HYDROLOGIC AND GEOMORPHIC ANALYSIS OF THE CLINTON RIVER WATERSHED: FINAL REPORT

Submitted to the Michigan Department of Environmental Quality & Macomb County Public Works Office

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Aerial View of the River Morphology
Upstream of the Clinton River Outlet

Submitted by:

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EXECUTIVE SUMMARY

INTRODUCTION

This project was funded under Section 319 of the Clean Water Act by the U.S. Environmental Protection Agency to the Michigan Department of Environmental Quality. The grant recipient was Macomb County Public Works Office. The study consists of detailed hydrologic and geomorphic assessments of the Clinton River Watershed. The hydrologic study comprised of careful analysis of over forty years of data from sixteen U.S. Geological Survey gages within the watershed. The geomorphic study comprised of historical stream location analysis, data collection from a forty square mile subwatershed, and detailed analysis of the data. Using Bank Erosion Hazard Index (BEHI), Rosgen techniques, and Pfankuch method, conclusions are drawn classifying the stability of the river and recommendations for site-specific Best Management Practices (BMPs) are then made. A protocol is then developed to identify the existing condition of any Southeast Michigan watershed as well as to select what specific BMPs may be implemented with a focus on sustained long-term success.

HYDROLOGIC ANALYSIS

An analysis of the sixty-one active and historical USGS gages showed that there are sixteen stations that are either currently active or historic, and have enough data points to allow for a statistically significant analysis. A detailed flow analysis at these sixteen gages investigated and quantified the following stream flow trends:

- Peak stream flows
- Annual mean streamflows
- Bankfull streamflows

Over the past forty years, on an average, the gages had an increase of 31% for the peak streamflows, a 54% increase for the annual mean flows, and a 13% increase for the bankfull flows. A measure of the historical and future landuse patterns was also conducted. Not surprisingly, this analysis showed that the gages where the most significant increases in flow trends have happened, are also the areas where the majority of development has occurred. The landuse analysis also highlighted specific communities that are expected to experience high levels of development in the next thirty years.

GEOMORPHIC ANALYSIS

<u>Pilot Site Selection:</u>

A detailed data collection to assess the geomorphic changes in the watershed was conducted. All gaged subwatershed within the Clinton River watershed were assessed based on the following parameters:

- Change in flow patterns (peak and annual mean)
- Change in population from 1900 to 2000
- Population Density
- Anticipated future population growth from 2000 to 2030
- Anticipated future job growth from 2000 to 2030

Additional considerations for the pilot site selection consisted of the following:

- The subwatershed's landuses compared with the overall Clinton River Watershed's landuses
- Known existing erosion problems
- Likely high levels of geomorphic activity in the subwatershed's streams

The Middle Branch of the Clinton River Watershed upstream of USGS gage 04164800 (located at Romeo Plank Road) was selected as the pilot subwatershed. This subwatershed is roughly 40 square miles, and represents the overall characteristics of the entire Clinton River watershed remarkably well.

Data Collection and Geomorphology Analysis:
The pilot study area was divided into thirty reaches where extensive field data was collected from June 2004, through December 2004. The collection of data followed the steps below:

- Initial development of a GIS based tracking interface
- Identify and map individual stream reaches in the Middle Branch
- Perform a substrate analysis using the Modified Wolman Pebble Count method
- Locate the bankfull stage using bankfull indicators
- Photograph cross section at the bankfull stage
- Monument the left bank at an approximate floodplain elevation
- Survey the cross section at a riffle from each of the thirty stream reaches
- Survey the slope of the river from a riffle section to a second riffle section
- Perform Bank Erosion Hazard Index
- Perform Pfankuch analysis
- Classify the river using the collected cross sectional area and substrate analysis

Once the field data was collected, geomorphic analyses was carried out using the following:

- Rosgen Level II classification
- Pfankuch analysis
- Bank Erosion Hazard Index

Geomorphic analyses outlined above provided quantitative and/or qualitative assessments of each of the following:

- Streambank erosion potential
- Stream's sensitivity to disturbance
- Stream recovery potential
- Sediment supply
- Influence of vegetation on river stability
- Cross sectional area departure from equilibrium condition at bankfull elevation
- Focused BMP implementation
- Health of lower and upper banks
- Health of channel bed

The following conclusions were drawn:

- Approximately 57% of the reaches studied are in an incised state (disconnected from the floodplain), which reflect high erosion potential
- The majority of the reaches that are connected to the floodplain are located in the upstream reaches, but the watercourse transitions to an incised state in the downstream reaches. This transition is evidence that the accumulating effect of increased flows generated from upstream reaches is beyond the original channel's capacity to handle the flows, resulting in excess erosion and downstream incision.
- Substantial log jams have been observed in the study area, which is evident of bank failures that may have had a relatively strong root system.
- The majority of the river reaches are in a degraded or unstable morphological state, based on the erosion analysis and regional curve data that was collected.
- Areas where specific Best Management Practices may be implemented have been identified

LANDUSE IMPACTS

Three landuse datasets (1978, 1992, and 2001) were analyzed to determine the specific development trends that have had the most significant effect on the degraded and unstable river morphology. The percent imperviousness for the pilot site watershed for these three time periods as follows:

- Impervious surface in 1978: 10.5% imperviousness
- Impervious surface in 1992: 14.1% imperviousness
- Impervious surface in 2001: 19.7% imperviousness

The landuse types that had the most significant changes are:

- High intensity residential: Increase
- Commercial, industrial, and transportation landuses (grouped as a single landuse): Increase
- Agricultural related landuses: Decrease

Finally, a protocol that may be implemented to other stream reaches within the Clinton River watershed or other similar watersheds was developed. This protocol, which may be used to determine river stability or the implementation impacts of BMP types, uses the following information:

- Percent imperviousness
- Bank Erosion Hazard Index and Pfankuch scores
- Upstream watershed drainage area
- A comparison of regional curve stream cross sectional area and surveyed cross sectional area.
- Aerial photography and USGS quadrangle maps to determine a Rosgen level I classification
- Field verification of Rosgen Level I classification at sampled sites.

Based on the protocol developed and other data collected throughout this study, a stable stream template for the Clinton River watershed was developed. This template is based on connecting the stream channel to a developed floodplain, which in some cases could be at a lower elevation than the existing top of banks. The stream is designed to meander within the belt-width of the floodplain to reduce slope, and provide naturally occurring sediment transport that is in a state of equilibrium. This stable stream template may be implemented in future developments within the watershed or for stream restoration projects.

The report concludes with an analysis of standard channel evolutionary models and its impact on restoration within the pilot site. Conclusions presented here-in may also be applied to other similar watersheds.

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1.0 INTRODUCTION

This project is a detailed study to develop an accurate picture of the geomorphic and hydrologic variability in the Clinton River and how that variability has been impacted by changes in landuse within the watershed. Additionally, this effort is designed to provide the information that could serve as a key input for future water quality studies (such as TMDL studies, nutrient management and/or in studies that provide advanced predictor models for beach closings) within the Clinton River watershed. Another key outcome of the work is the quantification of hydrologic/hydraulic driving forces that can help evaluate any future design and implementation of best management practices (BMPs) with more certainty than currently possible. These BMPs could be related to channel restoration, stabilizing stream banks, improving livestock pasture management, and improving road crossings (culverts and single span bridges) in the headwaters of the Clinton River Watershed. Specifically, results from this study will also directly help complete the BMP engineering design and implementation for five stream bank erosion sites that were identified and prioritized in the *Middle Branch of the Clinton River Road Crossing and Streambank Inventory Report (August 14, 2000)* by Environmental Consulting & Technology, Inc.

1.1 BACKGROUND OF THE CLINTON RIVER

The main channel of the Clinton River flows eighty miles from its headwaters to Lake St Clair near the city of Mt. Clemens. The Clinton River watershed consists of 760 square miles of industrial, urban, suburban and agricultural land, primarily in Oakland and Macomb Counties but including small portions of St. Clair and Lapeer Counties. Water quality problems in the Clinton River watershed include contaminated sediment, excess erosion and associated sediment accumulation, toxic bio-accumulative chemicals of concern (BCCs), and elevated nutrient levels. The river was designated as an Area of Concern (AOC) under the Great Lakes Water Quality Agreement and the first Remedial Action Plan (RAP) was developed in 1988. The AOC was expanded during the 1998 RAP update process to include the entire Clinton River watershed. According to the Clinton River Watershed Remedial and Preventive Action Plan Update (1998), there are eight impaired beneficial uses in the Clinton watershed including restrictions on fish and wildlife consumption, degradation of fish and wildlife populations, degradation of benthos, restrictions on dredging activities, eutrophication or undesirable algae, beach closings, degradation of aesthetics, and loss of fish and wildlife habitat. Additionally, the Clinton River adversely impacts the water quality of Lake St. Clair resulting in elevated bacterial levels and localized contaminated sediment concerns.

Industrial and municipal discharges were historically the primary causes of environmental degradation in the Clinton River. Most of these sources have been eliminated or treated to meet discharge permit restrictions, generally eliminating these historical inputs as a source of ongoing contamination in the Clinton River with the exception of the contaminated sediment that is an inheritance from past practices within the watershed. On-going contamination problems, particularly within the water column, are almost exclusively non-point source in origin. Urban storm water runoff as a category is probably the single greatest source of water quality degradation.

Very rapid urban expansion is the second major cause of environmental problems related to water quality in the Clinton River watershed. A comparison of Figure 1.1 (1950 land use) and Figure 1.2

(1990 land use) shows that the area that can be categorized as "urban" in Year 1990 is several times larger than that in Year 1950. A plot based upon a more recent SEMCOG data inventory taken in 2000 (Figure 1.3) shows that the trend to urbanize is continuing. This rapid urban expansion, and the associated increase in impervious area within the watershed, has resulted in greater instability in the river geomorphology. This instability, if not addressed, will lead to increasing soil erosion, continued deterioration of the river habitat, and increased flooding both locally and regionally.

Finally, this work will assess and ascertain the following:

- Is the hydrology of the Clinton River stable or has it drastically changed over the last few decades?
- What has been the impact of Clinton River hydrologic variations on the river geomorphology?
    - Within a representative pilot study area, if the river geomorphology is not stable, what land protection measures could be taken that would make it stable?
    - Within a representative pilot study area, if it is stable, where are the possible development hot spots that could cause changes in the future?
- What is the anticipated impact of proposed future development on the river morphology?

2.0 HYDROLOGIC CHANGES WITHIN THE CLINTON RIVER WATERSHED

Recognizing that the hydrologic and geomorphic changes are closely linked, a detailed analysis of all past hydrologic records in the entire Clinton River watershed was undertaken. The United States Geological Survey (USGS) currently maintains or has maintained a total of sixty-one flow measurement stations in the watershed (see Figure 2.1). Such a large number of measurement stations is an indication of the importance of this highly urbanized Michigan watershed.

2.1 STATISTICAL TREND ANALYSIS OF FLOWS

To understand the impact of the higher density of impervious surfaces in the watershed, a statistical trend analysis of three types of data-sets, namely peak stream flow, annual mean flows, and bankfull (or channel forming) flows were carried out. A meaningful statistical analysis showing hydrologic trends over several decades requires that the chosen measurement stations have data covering a substantially long time period. An analysis of these sixty-one measurement stations indicated that there are sixteen stations that are either currently active or historic, and have enough data points to allow for a statistically significant analysis. Statistical linear regression analysis was carried out at each of these stations, and detailed plots that show peak stream flows and annual mean stream flows at each of these stations over a forty year interval were generated. The approximate percent trend change was computed using regression analysis and is indicated on the plots presented in Appendix B. Tables 2.1 and 2.2 below contain a summary of these computed trend values. The standard formula for a linear regression analysis is $y=mx+b$, where:

x = four-digit year
y = flow, cfs
m = slope
b = intercept

These trend values are also shown graphically in Figures 2.2 and 2.3.

A second methodology for the analysis of the bankfull flow is credited to Mr. David Fongers of the MDEQ Hydrologic Studies Unit. Fongers method consisted of investigating the changes in the slope of the cumulative volume curve for each gage which indicate the change in the average flow over a certain time period. Secondly, the bankfull flow was calculated assuming that it had a recurrence period of once every 1.5 years. In many USGS gages, this bankfull flow increased substantially over the forty year time period. The plots of this analysis are also located in Appendix B, and the results are summarized in Table 2.3 and Figure 2.4.

Table 2.1 Change in peak flows within the Clinton River Watershed

USGS Station Number	m	b	Start Year	End Year	Years	Start Flow, cfs	End Flow, cfs	% Change Total	% Change in a 40 year interval
4160800	**0.236**	**-384.3**	1960	2001	41	78.692	88.3762	12.31%	12.0%
4160900	**0.788**	**-1413**	1960	2000	40	131.668	163.2	23.95%	23.9%
4161000	**19.597**	**-37701**	1936	1991	55	238.792	1316.627	451.37%	328.3%
4161100	**4.139**	**-8008**	1960	1991	31	105.228	233.5463	121.94%	157.3%
4161500	**-1.120**	**2376**	1956	1991	35	185.867	146.6773	-21.08%	-24.1%
4161540	**6.023**	**-11449**	1960	2001	41	355.688	602.6228	69.42%	67.7%
4161580	**-1.066**	**2242.6**	1965	2001	36	147.124	108.7336	-26.09%	-29.0%
4161800	**-0.338**	**933.31**	1959	2001	42	270.972	256.7719	-5.24%	-5.0%
4162900	**-12.211**	**24542**	1954	1988	34	681.706	266.532	-60.90%	-71.6%
4163400	**1.412**	**-2364**	1966	2001	35	412.085	461.5122	11.99%	13.7%
4164000	**28.358**	**-51924**	1949	2001	52	3345.74	4820.358	44.07%	33.9%
4164100	**-0.277**	**695.09**	1959	2000	41	152.055	140.69	-7.47%	-7.3%
4164300	**-0.184**	**738.65**	1959	2000	41	377.606	370.05	-2.00%	-2.0%
4164500	**-10.070**	**22591**	1948	2000	52	2974.64	2451	-17.60%	-13.5%
4164800	**7.504**	**-13888**	1959	1991	32	812.336	1052.464	29.56%	37.0%
4165500	**-42.408**	**90358**	1935	2000	65	8298.52	5542	-33.22%	-20.4%
				Average	**42.1**			**Average**	**31%**

Table 2.2 Change in annual mean flows within the Clinton River Watershed

USGS Station Number	a	b	Start Year	End Year	Years	Start Flow	End Flow	% Change Total	% Change in a 40 year interval
800	**0.124**	**-233.1**	1960	2000	40	10.764	15.74	46.23%	46.2%
900	**0.364**	**-668.4**	1960	2000	40	45.256	59.82	32.18%	32.2%
1000	**1.923**	**-3676**	1936	1981	45	46.6344	133.1649	185.55%	164.9%
1100	**0.298**	**-578.1**	1960	1990	30	6.538	15.487	136.88%	182.5%
1500	**0.331**	**-625.7**	1956	1990	34	20.758	31.995	54.13%	63.7%
1540	**0.366**	**-671.9**	1960	2000	40	45.842	60.49	31.95%	32.0%
1580	**-0.023**	**62.472**	1965	2000	35	17.67	16.872	-4.52%	-5.2%
1800	**0.245**	**-442.3**	1959	2000	41	37.8809	47.93	26.53%	25.9%
2900	**-0.383**	**766.84**	1959	1987	28	15.7594	5.0242	-68.12%	-97.3%
3400	**0.138**	**-258.9**	1966	2000	34	11.8282	16.51	39.58%	46.6%
4000	**2.588**	**-4718**	1949	2000	51	325.827	457.8	40.50%	31.8%
4100	**0.106**	**-192.9**	1959	2000	41	13.9704	18.3	30.99%	30.2%
4300	**0.079**	**-148.4**	1959	2000	41	5.7933	9.02	55.70%	54.3%
4500	**0.547**	**-952.4**	1948	2000	52	113.905	142.37	24.99%	19.2%
4800	**0.912**	**-1772**	1963	1981	18	18.7449	35.1663	87.60%	194.7%
5500	**4.191**	**-7679**	1935	2000	65	431.159	703.6	63.19%	38.9%
				Average	**39.7**			**Average**	**54%**

Table 2.3 Changes in bankfull flow within the Clinton River Watershed

USGS Station Number	Start Bankfull Flow, cfs	End Bankfull Flow, cfs	Years	% Change	% Change in a 40 year interval
4160800	72	72	40	0.0%	0.0%
4160900	149	149	40	0.0%	0.0%
4161000	230	480	45	108.7%	96.6%
4161100	112	154	30	37.5%	50.0%
4161500	100	185	34	85.0%	100.0%
4161540	340	340	40	0.0%	0.0%
4161580	130	99	35	-23.8%	-27.3%
4161800	239	239	41	0.0%	0.0%
4162900	410	147	28	-64.1%	-91.6%
4163400	260	260	34	0.0%	0.0%
4164000	2775	3185	51	14.8%	11.6%
4164100	115	115	41	0.0%	0.0%
4164300	246	246	41	0.0%	0.0%
4164500	2125	2125	52	0.0%	0.0%
4164800	410	644	18	57.1%	126.8%
4165500	5130	5130	65	0.0%	0.0%
	Average		**39.7**	**13%**	**17%**

As indicated in Tables 2.1, 2.2, and 2.3, the approximate average percent change over the last forty years in the peak stream flows, average annual mean flow, and average bankfull flows are 31%, 54% and 13%, respectively. This average increase is attributed to the effects of urbanization of the watershed that has occurred over the last forty years, rather than meteorological changes. The United States Geological Survey has also recognized the direct effect of urbanization and landuse changes on stream flows (Aichele, 2005). Figure 2.5 summarizes the data in Tables 2.1 through 2.3.

Understanding the relationship between percent change in peak stream flow and mean annual flow at each measurement station provides another approach to the interpretation of data. Due to the similarity in the statistical regression analysis performed on the peak flow data and the annual mean flow data, these data-sets are plotted (Figure 2.6) against each other to display the correlation between the data sets.

