USING AN INTEGRATIVE APPROACH TO RESTORE A NATURAL FLOW REGIME IN THE CLINTON RIVER WATERSHED

Revised Report Submitted to Michigan Sea Grant

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1.0 Executive Summary

This project is an attempt to address the causes, consequences and correctives of interrupted flows in the Upper Clinton River Subwatershed and the Main Clinton River Subwatershed that impact fish and wildlife habitat and recreational uses in the Clinton River watershed. The Upper Clinton and Clinton Main Subwatersheds of the Clinton River Watershed contain twenty-one separate level controlled impoundments and/or lakes, most of which have a court-authorized level. A majority of the court-authorized levels were set in 1966 independently of the other lakes in the system as was customary at the time based on legal standards.

The court-authorized levels are legally required to consider the "health, safety, and welfare" of the public, protect private property, and preserve the natural resources of the state. However, protection of "natural resources of the state" had a different connotation fifty years ago than today and was considered after the primary drivers of protection of property and public safety. Finally, judges setting lake levels were not required to consider, how each lake interacts with other lakes or the watershed as a system. As a result there is not a comprehensive management plan for the Clinton River to optimize system performance in meeting the varying stakeholder objectives within the system. On the contrary, the multiple independent operating plans are often contradictory and lead to abrupt, unnatural changes in water level which adversely impact fish and wildlife habitats and the species that rely upon them, as well as other water based objectives. This has placed stakeholders against each other. For example, lake owners prefer established and set lake levels to optimize recreational opportunities in the summer (primarily boating) and minimize property damage risk (flooding, ice, etc.). Conversely, river owners and users desire additional flow in the summer months for recreational, environmental, and aesthetic benefits. Restoring a more natural flow regime would help ameliorate negative impacts while hopefully resolving conflict between stakeholder interest.

The objectives for this Integrated Assessment (IA) were:

- Increase the general knowledge of the regions residents and project stakeholders on the status and trends of environmental, social and economic causes and consequences of the current conditions and trends related to interrupted flows in the Clinton River
- Increase the general knowledge of the regions residents and project stakeholders on the benefits of restoring a more natural flow regime in the Clinton River based on the status and trends documented
- Develop a simple hydrologic model for the system as an attempt to evaluate and demonstrate how the impoundments interact with each other (i.e. what is the hydrologic conductivity between the impoundments) as well as the downstream receiving waters (the Clinton River)
- Develop a comprehensive socio-economic-environmental model of the system that can be used as a tool for providing forecasts of likely future environmental, social, recreational and economic conditions based on the different policy and/or management options identified by the stakeholders along with uncertainty associated with those actions
- Provide recommendations to the Oakland County Water Resources Commissioners Office on how court ordered regulations might be altered to attempt to restore a natural flow regime,
- Provide recommendations to other federal agencies such as the National Oceanic and Atmospheric Association (NOAA), U.S. Environmental Protection Agency (USEPA), and U.S. Army

Corps of Engineers (USACE) on restoration projects they could undertake under the Great Lakes basin restoration programs
- Provide recommendations to the watershed's 63 communities/municipalities on ways to mitigate impact on the flow regime and dissemination/education/outreach programs across the region
- Develop a comprehensive integrated assessment case study for hydro-modification of a system that could be implemented in other watersheds across the Great Lakes region as communities further consider issues such as ecologic restoration, impoundment operation, and dam removal
- Develop a demonstration project that would serve as a pilot for other Great Lake basin watersheds suffering from un-natural flow regimes

To meet the objectives, the project leadership team utilized the integrated assessment process. The integrated assessment process brings together relevant environmental, economic, and social information to better support decision-makers' needs. The integrated assessment question to be addressed is "What are the causes, consequences and correctives of interrupted flows in the Upper Clinton River Subwatershed and the Main Clinton River Watershed that impact habitat and recreational uses in the Clinton River Watershed?"

As such, the project:
- Formed an advisory board to oversee project implementation and represent key stakeholder interests
- Synthesized existing environmental, economic, and social information
- Conducted stakeholder informational meetings
- Generated and widely distributed a stakeholder survey to gather opinions
- Developed a simplified mass-balance hydrologic model to represent how the watershed interacts
- Developed a socio-economic model to evaluate alternative management scenarios

Based on funding constraints and integrated assessment process requirements, the project did not include:
- Collecting additional environmental field data
- Developing a comprehensive hydrologic model or an ecosystem function model to quantify flow requirement for river ecology
- Engineering new lake-level control structures and the cost-benefit analysis associated with replacing existing control structures
- Incorporating future climate change or watershed management scenarios into the project

These represent potential future phases of the project. The project did yield important hydrologic, environmental, and socio-economic findings. Key findings of the hydrologic analysis include:
- Oakland County Water Resources Commissioner's office spends significant effort and resources managing a very complex hydrologic system
- River flow (both low and high discharge) can be influenced by lake level management
- Rapid release of water from rainfall events creates high peak flows and flashiness in the river compared with natural flow
- Delaying the release of rainfall events of 2" or less could reduce the peak flow in the Clinton River by 15% to 20%

- Steadily releasing volume of rain over the watershed over a two week period is enough to create a base flow for the river
- Management options can create a more natural flow regime and improved watershed interactions, flow, temperature, and channel morphology

Key findings of the environmental analysis include:
- Court ordered lake levels are compromising watershed ecosystem health under current conditions
- Moderate lake level changes could improve condition in the river and overall ecosystem health of the lakes and river
- A more natural flow regime will improve:
    - Flow and water quality in the river
    - Improved aquatic and riparian vegetative communities
    - Improved amphibian populations, macro-invertebrate communities, and improved spawning habitat
    - Improved fishing and wildlife viewing in river and lakes
- Endangered species and species of concern exist in the study area

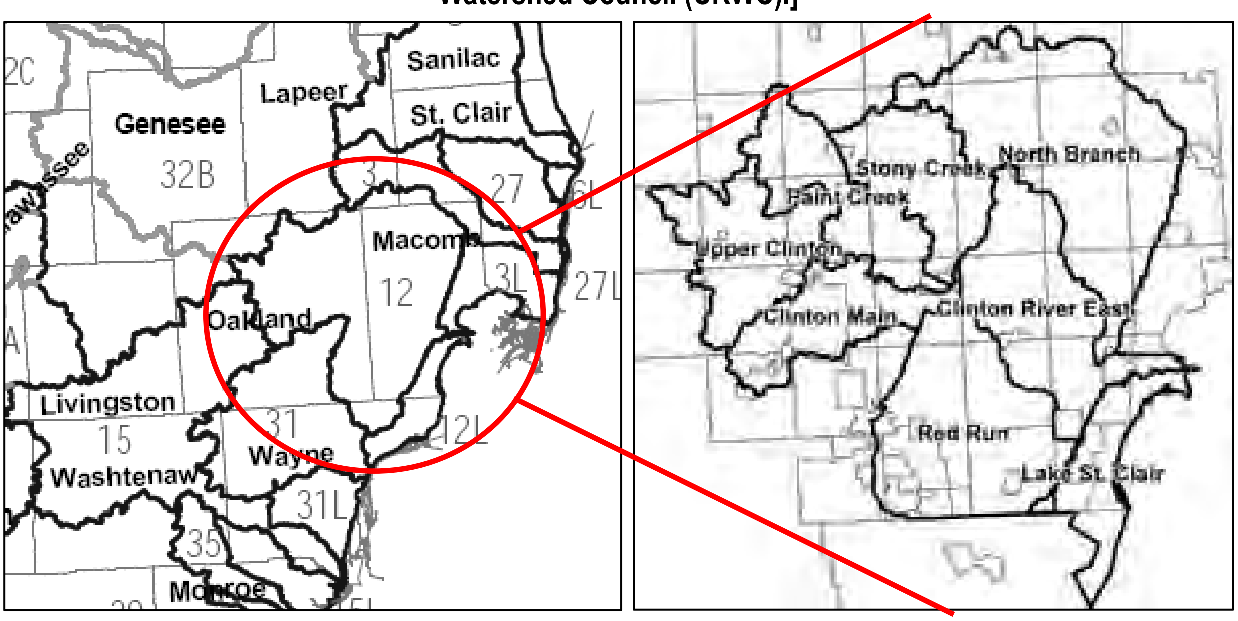
Key findings of the socio-economic analysis include:
- Clinton River watershed provides valuable services (recreation, aesthetics, etc.) to commercial entities and individual households
- Watershed management affects the economic and social welfare of the region
- Stakeholders would accept moderate lake level fluctuations for overall health of the lakes and river
- No significant adverse effects (including property values) to lake recreators or property owners from hydro-modification scenarios considered were found
- Increase in water flow provides more opportunities in Clinton River especially during extreme lows
- Millions of dollars of revenue in usage benefit associated with a more natural flow regime

Key implementation options discussed later on in this report, include the following:
- Maintain status quo
- Optimize lake management within the current legal framework
- Petition the court to revise individual lake levels
- Develop a recommended lake level in conjunction with lake associations and pursue a joint petition on behalf of all lakes
- Push for legislative action at the state level to mandate and fund a revision of all the court mandated water levels
- File a lawsuit to force a change
- Use green infrastructure to promote infiltration and minimize runoff to offset lake level related changes associated with urbanization

2.0 Project Introduction

The Upper Clinton and Clinton Main Subwatersheds of the Clinton River Watershed (see Figure 2.1) contain 21 separate controlled impoundments/lakes, most of which have a court-authorized level set independently of the other lakes in the system. A majority of the court-authorized levels were set in 1966 (13 of the lakes) with the earliest court ordered lake-level in the system set in 1958 (Lake Oakland) and the most recent in 2003 (Watkins Lake). The court-authorized levels are legally required to consider the "health, safety, and welfare" of the public, protect private property, and preserve the natural resources of the state. However, protection of "natural resources of the state" has a much different connotation fifty years ago than today and was considered after the primary drivers of protection of property and public safety. Finally, judges did not consider, and were not required to consider, how each lake interacts with other lakes or the watershed as a system when setting court-authorized levels. As a result there is no comprehensive management plan that addresses the varying stakeholder objectives within the system. In fact, the multiple independent operating plans are often contradictory and lead to abrupt, unnatural changes in water level which adversely impact numerous water based objectives. This integrated assessment addresses the causes and consequences of interrupted flows in the system that impact fish and wildlife habitat and recreational uses in the Clinton River watershed. Further, this assessment developed tools and metrics that can be used by the policy makers to identify, evaluate, and build consensus for revised flow management policies within the watershed. In conclusion, this project represents the exact opportunity that the Michigan Sea Grant Integrated Assessment Program is designed to address and will help restore a natural flow regime to mitigate the negative impacts. Finally, this project serves as a beneficial demonstration project on how to conduct integrated assessments on urbanizing/urbanized watersheds in the Great Lakes region.

Figure 2.1: (a) Left - Clinton River Watershed in Southeast Michigan (#12 in Map) and (b) Right - Clinton River Watershed showing subwatersheds including Upper Clinton and Clinton Main in Oakland County. [Figure 2(a) courtesy of MDNR and Figure 2(b) courtesy of Clinton River Watershed Council (CRWC).]



3.0 Objectives and Methodology

Objectives

The objectives for this Integrated Assessment (IA) were:

- Increase the general knowledge of the regions residents and project stakeholders on the status and trends of environmental, social and economic causes and consequences of the current conditions and trends related to interrupted flows in the Clinton River.
- Increase the general knowledge of the regions residents and project stakeholders on the benefits of restoring a more natural flow regime in the Clinton River based on the status and trends documented.
- Develop a hydrologic model for the system to evaluate and assess how the impoundments interact with each other (i.e. what is the hydrologic conductivity between the impoundments) as well as the downstream receiving waters (the Clinton River).
- Develop a comprehensive socio-economic-environmental model of the system that can be used as a tool for providing forecasts of likely future environmental, social, recreational and economic conditions based on the different policy and/or management options identified by the stakeholders along with uncertainty associated with those actions.
- Provide recommendations to the Oakland County Water Resources Commissioners Office on how court ordered regulations might be altered to attempt to restore a natural flow regime
- Provide recommendations to other federal agencies such as the National Oceanic and Atmospheric Association (NOAA), U.S. Environmental Protection Agency (USEPA), and U.S. Army Corps of Engineers (USACE) on restoration projects they could undertake under their Great Lakes basin programs
- Provide recommendations to the watershed's 63 communities/municipalities on ways to mitigate impact on the flow regime and dissemination/education/outreach programs across the region.
- Develop a comprehensive integrated assessment case study for hydro-modification of a system that could be implemented in other watersheds across the Great Lakes region as communities further consider issues such as ecologic restoration, impoundment operation, and dam removal.
- Develop a demonstration project that would serve as a pilot for other Great Lake basin watersheds suffering from un-natural flow regimes.

Methodology

The area addressed under this IA is the upper reaches of the Clinton River Watershed in Oakland County, Michigan which have been significantly modified by urbanization and impoundments [Figure 2.1(b)]. For this IA, there are 21 impoundments in the affected area and the amount of impervious surface in the watershed has risen from 10.5% in 1978 to 19.7% in 2001 (USGS 2005). Of further concern, the presence of the impoundments places many of the impacted constituents on opposite sides of the issues because of the contrasting needs of lake level control, including recreation, habitat, and flood control, depending on whether they are upstream or downstream of the impoundments. In fact, even individual lake owner associations are commonly divided on how to best manage the watershed. Thus, municipalities, special interest groups such as the aforementioned lake owners associations, and watershed managers are faced with the need for scientifically, ecologically, socially, and economically sound approaches to refine the policy relevant questions associated with mitigating the impacts of the altered hydrologic flow regime in the watershed.

The integrated assessment question to be addressed by this proposal is "What are the causes, consequences and correctives of interrupted flows in the Upper Clinton River Subwatershed and the Main Clinton River Watershed that impact habitat and recreational uses in the Clinton River Watershed?" The project team and Michigan Sea Grant adopted a 7-step Integrated Assessment approach to address the issue of interrupted flows in the Clinton River Watershed:

1. Document the status and trends of environmental, social, and economic causes and consequences of the current conditions and trends related to the interrupted flows.
2. Describe the environmental, social, and economic causes and consequences of the current conditions and trends related to the interrupted flows.
3. Provide forecasts of likely future environmental, social, and economic conditions under the various policy and/or management actions considered.
4. Provide technical guidance for the most cost effective means of implementing each policy and/or management action considered.
5. Provide an assessment of the levels of certainty associated with the information from Steps 1 – 4.
6. Peer Review of Integrated Assessment.
7. Public Comment on Integrated Assessment.

4.0 Status and Trends

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.

4.1 Current Status and Trends

To develop an understanding of status and trend in the study area, focus is placed on changes in the following:

- Changes in urbanization.
- Changes in land use management measures.
- Changes due to climate change.
- Changes in hydrology.
- Changes in water quality.
- Changes in biological communities excluding fisheries.
- Changes in fisheries within the system.

These statuses and trends are presented below.

4.1.1 Trend to Urbanization in Clinton River Watershed

Very rapid urban expansion is a major cause of environmental problems related to water quality in the Clinton River watershed. A comparison of Figure 4.1.1-1 (1950 land use) and Figure 4.1.1-2 (1990 land use) shows that the portion of the study 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 Southeast Michigan Council of Governments (SEMCOG) data inventory taken in 2000 shows that urbanization has already occurred (Figure 4.1.1-3). 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 has led to increasing soil erosion, continued deterioration of the river habitat, and increased flooding both locally and regionally.

Figure 4.1.1-1: 1950 Land Use in the Clinton River Watershed

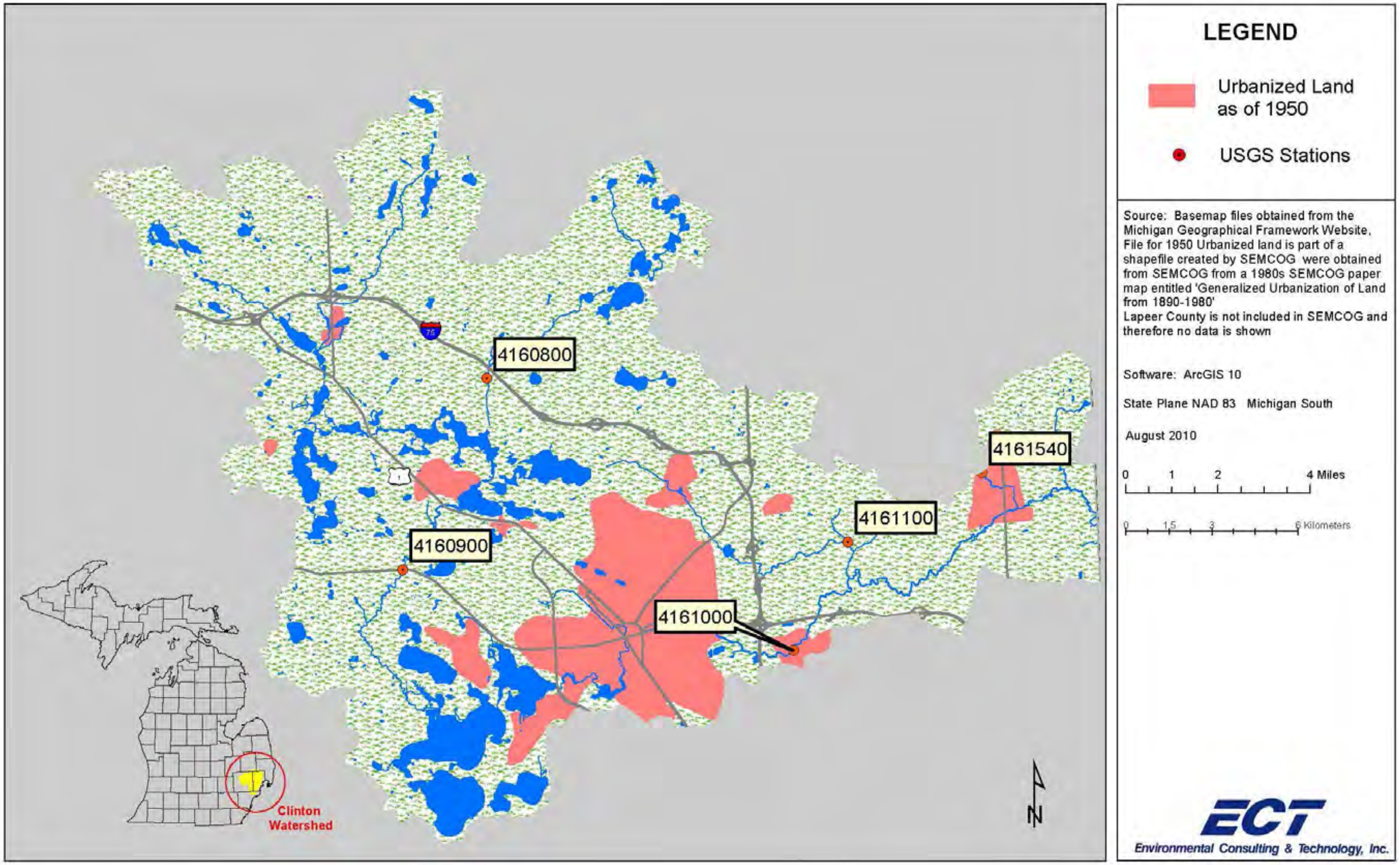


Figure 4.1.1-2: 1990 Land Use in the Clinton River Watershed

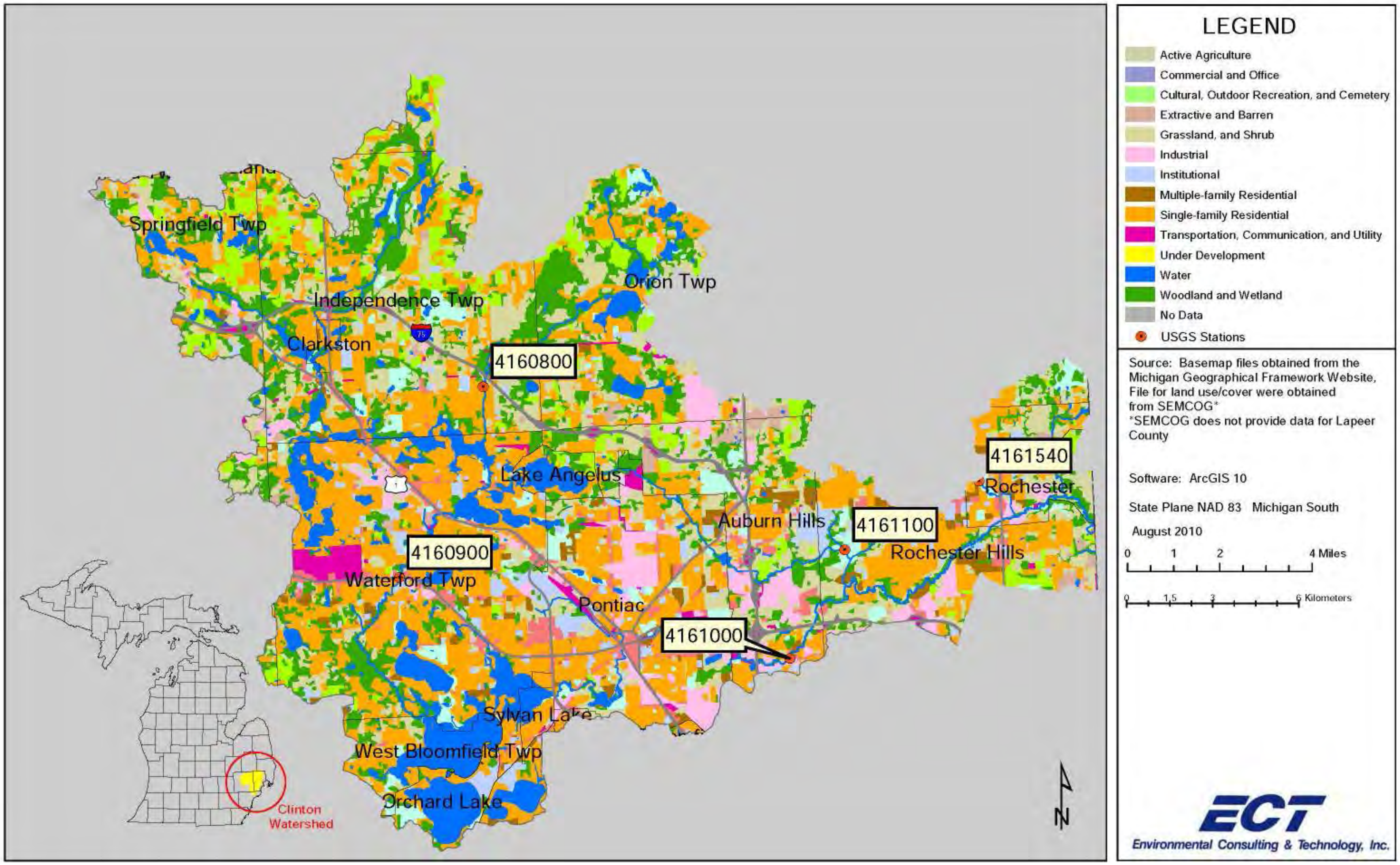
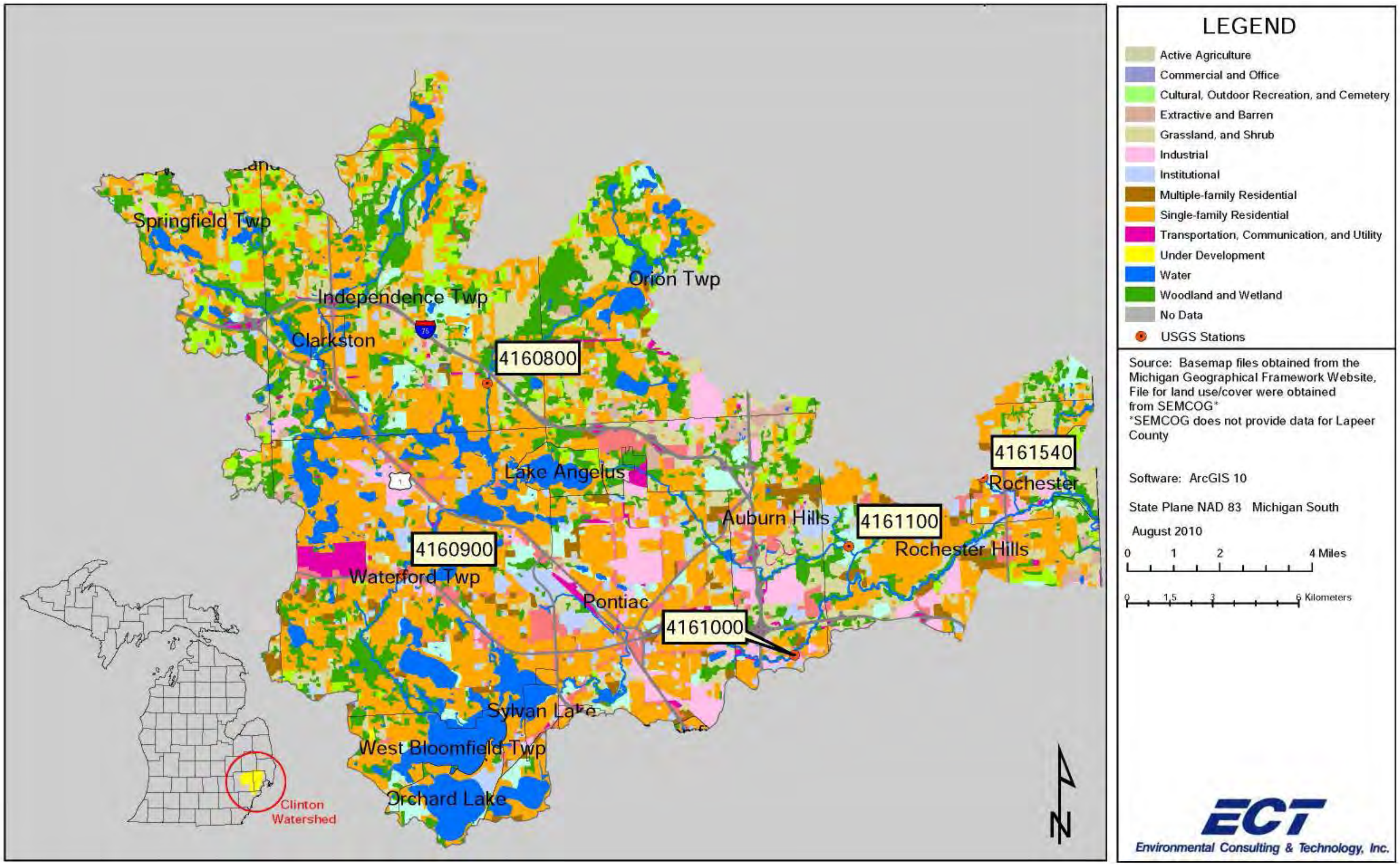


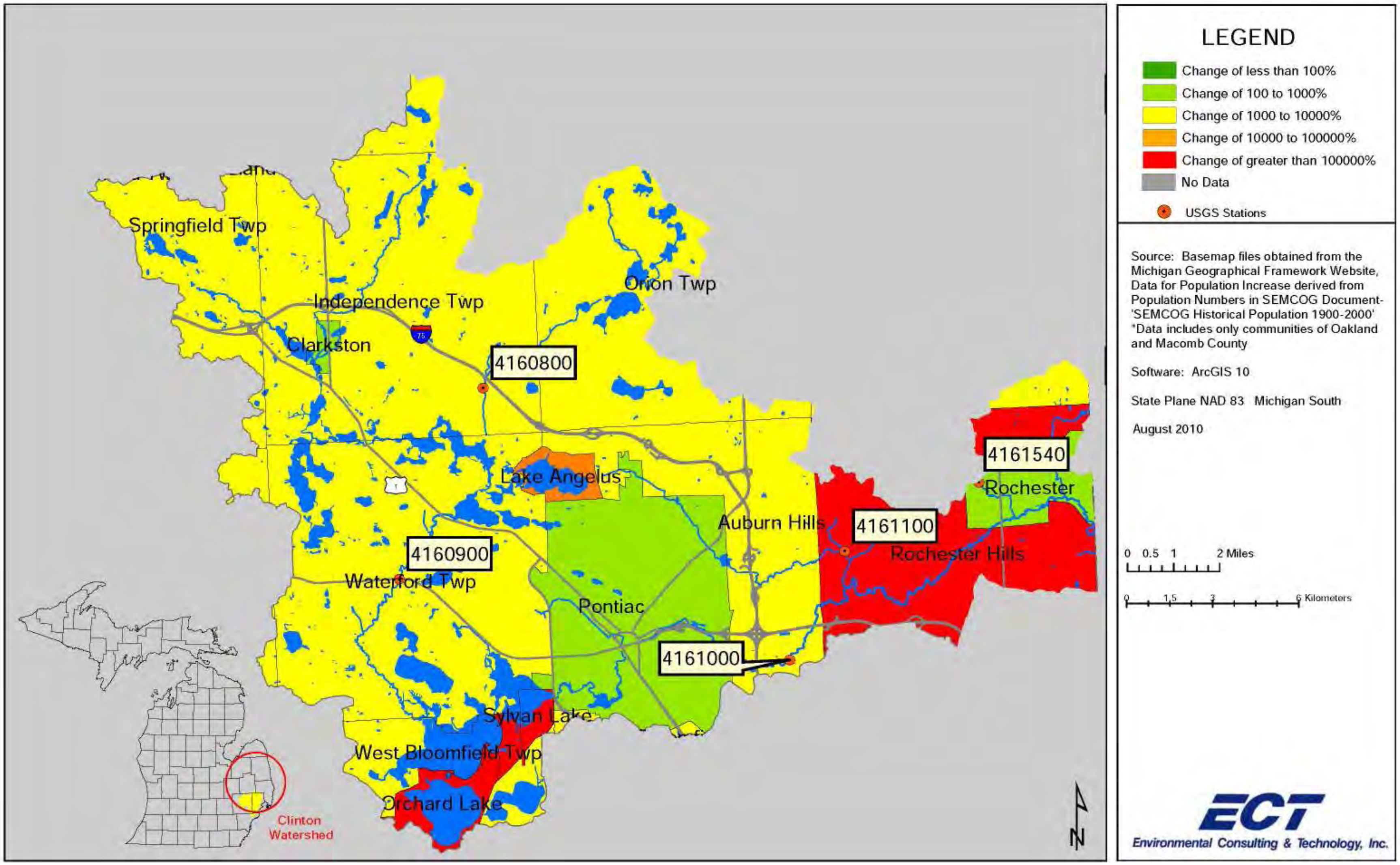
Figure 4.1.1-3: 2000 Land Use in the Clinton River Watershed



4.1.2 Land Management Measures within the Clinton River Upper and Main Subwatersheds

To understand the link between population increase and its subsequent impact on imperviousness, it is interesting to look at Figure 4.1.2-1 that indicates percent increase in population between 1900 and 2000. It is clear that the largest population increases are concentrated in the Rochester Hills area. Independence Township, Springfield Township, and Clarkston currently are largely rural areas of the study area. It is expected that the greatest potential for harmful and unstable future increases in flows are in these areas (that are currently categorized as rural).

Figure 4.1.2-1: Percent Change in Population from 1900 to 2000 in the Clinton River Watershed



In 1990 SEMCOG, forecasted that the suburban areas in the Clinton River watershed will continue to attract more population (Figure 4.1.2-2) in response to substantial job gain (Figure 4.1.2-3) in that region. This would have led to continued urbanization within the watershed.

Figure 4.1.2-2: Population Change (2000 - 2030) for the Clinton River Watershed

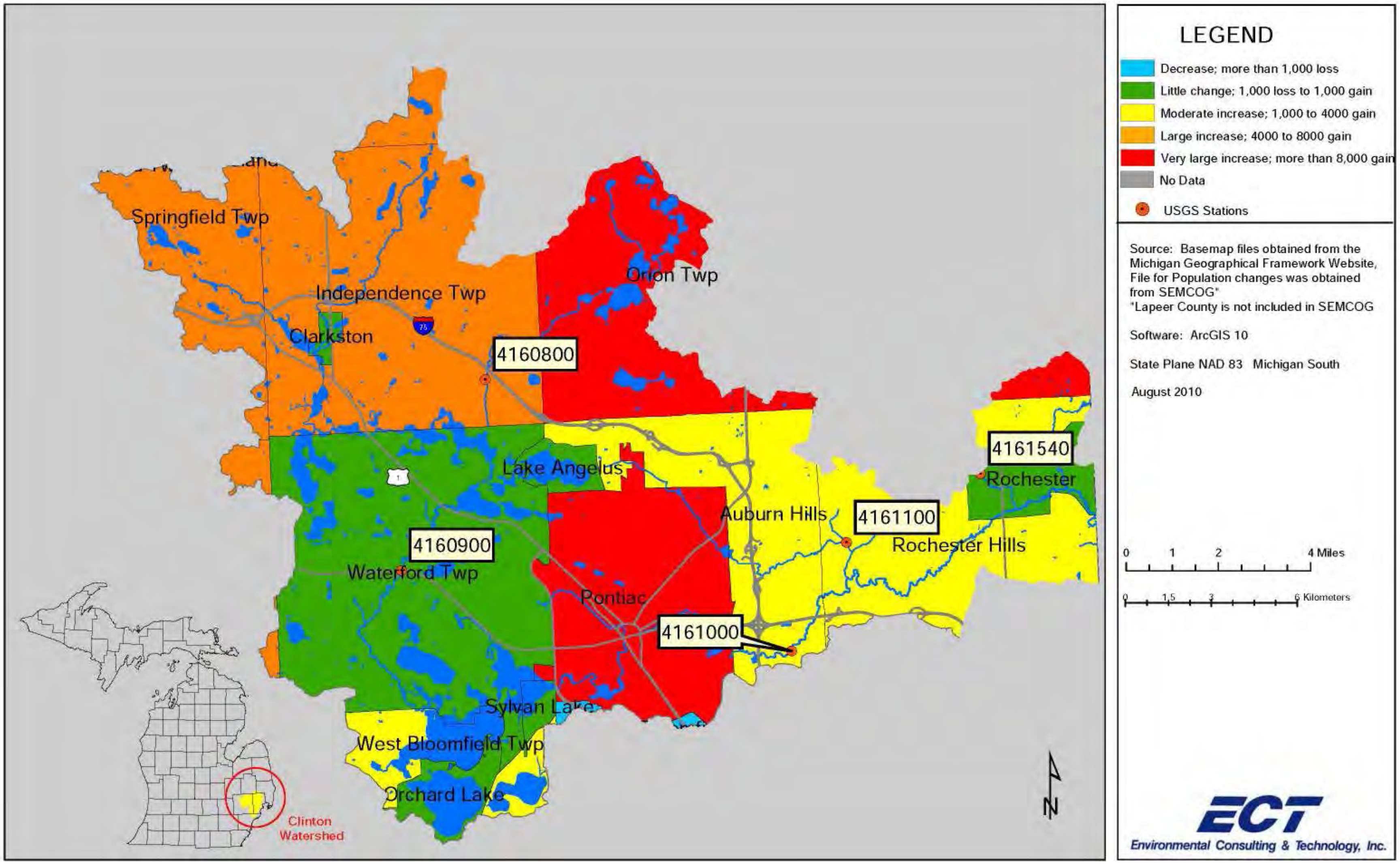
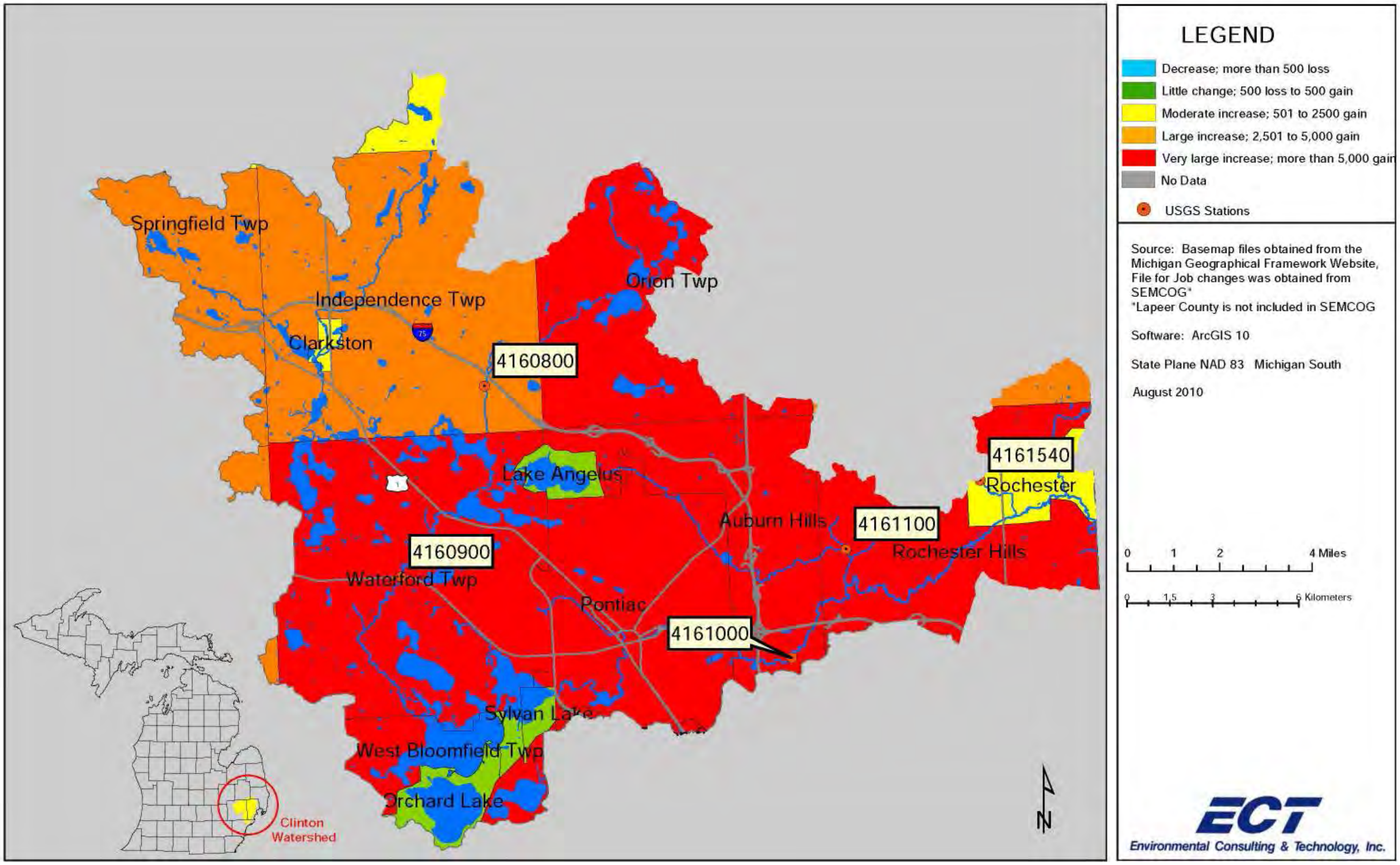


Figure 4.1.2-3: Projected Future Job Change (2000 - 2030) for the Clinton River Watershed



However, due to the economic uncertainties of the region in 2000-2010 decade, according to a report published by SEMCOG in April 2009, there actually has been an estimated 1.2% decline in population in Southeast Michigan between the years of 2000 and 2009. The average household size is showing a reversal of trend compared to previous decades, and the housing vacancy rate increased by an estimated 7 percent over this time. Although most of the counties within southeast Michigan have seen some population growth, Wayne County has seen a large decrease in population which is the primary reason for the net loss. SEMCOG reports that the turbulent economic and housing situations are the primary drivers for these trends (Population and Households in Southeast Michigan, 2010).

