Table 2.4-3 Hypothesized effects of dams within the catchment on flow metrics.

Flow characteristic	Flow metric	Hypothesized effect of dams in catchment on flow metric	Assumption or explanation
Summer/Fall – Magnitude	July, Aug, Sept, and Oct median flow	Decrease	Presence of reservoirs increase evaporation which leads to decreased stream flow. Increased reservoir storage also decreases streamflow.
Spring – Magnitude	March, April, May, and June median flow	Increase	Assuming reservoirs are frozen or full in spring, more precipitation is delivered to the stream network than if reservoirs / ponds were not present.
Low Flow Magnitude	7- day annual low flow	Decrease	Presence of reservoirs increase evaporation which leads to decreased stream flow. Increased reservoir storage also decreases streamflow.
High Flow Magnitude	3-Day annual high flow	Increase (higher flows)	Annual high flow usually occurs in spring, when reservoirs are frozen or full. This impervious surface concentrates flow and magnifies peakflow events.
Rate of Change	Flashiness Index	Increase	Presence of reservoirs increases flashiness in spring, but may decrease flashiness in summer. Overall, increases annual flashiness values.

These hypotheses are discussed for each of the four watersheds in Section 3 Watershed results.

3. WATERSHED RESULTS

3.1 Shiawassee River, Michigan

3.1 Watershed Results, Shiawassee River, Michigan

Location: The Shiawassee watershed is located south and west of Saginaw Bay in central Michigan and drains approximately 1160 square miles (742,400 Acres) via the Shiawassee River. The Shiawassee River flows northward into the Flint River and then joins the Tittabawasee and Cass Rivers to form the Saginaw River, which then flows into Saginaw Bay and Lake Huron. At least six subwatersheds drain the larger watershed and flow into the

Shiawassee River, including from north to south: Swan Creek, Beaver Creek, the Bad River, Jones Porter Drain, South Branch Shiawassee, and the Denton/North Ore Creek subwatershed.

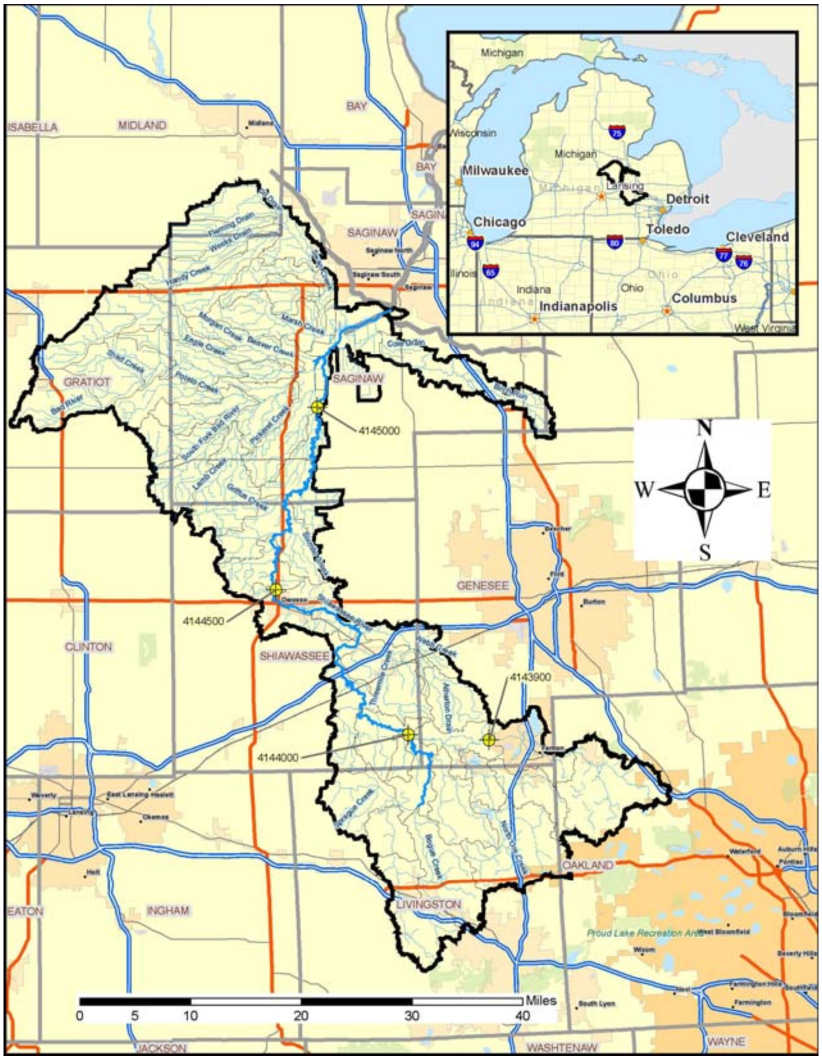

Figure 3.1-1 Location map for the Shiawassee watershed.

Geology: The southern half of the Shiawassee River basin consists of alternating east-west trending moraines, glacial till, and outwash plains. The moraines and outwash plains contain sand and gravel deposits that are more permeable than the fine-grained glacial till and lake clays found in the northern part of the basin. The southern half of the basin has variable (high) relief and is generally well-drained with numerous shallow aquifers that contribute groundwater flow to the headwaters of the Shiawassee River.

The northern half of the basin (north of Owosso) is predominately a low-relief till plain overlain by fine-grained glacial lake clays and relict beach deposits that were deposited when glacial Lake Saginaw covered much of the area. These fine-grained glacial lake clays and till plain deposits are relatively impermeable and are poorly-drained. Since the retreat of Laurentide (Wisconsin age) ice sheet, the Shiawassee River has eroded into the till plain surface and is now deeply incised. In the northern half of the basin, tributary streams and agricultural drains flowing into the Shiawassee River are deeply incised into the till plain surface, especially near the tributary confluence with the Shiawassee River mainstem.

Data Availability: Four USGS gages exist within the watershed that are either currently recording daily streamflows or have recorded them until recently. For this study, we analyzed streamflow data for the four sites that had more than 20 years of data. (Table 3.1-1 and Figure 3.1-2)

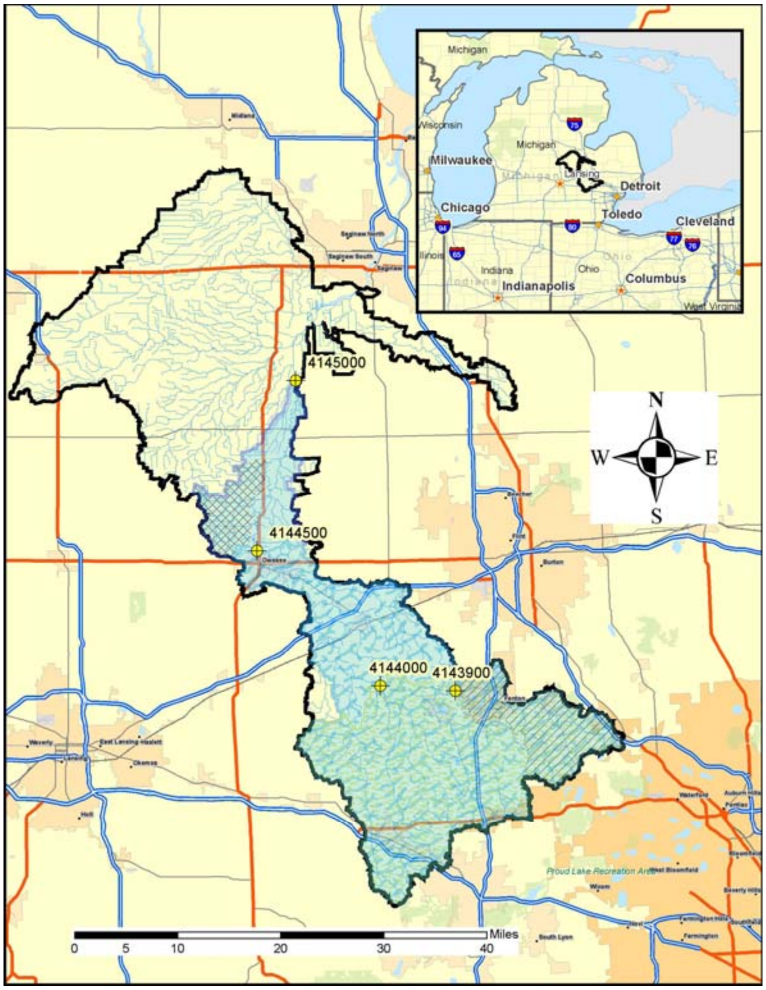

Figure 3.1-2 Location of USGS stream gages and drainage areas that contribute flow to those gages in the Shiawassee watershed. The Nature Conservancy's control and test subwatersheds are located upstream of the 414500 Fergus gage in the cross-hatched area.