Figure 2.5 Changes in Flow in the Clinton River Watershed Over Forty Years

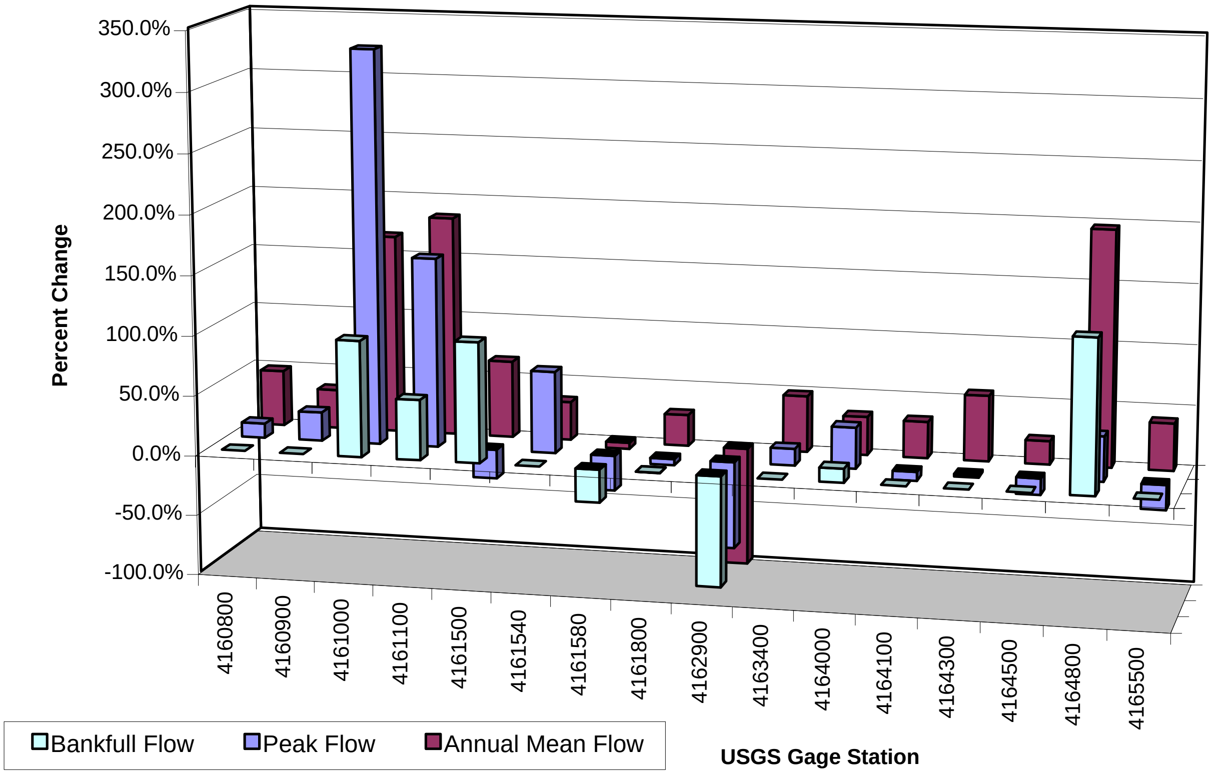


Figure 2.6 Relationship Between Peak Stream Flow and Annual Mean Stream Flow at USGS gages in Clinton River Watershed

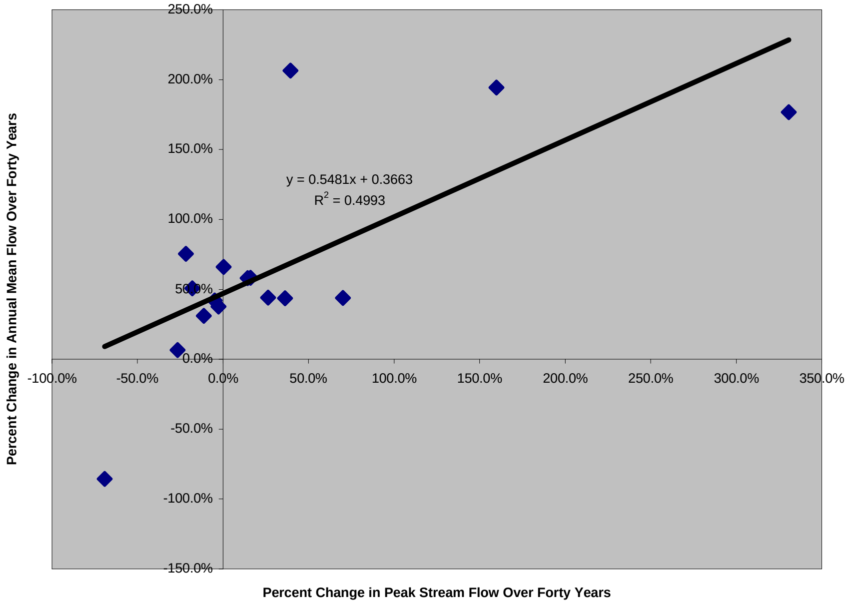


Figure 2.6 shows the percent change in peak stream flow versus the percent change in the annual mean flow. As expected, a simple regression analysis shows a moderate to high level of correlation between the two sets of data at each station.

Overall, reviewing the findings presented in Appendix B, Tables 2.1 through 2.3, and Figures 2.5 and 2.6, the following conclusions can be drawn:

- Peak stream flows as well as annual mean flows have increased over the past forty years. Urbanization and its direct and indirect effects have been attributed as the cause of these streamflow increases.
- There is a strong correlation between peak stream flows and annual mean flows. As indicated in Figure 2.6, a systematic increase in one is expected to lead to an increase in the other. Vice-versa, it is expected that a decrease in one will lead to a decrease in the other.
- The mean annual flows have increased more significantly than peak stream flows over the last forty years.
- There also appears to be a linear relationship between the trend in the bankfull flows to that of the trend in the annual mean and peak stream flows (Figure 2.5).

A point of caution is in order here. Although peak stream flows, mean annual flows, and bankfull flows are generally linearly correlated, as shown in Figure 2.6, there are deviations at some of the sixteen measurement stations. Many of these stations have a slightly negative trend in peak stream flows (between 0% and –10%) and have positive trends in the annual mean stream flow. In addition, at these locations, the changes are not overly large in either of the parameters. Finally, at station 04162900 in Sterling Heights, both the peak stream flow as well as the mean annual flow have gone down substantially over the last forty years. The two stations with the negative trends in the bankfull flow, namely station 04161580 and 04162900, are the same stations where the annual mean stream flow has a negative trend.

2.2 LAND MANAGEMENT MEASURES

To understand the link between population increase and its subsequent impact on imperviousness, it is interesting to look at Figure 2.7 that indicates percent increase in population between 1900 and 2000. It is clear that the largest population increases are concentrated in the south Clinton River watershed as well as in the Rochester Hills area. The northern portions of the watershed (e.g., Addison, Armada, Ray and Bruce townships) have not yet experienced substantial population increase and to this date, continue to be largely rural (see Figure 2.8). It is expected that the greatest potential for harmful and unstable future increases in flows are in areas that are currently categorized as rural. It is noted that within this watershed, the flows in the urban streams have largely stabilized (such as station 04162900 in Sterling Heights) whereas discharges in rural streams continue to go up (such as station 04164300 in Armada Township).

From the standpoint of beneficial future land use management measures, the following need to be underscored:

- It appears the largest changes in discharges are related to regions that still are mostly rural. Although future protection measures throughout the watershed will benefit water quality and habitat, the greatest positive impact in the watershed would probably result from storm water detention in the northern regions of the Clinton River watershed that are integrated with environmental considerations. The areas in which the greatest impact can be realized are:

    - Independence Township
    - Addison Township
    - Orion Township
    - Oakland Township
    - Bruce Township
    - Washington Township
    - Armada Township
    - Ray Township
    - Macomb Township
    - Auburn Hills
    - Waterford Township
    - Portions of Shelby Township

- Appropriate watershed protection measures would include, at a minimum, identifying appropriate detention facilities to reduce the peak discharges in the subwatershed and embracing the concepts of Low Impact Development (LID).

- SEMCOG forecasts that the suburban areas in the Clinton River watershed will continue to attract more population (see Figure 2.9) in response to substantial job gain (Figure 2.10) in that region. This would lead to continued urbanization within the watershed. Since this is so, it appears logical to carry out land use planning and storm water control design in advance to ensure appropriate measures are taken in the regions that expect dense build-up. These townships are the same as those listed above.

- The 2001 Generalized Land Use Plan (shown in Figure 2.11) shows that there is a definite awareness within the community and among the public officials to address the watershed issues as well as to take proactive measures to retain the characteristics of the watershed to the extent possible.

3.0 PILOT SITE SELECTION

Given the limited resources and the large size of the Clinton River watershed, a pilot study site needed to be selected so that a careful assessment of the recent changes in the river hydrology and geomorphology may be performed. Among others, two criteria needed to be met before a pilot study area is selected. These are a) the likelihood that the pilot site is geomorphically active, and b) the site is a good representation of the entire watershed. Additional considerations for the pilot site selection include the ability to provide information that can link the hydrologic changes within the watershed to the geomorphic changes caused in the river system, as well as being located in an area where the greatest impact of carefully selected Best Management Practices (BMPs) can be realized. This chapter presents a set of parameters thought to be crucial in that consideration as well as a simple methodology devised to aid in the identification of a pilot study area for the Clinton River watershed.

3.1 PILOT STUDY SELECTION PARAMETERS AND CLASSIFICATION

To carefully select a pilot study area in the Clinton River watershed, the following qualitative and quantitative parameters were selected as dominant variables that may either lead to geomorphic changes or are symptoms of such changes:

Quantitative

- Magnitude of anticipated changes in flow over time
- Magnitude/Density of development in the past one hundred years
- Density of current population
- Magnitude/density of future population growth
- Magnitude/density of future job growth

Qualitative

- Proximity to a USGS gage station or other areas where significant data exists
- Known erosion problems in the subwatershed

3.1.1 Classification Scheme to Delineate Geomorphic Activity in Subwatersheds

To further facilitate a quantitative comparison, a classification system was developed and applied to each of the sixteen statistically useful USGS gage stations within the Clinton River watershed. Note that only the quantitative parameters were used in the classification system. The qualitative parameters were used to support the individual sites based on the scores of the quantitative classification. A weighting factor was also added to each criteria based on the level of importance (3 = most important, 1 = least important) that any parameter had on the overall geomorphic activity of the river. The parameters used in the classification system were as follows:

- Absolute value of percent change in peak stream flow; multiplier = 3
- Absolute value of percent change in annual stream flow; multiplier = 3
- Percent change in population from 1900 to 2000; multiplier = 2
- Population density (in people per acre); multiplier = 2

- Expected future job growth from 2000 to 2030; multiplier = 2
- Expected future population growth from 2000 to 2030; multiplier = 1

Table 3.1 summarizes the results of the sixteen USGS gage stations.

Table 3.1: ***Summary of Sixteen USGS Gage Stations***

USGS Station	Absolute Value of Percent Change in Peak Stream Flow	Absolute Value of Change in Annual Mean Stream Flow	Percent Change in Population from 1900 to 2000	Population Density, people/acre	Expected Future Population Growth from 2000 to 2030	Expected Future Job Growth from 2000 to 2030
4160800	12.0%	46.2%	3821%	3.2	16.9%	42.3%
4160900	23.9%	32.2%	> 5000%	2.9	-0.4%	17.9%
4161000	328.3%	164.9%	1852%	3.9	5.9%	43.2%
4161100	157.3%	182.5%	> 5000%	1.4	5.5%	27.2%
4161500	24.1%*	63.7%	3994%	4.1	33.2%	90.3%
4161540	67.7%	32.0%	582%	6.6	6.3%	4.8%
4161580	29.0%*	5.2%*	580%	0.2	93.3%	78.4%
4161800	5.0%*	25.9%	1257%	0.9	93.8%	> 100%
4162900	71.6%*	97.3%*	> 5000%	6.9	0.4%	9.9%
4163400	13.7%	46.6%	> 5000%	3.4	0.4%	9.9%
4164000	33.9%	31.8%	> 5000%	3.1	13.0%	20.1%
4164100	7.3%*	30.2%	580%	0.3	93.3%	78.4%
4164300	2.0%*	54.3%	82%	0.2	7.6%	70.3%
4164500	13.5%*	19.2%	2910%	1.2	> 100%	> 100%
4164800	37.0%	194.7%	2910%	1.5	> 100%	> 100%
4165500	20.4%*	38.9%	> 5000%	3.1	13.0%	20.1%
Maximum	328.3%	194.7%	7166%	6.9	120.4%	207.2%
Minimum	2%	5.2%	82%	0.2	-0.4%	4.8%
Average	52.9%	66.6%	3340%	2.7	38.9%	66.5%
1st Quartile	13%	31%	582%	1.05	6%	19%
3rd Quartile	52%	81%	5261%	3.65	93%	84%

Note: * Denote a decrease in stream flow.

Next, four quartile ranges were calculated for each parameter and assigned the following scoring system:

- Value within 1st quartile range: Score = 1 times multiplier value
- Value within 2nd quartile range: Score = 2 times multiplier value
- Value within 3rd quartile range: Score = 3 times multiplier value
- Value within 4th quartile range: Score = 4 times multiplier value

Table 3.2 summarizes the scores of each USGS gage station.

Table 3.2: ***Geomorphic Activity Score of USGS Gage Stations***

USGS Station	Location	Chage in Peak Stream Flow Score	Change in Annual Mean Stream Flow Score	Percent Change in Population Score	Population Density Score	Expected Future Population Growth Score	Expected Future Job Growth Score	Sum
Oakland County								
4161000	Auburn Hills	12	12	4	8	1	4	41
4161100	Rochester Hills	12	12	8	4	1	4	41
4161500	Orion Twp.	6	6	6	8	2	8	36
4161540	Rochester	12	6	4	8	2	2	34
4160900	Waterford Twp.	6	6	8	6	1	2	29
4160800	Independence Twp.	3	6	6	6	2	4	27
Macomb County								
4162900	Sterling Heights	12	12	8	8	1	2	43
4164800	Macomb Twp.	6	12	4	4	4	8	38
4164000	Clinton Twp.	6	6	8	6	2	4	32
4165500	Clinton Twp.	6	6	8	6	2	4	32
4164500	Macomb Twp.	3	3	4	4	4	8	26
4161800	Washington Twp.	3	3	4	2	4	8	24
4164300	Armada	6	6	2	2	2	6	24

The scores are divided into the following categories:

- Score of 23-29: Low Geomorphic Activity Rating
- Score of 30-34: Moderate Geomorphic Activity Rating
- Score of 35-42: High Geomorphic Activity Rating

Table 3.3: ***Summary of Moderate to High Geomorphic Activity Ratings of USGS Gages***

USGS Station	Municipality Location	County	Score
4162900	Southwest Sterling Heights	Macomb	43
4161100	West Rochester Hills	Oakland	41
4161000	South Auburn Hills	Oakland	41
4164800	Northwest Macomb Township	Macomb	38
4161500	Northeast Orion Township	Oakland	36
4161540	City of Rochester	Oakland	34
4164000	Clinton Township	Macomb	32
4165500	Clinton Township	Macomb	32

3.2 POTENTIAL PILOT SITE DESCRIPTIONS

The preliminary site selection was narrowed down to six sites within the Clinton River watershed. These sites are presented in Figure 3.1 and were as follows:

- Western Rochester Hills
- Northwest Macomb Township
- Armada
- Southwest Sterling Heights
- Southwest Clinton Township
- Utica

Table 3.4 summarizes the Geomorphic Activity parameters for each site.

Table 3.4: ***Summary of site selection and suitability parameters***

Site	Historical Development	Population Density	Peak Flow Trend	Annual Mean Flow Trend	Anticipated Future Growth	Expected Job Growth	Close Proximity to USGS Gage
West Rochester Hills	Very High	Low	Very High	Very High	Moderate	Very High	Yes
Northwest Macomb Twp.	Moderate	Low	Moderate	Very High	Very High	Very High	Yes
Armada	Very Low	Very Low	Low	High	Low	Moderate	Yes
Utica	Low	Moderate	No data	No data	Low	Moderate	No
Southwest Clinton Twp.	Moderate	Moderate	Moderate	Low	Very High	Very High	Yes
Southwest Sterling Hgts.	Very High	Very High	High Decrease	High Decrease	Low	Low	Yes

Each site was evaluated based on the geomorphic activity parameters described above, as well as on some additional quantitative and qualitative parameters such as the proximity to USGS gage, relative subwatershed size, and proximity to known locations of stream bank erosion. A description of these parameters for each potential pilot site is as follows:

WEST ROCHESTER HILLS

Location:	Latitude 42°40'02"N, Longitude 83°12'02"W (NAD27)
Elevation:	820.78 (NGVD29)
Drainage Area:	17.90 square miles

Additional Notes:

This site is not located in Macomb County.

Figure 3.2: ***USGS Map of West Rochester Hills Location (no scale)***

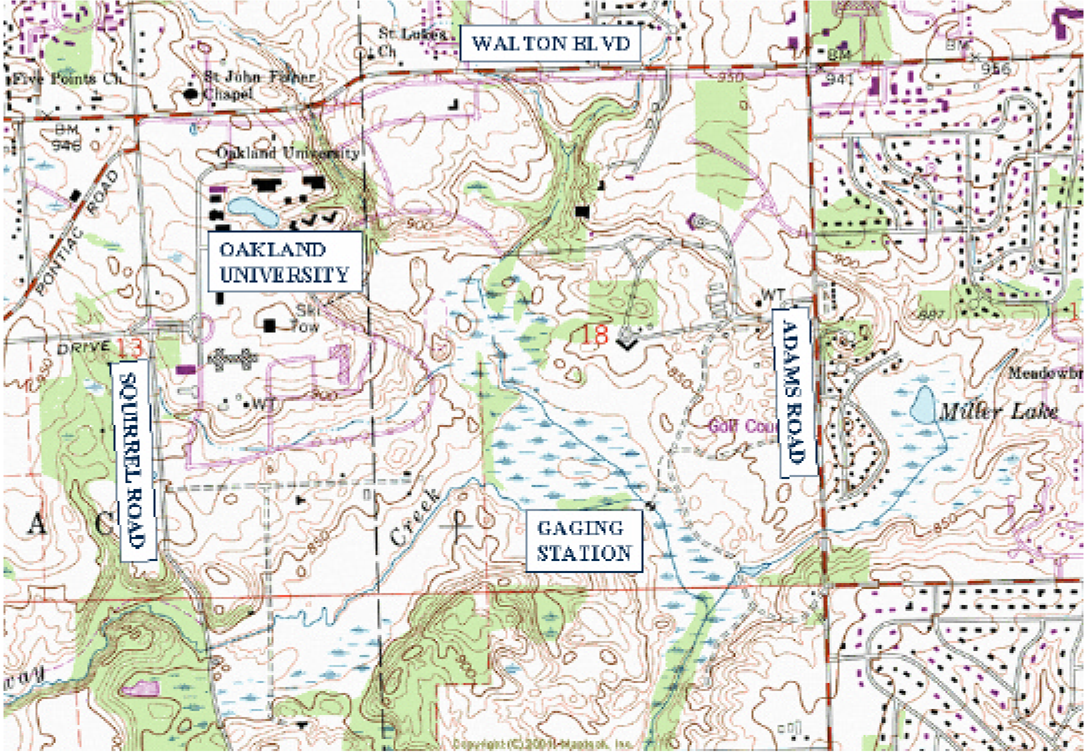
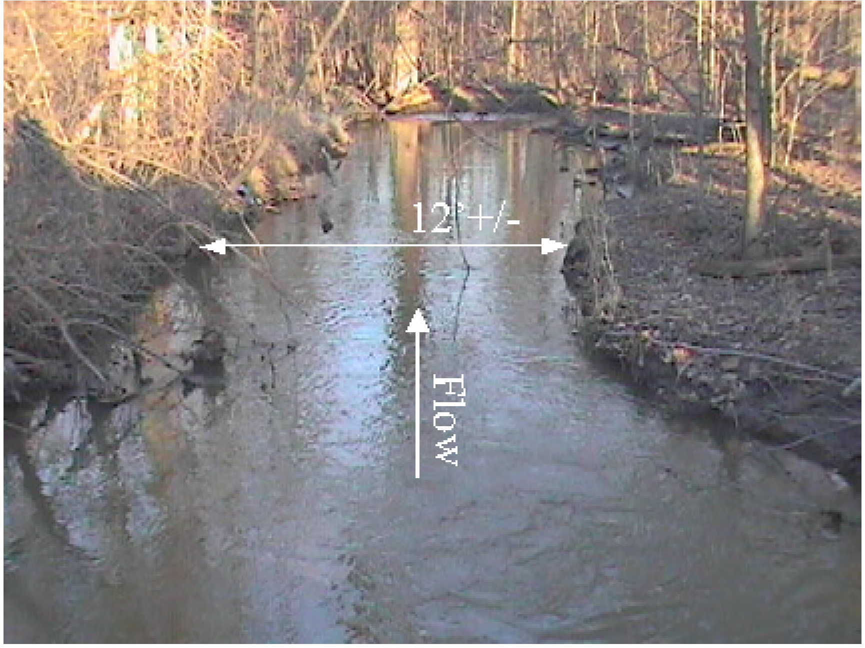


Figure 3.3: ***Upstream View of Rochester Location***

Figure 3.4: ***Downstream View of Rochester Location***



NORTHWEST MACOMB TOWNSHIP

Location: Latitude 42°42’23”N, Longitude 82°57’33”W (NAD27)
Elevation: 603.23 (NGVD29)
Drainage Area: 42.00 square miles

Additional Notes:

