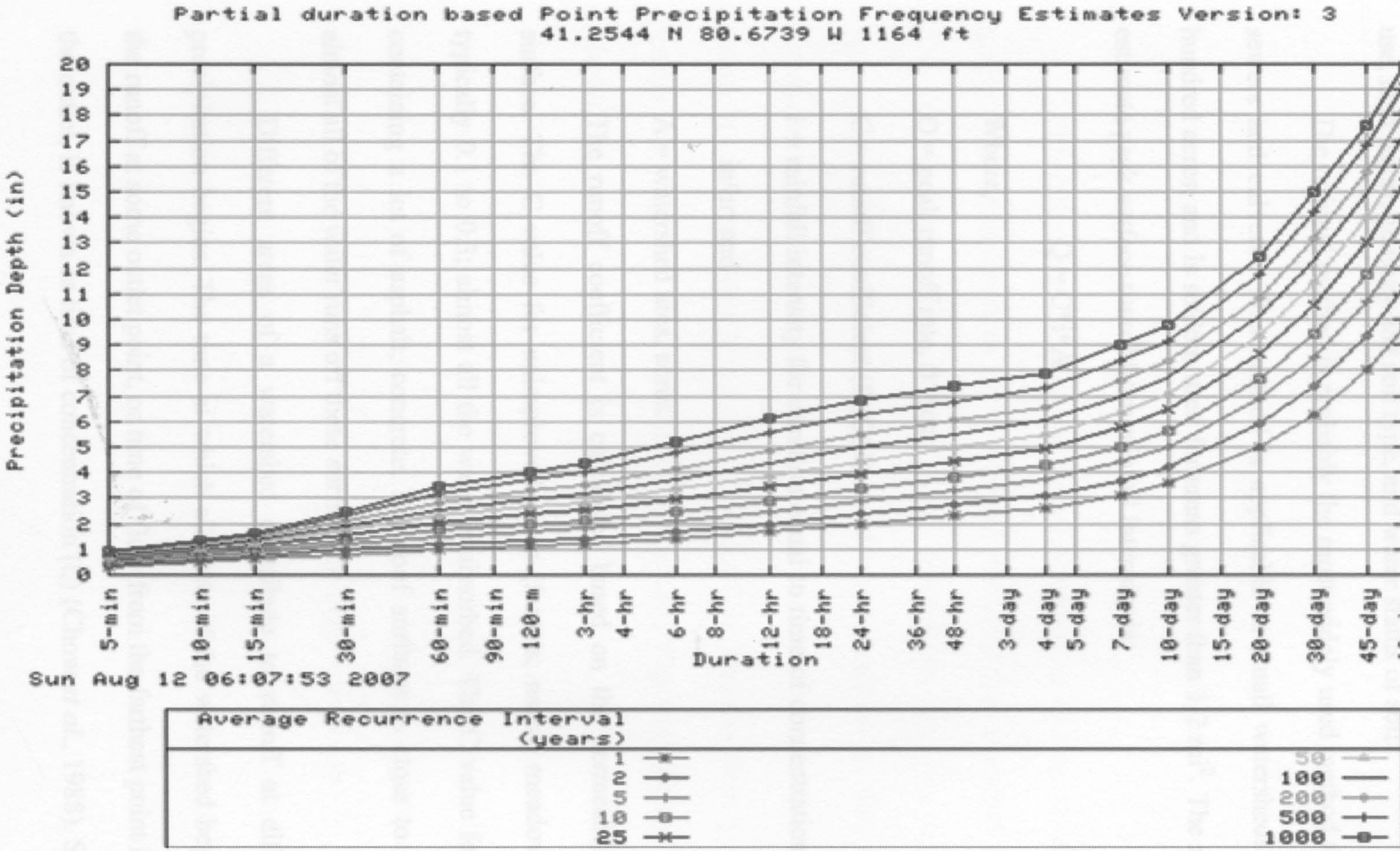

Figure 2.1 Precipitation-Duration-Frequency Curves for Youngstown (NOAA, 2007).

runoff. The rate and volume of watershed runoff are affected by several factors like rainfall duration, rainfall intensity, rainfall distribution, watershed size, topography, land use, land cover, geology and soil type, and water status of soil.

The rational method is probably the most widely used method for design of storm sewers and culverts. This method is applicable to small watersheds less than several hundred acres, and is seldom used for areas greater than 1-2 mi^2. The rational formula to estimate peak surface runoff from rainfall intensity is:

$$Q = C*i*A \quad \text{(Eq 2.2)}$$

Where,

Q = peak runoff rate, ft^3/sec

C = runoff coefficient ($0 \le C \le 1$)

i = rainfall intensity for duration equal to time of concentration of the watershed, in/hr; and

A = watershed area, acres.

The runoff coefficient is calculated based on the permeability of the ground surface. The C value for unimproved areas (forests, native meadows) is very low – typically 0.1 to 0.3; almost all the water is absorbed. The C value for downtown areas containing a lot of asphalt, concrete, and roof surfaces is close to 1.0, which means almost all of the water runs off these surfaces.

Different areas of a watershed contribute to runoff at different times after precipitation begins. The time at which all parts of the watershed begin contributing to the runoff at some outlet point, or time of flow from the farthest point in the watershed to the outlet, is known as time of concentration (t_c) (Chow *et al.*, 1988). Some of the factors affecting time of concentration are surface roughness, channel length and flow patterns, and slope (Sudas, 2006). There are several formulas to calculate time of concentration, According to Kirpich (1940):

$$t_c = 0.0078*L^{0.77}*S^{-0.385} \quad \text{(Eq. 2.3)}$$

Where,

L = length of channel/ditch from headwater to outlet, ft

S = average watershed slope, ft/ft

Streamflow and direct runoff are calculated using hydrographs. A hydrograph is a graph or table that describes the variation of flow over time at a given location of stream. The annual hydrograph and the storm hydrograph are two important types of hydrographs. The annual hydrograph is a plot of streamflow vs. time over a year, which shows the long-term balance of precipitation, evaporation, and streamflow (Chow *et al.*, 1988). A storm hydrograph is a plot of stream flow resulting from a precipitation event, versus time. Figures 2.2 and 2.3 show a typical annual hydrograph and storm hydrograph, respectively.

Peak flow in a watershed is calculated by different methods based on size of the watershed. Unit hydrograph (1 acre to 10 mi^2), Clark unit hydrograph, and S-hydrograph methods are used for small watersheds. Snyder unit hydrograph (10 to 10,000 mi^2), and the SCS method (less than 400 mi^2) are used for large watersheds.

The unit hydrograph of a watershed is defined as a direct runoff hydrograph resulting from 1 in (or 1 cm) of excess rainfall "runoff" generated uniformly over the drainage area. Unit hydrograph theory assumes that the watershed responds uniformly, which means the peak flow from 2 inches of excess rainfall is twice that from 1 inch of excess rainfall.

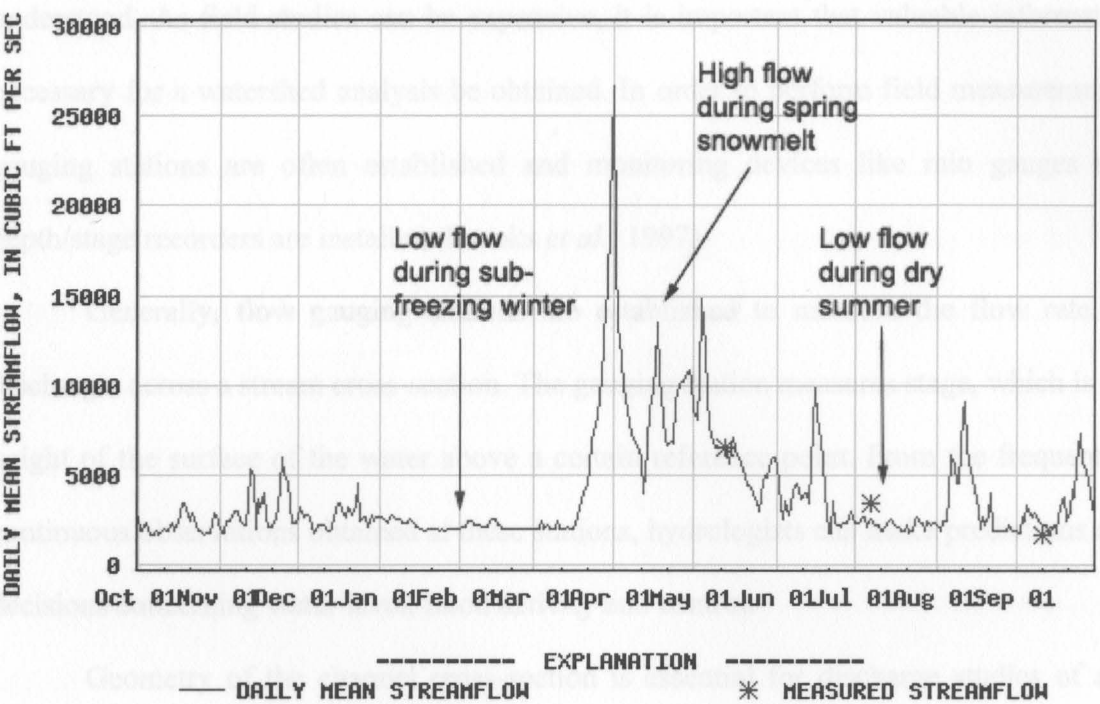

Figure 2.2 A Typical Annual Hydrograph (Bowdoin, 2001)

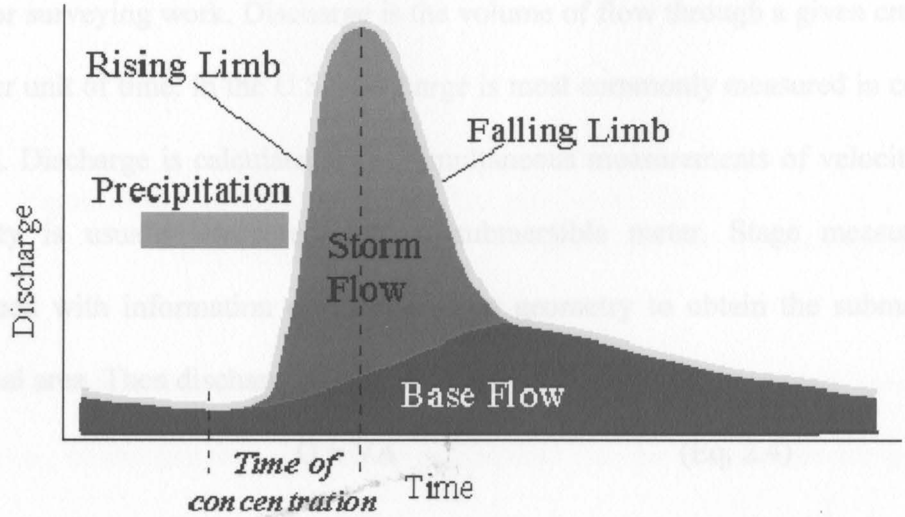

Figure 2.3 A Typical Storm Hydrograph (Van Es, 1997).

2.2 Field Measurements:

Field measurements are very important for watershed analysis and research. Before instituting field studies, it is essential that the objectives of the research are clearly understood. As field studies can be expensive, it is important that valuable information necessary for a watershed analysis be obtained. In order to perform field measurements, gauging stations are often established and monitoring devices like rain gauges and depth/stage recorders are installed (Brooks *et al.*, 1997).

Generally, flow gauging stations are established to measure the flow rate, or discharge, across a stream cross-section. The gauging station measures stage, which is the height of the surface of the water above a certain reference point. From the frequent or continuous observations obtained at these stations, hydrologists can make predictions and decisions concerning water level, flood activity and control.

Geometry of the channel cross-section is essential for discharge studies of any stream. For determination of channel cross-section, surveying work should be done at the stream. Generally, equipment like tape, surveyor's level, tripod, and a leveling staff are used for surveying work. Discharge is the volume of flow through a given cross-sectional area per unit of time. In the U.S., discharge is most commonly measured in cubic feet per second. Discharge is calculated from simultaneous measurements of velocity and stage. Velocity is usually measured with a submersible meter. Stage measurements are combined with information on cross-section geometry to obtain the submerged cross-sectional area. Then discharge is calculated using the formula:

$$Q = VA \qquad \text{(Eq. 2.4)}$$

Where,

Q = Discharge, in ft^3/sec

V = Velocity, in ft/sec

A = Cross-sectional area, in ft^2

The most common method for measuring rainfall over a watershed is using a series of rain gauges. There are two types of rain gauges; 1) standard or non-recording gauge, and 2) recording gauge. Standard gauges are economical, but they must be read periodically, normally every 24 hr at the same time each day. Recording gauges allow for continuous measurement of rainfall, but these are limited because of their higher cost. Weighing-type and the tipping-bucket (Figure 2.4) gauges are examples of recording rain gauges. Generally, the number of rain gauges required to measure the precipitation increases with the size of watershed and with the variability of precipitation (Brooks *et al.*, 1997).

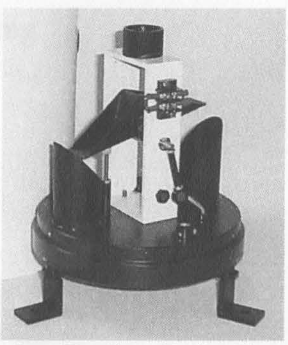

Figure 2.4 Tipping Bucket Rain Gauge - Inside View.
(http://www.novalynx.com/products-rain-gauges.html)

As water levels in the stream change rapidly during rain events, manual monitoring of the gauging stations is inadequate. So, for continuous depth recording a device called pressure sensor or water level logger (Figure 2.5) is used. The pressure sensors or water level loggers record water level, and possibly temperature, in streams, lakes, and freshwater wetlands. Different types of pressure sensors have different ranges for measuring water depths. For example, a pressure sensor of range 0 to 9 m (0 to 30 ft) was used for the depth recordings in this study. Water depth varies with the change in pressure or water density acting on a pressure sensor. Launching and data readout of a pressure sensor is done using software provided by the manufacturer. Barometric compenstion should be done to compensate for changes in atmospheric pressure. Stormy weather can produce barometric pressure sensor differences in the range of 25 mb during a single day, resulting an error of 2.5% in water level for a 30 ft range sensor (http://www.globalw.com/support/barocomp.html). However, if a stream is only 3 ft. deep, then 25 mb is eqivalent to about 25% error. Barometric pressure data can be collected on site using a recording barometer, or from a local weather station. Accuracy of a pressure sensor is affected by several factors such as over pressure, lightening strikes and improper use/handling.

Figure 2.5 A 30 ft "U20-001" HOBO pressure sensor.
(http://www.onsetcomp.com/solutions/products/loggers/_loggerviewer.php5?pid=384)

2.3 Rating Curves:

A rating table or curve is a relationship between stage and corresponding measurements of discharge. Generally, a rating curve is plotted with stream flow on the horizontal axis and stage on the vertical axis as shown in Figure 2.6. Once the rating curve is developed, then it is used to convert records of water level into flow rates. The rating curve should be checked periodically to ensure that the relationship between the discharge and gage height has remained constant. Since rating curves are sometimes developed with a small number of stage/discharge measurements, and measurements of high flows are rare, significant errors in rating curves at high flows are possible. Sometimes we observe different discharge for the same recorded stage; this can be because of scouring of the stream bed or deposition of sediment in the stream (Chow *et al.*, 1988).

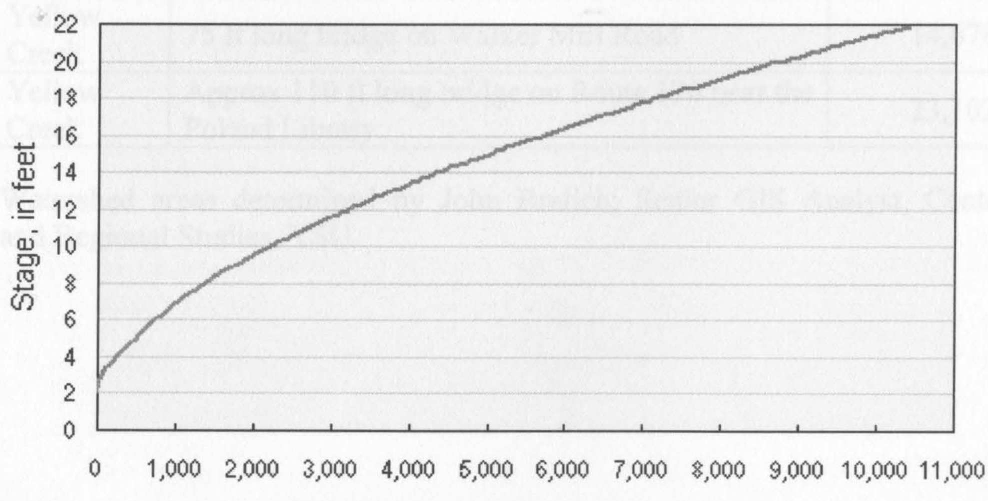

Figure 2.6 Typical Rating Curve. (http://ga.water.usgs.gov/edu/measureflow.html)

CHAPTER 3

METHODS AND PROCEDURES

3.1 Establishment of Gauging Stations:

Gauging stations were established at five stream locations in the Yellow Creek watershed (Figure 3.1). The locations are described in Table 3.1, along with the drainage area of each site.

Table 3.1 Location and Drainage Areas of Gauging Sites.

Site #	Stream Name	Location	Drainage Area (acres)
1	Drake's Run	6 ft diameter culvert in Poland Village Park	2,539
2	Burgess Run	30 ft long bridge at the intersection of Burgess Run Road and Walker Mill Road	4,890
3	Yellow Creek	40 ft long bridge on North Lima Road by Lake Evans dam	12,077
4	Yellow Creek	75 ft long bridge on Walker Mill Road	14,670
5	Yellow Creek	Approx 110 ft long bridge on Route 170 near the Poland Library	23,102

Note: Watershed areas determined by John Bralich; Senior GIS Analyst, Center for Urban and Regional Studies, YSU.