Table 3.1-1 Shiawassee Stream Gages

Streamflow Gage	Watershed Area (sq mi)	Period of Record	
		Start	End
4143900 Shiawassee @ Linden	83.7	1967-10-1	2003-9-30
4144000 Shiawassee @ Byron	365	1947-10-1	1983-10-12
4144500 Shiawassee @ Owosso	538	1931-3-1	2004-9-30
4145000 Shiawassee nr Fergus	637	1940-1-1	2004-9-30

Description of Anthropogenic Changes

The Shiawassee River watershed is predominately a rural watershed that is dominated by agriculture uses in the northern part of the watershed and agricultural and rural/small community residential uses in the southern part of the watershed. The most significant change in land use and land cover was the conversion of woody wetlands and mixed/deciduous forests into agriculture. Associated with the conversion to agriculture, significant hydrologic modifications were made including straightening and channelization of small streams, draining of wetlands and low-lying areas, and the installation of drain tile to facilitate the removal of water from poorly drained fields, especially in low-relief areas in the northern portion of the watershed.

In addition to agriculture, urban development associated with population centers is increasing, especially in areas associated with larger population centers located outside of, but immediately adjacent to, the Shiawassee watershed. Much of the urban development has resulted in the conversion of agricultural lands into residential and commercial land. These changes have resulted in increased wastewater and stormwater discharges into tributaries and the Shiawassee River mainstem.

Land Use/Land Cover: Figures 3.1-3 and 3.1-4 show both pre-settlement and current land use/land cover for the Shiawassee watershed. Pre-settlement land cover in the watershed was dominated by woody wetlands (~57%) and a deciduous/mixed forest (~38%). Woody wetlands were associated with the low relief poorly-drained till plain and glacial lakebed deposits located in the northern portion of the watershed. Deciduous, mixed, and coniferous forests are associated with well-drained morainal and glacial outwash deposits located in the central and southern portion of the watershed.

Current land cover within the watershed is primarily agricultural (~57%), deciduous/mixed forest (~14%), woody wetlands (~11%), grassland (~7%), and urban (~5%). Remnant woody wetlands are found in poorly drained low lying areas and in relict drainage swales in the northern portion of the watershed. Remnant forests and woody wetlands are found in well-drained high relief areas, generally steeper valley slopes and in small tributary floodplains in the southern portion of the watershed.

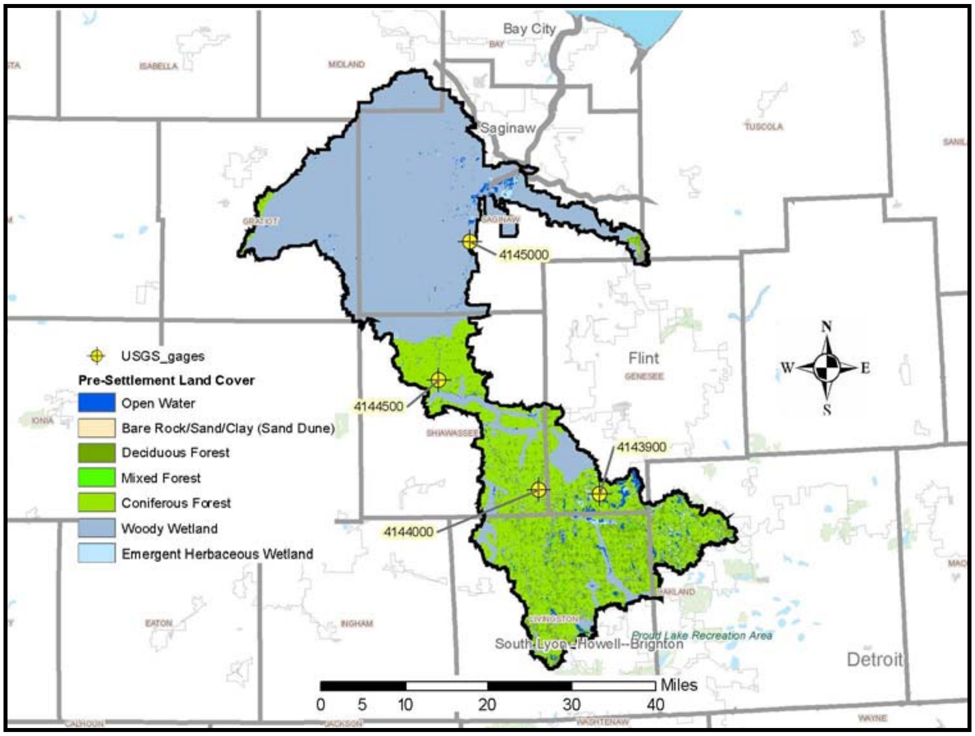

Figure 3.1-3 Presettlement land cover for the Shiawassee watershed. Woody wetlands were prevalent in the poorly-drained northern portion of the watershed, and forests dominated the well-drained southern portion of the watershed.

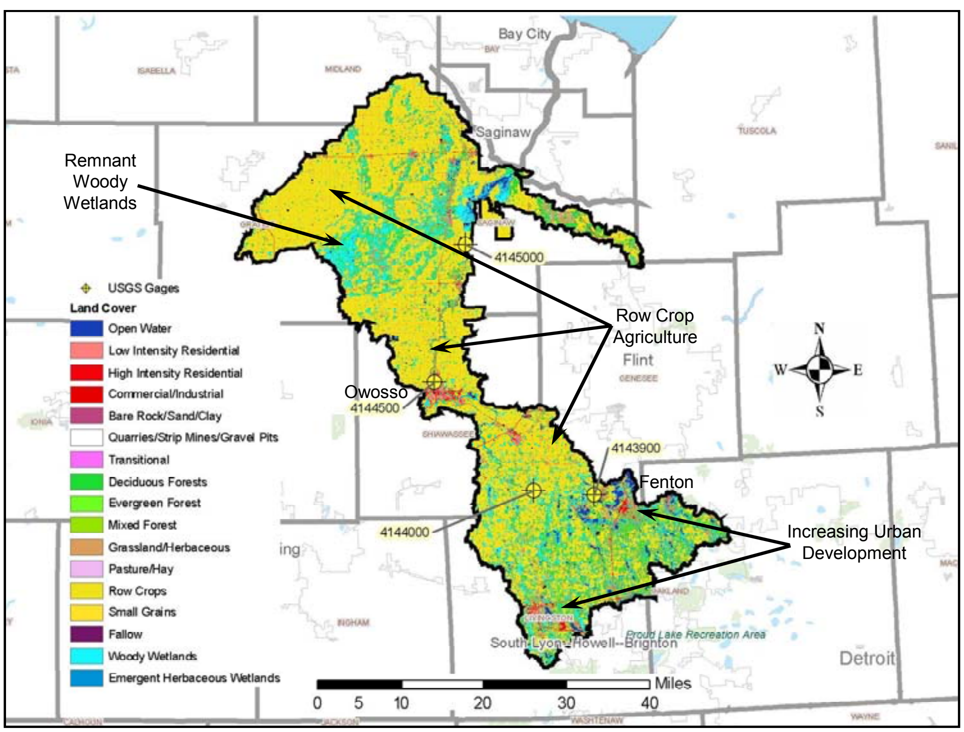

Figure 3.1-4 Present-day land cover for the Shiawassee watershed. Much of the central and northern portion of the watershed is in row crop agriculture.

Changes in land use and land cover are summarized in Table 3.1-2. In low-relief areas suitable for agriculture, deciduous and mixed forests were felled, woody wetlands drained, and the land converted to agricultural use. In total, more than half of the Shiawassee watershed has been converted from woody wetland or forest into agricultural lands with potentially profound hydrologic impacts.

In the northern portion of the watershed, woody wetlands were cleared and drained for agricultural purposes, and the loss of these wetlands represents the most historically significant land use/land cover change in the watershed. Natural swales and small tributary stream channels were straightened, enlarged, and deepened to facilitate catchment drainage. Tileage was installed to remove water as quickly as possible from agricultural fields. In the southern portion of the watershed, remnant forests are generally found in areas too small or difficult to convert to agricultural use, i.e. steep valley slopes and small tributary floodplains. Urban development is limited primarily to communities located in the central and southern portions of the watershed. There is also development pressure from communities located outside, but adjacent to, the Shiawassee watershed. This development is typified by increases in low-density residential development, especially in the Livingston area near Howell, and increases in high-density residential (and commercial) development along the U.S. 23 corridor near Fenton.

Also of interest in Table 3.1-2 is the fact that the current amount open water (~2.3%) appears larger than that of pre-settlement (~1.9%). This is due to the construction of impoundments (ponds, lakes, and reservoirs) for water supply (irrigation), flood control, and/or power production purposes. Increases in emergent herbaceous wetlands acreage since pre-settlement may also be related to increased availability of shallow open-water areas in ponds and reservoirs for colonization by wetland plant communities.