None

Figure 3.5: ***USGS Map of Macomb Township Location (no scale)***

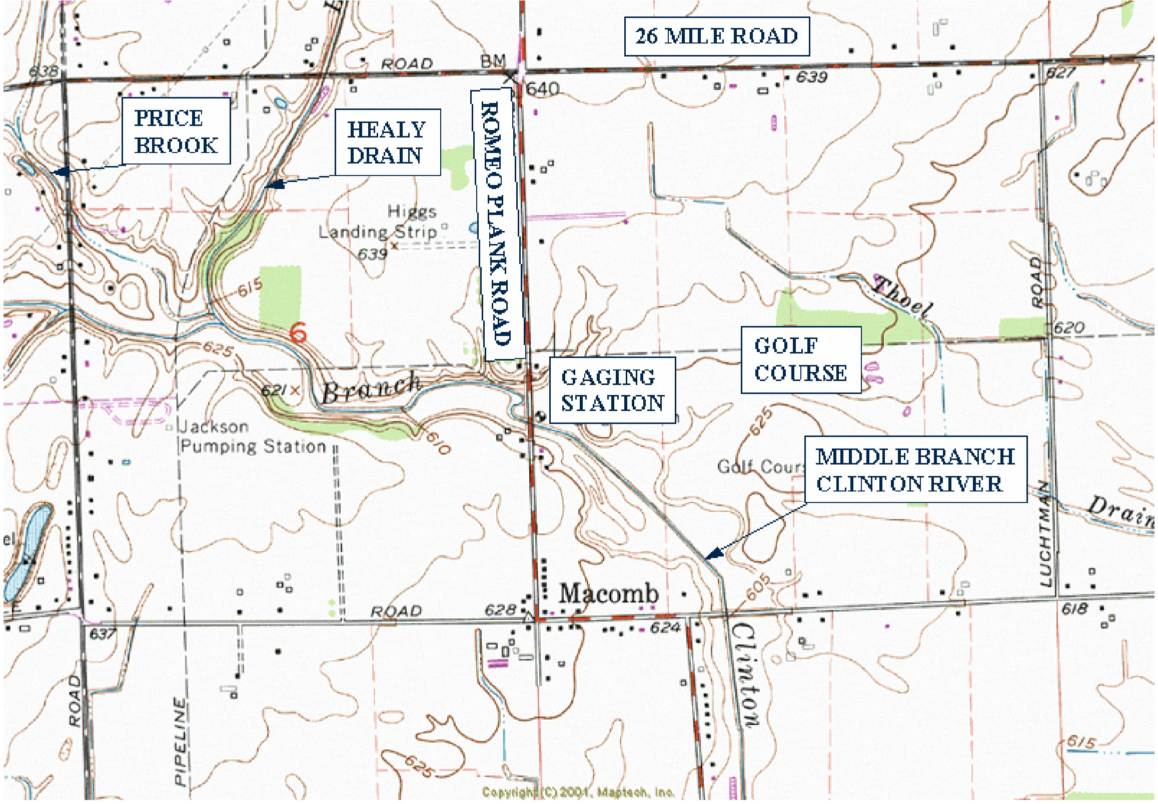


Figure 3.6: ***Upstream View of Macomb Township Location***

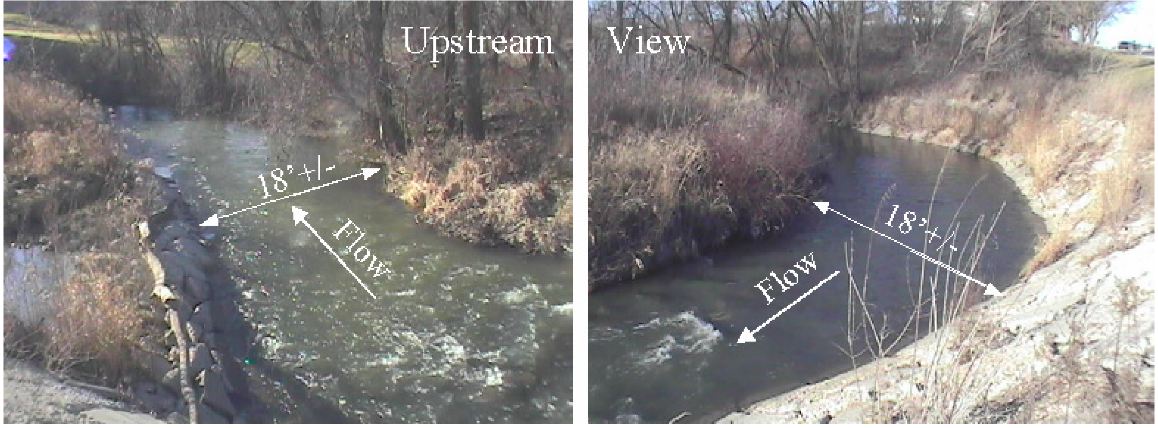
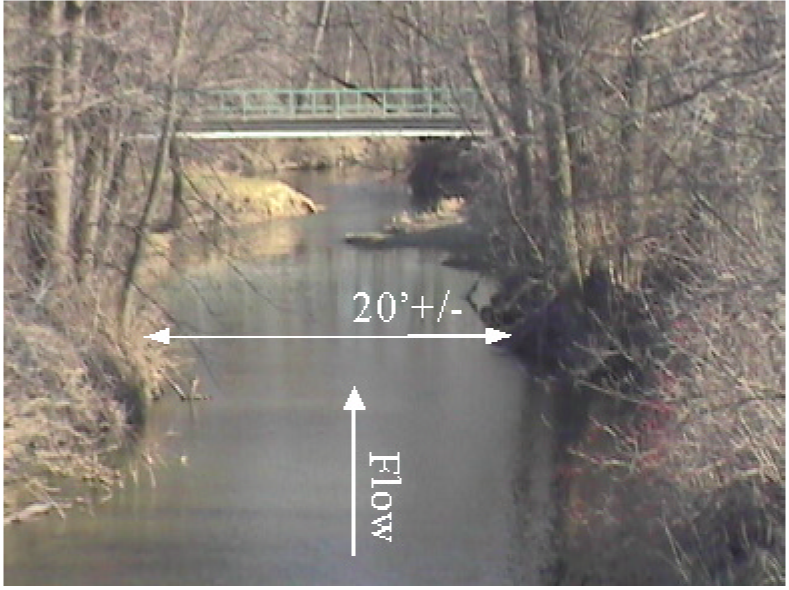


Figure 3.7: ***Downstream View of Macomb Township Location***



ARMADA

Location:	Latitude 42°50’45”N, Longitude 82°53’06”W (NAD27)
Elevation:	735.00 (NGVD29)
Drainage Area:	13.00 square miles

Additional Notes:

This site has the smallest subwatershed, which more easily enables a direct correlation between hydrologic changes and the geomorphic reaction of the river to those changes. This site, however, also has a very low geomorphic score.

Figure 3.8: ***USGS Map of Armada Location (no scale)***

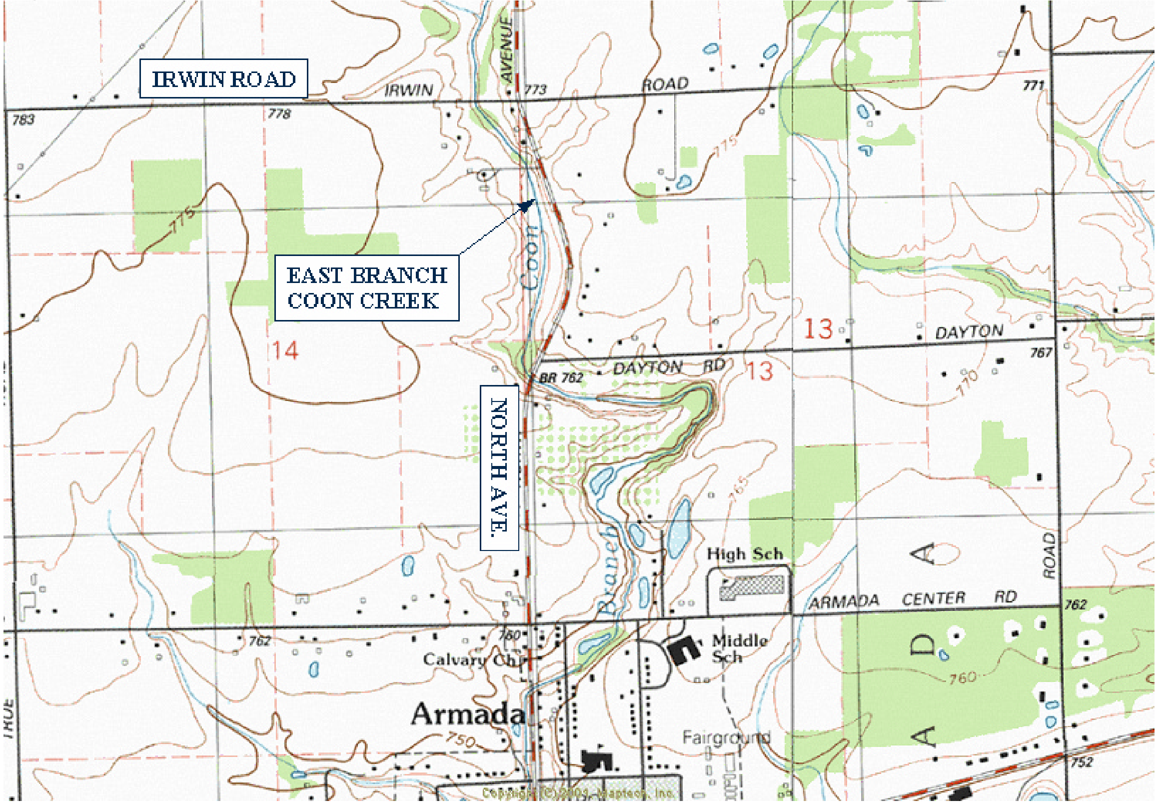


Figure 3.9: *Upstream View of Armada Location*

Figure 3.10: *Downstream View of Armada Location*

SOUTHWEST STERLING HEIGHTS

Location:	Latitude 42°32’31”N, Longitude 83°02’52”W (NAD27)
Elevation:	598.80 (NGVD29)
Drainage Area:	23.50 square miles

Additional Notes:

Both the annual mean flow trend and the peak flow trend have decreased in values over time. This site is not representative of the majority of the watershed because most of the watershed has large increases in both peak flows and annual mean flows.

Figure 3.11: ***USGS Map of Sterling Heights Location (no scale)***

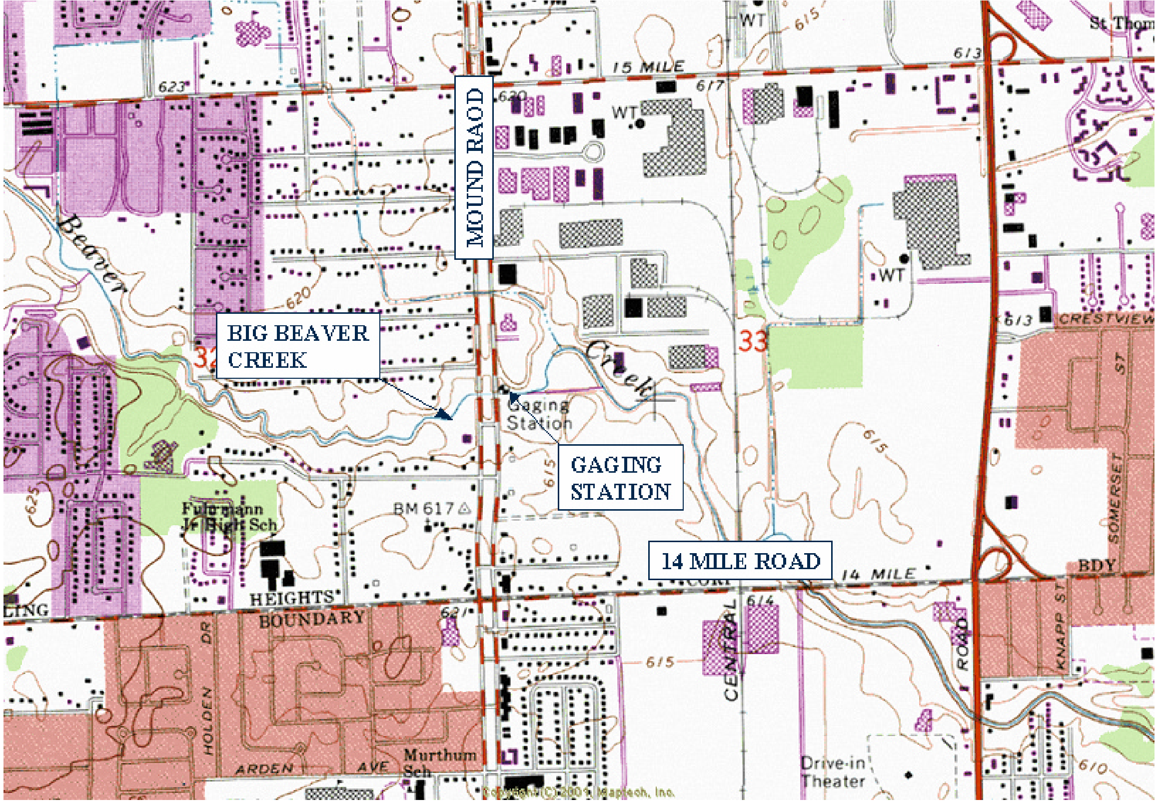


Figure 3.12: ***Upstream View of Sterling Heights Location***

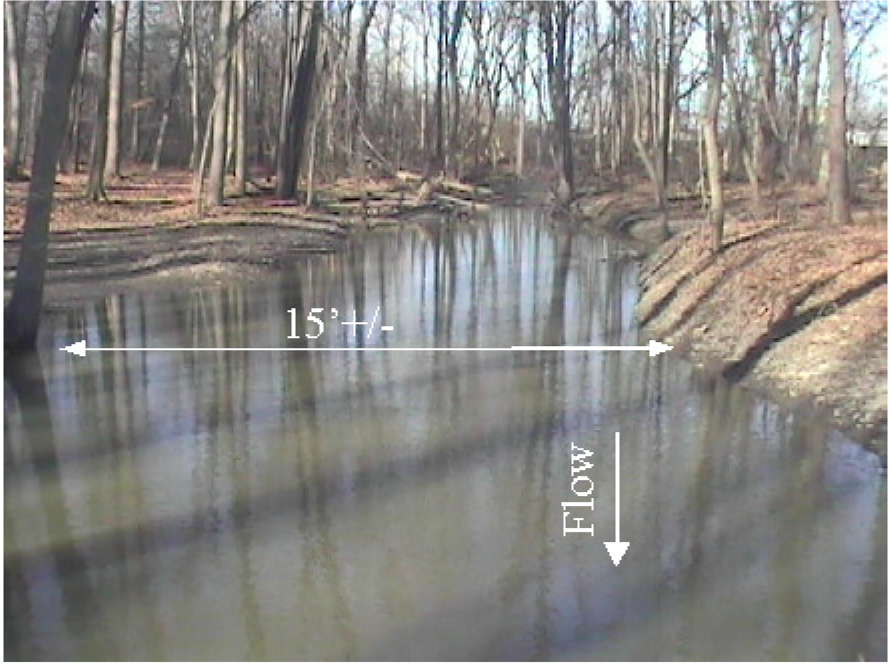


Figure 3.13: ***Downstream View of Sterling Heights Location***

SOUTHWEST CLINTON TOWNSHIP

Location:	Latitude 42°34’38”N, Longitude 82°57’05”W (NAD27)
Elevation:	577.71 (NGVD29)
Drainage Area:	444.00 square miles

Additional Notes:

This is the first USGS station downstream of the Utica site where there are known erosion hotspots.

This site has a geomorphic activity rating of 29, just below the moderately active cut-off value of 30.

This site has a very large subwatershed that will make it rather difficult to correlate the river changes to hydrologic changes. This subwatershed includes over half of the entire Clinton watershed.

Figure 3.14: *USGS Map of Clinton Township Location (no scale)*

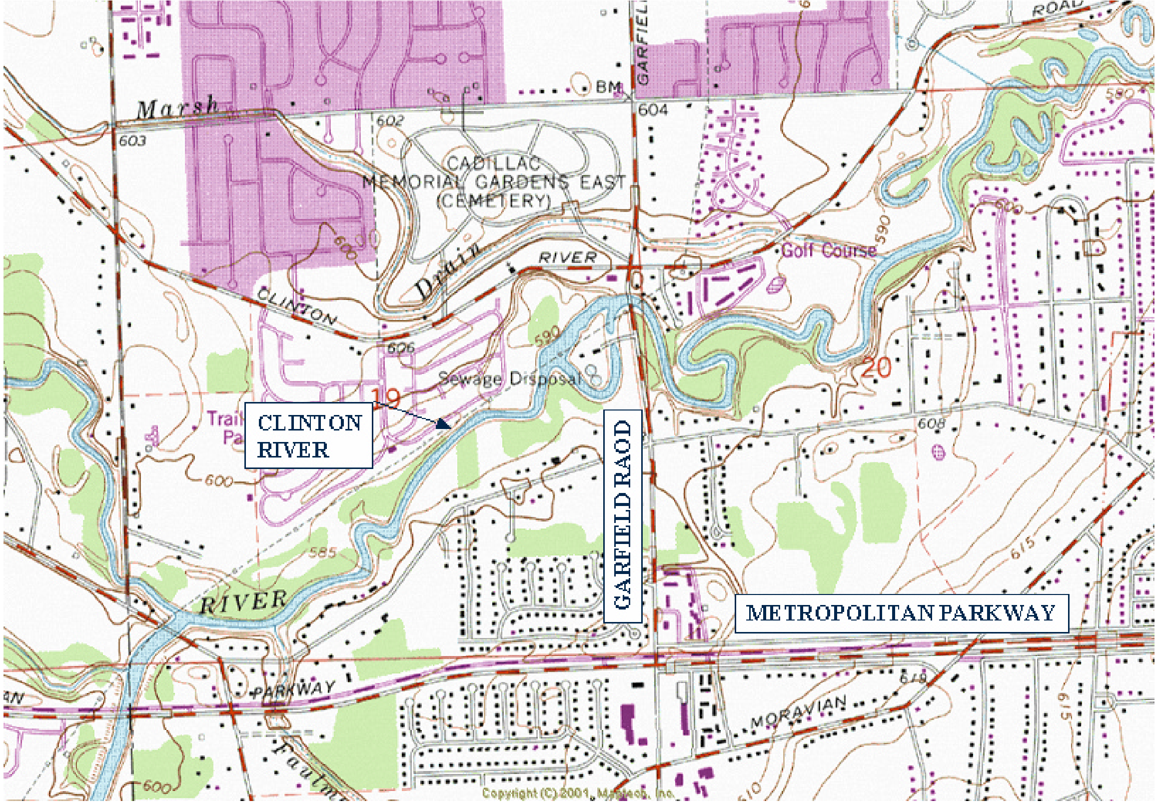


Figure 3.15: *Upstream View of Clinton Township Location*

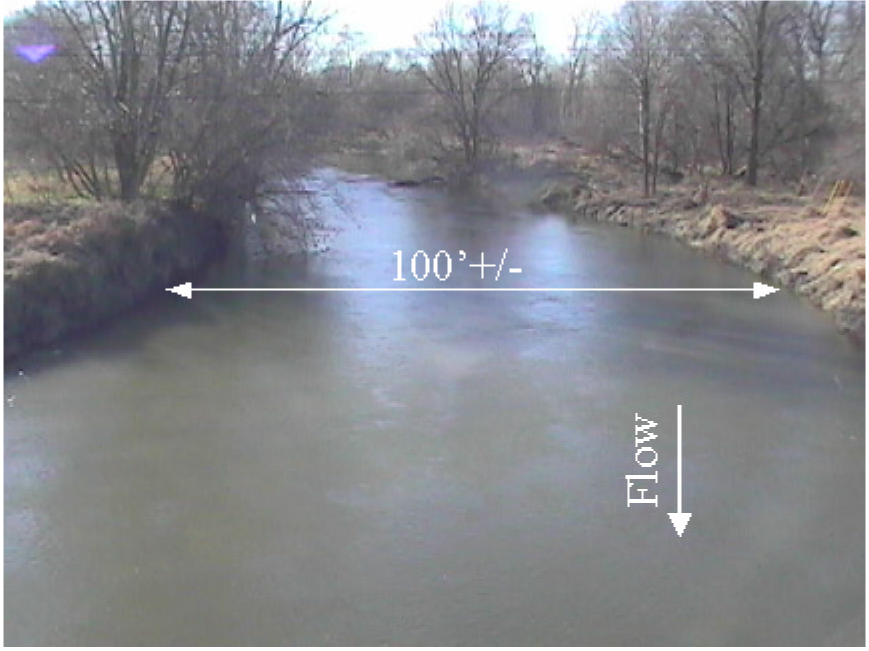
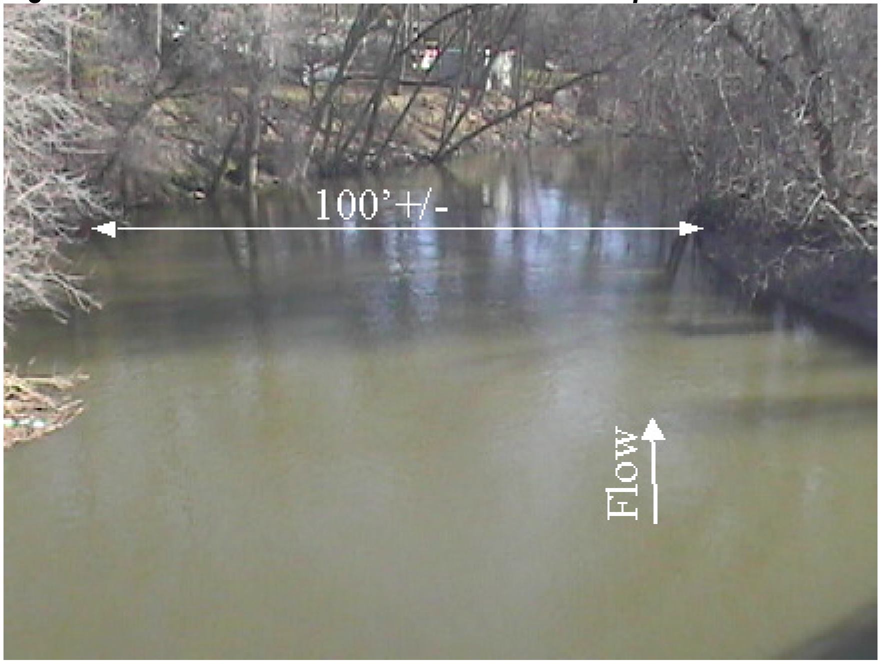


Figure 3.16: *Downstream View of Clinton Township Location*



UTICA

Location:	Latitude 42°37’12”N, Longitude 83°01’44”W (NAD27)
Elevation:	Unknown
Drainage Area:	Over 200 square miles

Additional Notes:

There are known erosion hotspots at this site located at Hall Road, however, there are no USGS stations located at this site.