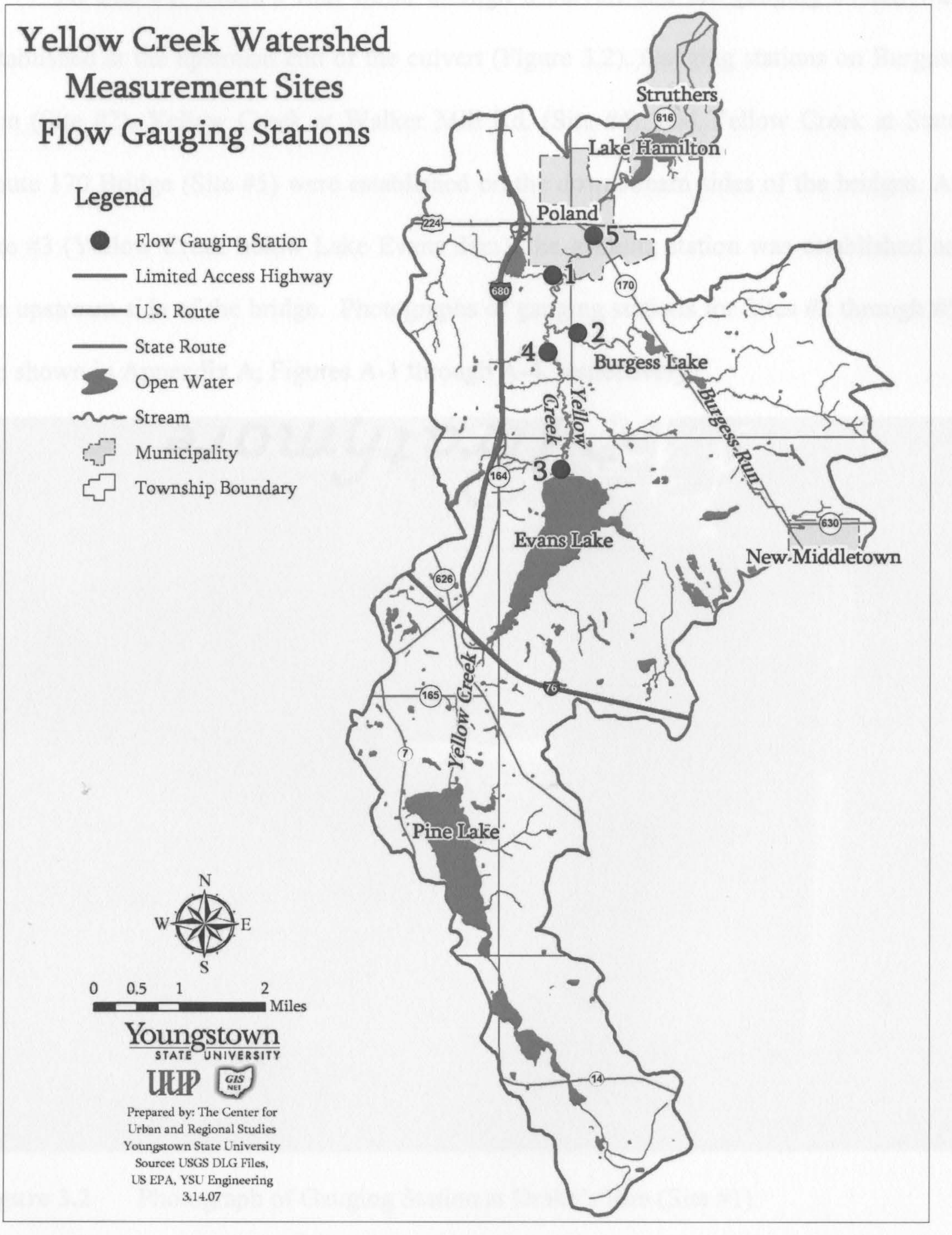

Figure 3.1 Locations of Gauging Stations (map provided by YSU Center for Urban and Regional Studies).

At Site #1, Drake's Run flows through a culvert and the gauging station was established at the upstream end of the culvert (Figure 3.2). Gauging stations on Burgess Run (Site #2), Yellow Creek at Walker Mill Rd. (Site #4), and Yellow Creek at State Route 170 Bridge (Site #5) were established on the downstream sides of the bridges. At Site #3 (Yellow Creek below Lake Evans dam), the gauging station was established on the upstream side of the bridge. Photographs of gauging stations for Sites #2 through #5 are shown in Appendix A, Figures A-1 through A-4, respectively.

Figure 3.2 Photograph of Gauging Station at Drake's Run (Site #1).

In June 2006, surveying work was carried out at the gauging stations to characterize the stream cross-section. Initially, a 100 ft surveyor's tape was used to establish a baseline along the railing of the bridge at Sites #2, #4, and #5. After a baseline was established, 5 ft intervals were marked along the baseline. A surveyor's level and a Philadelphia rod were used to measure the relative elevation of the bridge deck at the 5 ft intervals marked. The height (elevation) of the instrument was assumed to be 1000 ft at all stations. The height of the railing was measured from the bridge deck at each interval. Then distances to the ground, water surface, and/or stream bottom were measured from the top of railing at marked intervals. Distances to the ground and water surface were measured using a fiberglass tape graduated to 0.01 ft with a weight attached. The weight was a plastic bottle filled with sand, which added 0.78 ft to the length of the tape (Figure 3.3). Depth of water was measured with the scale on the velocity meter pole (Figure 3.4).

Figure 3.3 A 100 ft Surveyor's Tape Attached to 0.78 ft Bottle Filled With Sand.

Figure 3.4 Global Water Flow Probe.

The following calculations were performed in order to obtain ground elevation:

$$BDE = HI - RR \quad \text{(Eq 3.1)}$$

$$RE = BDE + HR \quad \text{(Eq 3.2)}$$

$$GE = RE - DG \quad \text{(Eq 3.3)}$$

Where (all in ft):

BDE = Bridge deck elevation

HI= Height of the instrument (assumed 1000 ft)

RR = Rod reading

RE = Railing elevation

HR = Height of railing

GE = Ground elevation

DG = Distance to the ground

* In some cases DG = distance to the water surface + depth of water

For Site #3, the baseline was established on the bridge deck, so ground elevation was calculated from the equation:

$$GE = BDE - DG \qquad \text{(Eq 3.4)}$$

At Site #1 (Drake's Run), flow normally passes through a 5 ft. diameter concrete culvert. During heavy storms, the culvert overflows and water flows over a paved spillway and hiking trail. At this site, the baseline was established along the hiking trail and spillway. Marks were placed at 5 ft intervals along the baseline. Using surveyor's level and Philadelphia rod, rod readings were noted at each interval. Assuming height (elevation) of the instrument as 1000 ft, the elevation at each point was calculated by subtracting rod reading (RR) from height of the instrument, i.e. GE = 1000-RR.

After ground elevations were calculated, the stream cross-sections were plotted for each gauging Site using Microsoft Excel, with distance along the baseline on the x-axis and ground elevation on the y-axis.

3.2 Flow Measurements:

Gauging stations were continuously monitored by citizens of Poland Village for two months from September, 2006 to October, 2006. Before gauging stations were established the sites were visited 5-6 times and preliminary data were obtained between the months of May, 2006 and July, 2006. Each visit involved measurement of water elevation using tape and/or water depth using the scale on the flow meter pole, and the velocity of flow using a Global Flow Probe (Figure 3.4). Each velocity value recorded was the average of two similar readings.

On each sampling date, the distance from the bridge railing at a specific marking to the water surface was measured using the weighted fiberglass tape. The distance obtained was subtracted from each corresponding railing elevation, resulting in the water surface elevation. Once water surface elevation was obtained, depth of the water throughout the channel width was obtained by subtracting ground elevation from water surface elevation. For Site #1, depth of water in the culvert was directly measured using the scale on the flow meter and only one velocity reading was taken.

In early September, 2006, stream gauges graduated to 0.01 ft. were installed at each site. These are shown in Figures 3.2, and A-1 through A-4, for Sites #1-5, respectively. After installation of the stream gauges, water level (or "stage") was read directly from the gauges.

At Sites #2-5, the stream width was divided into sections with approximately uniform velocity of flow. Average velocity was measured in each section using the Global Flow Probe. The Flow Probe (velocity meter) was moved slowly around the section of interest to get an average velocity reading. The cross-sectional area of each section was calculated and tabulated with the measured velocity in an Excel spreadsheet.

Calculations:

Site #1

At Site #1 (Drake's Run), calculations of flow through the culvert were performed using equations for the geometry of a circle and the formula:

$$Q = V*A \qquad \text{(Eq 3.5)}$$

Where,

Q = flow rate, ft^3/sec

V = velocity of the flow, ft/sec

A = cross-sectional area of flow, ft^2

Cross-sectional area of flow in the culvert was calculated by the formula (see Figure 3.5)

$$A = (A+A_1) - A_1 \qquad \text{(Eq 3.6)}$$

Where,

$$A+A_1 = \pi*R^2*(\theta/360) \qquad \text{(Eq 3.7)}$$

$$A_1 = (c*d)/2 \qquad \text{(Eq 3.8)}$$

$$c = 2*R*Sin(\theta/2) \qquad \text{(Eq 3.9)}$$

$$d = R-h \qquad \text{(Eq 3.10)}$$

$$\theta = 2*Cos^{-1}(d/R) \qquad \text{(Eq 3.11)}$$

h = depth of flow, ft

R = Radius of the culvert, ft (R = 2.5 ft)

c = length of water surface, ft

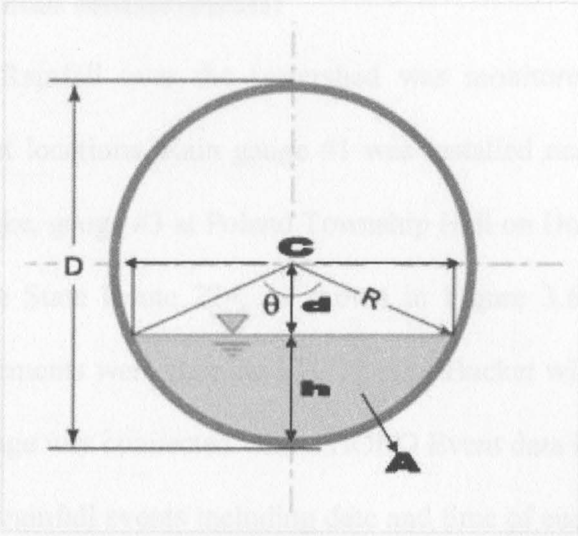

Figure 3.5 Geometry of Culvert.

Sites #2 through #5

At Sites #2, #3, #4 and #5, the same procedure was used for the flow calculations. Velocity of flow was measured at different intervals across the stream. Water surface elevation was measured by lowering a tape from the bridge railing. Cross-sectional area of each stream section was determined using the stream channel geometry. Then the flow rate was calculated by the following equation:

$$Q = \sum_{i=1}^{n} V_i A_i \qquad \text{(Eq 3.12)}$$

Where,

Q = flow rate, ft^3/sec

V_i = velocity of flow in section i, ft/sec

A_i = cross-sectional area of section i, ft^2/sec

n = number of stream sections.

3.3 Rainfall Measurements:

Rainfall over the watershed was monitored by rain gauges installed at four different locations. Rain gauge #1 was installed near the Lake Evans dam, gauge #2 at Pine Lake, gauge #3 at Poland Township Hall on Dobbins Rd, and gauge #4 at Boardman Park on State Route 224, as shown in Figure 3.6. The rain gauges used for rainfall measurements were Rainew 111 Tipping Bucket wired rain gauges. Each tipping bucket rain gauge was connected with a HOBO Event data logger. The HOBO Event data logger records rainfall events including date and time of each event; the data logger has 32 kb of memory and can store up to 8000 events. Each tip of the bucket represents 0.01 in. of rain and is considered one event (Onset, 2002).

Once rain gauges were connected with data loggers (Figure 3.7), the loggers were "launched" using an interface cable and BoxCar Pro 4.3 software. The HOBO H7 event data logger has a red LED that blinks every two seconds while it is logging. After the loggers were properly launched, the rain gauges were installed at their respective locations. A HOBO Shuttle was used for the retrieval of data from the loggers to avoid the risk of bringing the loggers back from the field or taking a computer into the field.

The data from the data logger was automatically downloaded by connecting a HOBO Shuttle to the data logger with a 1 ft long cable provided with the shuttle (Figure 3.8). Then, the HOBO shuttle was connected to a computer using an interface cable and the readout was done with BoxCar Pro 4.3 software. Once the data were downloaded from the shuttle, the shuttle was automatically relaunched and the shuttle clock synchronized with the PC clock. The HOBO Shuttle has 468 kb of memory, which is enough for 13 full 32 kb data loggers.

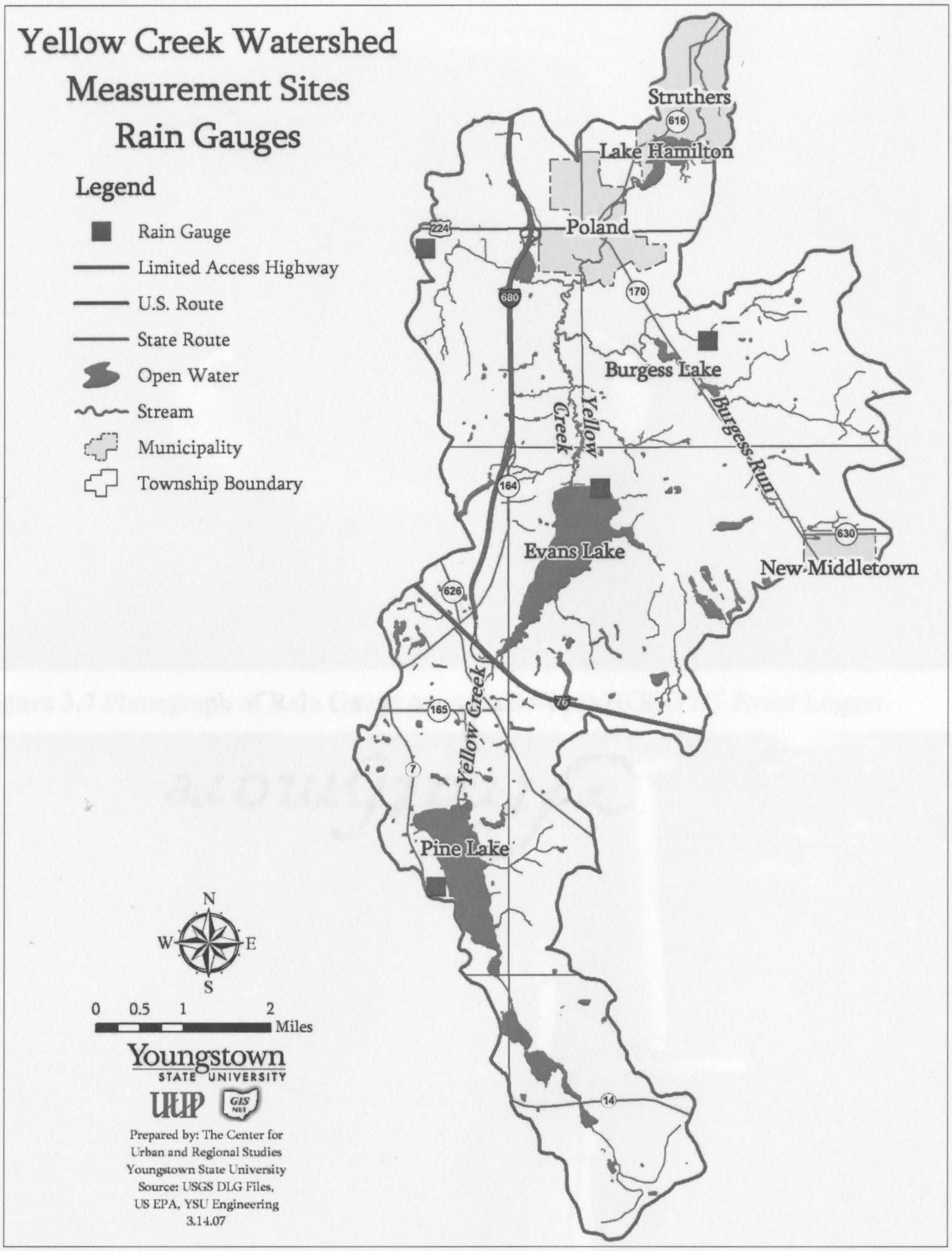

Figure 3.6 Yellow Creek Watershed Map Showing Rain Gauge Locations (map provided by YSU Center for Urban and Regional Studies).

Figure 3.7 Photograph of Rain Gauge connected with a HOBO H7 Event Logger.

Figure 3.8 Photograph of HOBO Shuttle connected to HOBO H7 Event logger.

3.4 Pressure/Depth Sensors:

Pressure/depth sensors were installed at Sites #4 and #5 for continuous depth recording. The pressure sensors are also referred to as water level loggers. Two HOBO Water Level loggers (U20-001 series) were used for the depth monitoring in Yellow Creek at Walker Mill Rd (Site #4) and State Route 170 Bridge (Site #5). HOBO water level loggers were connected to a computer using an Optic USB Base Station and launched using HOBOware software (Onset, 2006). After loggers were launched, they were placed at the deepest point on the stream cross-section and protected with large rocks. They were left in the stream for some period of time, after which they were retrieved and the data downloaded using Optic USB Base Station and HOBOware. The base station uses infrared light to transfer data from the logger. The pressure sensor at Site #4 was lost after it was placed into the stream for the second time.

3.5 Rating Curves:

Rating curves were developed for all the gauging stations, Sites #1 through #5. Rating curves for Sites #1-5 were plotted with discharge (in cubic feet per second) on the horizontal axis and stage (in feet) on vertical axis. For Site #5, the gauging scale starts at 3.33 ft at the top of a pier footing. When the water level is below the top of the pier footing, stage value is obtained by subtracting the reading from 3.33 ft. For measurements taken before the stream gauges were installed, water surface elevations measured by tape from the bridge railing were later converted to corresponding stage readings on the stream gauges.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Channel Cross-Sections at Gauging Stations

A plot showing the cross-section of the overflow channel and position of the 5 ft. diameter culvert at Site #1 is shown in Figure 4.1. Plots of channel cross-sections for Sites #2 through #5 are presented in Figures 4.2 through 4.5, respectively. The surveying data of the channel cross-sections for Sites #1 through #5 are summarized in Appendix B, Table B-1 through B-5, respectively.