Table 3.1-2 Land Use/Land Changes in the Shiawassee Watershed

		No Data	**Bare Rock/ Sand/Clay**	**Grasslands/ Herbaceous**	**Shrubland**	**Deciduous/ Mixed Forest**	**Evergreen Forest**
Pre-Settlement	*Acres*	-	69	-	-	296,001	3,030
	% of Total	0.0%	0.0%	0.0%	0.0%	38.0%	0.4%
Current	*Acres*	-	3,099	52,548	7,544	112,492	10,998
	% of Total	0.0%	0.4%	6.7%	1.0%	14.4%	1.4%
Change	*Acres*	0	3,030	52,548	7,544	-183,509	7,968
	% of Total	0.0%	0.4%	6.7%	1.0%	-23.5%	1.0%
		Open Water	**Emergent Herbaceous Wetlands**	**Woody Wetlands**	**Row Crops**	**Low Intensity Residential**	**High Intensity Residential**
Pre-Settlement	*Acres*	14,718	5,845	459,903	-	-	-
	% of Total	1.9%	0.7%	59.0%	0.0%	0.0%	0.0%
Current	*Acres*	18,173	6,897	83,001	443,619	27,937	12,975
	% of Total	2.3%	0.9%	10.7%	56.9%	3.6%	1.7%
Change	*Acres*	3,455	1,052	-376,902	443,619	27,937	12,975
	% of Total	0.4%	0.1%	-48.4%	56.9%	3.6%	1.7%

(white)	< 1.0 % change
(yellow)	1.0 % to 5.0 % change
(orange)	> 5.0 % change

To summarize, current planning and natural resource management efforts in the watershed are focused primarily on ways to manage and curb urban development and improve water quality. Even though impacts of urban development can be significant, Table 3.1-2 clearly shows that the most significant land use/land cover change to the watershed has been the conversion of woody wetlands and forests into agricultural lands.

Watershed Level Assessment

Stream Power Tool:

Differences in stream power can be presented in two ways: (For a full discussion of the tool see section 2.1.1 of this report.)

1) Using land cover from presettlement and recent time periods (and, in this case, a modeled future time period), changes in stream power can be calculated and compared using a percent power change calculation, i.e.

$$\textbf{Percent Power Change} = \frac{\textbf{Recent (and/or Future) Stream Power – Presettlement Stream Power}}{\textbf{Presettlement Stream Power}}$$

Figure 3.1-5 illustrates percent power change from presettlement to current conditions (IFMAP) and presettlement to modeled future conditions (MI LTM 2040) for the gaged subwatersheds and other selected subwatersheds in the Shiawassee River Watershed. This analysis suggests that patterns of landcover change have led to increased stream power in many reaches of the Shiawassee River watershed. The percent change in stream power increased in all gaged watersheds from approximately 62 to slightly over 91 percent from presettlement to current conditions. A similar pattern is also expected based on the Michigan Land Transformation Model (Pijanowski et al., 1996, Pijanowski et al., 2000) although the potential increases as a result of changes in landcover are not as pronounced as changes that have already occurred (Figure 3.1-5). Estimated landcover alteration based on this scenario would lead to further increases of 55 to 77% in modeled stream power.

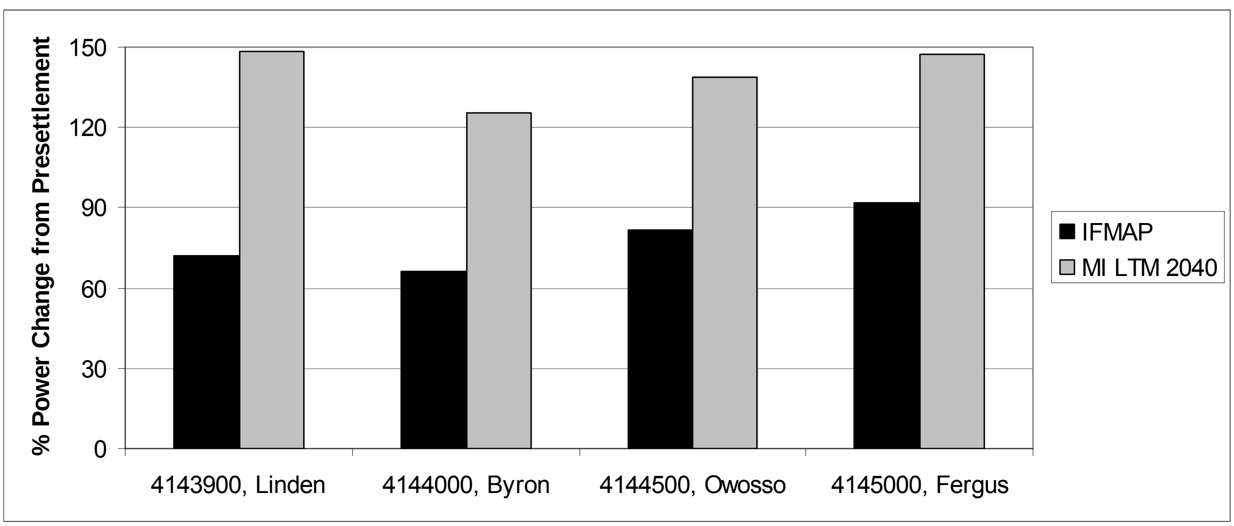

Figure 3.1-5 Percent Power Change from Presettlement in Gaged Subwatersheds in the Shiawassee River Watershed Under Current Land Cover (IFMAP) and Future Land Cover (Mi LTM 2040) Scenarios.

2) Calculating the maximum stream power change possible for each stream reach and compare the actual change (from presettlement conditions) to the maximum possible change (under hypothetical conditions). This power change metric provides a quantitative way to estimate hydrologic degradation (or improvement) relative to maximum possible degradation.

$$\textbf{Power Change Metric} = \frac{\textbf{Recent Stream Power – Presettlement Stream Power}}{\textbf{Paved Paradise Power – Presettlement Power}}$$

Figure 3.1-6 illustrates the power change metric for the one gaged subwatersheds in the Paw Shiawassee Watershed. This analysis suggests that patterns of landcover change have led to moderate power change metric values in many reaches of the Shiawassee River watershed. The power change metric ranged from approximately 8 to 13. A similar pattern is also expected based on the Michigan Land Transformation Model although the potential increases as a result of changes in landcover are not as pronounced as changes that have already occurred but are significant (Figure 3.3-6). Estimated landcover alteration based on this scenario would lead to further power metric increases of 8 to 10 units – bringing the total metric value of this modeled scenario from 16 to 21.

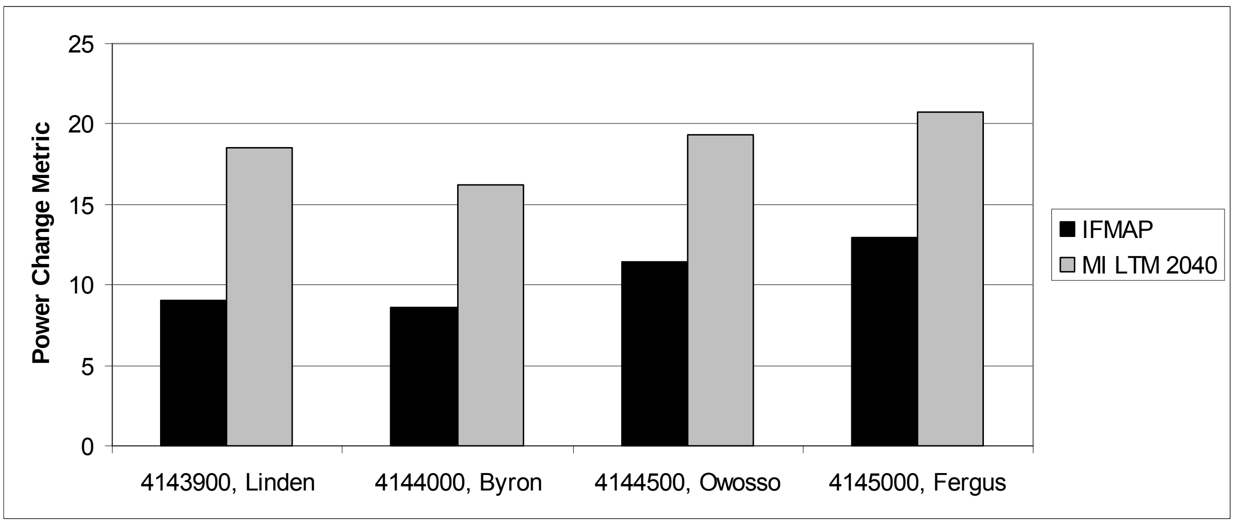

Figure 3.1-6 Power Change Metric in Gaged Subwatersheds in the Shiawassee River Watershed Under Current Land Cover (IFMAP) and Future Land Cover (Mi LTM 2040) Scenarios.

For the gage catchments in the Shiawassee watershed, values for the power change metric range from 8 to 13 and increase in a downstream direction (Linden to Fergus). Another way of stating this result is that, depending on the reach, stream power has increased between 8 to 13% of the maximum potential increase possible. Locally, where there are significant changes in land use/land cover the stream power metric may be considerably higher (Figure 3.1-7).