This site has a very large contributing subwatershed. A smaller subwatershed would be preferred as it would be easier to gauge the resulting river changes to hydrologic changes within the immediate surrounding area.

Figure 3.17: ***USGS Map of Utica Location (no scale)***

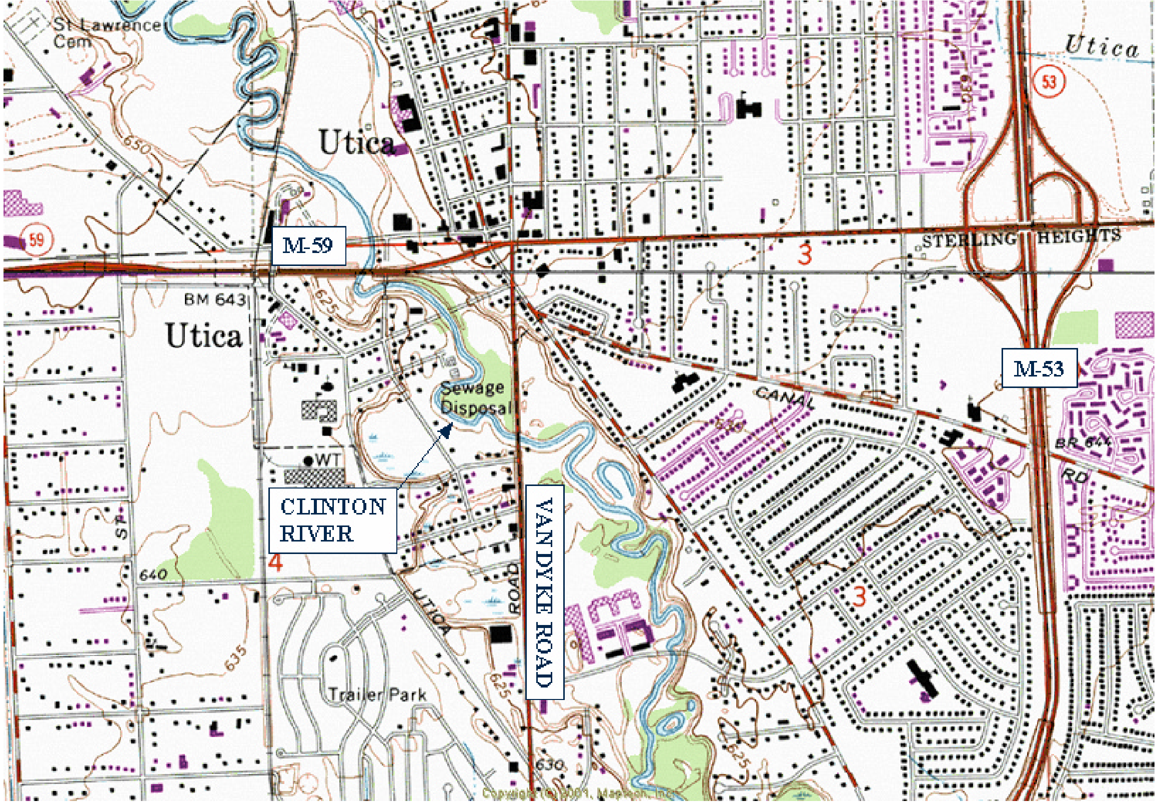


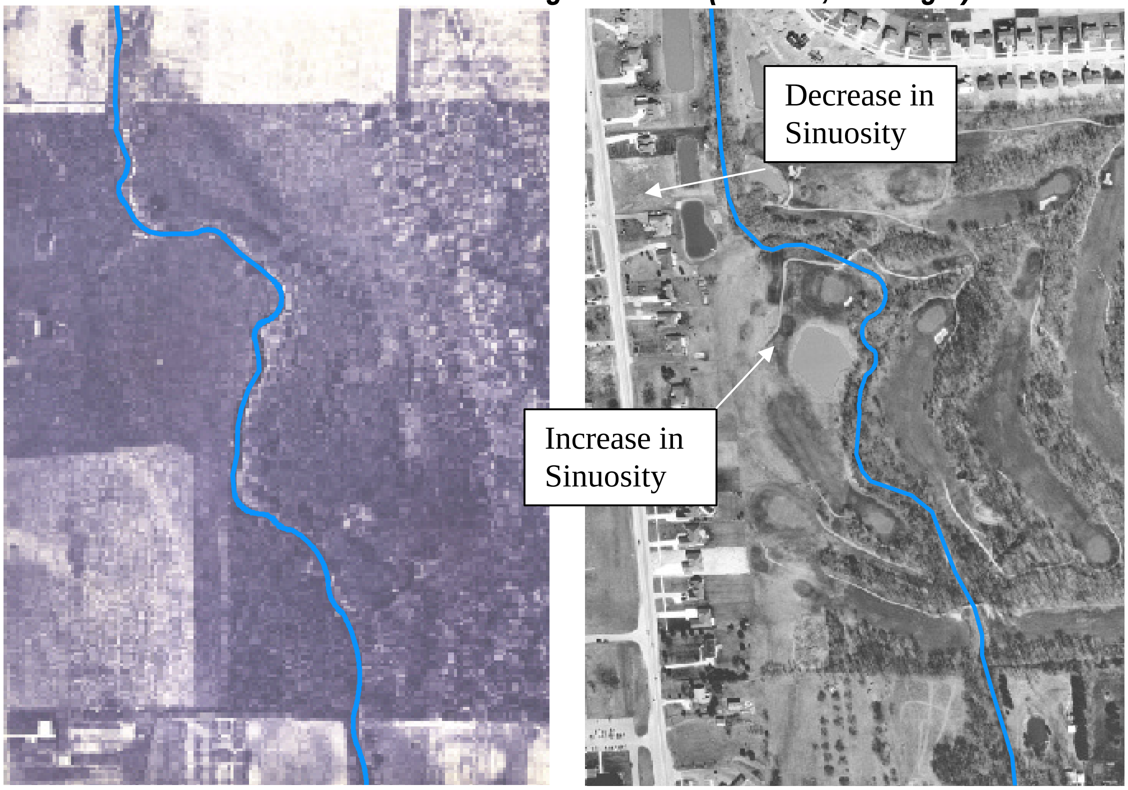
Figure 3.18: *Upstream View of Utica Location*

Figure 3.19: *Downstream View of Utica Location*

3.3 HISTORICAL PHOTOGRAPHS OF THE CLINTON RIVER WATERSHED

Historical aerial photographs were obtained throughout the Clinton River watershed in order to determine if there were substantial changes in its sinuosity. Overall, a noticeable change in the sinuosity of many of the river reaches and drains was observed throughout the watershed. An example of the historical change in sinuosity is shown in Figure 3.20, which shows a region located approximately one mile downstream of USGS gage 04164800.

Figure 3.20: ***Aerial Comparison of Middle Branch Clinton River Approximately One Mile Downstream of USGS Gage 04164800 (1964 left; 2000 right)***



Based on the data obtained, a suitable pilot study site appears to be the subwatershed of USGS gage 04164800 or the Middle Branch of the Clinton River. This is based on the following arguments:

- This subwatershed scored the highest geomorphic instability rating within Macomb County.
- The subwatershed is a manageable 42 square miles, and therefore, the entire Middle Brach could be investigated thoroughly.
- There exists changes in sinuosity due to the changes in hydrology to the subwatershed, which is an indication of geomorphic instability

3.4 SELECTION OF A REPRESENTATIVE PILOT SITE

Finally, along with likely geomorphic instability within the subwatershed, the pilot site needed to be representative of the Clinton River watershed as a whole. The first step to ascertain this was to investigate the land use patterns in the Clinton River watershed and its sub basins. Land use data is available from two sources, namely the Southeast Michigan Council of Governments (SEMCOG) and the United States Geological Survey (USGS). SEMCOG delineates landuse based on the zoning of individual parcels. Although this data is useful in showing approximate land use trends, it may lead to inaccurate landuse delineation because the zoning of a parcel is not always specific, and not always representative of what is on the site. For example, many communities have a combined Low-Density Residential and Agricultural as a single landuse delineation (with special use provisions), which may consist of woody 10-acre residential parcels, large areas of row-crops, or even large impervious parking lots used for temples, churches, or synagogues (as a special use provision). The USGS Land Cover Class Definitions (NLCD) landuse delineation uses data obtained from aerial photography and Landsat™ data, which makes this data more accurate as the landuses are delineated irrespective of zoning (see Appendix C for the distribution of the USGS landuse within each subwatershed). Moreover, the USGS data includes specific vegetation cover types, such as “Deciduous Forest”, “Evergreen Forest”, and “Mixed Forest”.

The SEMCOG landuse delineation is summarized for the entire Clinton River watershed and the subwatershed of USGS gage 04164800 in Table 3.5.

Table 3.5: *SEMCOG Landuse Types*

	Clinton River Watershed		USGS gage 04164800 Subwatershed		
Landuse Type	Total Square Miles within Watershed	Percent of Total	Total Square Miles within Subwatershed of 04164800	Percent of Total	Difference from Clinton River Watershed
Agricultural/Rural Residential	334	44.0%	15.9	40.0%	-4.0%
Low Density Residential	165	21.7%	14.4	36.3%	+14.6%
Medium Density Residential	92.9	12.2%	1.37	3.4%	-8.8%
Open Space/Conservation	36.6	4.8%	2.87	7.2%	+2.4%
Industrial	36.0	4.7%	1.55	3.9%	-0.8%
Institutional/Public/Quasi Public	25.0	3.3%	0.53	1.3%	-2.0%
High Density Residential	20.7	2.7%	0.86	2.2%	-0.5%
Commercial	15.2	2.0%	1.47	3.7%	+1.7%
Water	13.9	1.8%	0.25	0.6%	-1.2%
Office	8.04	1.1%	0.16	0.4%	-0.7%
Transportation/Communication/Utility	7.03	0.9%	0.34	0.9%	0%
Commercial/Mixed Use	3.49	0.5%	0.03	0.1%	-0.4%
Planned Unit Development/Other	1.75	0.2%	0.00	0.0%	-0.2%

The Middle Branch subwatershed area is predominately agricultural and low density residential (Figure 3.21). The values calculated in Table 3.6 are similar to the overall Clinton River watershed landuse patterns, which make the pilot study area a good representation of the Clinton River watershed as a whole.

Historical development patterns and SEMCOG future estimates indicate that over the next thirty years, much of the current agricultural/rural residential landuse types within the pilot study subwatershed will shift to low-density residential landuse as well as to small amounts of commercial and medium/high density residential. This shift in landuse will increase the amount of impervious area and, based on the conclusions of Chapter 2 in this report, could contribute to a further increase in both, the peak stream flows as well as the annual mean stream flows in the adjacent rivers and streams.

The 1992 USGS landuse classification of both the Clinton River watershed and its subwatersheds is summarized in Appendix C. See Figures C-1 through C-16 for subwatershed locations. The USGS landuse classification shows that the Middle Branch of the Clinton River subwatershed is highly representative of the Clinton River watershed as a whole (see Figure 3.22 and 3.23).

Figure 3.22: ***USGS Landuse Classification of the Middle Branch of the Clinton River Subwatershed and the Clinton River Watershed***

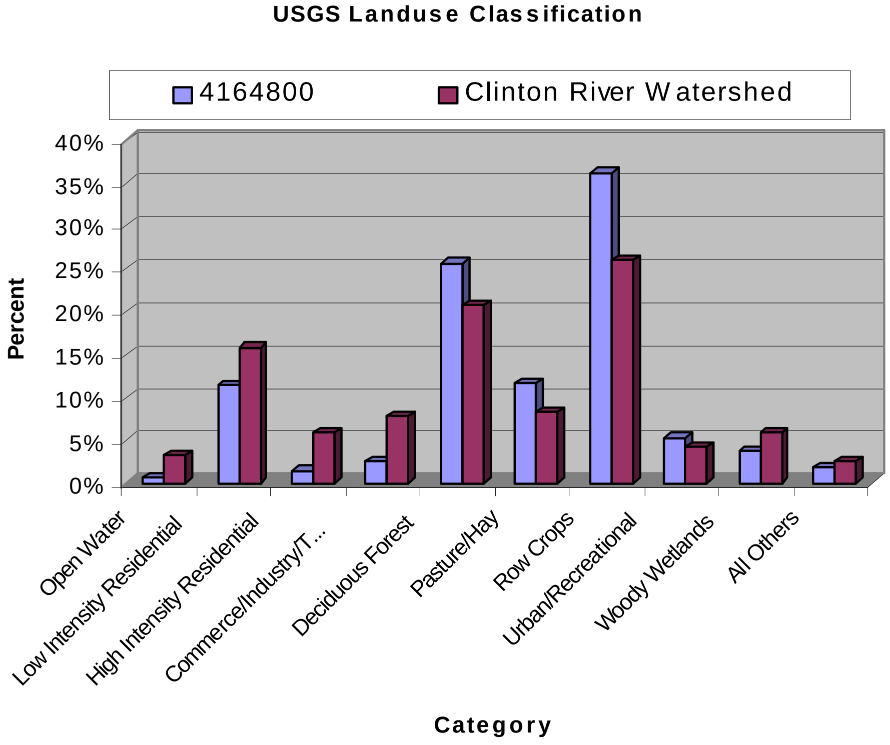
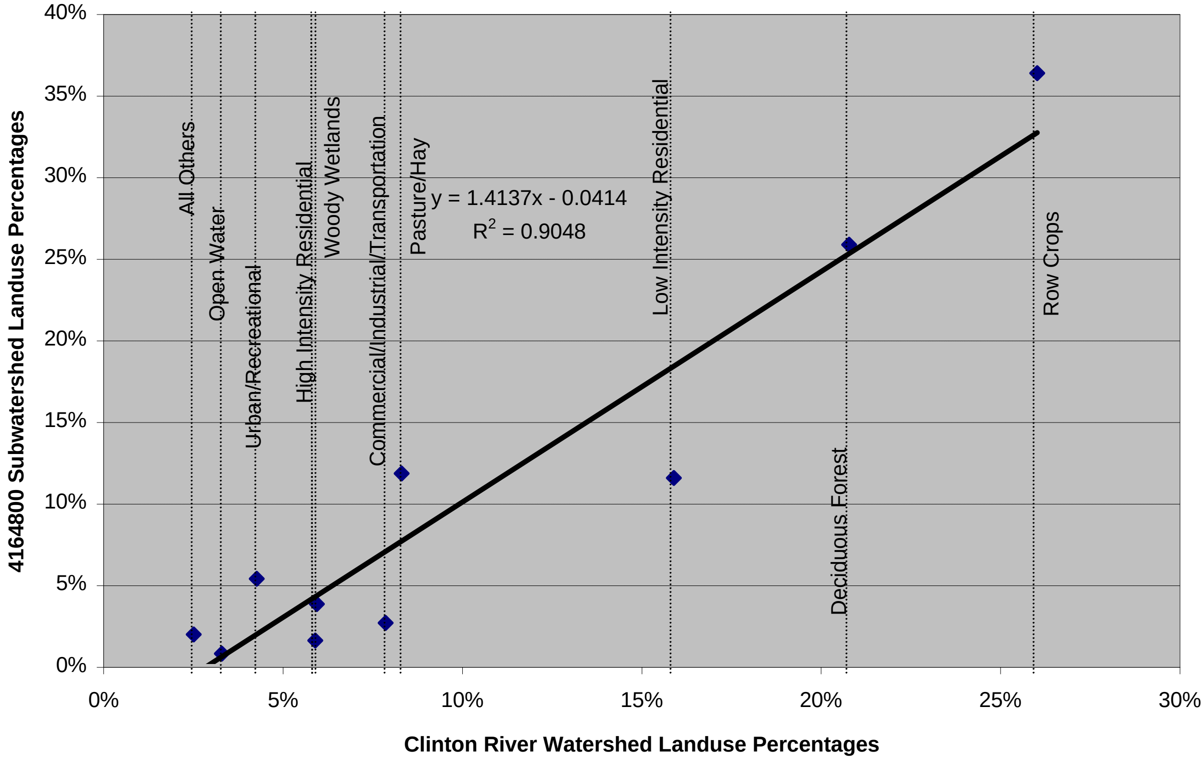


Figure 3.23: ***Statistical Regression of USGS Landuse between the Clinton River Watershed and the 04164800 Subwatershed***



From Appendix C and Figures 3.22 and 3.23, the following conclusions can be made:

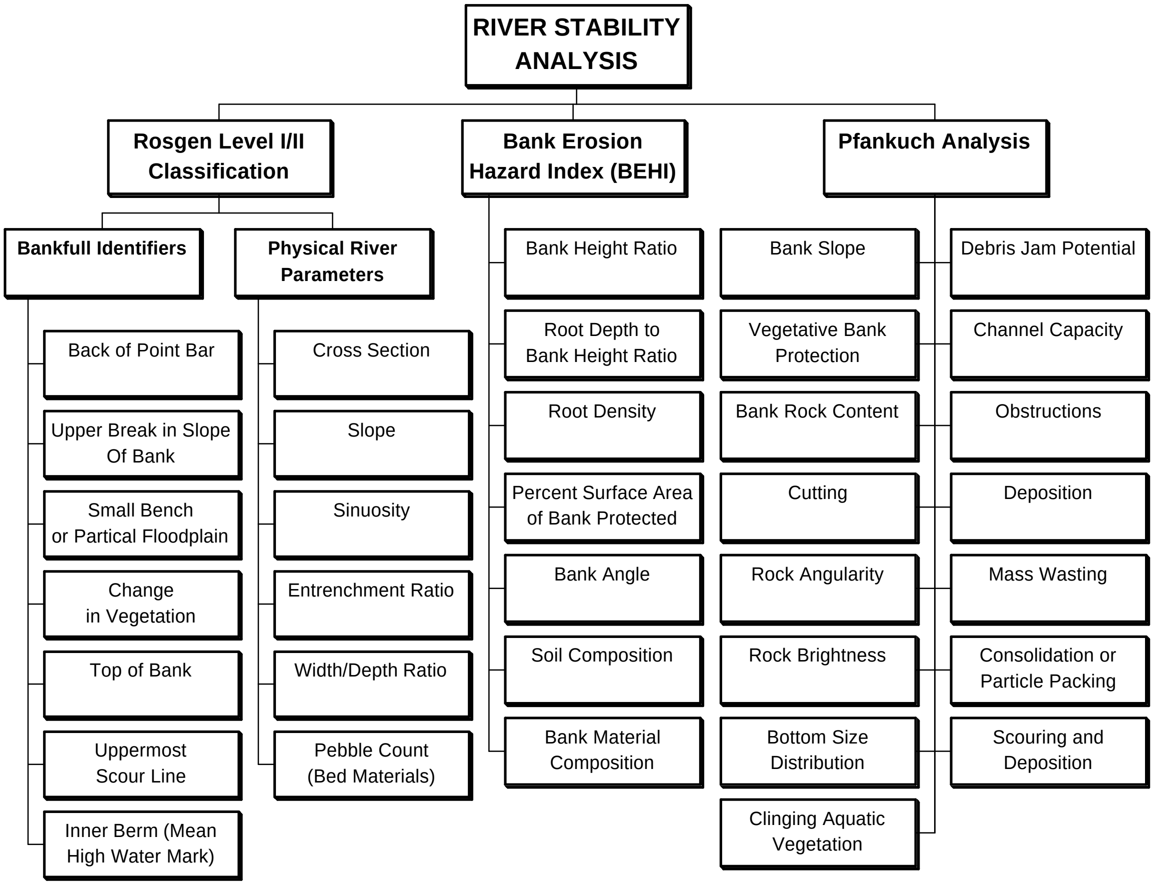
- Overall, landuse significantly varies between various subwatersheds within Clinton River.
- The Middle Branch subwatershed that contributes to USGS gage 04164800 is a good representative of the entire Clinton River watershed.