As there is always a possibility of error in the surveying measurements, some error in the geometry of channel cross-section is also possible. The sources for the errors can be natural, instrumental or human.

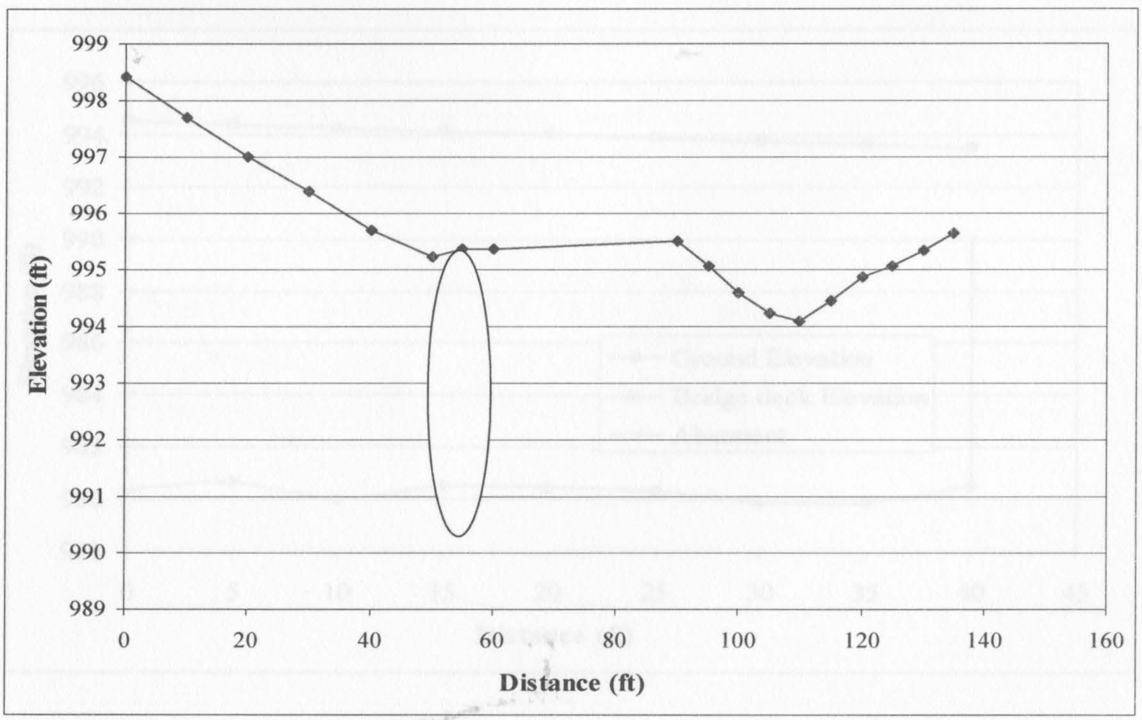

Figure 4.1 Plot of Culvert Pipe and Overflow Channel at Site #1, Drake's Run, looking Downstream.

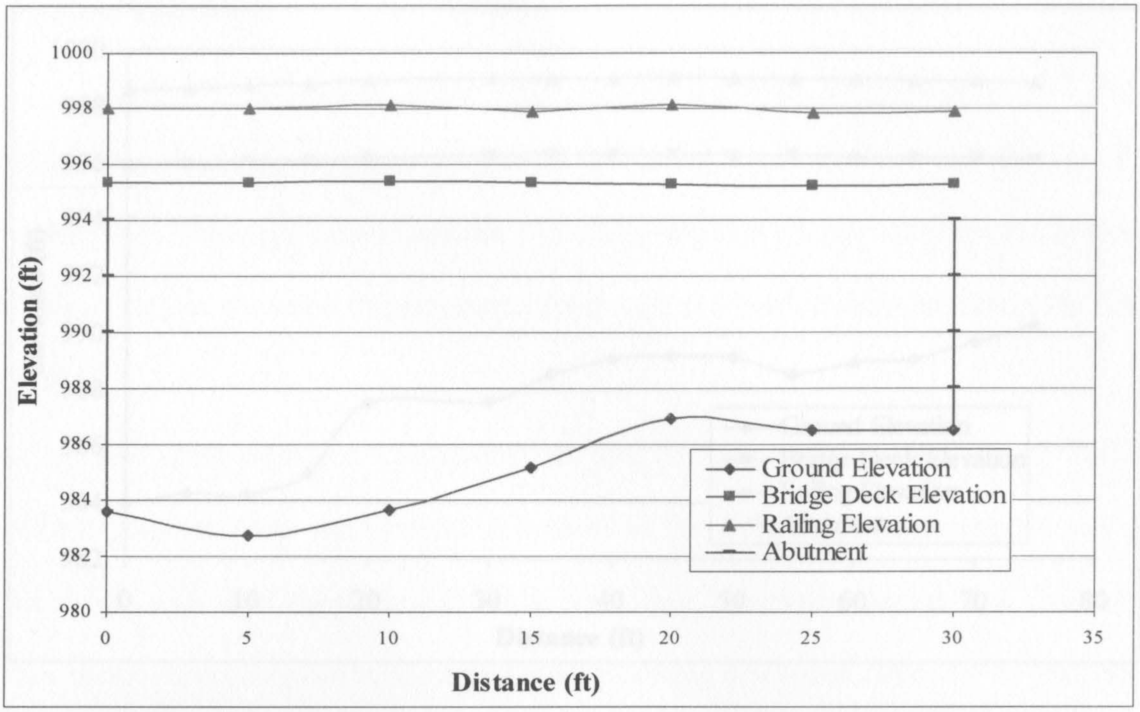

Figure 4.2 Plot of Stream Cross-Section at Site #2, Burgess Run at Walker Mill Rd, Looking Downstream.

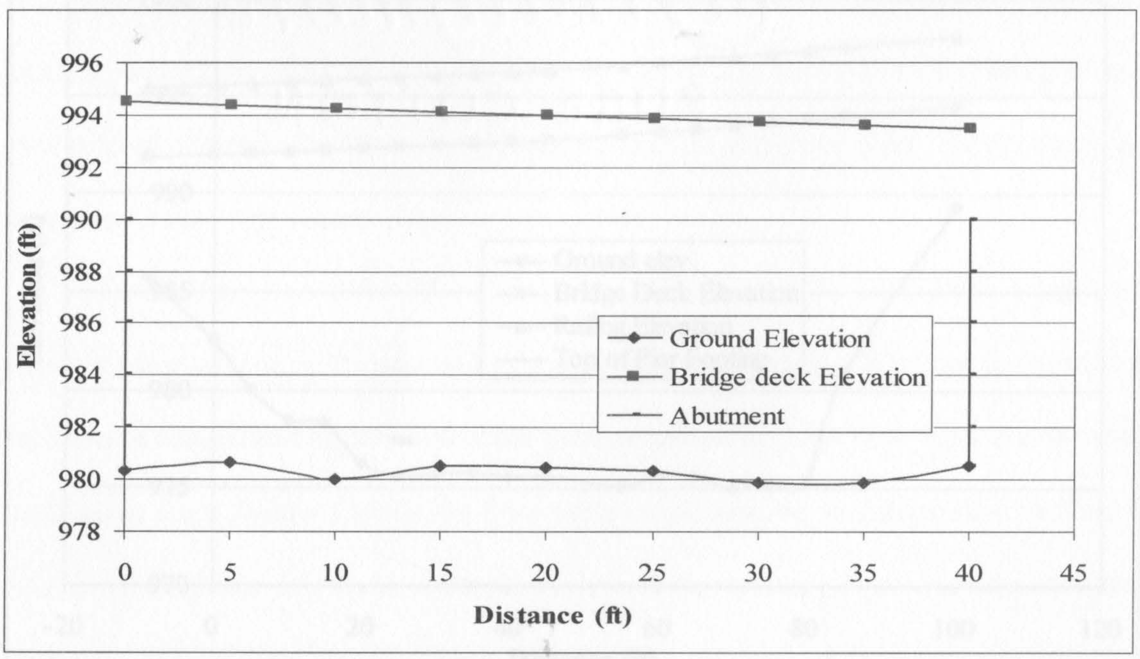

Figure 4.3 Plot of Stream Cross-Section at Site #3, Yellow Creek below Lake Evans Dam, Looking Upstream.

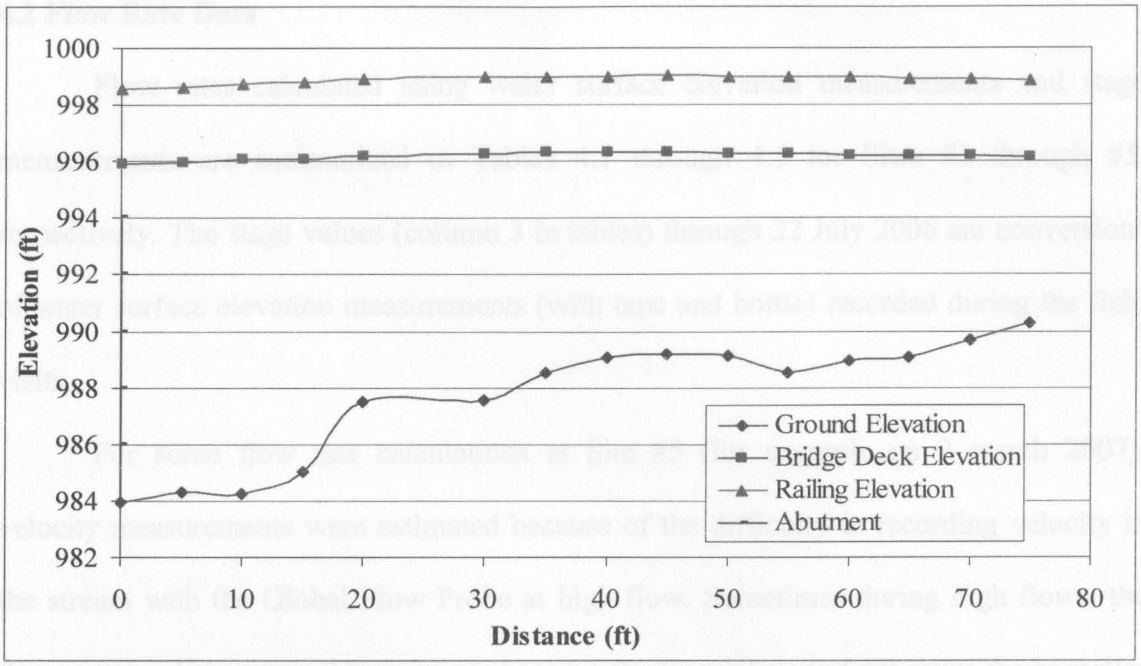

Figure 4.4 Plot of Stream Cross-Section at Site #4, Yellow Creek at Walker Mill Rd., Looking Downstream.

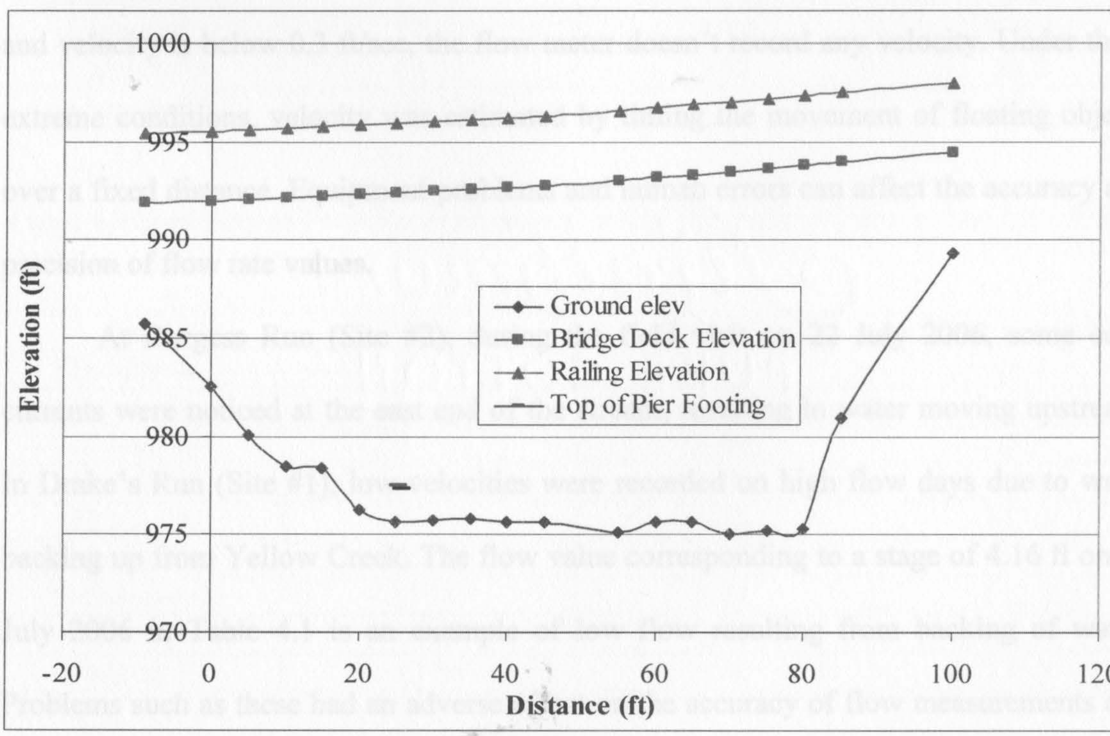

Figure 4.5 Plot of Stream Cross-Section at Site #5, Yellow Creek at State Route 170, Looking Downstream.

4.2 Flow Rate Data

Flow rates calculated using water surface elevation measurements and stage measurements are summarized in Tables 4.1 through 4.5 for Sites #1 through #5, respectively. The stage values (column 3 in tables) through 22 July 2006 are conversions of water surface elevation measurements (with tape and bottle) recorded during the field visits.

For some flow rate calculations at Site #5 (for example on 2 march 2007), velocity measurements were estimated because of the difficulty in recording velocity in the stream with the Global Flow Probe at high flow. Sometimes during high flows, the flow meter values may not be accurate because floating debris and silt cause the propeller to malfunction. Also, during high flows it is hard to hold the flow meter perpendicular to the flow and readings can only be taken near the stream bank. When the flow is very low and velocity is below 0.3 ft/sec, the flow meter doesn't record any velocity. Under these extreme conditions, velocity was estimated by timing the movement of floating objects over a fixed distance. Equipment problems and human errors can affect the accuracy and precision of flow rate values.

At Burgess Run (Site #2), during the field visit on 22 July 2006, some eddy currents were noticed at the east end of the stream, resulting in water moving upstream. In Drake's Run (Site #1), low velocities were recorded on high flow days due to water backing up from Yellow Creek. The flow value corresponding to a stage of 4.16 ft on 22 July 2006 in Table 4.1 is an example of low flow resulting from backing of water. Problems such as these had an adverse effect on the accuracy of flow measurements and rating curves.

Table 4.1 Summary of Flow Rates Measured at Site #1, Drake's Run.

Date	Time	Stage (ft)	Flow rate(cfs)
26 May 06		0.55	1.3
16 June 06		0.35	0.3
11 July 06		1.05	2.6
12 July 06		1.78	22.8
22 July 06		4.16	42.8
17 October 06	09:00	6.03	200.7
17 October 06	10:00	6.18	321.6

Table 4.2 Summary of Flow Rates Measured at Site #2, Burgess Run at Walker Mill Rd.

Date	Time	Stage (ft)	Flow rate(cfs)
26 May 06		1.11	19.9
2 June 06		0.81	6.1
16 June 06		0.60	2.6
11 July 06	17:50	1.01	9.6
12 July 06	12:15	1.47	21.2
22 July 06	14:45	2.92	143.0
17 October 06	09:30	3.25	265.5
21 October 06	09:50	1.20	18.8
2 March 07	12:30	2.95	239.3
3 March 07	08:22	1.62	58.2
4 March 07	08:25	1.14	22.9

Table 4.3 Summary of Flow Rates Measured at Site #3, Yellow Creek below Lake Evans Dam.

Date	Time	Stage (ft)	Flow rate(cfs)
26 May 06		1.59	21.8
2 June 06		1.21	5.2
16 June 06		0.85	0.0
12 July 06		1.66	18.6
22 July 06		3.26	147.5
20 October 06	07:25	2.65	78.8
20 October 06	17:10	2.78	112.6
21 October 06	10:20	2.32	84.6
2 March 07	13:30	3.40	131.3

Table 4.4 Summary of Flow Rates Measured at Site #4, Yellow Creek at Walker Mill Rd.

Date	Time	Stage (ft)	Flow rate(cfs)
26 May 06		1.45	18.5
2 June 06		0.91	9.6
16 June 06		0.59	1.1
11 July 06		1.29	15.6
12 July 06		1.37	21.8
22 July 06		3.97	143.2
17 October 06		4.90	261.2
21 October 06	10:00	2.57	86.8
2 March 07	13:10	4.40	205.5
3 March 07	8:30	3.62	111.7
4 March 07	8:25	2.65	75.6

Table 4.5 Summary of Flow Rates Measured at Site #5, Yellow Creek at State Route 170.

Date	Time	Water Surface Elevation	Flow rate (cfs)
26 May 06		2.02	84.7
2 June 06		1.57	14.1
16 June 06		1.78	3.9
11 July 06	17:05	1.88	28.0
12 July 06	11:30	2.22	112.3
22 July 06	14:15	3.84	512.0
17 October 06		3.78	604.0
20 October 06	06:45	2.93	241.5
20 October 06	16:45	2.89	239.2
21 October 06	09:35	2.17	114.3
2 March 2007	08:00	5.53	1345.6
2 March 2007	14:00	4.13	615.5
2 March 2007	17:30	4.93	844.6
3 March 2007	07:30	2.55	176.7
4 March 2007	07:40	1.98	65.4

4.3 Rating Curves

Rating curves developed for Sites #1 through #5 are presented in Figures 4.6 through 4.10, respectively. Functions relating stage to discharge for all the sites are summarized in Table 4.6. The functional relationships relating stage to discharge were obtained by making stage the independent variable and discharge the dependent variable.