Table 4.1.2: Population Trends in Southeast Michigan

County	April 1, 2000	Dec. 31, 2009	Change 2000-2009	Percent
Livingston	156,951	183,008	26,057	16.6
Macomb	788,149	827,984	39,835	5.1
Monroe	145,945	152,823	6,878	4.7
Oakland	1,194,156	1,196,891	2,735	0.2
St. Clair	164,235	166,842	2,607	1.6
Washtenaw	322,770	344,910	22,140	6.9
Wayne	2,061,162	1,903,307	-157,855	-7.7
Southeast Michigan	**4,833,368**	**4,775,765**	**-57,603**	**-1.2**

*Courtesy SEMCOG

4.1.3 Climate Change and its Impact on Southeast Michigan Watersheds

Over the course of the 20th century, meteorologists have documented an average annual increase in temperature of about 1 degree Fahrenheit and approximately 5 to 10% increase in precipitation (Francis and Haas 2006). Scientists argue that this trend will continue with greater magnitude into the 21st century with projected increases in temperature ranging from 5 to 9 degrees F on average over the next 100 years.

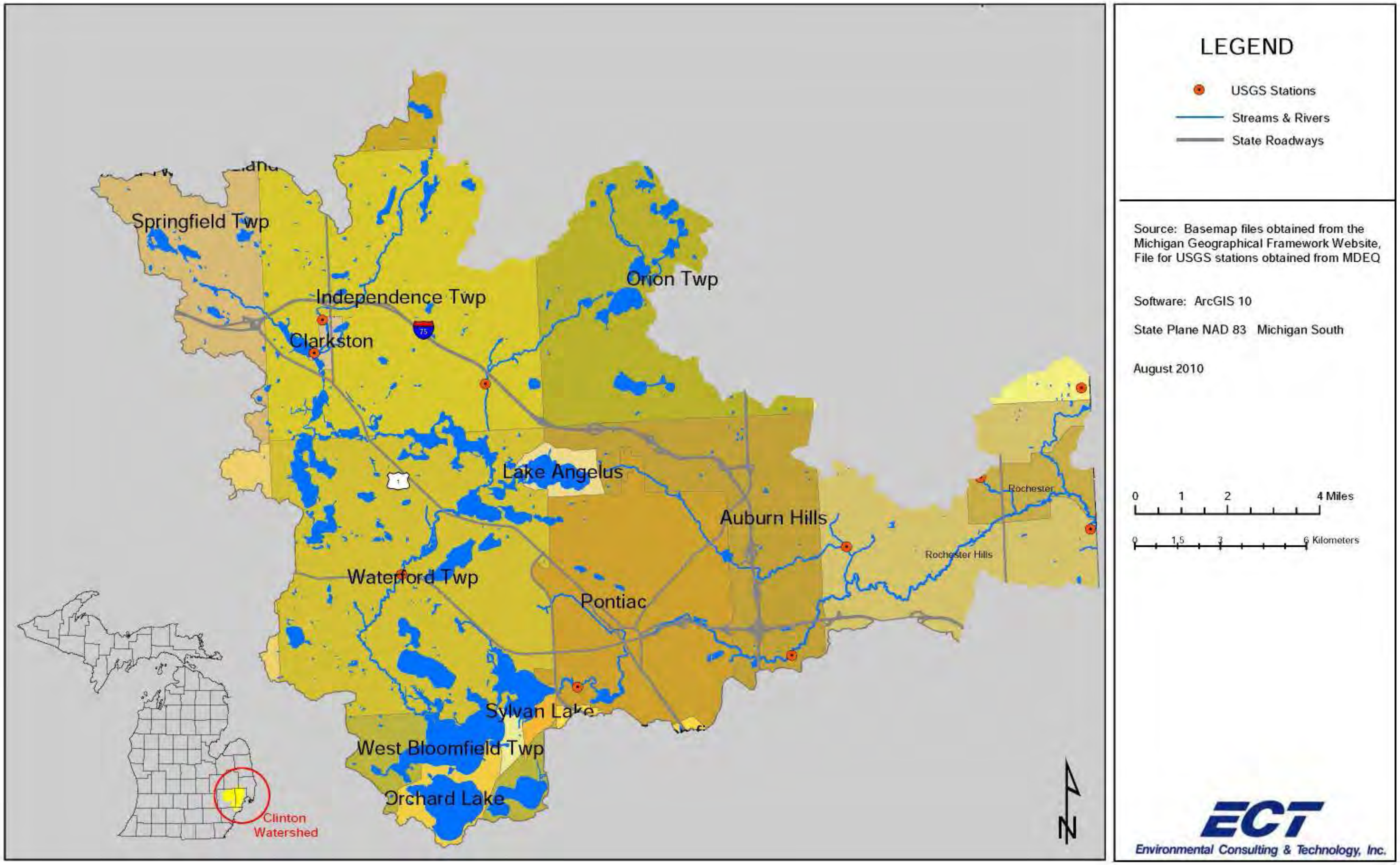
Some meteorologists have argued that one of the outcomes of global warming has resulted in the increase of El Nino events. During El Nino events, there is an irregular increase in sea surface temperatures off the coasts of Peru and Ecuador resulting milder and drier winters in the northern U.S. Historically, El Nino events have resulted in drier than normal conditions throughout the state of Michigan, but especially more so in the southern half of the Lower Peninsula where temperatures averaged 2-3 degrees F above normal.

Within the Clinton River Watershed, one of the highest precipitation years (1992) and one of the lowest precipitation years (1958), were during El Nino events. Francis and Haas (2006) believe that given this data, there does not appear to be a compelling correlation between El Nino events and annual precipitation amounts for Clinton River Watershed.

4.1.4 Hydrologic Changes within the Clinton River Upper and Main Subwatersheds

The United States Geological Survey (USGS) currently maintains or has maintained a total of sixty-one flow measurement stations in the watershed (see Figure 4.1.4-1). Such a large number of measurement stations are an indication of the importance of this highly urbanized Michigan watershed. Ten of these gauges are or were in Clinton Upper/Main subwatersheds. The analyses presented below targets five gauges that are currently active or were active until 1980. A majority of the subsequent analysis of the effect the lake management strategies have on the Clinton River are based on USGS 04161000 Clinton River at Auburn Hills, Michigan which is first gauge downstream of study area and is only USGS gauge in the project area active during this investigation.

Figure 4.1.4-1: Location of USGS Measurement Stations in the Clinton River Watershed



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 was carried out in Creech and Sinha (2006). Creech and Sinha (2006) presented a meaningful statistical analysis showing hydrologic trends over several decades by requiring that the chosen measurement stations have data covering a statistically significant time-period. In the entire Clinton River watershed, an analysis of these sixty-one measurement stations indicated that there are sixteen stations that are either currently active or historic with 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. Tables' 4.1.4-1 and 4.1.4-2 below contain a summary of these computed trend values for the active stations within the current project's study area. These trend values are also shown graphically in Figures 4.1.4-2 and 4.1.4-3. The standard formula for a linear regression analysis is y=mx+b, where:

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

Table 4.1.4-1: 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%
4161540	**6.023**	**-11449**	1960	2001	41	355.688	602.6228	69.42%	67.7%
				Average	**41.6**			**Average**	**117.4%**

Table 4.1.4-2: 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%
1540	**0.366**	**-671.9**	1960	2000	40	45.842	60.49	31.95%	32.0%
				Average	**39.0**			**Average**	**91.5%**

Figure 4.1.4-2: Percent Change in Peak Stream Flow over the Last Forty Years in the Clinton River Watershed

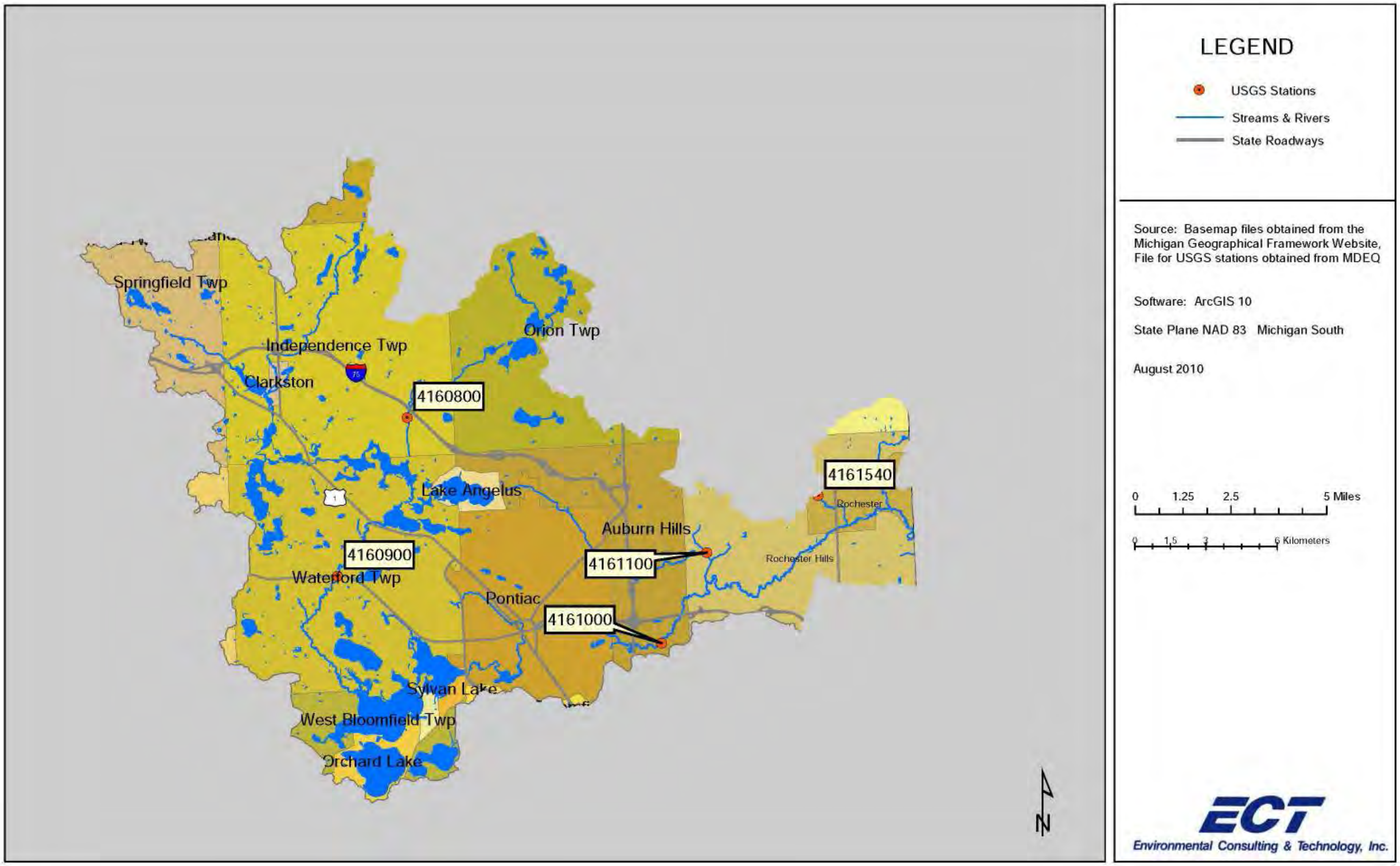
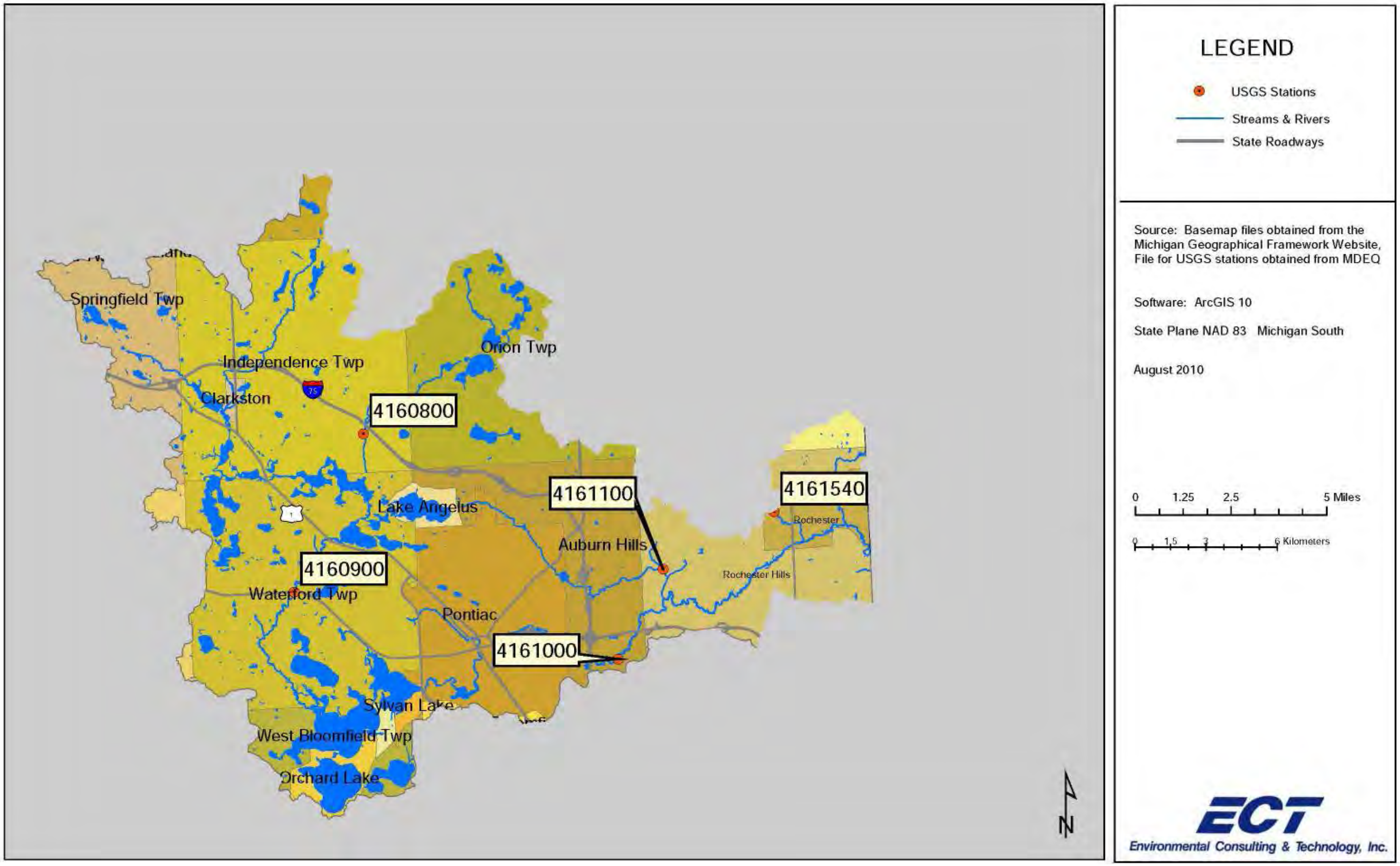


Figure 4.1.4-3: Percent Change in Mean Annual Flow over the Last Forty Years in the Clinton River Watershed



Creech and Sinha (2006) also presented a second methodology for the analysis of the bankfull flow, which they credited to David Fongers of the Michigan Department of Natural Resources and Environment's 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 gauges, this bankfull flow increased substantially over the forty year time period. The plots of this analysis are located in Appendix A, and the results are summarized in Table 4.1.4-3.

Table 4.1.4-3 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%
4161540	340	340	40	0.0%	0.0%
	Average		**39.0**	**29.2%**	**29.3%**

As indicated in Tables 4.1.4-1, 4.1.4-2, and 4.1.4-3, the approximate average percent change over the last forty years in the peak stream flows, average annual mean flow, and average bankfull flows are 41%, 39% and 39%, 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 land use changes on stream flows (Aichele, 2005).

Overall, reviewing the findings presented, the following conclusions can be drawn:

- The study area has recorded the largest changes in the entire watershed with peak stream flow and mean annual flow at one particular gage becoming four-times larger than they were forty years ago.
- Urbanization and its direct and indirect effects have been attributed as the cause of these stream flow increases.
- There is a strong correlation between peak stream flows and annual mean flows. A systematic increase in one seems to lead to an increase in the other.
- The mean annual flows have increased more significantly than peak stream flows over the last forty years.

4.1.5 Channel Morphology Changes within the Clinton River Upper and Main Subwatersheds

Characterization of channel morphology can be achieved by examining stream sinuosity and stream gradient. Stream sinuosity is measured as a ratio, devised from the length of the flow channel by the valley length, and stream gradient is the drop in elevation over the distance of a water course, and is generally measured in feet per mile.

Per Francis and Haas (2006), elevation at the upstream end of the Upper Clinton Watershed is approximately 1,040 ft above sea level and has a downstream elevation of approximately 993 ft. Given that the length of this reach is approximately 5 miles long, the average stream gradient is approximately 9.1 ft per mile which is considered to be a high enough gradient needed to support potential sport fisheries habitat. The sinuosity for this reach is measured at 1.33, classifying it as moderate sinuosity.

For the Clinton Main Subwatershed, the upstream end of the this reach is approximately 993 ft above sea level and has a downstream elevation of approximately 854 ft. Given that the length of this reach is about 30 miles long, the average stream gradient is approximately 4.6 ft per mile, which is considered low, indicating only modest potential for sport fisheries habitat. The sinuosity for this reach is measured at 1.36, classifying it as moderate sinuosity.

Over the entire Clinton River Watershed, the channel morphology has changed resulting in alterations to the flow regime. Several factors which include, dredging, straightening, high sediment loads, removal of natural vegetation, lack of woody structure, have all caused significant changes to the morphology of the all sections of the Clinton River. These factors cause the channel to be simple, over-widened, shallow, and lacking diversity. In addition, the increase in impervious surfaces associated with watershed urbanization increases the base flow which has changed the watershed flow regime, resulting in increased instances of stream bank erosion and altered habitat within the stream channels.

4.1.6 Water Quality Changes within the Clinton River Upper and Main Subwatersheds

Francis and Haas (2006) indicate that basin-wide water quality has improved since the 1970s due in large part from tougher water quality standards implemented by the Clean Water Act of 1972. With virtually all of the point sources now being regulated, the implementation of these standards has prompted the upgrade of wastewater treatment facilities that discharge to the waterways of the Clinton River Watershed.

4.1.7 Changes in Biological Communities within the Clinton River Upper and Main Subwatersheds

Over the last 40 years, sampling of invertebrate and mussel communities have been conducted to provide more direct indication of water trends within the Clinton River Watershed. During the 1973 sampling of the Upper Clinton River Watershed, there was an abundance of caddisfly and mayfly which are pollution intolerant species and indicative of good water quality. The most recent sampling in 1999, mayflies and caddisflies decreased in abundance and midges and damselflies became the most dominant taxa. These results show a decline in water quality.

For the Clinton River Main, there was an abundance of mayflies, scuds and caddisflies which also indicated good water quality. Downstream of Pontiac, the stream quality was severely degraded only supporting pollution tolerant species such as Oligochaetes, leeches, and midges. According to the latest data collected in 1999, the upstream portion of this segment was dominated by midges, scuds, and caddisflies. Overall, there was a decline in caddisflies and mayflies indicating a decline in water quality.

In addition to macroinvertabrate community, there have been several mussel collections conducted over the last 30 years. Though the species distribution is not consistent throughout the watershed, mussel populations are a good indicator of water quality and health of a biological community. According to data collected between 1870 and 1925, 31 different mussel species were collected in the Clinton River Watershed (Francis and Haas 2006). In the mid 1970's the Clinton River upstream of Pontiac supported 14 different mussel species, which included 4 that are on the state endangered species list. The only known population of purple lilliput exists within this area, but recent surveys indicate that its density is declining due to the proximity of a lake-level control structure and the blockage of species movement caused by structures. The Upper Clinton River also supports the only likely population of rayed bean in Michigan's streams. Downstream of Pontiac, within the Clinton Main Stem, the mussel populations are extremely degraded. During the last collection, no living specimens were found.

4.1.8 Changes in Fishery Species within the Clinton River Upper and Main Subwatersheds

There is little documentation about fish species that populated the watershed during the pre-settlement era. According to historical literature (Francis and Hass 2006), the Upper Clinton Watershed included fish species including, smallmouth bass and other centrachlids, darters, suckers and minnows. By the 1880's these areas of the Clinton River supported brook trout which was introduced from fish hatchery plants.

Settlement of the watershed brought about the need for small dams and power mills which had an adverse effect on fish biodiversity because of habitat modification and fragmentation. In addition, the conversion of undisturbed lands to agriculture or urban land use resulted in a decline of fish biotic integrity. These land use changes prompted increased runoff, flow destabilization, increase in temperature, altered channel morphology, and increased nutrients and sediments. Prior to the passage of the Clean Water Act in 1972, many rivers were seen as a dumping ground which severely reduced the abundance of quality fish habitat.

Since the passage of the Clean Water Act, there has been a recovery within the Upper and Clinton Main Subwatersheds. In 2001, fish collection in the Upper Clinton revealed 14 species including rainbow darter, fantail darter, largemouth bass, and grass pickerel being the most common species. These finding indicate that the fish habitat for this area is good and the fish community was rated excellent by the Michigan Department of Environmental Quality (MDEQ) (Francis and Hass 2006). Similarly, the Clinton Main Subwatershed was rated as good for species richness. Collection results included coolwater species such as creek chubs, bluegill, largemouth bass, and yellow perch. The abundance of bass, sunfishes, and perch is likely due to the large number of interconnected lakes that are interspersed throughout this reach. However, the main branch of the Clinton River downstream of the impounded section does not support the same level of diversity or rating.

4.2 Current Lake Level Operational Management

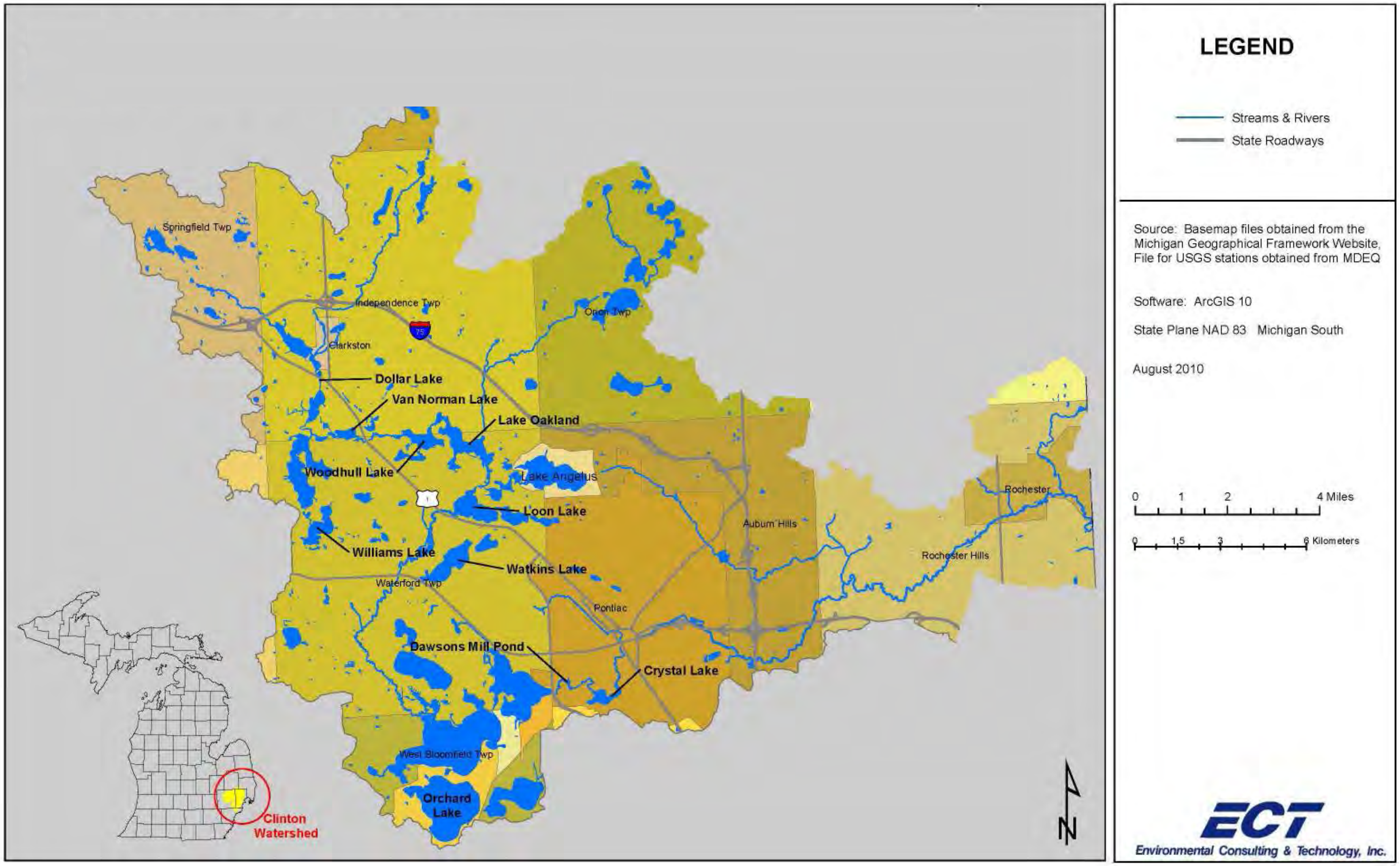
Normal fluctuations in lake levels are influenced by input from precipitation and snow melt runoff, groundwater seepage and upstream inflow; and output from outflows, water use, and evaporation. Seepage lakes are dependent upon precipitation and groundwater and their levels naturally tend to fluctuate more slowly and seasonally than drainage lakes that are fed by surface water runoff. Many of the lakes in this investigation are controlled by court ordered lake levels and not allowed to fluctuate naturally.

Legal lake levels are established by the Oakland County Circuit Court judges under state statue *Act 454 of 1994 – Part 307 Inland Lake Levels* in a manner defined below:

> "Normal level means the level or levels of an inland lake that provides the most benefit to the public; that best protect the public health, safety, and welfare; that best preserve the natural resources of the state; and that best preserve and protect the value of the property around the lake." (Act 454 of 1994 – Part 307 Section 324.30701)

The Oakland County Water Resource's Commissioner's Office conducts regular inspections of the lake control structures that they maintain. In these reports, they indicate the condition of the structure, recommend repairs, and document other potential issues that would affect the structure's performance. In addition to these assessments, the inspection reports also include the seasonal elevations that are set for each structure, the size (in acres) of the impoundment(s) for which the structures manage, the design specifications, and a description of the structure itself. As shown in Appendix B, Table B.1 provides an overview of the seasonal changes in elevation of each impoundment and Figure 4.2 indicating their location within the watershed. Appendix B also provides additional detail for each impoundment lake level control structures within the study area.

Figure 4.2: Lakes with Oakland County Maintained Control Structures



4.3 Effect of Current Lake Level Control Operations

The current lake level management influence on the flow in the Clinton River is based on operational data from the OCWRC and measurements at the USGS Gauge in Auburn Hills (USGS 04161000 Clinton River at Auburn Hills, Michigan) along with photographic evidence. This section clearly indicates the amount of human intervention associated with lake level maintenance and the subsequent effect is has on the downstream receiving waters of the Clinton River.

4.3.1 Lake Level Operation Data

To visualize how the hydraulic structures are manipulated in response to rainfall events several months of operational data for the OCWRC Lake Technicians were analyzed. Figures 4.3.1-1 through 4.3.1-4 are the operations, lake levels, and rainfall for May 2010 for eight lakes actively managed by the OCWRC Office. This month exhibited approximately 5.26 inches of rain which is slightly above the recent average of 4.12 inches. These figures are shown as an example of human interaction. In each figure, the rainfall is shown as a blue bar (scale on the right), the lake level data is shown in red (daily readings) in reference to the court ordered lake level, and the arrows with annotations represent when a hydraulic structure was manipulating to control lake levels. For example, on May 3 OCWRC lake technicians removed two 6ft board from the dam controlling Cemetery-Dollar Lake to allow more flow out in response to the ½" rain event. It should be noted that all lakes are shown as being at their court ordered levels the last three days of the month. In reality, there is no data for those days due to equipment malfunction.

Figure 4.3.1-1 shows that Cemetery-Dollar fluctuated from approximately 6 inches below court order to slightly above court order during the month. The technicians opened several bays early in the month to drain the lake and then closed one near the end of the month. For Van Norman Lake, the technicians routinely opened/closed gates and removed/replaced boards to maintain the lake level near court ordered levels. Figure 4.3.1-2 indicates that Loon Lake varied from approximately 0.2 ft below to 0.4 ft above the court ordered level during the month. Early in the month technicians were opening gates to release water and later in the month they were closing gates to maintain lake levels approximately 0.3 ft above court ordered levels. Watkins Lake was barely manipulated and stayed approximately 0.4 ft above court ordered levels for a majority of the month. Figure 4.3.1-3 shows that Orchard Lake was slightly below court ordered levels a majority of the month and only manipulated three times. Conversely, Cass Lake was approximately 0.5 ft above court ordered levels for most of the month and hydraulic control structures were modified 13 times. This figure demonstrates variability that exists between lakes and lake operations during a single month. Finally, Figure 4.3.1-4 indicates that both Crystal Lake and Dawson Mill Pond were very actively managed during the month and were significantly above the court ordered levels.