Since the Middle Branch of the Clinton River (subwatershed 04164800) is a likely geomorphically active site, and its landuse among the most representative subwatersheds in the Clinton River watershed, after a discussion with Michigan Department of Environmental Quality, it was agreed to use it as the pilot site.

4.0 ANALYSIS WITHIN PILOT STUDY AREA

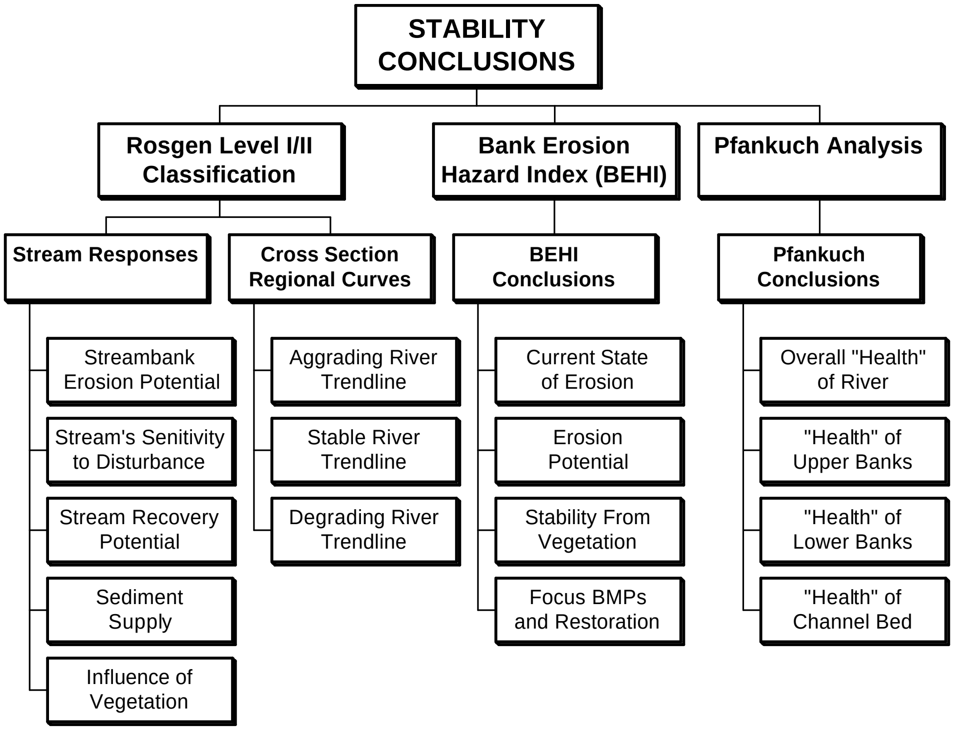
Having selected the Middle Branch of the Clinton River subwatershed as the pilot study area to conduct a detailed geomorphic analysis, the field study was conducted on approximately eight miles of the main channel of the river. The data collection procedure used (presented in the next Section) was agreed upon with the Michigan Department of Environmental Quality staff, and followed Dave Rosgen's procedure outlined in *Applied River Morphology* (Wildland Hydrology, 1996). Figure 4.1 displays three analyses that were conducted to determine stream stability and the data that was collected for each analysis. The data and analyses were conducted at thirty locations along the main channel of the Middle Branch of the Clinton River (Middle Branch).

Figure 4.1: ***Type of Stability Analysis & their Field Data Requirements***



The aim of the geomorphology study on the Middle Branch was to determine the overall stability of the study area so that recommendations may be made, from a policy and design standpoint, to maintain this watercourse in equilibrium. Figure 4.2 lists the policy or design conclusions and recommendations that may be determined using the data collected in Figure 4.1.

Figure 4.2: *Conclusions from Field Data Collection*



4.1 FIELD DATA COLLECTION PROCEDURE

The field data collection for the physical features of the river system is outlined below:

1. *Develop a GIS based tracking interface* - A Geographic Information System (GIS) database was developed for the Middle Branch subwatershed. The existing location of the hydrography was digitized using recent aerial photography of the entire subwatershed, which was provided by the Macomb County Planning Department. Field data maps were then created to assist in marking the location of the drain reaches during field data collection.

2. *Divide the Middle Branch into stream reaches* – The entire length of the Middle Branch was divided into reaches that were nearly thousand feet long. A 100-foot tape was used to mark off ten sections to delineate these reaches. Typically, roads or major culverts were also used to define the boundary of a reach and therefore, the reach lengths varied slightly.

3. *Perform a substrate analysis ("Pebble Count")* - The Modified Wolman Pebble Count method (Wolman, 1954 and modified by Rosgen, 1996) was used in the substrate analysis. This procedure began by determining the riffle/pool ratio of the stream, which was visually approximated during the stream reach delineation. A total of 100 pebble samples were recorded for each reach using this method, and the riffle/pool ratio was used to determine what percentage of the samples were to be recorded from each of the riffle and pool sections. Five

pebbles were measured at each of twenty transects in order to have a distributive sample of the channel material. Each pebble was measured along the intermediate axis and recorded in the data collector. This procedure does not use any sieve analysis and hence, no samples needed to be collected and removed from the site.

4. *Locate the bankfull stage* – The bankfull stage is the height of the water at which flooding typically occurs onto the floodplain in a natural and stable river system. In modified or disturbed channels, this elevation is typically not the top of banks and therefore bankfull identifiers must be used to determine this elevation. The identification process to locate bankfull stage in this study was adopted from multiple sources, including the U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, MDEQ, North Carolina Stream Restoration Institute, and Dave Rosgen's *Applied River Morphology*. Specifically, the primary bankfull identifiers in the Middle Branch included:

   - Back of a point bar
   - Upper break in slope of the bank
   - Small bench or partial floodplain
   - Change in vegetation
   - Top of bank
   - Uppermost scour line
   - Inner berm (mean high water mark)

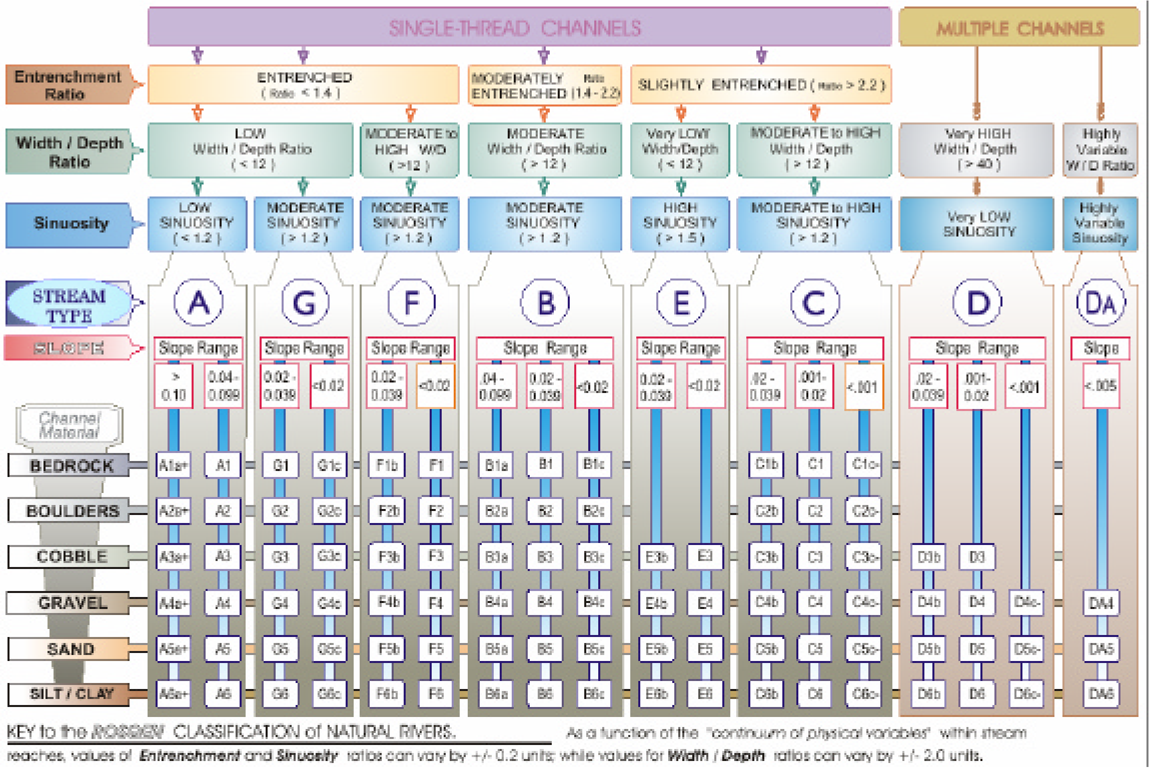
   These bankfull indicators were identified, flagged, and photographed in the field for each stream reach.

5. *Survey the cross section at a riffle for each stream reach* – A survey tape was laid perpendicular to the drain at the highest available location (top of bank or a location within the floodplain). To ensure that the tape was level, measurements were taken from the water surface at the right and left edges, and the tape was adjusted until it was level. A monument was then placed within the cross section, typically at the 0+00 station of the tape (left top of bank or floodplain). The elevation from the ground to the tape was measured along the cross section, taking special care to note changes in slopes. For constant or flat slopes, elevations were measured approximately every five feet in the floodplain, and every 2-3 feet within the banks.

These parameters were used primarily to determine the river classification at each stream reach. As indicated previously, the Rosgen classification was used in this project at the request of the Michigan Department of Environmental Quality. This methodology classifies the stream reach into one of the 8 different Rosgen Level I categories and into one of the 94 different Rosgen Level II categories. This classification is outlined in chapter 5 of David Rosgen's *Applied River Morphology*. The parameters used in the classification system are derived from the surveyed data or aerial photography and, are presented in Figure 4.1.

Figure 4.3 shows the Rosgen Classification Key for both Rosgen Level I and Rosgen Level II Classifications.

Figure 4.3: ***Rosgen Classification Key (from Applied River Morphology by Dave Rosgen)***



The river classification gives a wide variety of general information about the river reach such as the general shape of the river, how incised a river is, its material composition, its sensitivity to large flows and disturbances, as well as a number of other conclusions. However as presented in Figure 4.1 and Figure 4.2, the classification only gives a general description of the physical characteristics and how the river typically responds to changes in flows.

According to the MDEQ, a river is in equilibrium or is stable when the stream "over time, maintains a constant pattern, slope and cross-section, and neither aggrades or degrades" (*Stream Stability and Channel Forming Flows*, Michigan Department of Environmental Quality, Hydrologic Studies Unit). Therefore, information related to the sediment transport regime within the stream channel must be obtained. This additional data consists of erosion analysis as well as the use of regional curves.

4.1.1 Existing River Reach Condition and Erosion Analysis

To accurately estimate the existing state of the pilot study area, it was necessary to assess the existing state of erosion of the banks, and to determine the overall "health" of the river reach looking at the Upper Banks, the Lower Banks, and the Bed Material. This was done by conducting a Bank Erosion Hazard Index (BEHI) analysis and a Pfankuch analysis.

4.1.1.1 Perform a Bank Erosion Hazard Index (BEHI)

The BEHI analysis quantifies the existing erosion potential. This analysis has been developed by David Rosgen in *Applied River Morphology* (page 6-41, 1996). Parameters used in the BEHI analysis are presented in Figure 4.1.

A typical cross section is chosen in the river reach and each of the listed parameters is determined. From these values an overall BEHI value is calculated to determine the existing state of erosion of the river reach.

4.1.1.2 Perform a Pfankuch Analysis for the Entire Reach

The Pfankuch analysis was used to qualitatively characterize the entire reach under investigation. This procedure is outlined in the *Stream Reach Inventory and Channel Stability Evaluation* by Dale Pfankuch, 1978. A score of Poor, Fair, Good or Excellent is assigned to the categories shown in Figure 4.1. The sum of each of the parameters used determines an overall "health" of the river reach that was analyzed.

4.2 ANALYSIS OF FIELD DATA

4.2.1 Rosgen Level I Classification

Each segment of the Middle Branch was classified into one of the eight unique Rosgen Level I categories. A map showing the output of this classification is presented in Figure 4.4.

Of the eight possible Rosgen Level I classifications, the Middle Branch was found to contain four stream types namely "C", "E", "F" and "G". A description of these stream and their properties according to Rosgen (1996) are as follows:

C Stream Type – Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains and meandering channels.

E Stream Type – Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. This stream type is very efficient, highly sinuous, and stable with high meander-width ratio. The "E" stream is associated with broad valleys and meadows, as well as alluvial materials with floodplains.

F Stream Type – Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio. The "F" stream is typically entrenched in highly weathered material, has gentle gradients, and is typically laterally unstable with high bank erosion rates.

G Stream Type – Entrenched "gully" step/pool stream with low width/depth ratios on moderate gradients. The "G" stream typically has gully morphology in narrow valleys or is deeply incised in alluvial or colluvial materials. These streams are typically unstable with grade control problems and high bank erosion rates.

Within the Middle Branch, these four categories are found in the following manner:

- "C" Streams consist of 13% of the total length
- "E" Streams consist of 30% of the total length
- "F" Streams consist of 43% of the total length
- "G" Streams consist of 14% of the total length

The downstream portion of the study area is primarily classified as an "F" stream. Three reaches of the Middle Branch near M-53 are classified as a "G" stream, and the upstream reaches of the study area are mostly "E" streams. There are two reaches of "C" streams immediately downstream of Chestnut Lake as well as two additional reaches classified as a "C" stream type through the remaining reaches of the study area.

4.2.2 Rosgen Level II Classification

Of the 94 possible Rosgen Level II stream types, six exist within the Middle Branch subwatershed. These nine stream types are "C4", "E4", "E5", "F4", "F5", and "G5c". This classification is more detailed than the Rosgen Level I Classification in that it classifies the river not just based on the cross sectional dimensions, but also on river bed material and river slope. The numbers that follow the Level I category represent the bed material in the following manner:

- "1" represents a channel primarily comprised of bedrock
- "2" represents a channel primarily comprised of very large materials or boulders
- "3" represents a channel primarily comprised of large materials or cobbles
- "4" represents a channel with a median bed material size of gravel
- "5" represents a channel that is primarily a sand bed channel
- "6" represents a channel with a bed material primarily comprised of silts and clays

Additionally, the slope is considered in the Rosgen Level II classification. This is represented by a small case letter following the bed material size number. In most cases within the Middle Branch, there is an absence of a small case slope letter. This represents that the slope is within the typical range of that stream type. A small case "a" represents a slope that is much steeper than typically expected, a small case "b" represents a slope that is somewhat steeper than expected, and a small case "c" represents a slope that is gentler than typical slope values for that stream type. Figure 4.5 shows the different stream types found in the Middle Branch. More detailed descriptions for each specific Rosgen Level II stream type may be found in *Applied River Morphology* (Rosgen 1996).

The general conclusions from the Level II analysis are that the river bed material primarily consists of sands (two thirds of the total length). The remaining one third of the river length has a median bed material size classified as gravel. For both bed material conditions within the Middle Branch, slopes are primarily gentle, but within the expected range based on the stream type.

Rosgen states that several general conclusions may be drawn based solely on the river type. These conclusions are presented in Figure 4.2 and are also outlined in the following sections.

4.2.2.1 Streambank Erosion Potential

The Streambank Erosion Potential is a function of the shear stresses on the streambanks, the geometry of the cross section, and the amount and type of material that is available to be eroded. “F” stream types have the highest erosion potential due to the incised nature of the stream and the near vertical banks. “G” stream types also have very high erosion ratings primarily due to the incised nature of the stream, but are typically less than the “F” streams because of relatively less steeply sloped banks. The Middle Branch has streambank erosion potential values that consist entirely of either “High” or “Very High”, with most “Very High” values being in the downstream reaches of the pilot study area. See Figure 4.6 for the output of this analysis.

4.2.2.2 Stream Sensitivity to Disturbance

If a stream is susceptible to alterations caused by changes in the flow, sediment discharge, bank characteristics, or other factors then it is characterized as having a high sensitivity to disturbance. This value is mostly a function of bed material, with silt and sand channels having the highest sensitivity to any natural or human-induced disturbances. Primarily due to the sand and gravel nature of the bed materials, the Middle Branch is consistently classified as having “Very High” sensitivity to disturbance, with some reaches scoring an “Extreme” rating. See Figure 4.7 for a graphic of the Middle Branch’s sensitivity to disturbance.

4.2.2.3 Stream Recovery Potential

The stream recovery potential identifies a stream’s ability to naturally recover to an equilibrium condition after a disturbance has occurred. This parameter is mostly a function of the stream’s cross-section (i.e. the river classification) and whether or not the stream’s bankfull flow is at the floodplain elevation. Streams that are disconnected from its floodplain have very low potential to naturally recover from a disturbance. Due to the varied classifications that exist within the Middle Branch, the stream recovery potential ranges from “Good” to “Very Poor”. Overall, the upstream reaches are classified as “Good and the downstream reaches are classified as “Poor” (see Figure 4.8).

4.2.2.4 Sediment Supply

The sediment supply of a river reach refers to the amount of sediment that is available for erosion. This parameter is based both on the channel material as well as the channel dimensions. Sands and gravel streams typically have “Very High” sediment supply values due to the high erodibility of the material. Also, streams that are disconnected from the floodplains have larger surface contacts when flooding occurs, and therefore more sediment is available to be eroded. The Middle Branch sediment supply values range from “Moderate” to “Very High”. Overall, the upstream reaches are categorized as “Moderate” and the downstream reaches are rated as “Very High” (see Figure 4.9).

4.2.2.5 Vegetation Controlling Influence

Vegetation controlling influence refers to the ability of using vegetation as a stabilization technique. Most stream types have either "High" or "Very High" ratings for the use of vegetation to control stabilization, however there are a few exceptions. Using vegetation to stabilize most "F" stream types is typically ineffective because these streams are usually in a state that receives deposition. This is due to the wide channel bottoms and slow moving sediment associated with this geometry pattern. Therefore, although erosion is a concern under large flows in "F" streams, deposition is common after the flood has occurred, and stabilizing the banks may prevent some of the erosion, but will not address the depositional concerns associated with this stream type. The Middle Branch, therefore, typically has "High" to "Very High" values for the vegetation controlling influence, except where a moderate value is given at the "F" stream types. See Figure 4.10.

Although all of the above parameters are general conclusions based on the Rosgen Level II classification and must be used with caution, there are many fundamental justifications for the various conclusions. For example many "G" type channels have poor ratings for sensitivity to disturbance, recovery potential, and streambank erosion potential. This is because the flood flows are contained within the banks and therefore the shear stresses caused by increased flows never stabilize. Due to the high shear stresses, these types of streams are very susceptible to erosion and can easily become increasingly incised and have eroding banks. Once this stream is in this condition, it becomes very difficult for the river to come back to a stable state naturally, and only reaches equilibrium once the river's evolutionary processes converts the physical cross section to a new river type, most typically an "F" or an "E" stream type. On the other hand, "E" streams have well developed floodplains, and thus shear stresses on the banks stabilize even though flows continue to increase. This is due to slowly increasing water depths despite the large increases in flows once the waters have breached the streambanks. This stabilized shear stress reduces the erosion potential to a moderate rating, and also increases deposition potential from the slow moving floodplain, which allows the river to naturally recover to a stable "E" channel.