Table 4.6 Stage-Discharge Equations

Site	Description	Stage – Discharge Function	Correlation Index (R^2)
#1	Drake's Run	$D=9.5239S^2-21.173S+13.563$	0.97
#2	Burgess Run	$D=35.235S^2-41.753S+18.414$	0.94
#3	Yellow Creek Below Lake Evans	$D=7.271S^2+29.618S-38.395$	0.95
#4	Yellow Creek at Walker Mill Rd	$D=11.527S^2-6.724S+6.2348$	0.98
#5	Route 170 Bridge	$D=54.787S^2-72.349S-3.4609$	0.98

S = Stage, ft; D = Discharge, ft^3/sec

Based on the correlation index values, the relationships between stage and discharge are fairly good. However, the rating curve equations should be considered very tentative. Several more data points are needed over the entire range of flow conditions in order to produce reliable equations.

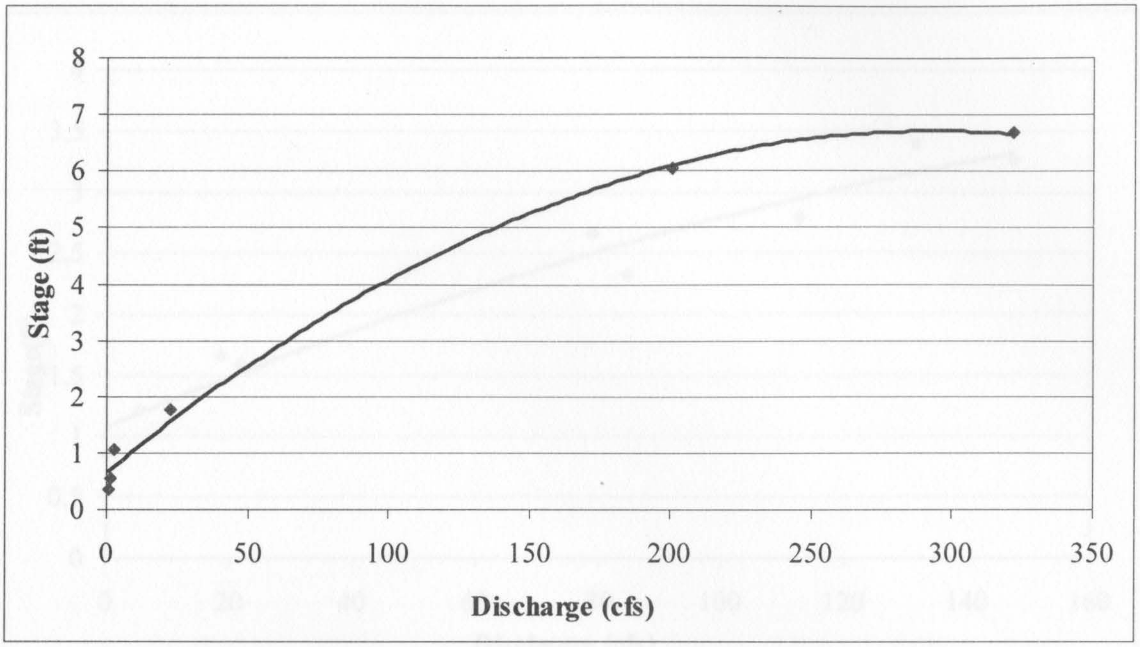

Figure 4.6 Rating Curve for Site #1, Drake's Run.

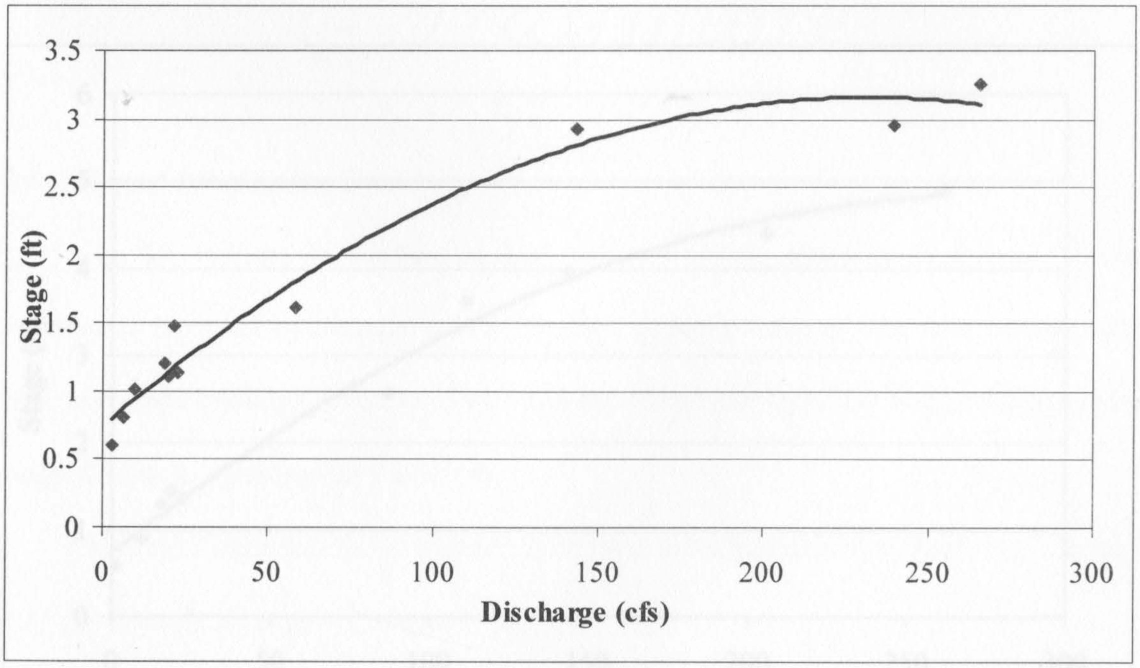

Figure 4.7 Rating Curve for Site #2, Burgess Run at Walker Mill Rd.

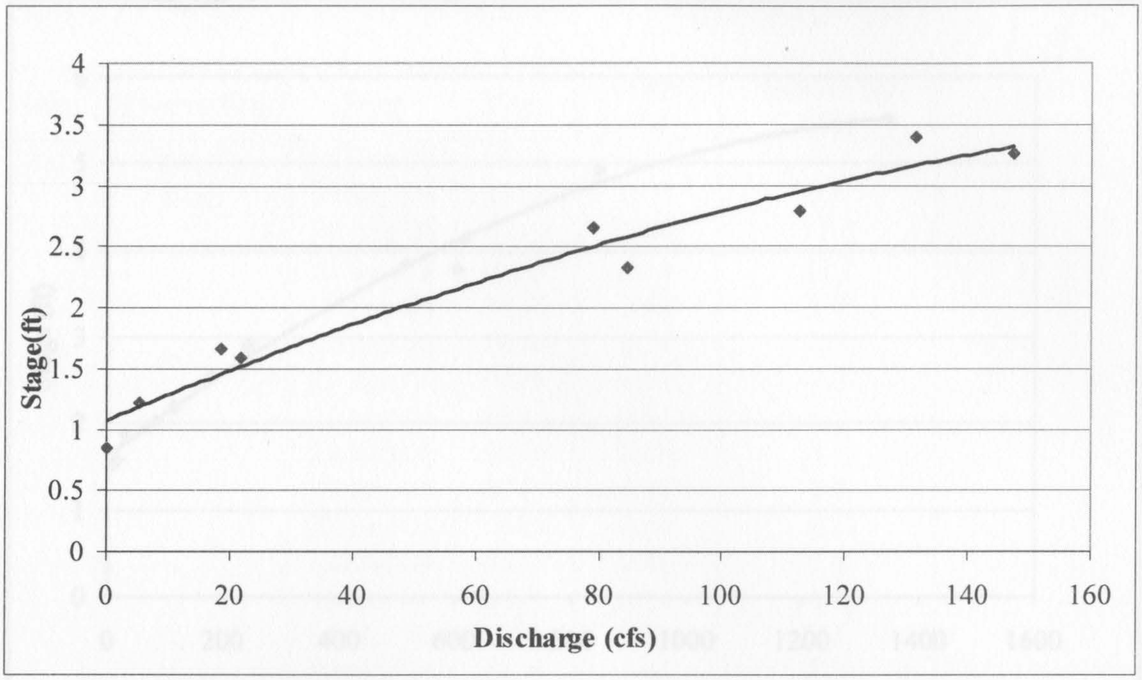

Figure 4.8 Rating Curve for Site #3, Yellow Creek below Lake Evans Dam.

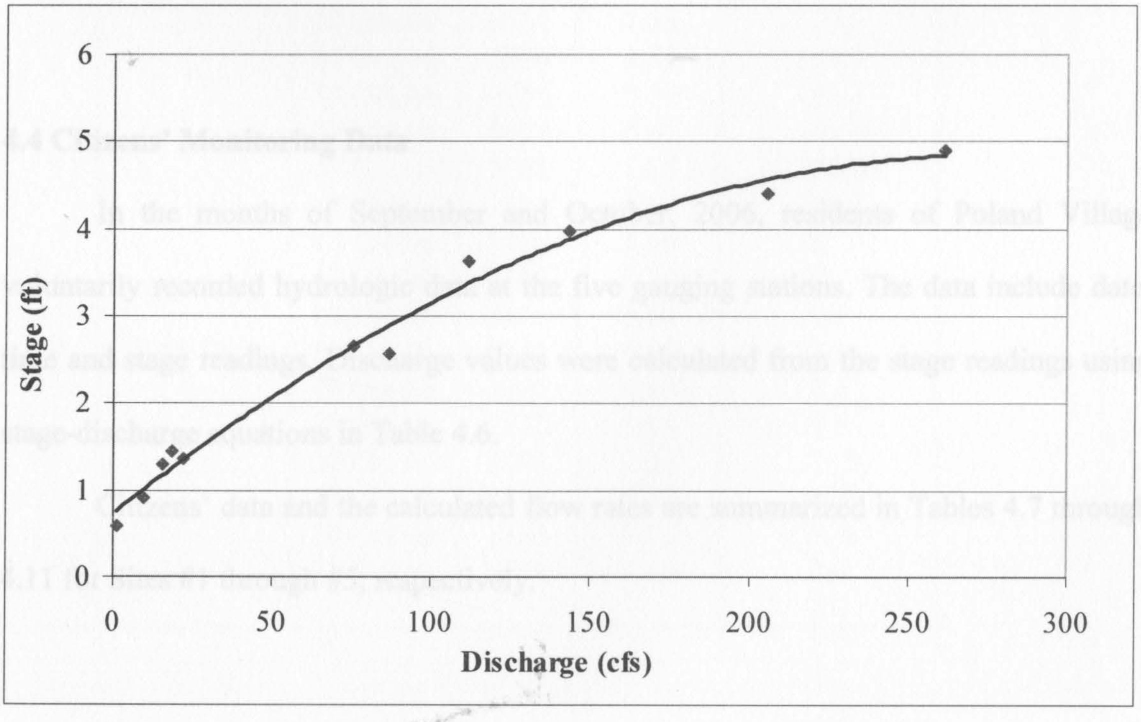

Figure 4.9 Rating Curve for Site #4, Yellow Creek at Walker Mill Rd.

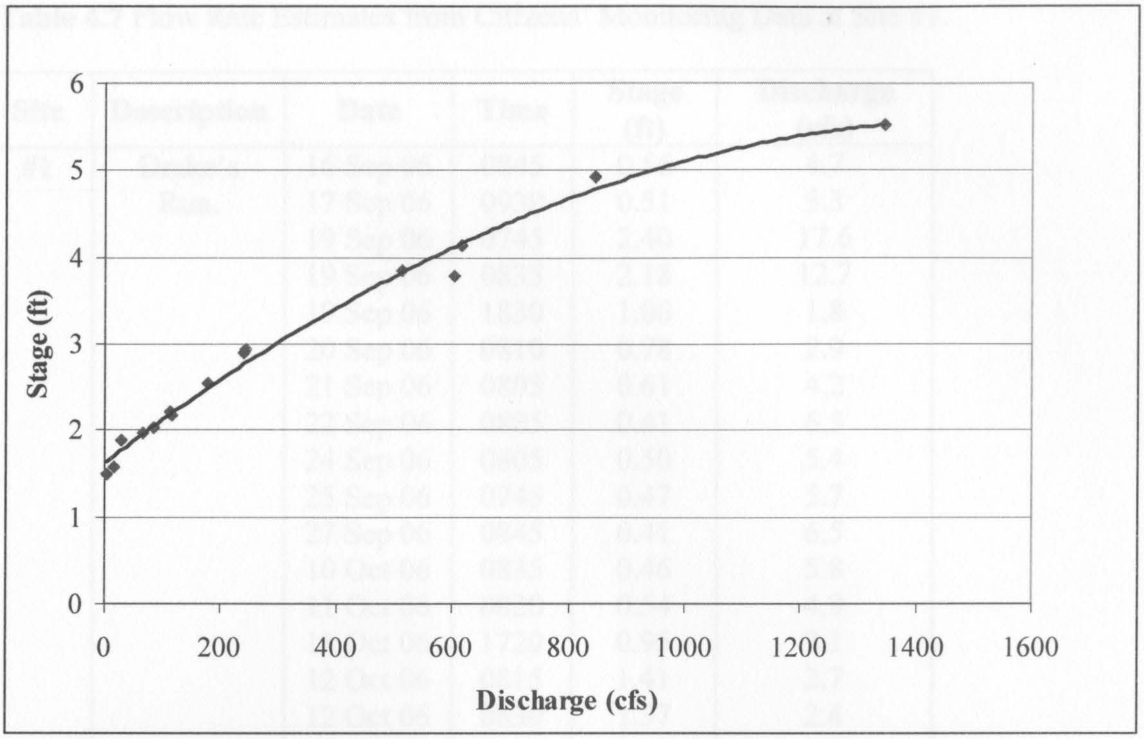

Figure 4.10 Rating Curve for Site #5, Yellow Creek at State Route 170.

4.4 Citizens' Monitoring Data

In the months of September and October, 2006, residents of Poland Village voluntarily recorded hydrologic data at the five gauging stations. The data include date, time and stage readings. Discharge values were calculated from the stage readings using stage-discharge equations in Table 4.6.

Citizens' data and the calculated flow rates are summarized in Tables 4.7 through 4.11 for Sites #1 through #5, respectively.

Table 4.7 Flow Rate Estimates from Citizens' Monitoring Data at Site #1.

Site	Description	Date	Time	Stage (ft)	Discharge (cfs)
#1	Drake's Run.	16 Sep 06	0845	0.56	4.7
		17 Sep 06	0930	0.51	5.3
		19 Sep 06	0745	2.40	17.6
		19 Sep 06	0835	2.18	12.7
		19 Sep 06	1830	1.06	1.8
		20 Sep 06	0810	0.78	2.9
		21 Sep 06	0805	0.61	4.2
		22 Sep 06	0805	0.41	6.5
		24 Sep 06	0805	0.50	5.4
		25 Sep 06	0745	0.47	5.7
		27 Sep 06	0845	0.41	6.5
		10 Oct 06	0835	0.46	5.8
		11 Oct 06	0820	0.54	4.9
		11 Oct 06	1720	0.95	2.1
		12 Oct 06	0815	1.41	2.7
		12 Oct 06	0830	1.37	2.4
		13 Oct 06	0905	0.67	3.7
		15 Oct 06	0830	0.47	5.7
		16 Oct 06	0830	0.44	6.1
		17 Oct 06	0315	0.47	5.7
		17 Oct 06	0635	1.36	2.4
		17 Oct 06	0830	4.85	134.9
		17 Oct 06	0905	5.50	185.2
		17 Oct 06	0915	5.65	198.0
		17 Oct 06	1125	6.07	236.0
		17 Oct 06	1415	6.40	268.2
		17 Oct 06	1715	5.20	161.0
		17 Oct 06	2140	3.20	43.3
		18 Oct 06	1010	1.64	4.5
		19 Oct 06	0825	0.95	2.1
		19 Oct 06	1545	0.95	2.1
		19 Oct 06	2315	1.64	4.5
		20 Oct 06	0305	2.62	23.5
		20 Oct 06	0700	3.58	59.8
		20 Oct 06	1455	2.73	26.8
		21 Oct 06	0915	1.40	2.6

Table 4.8 Flow Rate Estimates from Citizens' Monitoring Data at Site #2.

Site	Description	Date	Time	Stage (ft)	Discharge (cfs)
#2	Burgess Run.	12 Sep 06	1755	0.92	17.4
		12 Sep 06	2230	1.82	62.1
		13 Sep 06	0835	1.09	21.5
		14 Sep 06	0820	0.77	15.5
		16 Sep 06	0900	2.05	82.6
		19 Sep 06	0800	1.18	24.4
		20 Sep 06	0820	0.91	17.2
		21 Sep 06	0800	0.61	15.2
		24 Sep 06	0820	0.71	15.2
		28 Sep 06	1000	1.60	45.9
		28 Sep 06	1815	2.30	109.2
		05 Oct 06	1405	0.80	15.8
		10 Oct 06	0845	0.79	15.7
		11 Oct 06	0830	0.80	15.8
		11 Oct 06	1730	0.94	17.8
		12 Oct 06	0845	1.59	45.2
		13 Oct 06	0910	0.86	16.4
		17 Oct 06	0325	0.77	15.5
		17 Oct 06	0650	0.94	17.7
		17 Oct 06	0835	2.42	123.6
		17 Oct 06	1010	3.25	250.5
		17 Oct 06	1030	3.34	267.1
		17 Oct 06	1435	3.60	318.5
		17 Oct 06	1530	2.80	175.6
		17 Oct 06	2150	1.96	74.2
		18 Oct 06	1020	1.29	28.9
		18 Oct 06	1115	1.33	30.7
		19 Oct 06	0845	0.99	18.8
		19 Oct 06	1555	1.00	19.1
		19 Oct 06	2325	1.39	33.6
		20 Oct 06	0315	1.64	48.6
		20 Oct 06	0710	2.27	105.8
		20 Oct 06	0835	2.40	121.1
		20 Oct 06	1355	3.30	259.7
		20 Oct 06	1726	1.90	68.8
		21 Oct 06	0950	1.20	25.2
		27 Oct 06	0840	0.85	16.3
		27 Oct 06	1720	0.85	16.3
		27 Oct 06	1935	0.96	18.2
		27 Oct 06	2200	1.50	39.6
		28 Oct 06	0340	2.35	115.1
		28 Oct 06	0710	2.00	77.9
		28 Oct 06	0800	2.05	82.6
		28 Oct 06	0920	2.12	89.6
		28 Oct 06	1900	2.98	203.9
		29 Oct 06	0955	1.40	34.1
		30 Oct 06	0905	1.10	21.8
		31 Oct 06	0955	0.92	17.4

Table 4.9 Flow Rate Estimates from Citizens' Monitoring Data at Site #3.