The effects of land use/land cover change on stream power are additive downstream through the system. In the Shiawassee watershed, headwater streams are in generally good condition and stream power alterations in the upper reaches of the Shiawassee River are relatively small. However, as one moves downstream, the cumulative effect of degraded tributary flows gradually increases the power change metric with increasing downstream distance (Figure 3.1-7).

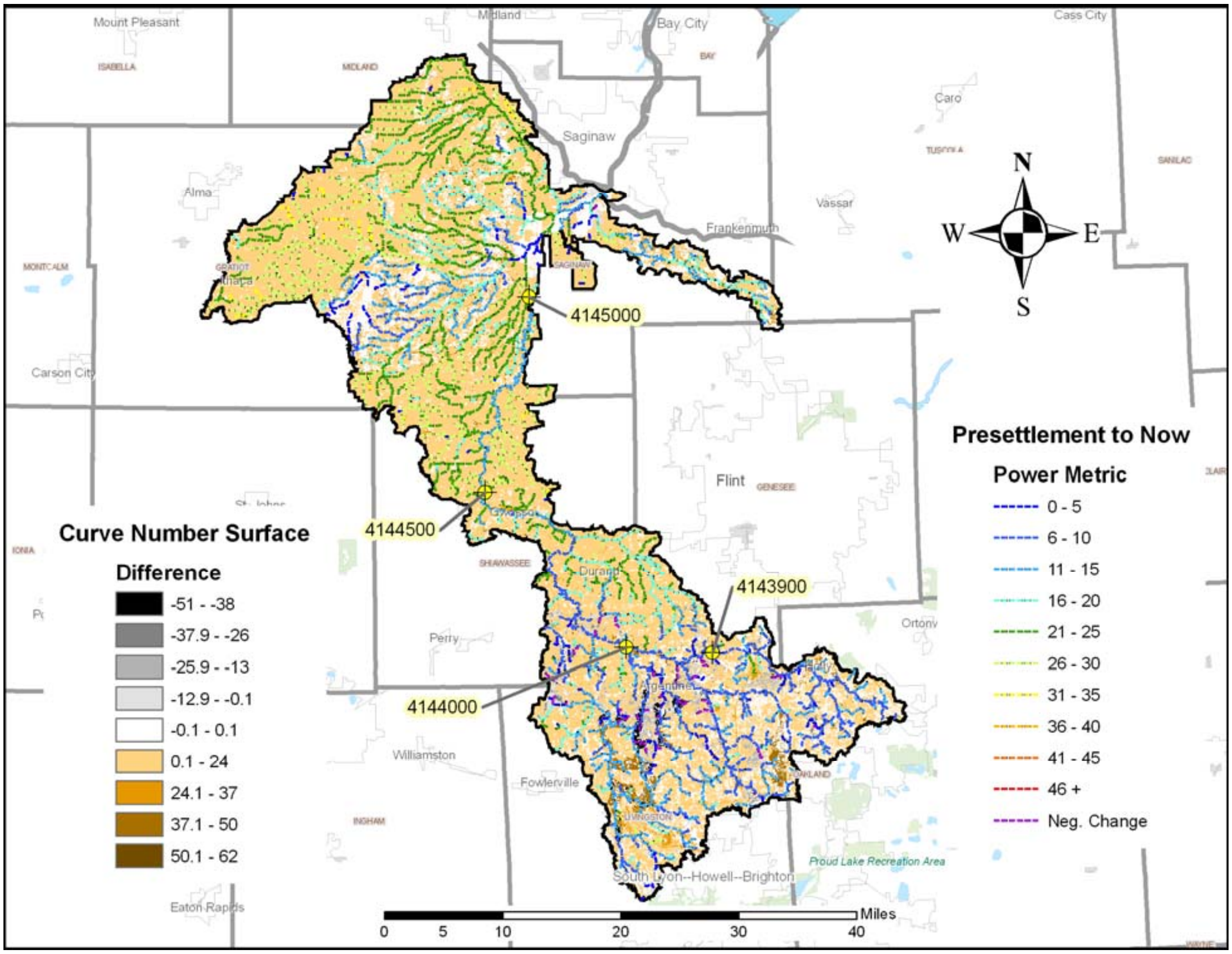

Figure 3.1-7 Stream power change metric map showing how stream power has changed in the Shiawassee watershed since presettlement. The CN change surface describes potential hydrologic alteration due to land use/land cover change across the landscape surface at a 30 m pixel resolution.

The stream power change metric is a measure that reflects the volume and rate at which water is conveyed across the landscape. Comparison of the power change metric with present-day land use/land cover shows a strong correlation between high power change metric values and agricultural land use. This is not surprising as agriculture is typically associated with highly efficient drainage systems designed to move water off the landscape as quickly as possible (Figure 3.1-8).

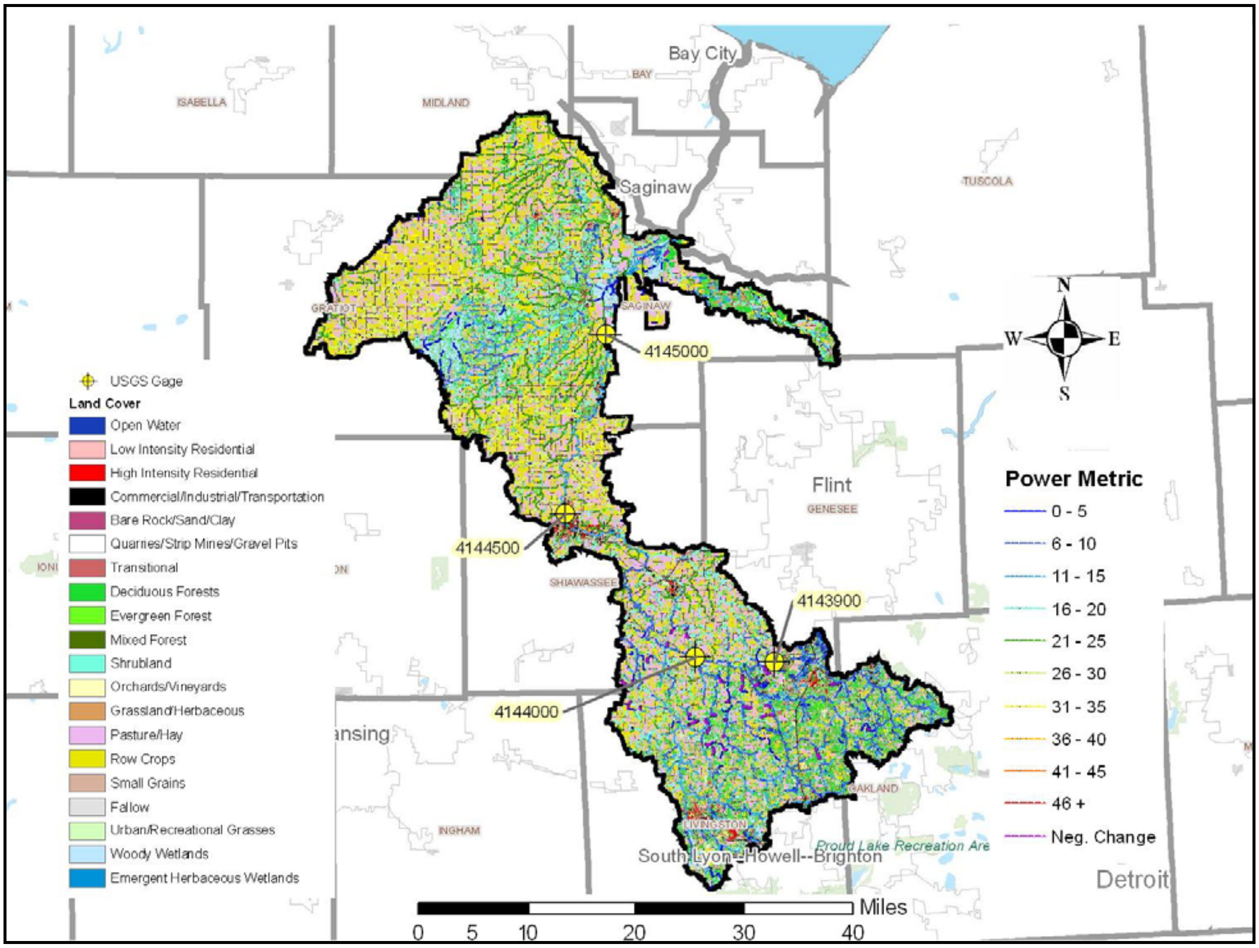

Figure 3.1-8 Stream power change metric map showing how stream power is related to present day land use/land cover in the Shiawassee watershed. Areas that have been converted to primarily agricultural land use are typically associated with higher stream power change values.