Figure 4.3.1-1: Operations Graph for Cemetery-Dollar Lake and Van Norman Lake

May 2010

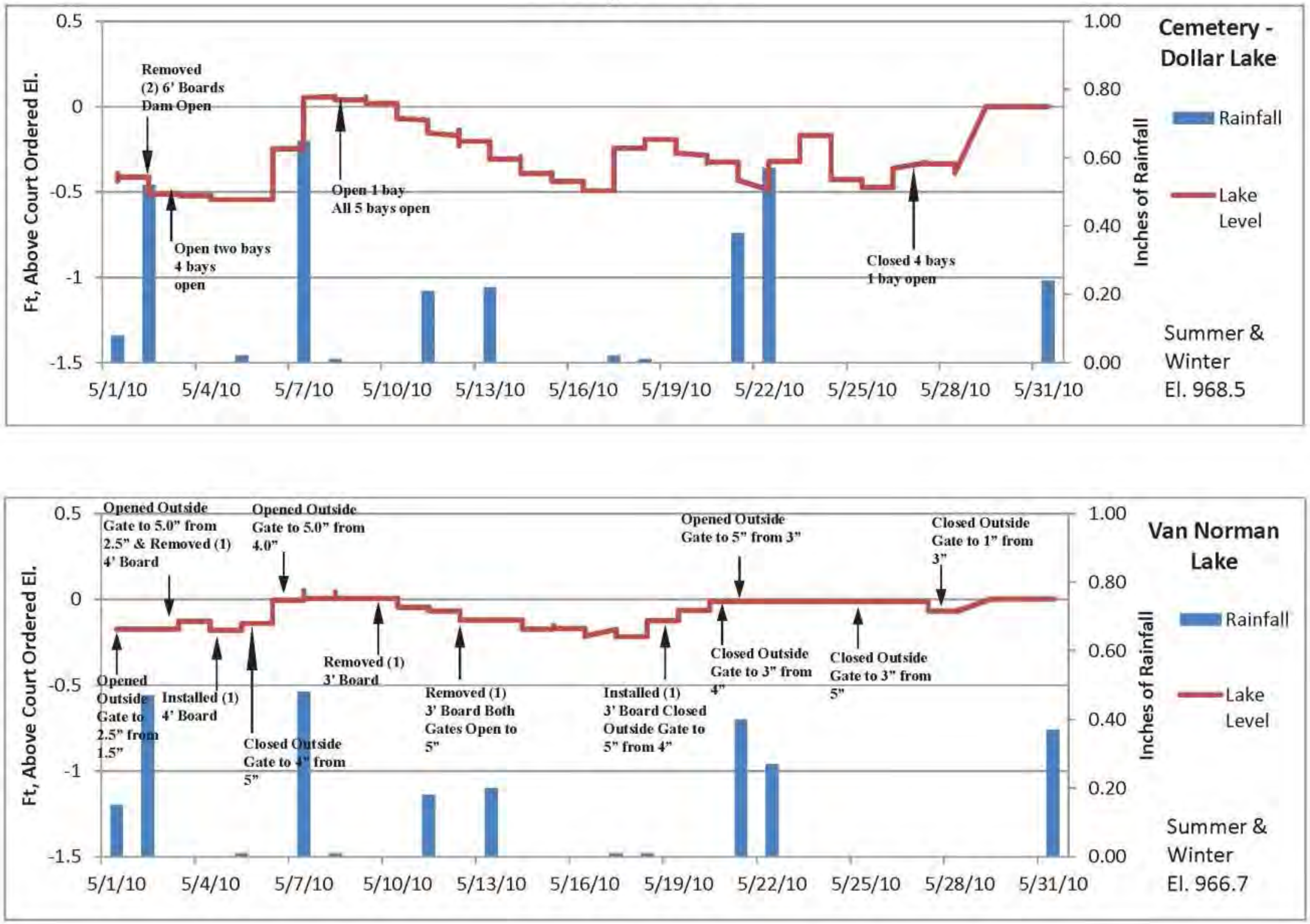
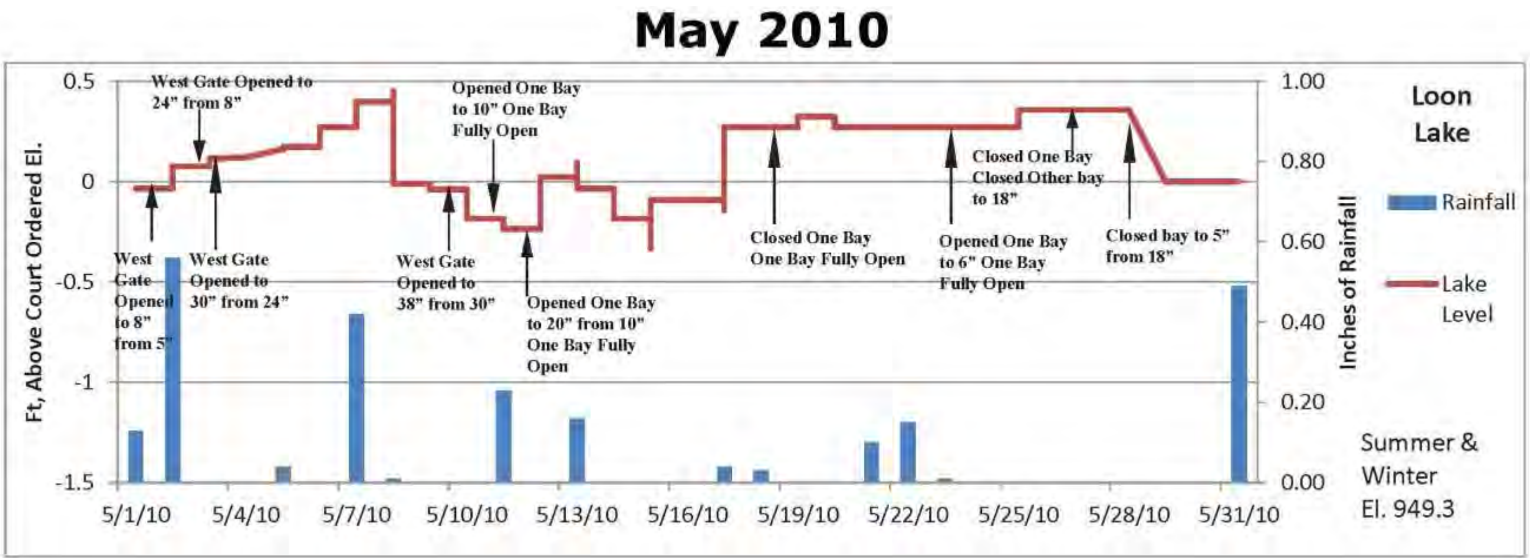


Figure 4.3.1-2: Operations Graph for Loon Lake and Watkins Lake



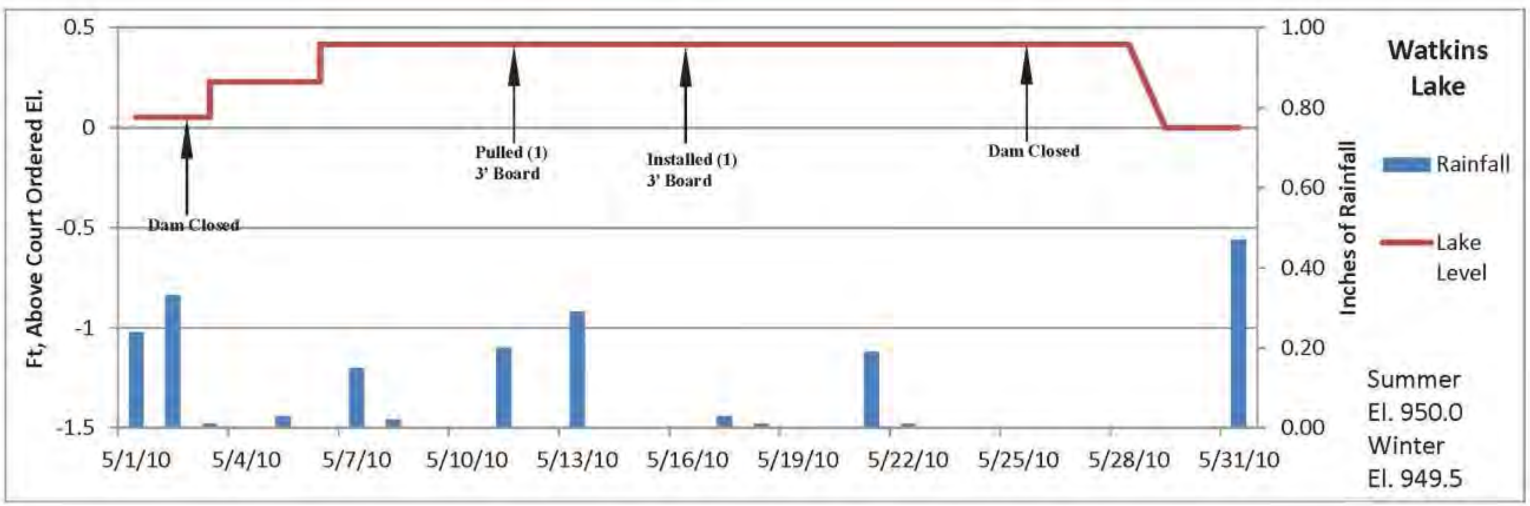
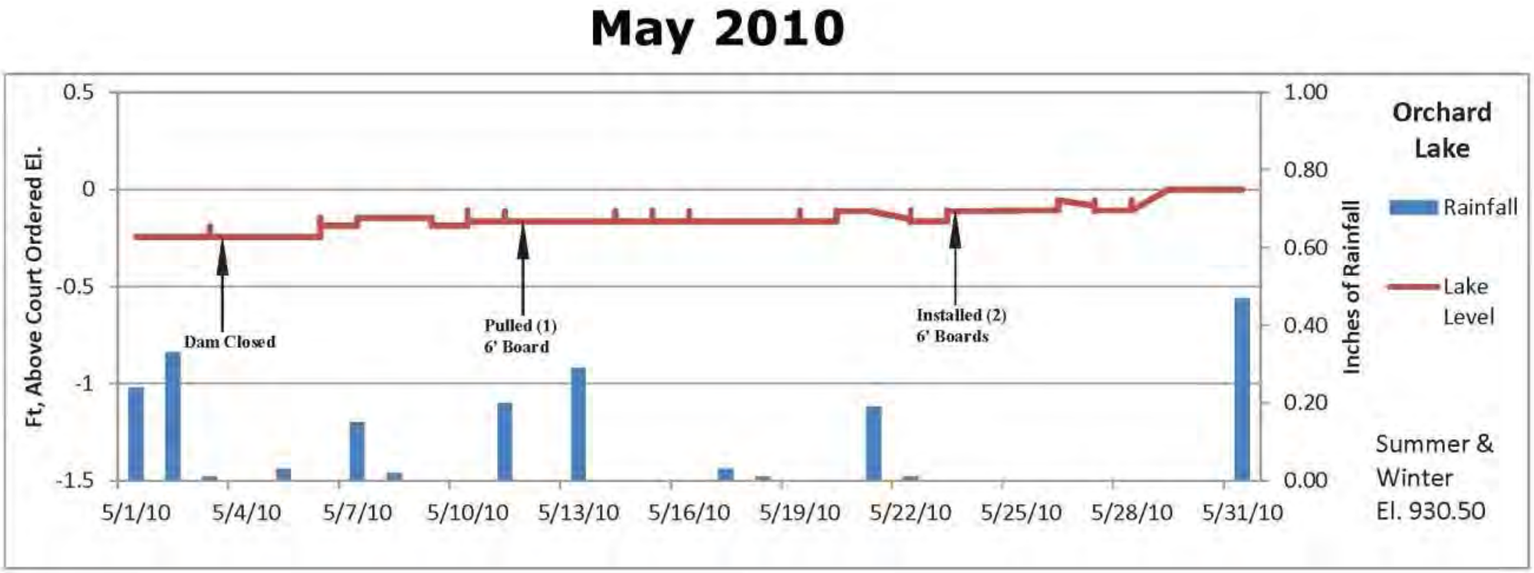


Figure 4.3.1-3: Operations Graph for Orchard Lake and Cass Lake



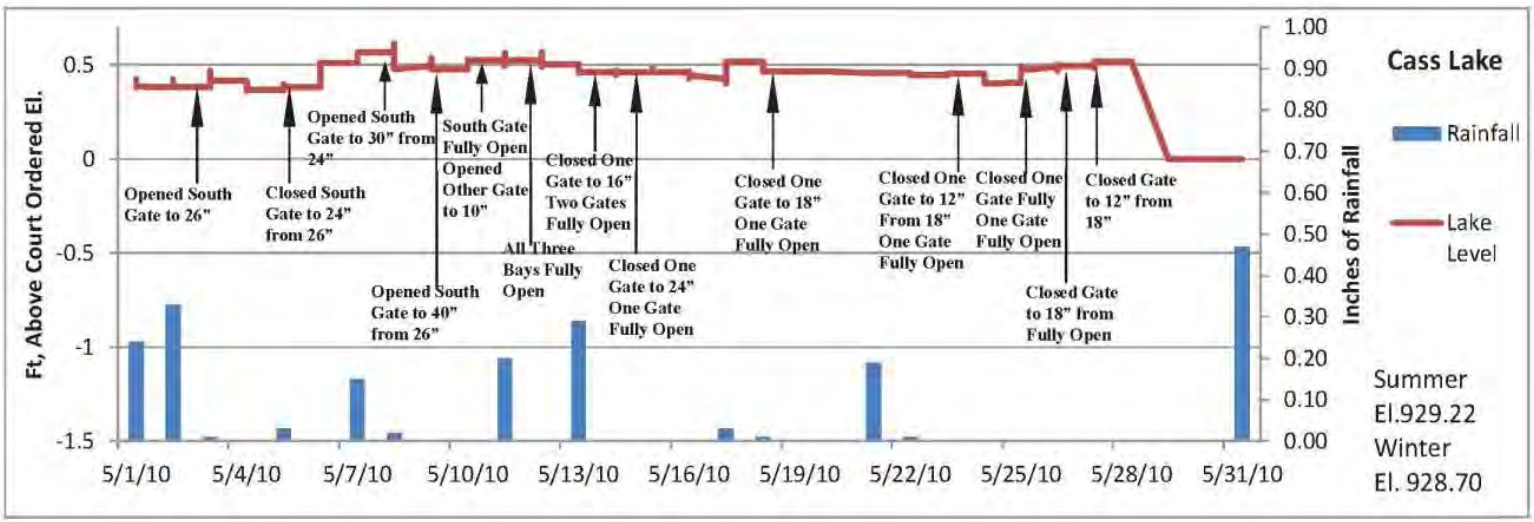
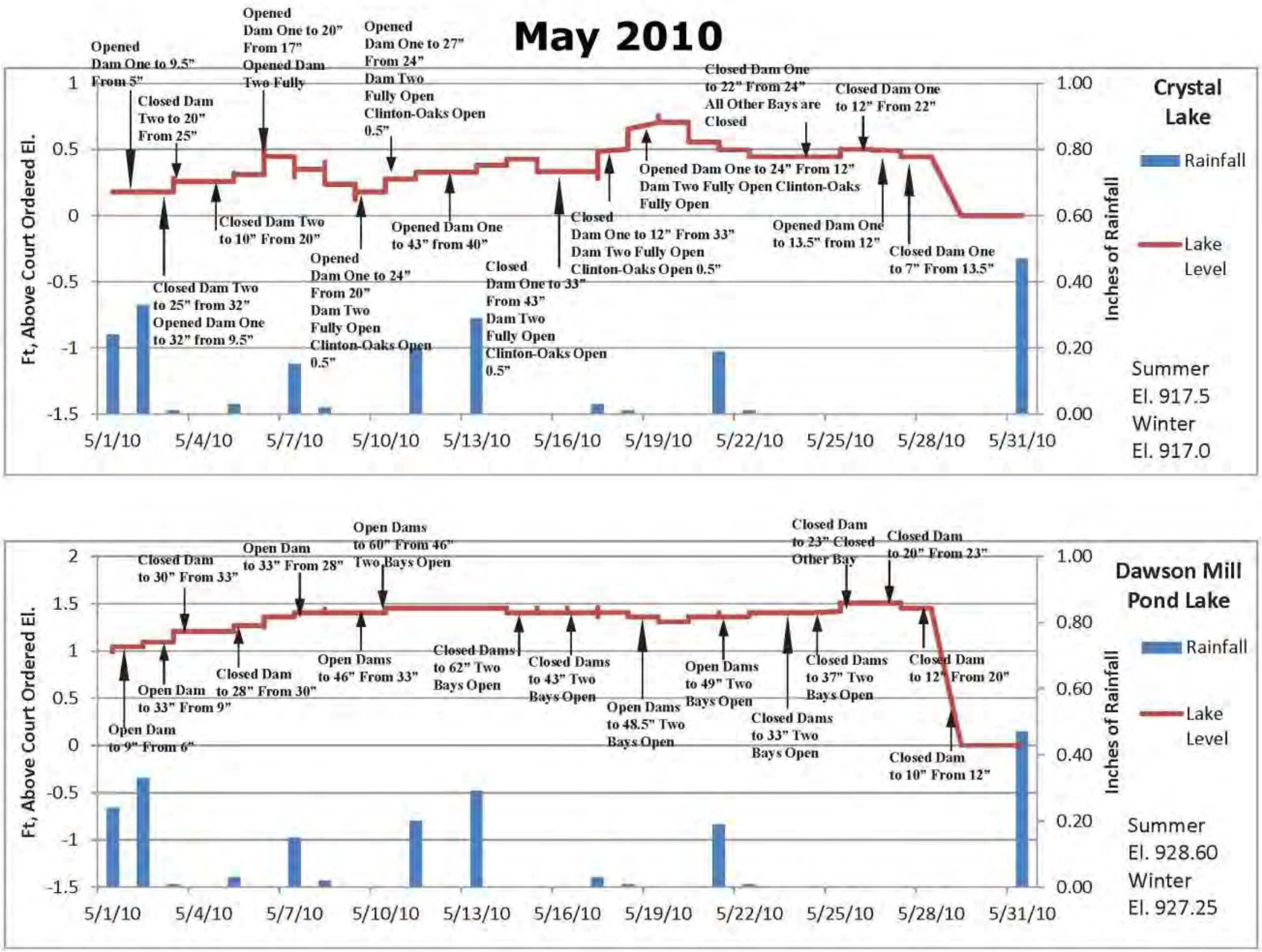


Figure 4.3.1-4: Operations Graph for Crystal Lake and Dawson Mill Pond Lake



4.3.2 Clinton River Response to Lake Level Operations and Rainfall Events

<u>May 21-25, 2004</u>

The storm event on May 23, 2004 caused extreme flooding in the Clinton River (Figure 4.3.2-1). The watershed received 2.72 inches of rain fell in 24 hours. This represents a 5 year rain storm return interval (Huff and Angel 92). The mean daily flow at the Auburn Hill's USGS gauge station on May 23, 2004 was 978 cfs with a maximum recorded discharge of over 2000 cfs based on rating curve extrapolation (Water Data Report for USGS Gauge 04161000) which is the all-time high discharge for this gauge. There was very little operation of the lake level control structures during this rainfall event. Most of the controls were opened to their maximum capacity to handle the large flow generated by the event (Table 4.3.2-1).

Figure 4.3.2-1: Clinton River Flooding at Avon Road and Livernois Road in Rochester Hills, Michigan on May 23, 2004 (Moore 2004)

Table 4.3.2-1: Lake Level Control Structure Operations Data from May 21, 2004 thru May 25, 2004 Recorded by OWRC Lake Level Technicians

	Cemetery Dollar	Van Norman	Loon	Watkins	Orchard	Cass	Dawson Mill Pond	Crystal
Existing Condition	One Bay Open with 6" Board	Outside Gate 1" Inside Gate 0"	Main Gate Open to 12"	Pump Off	Pump Running	1 Bay at 18", 1 Bay at 6"	1 Gate Opened to 24"	Clinton 10", Oaks wide open

	Cemetery Dollar	Van Norman	Loon	Watkins	Orchard	Cass	Dawson Mill Pond	Crystal
Operation Changes	None	None	None	None	None	5/24/04 - All Bays Open	5/24/04 - 2nd Gate to 50% Max	None

Before the rainfall event on May 23, 2004 the OCWRC controlled lakes were at or near their court ordered levels and this month was the wettest May since 2000. It is important to note that several lakes in the system rose approximately 1 to 2 ft during the event. It is evident that these two lakes help reduced the downstream flow in the Clinton River by storing water (Table 4.3.2-2). The hydrologic model in Section 6.0 indicates that using lakes to store storm water helps reduce the peak flow for the storm. Table 4.3.2-2 shows that a majority of the lakes were close to one foot or more over their court ordered levels. The lakes were holding back storm water, which helped reduce the peak flow recorded in the Clinton River.

Table 4.3.2-2: Difference between Court Ordered Lake Levels and Lake Levels Recorded by OWRC Lake Level Technicians (ft)

Date	Cemetery Dollar	Van Norman	Loon	Watkins	Orchard	Cass	Dawson Mill Pond	Crystal
5/21/04	0.05	0.05	0.40		-0.48			
5/22/04								
5/23/04								
5/24/04								
5/25/04		0.74	1.20		-0.16	0.98	0.90	2.00

July 15-19, 2008

Figure 4.3.2-2 depicts typical dry weather summer flow in the Clinton River on July 17, 2008 (Moore 2012). There was no rainfall from July 15-19 that would cause the river to rise from run-off and July of 2008 was slightly wetter than normal. This event is being used as a control case to compare to the high flow (5/23/2004) and low flow (7/06/2010) cases. The daily mean flow at the Auburn Hill’s USGS gauge station ranged between 40cfs and 70 cfs during these five days. There were very little operation of the lake level control structures two days before and after July, 17, 2008. Most of the controls were closed then marginally opened supplying additional flow to the Clinton River (Table 4.3.2-3).

Figure 4.3.2-2: Clinton River (Normal Flow) at Avon Road and Livernois Road in Rochester Hills, Michigan on July 17, 2008, (Moore 2008)

Table 4.3.2-3: Lake Level Control Structure Operations Data from July 15, 2008 thru July 19, 2008 Recorded by OWRC Lake Level Technicians

	Cemetery Dollar	Van Norman	Loon	Watkins	Orchard	Cass	Dawson Mill Pond	Crystal
Existing Condition	Outlet Closed	Outside Gate Closed	Gate Opened to 4”	Outlet Closed	Outlet Closed	One Gate at 2” other Gate Closed	Dam is Closed	Clinton Closed, Oak at 2”
Operation Changes	7/16/2008 - Outlet Closed	7/16/2008 - Main gate open at 7". 7/18/2008 - Opened outside gate to 1" 7/19/2008 - Open to 2" outside gate	7/16/2008 - Closed gate to 0" 7/18/2008 - Dam is closed.	7/16/2008 - Outlet Closed	7/16/2008 - Outlet Closed	7/16/2008 - Gate open at 3" 7/18/2008 - Opened gate to 8" 7/19/2008 - Dam open at 8"	7/18/2008 - Opened gate to 7 1/2" 7/19/2008 - Open to 8"	7/16/2008 - Dam is closed. 7/18/2008 - Opened Oaks gate to 5" 7/19/2008 - Dam open at 5"

Around July 17, the OCWRC controlled lakes were on average 3” above their respective court ordered levels (Table 4.3.2-4). Over the five days, the lake levels did not fluctuate and remained fairly consistent.

Table 4.3.2-4: Difference between Court Ordered Lake Levels and Lake Levels Recorded by OWRC Lake Level Technicians (ft)

Date	Cemetery Dollar	Van Norman	Loon	Watkins	Orchard	Cass	Dawson Mill Pond	Crystal
7/15/08								
7/16/08	0.03	0.14	-0.05	-0.11	0.20	0.18	0.15	0.12
7/17/08		0.24						
7/18/08	0.15	0.23	0.07		0.22	0.27	0.29	0.10
7/19/08						0.26	0.25	0.10

July 4-8, 2010

Figure 4.3.2-3 depicts extremely low flow in the Clinton River on July 6, 2010 (Moore 2012). There was no rainfall from July 4-8. The mean flow at the Auburn Hill's USGS gauge station on July 6, 2010 was 18 cfs.

Figure 4.3.2-3: Clinton River (Low Flow) at Avon Road and Livernois Road in Rochester Hills, Michigan on July 6, 2010, (Moore 2010)

There was very little operation of the lake level control structures two days before and after July 6, 2010. During the four days all the control structures were closed (Table 4.2.3-5).

Table 4.2.3-5: Lake Level Control Structure Operations Data from July 4, 2010 thru July 8, 2010 Recorded by OWRC Lake Level Technicians

	Cemetery Dollar	Van Norman	Loon	Watkins	Orchard	Cass	Dawson Mill Pond	Crystal
Existing Condition	One 5' Board Removed	Dam Closed to 7/8"	Dam Closed	Dam Closed	Dam Closed	Dam Closed	Dam Closed	Dam Closed
Operation Change	7/6/2010 - Installed (1) 6' Board 7/8/2010 - Dam Closed	7/6/2010 - Closed Outside Gate to 1", Inside Gate at 5" 7/8/2010 - Dam Closed	7/6/2010 - Dam Closed	7/7/2010 - Dam Closed	7/6/2010 - Dam Closed	7/6/2010 - Dam Closed	7/6/2010 - Dam Closed	7/6/201 - Dam Closed

Around July 6, 2010 the OCWRC controlled lakes were on average 1 to 2 inches below their respective court ordered levels (Table 4.2.3-6 and Table 4.2.3-9). Over the five days, the lake levels did not fluctuate and remained fairly consistent. This case shows during times of extreme drought the river had a mean flow of 18 cfs and the OCWRC controlled lakes were at or near their court ordered levels. It is also important to note that the Pontiac waste water treatment plant just upstream of the USGS Auburn Hills gauge station has a mean daily discharge of 11.60 cfs. Therefore, only approximately 6 cfs of flow in the Clinton River was from the upstream watershed, ground water infiltration, and other contributing sources. In this case, the river was experiencing extreme low conditions but the lake levels were normal.

Table 4.2.3-6: Difference between Court Ordered Lake Levels and Lake Levels Recorded by OWRC Lake Level Technicians, ft

Date	Cemetery Dollar	Van Norman	Loon	Watkins	Orchard	Cass	Dawson Mill Pond	Crystal
7/4/10								
7/5/10								
7/6/10	-0.18	0.02	0.02		0.15	0.06	0.08	-0.19
7/7/10				-0.08				
7/8/10	-0.10	0.05	0.08		0.05	0.06	0.12	-0.17

4.3.3 Low Flow Frequency Analysis

Of specific concern is the frequency of extreme low flows observed in the Clinton River over the past 10 years and the effect that is having on recreation and the environment. Table 4.3.3-1 and Table 4.3.3-2 provide the duration for which flow at USGS Gauge 04161000 in Auburn Hills, Michigan was below 20 cfs (Table 4.3.3-1) and 30 cfs (Table 4.3.3-2) for the period of record. Unfortunately, the gauge was not operational from October 1, 1983 through June 30, 2001 and October 1, 2002 through March 31, 2004 so there is no flow data to analyze during those time frames. The flow rate of 20 cfs was chosen because that was the typical discharge rate of the Pontiac Wastewater Treatment Plant in the 1970s so it would represent a no release (dry) condition. A flow rate of 30 cfs was considered an extreme low case. Of specific interest is that prior to 1984, a flow below 20 cfs was never recorded and only one case (11 days in 1966) of flow below 30 cfs was recorded. After 2001, flow measurements below 30 cfs became nearly yearly occurrences with 2002, 2005, 2007, and 2010 being particularly dry. In fact, there are four occasions when flow was never higher than 30 cfs for more than one month (30 days) and in 2010 the flow was not above 20 cfs for 35 straight days. As such, the flow in the river is measurably different now than what it was when a majority of the lake levels were established.

There are three likely reasons for the increased occurrence in low flow. The first is urbanization as documented in Section 4.1.1; the watershed is must more urbanized now than in the 1960s which causes high peak discharges and a reduced baseflow because of lower groundwater tables fed by infiltration (a syndrome known as “urban flashiness”). The second is a reduced discharge from the Pontiac Wastewater Treatment Plant, which is immediately upstream of this gauge. The current mean daily discharge from the Pontiac WWTP is approximately 11.6 cfs dry weather flow (conservative low estimate) (Korth 2011). The 2010 census listed a Pontiac population of 59,515 people which would provide the discharge for the WWTP. The population of Pontiac peaked in 1970 at 85,279 which, assuming a linear distribution of water usage would mean nearly 20 cfs was flowing from the Pontiac WWTP in 1970 (Korth 2011). This approximation does not account for an additional reduction in manufacturing the region has seen over the past 40 years which would also affect flow from the WWTP. It is almost certain that more than 20 cfs dry weather flow was emanating from the plant in the 1960s but that does not completely account for the reduction of flows less than 30 cfs that are being measured. Finally, climate change has changed weather patterns for southeast Michigan with more common prolonged droughts and heat waves in the past 10 years than were recorded in the 1960s (Section 4.1.3). This would also affect the flow in the river. While it is impossible to assign a percentage of flow change to each of these three influences, all three are almost certainty playing a role with the reduction of flow from the Pontiac WWTP being the most quantifiable influence.

Table 4.3.3-1: Days of Flow Under 20 cfs in the Clinton River for 7, 14, and 30 Days

Year	7 Days	14 Days	30 Days
1965	N/A	N/A	N/A
1966	N/A	N/A	N/A
1967	N/A	N/A	N/A
1968	N/A	N/A	N/A
1969	N/A	N/A	N/A
1970	N/A	N/A	N/A
1971	N/A	N/A	N/A
1972	N/A	N/A	N/A
1973	N/A	N/A	N/A
1974	N/A	N/A	N/A

Year	7 Days	14 Days	30 Days
1975	N/A	N/A	N/A
1976	N/A	N/A	N/A
1977	N/A	N/A	N/A
1978	N/A	N/A	N/A
1979	N/A	N/A	N/A
1980	N/A	N/A	N/A
1981	N/A	N/A	N/A
1982	N/A	N/A	N/A
1983	N/A	N/A	N/A
1984	*No Data	*No Data	*No Data
1985	*No Data	*No Data	*No Data
1986	*No Data	*No Data	*No Data
1987	*No Data	*No Data	*No Data
1988	*No Data	*No Data	*No Data
1989	*No Data	*No Data	*No Data
1990	*No Data	*No Data	*No Data
1991	*No Data	*No Data	*No Data
1992	*No Data	*No Data	*No Data
1993	*No Data	*No Data	*No Data
1994	*No Data	*No Data	*No Data
1995	*No Data	*No Data	*No Data
1996	*No Data	*No Data	*No Data
1997	*No Data	*No Data	*No Data
1998	*No Data	*No Data	*No Data
1999	*No Data	*No Data	*No Data
2000	*No Data	*No Data	*No Data
2001	*No Data	*No Data	*No Data
2002	8/27/2002 - 9/18/2002 (23 days)	8/27/2002 - 9/18/2002 (23 days)	N/A
2003	*No Data	*No Data	*No Data
2004	N/A	N/A	N/A
2005	N/A	N/A	N/A
2006	N/A	N/A	N/A
2007	N/A	N/A	N/A
2008	8/15/2008 - 8/22/2008 (8 days) 8/26/2008 - 9/2/2008 (8 days)	N/A	N/A
2009	N/A	N/A	N/A
2010	7/1/2010 - 7/7/2010 (7 days) 9/7/2010 - 9/10/2010 (35 Days) 9/19/2010 - 9/27/2010 (9 days)	9/7/2010 - 9/10/2010 (35 Days)	9/7/2010 - 9/10/2010 (35 Days)
2011	N/A	N/A	N/A

Table 4.3.3-2: Days of Flow Under 30 cfs in the Clinton River for 7, 14, and 30 Days

Year	7 Days	14 Days	30 Days
1965	N/A	N/A	N/A
1966	8/4/1966 - 8/14/1966 (11 days)	N/A	N/A
1967	N/A	N/A	N/A
1968	N/A	N/A	N/A
1969	N/A	N/A	N/A
1970	N/A	N/A	N/A
1971	N/A	N/A	N/A
1972	N/A	N/A	N/A
1973	N/A	N/A	N/A
1974	N/A	N/A	N/A
1975	N/A	N/A	N/A
1976	N/A	N/A	N/A
1977	N/A	N/A	N/A
1978	N/A	N/A	N/A
1979	N/A	N/A	N/A
1980	N/A	N/A	N/A
1981	N/A	N/A	N/A
1982	N/A	N/A	N/A
1983	N/A	N/A	N/A
1984	*No Data	*No Data	*No Data
1985	*No Data	*No Data	*No Data
1986	*No Data	*No Data	*No Data
1987	*No Data	*No Data	*No Data
1988	*No Data	*No Data	*No Data
1989	*No Data	*No Data	*No Data
1990	*No Data	*No Data	*No Data
1991	*No Data	*No Data	*No Data
1992	*No Data	*No Data	*No Data
1993	*No Data	*No Data	*No Data
1994	*No Data	*No Data	*No Data
1995	*No Data	*No Data	*No Data
1996	*No Data	*No Data	*No Data
1997	*No Data	*No Data	*No Data
1998	*No Data	*No Data	*No Data
1999	*No Data	*No Data	*No Data
2000	*No Data	*No Data	*No Data
2001	7/7/2001 - 8/12/2001 (37 days)	7/7/2001 - 8/12/2001 (37 days)	7/7/2001 - 8/12/2001 (37 days)

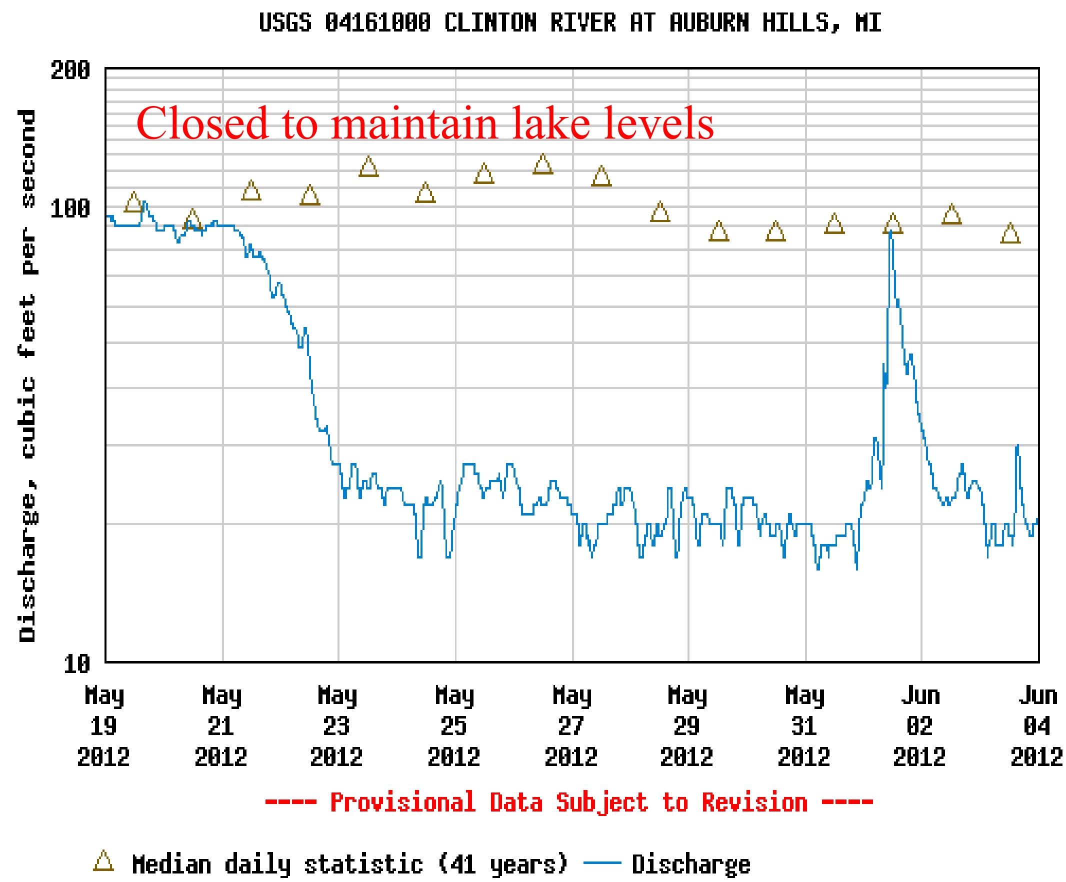
Year	7 Days	14 Days	30 Days
2002	7/2/2002 - 7/20/2002 (19 days) 7/31/2002 - 9/19/2002 (51 days) 9/22/2002 - 9/30/2002 (9 days)	7/2/2002 - 7/20/2002 (19 days) 7/31/2002 - 9/19/2002 (51 days)	7/31/2002 - 9/19/2002 (51 days)
2003	*No Data	*No Data	*No Data
2004	4/22/2004 - 4/30/2004 (9 days) 9/17/2004 - 10/13/2004 (27 days)	9/17/2004 - 10/13/2004 (27 days)	N/A
2005	8/2/2005 - 8/26/2005 (25 days) 8/30/2005 - 9/21/2005 (23 days) 10/4/2005 - 10/12/2005 (9 days) 10/18/2005 - 10/26/2005 (9 days)	8/2/2005 - 8/26/2005 (25 days) 8/30/2005 - 9/21/2005 (23 days)	N/A
2006	8/10/2006 - 8/18/2006 (9 days) 9/1/2006 - 9/8/2006 (8 days)	N/A	N/A
2007	6/16/2007 - 6/26/2007 (11 days) 6/30/2007 - 8/5/2007 (37 days) 8/9/2007 - 8/18/2007 (10 days) 9/1/2007 - 9/8/2007 (9 days) 9/13/2007 - 9/30/2007 (18 days) 10/6/2007 - 10/14/2007 (9 days)	6/30/2007 - 8/5/2007 (37 days) 9/13/2007 - 9/30/2007 (18 days)	6/30/2007 - 8/5/2007 (37 days)
2008	7/29/2008 - 8/22/2008 (25 days) 8/25/2008 - 9/6/2008 (13 days)	7/29/2008 - 8/22/2008 (25 days)	N/A
2009	N/A	N/A	N/A
2010	6/29/2010 - 7/14/2010 (16 days) 8/6/2010 - 9/15/2010 (41 days) 9/18/2010 - 9/27/2010 (10 days)	6/29/2010 - 7/14/2010 (16 days) 8/6/2010 - 9/15/2010 (41 days)	8/6/2010 - 9/15/2010 (41 days)
2011	7/9/2011 - 7/26/2011 (18 days)	7/9/2011 - 7/26/2011 (18 days)	N/A

*Note that from October 1, 1983 thru June 30, 2001 and October 1, 2002 thru March 31, 2004 there is no flow data on record.

4.3.4 Effect of a Dry Spring - May 2012

As a contrast to the relatively wet month of May observed in 2010 (Section 4.3.1), May of 2012 was dryer than normal. Prior to May 21, 2012, there was no significant rainfall event for approximately two weeks (between May 7 and May 21 only 0.6 inches of total rain fell based on the OCWRC Rain Gauge 0816 in Union Lake) and the Clinton River was flowing at approximately 90 cfs based on water released from the upstream lakes. The lake level controls were closed on May 21, 2012 in order to maintain the court ordered lake levels in the steadily falling lakes. Closing the hydraulic structures on the lakes caused a drastic drop in the flow in the Clinton River to about 20 cfs in less than two days (Figure 4.3.4). There was a small rainfall event on June 1 (less than 0.5 inches), 2012 that caused the flow in the river to rapidly rise to its historical daily average flow (represented as a triangle in the figure). However, the control structures remained closed to capture the rain event and raise the lakes towards their court ordered levels. This is because lake levels in the Clinton River watershed will continue to fall 0.1 to 0.2 inches per day based on evaporation (Johnson and Anderson 1964). Therefore, there was no significant flow from the upstream watershed and the Clinton River in Auburn Hills quickly dropped back down to around 20 cfs. This is another example of how during times of drought, the current lake level control strategies as dictated by court ordered lake levels are effecting the river disproportionately.