Site	Description	Date	Time	Stage (ft)	Discharge (cfs)
#3	Yellow Creek at Lake Evans.	12 Sep 06	1807	1.00	0.0
		13 Sep 06	0840	1.05	0.7
		14 Sep 06	0830	0.92	0.0
		19 Sep 06	0815	1.72	34.1
		28 Sep 06	1025	1.38	16.3
		28 Sep 06	1830	1.60	27.6
		05 Oct 06	1410	1.32	13.4
		12 Oct 06	0955	1.56	25.5
		17 Oct 06	0345	1.24	9.5
		17 Oct 06	0705	1.66	30.8
		17 Oct 06	0850	2.62	89.1
		17 Oct 06	1025	3.00	115.9
		17 Oct 06	1050	3.05	119.6
		17 Oct 06	1445	3.45	150.3
		17 Oct 06	1740	3.45	150.3
		17 Oct 06	2205	3.15	127.1
		18 Oct 06	1035	2.52	82.4
		18 Oct 06	1130	2.48	79.8
		19 Oct 06	0955	1.96	47.6
		19 Oct 06	1610	2.00	49.9
		20 Oct 06	0330	2.34	70.7
		20 Oct 06	0725	2.65	91.2
		20 Oct 06	0853	2.80	101.5
		20 Oct 06	1405	2.83	103.6
		20 Oct 06	1710	2.78	100.1
		21 Oct 06	1020	2.32	69.5
		27 Oct 06	0915	1.48	21.4
		27 Oct 06	1950	1.65	30.3
		27 Oct 06	2215	2.05	52.9
		28 Oct 06	0350	2.26	65.7
		28 Oct 06	0720	2.30	68.2
		28 Oct 06	0810	2.44	77.2
		28 Oct 06	0930	2.45	77.8
		28 Oct 06	1910	2.80	101.5
		29 Oct 06	1130	2.40	74.6
		30 Oct 06	0920	1.94	46.3
		31 Oct 06	0905	1.76	36.3

Table 4.10 Flow Rate Estimates from Citizens' Monitoring Data at Site #4.

Site	Description	Date	Time	Stage (ft)	Discharge (cfs)
#4	Yellow Creek at Walker Mill Rd.	12 Sep 06	1800	0.79	8.1
		12 Sep 06	2235	1.04	11.7
		13 Sep 06	0840	0.96	10.4
		14 Sep 06	0825	0.81	8.4
		16 Sep 06	0905	0.69	7.1
		19 Sep 06	0805	2.03	40.1
		19 Sep 06	1845	1.73	29.1
		20 Sep 06	0830	1.44	20.5
		05 Oct 06	1400	1.15	13.8
		10 Oct 06	0850	0.87	9.1
		11 Oct 06	0835	0.90	9.5
		11 Oct 06	1735	1.57	24.1
		12 Oct 06	0845	1.57	24.1
		13 Oct 06	0915	1.36	18.4
		17 Oct 06	0330	0.88	9.3
		17 Oct 06	0615	1.20	14.8
		17 Oct 06	0840	3.40	116.6
		17 Oct 06	1030	4.95	255.4
		17 Oct 06	1035	4.90	250.1
		17 Oct 06	1440	4.95	255.4
		17 Oct 06	1730	4.40	199.8
		17 Oct 06	2155	3.77	144.7
		18 Oct 06	1025	2.84	80.1
		18 Oct 06	1120	2.77	76.1
		19 Oct 06	0950	2.04	40.5
		19 Oct 06	1600	1.96	37.3
		19 Oct 06	2330	1.23	15.4
		20 Oct 06	0320	2.75	74.9
		20 Oct 06	0715	3.25	106.1
		20 Oct 06	0840	3.50	123.9
		20 Oct 06	1355	3.45	120.2
		20 Oct 06	1725	3.17	100.8
		21 Oct 06	1000	2.57	65.1
		27 Oct 06	0900	1.36	18.4
		27 Oct 06	1725	1.40	19.4
		27 Oct 06	1940	1.54	23.2
		27 Oct 06	2205	2.30	51.8
		28 Oct 06	0340	2.78	76.6
		28 Oct 06	0712	2.66	69.9
		28 Oct 06	0805	2.88	82.5
		28 Oct 06	0925	2.91	82.3
		28 Oct 06	1705	3.35	113.1
		29 Oct 06	1010	2.68	71.0
		30 Oct 06	0910	1.98	38.1
		31 Oct 06	0900	1.73	29.1

Table 4.11 Flow Rate Estimates from Citizens' Monitoring Data at Site #5.

Site	Description	Date	Time	Stage (ft)	Discharge (cfs)
#5	Yellow Creek at Route 170 Bridge.	12 Sep 06	1750	1.63	24.2
		12 Sep 06	2030	1.96	65.2
		13 Sep 06	0805	1.87	52.8
		14 Sep 06	0800	1.88	54.2
		16 Sep 06	0855	2.60	178.8
		19 Sep 06	0825	2.55	168.3
		19 Sep 06	1820	2.28	116.4
		24 Sep 06	0815	1.78	41.3
		10 Oct 06	0900	1.69	30.7
		11 Oct 06	0840	1.67	28.5
		11 Oct 06	1715	1.95	63.8
		12 Oct 06	0800	2.22	105.9
		13 Oct 06	0855	1.87	52.8
		17 Oct 06	0305	1.67	28.5
		17 Oct 06	0630	1.75	37.7
		17 Oct 06	0900	3.07	290.8
		17 Oct 06	1000	3.73	488.9
		17 Oct 06	1705	5.06	1033.2
		17 Oct 06	2135	3.23	334.4
		18 Oct 06	1015	2.41	140.4
		19 Oct 06	0835	2.30	120.0
		19 Oct 06	1535	2.06	80.0
		19 Oct 06	2300	2.25	111.1
		20 Oct 06	0255	2.43	144.2
		20 Oct 06	0645	2.93	254.9
		20 Oct 06	1645	2.89	245.0
		21 Oct 06	0935	2.17	97.5
		23 Oct 06	0830	1.93	61.0
		27 Oct 06	1630	1.91	58.2
		27 Oct 06	2020	2.00	71.0
		27 Oct 06	2250	2.23	107.7
		28 Oct 06	0420	2.93	254.9
		28 Oct 06	0830	2.82	228.2
		28 Oct 06	1930	2.85	235.4
		29 Oct 06	140	2.35	129.1
		30 Oct 06	1015	2.03	75.4
		31 Oct 06	0915	1.97	66.6

4.5 Rain Gauge Data:

The rainfall data obtained from four rain gauges are summarized in Table 4.12. An example of a rainfall graph generated by Boxcar Pro 4.3 software is shown in Figure 4.11. The rainfall graph represents the number of rainfall events (0.01 in. each) recorded over a period of time. Significant rainfalls (total greater than 0.5 inches) are summarized with date and time in Tables 4.13 through 4.16 for rain gauges #1 through #4, respectively. Problems occurred two times in offloading the data from the Event Logger to the HOBO shuttle. This was because of 1) low status of Event logger battery, and 2) communication failure between HOBO shuttle and the computer. Later these operational problems were fixed.

Table 4.12 Summary of Rain Gauge Data.

Rain Gauge	Description	Period of Record	Total Time (days)	Total Events	Rainfall (in)
#1	Pine Lake	1 Nov 06 - 21 Feb 07	113	817	8.17
#2	Lake Evans	27 Oct 06 - 14 Jun 07	228	2081	20.81
#3	Township Hall	24 Oct 06 - 01 Feb 07	91	1001	10.01
#4	Boardman Park	24 Oct 06 - 08 Jun 07	218	1694	16.94

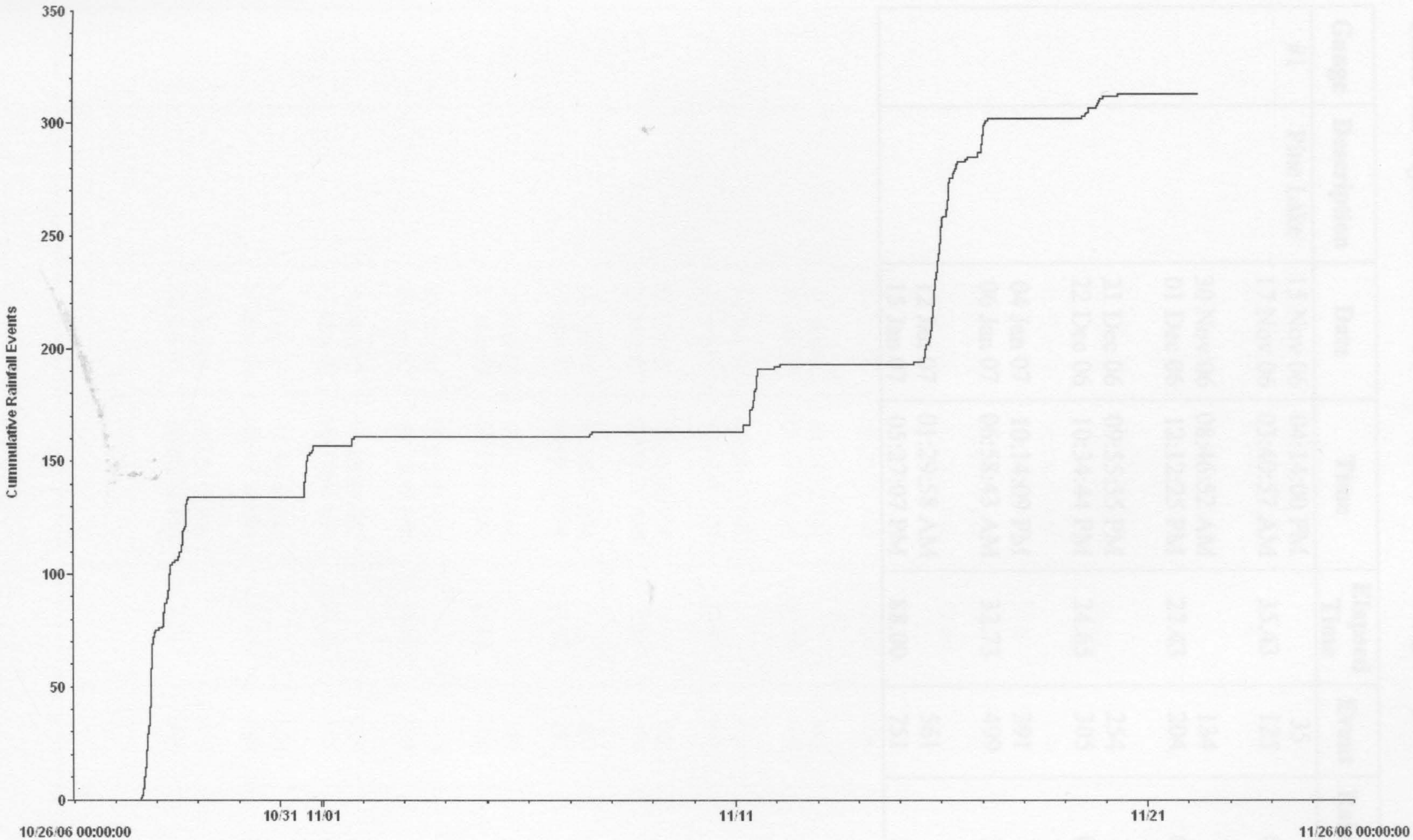

Figure 4.11 Rainfall Graph for Rain Gauge #2.

Table 4.13 Significant Rainfall (>0.5 inches) at Rain Gauge #1 (Pine Lake).

Gauge	Description	Date	Time	Elapsed Time	Event	Rainfall (in)
#1	Pine Lake	15 Nov 06	04:14:00 PM		35	
		17 Nov 06	03:40:57 AM	35.43	125	0.90
		30 Nov 06	08:46:52 AM		134	
		01 Dec 06	12:12:25 PM	27.43	204	0.70
		21 Dec 06	09:55:55 PM		254	
		22 Dec 06	10:34:44 PM	24.65	305	0.51
		04 Jan 07	10:14:09 PM		391	
		06 Jan 07	06:58:43 AM	32.73	499	1.08
		12 Jan 07	01:29:58 AM		561	
		15 Jan 07	05:27:07 PM	88.00	751	1.90

Table 4.14 Significant Rainfall (>0.5 inches) at Rain Gauge #2 (Lake Evans).

Gauge	Description	Date	Time	Elapsed Time	Event	Rainfall (in)
#2	Lake Evans	27 Oct 06 28 Oct 06	01:52:49 PM 05:31:40 PM	27.65	1 134	1.33
		15 Nov 06 17 Nov 06	02:49:45 PM 03:19:44 AM	36.50	195 301	1.06
		30 Nov 06 01 Dec 06	10:03:36 AM 12:32:50 PM	26.50	2 61	0.59
		21 Dec 06 22 Dec 06	10:11:15 AM 11:49:38 PM	37.60	110 163	0.53
		25 Dec 06 26 Dec 06	12:45:32 PM 04:33:20 PM	27.80	165 222	0.57
		04 Jan 07 06 Jan 07	11:21:10 PM 08:20:54 AM	33.00	268 386	1.18
		07 Jan 07 08 Jan 07	03:24:52 PM 08:02:43 AM	16.30	387 440	0.53
		12 Jan 07 15 Jan 07	07:06:14 PM 07:33:51 PM	72.45	451 661	2.10
		01 Mar 07 02 Mar 07	08:35:24 PM 03:38:12 AM	7.05	92 194	1.02
		14 Mar 07 15 Mar 07	05:08:40 AM 04:04:23 PM	34.93	205 342	1.37
		22 Mar 07 23 Mar 07	03:12:17 PM 02:03:46 PM	22.85	385 436	0.51
		25 Apr 07 25 Apr 07	08:05:57 AM 05:33:45 PM	9.46	617 691	0.74
		16 May 07 17 May 07	01:28:07 AM 05:33:45 PM	36.16	737 795	0.58
		26 May 07 27 May 07	12:58:10 PM 02:07:10 PM	25.15	807 869	0.62
		08 Jun 07 08 Jun 07	03:25:51 PM 06:08:08 PM	2.71	913 1057	1.44

Table 4.15 Significant Rainfall (>0.5 inches) at Rain Gauge #3 (Poland Township Hall).

Gauge	Description	Date	Time	Elapsed Time	Event	Rainfall (in)
#3	Poland Township Hall	27 Oct 06	01:34:42 PM		5	
		28 Oct 06	04:08:44 PM	26.56	141	1.36
		15 Nov 06	02:55:13 PM		205	
		17 Nov 06	04:39:55 AM	37.73	315	1.10
		30 Nov 06	10:10:24 AM		1	
		01 Dec 06	10:56:01 AM	24.76	56	0.55
		21 Dec 06	10:36:27 AM		108	
		23 Dec 06	12:03:30 AM	36.45	164	0.56
		25 Dec 06	12:48:26 PM		165	
		26 Dec 06	08:12:50 AM	19.40	219	0.54
		04 Jan 07	11:17:35 PM		264	
		06 Jan 07	08:22:47 AM	45.05	379	1.15
		12 Jan 07	07:49:52 PM		444	
		15 Jan 07	09:01:40 PM	73.20	642	1.98

Table 4.16 Significant Rainfall (>0.5 inches) at Rain Gauge #4 (Boardman Park).

Gauge	Description	Date	Time	Elapsed Time	Event	Rainfall (in)
#4	Boardman	27 Oct 06	02:13:18 PM		6	
	Park	28 Oct 06	04:04:55 PM	25.85	121	1.15
		15 Nov 06	02:55:13 PM		183	
		16 Nov 06	12:04:25 PM	21.00	265	0.82
		25 Dec 06	12:27:19 PM		132	
		26 Dec 06	07:19:30 AM	19.00	186	0.54
		04 Jan 07	11:19:47 PM		226	
		06 Jan 07	03:24:02 AM	28.00	310	0.84
		12 Jan 07	07:26:37 PM		361	
		15 Jan 07	03:57:25 PM	69.50	537	1.76
		01 Mar 07	12:44:25 PM		70	
		02 Mar 07	04:18:04 AM	15.56	160	0.90
		14 Mar 07	06:00:46 AM		172	
		15 Mar 07	05:13:20 PM	35.00	313	1.41
		25 Apr 07	07:28:32 AM		527	
		25 Apr 07	04:59:18 PM	9.52	592	0.65
		16 May 07	12:05:34 AM		642	
		16 May 07	02:24:25 PM	14.00	711	0.69
		01 Jun 07	05:11:08 PM		769	
		02 Jun 07	07:10:34 PM	26.00	837	0.68

The total rainfall at Pine Lake, Lake Evans, Township Hall, and Boardman Park for five storm events is summarized in Table 4.17, along with the average for the four locations.

Table 4.17 Comparison of Total Rainfall Around Watershed.

Date	Pine Lake	Lake Evans	Township Hall	Boardman Park	Average Rainfall
15-17 Nov 06	0.90	1.06	1.10	0.82	0.97
30 Nov-1 Dec 06	0.70	0.59	0.55	0.45	0.57
21-22 Dec 06	0.51	0.53	0.56	0.46	0.52
4-6 Jan 07	1.08	1.18	1.15	0.84	1.06
12-15 Jan 07	1.90	2.10	1.98	1.76	1.94

Note: All values are in inches.

For these storms, rainfall was fairly uniform around the watershed. The largest differences between individual measurements and the averages were 0.16 in (12-15 Jan 07 for Lake Evans and Boardman Park) and 23% (30 Nov-1 Dec 06 for Pine Lake). For all five of these storm events, rainfall at Boardman Park was below the watershed average and rainfall at Lake Evans was above the average.