Conversely, landscape features that retain and store water on the landscape (not necessarily lakes and ponds) will typically be associated with low power change metrics similar to natural presettlement conditions. Figure 3.1-9 shows the relationship between the power change metric and present-day wetland water storage by catchment. There is a strong correlation between wetland water storage and low power change metric values. Table 3.1-3 summarizes changes in wetland area and water retention/storage by USGS gage catchment for pre-settlement, current, and potentially restorable wetlands (PRWs) in the Shiawassee watershed. More than 50% of wetland water retention/storage capacity has been lost in the lower Shiawassee watershed between pre-settlement and current land use/land cover conditions.

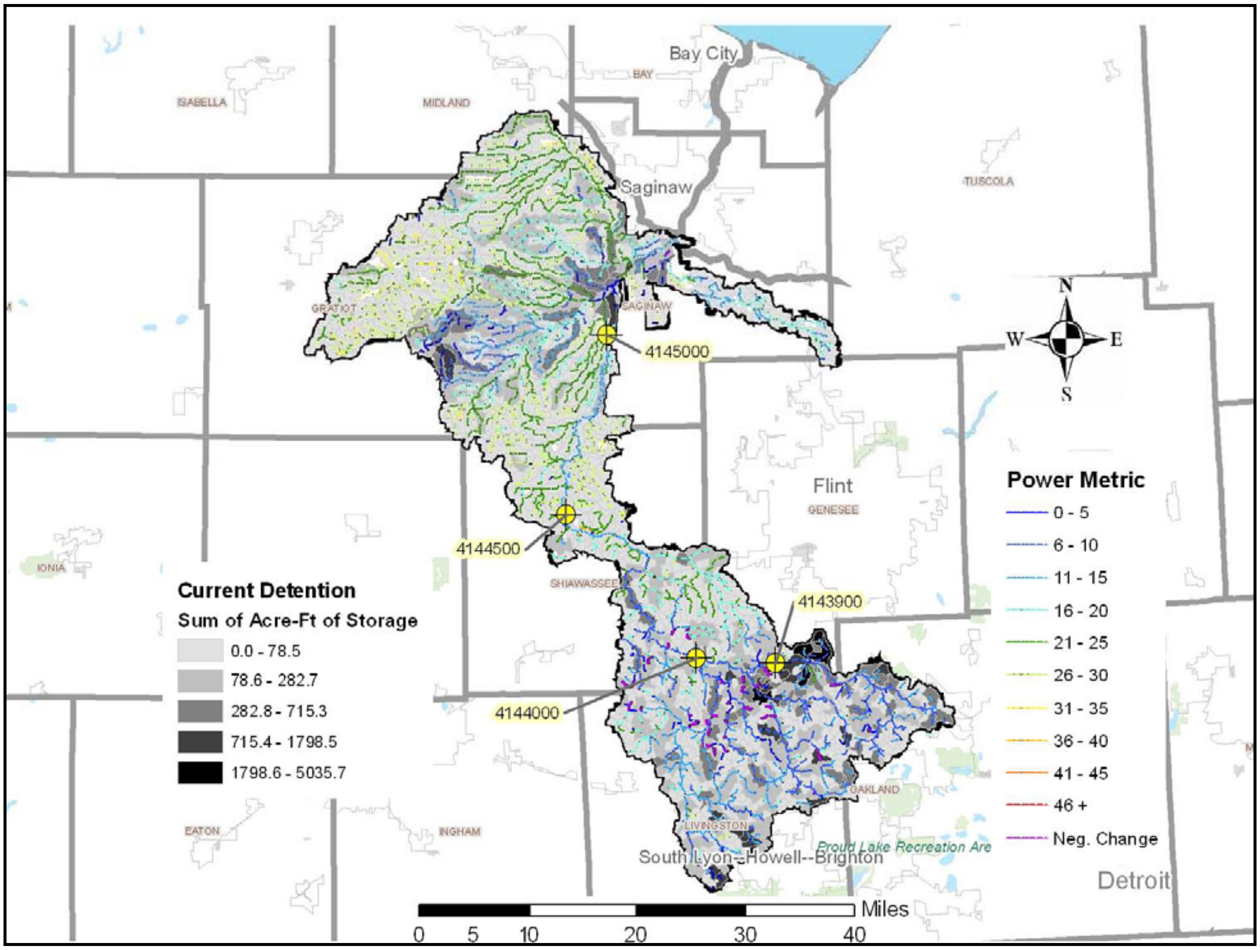

Figure 3.1-9 Map showing the relationship between the stream power change metrics and present-day wetland water storage by catchment. There is a high correlation between wetland water retention/storage (infiltration) and low power change metrics.

Table 3.1-3 Presettlement, Current and PRW Wetland Summary Statistics for the Shiawassee River Watershed.

Presettlement					
Gage	Wetlands (Acres)	Catchment % Wetland	% Acres Lost (of watershed total)	Total Retention (Acre-Ft)	% Retention Loss
4143900	14,914.75	29%	6%	3,281.24	20%
4144000	57,155.65	25%	6%	10,109.95	22%
4144500	85,976.89	26%	10%	14,688.40	39%
4145000	109,864.75	29%	14%	18,651.16	50%
Current					
	NWI (Acres)	Catchment % Wetland	Avg Retention (Ft)	Total Retention (Acre-Ft)	
4143900	11,841.20	23%	0.22	2,628.48	
4144000	44,116.40	19%	0.18	7,876.95	
4144500	52,572.73	16%	0.17	8,986.54	
4145000	54,896.71	14%	0.17	9,252.69	
PRWs					
	Wetlands (Acres)	Catchment % Wetland w All Restoration	Difference from Presettlement		
4143900	2,815.05	29%	-0.51%		
4144000	12,563.01	24%	-0.21%		
4144500	30,661.12	25%	-0.84%		
4145000	51,616.06	28%	-0.87%		

These maps clearly show areas where historic changes in land use/cover may have significantly altered the hydrology of the watershed. The stream power tool can also be used to predict the potential hydrologic impact of future land use/land cover changes. Figure 3.1-10 shows potential changes in the power change metric and the CN surface in response to anticipated future changes in land use/land cover based on a 30-year build out analysis for the Shiawassee watershed. In this example, present-day land use/land cover is the base case, and changes in stream power are being calculated on anticipated land use/land cover in 2040. Using this approach, “at risk” areas can be readily identified by potential increases in stream power and/or changes in the value of the CN surface. Areas at risk include the Livingston and Fenton areas in the southern (upstream) portion of the watershed and the Saginaw area in the northern (downstream) portion of the watershed.