Figure 4.3.4: Flow in the Clinton River at the USGS Gauge Station in Auburn Hills, Michigan (USGS 2012)



5.0 Stakeholder Engagement, Education, and Participation

5.1 Website

A project website was created in order to keep the stakeholders informed of meeting dates and project information. The website is located on the Great Lakes Storm Water Management Institute's website housed through Lawrence Technological University. The project website includes interactive maps depicting lake and dam location and information, court orders for lake levels, educational graphics, and documents pertaining to the project, survey information, survey results, public forum presentations, and public forum announcements. The projects website is https://www.ltu.edu/water/iaclintonrivershed.asp .

5.2 Displays, Presentations, and Project Marketing

The original project flyer (Figure 5.2) provided background information about the Clinton River Watershed, a description of the project, expected outcomes, and how stakeholder can become involved. This flyer was used to recruit members to the Advisory Board and to inform the general public about the project. The flyer was included along with a press release that was published by several local print outlets including Detroit Free Press, Oakland Press, Oakland Lakefront Magazine, and West Oakland Spinal Column.

Michigan Sea Grant and Lawrence Tech both created graphics for stakeholder education. Michigan Sea Grant created multiple graphics depicting natural and urbanized watersheds. The graphics demonstrate how a natural watershed and a developed watershed respond to wet and dry periods and the associated issues. Lawrence Tech created maps depicting the Clinton River and the connecting lakes and posters showing photos of low and high levels in the lakes and river. All the stakeholder graphics created for the project are included in Appendix C.

These graphics were critical for the PowerPoint presentations provided at the stakeholder engagement meetings. The dates, times, locations, and number of attendees of the four public meeting are as follows:

1. Nov 3, 2010 (7-9 pm), Waterford Township Auditorium, Waterford. Approximately 70 people were in attendance.
2. Nov 4, 2010 (7-9pm), Auburn Hills Community Center, Auburn Hills. Approximately 50 people were in attendance.
3. Nov 13, 2010 (9-11am), Gold Room C, Oakland Center, Oakland University, Auburn Hills. Approximately 50 people were in attendance.
4. June 6, 2012 (7-9pm), Oakland Room, Oakland Center, Oakland University, Auburn Hills. Approximately 35 people were in attendance.

Figure 5.2: Project Flyer

MICHIGAN SEA GRANT

Restoring Natural Flows in the Clinton River Watershed

INTEGRATED ASSESSMENT

BACKGROUND

The 80-mile long Clinton River has its headwaters in rural and urbanizing areas and then flows through heavily urbanized sections of southern Oakland and Macomb counties before eventually draining into Lake St. Clair in southeast Michigan. Although water quality in the Clinton River has improved over the last 30 years, the river faces a number of environmental challenges, including extreme fluctuation of water flow.

Twenty one separate impoundments – or dammed lakes – along the upper reaches of the river interrupt natural flows and block fish movement within the watershed. A majority of the lakes created by the impoundments have a court-authorized water level that is set independently of other lakes in the system and the downstream receiving waters. When lake control structures at the impoundments are adjusted, the result is a sudden, drastic change of water flow in the river. Although regulatory agencies are legally required to make these water level adjustments, the resulting abrupt changes in river flow adversely impact fish and wildlife habitat as well as recreational opportunities. Additionally, the presence of the impoundments puts many constituents on opposite sides of the issues; residents often have contrasting opinions about lake level control and river water use depending on where they are located in the watershed.

Project Description

This project will evaluate ecologically and economically sound approaches to managing the Clinton River. Researchers will use stakeholder input, a variety of existing data sources, and hydrologic and economic models to assess the causes, consequences and possible solutions for the current flow regime. The project will evaluate the impact of existing and potential river regulation policies on:

- Water quality
- Fish and wildlife habitat
- Recreational opportunities in and along the river
- Flood control and flow stabilization
- Property values, property rights, and insurance costs
- Taxes, wages and business income
- The influence of lake level control on adjoining lakes
- The effect on lake level control on the watershed
- Operational mechanics

Expected Outcomes

The overall goal is to develop a more comprehensive, holistic approach to water-level management. The project will develop tools and metrics that can be used by policy makers to identify, evaluate and build consensus for revised flow management policies. A more natural flow regime has the potential to create long-term benefits like, improved water quality and environmental health, increased recreational opportunities, reduced user conflicts, improved regional economic viability and lower operational costs associated with lake level controls.

Get Involved

The project team will gather input from all concerned stakeholders including landowners, lake-owner and riparian owner associations, municipal governments, county agencies, watershed managers, permit agencies, businesses and recreational users. For more information about the project and upcoming public meetings, visit the website, www.ltu.edu/IAclintonriverwatershed, or contact Dr. Sanjiv Sinha.

Sea Grant Michigan

Michigan Sea Grant enhances the sustainability of Michigan's coastal communities, residents, and businesses through research, outreach and education.

Principal Investigator: Donald D. Carpenter, Ph.D.
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Vice President & Corporate Director- Water Resources
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ssinha@ectinc.com

Lawrence Tech

ECT Environmental Consulting & Technology, Inc.

www.miseagrant.umich.edu/research/projects

MICHU-09-712

5.3 Advisory Board

A steering committee, or advisory board, was assembled to guide the project implementation. The advisory board had over 20 members was assembled by the project team leaders and included diverse representation including state and local government officials, community and homeowner associations, and local business owners. The following organizations and groups were represented:

- Oakland County Water Resources Commissioner's Office
- Oakland County Planning and Economic Development
- Clinton River Watershed Council
- City of Auburn Hills
- City of Rochester Hills
- City of Rochester
- Waterford Township
- Michigan Department of Environmental Quality
- Michigan Department of Natural Resources
- Sylvan Lake Association
- Lake Oakland Association
- Trout Unlimited
- Outdoor Escorts LLC
- Spalding DeDecker Engineering
- Other Local Business Owners and Concerned Citizens

Representation on the board varied between 20 and 25 members and the board met approximately three times per year during the 30 month project. In addition, a core technical sub-committee of the board met more frequently to discuss model development and results.

5.4 Survey

5.4.1 Methodology

A stakeholder's survey (Figure 5.4.1-1) was developed with input from the Advisory Board. The goal of the survey was to capture background knowledge of the watershed, how the watershed is being used, and opinions on current water management strategies. The stakeholder's survey was distributed in two forms with identical questions - digital (through Survey Monkey) and hard copy. The survey was advertised in conjunction with invitations to stakeholders meetings (Figure 5.4.1-2), on flyers at river related events (Figure 5.4.1-3) and on the project website (www.ltu.edu/water).

Approximately 89 completed surveys were collected in fall 2010 at the three public meetings listed in Section 1.2. In addition, 59 surveys were completed online around the same time for a total of 138 responses as of December of 2010. In an effort to collection additional information, flyers were distributed at the following river related events:

- ➢ May 16, 2011 (9am – 2pm), Clinton River Water Festival, Oakland University, Auburn Hills. 100's of students and teachers in attendance. Approximately 120 flyers distributed.

- June 11, 2011 (9am – 2pm), Auburn Hills Fishing Derby, Riverside Park, Auburn Hills. Over 120 people attended. Flyers distributed and project discussed.
- June 11, 2011 (9am – 2pm), CRWC River Fest Rochester Municipal Park, Rochester. 100s of people attended. Flyers distributed and project discussed.

Further, the Oakland County Water Resources Commissioners office sent mailers in fall 2010 to Lake Improvement Boards in the watershed to encourage citizen and community leaders to disseminate the public forums. In an effort to collect additional survey responses, a project information sheet with survey information was mailed to each lake improvement board member in the watershed in spring of 2011 (12 Boards and 93 members). A total of 10 online surveys were completed during 2011 as a result of disseminating the project at the three river events and the Oakland Count Water Resources Commissioners mailers. In all, a total 148 stakeholder surveys were collected.

5.4.2 Results

The survey results were analyzed and presented to the board in three different methods. The first method was analyzing the data in raw aggregate form (data not split or divided). The second method divided the results into three groups based upon the individuals ZIP Code response. GIS was used to assign ZIP codes into "River Region", "Lake Region", and Other (Outside of the "River Region" and "Lake Region". Figure 5.5.2-1 below shows the division of the "Lake Region" and the "River Region. Figure 5.5.2-2 shows the number of survey responses from each ZIP Code. The third method divided the data into three categories based upon the response to the question "My residence is:". The three categories are "On or has Lake Access", "Adjacent to the Clinton River", or "Neither". Appendix D includes all the survey results and analysis. Pertinent results were input into the socio-economic model (Chapter 8).

Figure 5.4.1-1: Stakeholder Survey

MICHIGAN SEA GRANT

Restoring Natural Flows in the Clinton River Watershed

STAKEHOLDER SURVEY

This survey is designed to help the project team better understand how stakeholders interact, understand, and use the Clinton River and the connecting lakes. Please provide your ZIP code for demographic purposes. ________________

Instructions: Please circle your response to each of the questions. However feel free to leave any additional comments near the question as well.

I believe I know what a watershed is: Yes No

I live: Outside the Clinton River Watershed | In the Clinton River Watershed | Near the Clinton River Watershed | Don't Know

My residence is:

On or Has Lake Access | Adjacent to the Clinton River | Neither

Who is responsible for maintaining the lake levels in the watershed?

Oakland County Water Resources Commissioner | Clinton River Watershed Council | My Lake Board or Homeowner Association | Michigan Department of Natural Resources and the Environment | None of the Above | Don't Know

What is the legal framework for establishing lake levels in a watershed?

Federal Law | State Law | County Law | Local Community Law | None of the Above | Don't Know

I believe the lake levels are maintained properly:

Yes | No | Unsure | If no, why? ________________________________

I believe the flow in the Clinton River downstream of Pontiac is: Stable | Unstable | Don't Know

Which activities have you or other members of your household participated in or near *LAKES* in this area during the past year? (circle all that apply)

Don't participate | Fishing | Boating | Canoeing | Kayaking | Picnicking | Biking | Swimming | Hiking/Walking | Bird Watching | Nature Viewing | Other | No response

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Restoring Natural Flows in the Clinton River Watershed

STAKEHOLDER SURVEY

Which activities have you or other members of your household participated in or near the *CLINTON RIVER* during the past year? (circle all that apply)

Don't participate   Fishing   Boating   Canoeing   Kayaking   Picnicking   Biking   Swimming

Hiking/Walking   Bird Watching   Nature Viewing   Other   No response

Please indicate your level of agreement with the following statement: "The quality of Clinton River affects Lake St. Clair and the Great Lakes."

Strongly Agree   Agree   Neither   Disagree   Strongly Disagree   Don't Know

What factors do you think should be considered when a lake level is established? (circle all that apply)

Lake Shore Owners   Lake Users   River Users   Habitat

Watershed Health   Weather   Adjacent Lakes   Downstream River Levels

Please indicate your level of agreement with the following statement: "Lake control structures have a positive influence on watershed health."

Strongly Agree   Agree   Neither   Disagree   Strongly Disagree   Don't Know

Please indicate your level of agreement with the following statement: "I would tolerate moderate fluctuation in lake level if it meant an overall healthier watershed."

Strongly Agree   Agree   Neither   Disagree   Strongly Disagree   Don't Know

If you live on a lake, please indicate which lake you live on and which adjoining lakes it is connected too. ____________________

____

How much fluctuation are you willing to tolerate on your lake for an overall healthier watershed:

None   2 inches   6 inches   1ft   more than 1ft

What would you like to see addressed in the project's final report?____________________

____

____

____

____

Sea Grant Michigan   Lawrence Tech   ECT Environmental Consulting & Technology, Inc.

REV. 10.27.2010

Figure 5.4.1-2: Stakeholder Meeting Invitation

MICHIGAN SEA GRANT

Restoring Natural Flows in the Clinton River Watershed

STAKEHOLDER MEETINGS

Dear Concerned Citizen and/or Community Leader,

You are invited to a public forum in November about water levels within the Clinton River watershed. We are looking for input from all concerned stakeholders including landowners, lake-owner and riparian owner associations, municipal governments, county agencies, watershed managers, permit agencies, businesses and recreational users.

We will discuss current conditions of the watershed and collect your input on watershed health and management. Each public meeting will provide the same information and the same opportunity to express your opinion.

When: Wed, Nov 3, 7 - 9pm Where: Waterford Township Auditorium 5200 Civic Center Drive Waterford, MI 48329 Room Size: 300 people	When: Thur., Nov 4, 7 - 9pm Where: Seyburn Room, Auburn Hills Community Center 1827 North Squirrel Road Auburn Hills, MI 48326 Room Size: 200 people	When: Sat., Nov 13, 9-11am Where: Gold Room C, Oakland Center, Oakland University 2200 North Squirrel Road Rochester, MI 48309 Room Size: 100 people

About the Project

Lawrence Tech University, ECT Inc., Michigan Sea Grant, and our partner community organizations are currently evaluating ways to restore a more natural flow pattern to the Clinton River. The project will develop tools and metrics that can be used by policy makers to identify, evaluate, and build consensus for revised flow management policies. A more natural system has the potential to create long-term benefits such as improved water quality and environmental health, increased recreational opportunities, reduced user conflicts, improved regional economic viability, and lower operational costs associated with lake level controls.

Your input is crucial to this project!

Advanced registration for the forums is suggested because space is limited and the Project Team would like to plan accordingly. For your convenience, registration is available on-line at http://www.surveymonkey.com/s/clintonriverrsvp .

If you would like additional information regarding this event visit the project website at http://www.ltu.edu/water/iaclintonrivershed.asp or e-mail greatlakes@ltu.edu.

Sincerely Yours,

Clinton River Integrated Assessment Planning Committee

Sea Grant Michigan | Lawrence Tech | ECT Environmental Consulting & Technology, Inc.

REV. 10.06.2010

Figure 5.4.1-3: Stakeholder Survey Flyer

M I C H I G A N   S E A   G R A N T

Restoring Natural Flows in the Clinton River Watershed

STAKEHOLDER ENGAGEMENT

Dear Concerned Citizen and/or Community Leader,

Lawrence Tech University, Environmental Consulting & Technology, Inc., Michigan Sea Grant, and our partner community organizations are currently evaluating ways to restore a more natural flow pattern to the Clinton River. The project will develop tools that can be used by policy makers to evaluate revised flow management policies. A more natural system has the potential to create long-term benefits such as improved water quality and environmental health, increased recreational opportunities, reduced user conflicts, improved regional economic viability, and lower operational costs associated with lake level controls.

Critical to this project is input from all concerned stakeholders including landowners, homeowner associations, municipal governments, county agencies, watershed organizations, permit agencies, businesses and recreational users.

As such, your input is crucial to this project! You are invited to complete a survey about water levels within the Clinton River watershed. Please visit the online survey website at http://www.surveymonkey.com/s/clintonriversurvey

Sincerely Yours,

Clinton River Integrated Assessment Planning Committee

If you would like additional information please visit the project website at http://www.ltu.edu/water/iaclintonrivershed.asp or e-mail greatlakes@ltu.edu.

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REV. 06.03.2011

Figure 5.4.2-1: Lake and River Region

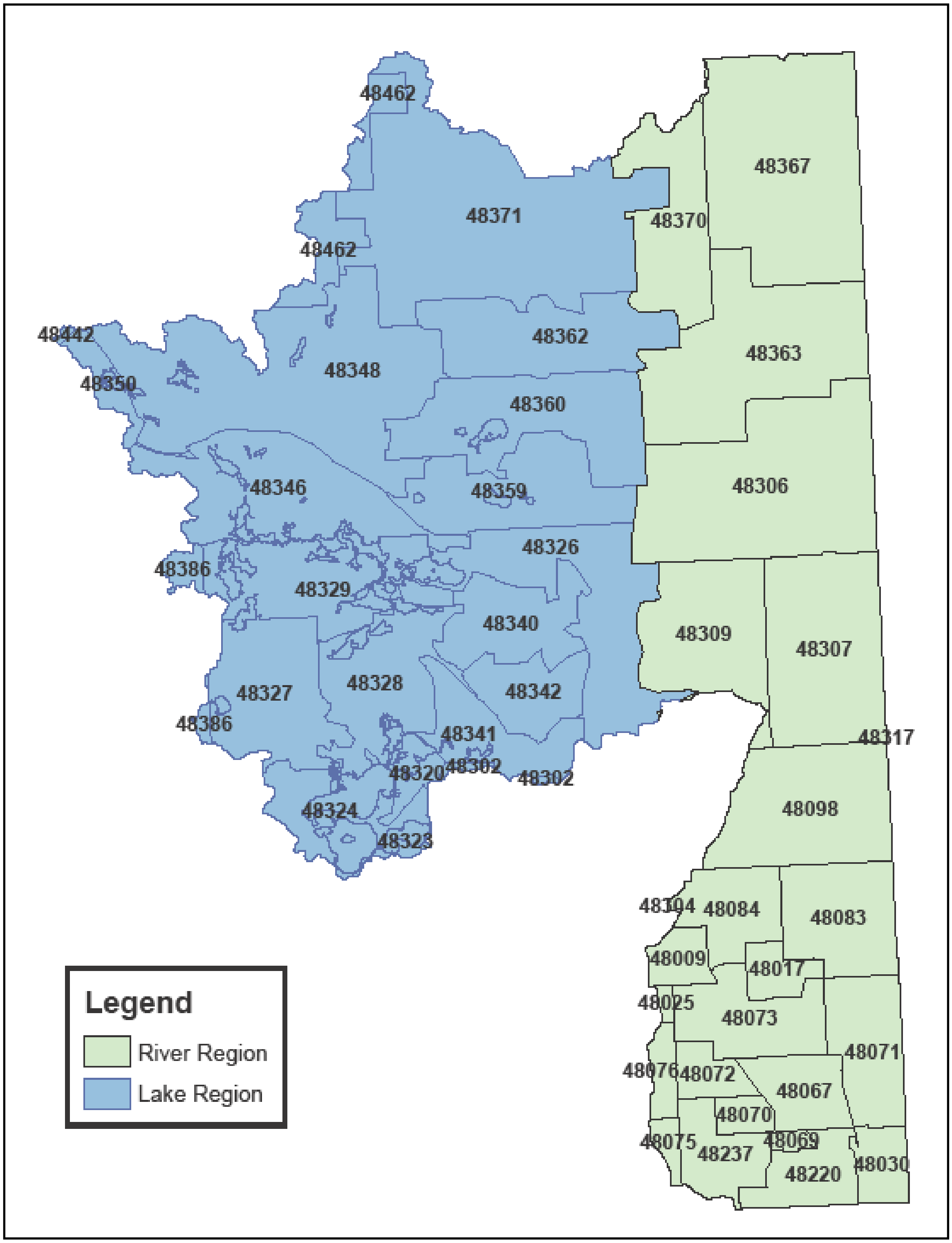
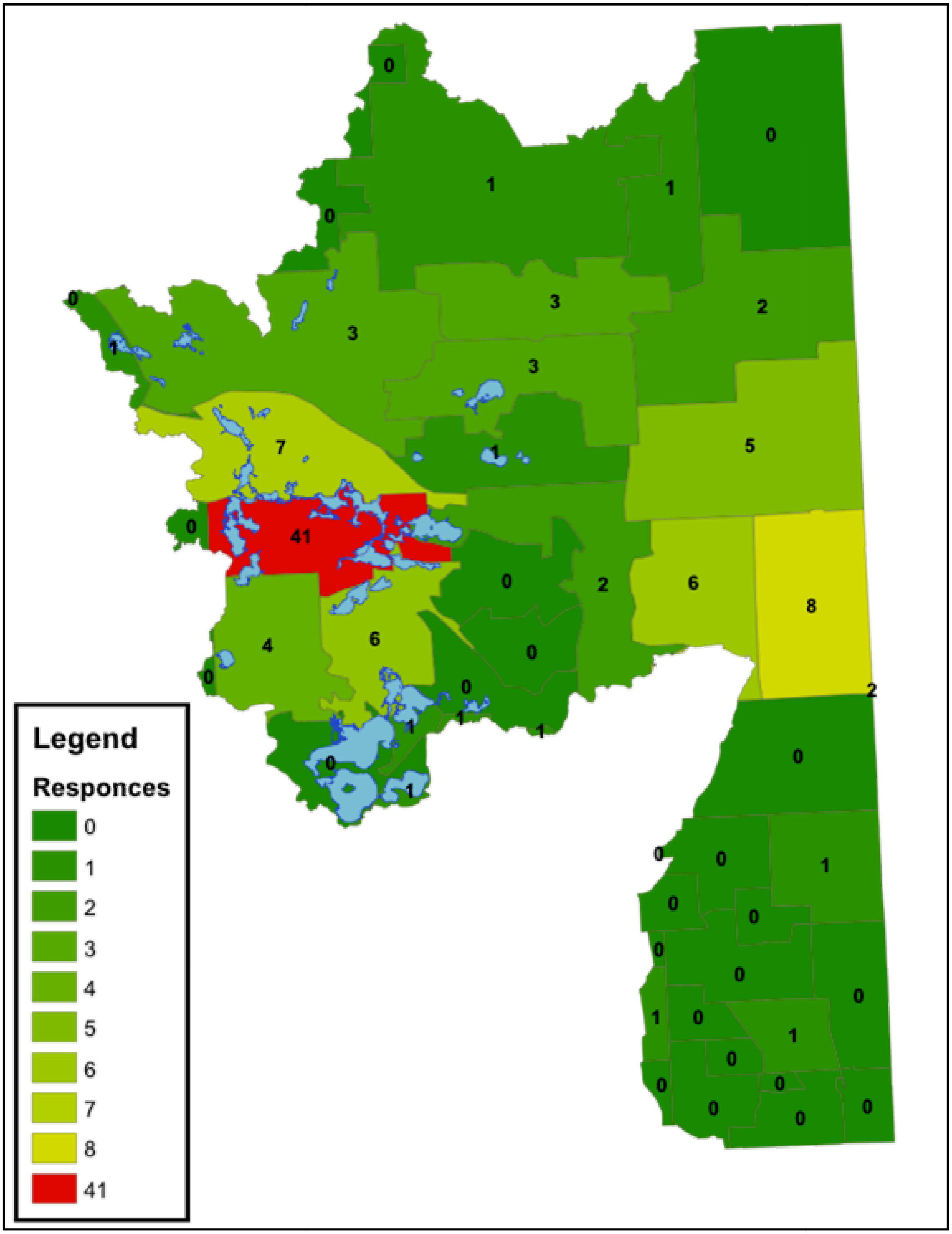


Figure 5.4.2-2: Survey Responses from Each ZIP Code



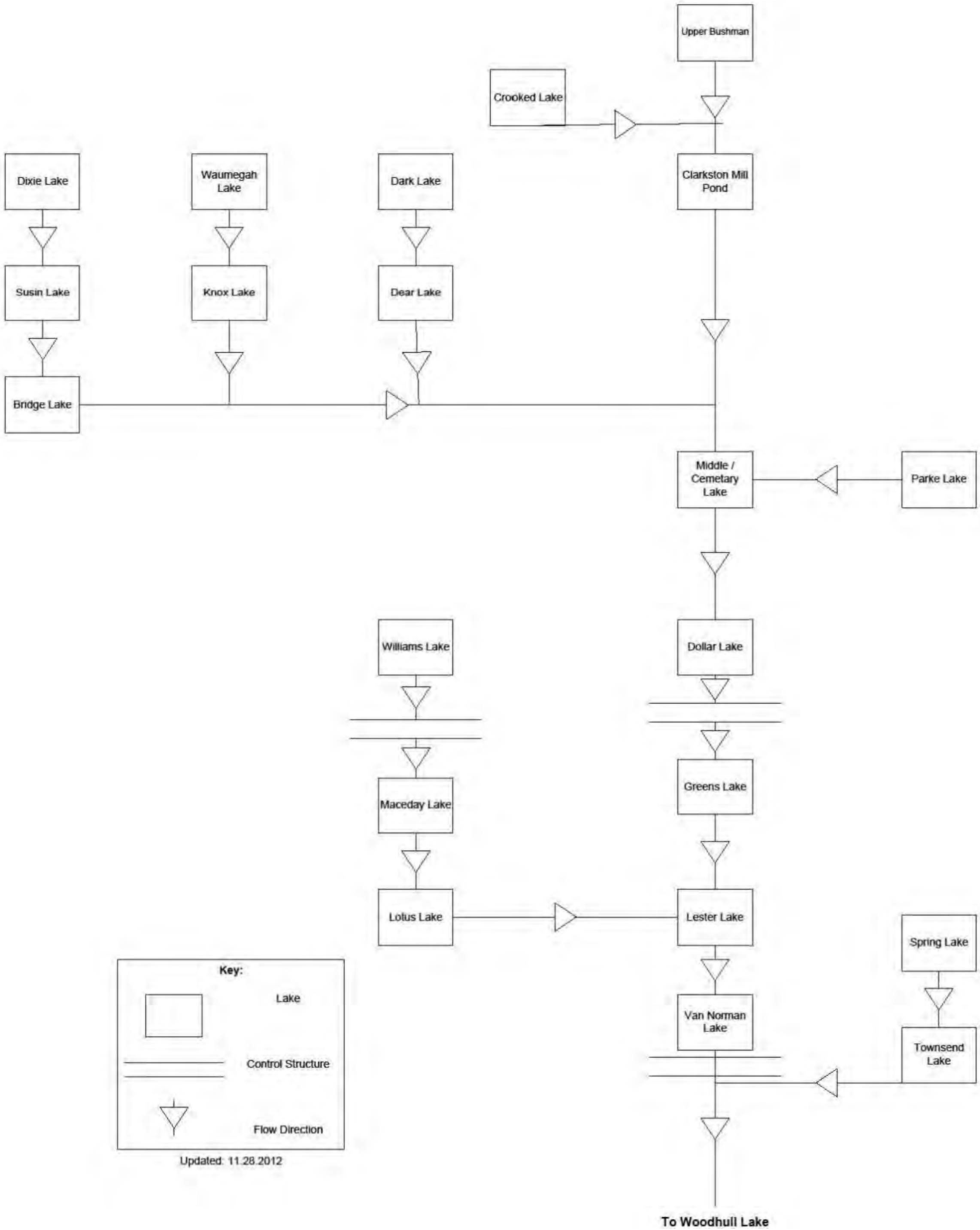
6.0 Hydrologic Modeling

6.1 Introduction

A simplified hydrologic model was used to investigate interactions of rainfall, surface runoff, river discharge, lakes, impoundments, and control structures. Two different scenarios were analyzed: water release and rainfall. Water release scenarios consist of releasing a specific amount of water from an individual lake or lakes over a set period of time. The water release scenarios are used to show the potential of the system to supplement flow in the river in times of drought. The rainfall scenarios were used to analyze how the system reacts to rain during wet and dry periods.

The hydrologic model includes 50 lakes over a 69,520 acre (108.6 sq miles) watershed (Figure 6.1). Each lake is identified as a separate subwatershed in the model. A GIS database [MDEQ 2011] was used to assign curve numbers based on land use and to determine contributing drainage area. Land use and drainages area were used to determine basin run-off using a standard Type II SCS rainfall-runoff model for the rainfall scenarios [Bedient and Huber, 2002]. The rainfall scenarios assume that the rainfall event was evenly distributed throughout the entire watershed. Finally, travel times between subwatersheds were estimated using channel information provided by the Oakland County Water Resources Commissioner's Office (Tetra Tech 2008). The simplified hydrologic model does not consider the time of concentration, but the time of concentration is indirectly accounted for by the subwatershed response time.

Figure 6.1: Schematic Diagram of the Watershed



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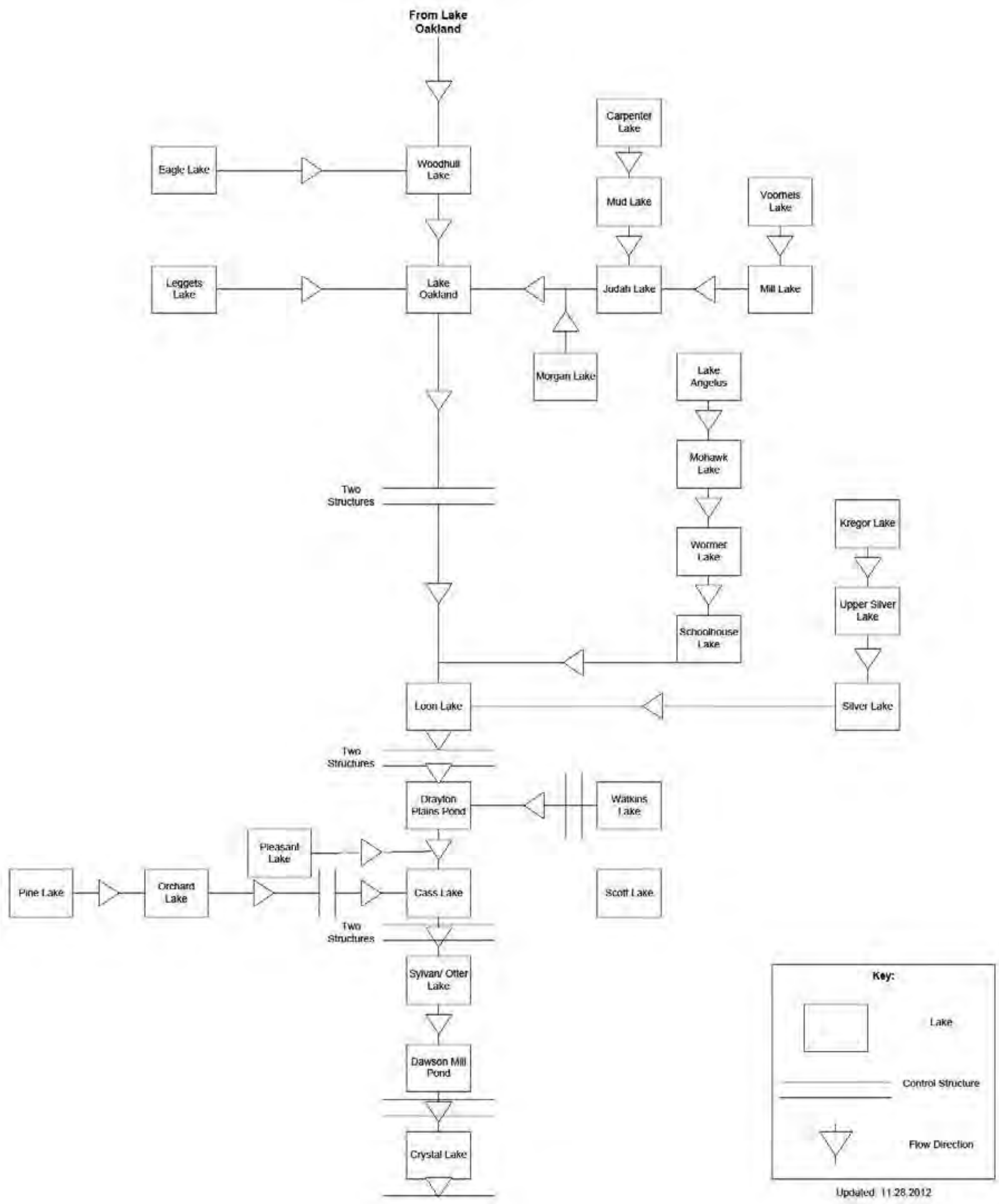


6.2 Model Development

Based on the goals of this integrated assessment investigation, it is not necessary to model all parameters of a watershed or to accurately depict complex flow conditions within the watershed. As such, a simplified dynamic SCS hydrologic model was chosen to analyze all 50 lakes in the target watershed based on pilot test results (Graham 2012). The model was created to demonstrate how the system reacts to different rainfall events, assessing the potential to store water in lakes to mitigate downstream flooding, and to supplement the flow of the river in times of drought.

Each lake is identified as a separate subwatershed in the model. The SCS method for determining runoff is based on a runoff Curve Number (CN). The CN is based on land cover type and hydrologic soil conditions and can be used to determine the effect of land use changes on potential abstraction and subsequent runoff on small watersheds (NRCS 1986). CN range from approximately 25 (dense woods on sandy soils) to 98 (impervious surfaces such as parking lots). Example curve numbers for this region include parks/meadows on good soils (CN = 60), 1/3 acre residential lots on clay soils (CN = 86), and dense downtown business districts (CN = 94). A GIS database (MDEQ 2010) was used to determine contributing drainage areas and to assign curve numbers based on land use using the method developed by the Hydrologic Studies Program of the MDEQ (2007). Finally, a composite curve number was calculated using area-weighted averaging (Table 6.2-1).

The Clinton River watershed layer, Digital Elevation Model (DEM), and Michigan Lake Polygon Layer (Michigan Geographic Data Library 2009) were used as the input files for the geo-processing. The DEM and the lake polygon layer were clipped to the shape of the Clinton River watershed layer. The lake polygon layer was used to identify where the break points for each subwatershed starting with the most upstream lake. A pour point, a point used to determine all contributing upstream flow, was placed near the outlet of each lake. ArcGIS then calculated the area that flows into that pour point (Table 6.2-2). For more information on watershed model development, see Graham (2012).

For the rainfall scenarios, curve number and drainages areas were used to determine basin run-off using a standard Type II SCS rainfall-runoff model (*Equation 6.1*) (Bedient and Huber 2002).

$$R = \frac{[P + 0.2S]^2}{[P + 0.8S]} \tag{6.1}$$

Where:	*R*	=	*Direct Runoff (in)*
	P	=	*Rainfall (in)*
	S	=	*Potential Abstraction (1000/CN) - 10*
	CN	=	*Runoff curve number*

The rainfall was evenly distributed throughout the entire watershed and the direct runoff was multiplied by the subwatershed drainage area to yield the volume of runoff. The volume of water captured by the lakes was calculated by multiplying the lake's surface area by the rainfall event. The total volume of water added to each lake by the rainfall event is the sum of the two (*Equation 6.2*).

$$V_r = DA_d + RA_l \tag{6.2}$$

Where:	V_r	=	*Volume of water generated by subwatershed and lake (ft^3)*
	D	=	*Direct runoff (in.)*
	A_d	=	*Drainage area (acres)*
	R	=	*Rainfall (in.)*
	A_l	=	*Lake area (acres)*

The water release scenarios are similar to the rainfall scenarios except that the volume of water released/generated from each lake is calculated by multiplying the lake surface area by the inches of water to be released by each lake (*Equation 6.3*).

$$V_{wr} = AH \tag{6.3}$$

Where: V_{wr} = *Volume of water released from lake (ft^3)*

A = *Area of lake (acres)*
H = *Inches of water released (in)*

The hydrologic model assumes the discharge leaving a lake is the same as the discharge entering the lake and a storage-indication method for pond routing was not implemented. However, the model does consider the travel time of the flood wave through the lake and the travel time through the connecting channels. The methodology to approximate the river segment velocities was provided by the Oakland County Water Resource Commissioners Office (Tetra Tech 2008). The length and slope of the river segments were determined using GIS. The channel was assumed to be a trapezoidal channel with a bottom of 10 feet, side slope of 3:1, and a river stage of 2 feet. The river channel travel times were approximated by calculating the velocity of the water using Manning's equation. The water velocity was converted to a wave velocity using *equation 5.4* (Bedient and Huber 2002).

$$V_{wave} = 1.5 \times V_{water} \tag{6.4}$$

Where: V_{wave} = *Velocity of wave (ft^3/s)*
V_{water} = *Velocity of water (ft^3/s)*

Due to the complexity of the Clinton River system, large amount of uncertainty, and preliminary approach associated with this model, a simplistic approach to estimate velocity/travel time of the flood wave flowing through a lake was devised. The length of the lake (from inlet to outlet) was divided by the averaged velocity to yield the estimated travel time through the lake. The travel time to the outlet of Crystal Lake from any lake in the system is the sum of the downstream river and lake travel times (*Table 6.2-3*). The longest travel time is 31.3 hours from the farthest lake modeled in the watershed (Lake Upper Bushman) to Crystal Lake outlet (receiving waters of the Clinton River near Pontiac).