4.6 Pressure Sensor Data

The deployment of pressure sensors is summarized in Table 4.18. The sensor depth measurements for Sites #4 and #5, plotted over the period of record, are shown in Figures 4.12 and 4.13, respectively, for the period 28 Aug – 7 Nov 06. Plots for other periods of record at Site #5 are shown in Appendix C, Figures C-1 to C-4. For all plots, a constant barometric pressure of 13.99 psi was assumed for the barometric compensation.

Table 4.18 Pressure Sensor Deployment

No	Site	Periods of Record
1	#4, Yellow Creek at Walker Mill.	28 Aug 06 -7 Nov 06
2	#5, Yellow Creek at Route 170 Bridge	28 Aug 06 - 7 Nov 06 8 Nov 06 - 14 Feb 06 29 Mar 07 - 23 May 07 30 May 07 - 16 July 07 17 July 07 - 24 July 07

For the pressure sensor at Site #4, the actual stage readings obtained from citizen's data and the calculated stage readings from the pressure sensor data are summarized in Table 4.19. In this table, barometric correction was performed using hourly data from NOAA for Youngstown airport. By comparing calculated to actual depth, the percentage of error was calculated. These values are listed in column 5 of Table 4.19. The percentage of error varies from 0 to 45%. This could be because of malfunctioning of the sensor or error in actual depth readings by citizens.

Generally, 1 psi of error in absolute or barometric pressure contributes an error of 2.31 ft in the water level (Solinst, 2007). Using hourly NOAA data from Youngstown airport (about 20 miles north of Site #4) might cause an error of 0.1 psi, or 0.23 ft, in calculated stage. However, this would not explain the errors indicated in Table 4.19.

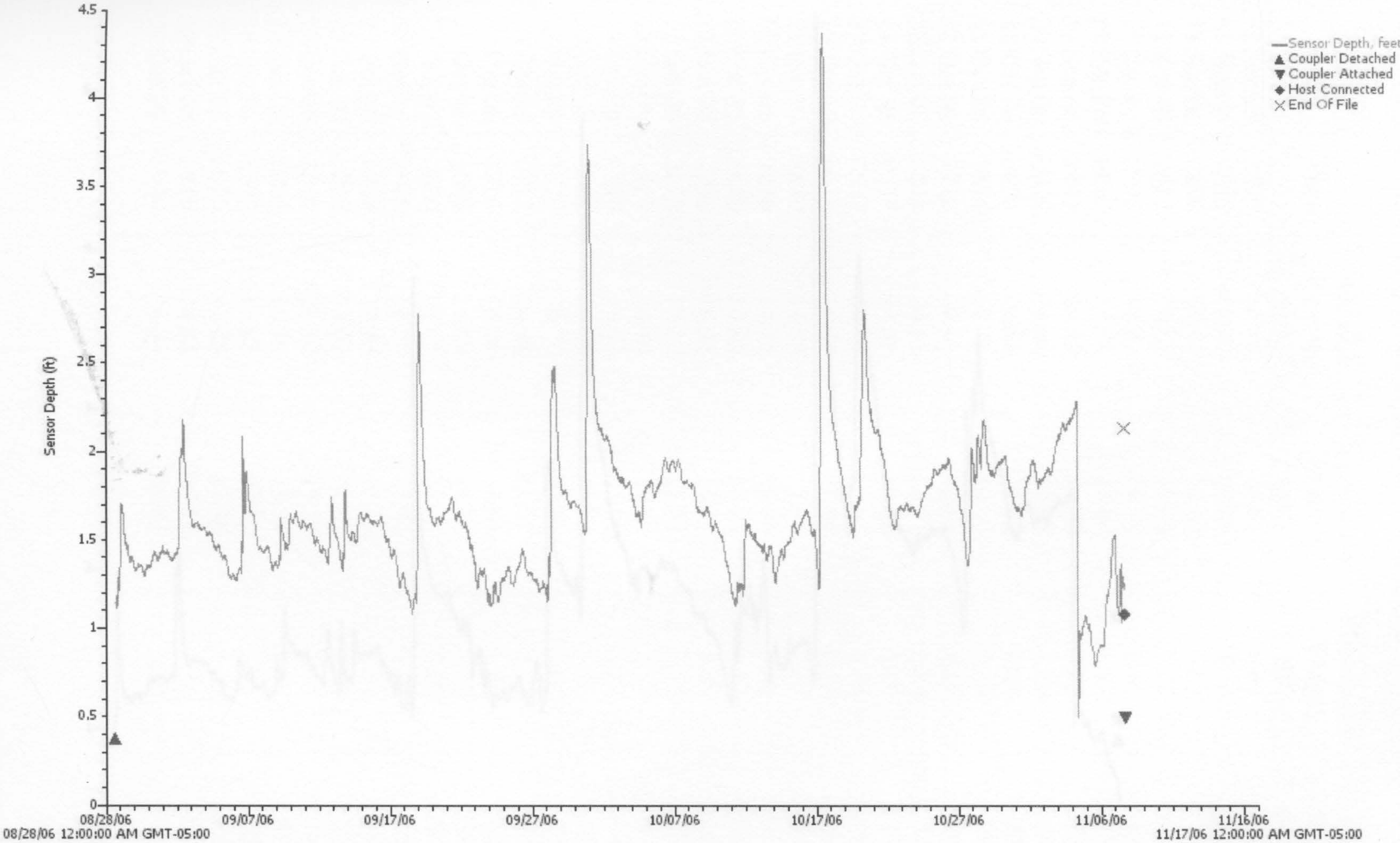

Figure 4.12 Pressure Sensor Data for Site #4, Yellow Creek at Walker Mill Rd.

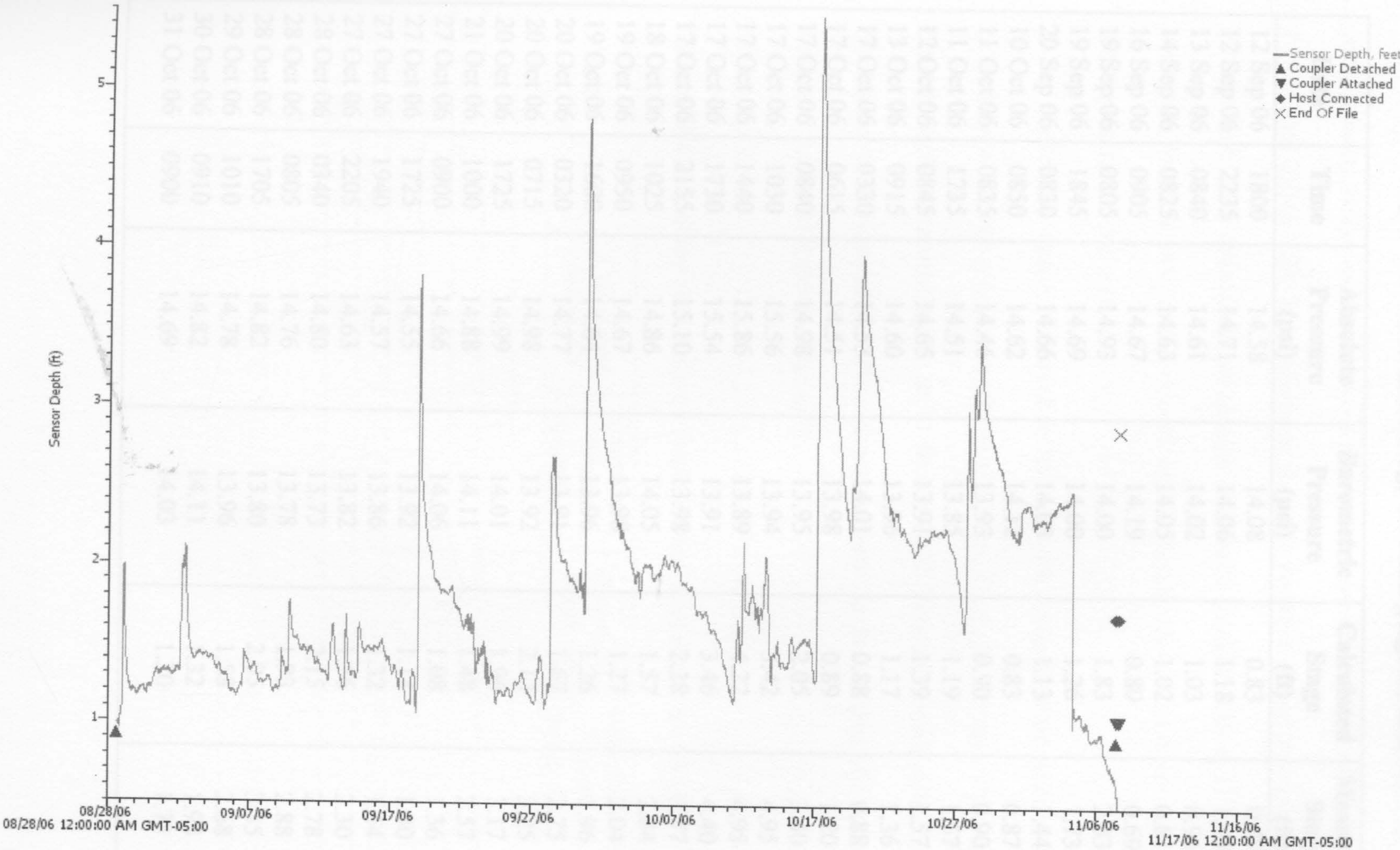

Figure 4.13 Pressure Sensor Data for Site #5, Yellow Creek at State Route 170.

Table 4.19 Comparison of Calculated Stage to Actual Stage for Site #4.

Date	Time	Absolute Pressure (psi)	Barometric Pressure (psi)	Calculated Stage (ft)	Measured Stage (ft)	% Error ±
12 Sep 06	1800	14.58	14.08	0.83	0.79	5.1
12 Sep 06	2235	14.71	14.06	1.18	1.04	13.5
13 Sep 06	0840	14.61	14.02	1.03	0.96	7.3
14 Sep 06	0825	14.63	14.05	1.02	0.81	25.9
16 Sep 06	0905	14.67	14.19	0.80	0.69	16.0
19 Sep 06	0805	14.93	14.00	1.83	2.03	9.9
19 Sep 06	1845	14.69	14.00	1.26	1.73	27.2
20 Sep 06	0830	14.66	14.03	1.13	1.44	21.5
10 Oct 06	0850	14.62	14.12	0.83	0.87	4.6
11 Oct 06	0835	14.46	13.93	0.90	0.90	0.0
11 Oct 06	1735	14.51	13.85	1.19	1.57	24.2
12 Oct 06	0845	14.65	13.91	1.39	1.57	11.5
13 Oct 06	0915	14.60	13.96	1.17	1.36	14.0
17 Oct 06	0330	14.53	14.01	0.88	0.88	0.0
17 Oct 06	0615	14.51	13.98	0.89	1.20	25.8
17 Oct 06	0840	14.98	13.95	2.05	3.40	39.7
17 Oct 06	1030	15.56	13.94	3.42	4.95	30.9
17 Oct 06	1440	15.86	13.89	4.22	4.95	14.8
17 Oct 06	1730	15.54	13.91	3.46	4.40	21.4
17 Oct 06	2155	15.10	13.98	2.28	3.77	39.5
18 Oct 06	1025	14.86	14.05	1.57	2.84	44.7
19 Oct 06	0950	14.67	13.98	1.27	2.04	37.8
19 Oct 06	1600	14.64	13.96	1.26	1.96	35.7
20 Oct 06	0320	14.77	13.91	1.67	2.75	39.3
20 Oct 06	0715	14.98	13.92	2.13	3.25	34.5
20 Oct 06	1725	14.99	14.01	1.96	3.17	38.2
21 Oct 06	1000	14.88	14.11	1.48	2.57	42.4
27 Oct 06	0900	14.66	14.06	1.08	1.36	20.6
27 Oct 06	1725	14.55	13.92	1.14	1.40	18.6
27 Oct 06	1940	14.57	13.86	1.32	1.54	14.3
27 Oct 06	2205	14.63	13.82	1.56	2.30	32.2
28 Oct 06	0340	14.80	13.73	2.15	2.78	22.7
28 Oct 06	0805	14.76	13.78	1.93	2.88	33.0
28 Oct 06	1705	14.82	13.80	2.05	3.35	38.8
29 Oct 06	1010	14.78	13.96	1.58	2.68	41.1
30 Oct 06	0910	14.82	14.11	1.32	1.98	33.3
31 Oct 06	0900	14.69	14.03	1.20	1.73	30.6

For Site #5, the stage and water depth readings obtained from citizens' data and corresponding values calculated from the pressure sensor data are summarized in Table 4.20. From Table 4.20, it is observed that the pressure sensor recorded significantly greater depth. The maximum percentage difference in depth values is 151%, which is very high. Pressure sensors may record depths greater than actual water depth only there is overpressure on the sensor.

A pressure sensor synchronizes its time with computer time when it is connected to the host computer using an optic base station. Daylight Savings Time ended on 29 October 2006 and started again on 11 March 2007. Pressure sensor data collected from 29 October to 7 November, 2006 did not account for the ending of Daylight Savings Time, and had to be corrected manually.

Table 4.20 Comparison of Calculated Depth to Measured Depth for Site #5.

Date	Time	Calculated Stage (ft)	Calculated Water Depth (ft)	Observed Stage (ft)	Observed Water Depth (ft)	% Difference in water depths
27 Oct 06	2250	4.24	3.34	2.23	1.33	151.1
28 Oct 06	0420	3.89	2.99	2.93	2.03	47.3
28 Oct 06	0645	4.04	3.14	2.84	1.97	59.4
28 Oct 06	0830	4.28	3.38	2.82	1.92	76.0
28 Oct 06	0915	4.38	3.48	2.88	2.01	73.1
28 Oct 06	1830	4.63	3.73	2.85	1.95	91.3
29 Oct 06	1040	3.75	2.85	2.35	1.45	96.6

4.7 Analysis of a Storm Event

To compare runoff patterns for different parts of the Yellow Creek watershed, a detailed analysis of a two-day storm event (27-28 October, 2006) was performed. For these dates, rainfall data are available from three locations, stage measurements are available from the sensor at Site #5, and streamflow was measured by direct observations at Sites #1-5. The rainfall and streamflow hydrographs for the storm event of 27-28 October 2006, for Sites #1 through #5 are shown in the Figures 4.14 through 4.18, respectively. The rating curve equation was used to convert water depth to discharge for the citizens' monitoring data. For Site #5, streamflow hydrographs from pressure sensor data and citizens' monitoring data are compared (Figure 4.18). The streamflow hydrographs were plotted for 108 hrs, because initially water soaks into the ground and is intercepted by vegetation, and runoff takes time to reach the stream. The rainfall stopped by hour 60, but hydrographs for the Yellow Creek Sites (#3-5) continued descending for at least another 40 hours.

From the 27-28 October 2006 storm hydrographs, total runoff volume, depth of direct runoff, and runoff coefficients for Sites #1-5 were calculated. The results are summarized in Table 4.21.

For this storm, a high percentage of the rainfall on the lower portion of the watershed (below Evans dam) ran off quickly into Yellow Creek. Some of the rain that fell on the upper part of the watershed (above Evans dam) was apparently retained in Pine Lake and/or Lake Evans resulting in lower runoff coefficients. Once these lakes are full, rain falling on the lake surfaces enters the stream directly, resulting in a significant increase in runoff coefficient.

Table 4.21 Comparisons of Rainfall and Runoff for Individual Gauging Stations, 27-31 October 2006.

Site	Description	Drainage Area (acres)	Rainfall Volume (ft^3)	Total Runoff Volume (ft^3)	Runoff Depth (in)	Runoff Coefficient, C
#1	Drake's Run	2,539	12,073,707	5,388,392.8	0.58	0.446
#2	Burgess Run	4,890	23,253,417	15,574,285.4	0.88	0.670
#3	Yellow Creek at Lake Evans	12,077	57,429,758	13,763,694	0.31	0.239
#4	Yellow Creek at Walker Mill Rd	14,670	69,760,251	13,442,403	0.25	0.192
#5	Yellow Creek at Route 170 Bridge	23,102	109,856,941	23,453,759	0.28	0.213

Total Rainfall = 1.31 in

Based on land use, the runoff coefficient for Burgess Run would be expected to be lower than for Drake's Run. Drake's Run watershed is mostly urban land (residential and commercial), while Burgess Run watershed is mostly agricultural and wooded land. Runoff coefficients of 0.5-0.7 are typical of urbanized areas like Drake's Run. More rural areas like the Burgess Run watershed would typically show runoff coefficients in the range of 0.2-0.4.

It should be noted that all flow rates for the hydrographs were calculated from stage readings using the rating curve equations. These equations are considered tentative, since they are based on a small number of stream measurements. This could be a source of error in the value of runoff coefficients.

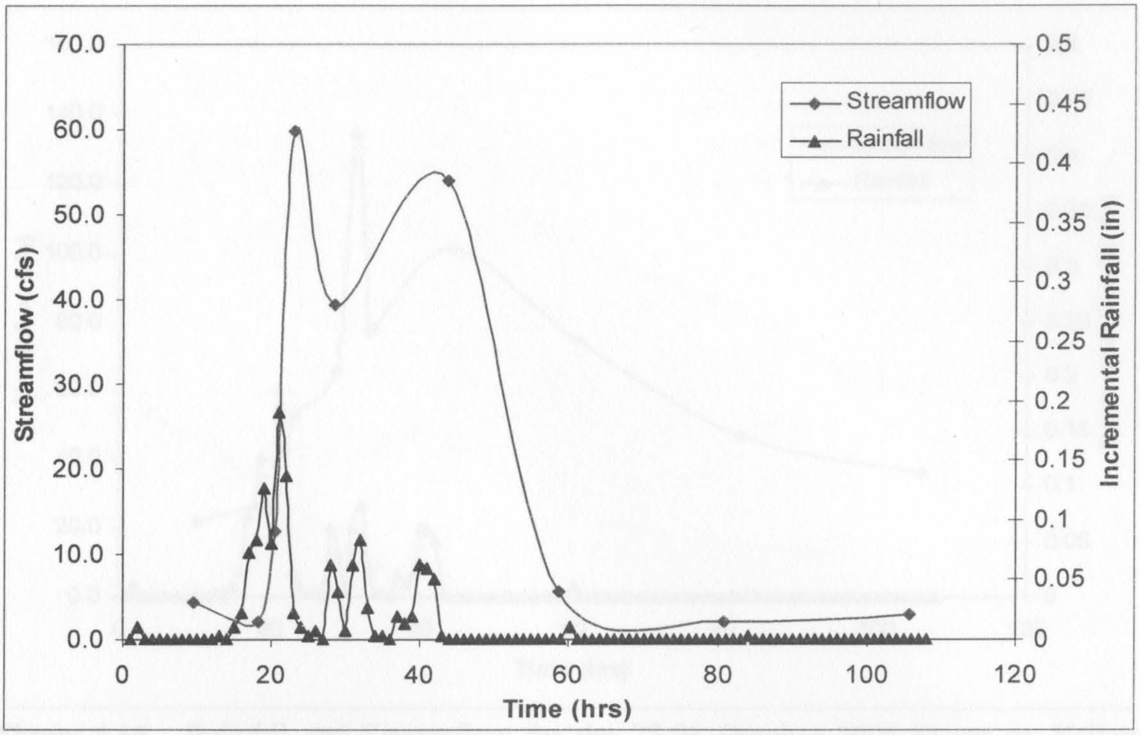

Figure 4.14 Rainfall and Streamflow for the 27-28 October 2006 Storm on Yellow Creek Watershed at Site #1, Drakes Run.