An additional requirement to accurately assess the existing state of the pilot study area was to assess the existing state of erosion of the banks, and to determine the overall "health" of the river reach looking at the Upper Banks, the Lower Banks, and the Bed Material. This was done by conducting a Bank Erosion Hazard Index (BEHI) analysis and a Pfankuch analysis.

4.2.3 Bank Erosion Hazard Index (BEHI) Evaluation

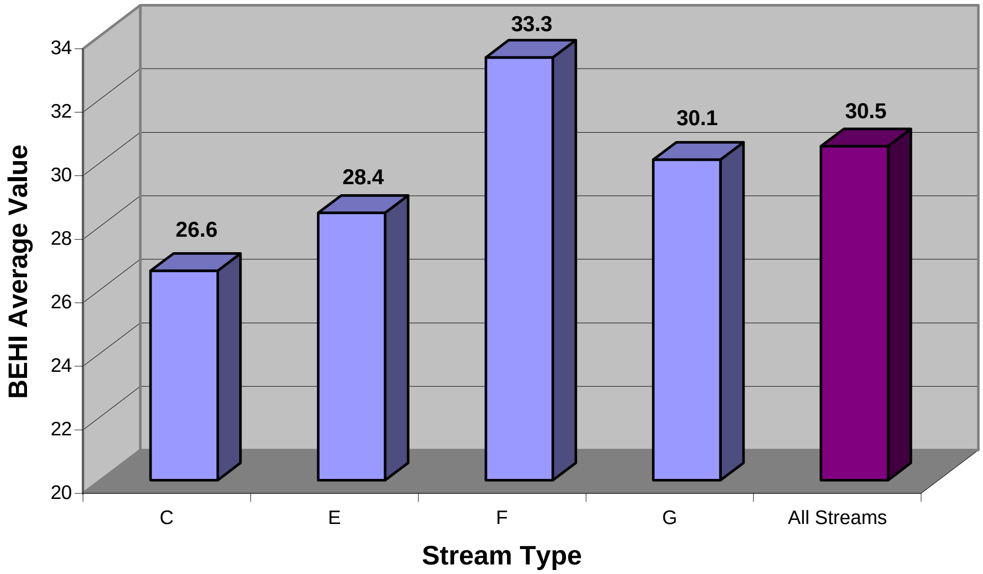
The BEHI analysis quantifies the existing erosion potential of the stream reach being analyzed. This analysis is described by David Rosgen in *Applied River Morphology* (page 6-41, 1996).

The BEHI analysis uses quantifiable data at a representative section of the river reach to determine the reach's current state of erosion. Each reach is scored and then it may be determined as to the severity of erosion for that section. Figure 4.11 shows the output of the BEHI analysis on the Middle Branch of the Clinton River.

The typical BEHI values for the study area are “Moderate” or “High”, with a single exception of reach number 27 having a BEHI score that is in the “Low” range. The downstream eleven reaches have scores of “High” and the remaining reaches alternate between “High” and “Moderate”.

The BEHI was also evaluated by correlating the BEHI values to the Rosgen Level I Classification. This correlation showed that “F” steam types have the highest BEHI values, and, therefore, could be considered as a priority site for restoration activities (see Figure 4.12).

Figure 4.12: ***BEHI Values for each Stream Type in the Middle Branch***



4.2.4 Pfankuch Channel Stability Evaluation

The Pfankuch analysis was used to qualitatively characterize the entire reach under investigation. This procedure is outlined in the *Stream Reach Inventory and Channel Stability Evaluation* by Dale Pfankuch, 1978. A score of Poor, Fair, Good or Excellent is assigned to the categories listed in Figure 4.1. The sum of each of these parameters determines an overall “health” of the river reach that was analyzed.

The Pfankuch Channel Stability Evaluation gives a general overview of the stream reach as a whole. Unlike the BEHI, the Pfankuch uses qualitative parameters to characterize the stream, but also looks at many more variables and considers more than just erosive parameters to determine the overall score of the river reach. A description of each of the variables is as follows:

Landform Slope - The steepness of the land adjacent to the stream channel. All other factors being equal, the steeper the land adjacent to the stream, the greater the potential of erosion to the streambanks.

Right: Middle Branch Channel Classified as "Poor" for having large side slopes at Reach #10.

Mass Wasting Hazard – This rating involves existing or potential detachment from the soil mantle and downslope movement into waterways of relatively large pieces of ground. Mass movement of banks by slumping or sliding introduces large volumes of soil and debris into the channel suddenly.

Right: Mass Wasting on Middle Branch Reach #13.

Debris Jam Potential – This parameter assesses the existence or potential for obstructions caused by tree trunks, limbs, twigs and leaves.

Right: Debris Jam rated "Poor" at Middle Branch Reach #5.

Vegetative Bank Protection – This parameter classifies the relative amount of vegetation that is controlling bank stability. Classification is determined by vegetation density.

Right: Vegetative Bank Protection rated "Excellent" due to highly dense ground cover at Reach #1.

Channel Capacity – This parameter defines the amount of cross sectional capacity to carry large flows before over topping the banks.

Right: Channel Capacity rated "Excellent". Despite severe rains, there is ample capacity for additional flows through this reach.

Bank Rock Content - This parameter looks at the density and size of the rocks greater than 1-3" in diameter within the channel banks. Higher densities and larger sizes constitute a better bank rock content condition.

Right: This bank is rated to have a poor bank rock content due to the absence of rocks in the banks.

Obstructions and Flow Deflectors – Objects within the stream channel such as large rocks, embedded logs and even bridge pilings change the direction of flow and may alter the velocities. A stream with many such features will have a poor rating for this element.

Right: Obstructions and Flow Deflectors rated "Poor" at Reach #5.

Cutting – This is defined as the scouring of the stream banks and is one of the first signs of channel degradation.

Right: This scouring of the right bank in this stream reach "Cutting" parameter as "Poor".

Deposition – This parameter defines the extent of sedimentation or deposition within the channel. A large amount of deposition is a sign that erosion processes are likely occurring upstream of the reach.

Right: Deposition within the channel of Reach #2 ranks this parameter as poor.

Rock Angularity – Rounded rocks within the channel are a sign of that the rocks have weathered over time in a stable environment. If angular rocks are present, then generally, this can be used as a sign of recent erosion within the watershed.

Right: The rock angularity would be ranked as "Excellent" at this stream reach.

Rock Brightness – Rocks in motion typically do not gather algae or stain and therefore as a general rule appear "bright". An "excellent" rating is achieved when the majority of the rocks within the reach are considered "dull".

Right: These rocks are considered relatively "bright" and therefore this Reach is characterized as "poor".

Consolidation (Particle Packing) – Under stable conditions, the array of rock and soil particle sizes pack together and the voids are filled. Therefore, a large distribution of particle sizes indicates a healthy stream bed condition.

Right: Due to the fairly high distribution of rock sizes, Reach #15as been characterized as "Excellent".

Bottom Size Distribution – In a small, flat watershed, it is expected that small particles make up the bed material due to deposition. Deviations from the expected bed condition will constitute lower ratings for this parameter.

Right: The gravels found in Reach #29 are typical of what is expected in this subwatershed and has been given an "Excellent" rating.

Scouring and/or Deposition – Evidence of significant scour and/or deposition will yield poor ratings for this parameter.

Right: This reach would be identified as "Poor" due to significant scour of the banks. Also, along this reach is significant deposition of the upstream eroded material.

Clinging Aquatic Vegetation – When some measure of river stability is achieved, the environment is ripe for moss and other clinging vegetation.

Right: If significant moss and clinging material such as that shown here occur throughout the stream reach an "Excellent" rating would be given

Once each Pfankuch parameter has been identified and scored, the overall score for the reach is calculated based on a weighted average of the most important parameters. From this information the general "health" of the stream can be qualitatively determined. Figure 4.13 shows the output of the Pfankuch analysis on the Middle Branch.

Of the four possible outcomes for the Pfankuch analysis (Excellent, Good, Fair, and Poor), only ratings of Good, Fair, and Poor exist for the Middle Branch of the Clinton River. Overwhelmingly, the River is scored as having "Fair" rating with some "Good" ratings sparsely distributed. There is a single "Poor" rating at reach 21. See Appendix D for all collected field data.

4.3 DEVELOPING REGIONAL CURVES

A Regional Curve is a plot of collected data that compares a single parameter, such as bankfull cross sectional area, width at bankfull, or average bankfull depth to the total watershed drainage area. These parameters are plotted on a log-log plot, and a power regression line is used to interpret the relationships between the drainage area and the specific parameter being analyzed. Regional curve data has been collected for the "Thumb" area of Michigan in a study conducted for the St. Clair County Drain Commissioner's Office for the Galbraith Drain Restoration Project. Data collected from the Galbraith Project was used to verify the collected regional curve data for this study. Additionally, data from the STREAM (Spreadsheet Tools for River Evaluation, Assessment and Monitoring) model that has been developed by the Ohio Department of Natural Resources (Mecklenburg and Ward) lists regional curves for the "Eastern United States" (data obtained from Dunne and Leopold, 1978), the Ohio Lake Erie Watershed, and the N.W. Ohio Drainage districts, which will also be used to compare the collected regional curve data for the Middle Branch.

Studies conducted by the Michigan Department of Environmental Quality have shown that there is a significant positive correlation between the bankfull cross sectional area and the watershed drainage area, as compared with other regional curve parameters. Therefore, the cross sectional area at the bankfull elevation was carefully compared with the regional curve data collected for the "Thumb" area of Michigan, and may be seen in Figure 4.14.

Figure 4.14: ***Eastern U.S. and some Midwest Regional Curves***

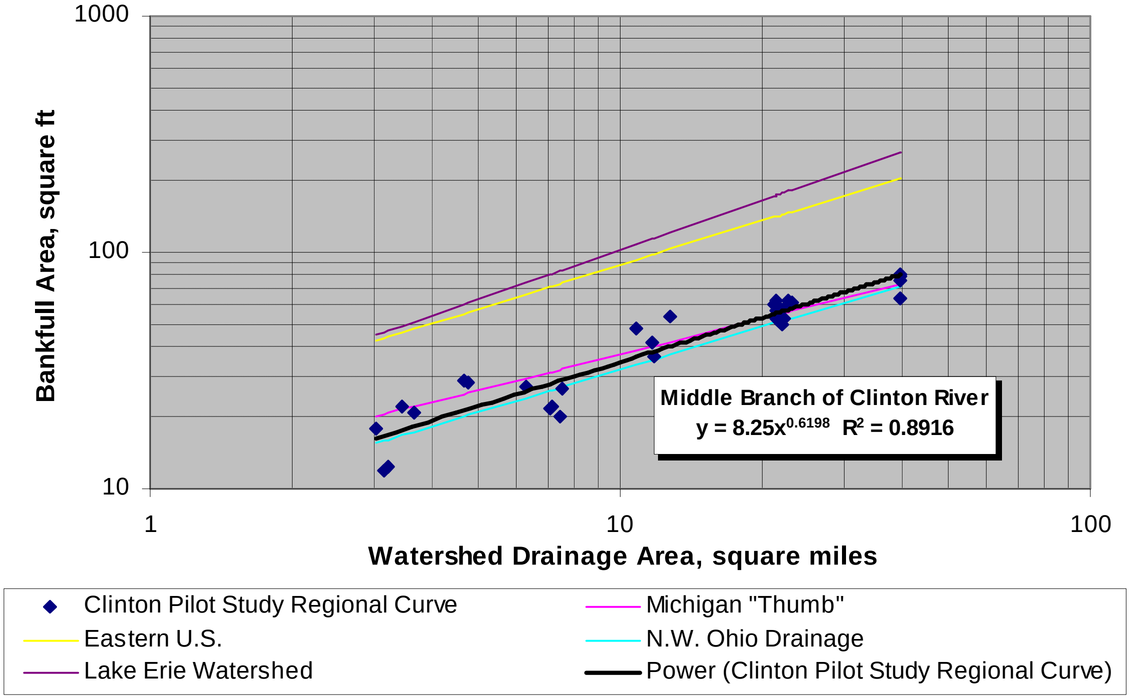


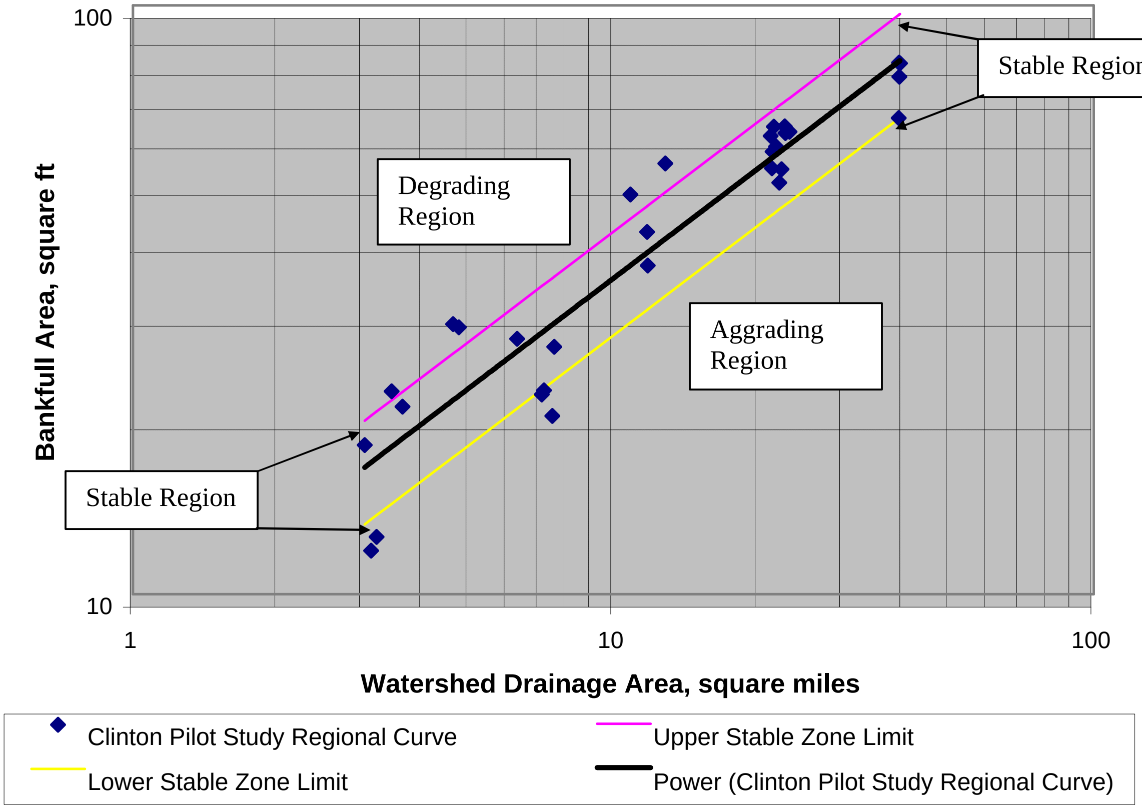
Figure 4.14 shows a significant positive correlation of the Middle Branch Regional Curve data that was collected. This figure also shows that the regional curve data collected within the Middle Branch channel closely matches that collected in other stable channels within the Thumb area of Michigan, as

well as the N.W. Ohio Drainage District. The data does not match the collected data in more eastern portions of Ohio or the courser region of the “Eastern United States”.

The final step in determining the stability of the Middle Branch uses the regional curve data to assign a rating of “stable”, “aggrading”, or “degrading” to each reach of the river. This rating is given based on the deviation from the regional curve value for the cross sectional area. A significant deviation from the regional curve’s calculated value tends to predict an aggrading or a degrading stream. A cross sectional area that is significantly less than the predicted regional curve value will tend towards an aggraded stream, whereas a cross sectional area significantly greater than the regional curve tends to predict a degraded stream.

Although the departure from equilibrium cannot be definitively determined solely based on the deviation from the predicted cross sectional area provided by the regional curve, this data may be used as a factor in determining the stability of each river reach. Therefore, a range of deviation of plus or minus 20% from the regional curve value has been chosen to be the upper and lower limits of assessing a stable, aggrading or degrading value to each river reach. The value of 20% represents the approximate upper and lower quartile ranges of measured cross sectional area versus predicted cross sectional area from the regional curve. See Figures 4.15 and 4.16 for the output of this analysis.

Figure 4.15: ***Stability Ratings based on the Middle Branch Regional Curve***



5.0 ASSESSMENT OF FUTURE DEVELOPMENT IMPACT AND FORMULATION OF RELATED PROTECTION MEASURES

Converting landuses from those that have low stormwater runoff coefficients (forested, agricultural) to those that have high runoff coefficients (urban, residential, commercial) results in a negative effect on both the watershed hydrology and river morphology. However, with the understanding of the river morphology, and the set of predictive protocols that have been developed as a result of this project, landuse managers and engineers can successfully apply Best Management Practices to these landuse changes to prevent and/or correct an extensive variety of hydrologic and geomorphic problems that have historically resulted from poor planning and practices.

The following sections address the historical relationship that development has had on stream degradation within the Middle Clinton River study area and presents several protocols that could be implemented to reduce future impacts caused by regional landuse development.

5.1 LANDUSE EFFECTS ON STREAM DEGREDATION

The direct and indirect effects of landuse development have been attributed to be the largest contributor to the river morphology's decline within the urbanizing Clinton River Watershed. This is evident within the pilot study area in the following ways:

- Little or no drain/river construction projects have occurred within the Middle Branch of the Clinton River within the last forty years, however, many banks have substantial instabilities evidenced by mass wasting and bank failures (see Figure 5.1).
- Approximately 57% of the total length of the pilot study area is disconnected from the floodplain due to the incised nature of the stream.
- Substantial log jams have been noted in the Middle Branch reaches, which is evidence of bank failures in areas that may have a relatively strong root system (see Figure 5.2).
- The river system in the upstream reaches has a well-connected, developed floodplain. Gradually, the stream morphology transitions to an incised river system. This transition is evidence that the accumulating effect of increased flows generated from upstream reaches is beyond the original channel's capacity to handle the flows, resulting in excess erosion and incision on the downstream reaches.
- The hydrology data located at USGS gage 04164800 (the most downstream point of the pilot study area) has shown a substantial increase in flows over the monitoring time period corresponding to the increased development pressure in the area. The change in streamflow trends for the peak flows, annual mean flows, and bankfull flows for the collected time periods increased 30%, 87% and 57% respectively.
- The pilot study area is located in the portion of the watershed that has experienced the most amount of development in the past 50 years. The development pattern within the Clinton River Watershed has been moving in a primarily south to north direction. The flow trends recorded in the gages in the southern portions of the watershed have primarily stabilized, or have begun to decrease as evidenced at gage 04162900 located in Sterling Heights indicating that development in this area has peaked and/or limited storm water BMPs have been installed in these tributary areas. Similarly, gages in the northern most portions of the watershed have not

experienced substantial changes in recorded flow patterns due to the limited development in those regions. The majority of the gages that have experienced dramatic increases in flow trends are located in communities that are experiencing significant development, located to the north of the highly urban communities (see Figure 2.2 through 2.4).

Figure 5.1: ***Mass Wasting and Bank Failure located at Reach 13 in the Pilot Study Site***

Figure 5.2: ***Log Jam located at Reach 05 in the Pilot Study Site***

The 1978, 1992, and 2001 landuse datasets, from the USGS National Landcover Class Definitions (NLCD) dataset were compared to determine the changes in landuse patterns within the Middle Branch of the Clinton River Watershed. The three datasets do not include the same landuse categories, and therefore the 1978 and 2001 data were reclassified to match the more general classification that is available in the 1992 dataset. Table 5.1 lists the 1978 classification and how each category was reclassified to match the 1992 dataset. Similarly, Table 5.2 lists the 2001 classification and the 1992 landuse equivalent. Table 5.3 summarizes the landuse data for each dataset.