Table 6.2-1: Lake Subwatershed Curve Numbers (CN)

Lake Subwatershed	CN
Crystal Lake	70.7
Dawsons Mill Pond	72.3
Otter Lake	72.0
Sylvan Lake	72.1
Cass Lake	69.4
Orchard Lake	62.1
Pine Lake	63.6
Watkins Lake	72.3
Scott Lake	72.9
Pleasant Lake	61.7
Drayton Planes Pond	65.6
Loon Lake	71.4
Lake Oakland	63.8
Schoolhouse Lake	63.5
Wormer Lake	58.5
Silver Lake	67.1
Mohawk Lake	59.7
Lake Angelus	66.4
Upper Silver Lake	73.4
Leggets	59.3
Kreger Lake	66.9
Woodhull Lake	61.5
Eagle Lake	60.7
Morgan Lake	64.8
Van Norman Lake	68.0

Lake Subwatershed	CN
Townsend Lake	68.0
Spring Lake	62.9
Mill Lake	62.5
Lester Lake	69.2
Voorheis Lake	64.1
Judah Lake	58.2
Lotus Lake	62.5
Greens Lake	64.5
Mud Lake	58.2
Maceday Lake	50.1
Carpenter Lake	65.3
Dollar Lake	71.9
Middle Lake	73.4
Williams Lake	59.8
Deer Lake	68.5
Clarkston Mill Pond	68.5
Parke Lake	65.8
Dark Lake	65.5
Bridge Lake	70.1
Knox Lake	65.0
Waumegah Lake	68.4
Susin Lake	60.6
Dixie Lake	64.7
Crooked Lake	64.9
Upper Bushman Lake	71.0

Table 6.2-2: Lake Subwatershed Areas

Lake Subwatershed	Area (acres)	Lake Subwatershed	Area (acres)
Crystal Lake	1064	Townsend Lake	787
Dawsons Mill Pond	788	Spring Lake	268
Otter Lake	2358	Mill Lake	886
Sylvan Lake	1365	Lester Lake	65
Cass Lake	10231	Voorheis Lake	4620
Orchard Lake	1578	Judah Lake	968
Pine Lake	1259	Lotus Lake	1659
Watkins Lake	684	Greens Lake	1190
Scott Lake	260	Mud Lake	53
Pleasant Lake	1587	Maceday Lake	539
Drayton Planes Pond	156	Carpenter Lake	1115
Loon Lake	1914	Dollar Lake	66
Lake Oakland	9368	Middle Lake	426
Schoolhouse Lake	243	Williams Lake	1193
Wormer Lake	110	Deer Lake	3380
Silver Lake	392	Clarkston Mill Pond	446
Mohawk Lake	171	Parke Lake	4969
Lake Angelus	1731	Dark Lake	111
Upper Silver Lake	270	Bridge Lake	632
Leggets	132	Knox Lake	1121
Kreger Lake	129	Waumegah Lake	1399
Woodhull Lake	1060	Susin Lake	628
Eagle Lake	286	Dixie Lake	1954
Morgan Lake	717	Crooked Lake	930
Van Norman Lake	532	Upper Bushman Lake	1730

Table 6.2-3: Travel Times to the Outlet of Crystal Lake

Lake	Time to Outlet (hr)
Crystal Lake	0.0
Dawsons Mill Pond	1.4
Otter Lake	2.1
Sylvan Lake	3.1
Cass Lake	4.0
Orchard Lake	6.4
Pine Lake	8.1
Watkins Lake	11.8
Scott Lake	13.1
Pleasant Lake	17.5
Drayton Planes Pond	17.5
Loon Lake	17.8
Lake Oakland	18.8
Schoolhouse Lake	18.8
Wormer Lake	19.3
Silver Lake	19.4
Mohawk Lake	19.7
Lake Angelus	20.0
Upper Silver Lake	20.5
Leggets	20.6
Kreger Lake	21.2
Woodhull Lake	22.0
Eagle Lake	22.9
Morgan Lake	23.5
Van Norman Lake	24.4

Lake	Time to Outlet (hr)
Townsend Lake	24.4
Spring Lake	25.0
Mill Lake	25.5
Lester Lake	25.6
Voorheis Lake	25.9
Judah Lake	25.9
Lotus Lake	26.2
Greens Lake	26.2
Mud Lake	26.9
Maceday Lake	27.1
Carpenter Lake	27.2
Dollar Lake	27.9
Middle Lake	28.1
Williams Lake	28.6
Deer Lake	28.6
Clarkston Mill Pond	28.6
Parke Lake	28.6
Dark Lake	30.1
Bridge Lake	31.3
Knox Lake	31.6
Waumegah Lake	31.6
Susin Lake	32.1
Dixie Lake	32.9
Crooked Lake	34.1
Upper Bushman Lake	34.1

6.3 Model Validation

To validate the model's results, an average rainfall event was chosen to compare against model results (rainfall event of 0.856 inches on August 9, 2011). It was assumed that the rainfall was evenly distributed throughout the Upper Clinton River Watershed.

6.3.1 Methodology

The 0.856 inches of rainfall was used as input for the dynamic routing model to calculate the approximate outflow hydrograph of the Clinton River in Pontiac. Previous to the rainfall event on August 9, 2011 there was a 158 cfs base flow in the Clinton River. Since the dynamic model calculates only flow derived from a rainfall event and does not incorporate a base flow, the 158 cfs base flow was added to the Dynamic model results.

The total volume of water generated by the rainfall event was determined for both the actual data and the dynamic model results (*Table 6.3-1*) in order to accurately compare both sets of data. The dynamic model calculates flow based upon volumes incrementally divided over time and the incremental volumes were added together to determine the total volume of the rainfall event. The volume of water for the actual USGS data was calculated by calculating the area under the hydrograph. The base flow was subtracted from the USGS flow data in order to accurately calculate the volume of water added to the system by the rainfall event.

6.3.2 Model Validation Results

The model hydrograph was plotted with the actual USGS flow data from the Auburn Hills gauge station (approximately 5.5 miles downstream of Crystal Lake). There are distinct differences in the hydrograph shape, peak discharge, and volume of water generated by the rainfall event (*Figure 6.3*). These differences can be explained by a few parameters not accurately depicted in the simplified dynamic routing model.

First, the difference in the hydrograph shape is attributed to the model not reacting quickly enough to the rainfall event. This is attributed to the standard watershed response time of 12 hours. In reality, the water being generated by the rainfall event is not over 12 hours (the set watershed response time). Reducing the watershed response time would minimally increase the peak flow and minimally reduce the duration of flow.

Second, the model is calculating discharge at the outlet of Crystal Lake and the actual data is recorded approximately 5.5 miles downstream in Auburn Hills. Between Crystal Lake and the USGS gauge there is an additional 30,891 acres of contributing watershed and approximately 11.6 cfs of flow from the Pontiac Wastewater Treatment Plant.

Finally, the model does not account for storage of water in the lakes. For this case, the lake levels were low and not all the runoff from the watershed was released downstream. This would considerably reduce the volume of water accounted for at the Auburn Hills gauge (*Table 6.3-1*). The difference in volume (206.2 acre - ft) would approximately raise every lake in the system 0.35 inches. Therefore, the 59.2% difference in volume between the actual data and the simplified dynamic model could easily be attributed to water storage in the lakes or that less than 0.856" of rain fell on portions of the watershed.

Overall, given the purpose of the model was not to accurately represent discharge in the Clinton River, but rather to demonstrate watershed interactions and the potential for hydromodification; it was determined that the model is accurate enough for the purposes of this investigation.

Figure 6.3 USGS Actual Flow vs Dynamic Model During a 0.856 Inch Rainfall (Volume generated by the rainfall event was released from each lake over 12 hours)

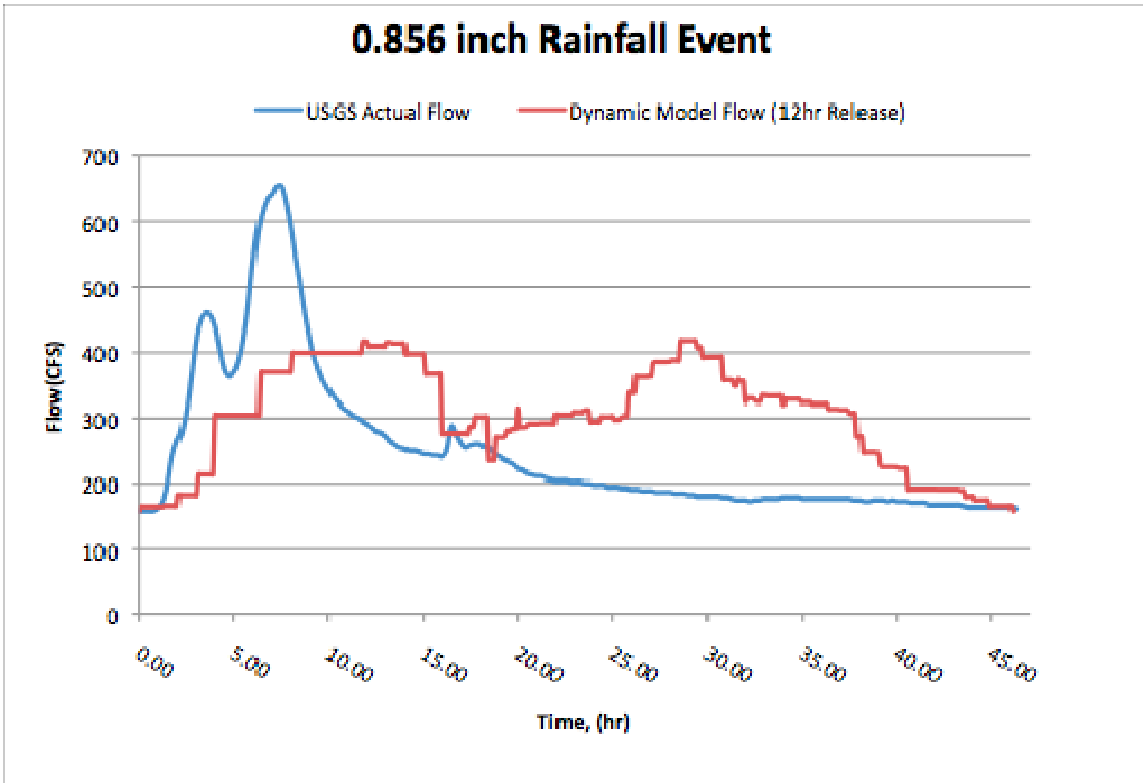


Table 6.3-1 Volumes of Water Generated by the Dynamic Model and Calculated Actual Volume (0.856 inches of rainfall)

	Volume, acre-ft
Dynamic Model	554.4
USGS Actual Volume	348.2
Percent Different, %	59.2%

Note: Percent Difference (%) =100* [Dynamic (acre-ft)-USGS (acre-ft)] / USGS (acre-ft)

6.4 Rainfall Scenarios

The rainfall scenarios represent the response of the watershed to rainfall events and hypothetical management strategies in response to those events. The model assumes that rainfall is evenly distributed over the entire watershed. The three rainfall rates are 0.9" (the 90% exceedance storm for Oakland County [Huff and Angel 1992]), 1.0" and 2.0".

6.4.1 Twelve (12) Hour Response of Various Rainfall Events

There were ten rainfall scenarios conducted using the curve number rainfall-runoff model. A basic response rate of 12 hours is used to model a lake response to a rainfall event. This is considered the standard time that run-off generated during the event will flow out of a lake (a combination of subwatershed area and lake response time). A summary of results can be located in Table E1 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. No Delay of Lakes - 0.9 Inch of Rain
2. No Delay of Lakes - 1.0 Inch of Rain
3. No Delay of Lakes - 2.0 Inches of Rain
4. Orchard Delayed 24 Hours - 1.0 Inch of Rainfall
5. Orchard Delayed 48 Hours - 1.0 Inch of Rainfall
6. Oakland and Orchard Delayed 24 Hours - 1.0 Inch of Rainfall
7. Crystal, Cass, and Orchard lakes delayed 24 hours before release of water over 12 hours - 1.0 Inch of Rainfall
8. Crystal, Cass, and Orchard lakes delayed 24 hours before release of water over 24 hours - 1.0 Inch of Rainfall
9. Crystal, Cass, Orchard and Oakland delayed 24 hours before release of water over 12 hours - 1.0 Inch of Rainfall
10. Crystal, Cass, Orchard and Oakland delayed 24 hours before release of water over 24 hours - 1.0 Inch of Rainfall

Results

Results of these scenarios include:

- By adjusting the delay time from 12 hours to 24 hours on one lake, the peak flow decreased by 48 cfs and the duration of flow was increased by 20.3 hours.
- Adjusting the delay time of Crystal, Cass, and Orchard from 12 hours to 24 hours, the peak flow decreased by 96.6 cfs and the duration of flow increased by 8.3 hours.
- For rain events of 2" or less across the watershed, delaying the release of lakes can cause the peak to decrease 15 to 20%.

6.4.2 Twenty Four (24) Hour Response of Various Rainfall Events

These scenarios are the same as Section 6.4.1 with the exception of the longer base duration of 24 hours instead of 12 hours. A summary of results can be located in Table E2 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. No Delay of Lakes - 0.9 Inches of Rain
2. No Delay of Lakes - 1.0 Inch of Rain
3. No Delay of Lakes - 2.0 Inches of Rain
4. Orchard Delayed 24 Hours - 1.0 Inch of Rainfall
5. Orchard Delayed 48 Hours - 1.0 Inch of Rainfall
6. Oakland and Orchard Delayed 24 Hours - 1.0 Inch of Rainfall
7. Crystal, Cass, and Orchard lakes delayed 24 hours before release of water over 12 hours - 1.0 Inch of Rainfall
8. Crystal, Cass, and Orchard lakes delayed 24 hours before release of water over 24 hours - 1.0 Inch of Rainfall
9. Crystal, Cass, Orchard and Oakland delayed 24 hours before release of water over 12 hours - 1.0 Inch of Rainfall
10. Crystal, Cass, Orchard and Oakland delayed 24 hours before release of water over 24 hours - 1.0 Inch of Rainfall

Results

Results of these scenarios include:

- A 2" rainfall will cause a discharge of almost 750 cfs with a peak response time of 26.9 hours.
- In scenarios 4 and 5, Orchard Lake was delayed 24 and 48 hours respectively. Orchard Lake (given its size and location in the watershed) does affect peak discharge slightly. Delaying Orchard Lake 48 hours decreased the peak by 38.2 cfs when compared to the base case (scenario 2).
- In scenarios 7 and 8, the duration of flow increases by approximately 12 hours and the peak discharge decreases by 15 to 20%.
- The benefits of delaying the release of more than one lake can be observed with peak discharge being lower than any single lake case.

6.4.3 Fourteen (14) Day Response

There were three rainfall scenarios conducted where a fourteen day response rate was used instead of a 12 to 24 hours response rate. This case represents a slow water release over fourteen days for every lake in the watershed and really represents steady flow from lakes when rainfall occurs over longer periods of time (evenly distributed intermittent rain). In this case, fourteen days represents the standard time that run-off generated during the event will flow out of a lake (lake response time). A summary of results can be located in Table E3 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. No Delays - 0.9 inches of Rain
2. No Delays - 1.0 inch of Rain
3. No Delays - 2.0 inches of Rain

Results

Results of these scenarios include:

- The peak flow increased by 53.1 cfs and the duration of flow over 15 cfs was increased by 44.6 hours, when comparing scenario 1 to 3.
- Using a response rate of 14 days instead of 12 hour (Table E1) or 24 hour rainfall events (Table E2) creates a much lower peak discharge.
- Steadily releasing volume of rain over the watershed (instead of holding it back to fill impoundments) could create a base flow for the river.

6.5 Water Release Scenarios

The water release scenarios were conducted to demonstrate how the Clinton River watershed would react to specific amount of water being released from all the lakes or specific lakes over a length of time. The release scenarios represent a release of water stored in lakes to supply the Clinton River with a base flow during times of low water/drought.

6.5.1 Twelve (12) Hour Release

There were three water release scenarios conducted using a basic release rate of 12 hours. This is considered the standard time that water could be released from a lake. A summary of results can be located in Table E4 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. No Delays - 1 inch
2. No Delays - 2 inches
3. Crystal, Cass, Orchard and Oakland Delayed 24 hours and released over 12 hours - 1 inches
4. Crystal, Cass, Orchard and Oakland Delayed 24 hours and released over 24 hours - 1 inches

Results

Results of these scenarios include:

- Scenario 1 represents 1.0” released from lakes which is less than 1.0” of rainfall over entire watershed. The peak discharge in scenario 1 is 299.1 cfs (Table E4) compared with 307.2 cfs for 1.0” rainfall case (Table E1).
- Releasing even small depths of water over short times will create high discharge peaks (over 300 cfs) and increased flashiness in the system.

6.5.2 Twenty Four (24) Hour Release

There were two water release scenarios conducted using a basic release rate of 24 hours. This is considered the standard time that water can be safely released from a lake. A summary of results can be located in Table E5 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. No Delays - 1.0 inch
2. No Delays - 2.0 inches

Results

Results of these scenarios include:

- A 24 hour release rate causes a drop of approximately 20% in the peak discharges when compared with the 12 hour release rate (Table E4).

6.5.3 Fourteen (14) Day Release

There were fifteen water release scenarios conducted using a basic release rate of 14 days instead of a 12 to 24 hours release rate. It is not possible under the current management structure to control and slowly release water over 14 days for every lake in the watershed so this case really represents steady flow from lakes when water is flowing over longer periods of time instead of being retained by hydraulic structures. In addition, Scenarios 4 through 15 were used to determine additional base flow in the Clinton River generated by releasing water from specific lake(s) assuming the remaining lakes are not contributing flow. The amount of water released from each lake was determined based upon the variability (minimum and maximum levels) of the four lakes (Table 6.5.3). The variability of the four lakes was determined by the Oakland County Water Resource Commissioner's Lake Level Technicians as having the ability to store and slowly release water. Figures 6.5.3-1 and 6.5.3-2 are a graphical representation of the lake level tolerances in inches and volume of storage potential in acre-ft. Where acre-ft is defined as one acre covered by one ft of water. Therefore 100 acre-ft could be either 100 acres covered by one ft of water or 400 acres covered by 3 inches of water. The figures demonstrate that while Crystal Lake has the greatest potential for fluctuation (27 inches) it can only store approximately 200 acre-ft because of its small surface area. Alternatively, Orchard Lake can store approximately 675 acre-ft, but can only fluctuate 9 inches. In each case, first release is only from Crystal Lake and then from all four lakes that have storage capacity. A summary of results can be located in Table E6 in Appendix E with more detailed descriptions of the scenarios considered.

Table 6.5.3 Lake Variability - Minimum and Maximum

Lake	Tolerance Below Court Ordered Level	Tolerance Above Court Ordered Level
Oakland	3”	3”
Cass	0”	3”
Orchard	3”	6”
Crystal	12”	15”

Figure 6.5.3-1 Lake Variability - Minimum and Maximum (Inches)

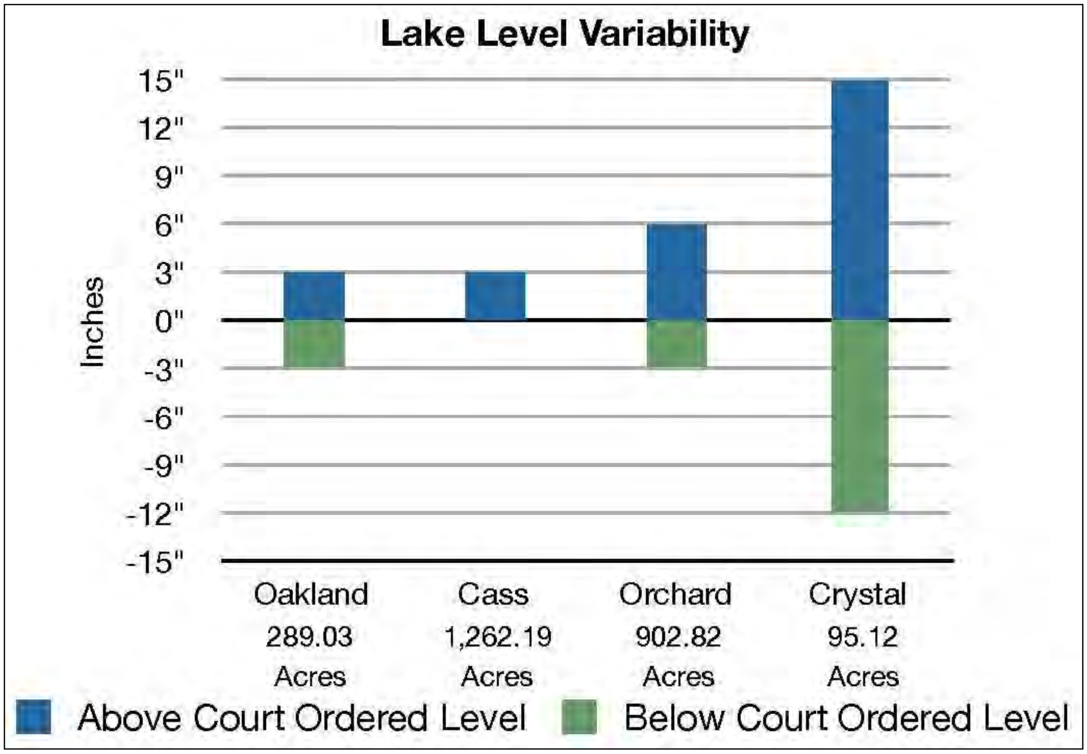
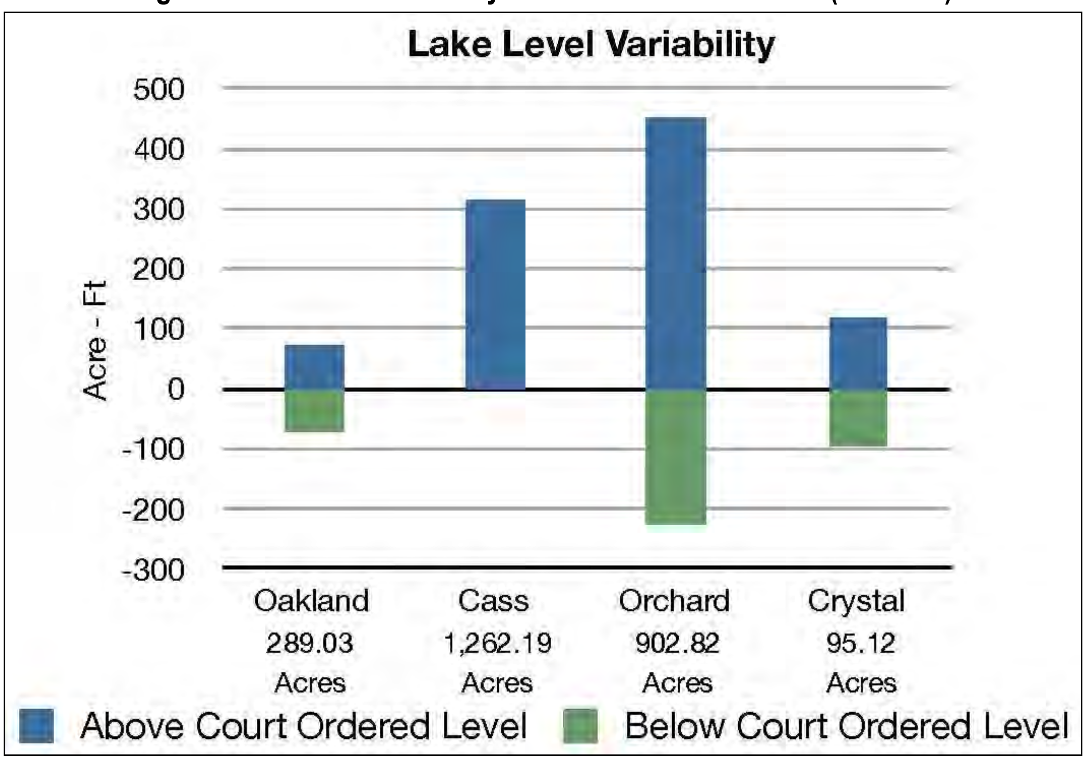


Figure 6.5.3-2 Lake Variability - Minimum and Maximum (Acre - Ft)



Scenarios

1. No Delays - 2.0 Inches
2. No Delays - 6.0 Inches
3. No Delays - 12.0 Inches
4. No Delays - Just Crystal Lake - 2 Inches
5. No Delays - Just Crystal, Cass, Orchard, and Oakland - 2 Inches
6. No Delays - Just Crystal Lake - 6 Inches
7. No Delays - Just Crystal, Orchard, and Oakland - 6 Inches; Cass - 3 Inches
8. No Delays - Just Crystal Lake - 12 Inches
9. No Delays - Just Crystal - 12 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
10. No Delays - Just Crystal Lake - 18 Inches
11. No Delays - Just Crystal - 18 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
12. No Delays - Just Crystal Lake - 24 Inches
13. No Delays - Just Crystal - 24 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
14. No Delays - Just Crystal Lake - 27 Inches
15. No Delays - Just Crystal - 27 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches

Note: A simplified dynamic model, excluding watershed travel times, was used to calculate scenarios 4 – 15 since the 32 hour travel time is a fraction of the 336 hour (14 day) hydrograph and does not significantly influence results.

Results

Results of these scenarios include:

- If every lake in the watershed contributed 2" of water over a two week period, a 42.2 cfs base flow would occur.
- Scenarios 4, 6, 8, 10, 12, and 14 created small base flows for 14 days using only water stored and released from Crystal Lake.
- Releasing stored water from Crystal, Cass Orchard, and Oakland (Scenarios 5, 7, 9, 11, 13, and 15), a base flow of 15 cfs is created for 14 days. Conversely, Crystal Lake would need to be drawn down 12" to create just a 3 cfs base flow if it is the only lake contributing.
- A maximum drawdown of 27" from Crystal, 9" from Orchard, 6" from Oakland, and 3" from Cass causes nearly a 50 cfs flow in the river (Table E6).

6.5.4 Thirty (30) Day Release

There were fifteen water release scenarios conducted using a basic release rate of 30 days instead of a 14 day release rate as shown in Section 6.4.3. A summary of results can be located in Table E7 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. No Delays - 2.0 Inches
2. No Delays - 6.0 Inches

3. No Delays - 12.0 Inches
4. No Delays - Just Crystal Lake - 2 Inches
5. No Delays - Just Crystal, Cass, Orchard, and Oakland - 2 Inches
6. No Delays - Just Crystal Lake - 6 Inches
7. No Delays - Just Crystal, Orchard, and Oakland - 6 Inches; Cass - 3 Inches
8. No Delays - Just Crystal Lake - 12 Inches
9. No Delays - Just Crystal - 12 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
10. No Delays - Just Crystal Lake - 18 Inches
11. No Delays - Just Crystal - 18 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
12. No Delays - Just Crystal Lake - 24 Inches
13. No Delays - Just Crystal - 24 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
14. No Delays - Just Crystal Lake - 27 Inches
15. No Delays - Just Crystal - 27 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches

Results

Results of these scenarios include:

- If every lake in the watershed contributed 2" of water over a thirty day period, a 19.7 cfs base flow would occur.
- If only four lakes contribute water (Crystal, Cass, Orchard, and Oakland), then a 7.14 cfs base flow is created by reducing their level 2 inches.
- Scenarios 4, 6, 8, 10, 12, and 14 created small base flows for 30 days using only water stored and released from Crystal Lake.
- Scenarios 7, 9, 11, 13, and 15 created base flows that were over 15 cfs for 30 days. If Crystal, Cass, Orchard, and Oakland are all used to store and release water, a maximum drawdown for those four lakes would create nearly a 22.71 cfs flow in the river (Table E7).
- It is no longer possible to maintain a 30 cfs flow for 30 days without significant contributions from every lake in the watershed.

6.5.5 Release Rate to Sustain 30 cfs

There were five water release scenarios conducted to calculate the release rate needed to sustain 30 cfs in the Clinton River when various amounts of water are released from Crystal, Cass, Oakland, and Orchard Lakes. A summary of results can be located in Table E8 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. No Delays - Just Crystal, Orchard, and Oakland - 6 Inches; Cass - 3 Inches
2. No Delays - Just Crystal - 12 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
3. No Delays - Just Crystal - 18 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
4. No Delays - Just Crystal - 24 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches
5. No Delays - Just Crystal - 27 Inches; Orchard - 9 Inches; Oakland - 6 Inches; Cass - 3 Inches

Note: A simplified dynamic model, excluding travel times, was used to calculate scenarios 1 - 5

Results

The goal of these scenarios was to determine how long 30 cfs could be maintained in the Clinton River downstream of the study watershed. Scenario 1 concludes storing and slowly releasing 6" of water from Crystal, Orchard and 3" from Cass will sustain a 30 cfs base flow in the Clinton River for 16.1 days. Storing and releasing 27" from Crystal, 9" from Orchard, 6" from Oakland, and 3" from Cass will sustain a 30 cfs base flow in the Clinton River for 22.7 days (Table E8). Therefore it is theoretically possible to maintain a 30 cfs base flow in the river for two to three weeks if maximum storage is available to be slowly released.

Results of these scenarios include:

- Scenario 1 concludes storing and slowly releasing 6" of water from Crystal, Orchard and 3" from Cass will sustain a 30 cfs base flow in the Clinton River for 16.1 days.
- Storing and releasing 27" from Crystal, 9" from Orchard, 6" from Oakland, and 3" from Cass will sustain a 30 cfs base flow in the Clinton River for 22.7 days (Table E8).
- It is theoretically possible to maintain a 30 cfs base flow in the river for two to three weeks if maximum storage is available to be slowly released.

6.6 Lake Recharge

6.6.1 Raise Specified Lakes from Drawdown Level - All Upstream Lakes at Court Ordered Level

There were seven scenarios conducted using the curve number rainfall-runoff model to calculate the rainfall events needed to refill Oakland, Cass, Orchard, and Crystal lakes to their respective court ordered levels and to full storage capacity following previous release of the water. This is assuming that all other lakes were at their court ordered level and all contributing runoff and flow passed through and were not retained by hydraulic structures upstream. The amount of rainfall required is assumed to have fallen evenly on the entire contributing watershed. The curve number rainfall-runoff model was not used in several scenarios because it is not valid for rainfall events under 1.0 inch. In those cases, a simplified volumetric runoff coefficient method was used (SEMCOG 2010). A summary of results can be located in Table E9 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. Oakland - 3 inches to legal limit
2. Oakland - 6 inches to full storage
3. Cass - 3 inches to full storage
4. Orchard - 3 inches to legal limit
5. Orchard - 9 inches to full storage
6. Crystal - 12 inches to legal limit
7. Crystal - 27 inches to full storage

Results

It is worth noting that these volumes were calculated using a small watershed runoff volume coefficient method (SEMCOG 2010) and therefore only accurate to about 0.25 inches. Results of these scenarios include:

- These seven scenarios prove that the rainfall events needed to refill the lakes identified as having potential storage are very small, except for Orchard Lake. This is due to it small contributing watershed and very little upstream flow.
- It takes less than 0.25" of rain to create the flow necessary to replenish most lakes with Orchard Lake in scenario 6 and 7 requiring 1.98" and 4.07" respectively (Table E9).

6.6.2 Raise Specified Lakes from Drawdown Level - All Upstream Lakes 3" Low

There were eight scenarios conducted to calculate the rainfall events needed to raise Oakland, Cass, Orchard, and Crystal lakes to their respective court ordered levels and to full storage capacity following release of water. This is identical to scenarios considered in Section 6.6.1 but assumes that all upstream lakes are 3 inches below their court ordered level or 3 inches below "normal" for lakes without a court ordered level. The upstream lakes in the watershed will need to fill 3 inches to their court ordered or normal levels before they will convey flow downstream to fill the depleted lakes. The following scenarios are used to show how the Clinton River watershed would react in a drought condition (all lakes 3 inches low). A summary of results can be located in Table E10 in Appendix E with more detailed descriptions of the scenarios considered.

Scenarios

1. Oakland - 3 inches to legal Limit
2. Oakland - 6 inches to full storage
3. Cass - 3 inches to legal Limit
4. Cass - 3 inches to full storage
5. Orchard - 3 inches to legal Limit
6. Orchard - 9 inches to full storage
7. Crystal - 12 inches to legal Limit
8. Crystal - 27 inches to full storage

Results

These eight scenarios are exactly the same as the ones in Section 6.2.6, except that all the other lakes in the system are 3 inches low. If all lakes were drawdown to maximum levels, this would represent drought conditions so remaining lakes in the watershed would also likely be low (unlike Section 6.2.6). Results of these scenarios include:

- These scenarios prove that the rainfall events needed to refill the lakes identified to have possible storage are relatively significant when the whole system is lacking water.
- The rainfall events are considerably bigger than the ones calculated in Section 6.2.6. This is because every lake in the system has to recharge the 3 inches before they contribute flow downstream.
- The increase in volume to balance the system increases the required rainfall event. Between 1.8" and 4.5" of rain is required to refill without additional flow out from the lakes (Table E10).

6.7 Lake Storage

6.7.1 Twelve (12) Hour Release - Lake Storage

There were four scenarios conducted using the curve number rainfall-runoff model. The scenarios demonstrate using Crystal, Orchard, Oakland, and Cass to store rainfall will affect the peak flow in the Clinton River. The scenarios assume that the four lakes are at their lowest possible draw down level providing the maximum amount of storage. A basic response time rate of 12 hours is used to model a lake response to a rainfall event. This is considered the standard time that run-off generated during the event will flow out of a lake (subwatershed and lake response time). A summary of results can be located in Table E11 in Appendix E with more detailed descriptions of the scenarios considered.

1. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 1.0 Inch of Rainfall - All Upstream Lakes at Legal Limit
2. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 2.0 Inch of Rainfall - All Upstream Lakes at Legal Limit
3. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 1.0 Inch of Rainfall - All Upstream Lakes 3" Low
4. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 2.0 Inch of Rainfall - All Upstream Lakes 3" Low

Results

Results of these scenarios include:

- These four scenarios demonstrate that Crystal, Orchard, Oakland, and Cass Lakes can be used to greatly decrease the peak flow in the Clinton River.
- Comparing Scenario 2 in Table D11 to Scenario 3 in Table D1 the peak flow was reduced by 145.7 cfs.
- In Scenario 3, a 1 inch rainfall event is not sufficient to fill the four lakes to maximum capacity and raise other lakes in the system 3 inches.
- Scenario 4 replicates the effects of the storage in times of drought (all other lakes in the system are 3 inches low). The peak flow was decreased by 574.9 cfs when comparing Scenario 4 and 2.

6.7.2 Twenty Four (24) Hour Release - Lake Storage

These scenarios are the same as Section 6.7.1 with the exception of the longer base duration of 24 hours instead of 12 hours. A summary of results can be located in Table E12 in Appendix E with more detailed descriptions of the scenarios considered.

1. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 1.0 Inch of Rainfall - All Upstream Lakes at Legal Limit
2. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 2.0 Inch of Rainfall - All Upstream Lakes at Legal Limit
3. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 1.0 Inch of Rainfall - All Upstream Lakes 3" Low
4. No Delay of Lakes - Storage - Crystal 27 Inches below maximum level, Orchard 9 Inches below maximum level, Oakland 6 Inches below maximum level, and Cass 3 Inches below maximum level - 2.0 Inch of Rainfall - All Upstream Lakes 3" Low

Results

Results of these scenarios include:

- Scenarios 1 - 4 show the effect of a 24 hour response instead of a twelve hour release as in Table D11.
- The peak flows were decreased in scenarios 1, 2, 3, and 4 by 41.7%, 34.0%. 0% and 50%, respectively, and the duration of flow was extended by 12 hours (Table E12).

6.8 Hydraulic Relationships

6.8.1 Fourteen (14) Day Release Hydraulic Relationships

A cross-section of the concrete channel (Figure 6.8.1-1) in Pontiac and of the Clinton River in Riverside Park were programmed into a one dimensional uniform flow software (Bentley's Flowmaster) to determine the water depth and wetted parameter at the peak flows calculated in Section 6.4.3. Further, the water depth and wetted parameter at Riverside Park was determined at the peak flows from Section 6.4.3 with the additional 11.6 cfs flow from the Pontiac Wastewater Treatment Plant (WWTP). The 11.6 cfs is a dry weather flow discharged from the Pontiac WWTP (conservative estimate based on plant flow meter operations log for 2010). (A summary of results can be located in Table 6.8.1 and the rating curves in Figures 6.8.1-3 and 6.8.1-6.)