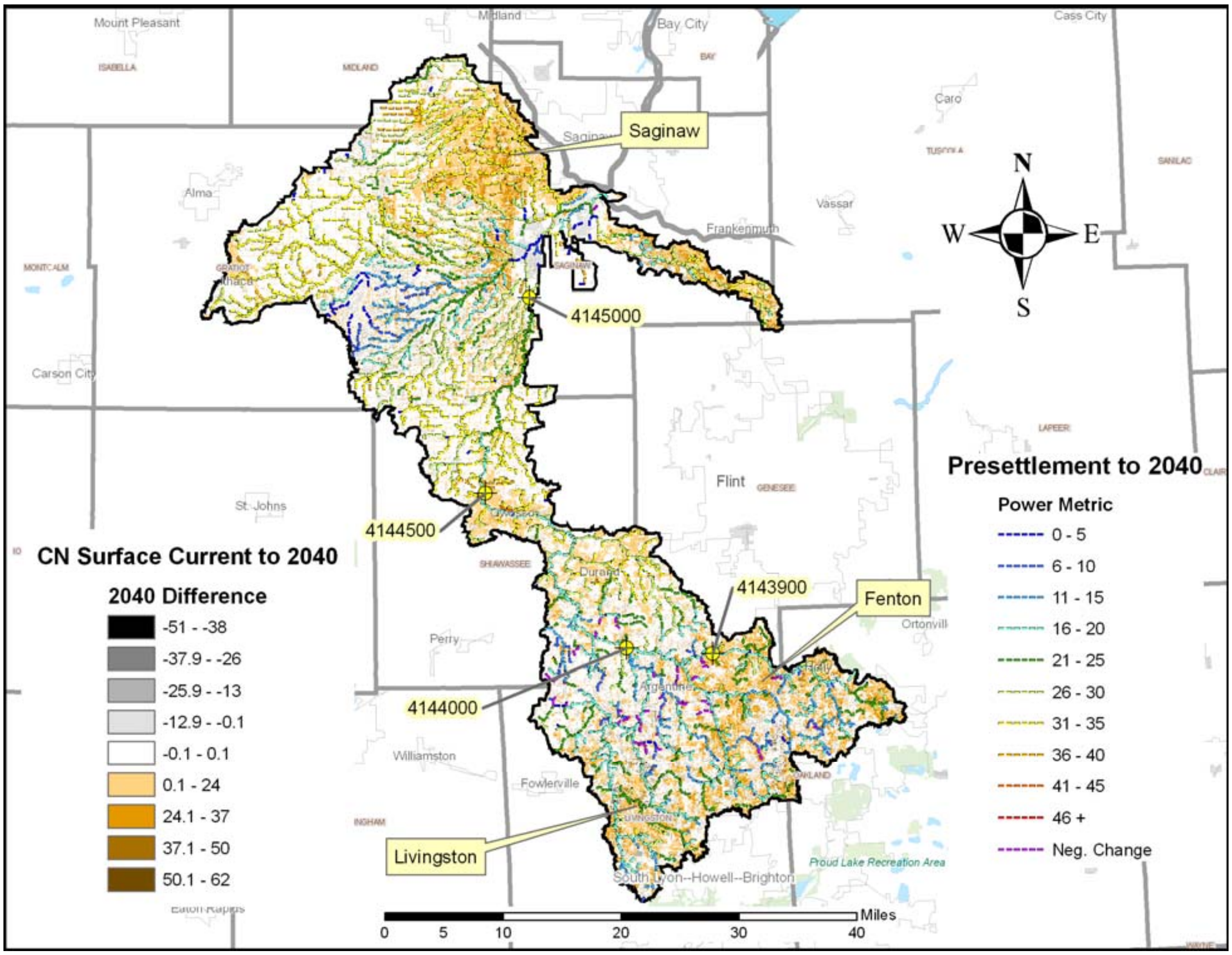

Figure 3.1-10 Map showing power change metric values and CN surface change (from current condition CN values) in response to anticipated future land use/land cover based on a 30-year build out analysis for the Shiawassee watershed (MI LTM). Areas at risk include the Livingston and Fenton areas in the southern (upstream) portion of the watershed and the Saginaw area in the northern (downstream) portion of the watershed.

Multi-Linear Regression Flow Duration Curves:

This analysis predicts that both high and low flow magnitudes have decreased in the Shiawassee River watershed from pre-settlement to now. It also shows that both high and low flow magnitudes decrease with increasing distance downstream.

Table 3.1-4 Results of Flow Duration Curve analyses for the Shiawassee watershed.

exceedence flows in cms	USGS				Relative Percent Change (Recent-Presettlement)/((Recent+Presettlement)/2)				Flow Direction	Summary of changes to high flow magnitude (Q10):	Summary of changes to low flow magnitude (Q90):
Site	Gage	Q5	Q10	Q25	Q50	Q75	Q90	Q95		High flows	Low flows
Shiawassee River (MI)	4143900 Linden	-0.05	-0.06	-0.07	-0.11	-0.20	-0.29	-0.35		decrease	decrease
Shiawassee River (MI)	4144000 Byron	-0.06	-0.07	-0.10	-0.17	-0.30	-0.43	-0.51		decrease	decrease
Shiawassee River (MI)	4144500 Owosso	-0.08	-0.09	-0.12	-0.22	-0.39	-0.55	-0.65		decrease	decrease
Shiawassee River (MI)	4145000 Fergus	-0.09	-0.10	-0.14	-0.26	-0.44	-0.62	-0.73		decrease	decrease

Flow Path Analyses: The potential effects of flow path changes on the Shiawassee watershed were evaluated by considering regional flow patterns resulting from water withdrawal, flow diversion, return flow, and the type or source and receiving waters. In the Shiawassee watershed, groundwater is the primary source of water for anthropogenic use. Surface waters are used for irrigation purposes only and represent less than 10% of the total volume of water used in the watershed. Factors considered in the pathways analysis for the Shiawassee watershed include:

Source Waters and Diverted Flows – Groundwater withdrawals occur from both shallow and deep aquifers. For the purpose of this project, shallow groundwater sources are defined by producing depths generally less than 60 feet with a reasonable expectation that local surface-groundwater interaction may occur. Deep groundwater sources are defined by producing depths greater than 60 feet with a reasonable expectation that local surface-groundwater interaction will not occur.

In the Shiawassee watershed there are more than 15538 producing water wells, of which 545 are publicly owned and operated. These public wells provide water to local communities where groundwater is collected, treated, stored, and then distributed through a public water supply system. There are more than 14,400 private household wells (self supply) where groundwater is withdrawn on an “as needed” basis (Michigan CGI 2006, Michigan State University 2006). Groundwater wells are summarized below by type, producing depth, flow yield, and potential for flow path diversion (Table 3.1-5).

Table 3.1-5 Summary of Groundwater Wells for Shiawassee County (Michigan CGI 2006)

		Producing Depth		Average Yield (gpm)		
Well Type	**No. Wells**	**< 60 feet**	**> 60 feet**	**< 60 feet**	**> 60 feet**	**n/a**
Houshld	14435	3497	7515	105.9	339.3	3424
Public Type I	133	9	39	406.3	1746.5	85
Public Type II	337	27	127	75.6	560.7	183
Public Type III	75	18	40	94.5	365.0	17
Irrigation	112	22	62	95.5	716.3	28
Industrial	11	2	4	58.9	256.3	5

(green)	Low Flow Diversion Potential
(orange)	High Flow Diversion Potential
(cyan)	Average Maximum Yield (gpm)

In the Shiawassee watershed, water is withdrawn from deeper aquifers in the southeastern and north central portions of the watershed and shallower aquifers in the central portion of the watershed (Figure 3.1-11). The potential for flow path diversion (flow augmentation) is highest where deep groundwater is diverted and returned to surface waters.

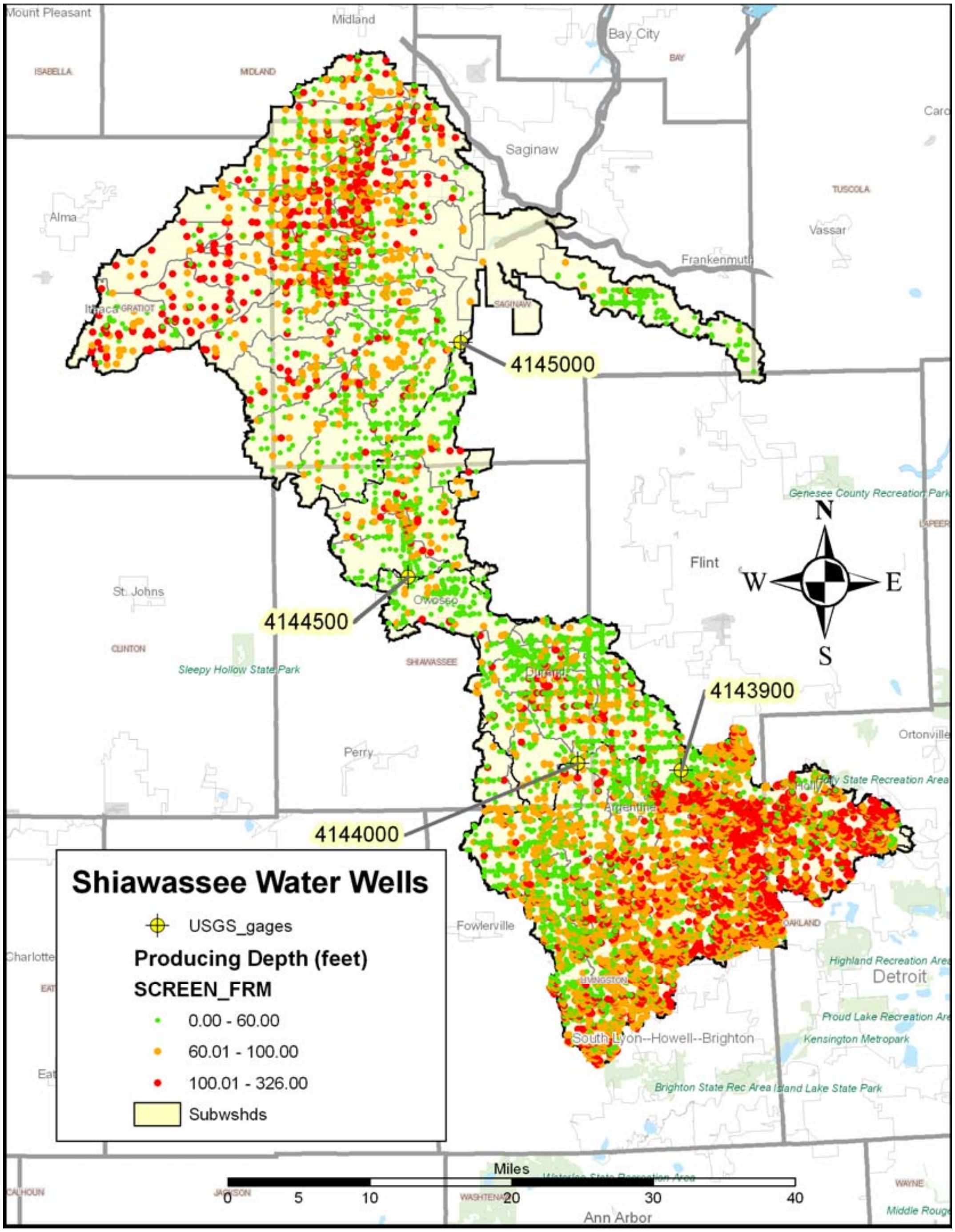

Figure 3.1-11 Spatial distribution of shallow and deep groundwater wells in the Shiawassee watershed. Water is produced from deeper aquifers (orange and red symbols) in the southeastern and north central portions of the watershed. Water is produced from shallower aquifers (green symbols) in the central portion of the watershed. Deep groundwater that is diverted and returned to surface waters is considered to be a major flow path diversion.