Table 5.1: ***1978 Reclassification based on 1992 NCLD Classification***

1978 Code	1978 Classification Name	Converted to 1992 Code	Converted to 1992 NLCD Classification Name
12	Commercial, Services, and Institutional	23	Commercial, Industrial, Transportation
13	Industrial	23	Commercial, Industrial, Transportation
19	Open and Other	33	Transitional
21	Cropland, Rotation, and Permanent Pasture	82	Row Crops
22	Orchards, Vineyards, and Ornamental	82	Row Crops
23	Confined Feeding Operations	81	Pasture/Hay
24	Permanent Pasture	81	Pasture/Hay
29	Other Agricultural Land	81	Pasture/Hay
31	Herbaceous Rangeland	81	Pasture/Hay
32	Shrub Rangeland	81	Pasture/Hay
52	Lakes	11	Open Water
53	Reservoirs	11	Open Water
112	Multi-Family-Low Rise	22	High Intensity Residential
113	Single Family, Duplex	21	Low Intensity Residential
115	Mobile Home Park	22	High Intensity Residential
121	Central Business District	23	Commercial, Industrial, Transportation
122	Shopping Center, Mall	23	Commercial, Industrial, Transportation
124	Neighborhood Business	23	Commercial, Industrial, Transportation
126	Institutional	23	Commercial, Industrial, Transportation
144	Road Transportation	23	Commercial, Industrial, Transportation
145	Communication Facilities	23	Commercial, Industrial, Transportation
146	Utilities, Waste Disposal	23	Commercial, Industrial, Transportation
171	Open Pit	32	Quarries/Strip Mines/Gravel Pits
173	Wells	11	Open Water
193	Outdoor Recreation	85	Urban/Recreational
194	Cemeteries	85	Urban/Recreational
412	Central Hardwood	41	Deciduous Forest
414	Lowland Hardwood	91	Woody Wetland
421	Pine	42	Evergreen Forest
612	Shrub/Scrub Wetland	91	Woody Wetland
621	Aquatic Bed Wetland	92	Emergent Herbaceous Wetland
622	Emergent Wetland	92	Emergent Herbaceous Wetland

Table 5.2: ***2001 Reclassification based on 1992 NCLD Classification***

2001 Code	2001 Classification Name	Converted to 1992 Code	Converted to 1992 NLCD Classification Name
1	Low Intensity Urban	21	Low Intensity Residential
2	High Intensity Urban	22	High Intensity Residential
3	Airports	23	Commercial, Industrial, Transportation
4	Roads / Paved	23	Commercial, Industrial, Transportation
5	Non-vegetated Farmland	81	Pasture, Hay
6	Row Crops	82	Row Crops
7	Forage Crops / Non-tilled herbaceous	82	Row Crops
9	Orchards / Vineyards / Nursery	82	Row Crops
10	Herbaceous Openland	81	Pasture, Hay
12	Upland Shrub / Low-density trees	81	Pasture, Hay
13	Parks / Golf Courses	85	Urban, Recreational
14	Northern Hardwood Association	41	Deciduous Forest
15	Oak Association	41	Deciduous Forest
16	Aspen Association	41	Deciduous Forest
17	Other Upland Deciduous	41	Deciduous Forest
18	Mixed Upland Deciduous	41	Deciduous Forest
19	Pines	42	Evergreen Forest
20	Other Upland Conifers	42	Evergreen Forest
21	Mixed Upland Conifers	42	Evergreen Forest
22	Upland Mixed Forest	43	Mixed Forest
23	Water	11	Open Water
24	Lowland Deciduous Forest	91	Woody Wetland
25	Lowland Coniferous Forest	91	Woody Wetland
26	Lowland Mixed Forest	91	Woody Wetland
27	Floating Aquatic	91	Woody Wetland
28	Lowland Shrub	91	Woody Wetland
29	Emergent Wetland	92	Emergent Herbaceous Wetland
30	Mixed Non-Forest Wetland	92	Emergent Herbaceous Wetland
31	Sand / Soil	32	Quarries, Strip Mines, Gravel Pits
32	Exposed Rock	32	Quarries, Strip Mines, Gravel Pits
33	Mud Flats	32	Quarries, Strip Mines, Gravel Pits
35	Other Bare / Sparsely Vegetated	32	Quarries, Strip Mines, Gravel Pits

Table 5.3: ***Summary of Landuse Classifications for 1978, 1992, and 2001 Data Sets***

1992 NLCD Code	1992 NLCD Classification	Area of Landuse in 1978, square miles	Area of Landuse in 1992, square miles	Area of Landuse in 2001, square miles
11	Open Water	0.18	0.25	2.96
21	Low Intensity Residential	7.68	4.68	4.34
22	High Intensity Residential	0.20	0.58	4.12
23	Commercial, Industrial, Transportation	2.47	1.02	3.95
32	Quarries/Strip Mines/Gravel	0.06	0.00	0.08
33	Transitional	0.01	0.06	0.00
41	Deciduous Forest	2.05	10.58	7.53
42	Evergreen Forest	0.12	0.54	1.85
43	Mixed Forest	0.00	0.09	0.91
81	Pasture/Hay	9.57	4.80	8.62
82	Row Crops	15.92	14.91	0.31
85	Urban/Recreational	0.17	2.14	0.35
91	Woody Wetland	2.71	1.51	4.32
92	Emergent Herbaceous Wetland	0.06	0.04	1.88

The impact of landuse data on watershed hydrology is often determined by calculating the percent imperviousness for each landuse type. Table 5.4 reflects the generally accepted percent impervious values for various land use classifications that were developed as part of the EPA's PLOAD version 3.0 User's Manual, January 2001.

Table 5.4: ***Table of Percent Impervious***

1992 NLCD Code	1992 NLCD Classification	Percent Imperviousness
11	Open Water	100%
21	Low Intensity Residential	15%
22	High Intensity Residential	40%
23	Commercial, Industrial, Transportation	85%
32	Quarries/Strip Mines/Gravel	20%
33	Transitional	30%
41	Deciduous Forest	2%
42	Evergreen Forest	2%
43	Mixed Forest	2%
81	Pasture/Hay	2%
82	Row Crops	2%
85	Urban/Recreational	75%
91	Woody Wetland	100%
92	Emergent Herbaceous Wet	100%

Table 5.5 calculates the percent imperviousness in the sub watershed for the three time periods in the NLCD datasets. Surface water and wetlands were subtracted from these areas for the percent imperviousness analysis in order to calculate the percent imperviousness for developable land only.

Table 5.5: *Percent Impervious for the Pilot Study Area based on 1978, 1992, and 2001 Data Sets*

1992 NLCD Code	**1992 NLCD Classification**	**Impervious Area in 1978, square miles**	**Impervious Area in 1992, square miles**	**Impervious Area in 2001, square miles**
21	Low Intensity Residential	1.15	0.70	0.65
22	High Intensity Residential	0.08	0.23	1.65
23	Commercial, Industrial, Transportation	2.10	0.87	3.36
32	Quarries/Strip Mines/Gravel	0.01	0.00	0.02
33	Transitional	0.00	0.02	0
41	Deciduous Forest	0.04	0.21	0.15
42	Evergreen Forest	0.00	0.01	0.04
43	Mixed Forest	0.00	0.00	0.02
81	Pasture/Hay	0.19	0.10	0.17
82	Row Crops	0.32	0.30	0.01
85	Urban/Recreational	0.13	1.61	0.26
Total Impervious Surface Area (Without Surface Water Area)		4.03	5.55	6.31
Total Subwatershed Area (Without Surface Water Area)		38.25	39.40	32.04
Percent Impervious		**10.5%**	**14.1%**	**19.7%**

The output of Table 5.5 highlights the landuse changes within this developing subwatershed. When compared with the earlier datasets, the 2001 landuse data had the most significant changes in the following landuses:

- Increase in High Intensity Residential
- Increase in Commercial, Industrial, Transportation
- Decrease in Agricultural related landuses

These observations are consistent with the current development trends, which primarily consists of the conversion of agricultural land (active and fallow) to residential and commercial land. Due to these development patterns, the resultant increase in impervious surface area, and the observed increase in numerous streamflow parameters, it is concluded that the conversion of previously agricultural land to urban uses such as residential, commercial, industrial and transportation has had the most significant negative effect on the watershed hydrology.

5.2 STREAM SENSITIVITY IDENTIFICATION

In order to implement watershed-wide restoration or ordinance development, specific target goals must be kept in mind. These goals may include a) preserving existing high quality waters; b) controlling storm water runoff to prevent further destabilization in areas where development has adversely affected adjacent streams; and c) controlling sediment transport and pollution in areas where extreme urbanization has altered the stream so significantly that the watercourses may be considered artificial, and natural river evolutionary processes are no longer present. These varying goals require the implementation of specific Best Management Practices based upon the existing watershed condition. This condition is typically a function of percent impervious surfaces, and therefore, a quantitative impervious value may be one of the factors used to determine stream sensitivity.

If a stream is susceptible to alterations caused by changes in the flow, sediment discharge, bank characteristics, or other factors then it is characterized as having a high sensitivity to disturbance. This value is mostly a function of bed material, with silt and sand channels having the highest sensitivity to any natural or human-induced disturbances. The degree of imperviousness and the potential for bank erosion and other physical changes to the stream morphology can be used to determine the state of the river and the potential for flow induced changes.

5.2.1 Impervious Surface of Subwatersheds

The Center for Watershed Protection cites that “a watershed with 11-25 percent impervious cover will result in adverse impacts to streams, and 25% or greater will result in seriously degraded streams”. Therefore, based on a simple landuse analysis a sub watershed sensitivity may initially be categorized as follows:

- Less than 10% impervious yields a qualitative “Low” sensitivity value
- Between 10% and 25% impervious yields a qualitative “Medium” sensitivity value
- Greater than 25% imperviousness yields a qualitative “High” sensitivity value

5.2.2 Bank Erosion Hazard Index and Pfankuch Values

The Bank Erosion Hazard Index (BEHI) and Pfankuch scores provide information on the existing and potential erosion condition of a stream. Unlike the Impervious Surface values, which may be calculated using existing GIS data, the BEHI and Pfankuch are calculated based on data collected in the field. These values provide a more accurate “real world” depiction of actual stream conditions due to the measurable stream parameters collected in these analyses.

The BEHI is a quantitative measurement of various stream and river bank values, however, the BEHI condition is a qualitative value as defined by Rosgen’s modified method (Table 5.6).

Table 5.6: ***BEHI Scores and Relative Erosion Hazard***

Hazard or Risk Description	**BEHI Total**
Very Low	5 – 9.5
Low	10 – 19.5
Moderate	20 – 29.5
High	30 – 39.5
Very High	40 – 45
Extreme	> 45

Similarly Rosgen provides a modified Pfankuch value based on stream type. These values for each stream type that are located within the Middle Branch of the Clinton River Watershed are listed in Table 5.7.

Table 5.7: ***Pfankuch Scores and Relative Erosion Hazard***

Stream Type	**“Good” Pfankuch Values**	**“Fair” Pfankuch Values**	**“Poor” Pfankuch Values**
C4	70 - 90	91 - 110	> 110
E4	50 - 75	76 - 96	> 96
E5	50 - 75	76 - 96	> 96
F4	85 - 110	111 - 125	> 125
F5	90 - 115	116 - 130	> 131
G5	90 - 112	113 - 125	> 126

When attempting watershed-wide restoration or prioritization of areas within a watershed, the BEHI or Pfankuch values will not be available at every location. Therefore an initial screening may be useful to prioritize likely sensitive streams. As shown previously, the BEHI values are typically higher for streams that are classified as a “G” or an “F” stream type (see Figure 4.12). The “G” and “F” streams are incised streams that are disconnected from an active floodplain. These stream types typically have higher BEHI values due to the very large shear stresses that occur on the river banks under flood conditions. “C” and “E” streams typically have lower Pfankuch and BEHI values due to the active floodplain, which will spread out the flow across a much larger area, thus minimizing shear stress at a single location, such as the river banks (these lower Pfankuch values for the “C” and “E” stream types are also shown in Table 5.8). Therefore, an initial classification using Aerial Photos, USGS maps and other GIS data may be used to determine areas that are sensitive based initially on stream types. It will be necessary however to verify the conclusions of this initial screening analysis through the establishment of several ground control points within the restoration and/or prioritization area to confirm the actual filed conditions.

ECT conducted this type of geomorphic analysis on all streams with a watershed drainage area greater than one square mile in Oakland Township, Michigan. Alluvial streams were classified using the following available indicators:

- Highly meandering streams with apparent flat adjacent areas (floodplains) were classified as "E"
- Wide streams with lower meander patterns and with evidence of an adjacent floodplain were classified as "C"
- Straight narrow rivers adjacent to locally steep valleys were classified as "G"
- Streams that had a noticeable meander pattern but locally steep valleys were classified as "F"

Colluvial streams were typically classified as a "B" stream type if a well-defined colluvial valley was present.

These streams were then classified using a Rosgen Level I classification at 22 sites with field methods that have described previously in this report. Longley et al. describes the use of geostatistics and the confusion matrix to determine the goodness of fit for a resampled discrete classification dataset, such as a Rosgen Level 1 classification. The following matrix displays the data for the Oakland Township study.

Table 5.8: ***Matrix of Initial vs. Field Verified Stream Classifications in Oakland Township Study***

	Initial Classification						
		B	C	E	F	G	**Total**
Field Verified Classification	B	0	0	1	0	0	**1**
	C	0	2	0	1	0	**3**
	E	0	2	10	2	2	**16**
	F	0	0	0	0	0	**0**
	G	0	0	0	1	1	**2**
	Total	**0**	**4**	**11**	**4**	**3**	**22**

These data yield a Percent Correctly Classified (PCC) value of 59.1%. The Kappa index was also calculated for this data set, which is a value ranging from -1 to 1 and represents whether or not the data is distributed randomly or not. A Kappa index value of approximately zero suggests a random distribution within the confusion matrix; a value less than one represents that the classification method used will typically misclassify the data; and a value greater than one suggests that the classification method yields results that are correlated. The value of the Kappa Index for this data set is 31.7%, representing a good correlation between the initial classification and the field verified classification and substantiating that this stream analysis approach will provide useful information for determining critical watershed areas for BMP implementation. This value would warrant the need for ground control points to be collected, but only a sample of the total number of sites would need to be collected.

5.2.3 Regional Curves

The regional curve information may be applied to determine the current state of a river reach from an erosion and sedimentation perspective. Due to the representativeness of the pilot study area to the Clinton River Watershed as a whole, the data collected in Middle Branch of the Clinton River provides a baseline value that may be applied throughout the watershed. The bankfull cross sectional area in square feet (Bf_A) has been calculated as a function of the watershed drainage area in square miles (W_A) using the following equation:

$$Bf_A = 8.25 W_A^{0.62}$$

It is anticipated that larger bankfull cross sectional areas will be measured in the extreme urban settings in the southern portions of the Clinton River Watershed, and that slightly smaller cross sectional areas will be found in the northern portions of the watershed. Therefore, this equation provides a baseline to determine whether an existing reach has a bankfull area that is similar to an urban stream, rural stream or developing stream.

5.2.4 Protocol to Determine Stream Stability

Given the information in the previous sections, the stream stability for a site within the Clinton River Watershed may be determined using the following procedure:

1. Calculate the percent imperviousness for the subwatershed where the site is located
2. Calculate the BEHI values and the Pfankuch values for the site
3. Identify bankfull indicators and survey the stream's bankfull cross sectional area at a riffle section in the watercourse
4. Calculate the upstream watershed drainage area.
5. Calculate the expected bankfull cross sectional area using the regional curve equation for the Middle Branch of the Clinton River Watershed.

These steps should be repeated at multiple locations for regional projects or watershed management projects. Also, two additional steps should be conducted for these types of projects:

6. Using aerial photography and USGS quadrangle maps, identify the streams within the subwatershed and classify the watercourses to a Rosgen Level I classification
7. Field determine several locations to verify the Rosgen classification.

5.2.5 Stream Stability Interpretation and Application

For sites in subwatersheds with a percent imperviousness value less than 10%:

- The surveyed bankfull cross sectional area is expected to be slightly less than the calculated cross sectional area based on the regional curve information. Sites with cross sectional areas greater than the regional curve are expected to be in an eroded and sensitive state.
- For sites that have a measured cross sectional area less than the expected value based on the regional curve, the stream is likely stable, but a very high Pfankuch or BEHI value may determine that the site is sensitive.

Restoration priorities in these watersheds should be based on whether the stream is connected to the floodplain and on the BEHI/Pfankuch values.

For sites in subwatersheds with a percent imperviousness value between 11% and 25%:

- If the surveyed bankfull cross sectional area is approximately equal to the regional curve value, then the site stability is based on the BEHI and Pfankuch values.
- If the surveyed bankfull cross sectional area is much less than the regional curve value, then the site is in an aggraded state, which is evidence of instabilities upstream of the site.
- Sites that have a higher surveyed bankfull cross sectional area than expected are in a morphologically unstable state.

Ordinances to reduce the allowable storm water discharge rate per acre may be best suited in these watersheds with impervious surfaces between 11% and 25%. Also, bank stability restoration projects in these watersheds should be based on the areas that have significantly higher bankfull cross sectional areas than the calculated expected value.

For sites in subwatersheds with a percent imperviousness value greater than 25%:

- The surveyed bankfull cross sectional area is expected to be slightly more than the calculated cross sectional area based on the regional curve information. Sites with cross sections less than the regional curve are expected to be in an aggregated state.

Projects that implement the control of sediment transport are most applicable in watersheds with very high percent impervious surface values.

The previous listed protocols may be used as guidelines as to whether a stream is morphologically unstable and provide a description of what data is most important in determining the stream stability. The actual determination of a stream’s departure from equilibrium, and the likely success of an engineering project or Best Management Practice can only be determined by a trained river morphologist.