Results

The following results demonstrate how the Clinton River will react to the flows calculated in Section 6.4.3. Results of these scenarios include:

- By releasing 2 inches of water from only Crystal Lake (Scenario 4) over 14 days the Clinton River will rise 3 inches in River Side Park. However, in a dry weather scenario when the river virtually has no flow, the same 3 inches from Crystal in combination with the flow from the WWTP would raise the river 9.4 inches.
- In Scenario 11 (Table D6) Oakland, Cass, and Orchard are releasing the maximum amount of water into the system. When comparing scenario 11 with scenario 13 and 15 the rise in the river at Riverside Park is only 0.01 ft and 0.02 ft, when increasing the volume of storage in Crystal. Therefore the effect of Crystal on the system in comparison to the other lakes is minimal

The rating curves for concrete channel in Pontiac (Figure 6.8.1-3) and Riverside Park (Figure 6.8.1-6) demonstrate the “break points” or the critical flows at which the water depth greatly changes. These break points are due to changes in the geometry of the channels cross-section. Since the concrete channel in Pontiac is virtually a uniform channel with vertical walls (Figure 6.8.1-1 and Figure 6.8.1-2), there are no significant break points to note (Figure 6.8.1-3). When comparing the Riverside Park rating curve to the Pontiac rating curve it has the same basic shape but with two distinct break points (Figure 6.7.1-6). The first break point is at approximately 10 cfs. Before 10 cfs the depth drastically changes as the flow increased. After 10 cfs the rate in which the depth increases slowed. This is due to the channels cross-section becoming considerably larger. The last break point is at 413 cfs, the depth of the river levels off till the flow reaches 430 cfs. The rivers cross-section dramatically increases in size, thus, slowing the rise in depth.

Figure 6.8.1-1 Pontiac Concrete Channel

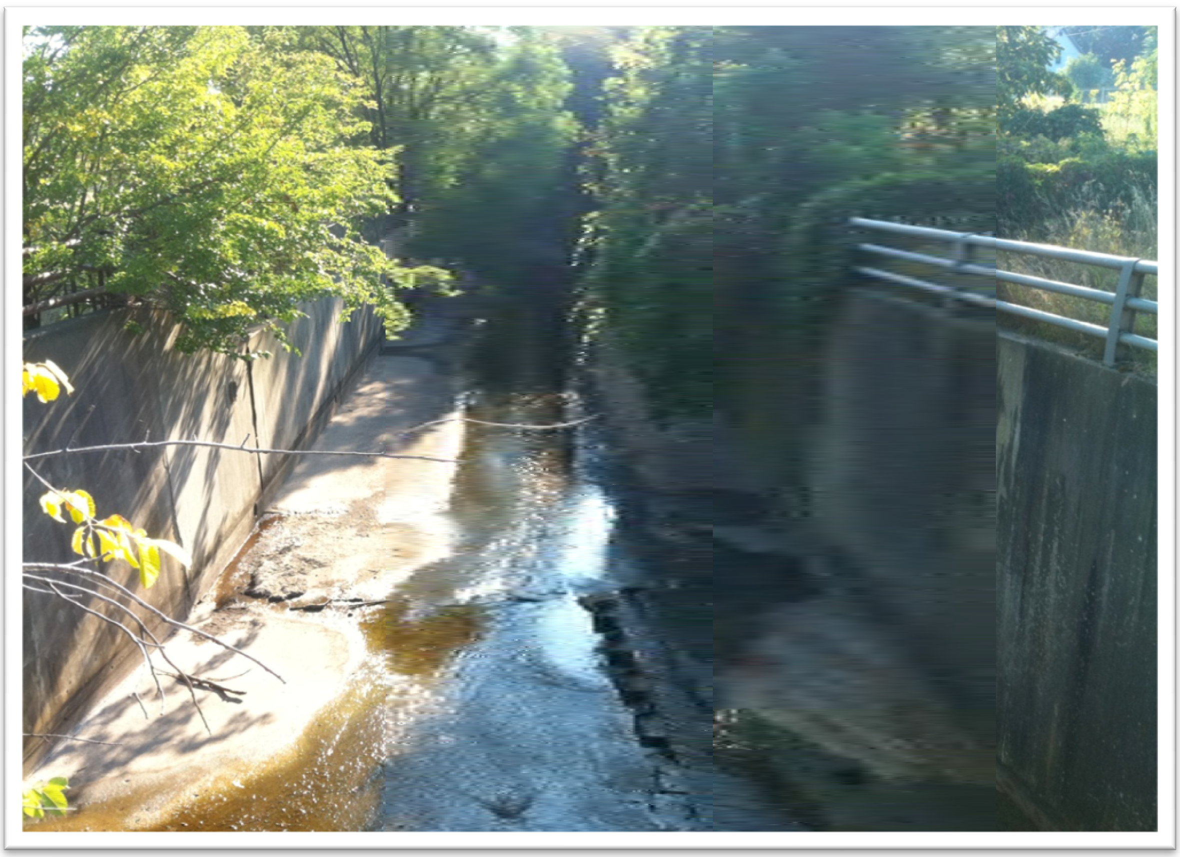


Figure 6.8.1-2: Pontiac Concrete Channel Cross-Section

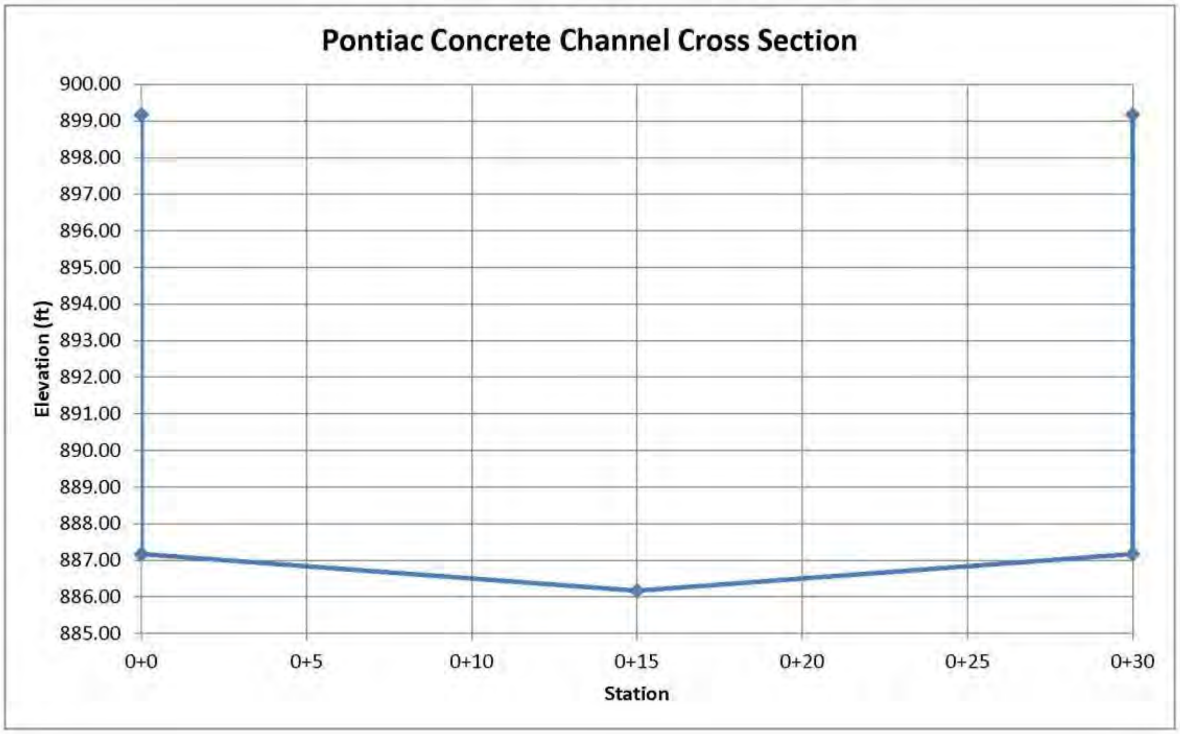


Figure 6.8.1-3: Pontiac Concrete Channel Rating Curve

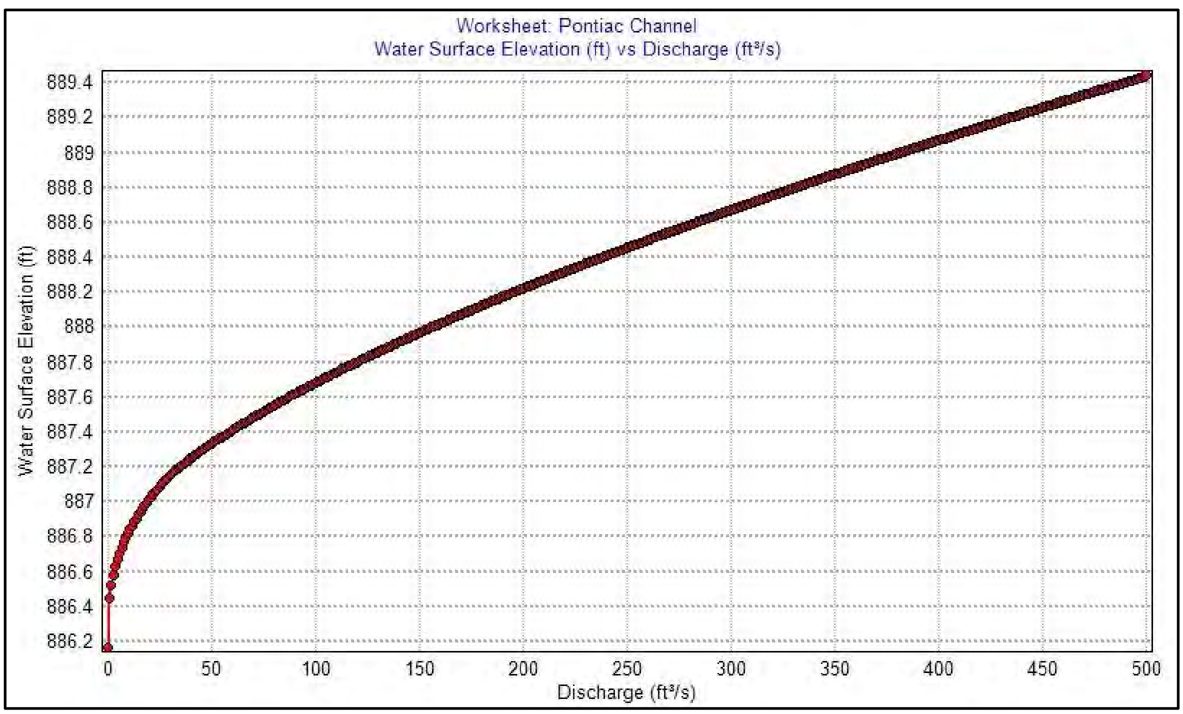


Figure 6.8.1-4: Riverside Park, Auburn Hills

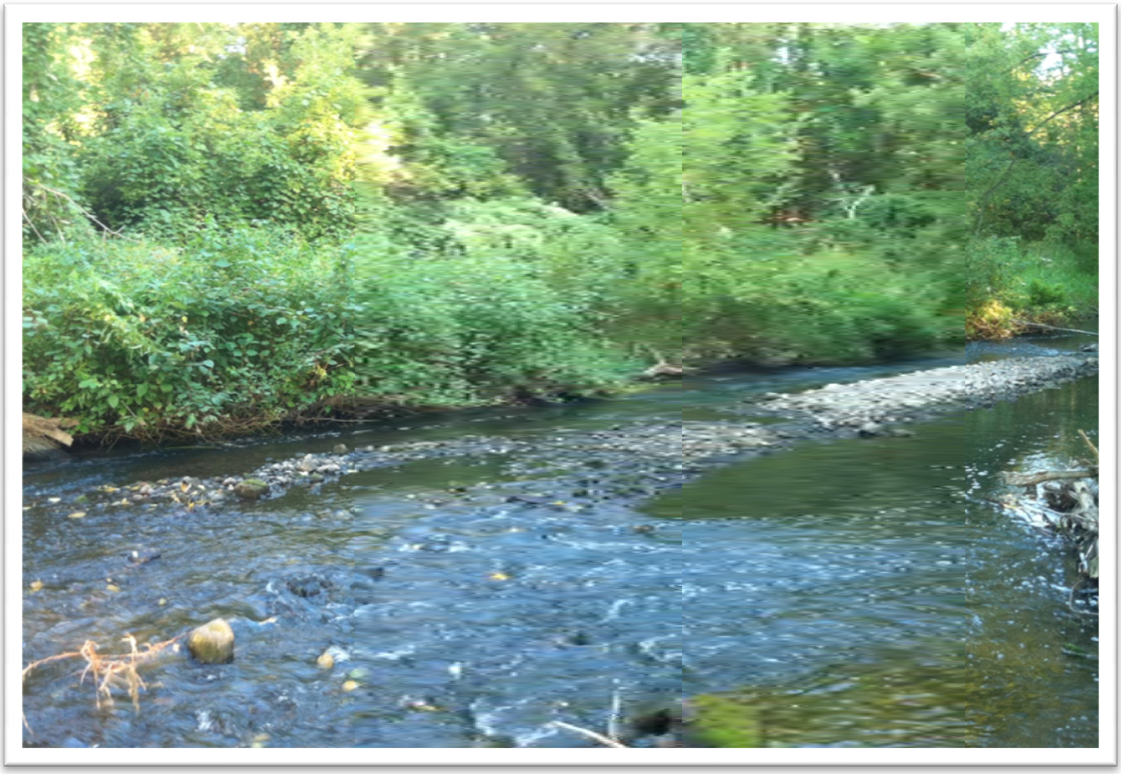


Figure 6.8.1-5: Riverside Park Cross-Section

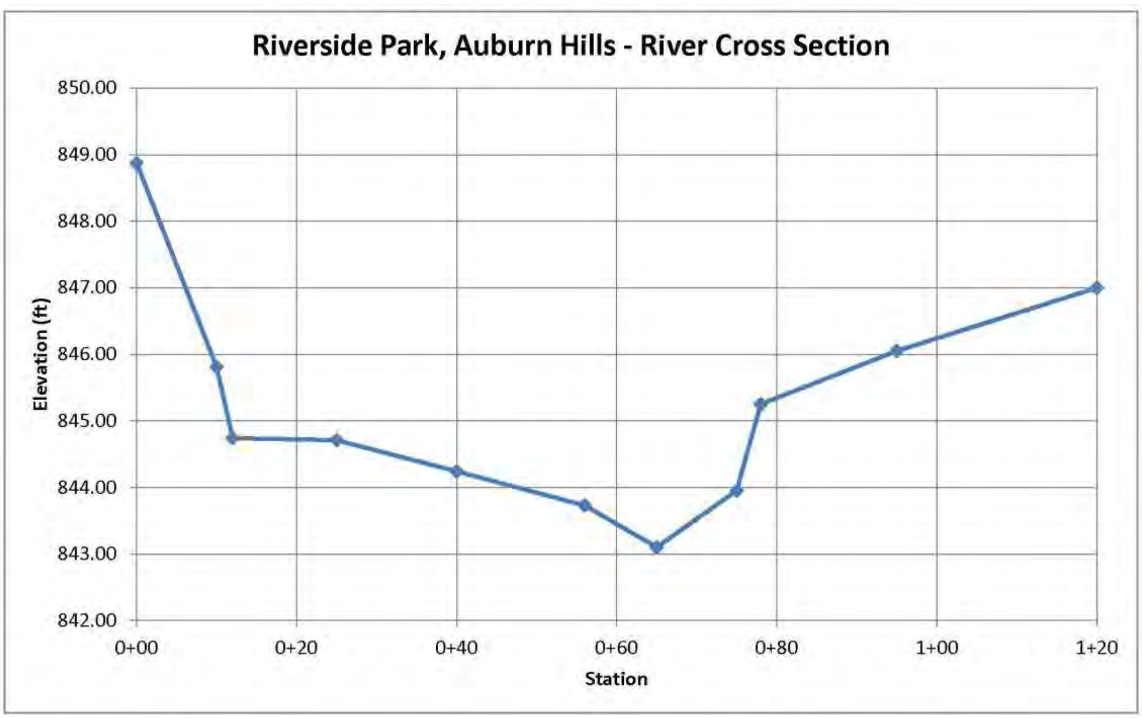


Figure 6.8.1-6: Riverside Park, Auburn Hills Rating Curve

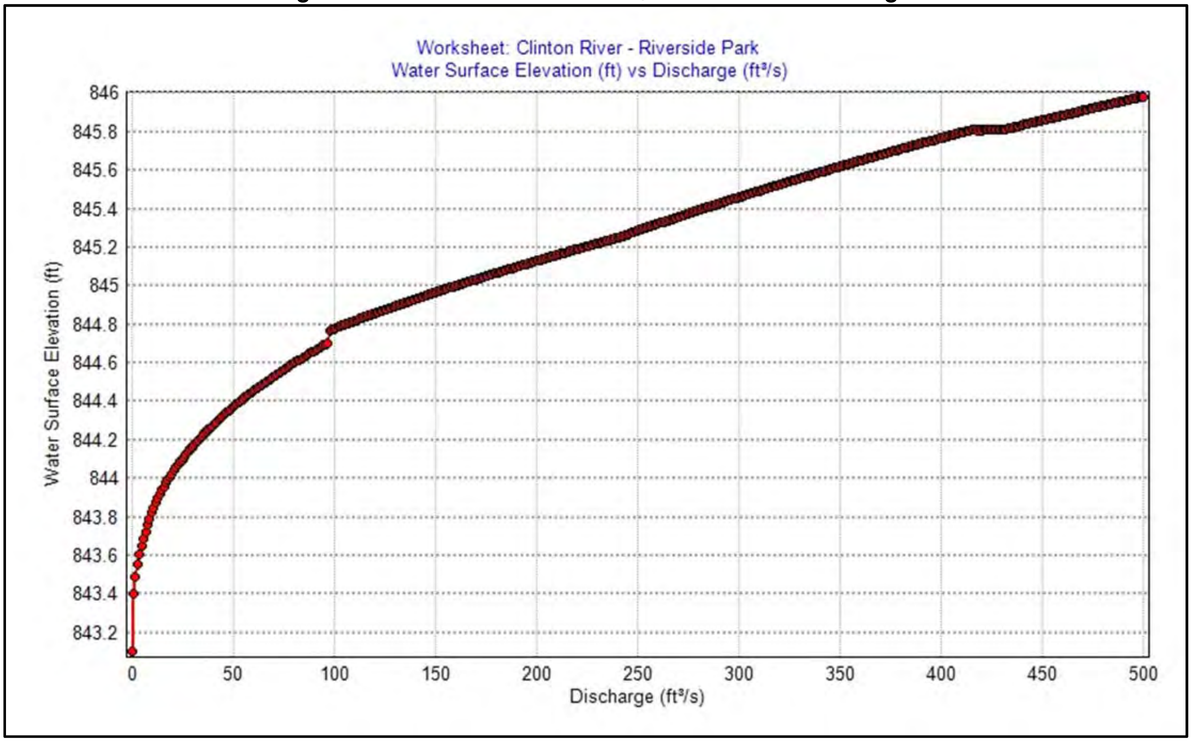


Table 6.8.1-1: Fourteen (14) Day Release Hydraulic Relationships

		Pontiac Channel		Riverside Park			
Scenario	Peak Flow (cfs)	Water Depth (ft)	Wetted Perimeter (ft)	Water Depth (ft)	Wetted Perimeter (ft)	Water Depth with WWTP Flow (ft)	Wetted Perimeter with WWTP Flow (ft)
1. No Delays - 2.0 inches	42.2	1.10	30.26	1.20	37.79	1.30	41.45
2. No Delays - 6.0 Inches	126.5	1.67	31.40	1.78	65.72	1.83	65.92
3. No Delays - 12.0 Inches	253	2.30	32.66	2.20	68.56	2.24	69.54
4. No Delays - Just Crystal Lake - 2 Inches	0.57	0.22	6.66	0.24	6.37	0.78	22.92
5. No Delays - Crystal, Cass, Orchard, and Oakland - 2 Inches	15.30	0.76	22.89	0.85	25.85	1.03	31.92
6. No Delays - Just Crystal Lake - 6 Inches	1.71	0.33	10.06	0.37	9.61	0.81	24.05

Scenario	Peak Flow (cfs)	Pontiac Channel: Water Depth (ft)	Pontiac Channel: Wetted Perimeter (ft)	Riverside Park: Water Depth (ft)	Riverside Park: Wetted Perimeter (ft)	Riverside Park: Water Depth with WWTP Flow (ft)	Riverside Park: Wetted Perimeter with WWTP Flow (ft)
7. No Delays - Crystal, Orchard, and Oakland - 6 Inches Cass - 3 inches	34.54	1.03	30.12	1.12	35.04	1.24	39.10
8. No Delays - Just Crystal Lake - 12 Inches	3.43	0.43	13.06	0.48	12.48	0.84	25.62
9. No Delays - Crystal - 12 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	44.38	1.11	30.29	1.22	38.52	1.32	42.07
10. No Delays - Just Crystal Lake - 18 Inches	5.14	0.51	15.20	0.56	14.53	0.87	26.77
11. No Delays - Crystal - 18 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	46.09	1.13	30.32	1.24	39.08	1.34	42.56
12. No Delays - Just Crystal Lake - 24 Inches	6.85	0.56	16.93	0.62	16.18	0.90	27.74
13. No Delays - Crystal - 24 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	47.80	1.14	30.35	1.25	39.62	1.35	43.03
14. No Delays - Just Crystal Lake - 27 Inches	7.71	0.59	17.70	0.65	17.34	0.92	28.21
15. No Delays - Crystal - 27 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	48.66	1.15	30.37	1.26	39.89	1.36	43.27

6.8.2 Thirty (30) Day Release Hydraulic Relationships

These scenarios are the same as Section 6.8.1 with the exception of the longer base duration of 30 days instead of 14 days. A summary of results can be located in Table 6.8.2.

Results

Results of these scenarios include:

- When comparing the two scenarios, the rise in water depth at Riverside Park decreased from 3 inches to 2.2 inches, however the dry weather scenario was virtually unchanged.

Table 6.8.2: Thirty (30) Day Release Hydraulic Relationships

		Pontiac Channel		Riverside Park			
Scenario	Peak Flow (cfs)	Water Depth (ft)	Wetted Perimeter (ft)	Water Depth (ft)	Wetted Perimeter (ft)	Water Depth with WWTP Flow (ft)	Wetted Perimeter with WWTP Flow (ft)
1. No Delays - 2.0 inches	19.7	0.84	25.16	0.92	28.42	1.08	33.77
2. No Delays - 6.0 Inches	59.0	1.23	30.53	1.35	42.92	1.43	45.94
3. No Delays - 12.0 Inches	118.1	1.62	31.31	1.75	65.57	1.79	65.78
4. No Delays - Just Crystal Lake - 2 Inches	0.27	0.17	5.03	0.18	4.81	0.77	22.61
5. No Delays - Crystal, Cass, Orchard, and Oakland - 2 Inches	7.14	0.57	17.20	0.63	16.44	0.91	27.90
6. No Delays - Just Crystal Lake - 6 Inches	0.80	0.25	7.57	0.28	7.23	0.78	23.15
7. No Delays - Crystal, Orchard, and Oakland - 6 Inches Cass - 3 inches	16.12	0.78	23.34	0.86	26.39	1.04	32.28
8. No Delays - Just Crystal Lake - 12 Inches	1.60	0.33	9.81	0.36	9.38	0.80	23.95
9. No Delays - Crystal - 12 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	20.71	0.85	25.64	0.94	28.96	1.09	34.18

		Pontiac Channel		Riverside Park			
Scenario	Peak Flow (cfs)	Water Depth (ft)	Wetted Perimeter (ft)	Water Depth (ft)	Wetted Perimeter (ft)	Water Depth with WWTP Flow (ft)	Wetted Perimeter with WWTP Flow (ft)
10. No Delays - Just Crystal Lake - 18 Inches	2.40	0.38	11.43	0.42	10.92	0.82	24.70
11. No Delays - Crystal - 18 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	21.51	0.86	26.01	0.95	29.37	1.10	34.49
12. No Delays - Just Crystal Lake - 24 Inches	3.20	0.42	12.73	0.47	12.16	0.84	25.42
13. No Delays - Crystal - 24 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	22.31	0.88	26.37	0.96	29.77	1.11	34.80
14. No Delays - Just Crystal Lake - 27 Inches	3.60	0.44	13.3	0.49	12.71	0.85	25.77
15. No Delays - Crystal - 27 inches Orchard - 9 inches Oakland - 6 Inches Cass - 3 inches	22.71	0.88	26.54	0.97	29.97	1.12	34.95

6.9 Hydrologic Modeling Conclusions

A multitude of different scenarios were run with varying amounts of rainfall and release rates. The primary result of all these scenarios was that delaying the release of water from a couple lakes in the system could decrease the peak flow by 15 to 20%. This is imperative in times of very wet weather when the river floods. Delaying the water generated by the delayed lake's contributing subwatershed for 12 to 24 hours can level out peak discharge and slow down the release of water generated by a particular storm event; thus, reducing the drastic rise of the river downstream. However, this needs to be balanced by the potential flooding of lakefront property if water is retained in the lakes. Finally, it was shown that releasing rainfall downstream instead of continuously filling impoundments could provide a base flow for the Clinton River.

The general finding from the water release results is that a single lake does not have enough storage capacity to sustain a sufficient base flow in the Clinton River during times of extreme or prolonged drought. When considering Scenario 14 in Table 6.7.2-1, Crystal Lake is releasing 27 inches of water over 30 days and the river is only at a stage of 0.85 ft at Riverside Park. Comparing Scenario 14 to Scenario 15 in Table 6.7.2-1, which adds additional water being released by Oakland, Crystal, and Cass lakes, there is an additional 0.27 ft of water at Riverside Park. This same principle also applies to wet weather cases as well. A single lake does not have the storage capacity to store/hold back enough water to decrease the possible flooding of the Clinton River.

Currently, Crystal Lake is being used as storage in wet and dry weather scenarios. Oakland County Water Resource Commissioner's lake level technicians normally use Crystal Lake in extreme wet weather scenarios to help prevent flooding downstream (Korth 2011). Further, the stored water in Crystal Lake is used to supplement the river in times of dry weather. However, Crystal Lakes' surface area is relatively small compared to the other three lakes identified as having storage capabilities. Therefore even though Crystal has the most variability in water surface elevation, it does not have enough volume to store excess rainfall/upstream flow and to sustain a constant baseflow in dry times. Thus, a combination of the other three lakes is needed to manage flow in the Clinton River with the potential existing to maintain base flows in dry weather period.

7.0 Environmental

Inland lake levels within the Great Lakes basin naturally fluctuate on a seasonal as well as year-to-year basis on the order of less than a foot to several meters, depending on the size and type of lake (WI DNR, 2008). Normal fluctuations in lake levels are influenced by input from precipitation and snow melt runoff, groundwater inflow and upstream inflow; and output from outflows, water use, and evaporation. Seepage lakes are dependent upon precipitation and groundwater and their levels naturally tend to fluctuate more slowly and seasonally than drainage lakes that are fed by surface water runoff. As previously documented, many of the lakes in this investigation are controlled by court ordered lake levels (Section 6.0) and not allowed to fluctuate naturally which has significant negative environmental impacts. In addition, with urbanization (Section 4.0), the hydrology is increasingly influenced by surface runoff and not groundwater seepage. This chapter will further explore the environmental impacts of the current flow management policies on the lakes, adjacent wetlands, and the Clinton River based on the deviation from normal lake level fluctuations as well as the endangered and threatened species that exist in the watershed (Appendix F).

7.1 Impacts of Water Levels and Their Fluctuations on Lakes

Lake levels affect the ecology of the lake and surrounding ecosystems (wetlands, riparian habitat, streams, etc.) in some ways that are self-evident, but other times, unpredictable. For example, increasing or decreasing the mean lake level impacts the size of habitat for aquatic species. Many aquatic plants germinate in very shallow water or in contact with air exposure, thus, temporary low water periods offer an opportunity to establish in recently exposed areas. Lakeside vegetation under low water levels later becomes important habitat for fish when the water levels rise again and inundate the vegetation. When water levels reach their peak in the cycle, much of the visible vegetation is removed by wave and ice action, but roots are still viable below the surface where they hold sediments in place. If plants are removed by people for aesthetic reasons, the habitat is lost.

An example of something less predictable is the effect that water levels have on native plant communities. For example, periodic flooding can expand the range of certain macrophytes; flooding can help to break up and transport macrophyte mats. This can be considered a detriment, however, when the macrophytes are invasive, but is considered important for native species. While a periodic drop in lake levels can disrupt and therefore discourage growth of monocultures (e.g., invasive species) in favor of increased species diversity, Barko et al. (1999) suggest that submerged plants that are sensitive to water level reductions may die, thereby providing an opportunity for nonindigenous species to spread. Catford et al. (2011) suggest that flow regulation of natural systems, such as found in the Clinton River watershed, favors invasive species by reducing native species unsuited to the modified conditions, in this case set lake levels. Conversely, Moles et al. (2008) postulated that lake level fluctuations can favor exotic species, but only when the pool of native species lacks sufficient biodiversity. Overall, water level fluctuations do affect aquatic biota in lakes in terms of species composition, distribution and productivity of the shallow-water littoral zone communities (MfE 2008).

The effects of water levels on the structure of lake nearshore zones and wetland vegetation are important for periphyton (algae, microbes, and detrirus), macroinvertebrate, and invertebrate communities and affect the availability of habitat for fish and birds. Therefore, a more natural flow regime that allowed greater lake level fluctuations would provide additional environmental benefits in the lakes, through improved communities of the lowest levels of the food chain (periphyton and macroinvertebrates), and subsequently additional recreational opportunities (Section 8.0).

Meeker and Wilcox (1991, 1992) investigated the effects of water-level regulation on aquatic macrophyte communities, individual plant species, and potential faunal habitat in regulated lake systems (Rainy Lake and Namakan Reservoir) and an unregulated lake (Lac La Croix) in nearby Minnesota. The regulated lake (Rainy) that had lower water levels than normal and the regulated lakes in Namakan Reservoir that had higher than normal lake levels both had lower biodiversity than a reference lake that was not controlled. They found differences in macrophyte communities, and faunal habitat. The lowest biodiversity was in the Rainy Lake in a part that was never dewatered. They also found that where drawdown occurred in early winter, that there was a dominance of rosette and mat-forming species which gave minimal faunal habitat. They speculated that the timing and extent of winter drawdowns may have reduced access to macrophytes as food for muskrats and as spawning habitat for northern pike and yellow perch (Wilcox and Meeker, 1992).

A reduction in through-flow and increase in residence time of water in a lake (i.e., volume of lake divided by flow in or out of the lake) increases the likelihood of algal blooms and other plant growth as nutrients are introduced and not flushed out. Changes in residence time are most likely to affect smaller lakes.Higher water levels adjacent to fertilized lawns can cause increasing mass transport of nutrients to deep waters.

Periodic drops in lake levels expose sediments that can then be oxygenated, allowing for decomposition of organic matter. This consumes the oxygen in the process, but in shallow waters, dissolved oxygen can more readily be replaced by diffusion from air above so this allows the lake to be more oxygenated. Conversely, the build-up of organic matter on lake bottoms in deeper waters can lead to anaerobic digestion of organic matter; anoxic conditions produce carbon dioxide and methane (global warming gases), and sulfides (odor problems). Therefore, allowing water fluctuations effectively reverses the aging process of the lake (Fusilier 2010).

Erosion is also affected by fluctuations in lake levels from wind, wave energy, and sliding and slumping. The distribution of incident wave energy across the foreshore is dependent on the fluctuation of water level combined with the timing of storm events (Lorang et al. 1993). Lowering of a lake level before storm season may reduce wave action on the nearshore, preventing shoreline erosion (banks and bluffs). On the other hand, during low lake levels, the nearshore lakebed is subject to higher water velocities from wave motion and the zone of wave breaking where erosion is highest occurs further offshore than during high lake level periods (USACE 2011). Overall, fluctuating water levels keep from focusing water energy at a single point on a water line which will decrease overall bank erosion and recession.

7.2 Impacts of Water Levels and Their Fluctuations on Adjacent Wetlands

Connectivity for fish access, and habitat requirements for birds and amphibians are critical flow-related factors for wetlands (MfE 2008, Blaustein et al. 2010) as they are for the lakes. Wetlands are particularly sensitive to water levels, inflows and outflows; the hydrology along with soil characteristics and vegetation type are the hallmarks of wetland delineation, with hydrology being the most important feature that determines the wetland type and its sustainability. Species diversity is generally highest in wetlands with moderate water level fluctuations. It decreases if the water level remains constant or fluctuates widely (MfE 2008).

Since the live roots of most wetland species occur mostly in the top one foot, a significant and long lasting drop in the water table resulting in a drying of this zone allows terrestrial species to invade (MfE 2008). Catford et al. (2011) studied the impact on wetlands from flow regulation of several streams; the lack of periodic water level rise favors plant cover by exotic species over native species. The invasive European phragmites (common reed), *Phragmites australis*, has a tendency to overtake cattails, especially when water levels drop, and is not suitable for any birds, for example. Trexel-Knoll and Franko (2003) report the expansion of invasive Phragmites australis in Old Woman Creek Wetland (estuary and creek flowing into Lake Erie) during 2000-2001 when water levels were low compared to high water levels in 1993-95. When water levels were high, Phragmites was restricted to shorelines. The types of vegetation and flora in wetlands are important for the food chain. Birds depend on having certain vegetation as they have preferences for feeding and nesting strategies.

Where wetlands serve as fish nurseries, extreme low water levels can affect fish populations. Amphibians can adapt to changing water levels; however, metamorphosis (the physical development after hatching) accelerates when their ponds dry (Denver et al. 1998). Denver et al. (1998) studied fish in the environment and in laboratory experiments to determine the mechanism of this increase in metamorphosis. They concluded that the increased metamorphosis was related to reduce swimming activity and foraging in lower water levels. Food restriction under high water levels also resulted in increased metamorphosis (a laboratory control scenario to bear out the mechanism of accelerated metamorphosis) whereas high water levels without food restriction decreased the rate of metamorphosis. Laurila and Kujasalo (1999) proved that temperature change (from decreased water levels) was not the cause of the change in metamorphosis in the common frog (Rana temporaria), although the development of some frog species may be affected by temperature. Overall, fluctuating water levels are found to promote healthier and more diverse populations of native plants, macroinvertabrates, and amphibians in the adjacent wetlands. Similar to lakes, this provides additional environmental benefits and recreational opportunities (Section 8.0).