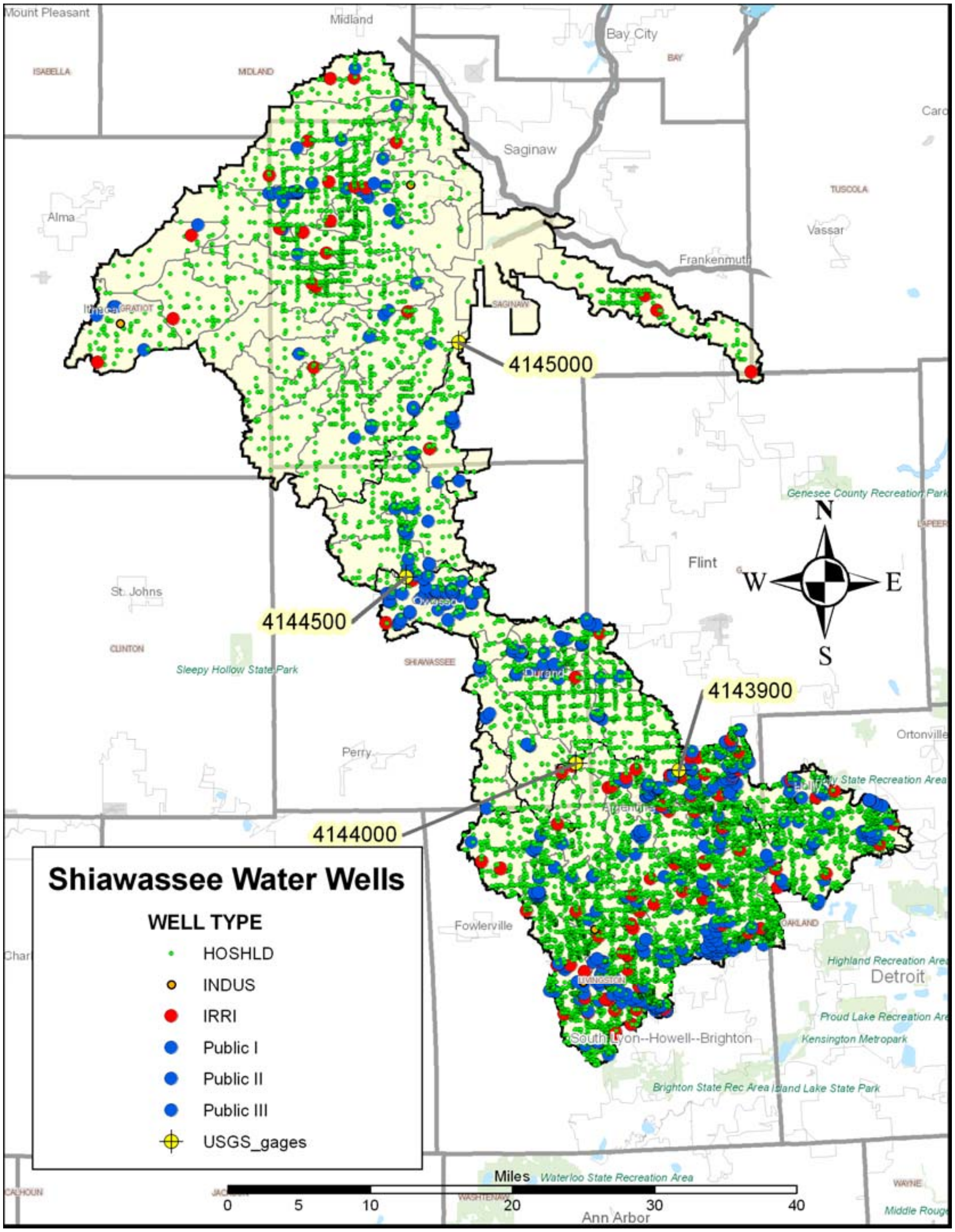

Figure 3.1-12 Spatial distribution of public and self-supply groundwater wells in the Shiawassee watershed. High capacity public water supply wells (blue dots) supply water to local communities. These waters are then collected, treated, and returned via a wastewater treatment plant to the Shiawassee River and/or one of its tributaries, thereby augmenting surface water flows in the Shiawassee River. Deep groundwater diverted and returned to surface waters is considered to be a major flow path diversion.

Unfortunately, water withdrawals from private household wells are typically not reported. Estimates of per capita household water use ranges from 60 to more than 80 gpd in the Great Lakes region (Great Lakes Commission 2001). Using an estimated average water use of ~230 gpd per household, it is possible to estimate the volume of groundwater withdrawn for private (self supply) use. Combining this information with annual reporting data for public water supplies and irrigation, it is possible to estimate total groundwater withdrawals by well type and producing depth for the Shiawassee watershed (Tables 3.1-6 and 3.1-7).

Table 3.1-6 Estimated Groundwater Withdrawals by Well Type and Producing Depth for the Shiawassee watershed.

		Producing Depth (# Wells)			GW Withdrawl (Mgd)			
Well Type	No. Wells	< 60 feet	> 60 feet	n/a	< 60 feet	> 60 feet	n/a	Total
Houshld	14435	3497	7515	3424	0.80	1.73	0.79	3.32
Irrigation	112	22	62	28	0.39	1.11	0.50	2.00
Public Supply	545	54	206	285	0.95	3.62	5.00	9.57
				Totals:	2.15	6.45	6.29	14.89

(green)	Low Flow Diversion Potential
(orange)	High Flow Diversion Potential

Table 3.1-7 Reported Public Water Supply and Irrigation Withdrawals for Years 1997 – 2004 for the Shiawassee watershed (Michigan DEQ 1997-2004)

Public Water Supply

Year	Lake (Mgd)	SW (Mgd)	GW (Mgd)	Total (Mgd)	Lake	SW	GW
1997	0.00	0.00	8.27	8.27	0.0%	0.0%	100.0%
1998	0.00	0.00	8.85	8.85	0.0%	0.0%	100.0%
1999	0.00	0.00	9.02	9.02	0.0%	0.0%	100.0%
2000	0.00	0.00	9.61	9.61	0.0%	0.0%	100.0%
2001	0.00	0.00	9.57	9.57	0.0%	0.0%	100.0%
2002	0.00	0.00	11.14	11.14	0.0%	0.0%	100.0%
2003	0.00	0.00	11.06	11.06	0.0%	0.0%	100.0%
2004	0.00	0.00	9.07	9.07	0.0%	0.0%	100.0%
Mean:	0.00	0.00	9.57	9.57			

Irrigation

Year	Lake (Mgd)	SW (Mgd)	GW (Mgd)	Total (Mgd)	Lake	SW	GW
1997	0.00	0.95	1.02	1.97	0.0%	48.2%	51.8%
1998	0.00	2.35	1.64	3.99	0.0%	58.9%	41.1%
1999	0.00	1.13	1.41	2.54	0.0%	44.5%	55.5%
2000	0.00	0.89	1.18	2.07	0.0%	43.0%	57.0%
2001	0.00	1.18	1.67	2.85	0.0%	41.4%	58.6%
2002	0.00	2.89	3.44	6.33	0.0%	45.7%	54.3%
2003	0.00	2.7	3.05	5.75	0.0%	47.0%	53.0%
2004	0.00	2.33	2.55	4.88	0.0%	47.7%	52.3%
Mean:	0.00	1.80	2.00	3.80			

Based on these data, 13.30 Mgd of the groundwater used for water supply purposes and 1.8 Mgd of the surface water used for irrigation purposes in the Shiawassee watershed are redirected along altered flow paths where water is returned either to a different hydrologic regime or to a location that is distinctly different (catchment or subwatershed) from where the groundwater originated. In summary, the groundwater Diversion Ratio (D_{GW}) for the Shiawassee watershed (V_{DIVg}/V_{GW}) is 0.76 or 76%. The surface water Diversion Ratio (D_{SW}) is 1.0 or 100%. The Diversion Ratio (D) for all water withdrawals in the Shiawassee watershed is 0.79 or 79%.

Return Flows and Receiving Waters – In larger communities and in areas with public (or private) sewerage, wastewater is collected, treated, and then returned to surface waters of the Shiawassee watershed – primarily the Shiawassee River or its tributaries (Table 3.1-8). In private systems (primarily households), wastewater is processed in a septic system and returned to shallow aquifers, generally less than 15 feet below the surface. Since groundwater is the primary source of water for consumptive use in the Shiawassee watershed, waters collected by public wastewater treatment plants will be diverted from a groundwater source and returned to a surface water source (the Shiawassee River). This represents a major flow path diversion where waters are being removed from one type of hydrologic regime (groundwater) and added to another hydrologic regime (surface water).