5.3 STABLE STREAM TEMPLATES

“C” and “E” stream types provide the most stable stream system for alluvial valley systems, such as those commonly found in Southeast Michigan,. This is due to the established connection to a floodplain for these river types. Therefore, the goal for an alluvial stream system is to provide either an actual or pseudo floodplain in order to reduce shear stresses on the banks at very large flows. The North Carolina Stream Restoration Institute has identified four restoration options for incised channels,. These include the following:

- Priority 1: Establish bankfull stage at the historical floodplain elevation
- Priority 2: Create a new floodplain and stream pattern with the stream bed remaining at the present elevation
- Priority 3: Widen the floodplain a the existing bankfull elevation
- Priority 4: Stabilize existing streambanks in place

Figures 5.3 through 5.5 show an example of Priority 1-3 restoration options (figures from the *Stream Restoration: A Natural Channel Design Handbook*, by the North Carolina Stream Restoration Institute):

Figure 5.3: *Priority 1 Restoration*

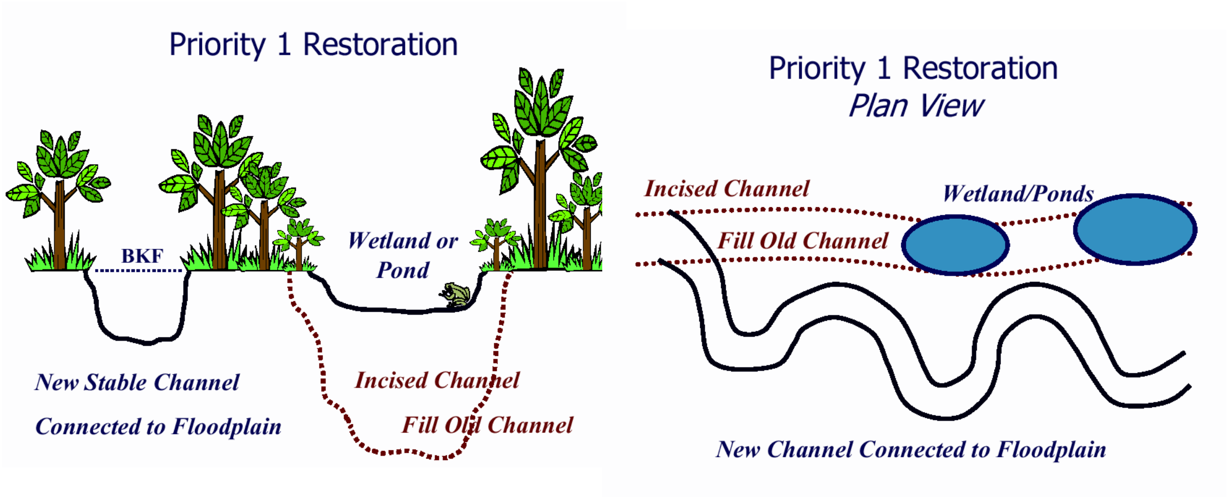


Figure 5.4: *Priority 2 Restoration*

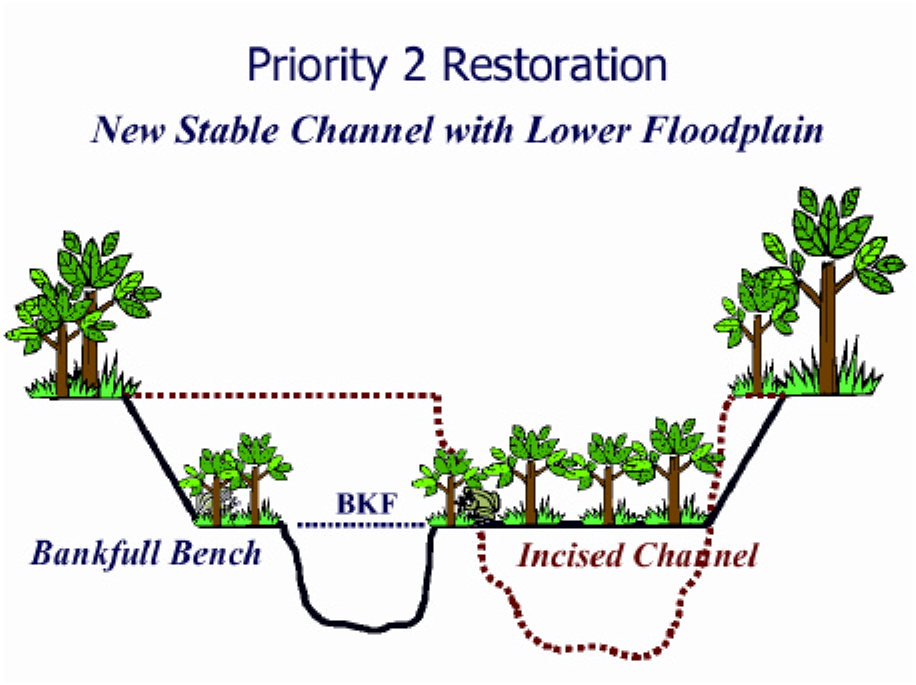
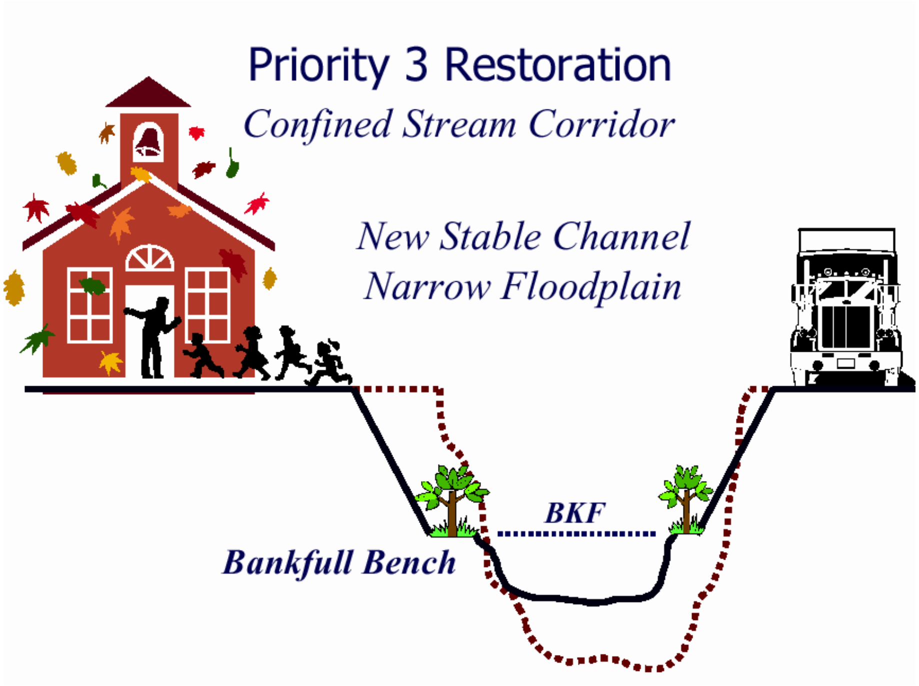


Figure 5.5: Priority 3 Restoration



The North Carolina Stream Restoration Institute cites several advantages and disadvantages to each of the four priority restoration types. These are summarized in Table 5.9.

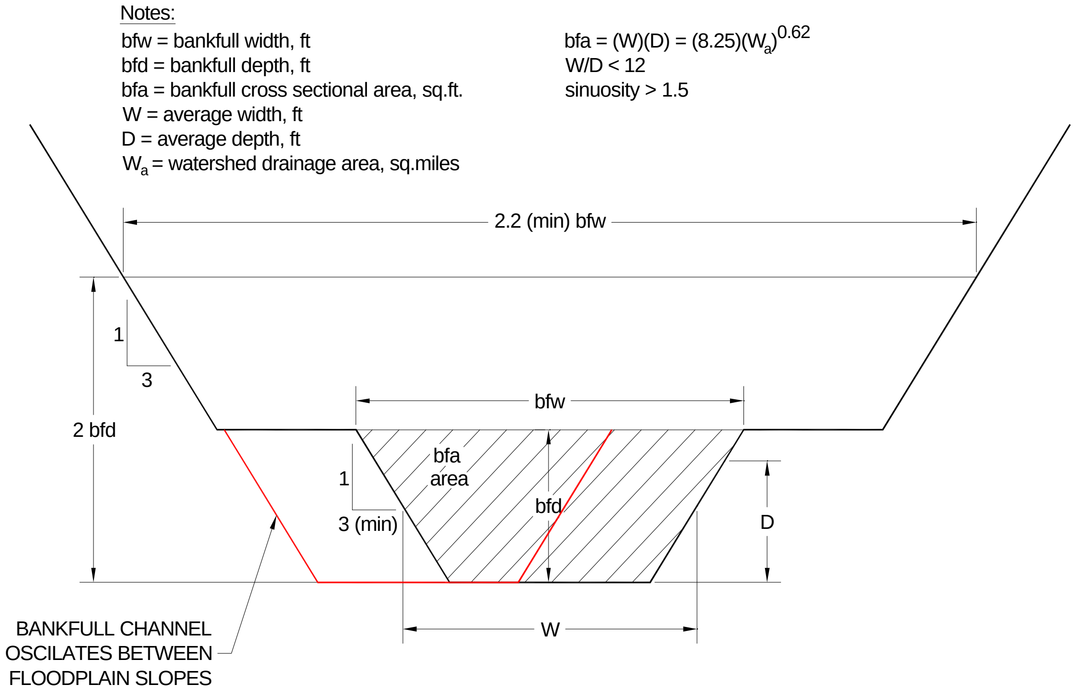
Table 5.9: ***Advantages and Disadvantages of Restoration Options for Incised Streams***

Option	Advantages	Disadvantages
1	• Results in long-term stable stream • Restores optimal habitat values • Enhances wetlands by raising water table • Minimal excavation required	• Increases flooding potential • Requires wide stream corridor • Unbalanced cut/fill • May disturb existing vegetation
2	• Results in long-term stable stream • Improves habitat values • Enhances wetlands in stream corridor • May decrease flooding potential	• Requires wide stream corridor • Requires extensive excavation • May disturb existing vegetation • Possible imbalance in cut/fill
3	• Results in moderately stable stream • Improves habitat values • May decrease flooding potential • Maintains narrow stream corridor	• May disturb existing vegetation • Does not enhance riparian wetlands • Requires structural stabilization measures • May require maintenance
4	• May stabilize streambanks • Maintains narrow stream corridor • May not disturb existing vegetation	• Does not reduce shear stresses • May not improve habitat values • May require costly structural measures • May require maintenance

The applicability of each restoration option depends on factors such as costs, feasibility, maintenance requirements, and structural restrictions (roads, buildings, etc).

Due to the strong correlation between low BEHI values and the presence of a floodplain, it is the recommendation of this study to design future restoration projects based on a floodplain that is as wide as approximately 2.2 times the bankfull width. The following stream template may be used for future restoration design on incised reaches within an urbanizing watershed (Figure 5.6):

Figure 5.6: ***Incised Stream Restoration Design Template***



Notes:
bfw = bankfull width, ft
bfd = bankfull depth, ft
bfa = bankfull cross sectional area, sq.ft.
W = average width, ft
D = average depth, ft
W_a = watershed drainage area, sq.miles

$bfa = (W)(D) = (8.25)(W_a)^{0.62}$
$W/D < 12$
sinuosity > 1.5

5.4 PILOT STUDY SITE RESTORATION STRATEGY

A detailed restoration prioritization and strategy has been developed for the pilot study area based on the findings of this study. A watershed restoration plan for the pilot study area should have the following goals and objectives:

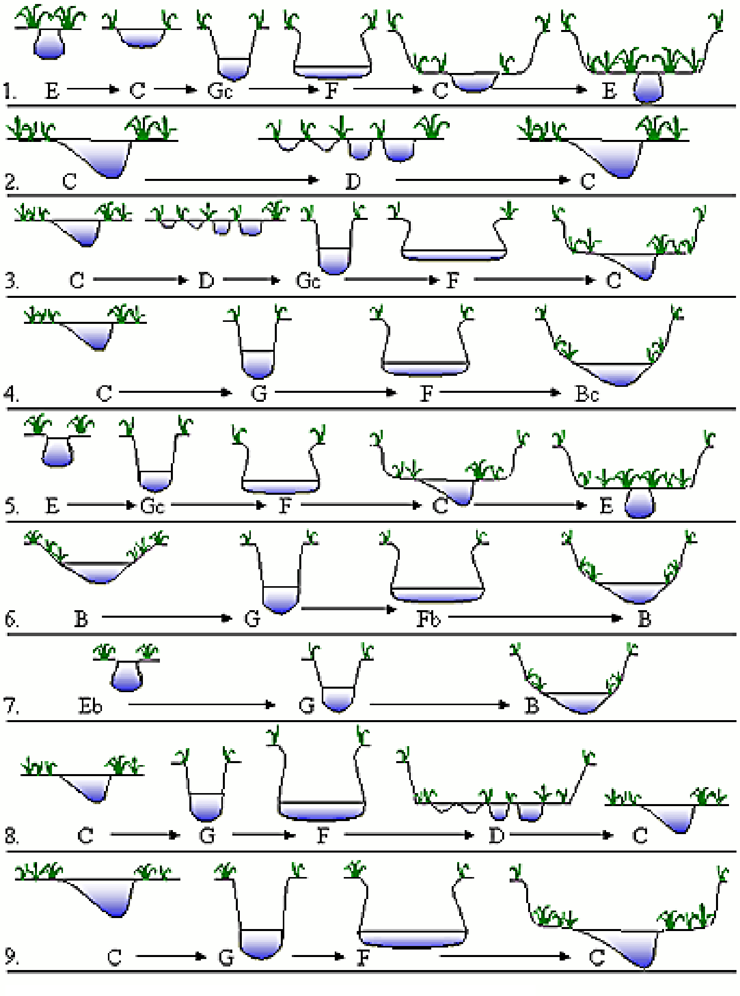
- Reduce sediment loading to the Clinton Main branch by reducing the amount of streambank erosion
- Reduce non-point pollution generated in the watershed by creating or enhancing buffer zones or wetlands adjacent to the stream
- Stabilize the hydrology of the stream by limiting the rate of storm water discharge and increasing detention/retention in future development.

5.4.1 Existing Stability of Pilot Study Area

The existing Rosgen Level II classification, which identifies the current type of river based on quantifiable parameters, has been determined for each of the thirty stream reaches within the pilot study area,. It is also important when designing Best Management Practices and restoration plans to identify if the river morphology is so active that it is converting the existing river type to another river type. Ignoring this high state of activity may result in the selection of an inappropriate BMP or failure of implemented BMPs.

U.S. Environmental Protection Agency identifies several channel evolutionary models in their Watershed Assessment of River Stability and Sediment Supply (WARSSS) program. Figure 5.7 graphically displays these typical river evolutionary patterns using the Rosgen classification nomenclature:

Figure 5.7: ***Identified River Evolutionary Patterns***



(Figure from EPA's WARSSS program)

The pilot study watershed's reaches are shown in Figure 5.8 and are summarized as follows:

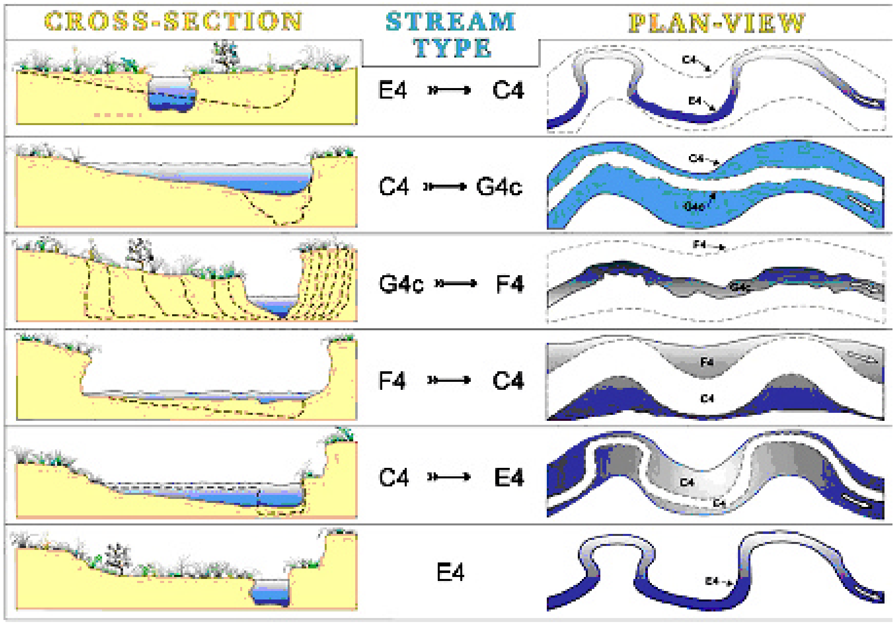
Downstream reaches 1-16: The downstream reaches of the pilot study area consist of a wide, shallow stream type that is primarily disconnected from the floodplain. This river type is classified as an "F" stream in the Rosgen classification system. Although the cross sectional area of this portion of the river closely matches this watershed's and other local regional curves, there is aggradation of sediment, which is evident that the stream is evolving into an "E" stream type and is beginning to create a terrace, or abandon the previous floodplain. Additionally, there are log jams and portions of spotty (but severe) erosion.

Middle reaches 17-19: The middle reaches of the pilot study area consist of a narrow and deep river type that is disconnected from an established floodplain (Rosgen "G" stream type). The cross sectional area of the river is larger than the regional curve would predict which would predeict severe erosion problems. These severe erosion problems are generally not exhibited due to the dense vegetation throughout this section of river. This portion of the river does not appear to be evolving to another stream type, however, if shear forces exceed the vegetation's ability to maintain its root structure, then it would be expected that this "G" stream will begin to evolve into an "F" streamtype.

Upstream reaches 20-30: The upstream reaches consist of a meandering deep river of medium width that is primary connected to a floodplain. This river type is an "E" stream in Rosgen's classification, however, these reaches have wider cross sections than a typical "E" stream. This is evidence that the stream is evolving to a "C" stream. Although "E" streams are naturally formed and expected in the Middle Clinton's valley type, there is alternating erosion and deposition sections throughout these stream reaches, which is a sign of instability.

Based on the field observations, the prevalent channel evolutionary model that is exhibited in the Middle Branch of the Clinton River Watershed is an E-C-G-F-C-E pattern, where the final "E" stream type develops at a lower elevation and abandons the previous floodplain, resulting in terraces. See Figure 5.9 for a graphical example of the morphological processes that are occurring in the pilot study area.

Figure 5.9: ***Morphological Evolution in the Middle Branch of the Clinton River Watershed***



(Figure from Dave Rosgen's Applied River Morphology)

5.4.2 Pilot Study Area Restoration Recommendations

A restoration strategy that prioritizes areas for restoration, and identifies successful restoration BMPs has been established for the pilot study area bearing in mind the existing stage of the channel evolutionary model.

Upstream reaches 20-30:

These reaches are predominately classified as "E" or "C" stream types and are in the beginning of the channel evolutionary process. The E-C-G-F-C-E pattern begins by first widening and then incising a previously stable E stream (evidence of both of these processes are occurring in these stream reaches). Grade control structures such as cross vanes in straight riffle sections are suggested to prevent further incision,. Rootwads or other streambank stabilization techniques are suggested at critical bends in the river to prevent further widening,. The priority of many of these reaches are considered high due to the large potential for future stream changes.

Middle reaches 17-19:

These reaches have converted from the "E" and "C" stream types to the "G" stream type and are incised and disconnected from the floodplain. This is a very unnatural stream type for the watershed's valley type and will ultimately widen to an "F" stream type (as has already occurred downstream of these reaches). Streambank stabilization is not recommended In eroded sections of these river reaches due to the high likelihood of failure. Grade control structures are also not necessary due to the already incised nature of the stream. A floodplain reconnection using a Priority 1 restoration scenario is recommended, which will reconnect the channel to the previous floodplain and convert it back to the original "E" stream (similar to upstream reaches). A Priority 2 restoration plan may also be executed which will advance the stream to the final "E" type in the E-C-G-F-C-E pattern. A Priority 3 design may be incorporated if there are structural limitations, however, it is likely to have a lower success rate than the Priority 1 or 2 restoration types. The priority of these reaches for restoration is considered medium due to the existing relative stability on these reaches caused by the existing vegetation. However, there is also high potential for future stream changes due to the stream being disconnected from the floodplain.

Downstream reaches 1-16:

The sixteen downstream reaches are primarily an "F" stream type. Although engineering projects have contributed to the river morphology in these reaches, the F stream is beginning to convert to a "C" and ultimately will change to a stable "E" type. Similarly to reaches 17-19, bank stabilization projects are likely to have limited success in these areas. A Priority 2 restoration plan may be implemented in these reaches to convert the stream back to a stable "E" system. Other restoration types that are applicable for these reaches are buffer strips, wetlands, in-line detention and sediment traps to control additional erosion and accelerate aggradation. Restoration is considered medium to low for these reaches due to the stream's natural tendency to correct itself back to an "E" stream. This will, however, only occur naturally once the hydrology of the system has been stabilized.

Watershed Wide Ordinance Recommendations:

Due to the noted instabilities in the hydrology of the entire system, it is recommended that storm water discharge rates within the pilot study area be reduced in future developments. Low-impact development techniques or increasing detention/retention in future developments are suggested methods to reduce storm water discharges. If local zoning ordinances based on impervious surface or stream conditions are considered then the pilot study area should be considered as a low-impact development zone.

6.0 CONCLUSIONS

A large portion of the Clinton River Watershed is currently not in a state of equilibrium from both a hydrologic and geomorphic standpoint. This is particularly evident in the Middle Branch of the Clinton River Watershed where a pilot study site to characterize the stream condition in this urbanizing watershed. With the understanding of the river morphology, and the set of predictive protocols that have been developed as a result of this project, landuse managers and engineers can apply successful Best Management Practices to address an extensive variety of hydrologic and geomorphic problems related to past and future development pressures within the region. These tools include:

- Analyzing various hydrologic parameters to determine numerous flow trends in the watershed. This highlights regions where flow variability is greatest within a watershed which can then be addressed by local ordinances.
- Characterizing the existing state of a watershed using land use analysis and development trends. These trends can then be compared with development trends to initially determine a link between flow variability and local development practices.
- River classification and erosion analyses to assess the watershed’s streams and determine the existing departure from equilibrium. These analyses assist in determining the stream’s erosion potential, natural recovery potential, and numerous other parameters that may assist in determining the content and success of a restoration strategy.
- Developing regional curves to characterize and quantify if the stream is currently in an eroded or aggraded state
- The use of a drain/stream design template for future developments or stream modification projects based on regional curve information
- Determination of the current state of a river system in a channel evolutionary model in order to prioritize restoration and quantify the success rate of applied Best Management Practices.

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