7.3 Impacts of Water Levels and Their Fluctuations on the Clinton River

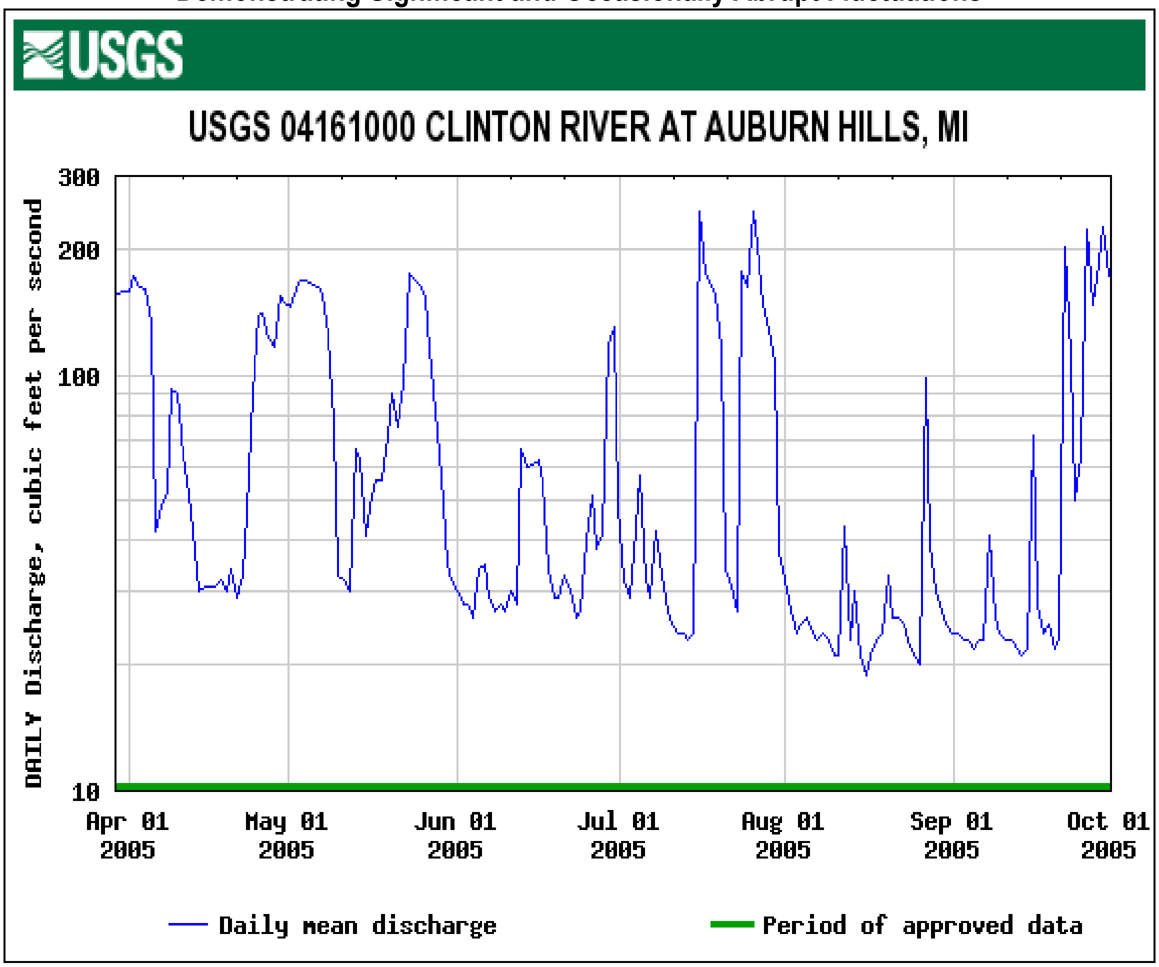
For rivers and streams, one of the most important aspects of hydrologic alteration is maintaining connectivity to lakes, wetlands, and other habitat. Connectivity in riverine systems is important for sediment and nutrient transport, biogeochemical cycling, plant succession (riparian, mainly), fish migration, and increased species abundance and diversity. Longitudinal connectivity means fish can freely move upstream-downstream. Lateral connectivity to floodplains creates spawning and nursery habitat for fish, as well as foraging habitat for fish and other organisms. Vertical connectivity provides groundwater feeds to streams.

The Clinton River is heavily urbanized downstream. The lower stretch of the main branch of the Clinton River is too altered in some sections to allow for healthy fish habitat and migration. Thus, it is more important that fish have access to move upstream to where habitat and hydrologic conditions would be more favorable for them. Fish are also more vulnerable downstream to being caught, exposed to contaminated sediments, and injured during storms due to the dense human population and development. Therefore, an ecologically healthy upper reach of the Clinton River is critical but not currently available because of lake level control structures blocking movement and restricting flow.

It is difficult to achieve desired outcomes of restoring a more natural flow regime to the Clinton River, or make decisions about regulated flows without a complex understanding of the relationships between variables for a specific system. For example, it is not just as simple that an increase in stream flow would result in an increase in the population of a specific game fish but it should promote an overall healthier population of fish in the river.

The channel geomorphology is dependent on a range of natural flows including flood flows and channel forming discharges. In an urbanized and regulated system there exist extreme peaks and extreme lows (Figure 7.3-1) which influence sediment transport. Reductions in channel-forming flows reduce channel migration, an important phenomenon in maintaining high levels of habitat diversity across floodplains, and maintain channel formation.

Figure 7.3-1: USGS Flow Data for the Clinton River Downstream of the Impoundment Area Demonstrating Significant and Occasionally Abrupt Fluctuations



Impoundments that do not allow for adequate sediment transport can affect nutrient levels downstream and reduce structural habitat for fish spawning. The increase in flow may disrupt redd (spawning habitat – eggs on gravel, etc.), and increase sediment resuspension, mobilizing contaminants that then become bioavailable affecting egg hatching success and juvenile development. On the other hand, instream flows remove undesirable accumulations of sediment. Fine sediments and sand accumulate on and in gravels during periods of low flow and must be removed (flushed) periodically for the gravel to remain suitable for aquatic habitat (Milhous 1998). Sediment of all sizes can also fill pools in the river and must be removed in order to maintain pool habitat. Under moderate flow conditions, periphyton can be flushed from courser sediments, improving water quality without disrupting macro invertebrates that may take shelter under courser gravel.

In the Clinton River, the 2004 flood event was extreme, having flushed over a foot of sediments near the Yates dam downstream exposing glacial clay on the bottom in some erosion zones. Habitat would obviously have been affected in those parts of the stream. River flashiness can dislodge fish roe and macro invertebrates, and then a sudden drop in water volume can leave organisms exposed. It is presently unclear whether this phenomenon has greatly affected fish populations within the Clinton River watershed.

Although water quality has improved over the past thirty years in the headwaters and North Branch of the Clinton River, fish diversity and species richness have decreased due to the increase in hydrologic flashiness (MDNR 2006). Macro invertebrates are routinely assessed in the Clinton River in conjunction with the Clinton River Watershed Council, but not specifically as a function of the hydrology. A study could easily be done to incorporate hydrologic measures before-and-after sudden releases and/or storms to see the effects on macro invertebrates.

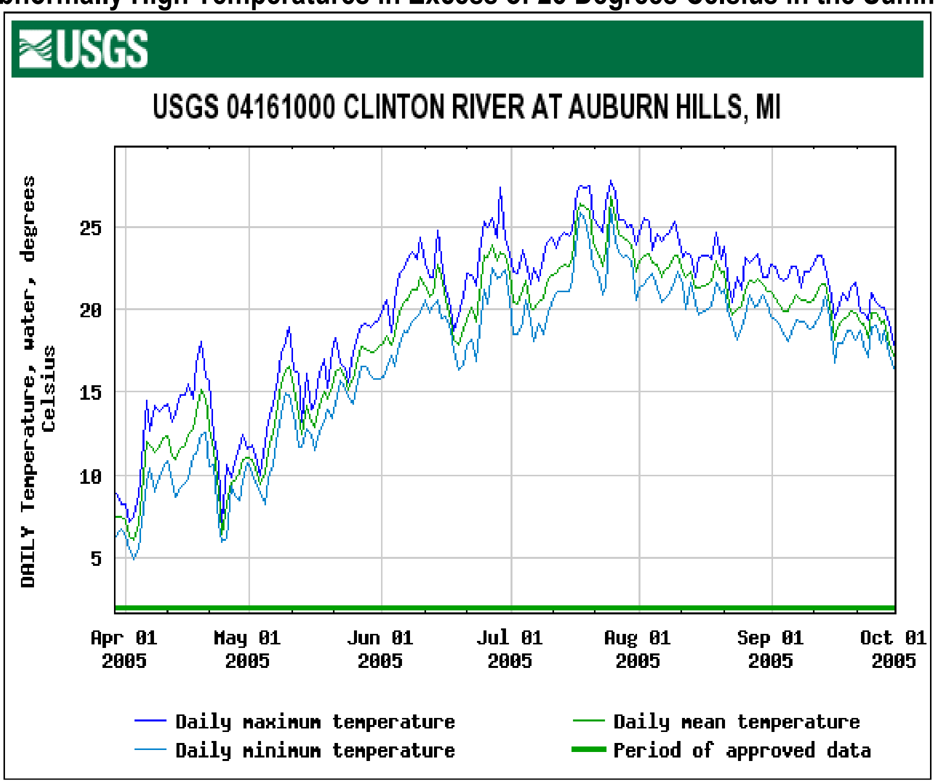
In addition to macroinvertabrate community, there have been several mussel collections conducted over the last 30 years. Though the species distribution is not consistent throughout the watershed, mussel populations are a good indicator of water quality and health of a biological community. According to data collected between 1870 and 1925, 31 different mussel species were collected in the Clinton River Watershed (Francis and Haas 2006). In the mid 1970's the Clinton River upstream of Pontiac supported 14 different mussel species, which included 4 that are on the state endangered species list. The only known population of purple lilliput exists within this area, but recent surveys indicate that its density is declining due to the proximity of a lake-level control structure. The Upper Clinton River also supports the only likely population of rayed bean in Michigan's streams. Downstream of Pontiac, within the Clinton Main Stem, the mussel populations are extremely degraded. During the last collection, no living specimens were found.

Flood pulses may serve as a disturbance depending on river style as well as on timing, duration and magnitude of flooding (Tockner et al. 2010). River autotrophs including the periphyton, macrophytes, and small phytoplankton, can be affected by discharge and water depth. Periphyton are common in all rivers, but favored by smaller rivers, whereas macrophytes are most abundant in mid-sized rivers and backwaters of larger rivers, and phytoplankton are favored by large lowland rivers of modest flow (Allan, 2004). The major source of phytoplankton in rivers is from washout of the benthos/sloughing of attached autotrophs. Thus, impoundments and standing water in general promote planktonic growth. Plankton populations of rivers is heavily influenced by current and discharge, with an inverse relationship between phytoplankton abundance and river discharge (Allan, 2004). Ibanez et al. (2012) provided an example of an ecological regime shift in a river from periphyton dominance to macrophyte dominance as a result of declining phosphorus levels due to decreased natural flooding. The ecological shift included a proliferation of black flies and other changes in macro invertebrates. Finally, the volume of flow, timing and ramping rate of spring floods, and magnitude of seasonal pulsed flows have potentially negative effects on the early life stages of amphibians. Increasing flows displace tadpoles of the yellow-legged frog (Rana boylii) in both modeled and simulated pulse flow experiments (Yarnell et al. 2010, Kupferberg et al. (2011).

Turbidity increases with higher turbulent flows that are associated with urban flooding events found in the Clinton River. Turbidity affects light penetration. In large rivers, light penetration is usually 1-2 meters (Allan 2004) under normal turbidity levels when not limited by phytoplankton self-shading. Low river discharge yields low turbidity favoring the growth of submerged aquatic vegetation (Soto 2004). If stream flow is too reduced, however, it can reduce large particle (gravel) transport that helps build proper substrate (structural habitat) for fish spawning.

Reduced stream flow can also increase fish predation; alter water quality parameters resulting in increased concentrations of salt, metals, and ammonia (fish waste); decrease dissolved oxygen levels (Nislow et al. 2004), and increased temperatures. Sudden increase in river temperature, especially associated with summer flood events, has caused documented mass fish extinction in the Clinton River. An example of extremely high temperatures that can be found in the river is shown in Figure 7.3-2. Impoundments can modify the temperature regime due to changes in depth and flow, leading to shifts in biota. For example, the hydraulic structures can create favorable conditions for the invasion of non-native species, thus exerting further pressures on the biota (Stanford et al. 1996, Johnson et al. 2008). Fish may delay spawning and produce offspring at the wrong time of year, such as when food is scarce and temperatures are too cold for the offspring to survive (Cave 1998). Lower stream flow can also reduce the delivery of litter and invertebrates from riparian zones, and can leave macro invertebrates stranded if water levels drop.

Figure 7.3-2: USGS Temperature Data for the Clinton River Downstream of the Impoundment Area Showing Abnormally High Temperatures in Excess of 25 Degrees Celsius in the Summer Months



Fish are adapted to fluctuating stream flow, but just because a species is adapted to fluctuating lake levels and/or river flows, does not mean that it will be negatively affected in the absence of such extremes. It partly depends on the type of stream. Streams that receive high sediment inputs must frequently flood to flush out the sediments or the habitat quality will likely be degraded. Streams that do not receive a lot of sediments are more likely to provide high habitat quality for macro invertebrates and fish with lower flows (MtF 2008). The amount and quality of habitat at low flow varies with stream size and the flow recession rate and time between high flows (MtF 2008). Fluctuations in stream flow can be expected to be more deleterious for small streams than large streams, since stream size generally affects flow rates and water depth. Because a change in depth can also affect temperature, light, and other water parameters, stream flow can affect the type of fish that the stream supports.

Many plant and animal species are adapted to conditions of periodic flooding. Some species depend on periodic flooding for reproductive success. Floods create shallow backwater areas and protection from large predators (Cave 1998). Flooding is a disturbance that is essential for floodplain tree species (Stallins et al. 2010). If the water table drops, riparian trees may be stranded, leading to recruitment of upland species (Schmitz et al. 2009). While species adapt to the natural fluctuations of uncontrolled lakes and rivers, it does not mean that flow regulations have to result in lower species diversity. For example, regulated lakes may be spared from severe events (e.g., flood or drought) that can disrupt ecosystems. A greater understanding an appreciation for how the fluctuations affect different plant and animal communities can be taken into account in controlling lake levels in order to minimizing ecosystem effects.

The seasonal timing of floods may be shifted by flow regulation as has been documented in the Clinton River (Section 6.0), with ramifications for aquatic and terrestrial biota. Ward & Stanford (1995) examine the dynamic nature of alluvial floodplain rivers as a function of flow and sediment regimes interacting with the physiographic features and vegetation cover of the landscape. During seasonal floods, flow regulation resulted in reduced connectivity and altered successional trajectories in downstream reaches. In the Clinton River, they are effect by hydraulic structure manipulation. For example, normal spring floods in 2012 were limited because the limited amount of rain received was direct to filling lakes to court ordered levels.

8.0 Socioeconomic Assessment

8.1 Socioeconomic Analysis of Clinton River Flow Management

The Clinton River provides valuable services to commercial interests and households (e.g., recreation, aesthetics). The river and the surrounding watershed affect the economic and social welfare of area residents. This section focuses on the socioeconomic component of the integrated assessment that considers restoring a more natural flow condition in the Clinton River watershed by exploring lake level management options. Background information on characteristics and recreational activity that support this analysis are located in Appendix G.

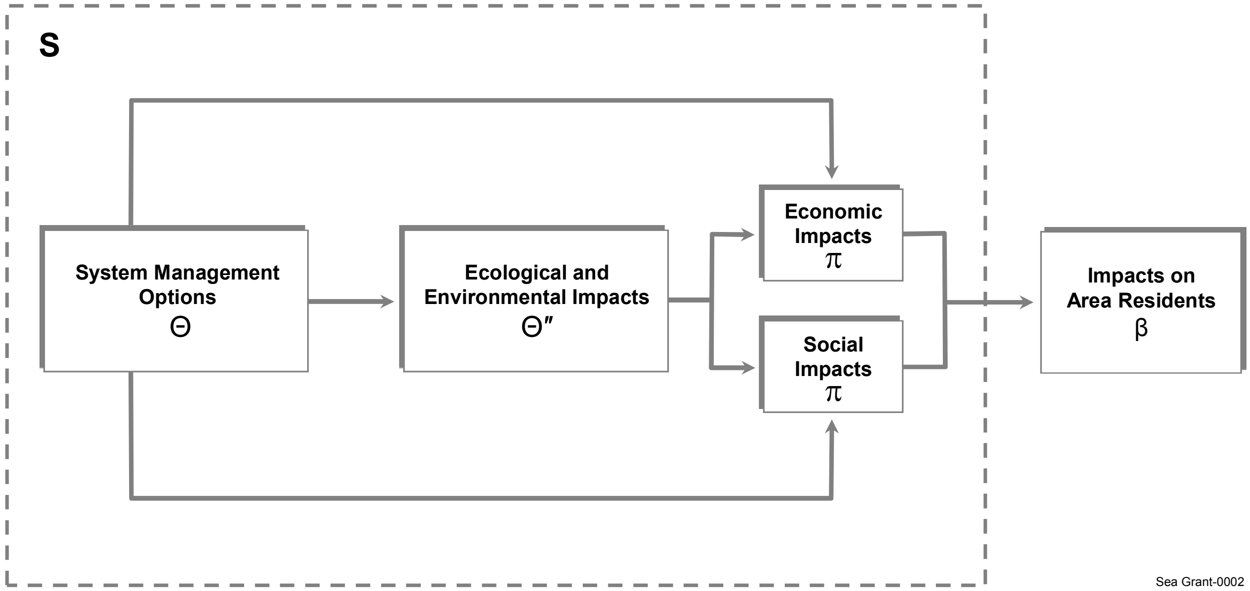
Management options may change watershed interactions, the river morphology, discharge, water temperature and sediment transport. Some of these hydrological impacts such as flow changes would be directly experienced by area residents. Hydrological impacts will also affect the riverine ecosystem. For example, there may be changes in the number and composition of fish species and in mammal and waterfowl habitats. Hydrological and ecological effects impact the economic system by potentially changing the prices of market goods (e.g., real estate) and the quality and quantity of nonmarket goods and experiences—for example, recreational activities. Households could experience changes in their economic welfare because of their original position (e.g., income levels), preferences (e.g., the importance of in-water and near-water recreation to a given household), and property ownership (e.g., residences on impoundments and on the river).

To identify useful flow management policies, the socioeconomic evaluation considered several of the hydrologic scenarios with the objective of identifying those which most improve ecological conditions and recreation opportunities on the river without unduly impacting lake recreators or property owners. An increase in the water flow will provide more opportunities for recreators using portions of the Clinton River by restoring flow during low-flow conditions. When the river reaches extreme lows during August and September, for example, kayakers and canoeists cannot paddle near Riverside Park in Auburn Hills. Decreased fishing opportunities lead to fewer angling visits as well as decreased visits at parks on or near the river.

8.2 Integrated Process

Simulation modeling was an important tool used to identify outcomes. The implications of management strategies for physical changes in conditions on the river through socioeconomic outcomes were quantitatively integrated using the over-arching structure of Figure 8.2.

Figure 8.2: Structure for the Integrated Assessment



For quantitative integration purposes, the Clinton River system was mathematically characterized as (S,Θ). In this framework S represents the integrated physical, hydrologic, ecological, environmental, and socioeconomic relationships that link flow-management alternatives with socioeconomic outcomes.

Flow-management alternatives that are relevant to local socioeconomic conditions are represented by Θ. Prime notation is used to represent level of control. Factors that can be directly controlled relate directly to the policy and include water levels and flow rates. Relevant, indirectly controllable hydrologic, ecologic, and environmental characteristics are represented by Θ ' and Θ".[1] Consequently, the specification of a resource characteristic as means that it is both relevant to socioeconomic processes and either directly or indirectly related to the physical status of the Clinton River.

Economic benefit estimates were based on the simulation of observable socioeconomic processes following the structure detailed in Vining (1984). Socioeconomic processes that are impacted by changes to are represented by π. These are specific, continually occurring collections of events. A particular person choosing how to spend a day off is an example of a socioeconomic process as is a real estate transaction.[2] Because the complete properties of socioeconomic processes are rarely observed, quantitatively assessing the system's performance requires using indicators that represent these processes. In the mathematical structure, these indicators are identified as β.[3]

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[1] The use of prime notation to represent degree of control (and thus degree certainty) recognizes that expert judgment and reduced form modeling (as opposed to detailed structural modeling) may be used to identify changes to the Θ.

[2] Mathematically this is represented with π, subscripting by i for time periods and j for individuals and superscripting by R for recreation.

[3] These properties are developed as part of the public policy model of Vining (1984).

To ensure that indicators are both mathematically tractable and useful for policy analysis, we require that they have the following qualities:

1. They are generated through socioeconomic activities.
2. They are real numbers that can be measured.
3. Evaluating their statistical properties conveys a sense of system performance.
4. Structural simulation modeling allows conducting policy experiments by comparing baseline and counterfactual outcomes.
5. Measures of changes in economic welfare are available from models that simulate changes in the indicators.

Recreational pressure provides an important example. Recreational pressure estimates meet requirements 1 and 2 because the number of trips taken to the Clinton River over a particular time period is a measurable quantity that is generated through a socioeconomic process. With respect to requirement 3, recreational pressure does provide an indication of system performance. For example, an estimate of average recreational pressure that is “high” combined with an estimate of variation in pressure that is “low” could indicate “good” performance. As for 4 and 5, behavioral models of recreation site choice are specifically designed to predict both trips and economic welfare under baseline and counterfactual conditions.

Because alternatives are evaluated through the identification of changes in Θ and simulation of changes in β, identifying expected changes in β requires characterizing Θ and β in Baseline and mathematically modeling the relationship between Θ and β to allow simulating outcomes under various flow-management alternatives. Following EPA (2010a), policy implications are identified by evaluating differences across Θ and β in Baseline and counterfactual experiments in a mathematical simulation.

8.3 Flow Management Options

Beginning at the left of Figure 8.2, flow management policies were quantitatively evaluated by performing a series of simulation-based policy experiments in which changes in resource conditions, pressure, and value were quantitatively assessed by integrating the water flow and resource-economic simulation models. Applying this approach requires identifying site characteristics under baseline conditions and simulating changes to them under counterfactual policy scenarios. With respect to baseline flow, the U.S. Geological Survey (USGS) flow gauge 04161000 on the Clinton River at Auburn Hills was used to determine what the baseline flow would be for this modeling exercise. The table below lists consecutive days below 20 cfs and 30 cfs. The 20 cfs and 30 cfs criteria were selected because the 20 cfs condition is essentially a dry Clinton River (96% exceedance), with flow coming primarily from the wastewater treatment plant and the 30 cfs is a very low-flow case (89.5% exceedance) that is used as a point of reference for purposes of this analysis.

Table 8.3: Baseline Flow Conditions at USGS Gauge 0416100

Year	Consecutive Days of Flow < 30 CFS	Consecutive Days of Flow < 20 CFS
2001	37, July–August	None
2002	19, July 51, July–September 9, September	23, August–September
2003	No data	No data
2004	9, April 27, September–October	None
2005	25, August 23, August–September 9, October 9, October	None
2006	9, August 8, September	None
2007	11, June 37, June–August 10, August 9, September 18, September 9, October	None
2008	25, July–August 13, August–September	8, August 8, August–September
2009	None	None
2010	16, June–July 41, August–September 10, September	7, July 35, August–September 9, September
2011	18, July	None

The flow data indicate the dry periods from 2001–2011 at gauge 04161000 most often occur during August and September with a lesser number occurring in July and August and only two events outside the June to September months. Impacts by year also vary a good deal, with no extended low flow events occurring in 2009, but particularly flows low during August and September 2010, with many consecutive days of river flows less than 20 cfs (USGS 2012).[4]

The effect of flow-management policies would be to increase flows above Baseline with the timing and amount of flow increases being related to the policy and the situations that trigger the management. Management using two different groups of lakes was considered (see Section 6.0 – Hydrologic Modeling). In the first, the four lakes (Cass, Orchard, Oakland, and Crystal) are allowed to fluctuate with drawdowns ranging from 2 to 27 inches for the four lakes over 14 and 30 days.[5] This approach requires larger lake-

[4] Gauge height at 17 cfs was 0.86 feet on September 24, 2010.

[5] The maximum drawdowns from each lake are 3 inches at Cass, 6 inches at Oakland, 9 inches at Orchard, and 27 inches at Crystal.

level fluctuations and produces less downstream flow than the second approach. The second approach allows all connected lake levels to fluctuate. This approach provides a good deal more flow and requires only minor lake level fluctuations (2 inches), but the ability to implement the approach is restricted by the existing lake-management court orders and the current inability to set incremental discharge rates from a majority of lakes.

8.4 Hydrological Outcomes Associated Flow Management Policies

Quantitatively modeling the implications of a flow management policy requires projecting future conditions, understanding how the policy is triggered (both on and off), and modeling the implied outcomes (i.e., counterfactuals) of the policies. With respect to future conditions, the historical data indicate that one extended low flow event below 30 cfs can be expected each summer. Sometimes, these events exceed 30 days, and sometimes there is more than one such event. Extreme low flow events below 20 cfs are more rare, occurring every third year on average. However, in these years, there were several extended periods (5 in 2 years) with flow below 20 cfs. Given this complexity, a challenge is to predict future flow levels and how effective any particular flow management policy would be. The modeled future is one in which there is a single 30-day period below 30 cfs every year, and that every other year, the last 14 days of the 30 day drought lead to flows that are below 20 cfs. Although multiple extended droughts are possible, these are not modeled because it is unknown whether the lakes would have recharged between events.

With this in mind, the historical flow data were evaluated for two potential "on" policy triggers.[6] These triggers include flow dropping below 20 cubic feet per second for a day and flow dropping below 30 cfs for a day. The revised management policy is specified to trigger "off" when natural flow above the trigger is restored. The maximum drawdown (four lakes) would result in a nearly 49 cfs increase in flow for 14 days and 23 cfs increase in flow for 30 days.[7] The water flow and depth would vary in different parts of the river. For example, under the 14 and 30 day release scenarios the following outcomes are expected at Riverside Park, Auburn Hills:

- Peak water flow would increase by 48.7 cfs, with an additional water depth of 1.3 feet over 14 days.
- Peak water flow would increase by 22.7 cfs, with an additional water depth of 1.0 feet over 30 days.

In the second set, all lakes were considered. This is more difficult to make happen legally and technically, but could restore up to 598.1 cfs and 3.12 feet of water (Riverside Park, Auburn Hills) with minimal (2 inches) fluctuations in lake levels. As such, there are possible flow management options that could restore a more natural flow regime to the Clinton River.

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[6] Although it is possible to use policy triggers other than flow gauge measures, this is convenient for analysis and also provides a clear policy trigger.

[7] Releasing water from the lakes over a 24-hour period could result in a peak flow of about 239 cfs in the Clinton River for 1 inch of water and about 478 cfs for 2 inches of water.

8.5 Ecological and Environmental Outcomes Arising from Hydrologic Impacts

Managing flow using either of these approaches would have ecological and environmental impacts. Ecological impacts would primarily arise from increased water-level fluctuation in the impoundments during the summer and increased flow and connectivity during low flow periods. Lake levels affect the ecology of the lake and surrounding ecosystems (wetlands, riparian habitat, streams, etc.) in ways that can be self-evident, but are sometimes unpredictable. Generally speaking, fluctuating water levels is good for lake ecosystems. As the water line moves in and out due to the water level changes, it creates habitat (water depths) that favors different wetland plant species. Because of the changing water levels, it creates a diverse wetland compared to a lake that has static water levels. This diverse wetland provides many benefits including habitat for aquatic and terrestrial wildlife, provides a buffer against the introduction of exotic plants, and reduces shore line erosion.

With respect to increased flow, for rivers and streams, one of the most important aspects of hydrologic alteration relates to connectivity between lakes, wetlands, and other habitat. Connectivity in riverine systems is important for sediment and nutrient transport, biogeochemical cycling, plant succession (riparian, mainly), fish migration, and species abundance and diversity. It is difficult to achieve desired outcomes or make decisions about regulated flows without an understanding of the relationships between variables for a specific system. One of the limitations to modelling is that every river has its own natural flow regime which shapes the evolution of aquatic biota and ecological processes. Models such as Instream Flow Incremental Methodology (IFIM) and related physical habitat simulation models (PHAB-SIM), provide methods for quantifying effects of stream flow on fish and invertebrate habitat and riparian communities (Souchon et al. 2008; Environment Canada 2004). Such models were not applied in this analysis. Rather, a more holistic approach based on professional judgement of fishery professionals was employed.

8.6 Affected Socioeconomic Processes

Changes in the hydrological characteristics of the river may have socioeconomic impacts that occur directly and also indirectly through changes in ecological characteristics. For example, increased flow can directly improve canoeing services while indirectly improving catch rates and supporting less tangible values, such as those associated with the ecological services of more naturally flowing river segments. Socioeconomic processes considered were those that are tied to ecological values, property values and recreation resource values.

8.6.1 Ecological Values

The identification of economic value was initially limited to the study of markets and indicated by value in exchange (prices). This was later extended to value-in-use (i.e., willingness to pay). The value-in-use concept and related techniques are relied upon extensively in environmental economics and this report. Using these techniques, the values of resources without observable prices are identified by observing behaviors (such as trip-taking) that are not market exchanges. A much broader class of values that include social, aesthetic, and intrinsic, values has also been identified. These have most commonly been called ecological and nonuse values. Nonuse values are the values that people may hold for a resource independent of their use of the resource. These values arise through knowledge of a resources existence or changes in its quality. Sources for these values include wanting it to be available for people to use in the future and belief that a resource has an inherent right to exist. The economic literature commonly refers to these two components of nonuse values as “bequest” (or “altruistic”) values and “existence” values.

Measuring nonuse values through revealed behavior is not feasible because no behavior is required to experience a nonuse value. For this reason, economists have developed hypothetical valuation methods. With these methods, respondents are asked hypothetical valuation questions in a survey setting. Responses are used to measure willingness to pay at the individual level and extrapolated to the affected population to recover resource values. When original studies are not feasible, transferred values are sometimes employed. Fisher and Raucher (1984) identified a 50-percent approximation of use values based on an average of resources for which both use and nonuse values have been calculated. Studies by Sutherland and Walsh (1985) and Sanders et al. (1990) indicate that nonuse values for angling improvements may be greater than 50 percent of the corresponding use values.

Unfortunately, high-quality studies that employ hypothetical surveys and consider similar ecological impacts and affect similar populations of people are rarely available. Original studies that use hypothetical survey techniques to measure resource values can be complicated and are often subject to disagreement over results. For this reason, alternative cost-based approaches are sometimes employed. The cost-based process involves quantifying ecological impacts, identifying habitat/resource requirements and alternatives that are equivalent, and estimating the lowest cost of creating those habitats/resources in some alternative manner. Although this approach does not identify economic value, it can be useful in identifying cost-effective watershed management plans and is often used to resolve natural resource damage cases. Tools for identifying nonuse/ecological values were not readily available for this project. The omission of these in valuation leads to underestimating the total satisfaction that would arise from Clinton River flow management.

8.6.2 Property Values

Although ecological conditions are likely to improve with lake-level fluctuation, such fluctuations could potentially impact property values and recreation opportunities on the lakes. To accommodate this concern, an overarching consideration was that lake-level fluctuations were limited to acceptable amounts as revealed in the Stakeholders Survey of residents living in the Clinton River Watershed (see Section 5.0 – Stakeholder Engagement). This survey provided input from residents living on a lake or having lake access (Lake Region), those living adjacent to the Clinton River (River Region), and those not living near a lake or the Clinton River (Other Region). A majority of survey respondents agreed or strongly agreed when asked: “Please indicate your level of agreement with the following statement: ‘I would tolerate moderate fluctuation in lake levels if it meant an overall healthier watershed’.”

- 56 percent of residents living in the Lake Region
- 89 percent of residents living in the River Region
- 87 percent of residents living in the Other Region.

Overall, 72 percent of survey respondents agreed or strongly agreed with the statement.

Of stakeholders responding to the question, “How much fluctuation are you willing to tolerate on your lake for an overall healthier watershed?”

- Nearly 36 percent of the stakeholders were willing to tolerate fluctuations of 6 inches or more.
- Slightly more than 32 percent of the stakeholders were willing to tolerate fluctuations of 2 inches.

An implication of this consideration is that flow-management policies that would lead to large and frequent lake level fluctuations were deemed unacceptable. With this constraint on potential policies, there is expected to be minimal impact on property values.

8.6.3 Recreation Resource Values

Recreation resource values are likely to be most impacted. Free-flowing sections of the river are more likely to support coldwater species (e.g., trout). Impounded sections of the river tend to support coolwater and warmwater species (e.g., walleye).

High-gradient, fast-flowing portions of rivers are valuable for canoeing and kayaking. Furthermore, rapids provide ideal landscape for camping and hiking. Slower water in impoundments is better suited to flat-water canoeing and boating opportunities. According to OutdoorEscorts.com (2010), the Clinton River consists of many levels of paddling, including "class 2–3 River with many rapids and turns." The presence of local canoeing clubs, such as the Clinton River Kayak Club, illustrates the high level of local interest in canoeing. The numerous impoundments throughout the watershed offer boating opportunities for recreators. Many of the impoundments have public boat launches.

It is determined through the hydrological and ecological assessment that flow conditions and overall ecological productivity would improve. This would in turn lead to higher catch rates and improved paddling conditions. These would impact socioeconomic processes as recreation trip taking would change to take advantage of better opportunities. As a result, economic welfare would improve.

8.7 Recreation Resource Models

Recreation resource changes are expected to have the most impact on economic welfare, and simulation models were constructed to evaluate impacts.

8.7.1 The Mathematical Structure

The mathematical structure applied for recreation simulations is the probabilistic site choice model. This modeling structure, based on choice theory, has the advantages of being professionally accepted, useful for policy-simulation predictions, consistent with economic theory, and capable of identifying changes in resource values.[8]

These models identify the probability of a specific outcome (in this case, the selection of a recreation site), conditioned on the site characteristics of all relevant choices for recreators (e.g., distance from the site to the angler's home, expected catch rates, etc.). In the site choice framework, a recreator chooses a site by comparing characteristics across all sites.

[8] The statistical basis for choice theory is the standard conditional logit model (McFadden 1974, 1981).

The mathematical structure is presented in Equation 8.1 below.

$$P_i(j) = \frac{\exp(V_{ij})}{\sum_{j=1}^{J} \exp(V_{ik})} \tag{8.1}$$

where $V_{ij} = f(\Theta, \text{S})$

This equation represents the probability that on any particular recreation choice occasion, a recreator (identified by i) will choose to visit a particular site (identified by j). Note that this likelihood, identified by $P_i(j)$, is determined on the basis of both site characteristics (Θ) and parameters representing the values recreators hold for those site characteristics (S).

This mathematical construct identifies visitation likelihood. However the probability that a recreator will visit a site is not an observable β that can be used to evaluate the performance of the system. Pressure is a closely related and commonly employed β. To estimate pressure for any given site *j*, $P_i(j)$ is summed over all recreators' choice occasions.[9]

The hedonic decomposition of recreation sites into site characteristics and the representation of these site characteristics in the site-choice framework allow an evaluation of important information including changes in visitation probability, changes in site pressure, and changes in resource value. This is accomplished by developing an equivalent mathematical structure with appropriately altered Θ for policy alternatives and finding the difference in trips between this policy simulation model and the base case. Equation 8.2 presents the mathematics for an individual.

$$AnnualChoiceOccasions_i \left[\frac{\exp(V_{ij})}{\sum_{j=1}^{J} \exp(V_{ik})} - \frac{\exp(\overline{V}_{ij})}{\sum_{j=2}^{J} \exp(\overline{V}_{ik})} \right] \tag{8.2}$$

where $V_{ij} = \int(\Theta, S) \overline{V}_{ij} = \int(\overline{\Theta}, S)$

Aggregating over individuals identifies changes in trips for each site due to the policy that changes Θ to $\overline{\Theta}$. Estimates of changes in economic value improve the ability to assess resource performance. The distance from an individual's home to a site is a critical variable in a site-choice model because it represents the fuel cost and travel time required to visit each site.

When distance is converted to travel cost, the site-choice framework supports the calculation of monetary changes in value associated with changes in site characteristics. The mathematical form used to identify dollar-based changes in value associated with a policy that changes Θ to $\overline{\Theta}$ is the difference between the utility levels scaled by the relative impact of travel costs. Equation 8.3 presents the mathematical

[9] In the simulation context, this is accomplished by multiplying the likelihood of selecting each site (Equation 1) by the total number of trips.

structure used to evaluate the change in annual value that a recreator attributes to the policy that changes Θ to $\overline{\Theta}$.

$$CV_i = \frac{AnnualTrips_i}{\varphi_i}\left[\ln\left(\sum_{j=1}^{J} e_{ij}^{V}\right) - \ln\left(\sum_{j=1}^{J} e_{ij}^{\overline{V}}\right)\right] \quad (8.3)$$

where $V_{ij} = \int(\Theta, S)\overline{V}_{ij} = \int(\overline{\Theta}, S)$

CV_i refers to the compensating variation or dollar valued willingness-to-pay that recreator *i* has for the change from Θ to $\overline{\Theta}$. This is the amount of money that would make him indifferent between Θ and $\overline{\Theta}$.[10] Summing over recreators allows recovering the change in aggregate economic welfare.

8.7.2 The Transferred Recreation Resource Demand Models

Three system models of recreation were created for this analysis to estimate the effect on visitation to recreation sites on or near the Clinton River if the river flow changes. The recreation models use site characteristics that are unique to each of these recreational opportunities:

- Fishing
- Canoeing/kayaking
- Other recreation, such as visits to trails.

The recreational fishing demand model presented in Bingham et al. (2011) provides the angler preference function used for the analysis. The angler preference function presented in Bingham et al. (2011) evaluates anglers' choices of where to fish and what species to target, assuming the angler chooses to go fishing. Site characteristics included in this model include advisory, boat ramp and several expected catch variables.