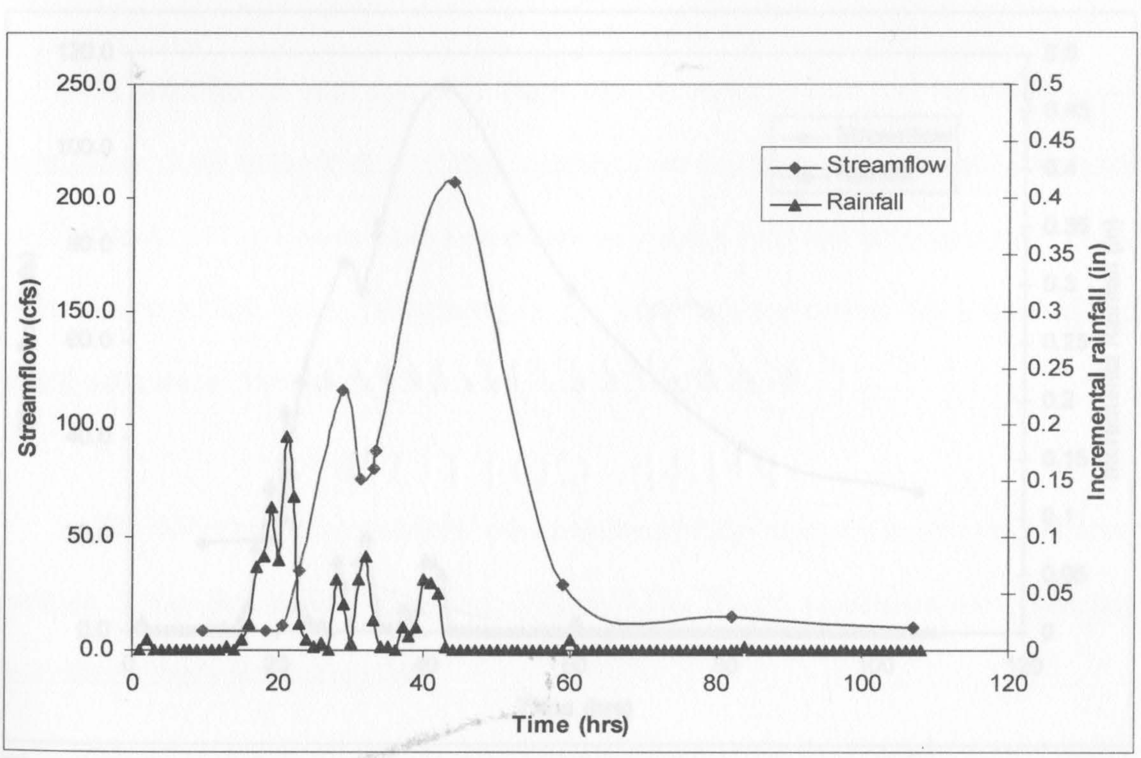

Figure 4.15 Rainfall and Streamflow for the 27-28 October 2006 Storm on Yellow Creek Watershed at Site #2, Burgess Run at Walker Mill Rd.

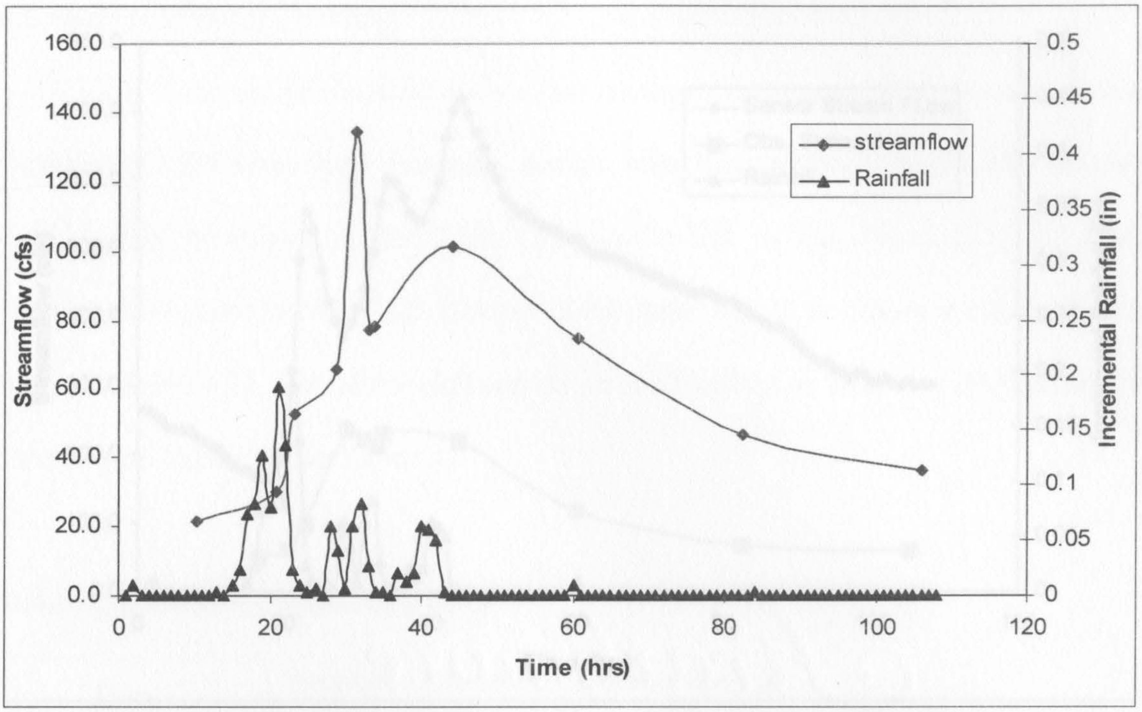

Figure 4.16 Rainfall and Streamflow for the 27-28 October 2006 Storm on Yellow Creek Watershed at Site #3, Yellow Creek at Lake Evans.

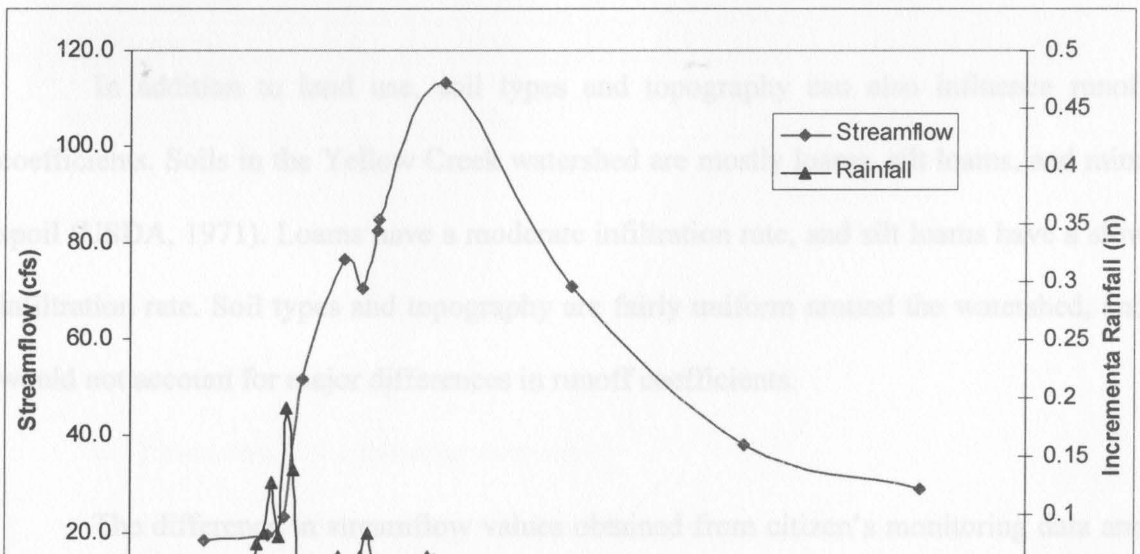

Figure 4.17 Rainfall and Streamflow for the 27-28 October 2006 Storm on Yellow Creek Watershed at Site #4, Yellow Creek at Walker Mill Rd.

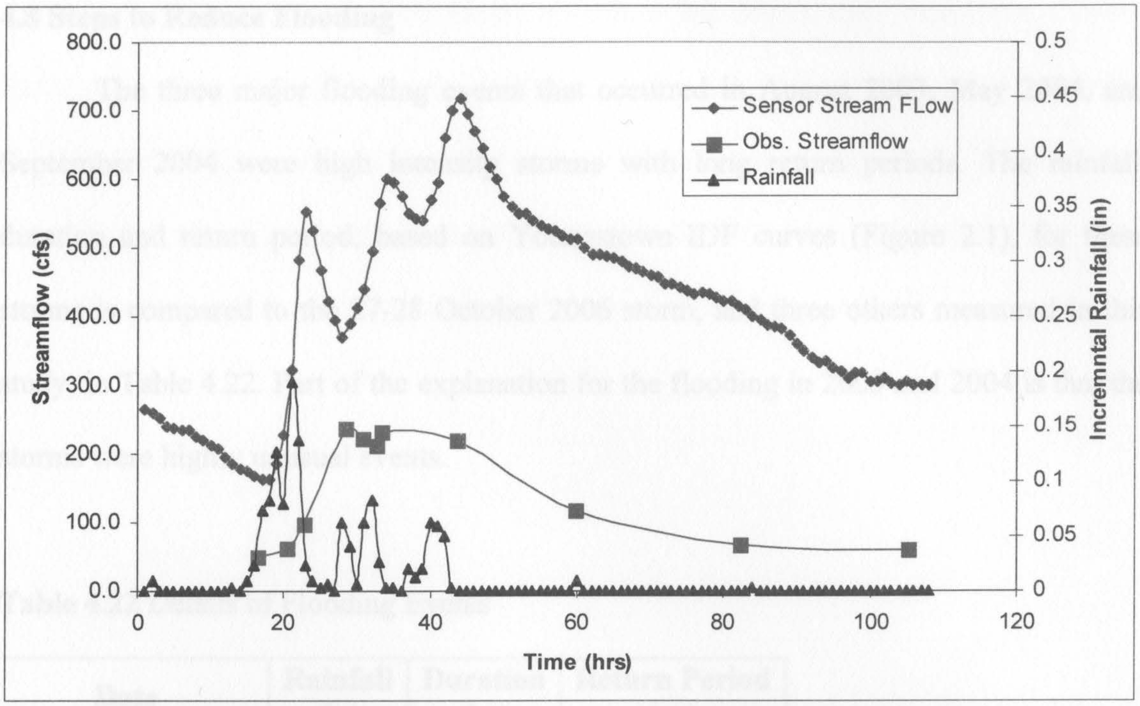

Figure 4.18 Rainfall and Streamflow for the 27-28 October 2006 Storm on Yellow Creek Watershed at Site #5, Yellow Creek at State Route 170.

In addition to land use, soil types and topography can also influence runoff coefficients. Soils in the Yellow Creek watershed are mostly loams, silt loams, and mine spoil (USDA, 1971). Loams have a moderate infiltration rate, and silt loams have a slow infiltration rate. Soil types and topography are fairly uniform around the watershed, and would not account for major differences in runoff coefficients.

The difference in streamflow values obtained from citizen's monitoring data and pressure sensor data at Site #5 is high (Figure 4.18). Runoff coefficient was calculated from the citizen's monitoring data.

4.8 Steps to Reduce Flooding

The three major flooding events that occurred in August 2003, May 2004, and September 2004 were high intensity storms with long return periods. The rainfall, duration and return period, based on Youngstown IDF curves (Figure 2.1), for these storms is compared to the 27-28 October 2006 storm, and three others measured in this study, in Table 4.22. Part of the explanation for the flooding in 2003 and 2004 is that the storms were highly unusual events.

Table 4.22 Details of Flooding Events

Date	Rainfall (in)	Duration (hr)	Return Period (yr)
09 August 03	3.6	2.25	350
22 May 04	1-3	2.75	100
08,09 September 04	5-9	5.00	1000
27,28 October 06	1.3	30.00	0.5
12-15 January 07	1.9	76.00	0.5
14,15 March 07	1.4	70.00	0.4
8 June 07	1.4	2.71	2

Some steps can be taken to reduce the chance of future flooding in the Yellow Creek watershed. These include:

- Protecting and expanding wetlands;
- Protecting and expanding riparian areas along stream banks; and
- Installing and maintaining proper stormwater retention basins in developed areas.

Two documents addressed the importance and condition of wetlands and riparian areas in the Yellow Creek watershed – “Wetland Mitigation for Mill Creek, Yellow

Creek, and Meander Creek Watersheds" (Martin *et al.*, 2003), and "Preliminary Stream Restoration Plan for Mill Creek, Yellow Creek, and Meander Creek Watersheds" (Martin, 2003). These reports state that most of the wetland acreage in the Yellow Creek watershed is found in riparian corridors, and that Drake's Run and Burgess Run have narrow riparian width, which provides little protection from high runoff.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were drawn from the study on runoff rates and flow dynamics of Yellow Creek and its tributaries:

1. At Drake's Run (Site #1), backing of water from Yellow Creek during storm events sometimes results in low flow rates.
2. For a storm event on 27-28 October 2006, a runoff coefficient of 0.24 was observed for the upper Yellow Creek watershed indicating that some of the storm water was retained it Pine Lake and/or Lake Evans.
3. For the storm event of 27-28 October 2006, runoff coefficients of 0.45 and 0.67 were calculated for Drake's Run and Burgess Run watersheds, respectively. The value for Burgess Run is higher than expected based on land use. Inaccuracy in the rating curve used to calculate flow rates could cause an error in the runoff coefficient.
4. The rainfall at individual locations throughout the watershed can vary ±20% from the average.
5. The return period for storms observed during this study are low compared to the events that caused flooding problems in 2003 and 2004.
6. A high percentage of error was found between pressure sensor and direct observations of water level. Causes of the error have not been determined.
7. The pressure sensor used in this study does not correct for Daylight Savings Time.

Based on the results of this study, it is recommended that:

1. More medium and high flow measurements be obtained to improve rating curves;
2. The pressure sensor errors should be identified and corrected;
3. Runoff coefficients should be calculated for additional storms, preferably occurring when Pine Lake and Lake Evans are full;
4. The gauging station on Drake's Run should be moved upstream to eliminate back water effects from Yellow Creek; and
5. Hydrologic models of the Yellow Creek watershed should be developed in order to predict runoff for a variety of conditions.

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APPENDIX A

Figure A-1 Photograph of Gauging Station at Burgess Run (Site #2).

Figure A-2 Photograph of Gauging Station at Yellow Creek near Lake Evans (Site #3).

Figure A-3 Photograph of Gauging Station at Yellow Creek on Walker Mill Rd (Site #4).

Figure A-4 Photograph of Gauging Station at Route 170 Bridge (Site #5).

APPENDIX B

Table B-1 Surveying Data of Overflow Channel at Site #1.

Date	Height of Instrument (HI) (ft)	Distance (ft)	Rod Reading (RR) (ft)	Elevation HI – RR (ft)
16 June 2006	1000	0	1.59	998.41
		10	2.31	997.69
		20	3.00	997.00
		30	3.62	996.38
		40	4.30	995.7
		50	4.78	995.22
		55	4.64	995.36
		60	4.64	995.36
		90	4.51	995.49
		95	4.94	995.06
		100	5.42	994.58
		105	5.78	994.22
		110	5.91	994.09
		115	5.56	994.44
		120	5.14	994.86
		125	4.94	995.06
		130	4.66	995.34
		135	4.37	995.63

Table B-2 Surveying Data of Channel Cross-Section at Site #2.

Date	Height of Instrument (HI)	Distance	Rod Reading (RR)	Height Of Rail (HR)	Depth To Water	Depth Of Water	Depth To Ground (DG)	Ground Elevation (GE) = HI-RR+HR-DG
16 June 2006	1000	0	4.65	2.68	12.04	2.4	14.44	983.59
Edge of the water is at 17.50		5	4.64	2.62	11.98	3.30	15.28	982.70
		10	4.60	2.70	12.14	2.34	14.48	983.62
		15	4.64	2.51	11.96	0.76	12.72	985.15
		20	4.73	2.85			11.23	986.89
		25	4.80	2.60			11.33	986.47
		30	4.86	2.64			11.39	986.51

Note : All Values measured in ft.

Table B-3 Surveying Data of Channel Cross-Section at Site #3.

Date	Height of Instrument (HI	Distance	Rod Reading (RR)	Depth To Water	Depth Of Water	Depth To Ground (DG)	Ground Elevation (GE) = HI-RR-DG
16 June 2006	1000	0	5.52	12.69	1.45	14.14	980.34
No water coming over dam.		5	5.60	12.61	1.12	13.73	980.67
		10	5.72	12.50	1.78	14.28	980.00
		15	5.86	12.40	1.20	13.60	980.54
		20	6.00	12.29	1.28	13.57	980.43
		25	6.14	12.17	1.38	13.55	980.31
		30	6.26	12.07	1.78	13.85	979.89
		35	6.39	11.97	1.75	13.72	979.89
		40	6.53	11.88	1.05	12.93	980.54

Note: All Values measured in ft.