Modeling site-choice for paddling on the Clinton River requires identifying both site characteristics and parameterization of the relative importance that paddlers attach to each of these characteristics. One study presents a statistically estimated demand function for paddling; however, it was developed in Ireland. To apply this study (Hynes, Hanley, and Garvey 2007), we calibrated the parameters to reflect the specifics of the Boardman River and the surrounding area. To accomplish this calibration for site characteristics, we rely on expert judgment. The relevant site characteristics are:

- perceived whitewater quality
- perceived quality and safety of parking
- perceived crowding
- perceived water pollution
- perceived scenic quality

[10] This information is useful for evaluating changes via a utilitarian perspective, such as benefit-cost analysis (Dower 1989).

- perceived predictability of the water level prior to arrival.

The transferred demand model for other outdoor recreation is transferred from Kinnell et al. (2006). Variables in this model include the following:

- Site-related variables
- Acres: recreation area acres
- Trails indicates trails present at site
- Trail miles: trail mileage available at the site
- Picnic area indicates picnic area present at site
- Sports facilities indicates sports facilities (i.e., fields, basketball/tennis courts, etc.) present at site
- Swimming indicates swimming facilities available at site
- Boat launch indicates boat launch present at site
- Waterbody indicates waterbody (i.e., lake, river) present at site
- Bathrooms indicates bathroom facilities available at site
- Playground indicates playground present at site.

These models are able to calculate value for each recreational site based on the site characteristics, for example, the availability of fishing, boat launches, recreation acres, trails, and other amenities. The relative magnitudes of the coefficients show that the presence of a waterbody, picnic area, and trail are the three most influential site-related factors in determining recreator site choice.

8.7.3 The Baseline Information

In addition to the mathematical structures that link policies to outcomes we must identify Baseline conditions. An important consideration is that spatial and temporal dimensions are particularly important for recreational demand—the economic value of water in stream for recreational fishing varies seasonally and spatially (Olmstead 2010). For example, fishing for warm water species and cold water often occurs at the same time, but at a different place. Ice fishing could occur at the same place, but is a different type of activity that occurs at a different time of year. Value of water for on-water activities also varies seasonally (i.e., much lower in winter). Within a season, these are related to depths and flows up to a point. For example, paddlers require a certain depth to support activities over a waterbody. Therefore, during periods when canoeing is viable (i.e., not winter) they have significant values for flows (river segments) and depths (rivers and impoundments) that support canoeing/kayaking. Once flows/depths are sufficient to support the activity there is little additional value held for additional increments.[11] Likewise, water skiers hold significant value for impoundments with sufficient depth to support the activity but much lower value for additional increments of depth.

Information requirements include:

1. The population of affected recreators

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[11] Daubert and Young (1979) and Leones (1997) contain empirical valuations of flow with respect to rafting.

2. Locations of recreation resources (potentially affected and substitutes)
3. Travel costs from recreator origins to sites and monthly site characteristics
4. Monthly site pressure estimates by activity.

Populations of Affected Recreators

The population of affected recreators was specified to be all those within Oakland County. Their spatial location and density were identified at the ZIP code level. To establish the baseline of affected recreators we relied on the statistics reported in *Economic Impact of Oakland County's Water Resources* (Public Sector Consultants Inc. [PSC] 2009).

PSC conducted a household survey of Oakland County residents to examine their recreational use of water resources. The survey results suggest that 40 percent of county residents visit parks, trails, lakes, wetlands, rivers, or undeveloped open space at least weekly. Table 8.7.3-1 lists the average annual visitation rate to Oakland County's outdoor recreation sites, with estimated lower and upper bounds and midpoints on the range (PSC 2009).

Table 8.7.3-1: Annual Visitation Rates to Recreational Resources: Oakland County Residents

	Average Annual Visitation: Days per Year per Household		
Recreational Resource	**Midpoint**	**Lower Bound**	**Upper Bound**
Wetlands	29	17	41
River or stream	27	16	37
Private lake	25	15	35
Parks	23	14	32
Trails	23	14	31
Public lake	22	13	31
Undeveloped	18	11	25

Source: PSC (2009)

PSC's survey asked respondents how frequently they engaged in water-based recreation in Oakland County. Table 8.7.3-2 lists the estimates of average annual water-based recreational visits in Oakland County during 2007. Oakland County had an estimated 478,527 households during 2006. Multiplying the number of households times the number of visits for All Residents (column 2) yields the estimated number of annual visits by activity for Oakland County residents (column 3) during 2007 (PSC 2009).

Table 8.7.3-2: Average Annual Visits (2007), Water-Based Recreation: Oakland County Residents

Recreational Activity	Number of Visits: All Residents	Total Annual Visits
General recreation	19.36	9,264,283
Watching wildlife	11.06	5,292,509
Swimming or using a beach	8.17	3,909,566
Power boating or jet skiing	4.78	2,287,359

Canoeing, kayaking, sailing	2.36	1,129,324
Fishing	2.22	1,062,330

Source: PSC (2009)

This information was used to specify the population of affected anglers.

List/Locations of Recreation Resources

Recreators visit resources that are attractive to them because of proximity, angling catch rates, amenities such as boat launches and parks, and other characteristics. Studies show that recreators often travel 50 miles or more to go fishing or boating, visit a park, or participate in other outdoor recreation. Thus, the economic model evaluated waterbody resources along the Clinton River and its impoundments and alternate locations that recreators could visit in Genesee, Lapeer, Livingston, Macomb, Monroe, Oakland, Washtenaw, and Wayne Counties. These sites were selected because of proximity to the Clinton River or areas near potential recreators, similarity or range of amenities, or additional recreational opportunities. Table 8.7.3-3 lists impoundments of the Clinton River and alternative recreation locations, which were included as recreation resources in the simulation modeling.

Table 8.7.3-3: Waterbody Resources Evaluated in the Study

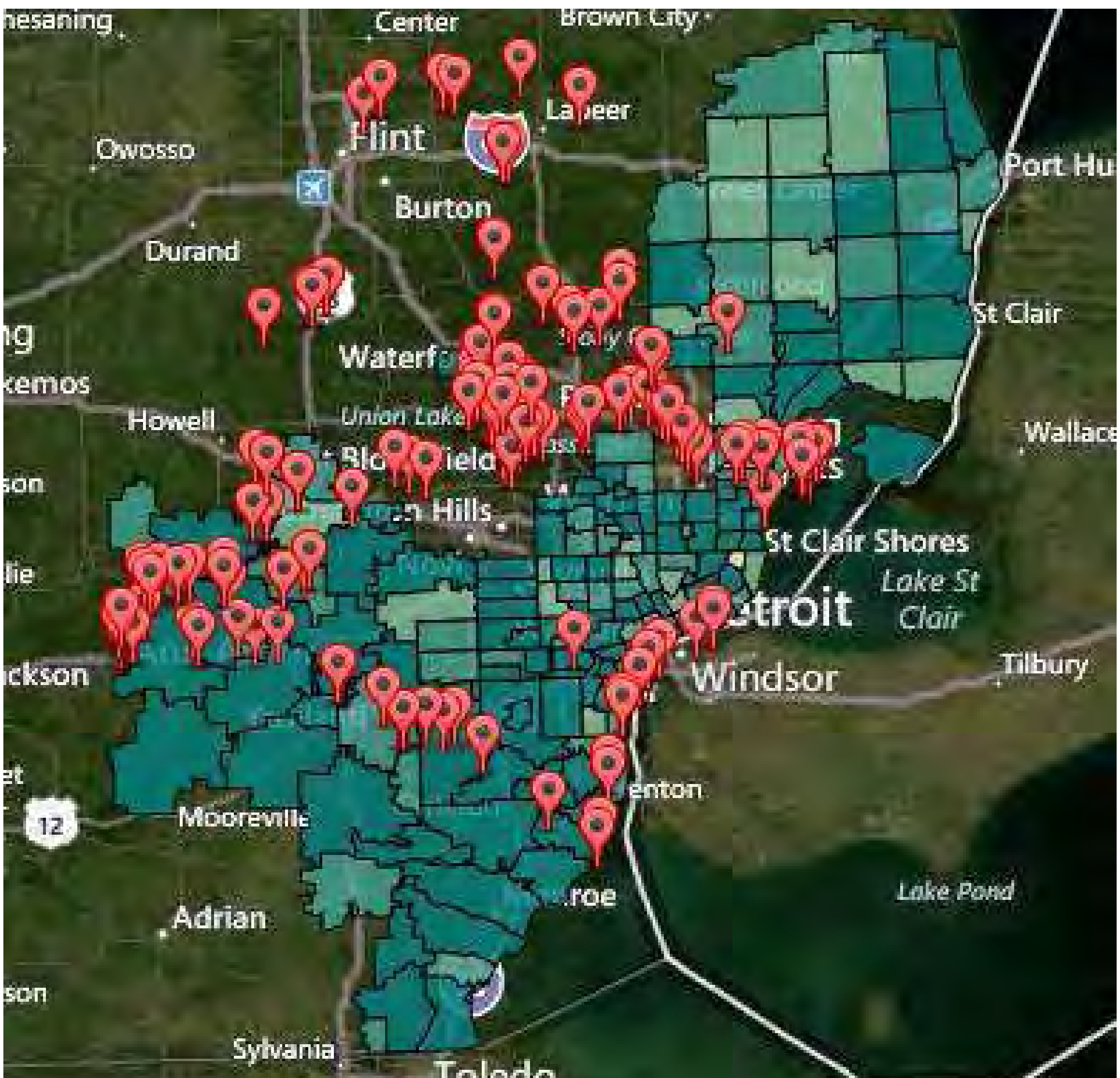
Location of Waterbody Resources Evaluated in the Study		
Appleton Lake, Livingston County	Greens Lake, Oakland County	Nepessing Lake, Lapeer County
Belleville Lake, Wayne County	Half-Moon Lake, Washtenaw County	Orchard Lake, Oakland County
Big Fish Lake, Lapeer County	Holloway Reservoir, Genesee and Lapeer Counties	Otter Lake, Oakland County
Bruin Lake, Washtenaw County	Huron River, Washtenaw County	Pontiac Lake, Oakland County
Cass Lake, Oakland County	Huron River, Oakland County	Portage Lake, Washtenaw County
Cemetery Lake, Oakland County	Huron River, Wayne County	Rouge River, Wayne County
Chilson Impoundment, Livingston County	Independence Lake, Washtenaw County	Sawdel Lake, Lapeer County
Clinton River, Macomb County	Joslin Lake, Washtenaw County	Schoolhouse Lake, Oakland County
Clinton River, Oakland County	Lake Chemung, Livingston County	Silver Lake, Oakland County
Crescent Lake, Oakland County	Lake Fenton, Genesee County	South Lake, Washtenaw County
Crooked Lake, Oakland County	Lake Oakland, Oakland County	Squaw Lake, Oakland County
Crooked Lake, Washtenaw County	Lake Orion, Oakland County	Stony Creek Lake, Macomb County
Crystal Lake, Oakland County	Lake Ponemah, Genesee County	Sugarloaf Lake, Washtenaw County
C.S. Mott Lake, Genesee County	Lake St. Clair, Macomb County	Sylvan Lake, Oakland County
Dawson's Mill Pond, Oakland County	Lakeville Lake, Oakland County	Upper Silver Lake, Oakland County
Detroit River, Wayne County	Lester Lake, Oakland County	Van Norman Lake, Oakland County
Detroit River, Lake Erie access	Lobdell Lake, Genesee County	Watkins Lake, Oakland County
Dollar Lake, Oakland County	Long Lake, Lapeer County	Whitmore Lake, Livingston County
Flint River, Genesee County	Loon Lake, Oakland County	Williams Lake, Oakland County
Ford Lake, Washtenaw County	Lotus Lake, Oakland County	Winnewanna Impoundment, Oakland County
Four Mile Lake, Washtenaw County	Maceday Lake, Oakland County	Woodland Lake, Livingston County

Graham Lakes, Oakland County	Mill Lake, Washtenaw County	Wormer Lake, Oakland County
Green Lake, Washtenaw County	Mohawk Lake, Oakland County	

Sources for Table 8.7.3-3 include DeLorme (2006); Francis (2005, 2007); Francis and Haas (2006); Goudy (1981); Leonardi, and Gruhn (2001); Lockwood, Clark, and Merna (1995); Michigan Department of Natural Resources (2003, 2010); Michigan Department of Natural Resources, Parks and Recreation Division (2006); Michigan State University Extension (undated); Nikoloff and Herbowicz (2003); Oakland County (undated 2; 2010a, 2010b); Oakland County Planning & Economic Development Services-Environmental Stewardship Program (undated); Public Sector Consultants Inc. (2009); Schneider, Waybrant, and O'Neal (1991); Su, Lockwood, and Sutton (2006); and Thomas and Haas (2002).

<u>Travel Costs and Site Characteristics</u>
To specify the supply curve for local water resource recreation opportunities, travel costs were calculated for travel *to* the Clinton River, its impoundments, and substitute sites *from* ZIP codes of recreators in Oakland County. ZIP codes and site locations depicted in Figure 8.7.3 were included.

Figure 8.7.3: Location of Sites and ZIP Codes Used for Trip Simulations



Travel costs were calculated from the center of the 265 ZIP codes outlined and shaded green in Figure 8.7.3 to the 313 sites depicted in Figure 8.7.3 using the most recent version of a transportation routing software called PC*Miler. The travel-cost calculation measured the distance from each ZIP code to each recreation site by using at least one latitude/longitude point for that site. Travel costs reflect both direct costs and travel time costs. Direct costs are calculated by multiplying the round-trip miles by the standard per mile reimbursement (GSA 2012). The average hourly wage of each ZIP code within the 50-mile radius was calculated by dividing household income from the U.S. Census by 2,000 work hours per year. Travel speed was assumed to average 50 miles per hour. The round-trip time estimate (round trip distance divided by speed of travel) was multiplied by one-third of the average hourly wage rate to reflect the opportunity cost of time. The travel cost included in the model is the sum of the direct travel cost and the travel time costs.

Our analysis gathered data on characteristics for each Clinton River site, impoundment, and substitute site. Resources for the data included reports and studies, websites, and communications with site experts.

Monthly Site Pressure Estimates

This analysis relied on many sources for visitation and recreation estimates, as well as angler catch rates. Those estimates rely principally on Public Sector Consultants Inc. (2009), HyettPalma (2009), and recreational fishing studies conducted by the Michigan Department of Natural Resources.
Communications with local canoeing and kayaking experts also yielded the following pertinent information about paddling on the Clinton River (Outdoor Escorts, LLC 2011; Pool 2011):

- **Paddling pressure estimates**—On some sections during peak days (Saturday and Sunday), 200 to 500 people paddle the river (an average 2 or 3 people per canoe). During weekdays, about 10 to 30 canoes/kayaks paddle the river. The experts noted that they expect about 1,000 to 2,500 people paddling during a busy month. September is busiest month with up to 700 people in a week. The highest water usually occurs during March, April, and May. During June, water levels start to drop.
- **Dam management and paddling quality**—Dams are managed with consideration of lake levels: they are either on "high" or "low." The general strategy brings up lake levels before the 4th of July and brings them down after Labor Day. The strategy includes some flood management. Lake levels can have water high enough to cancel intermediate-level paddling trips until June, when all dams are closed to fill the lakes. When the river is dry from Yates dam upriver to Squirrel road, canoeing/kayaking companies move 1-, 2-, and 3-hour trips from Yates Dam down river to Van Dyke because the section above the dam becomes unusable. Canoeing/kayaking experts note that about 10 miles of 20 total groomed river miles are useable when the water level at the Auburn Hills gauge is below 1.3 feet.
- **Other economic impacts**—Perhaps half of the canoeing is rental, half personal craft. There is a local tax for rental canoes. The quality of Clinton River paddling ties into sales of gear in local stores, as well as improved sales at local restaurants/bars. Canoeing/kayaking companies pay for every oat put into the river. There is no charge to anyone putting in his or her own boat.

8.8 Implications of Scenarios

The hydrological and ecological evaluation indicates that flow would be improved in certain river parts during summer months. This would improve paddling conditions. Also, because the connectivity of the river would be better and because of more natural fluctuations in the lakes, catch rates could improve in the impoundments as well as river sections. Finally, park trips to affected areas would be positively impacted by the presence of water.

- Table 8.8-1 lists baseline fishing conditions at potentially affected sites.
- Table 8.8-2 lists baseline paddling conditions at potentially affected sites.
- Table 8.8-3 lists baseline park conditions at potentially affected sites.

Table 8.8-1: Specified Baseline Fishing Conditions at Potentially Affected Sites

Affected Waterbody	Baseline Angler Catch Rate	Baseline Visitation
Clinton River	Brown trout 0.0187 Carp 0.0009 Steelhead 0.0165 Rainbow trout 0.0059 Sucker 0.0771 Walleye 0.0247	5,000 trips
Cass Lake	Black crappie 0.0113 Bluegill 0.0815 Carp 0.0021 Largemouth bass 0.0153 Pumpkinseed 0.0004 Smallmouth bass 0.0160 Walleye 0.0021 Yellow perch 0.0098	1,837 trips
Crystal Lake	Black crappie 0.0601 Bluegill 0.5521 Largemouth bass 0.0070 Pumpkinseed 0.0426	118 trips
Oakland Lake	Bluegill 0.5521 Largemouth bass 0.0070	1,747 trips
Orchard Lake	Largemouth bass 0.0070 Smallmouth bass 0.0009 Yellow perch 0.0119	1,161 trips

Table 8.8-2: Baseline Paddling Conditions at Potentially Affected Sites

Affected Waterbody	Whitewater Quality	Parking Quality	Crowding	Water Quality	Scenic Rating	Predictability of Water Level	Specified Trips
Clinton River upstream of Paint Creek	2	4	5	4	3	3	1,655

Table 8.8-3: Baseline Park Conditions and Trips at Potentially Affected Sites

Affected Waterbody	Baseline Conditions	Baseline August Trips
Clinton River	Sometimes dry in summer (waterbody=0)	2,500 trips at Riverside Park, Auburn Hills
Clinton River	Sometimes dry in summer (waterbody=0)	8,000 trips at Riverbend Park, Auburn Hills
Clinton River	Sometimes dry in summer (waterbody=0)	16,500 trips at River Woods Park, Auburn Hills
Clinton River	Sometimes dry in summer (waterbody=0)	15,900 trips at Bloomer Park, Rochester Hills

Changes in recreation behaviors and resource values were assessed by applying the models described earlier to the counterfactual site conditions expected to arise from the flow management policy. Tables 8.8-4 – 8.8-6 contain expected changes and site conditions and resulting changes in pressure.

Table 8.8-4: Counterfactual Fishing Conditions at Potentially Affected Sites

Affected Waterbody	Change in Catch Rate	Change in Angling Pressure
Clinton River upstream of Paint Creek	+10%	+5%
Cass Lake	+5%	+2%
Crystal Lake	+5%	+2%
Oakland Lake	+5%	+2%
Orchard Lake	+5%	+2%

Table 8.8-5: Counterfactual Paddling Conditions at Potentially Affected Sites

Affected Waterbody	Whitewater Quality	Parking Quality	Crowding	Water Quality	Scenic Rating	Predictability of Water Level	Change in Trips
Clinton River upstream of Paint Creek	+1	same	same	same	same	+1	+ 22%

Table 8.8-6: Counterfactual Park Conditions and Trips at Potentially Affected Sites

Affected Waterbody	Conditions	Change in Summer Trips
Clinton River at Riverside Park	Not dry in summer (waterbody=1)	+ 9%
Clinton River at Riverbend Park	Not dry in summer (waterbody=1)	+ 9%
Clinton River at River Woods Park	Not dry in summer (waterbody=1)	+ 9%
Clinton River at Bloomer Park	Not dry in summer (waterbody=1)	+ 9%

As Table 8.8-4 indicates, relatively minor catch and pressure increases are expected due to the more natural flow regime. Applying the welfare economic mathematics of Equation 3, the higher catch rates are valued at $5,500 annually. Providing a more stable flow and depth in the Clinton River would improve paddling conditions on the river. As depicted in Table 8.8-5, simulations of these improved paddling conditions indicate that in addition to improving the experience for baseline trips, a 22% increase in paddling trips is expected when comparing activity during periods when the river would otherwise be at very low flow. This increase in flow is expected to improve the Clinton River's value for canoeing and kayaking by approximately $12,000 in years when low flow is restored. Maintaining flow at the Clinton River parks during summer months will make the area more attractive for park visitors. As Table 8.8-5 indicates, in addition to improving the quality of baseline trips, restoring flow when it is low is expected to increase trips to affected parks by approximately 9%. Restoring flow is expected to increase the social value of affected parks by about $130,000 per year in years when low flow is restored.

The total improvement in recreation resource values will depend upon the frequency and timing of flow interventions. For this assessment, we specify that the flow intervention occurs every other year, beginning in 2012. This leads to better paddling and park visits every other year. Fishery improvements are specified to begin in 2014 and continue on in each year. Under this scenario, the total present value (discounted at 3% from 2012 through 2042) for outdoor recreation benefits is estimated to be $1,732,000. This estimate reflects all value-in-use accrued over that 30 year period. Non recreational use/ecological values would greatly increase this total, but were not quantified due to lack of information. This total also does not include increased business use and land values in established and emerging commercial areas in Auburn Hills, Rochester, and Rochester Hills which would be expected if a more regular flow regime existed in the river. Finally, if a more natural flow regime existed on a regular basis with modification occurring annually (instead of every other year) than this number could be doubled to approximately $3.5 million over a 30 year time period.

9.0 Results and Discussion

This integrated assessment addressed the causes and consequences of interrupted flows that impact fish and wildlife habitat and recreational uses in the Clinton River watershed. Further, this assessment helped develop some of the tools and metrics that can be used by the policy makers to identify, evaluate, and build consensus for revised flow management policies within the watershed. In conclusion, this project represented the exact opportunity that the Michigan Sea Grant Integrated Assessment Program is designed to serve, which is as a beneficial demonstration project on how to conduct integrated assessments on urbanizing/urbanized watersheds in the Great Lakes region.

9.1 Implementation Strategies

Based on the public forum meetings and advisory board discussions, there are a series of implementation strategies that could be considered by the OCWRC office, affiliated policy makers, local government organizations, and community organizations to mitigate the interrupted flows in the Clinton River watershed.

1. Maintain status quo. One option is to maintain status quo and make no significant changes. The OCWRC office now has better awareness of the situation as this project has brought additional information to their attention. The lake technicians are more likely to modify their actions related to the management of the structures by considering the downstream receiving water of the Clinton River. The conditions could get worse if climate trends from the last 20 years continue and more instances of extreme low flow are observed, but finding a compromise and a new legal framework will be difficult. Conversely, there is a plan for the Pontiac WWTP to be modified to intake more water from Oakland County (OHM 2011) which would add an ***additional*** 18 cfs of discharge to the Clinton River below the outlet, but sections of the river above the WWTP outlet would still be dry during periods of drought. However, this would not represent a "more natural" flow regime as was the stated goal of the project. Finally, this option does not resolve conflicts between individual lakes or broader flow management issues in the watershed. It would only provide a low level of discharge (~30 cfs total) during periods of extreme drought.

2. Optimize lake management within the current legal framework. This option would require the OCWRC to manage lakes in a more optimal manner but within the current legal framework. The exact management strategies would take additional study, and perhaps a more complex hydrologic model but there might be a couple different strategies to consider including more advanced technology associated with monitoring lake levels and adjusting control structures to maintain a more natural water balance in the watershed for the benefit of the lakes and the receiving waters of the Clinton River. This option could also include upgrading the control structures so they are capable of more detailed resolution of flow release. In many cases, the structures can only manipulated by adding/removing boards which would greatly increase or decrease flow in larger increments instead of steadily releasing smaller volumes of water. Finally, it might be possible to maximize lake storage without damaging properties through timing of release, etc. This would allow the four lakes (Orchard, Oakland, Cass, and Crystal) with higher storage capacity to be utilized now if the current legal framework allows.

3. Petition the court to revise individual lake levels. There is significantly more known now about the hydrology of the watershed and the effects of the current operational requirements than in 1966 when most of these lake levels were set independent of each other (see Appendix B).

Legal lake levels are established by the Oakland County Circuit Court judges under state statue *Act 454 of 1994 – Part 307 Inland Lake Levels* in a manner defined below:

"Normal level means the level or levels of an inland lake that provides the most benefit to the public; that best protect the public health, safety, and welfare; that best preserve the natural resources of the state; and that best preserve and protect the value of the property around the lake." (Act 454 of 1994 – Part 307 Section 324.30701)

Furthermore, Section 324.30707 states that in determining a normal level of an inland lake, the court should consider the "hydrology of the watershed, downstream flow requirements and impacts on downstream riparians, fisheries and wildlife habitat protection and enhancement, and rights of riparians" among others factors. In other words, the effect of the lake levels on the surrounding watershed, and more importantly the Clinton River, should be considered.

This option would mean petitioning the court to revise the lake levels such that the interacting bodies of the watershed and the Clinton River are considered as a part of the lake level establishment process. However, if each lake is revisited individually instead of the system as a whole, then this option will be less effective. In addition, a single court ordered lake level will not address the benefits associated with fluctuating lake levels or restore a more natural flow regime. This option might be better than the current situation but may not be an ultimate solution to the issues observed in the watershed. Finally, this option requires individual lake associations to petition the county board of commissioners (two-thirds of lakefront property owners) and conduct engineering studies that could cost $10,000 to $30,000 per lake. The likelihood of the lake boards and/associations voluntarily petitioning the board for a subsequent court ruling as well as paying for the engineering study is unlikely.

4. Develop a recommended lake level in conjunction with lake associations and pursue a joint petition on behalf of all lakes. This is a "compromise" strategy that builds upon above alternatives but would be very difficult to implement because of the required coordination between multiple lakes. While the stakeholder surveys indicated that lake residents were willing to tolerate moderate lake level fluctuations for an overall healthier watershed, getting two-thirds of residents on each controlled lake to simultaneously petition the county is extremely unlikely.

5. Push for legislative action at the state level to mandate and fund a revision of all the court mandated water levels. This option also builds upon the previous options, however all lakes will be considered simultaneously and management would be based on legislative action instead of working within the current framework. A revised law could allow for variable lake levels and provide the OCWRC office with flexibility in management instead of a fixed level for the lakes.

6. File a lawsuit to force a change. Unfortunately, it may be necessary to file a lawsuit to force a change in the management of system. There are two likely alternatives for this option. One would be for an outside entity to challenge current court rulings on lake levels under the basis that current set lake levels are compromising the health of the watershed and not considering all parts of the law (as described in option

4). The law is written that hydrology and downstream impacts should be considered when setting lake levels but the argument could be made that in 1966 these factors were not considered. In addition, the watershed is very different than in 1966 and therefore the lake levels need to be revisited and consider the entire Clinton River watershed in the analysis. The second option is to file a lawsuit based on federally protected endangered species. Table 9.1-1 and Table 9.2-2 provide the 2007 List of threatened (T), endangered (E), and special concern (SC) species within Upper Clinton River and Main Clinton River subwatersheds based on the Endangered Species Act (ESA). The ESA's goal is to prevent the extinction of imperiled plant and animal life and to recover populations by removing threats to their survival. Lawsuits would likely focus on one or more of these species. For example, the purple Lilliput mussel is only found in the receiving waters downstream of the impoundments and is listed as an endangered (E) species. The Upper Clinton River also supports the only likely population of rayed bean in Michigan's streams (also endangered) (Morowski, James, and Hunter 2009). Recent surveys indicate that the density of mussels are declining due to lake-level control structures (Morowski, James, and Hunter 2009).

Table 9.1-1: Threatened, Endangered and Special Concern Species in the Upper Clinton Subwatershed

SCIENTIFIC NAME	*COMMON NAME*	*STATE STATUS**
Carex richardsonii	*Richardson's Sedge*	*SC*
Cypripedium candidum	*White Lady-slipper*	*T*
Drosera anglica	*English Sundew*	*SC*
Linum virginianum	*Virginia Flax*	*T*
Platanthera ciliaris	*Orange or Yellow Fringed Orchid*	*T*
Trichostema dichotomum	*Bastard Pennyroyal*	*T*
Buteo lineatus	*Red-shouldered Hawk*	*T*
Erynnis baptisiae	*Wild Indigo Duskywing*	*SC*
Oecanthus laricis	*Tamarack Tree Cricket*	*SC*
Oecanthus pini	*Pinetree Cricket*	*SC*
Clinostomus elongatus	*Redside dace*	*E*
Pyrgulopsis letsoni	*Gravel pyrg*	*SC*
Ammocrypta pellucida	*Eastern sand darter*	*T*
Sistrurus catenatus	*Eastern Massasauga Rattlesnake*	*SC*
Villosa fabalis	*Rayed bean mussel*	*E*
Toxolasma lividus	*Purple Lilliput mussel*	*E*
Epioblasma triquetra	*Snuffbox mussel*	*E*
Lampsilis fasciola	*Wavy-rayed lamp-mussel*	*T*
Pleurobema sintoxia	*Round pigtoe mussel*	*SC*
Villosa iris	*Rainbow mussel*	*SC*
Ptychobranchus fasciolaris	*Kidney shell*	*SC*

*SC = special concern, T=threatened, E=endangered

Table 9.1-2: Threatened, Endangered and Special Concern Species in the Main 1-2 Clinton River Subwatershed

SCIENTIFIC NAME	*COMMON NAME*	*STATE STATUS**
Carex richardsonii	*Richardson's Sedge*	*SC*
Cypripedium candidum	*White Lady-slipper*	*T*
Drosera anglica	*English Sundew*	*SC*
Linum virginianum	*Virginia Flax*	*T*
Platanthera ciliaris	*Orange or Yellow Fringed Orchid*	*T*

Trichostema dichotomum	*Bastard Pennyroyal*	*T*
Buteo lineatus	*Red-shouldered Hawk*	*T*
Erynnis baptisiae	*Wild Indigo Duskywing*	*SC*
Oecanthus laricis	*Tamarack Tree Cricket*	*SC*
Oecanthus pini	*Pinetree Cricket*	*SC*
Sistrurus catenatus	*Eastern Massasauga Rattlesnake*	*SC*
Toxolasma lividus	*Purple Lilliput mussel*	*E*
Villosa fabalis	*Rayed bean mussel*	*E*
Epioblasma triquetra	*Snuffbox mussel*	*E*
Epioblasma torulosa rangiana	*Northern riffleshell mussel*	*E*
Lampsilis fasciola	*Wavy-rayed lamp-mussel*	*T*
Pleurobema sintoxia	*Round pigtoe mussel*	*SC*
Villosa iris	*Rainbow mussel*	*SC*

*SC = special concern, T=threatened, E=endangered

7. Green infrastructure. Green infrastructure (also known as low impact development (LID) or conservation site design) was not a focus of this investigation but could help mitigate the amount of impervious surface across the watershed. The LID process holistically considers the landscape during design to protect the environment through practices that enhance water and air quality while preserving open green space. LID is especially important in urban and urbanizing areas such as southeast Michigan, where it' is crucial to protect our waterways and remaining green space. Constructed LID techniques include porous pavement, rain gardens, bioswales, riparian buffers, stormwater treatment wetlands, and native vegetation/naturalization. A number of strategies could help improve storage and minimize impacts of floods and droughts on both the lakes and rivers. LID techniques will also improve groundwater levels which can recharge the surface waters during the summer. However, to widely implement LID practices in the watershed, there needs to be a significant multi-prong educational effort and a planning strategy for implementation. Wide implementation of green infrastructure/LID in the upper watershed would improve water quality and recharge the lakes but the hydraulic structures would limit the amount of water recharge being directed downstream. As such, the benefits of constructing green infrastructure would not be measureable for considerable time and would not benefit the Clinton River unless management of the structures was also addressed.

9.2 Future Research

The next phase of this project should include connecting water discharge and depth scenarios with water quality and in-stream habitat. As such, future research goals would include:

1. Develop a more robust hydrologic model.
2. Developing an ecosystem function model to quantify benefits to the river ecology.
3. Developing a design for upgrading lake-level control structures, and carry out a cost-benefit analyses.
4. Incorporate climate change adaptation measures and use of green infrastructure into final watershed projects.

9.2.1 Hydrologic Modeling

The hydrologic model developed for this project was a simplified mass balance model that demonstrated the connectivity and possible management strategies but a more complex computational model and the additional collection of hydraulic data would yield a more complete hydrologic model of the system which would aid in decision-making. This could be accomplished with an interconnected pond routing model (ICPR). The complexity of the system, the number of hydraulic structures, and paucity of data made the development and calibration of a routing model not practical for this investigation. A more complex model could include groundwater interactions with surface water and be used in support of the other future research plans.

9.2.2 Ecosystems Function Model

It is difficult to achieve desired outcomes of restoring a more natural flow regime to the Clinton River, or make decisions about regulated flows without a complex understanding of the relationships between variables for a specific system. For example, it is not just as simple as thinking that an increase in stream flow would result in an increase in the population of a specific game fish. A key point of uncertainty is how much additional flow would be required in the Clinton River to provide a measureable improvement in habitat. Ecosystem models such as Instream Flow Incremental Methodology (IFIM) and related physical habitat simulation models (PHAB-SIM), provide methods for quantifying effects of stream flow on fish and invertebrate habitat and riparian communities (Souchon et al., 2008; Environment Canada, 2004). Ecosystem models such as PHABSIM integrate the changing hydraulic conditions with discharge and the habitat preferences of one or more selected species. The method relies on three principles: (1) the chosen species exhibits preferences within a range of habitat conditions that it can tolerate; (2) these ranges can be defined for each species; and (3) the area of stream providing these conditions can be quantified as a function of discharge and channel structure (Petts 2009). Therefore, the critical species (such as fish or mussels) would have to be identified for the Clinton River and then the critical habitat mapped. Parasiewicz (2001) incorporated mesohabitats such as runs, riffles, or pools into the PHABSIM, called, MESOHABSIM which would be another alternative modelling approach. One of the limitations to modelling is that every river has its own natural flow regime which shapes the evolution of aquatic biota and ecological processes. An important aspect to this approach is to conduct monitoring for validation which test assumptions of the models.

Table 9.2 shows a list of suggested parameters that can be monitored to evaluate the ecological effects of water fluctuations and to be used as an assessment tool for evaluating ecological impacts from flow and lake level regulation for future improvements in the watershed.

Table 9.2: Suggested Parameters for Assessment and Decision Criteria for Flow and Lake Level Regulation

Sediments	Water Column	Organisms/Fauna	Vegetation/Flora	Other
REDOX	Dissolved Oxygen (DO)	Macro invertebrates	Tree branch debris	Photos
Depth	Depth	Mosquito larvae	Riparian species	Air photos
Grain Size	Temperature	Daphnia	Special status (T&E etc.)	GPS data
Resuspension	Discharge	Mites	Habitat/range	GIS mapping

Organic Chemicals	Organic Chemicals	Species Richness	Invasive Species	Land Use, changes in % impervious surfaces
Trace Elements	Trace Elements	Fish species	Diatoms	
Nutrients	Nutrients	Amphibians	Algae/muck	Physical conditions of infrastructure (likelihood to fail)
Total Organic Carbon (TOC)	Dissolved Organic Carbon (DOC)	Birds	Emergent spp. (cattails)	
Radionuclides		Reptiles	Woody spp.(alder, willow)	
		Fish migration		
		Invasive Species		
		Microorganisms		
		Schistosomes		

9.2.3 Hydraulic Structure Design

To improve the ability of the OCWRC office to regulate flow in the watershed, an investigation on hydraulic structure improvements needs to be undertaken. This investigation is closer to design than research, but it is an important next step for the system. The current hydraulic structures are unable to release water in the volumes and precision necessary based on current hydrologic modelling scenarios. In addition to hydraulic control structure upgrades, the system could be automated to allow for a more detailed quantification of water levels and flow across the watershed and then the flow control optimized accordingly.

9.2.4 Climate Change and Green Infrastructure

As weather becomes more unpredictable and the world grows warmer, it is going to be important to consider the effect of climate change adaptation measures on the watershed and how climate change could be integrated into the previously listed future research projects. Similarly, green infrastructure as a tool for stormwater management is on the rise due to more stringent environmental regulations and a general public desire to be "green." Widespread implementation of green infrastructure in the upper Clinton River watershed would improve water quality and recharge the lakes but the measureable effect of widespread implementation would need to be studied. Finally, the effect of watershed response to green infrastructure would also need to be considered in future hydrologic and EFM models.

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