Table B-4 Surveying Data of Channel Cross-Section at Site #4.

Date	Height of Instrument (HI)	Distance	Rod Reading (RR)	Height Of Rail (HR)	Depth To Water	Depth Of Water	Depth To Ground (DG)	Ground Elevation (GE) = HI-RR+HR-DG
16 June 2006	1000	0	4.08	2.66	13.36	1.27	14.63	983.95
2.4 ft. diameter Pier at 25 ft and 50 ft.		5	4.04	2.68	13.45	0.88	14.33	984.31
		10	3.95	2.69	13.50	0.98	14.48	984.26
		15	3.90	2.71	13.54	0.28	13.82	984.99
		20	3.83	2.73			12.16	987.52
		25	3.76	2.95			11.63	987.56
		30	3.73	2.69			11.42	987.54
		35	3.71	2.70			10.45	988.54
		40	3.69	2.69			9.95	989.05
		45	3.70	2.71			9.80	989.21
		50	3.72	2.70			9.88	989.10
		55	3.74	2.69			10.40	988.55
		60	3.78	2.73			10.00	988.95
		65	3.80	2.72			9.88	989.04
		70	3.82	2.72			9.25	989.65
		75	3.86	2.71			8.60	990.25

Note: All values measured in ft.

Table B-5 Surveying Data of Channel Cross-Section at Site #5.

Date	Height of Instrument (HI)	Distance	Rod Reading (RR)	Height Of Rail (HR)	Depth To Water	Depth Of Water	Depth To Ground (DG)	Ground Elevation (GE) = HI-RR+HR-DG
16 June 2006	1000	-9	8.16	3.54			9.63	985.75
		0	8.00	3.54			12.98	982.56
		5	7.98	3.53			15.53	980.03
		10	7.86	3.53			17.20	978.47
		15	7.73	3.53			17.41	978.39
		20	7.66	3.53			19.59	976.28
		25	7.57	3.50			20.32	975.61
		30	7.51	3.54			20.33	975.70
		35	7.39	3.52			20.31	975.82
		40	7.31	3.54			20.56	975.67
		45	7.23	3.53			20.64	975.66
		55	6.94	3.52	20.88	0.55	21.43	975.15
		60	9.80	3.53	21.01	0.1	21.11	975.62
		65	6.68	3.56	21.13	0.1	21.23	975.65
		70	6.52	3.52	21.27	0.70	21.97	975.03
		75	6.38	3.52	21.40	0.55	21.95	975.19
		80	6.20	3.52	21.56	0.48	22.04	975.28
		85	6.02	3.51			16.56	980.23
		90	5.87	3.52			12.67	984.98
		95					9.27	
		100	5.53	3.53			8.68	989.32

Note: All Values measured in ft.

APPENDIX C

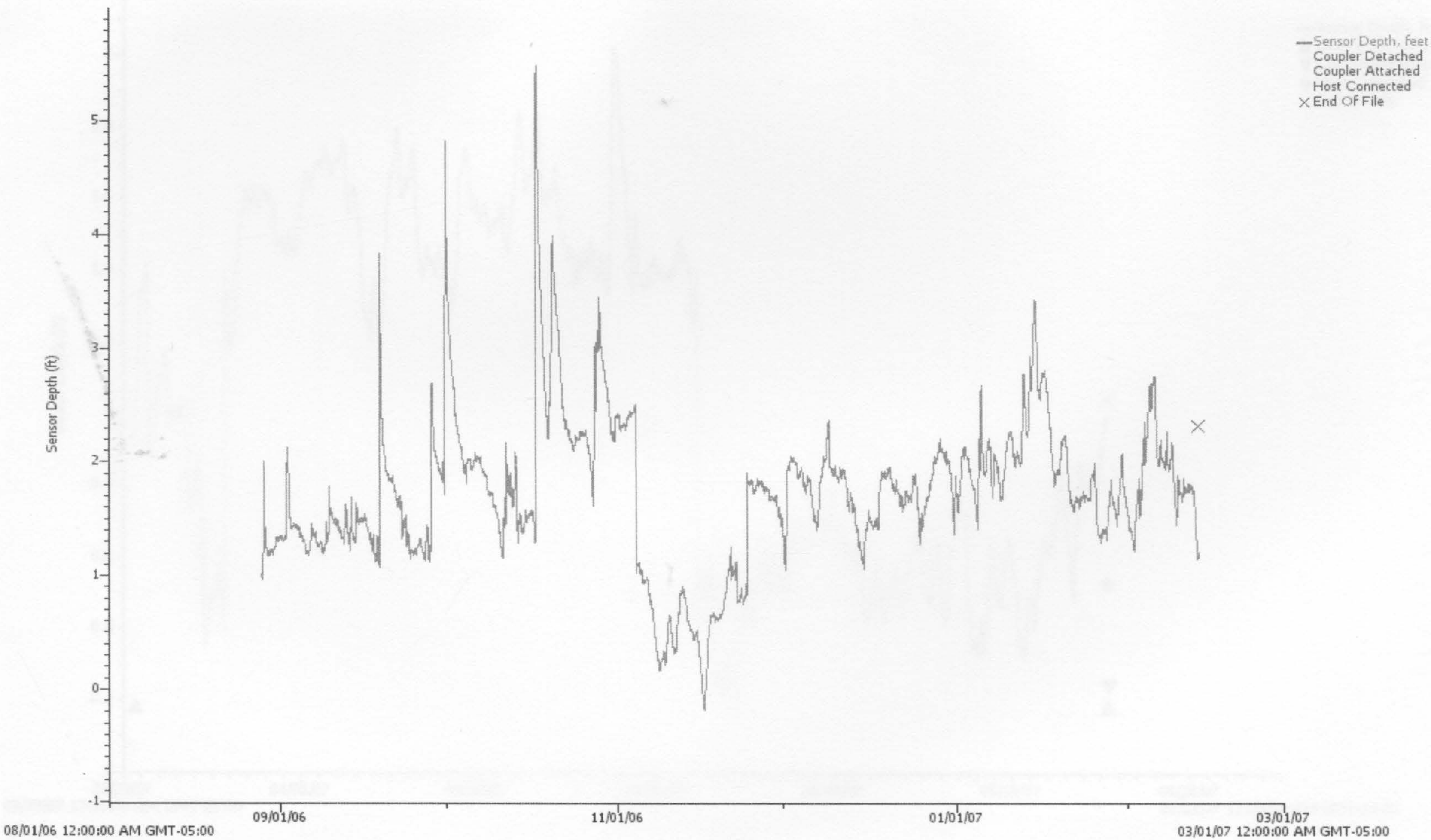

Figure C-1 Pressure Sensor Data for Site #5 (cumulative, 28 Aug 06-14 Feb 07).

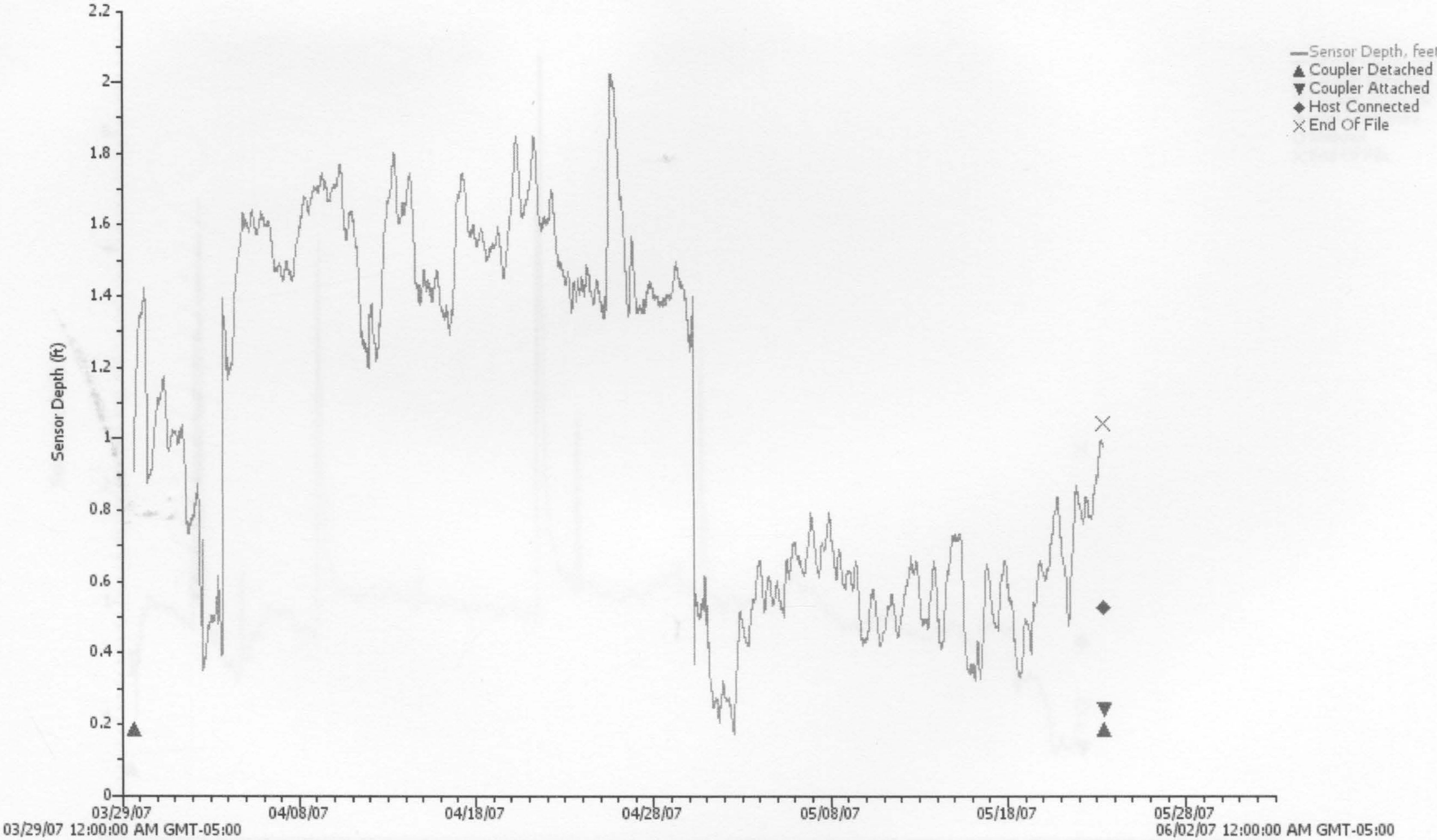

Figure C-2 Pressure Sensor Data for Site #5 (29 Mar 07-23 May 07).

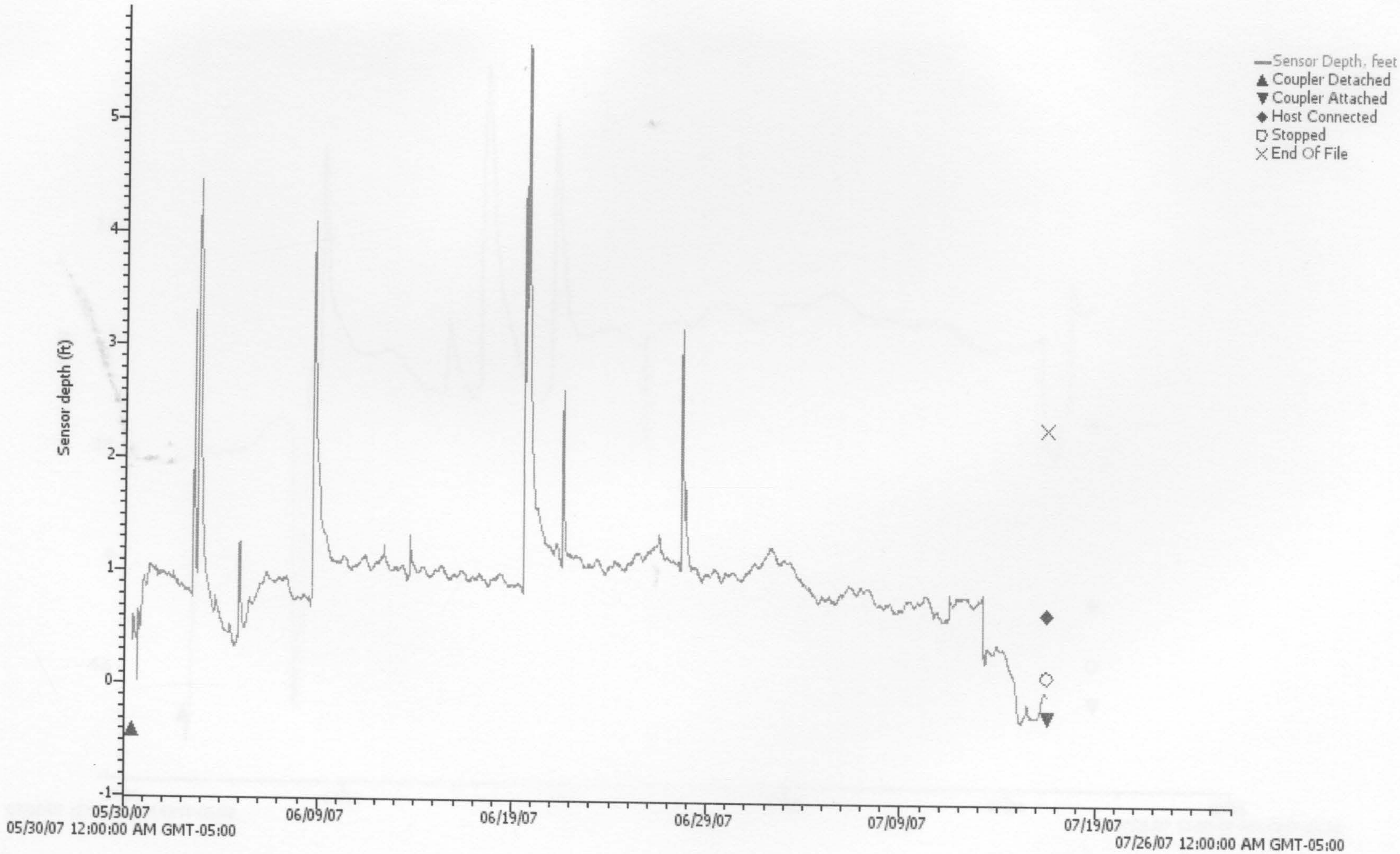

Figure C-3 Pressure Sensor Data for Site #5 (30 May 07-16 July 07).

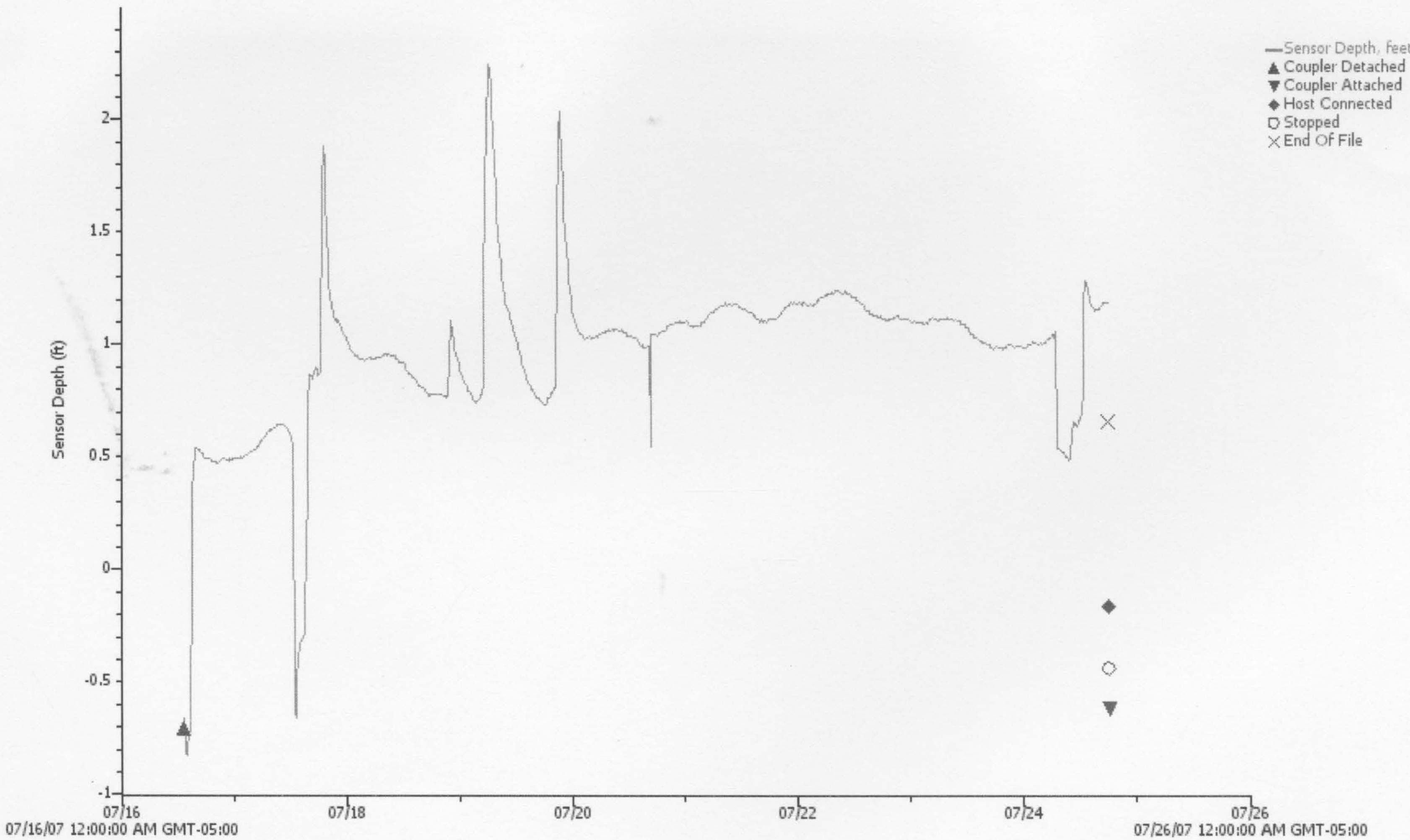

Figure C-4 Pressure Sensor Data for Site #5 (17 July 07-24 July 07).