Table 3.1-8 Public Wastewater Treatment Plant Capacities for the Shiawassee Watershed (U.S. EPA 1996)

Facility	City	County	Existing flow (Mgd)	Max Flow (Mgd)
Linden WWTP	Linden	Genesee	4.500	11.000
Ithaca WWSL	Ithaca	Gratiot	0.339	0.389
Brighton STP	Brighton	Livingston	0.679	1.519
Howell STP	Howell	Livingston	1.800	2.450
Holly STP	Holly	Oakland	0.873	1.159
Byron WWTF	Byron	Shiawassee	0.039	0.039
Durand WWTF	Durand	Shiawassee	0.619	1.119
Owosso WWTP	Owosso	Shiawassee	4.059	6.000
Chesaning STP	Chesaning	Saginaw	0.579	0.579
Merrill STP	Merrill	Saginaw	0.099	0.139
Richland Township STP	Richland	Saginaw	0.169	0.179
St. Charles STP	St. Charles	Saginaw	0.189	0.239
		Total:	13.944	

(Shaded rows:) Major wastewater treatment plants

Comparing tables 3.1-7 and 3.1-8, average public water supply groundwater withdrawals total 9.57 Mgd and approximately 13.94 Mgd of wastewater are treated and returned to the Shiawassee watershed. The difference may, in part, be due to stormwater that is collected by storm sewers and treated by wastewater treatment plants and/or waters diverted into the watershed from water sources outside of the Shiawassee watershed. These waters are diverted along altered flow paths as well.

The location of facilities with active NPDES wastewater discharge permits is shown in Figure 3.1-13. Significant discharges of wastewater occur at the Linden, Owosso, and Howell WWTPs. The Linden plant was recently upgraded to 11.0 Mgd capacity as it now receives wastewater from the Hartland, Tyrone, and the Fenton areas. Virtually all groundwater withdrawn for public use in the southeastern portion of the Shiawassee watershed is treated by the Holly and Linden WWTPs. The Linden WWTP discharges 4.5 Mgd of wastewater into the Shiawassee River just below the USGS gage site at Linden. The Owosso WWTP collects wastewater from Owosso, Corunna, and surrounding communities and discharges more than 4.0 Mgd into the Shiawassee River. Groundwater withdrawn for public use in the southern portion of the Shiawassee watershed is treated by Howell STP and discharged into Bogue Creek and the South Branch of the Shiawassee River. In all cases, these discharges result augmented flows in the Shiawassee River (Figures 3.1-14a,b). Table 3.1-9 lists annualized diverted flow volumes (return flow - wastewater) for each of the USGS gage catchments.

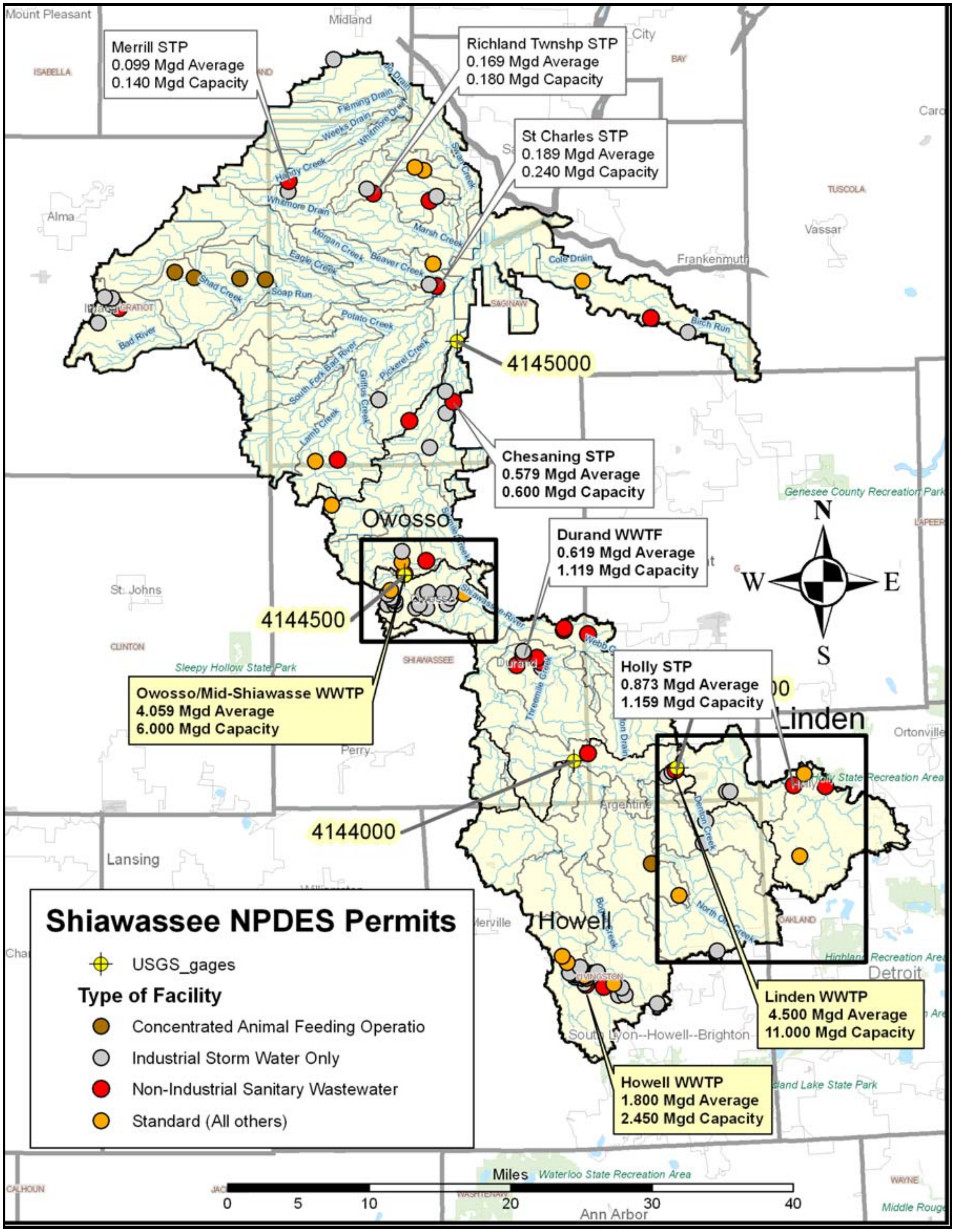

Figure 3.1-13 Location of wastewater discharges in the Shiawassee watershed. The Linden, Howell, and Owosso WWTPs discharge significant quantities of wastewater into the Shiawassee River. All of these waters are diverted along altered flow paths and result in base flow augmentation of the Shiawassee River. Rectangles identify areas where more detailed flow path data are available (see Figures 3.1-14a,b).

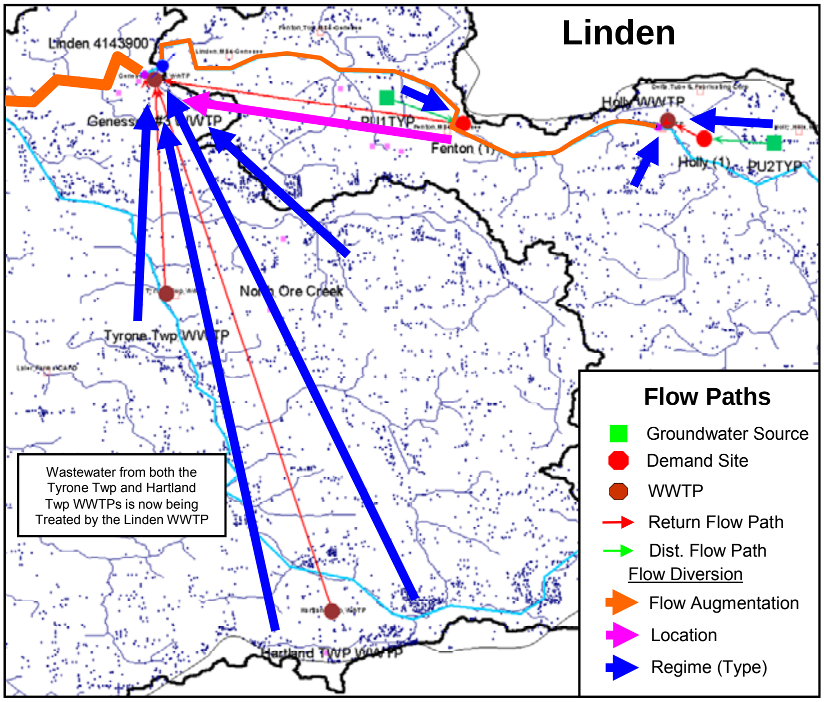

Figure 3.1-14a Groundwater is withdrawn, diverted, and returned to the Shiawassee River at the Holly and Linden WWTP. The Linden WWTP returns ~4.5 Mgd (6.94 cfs) of wastewater to the Shiawassee River.

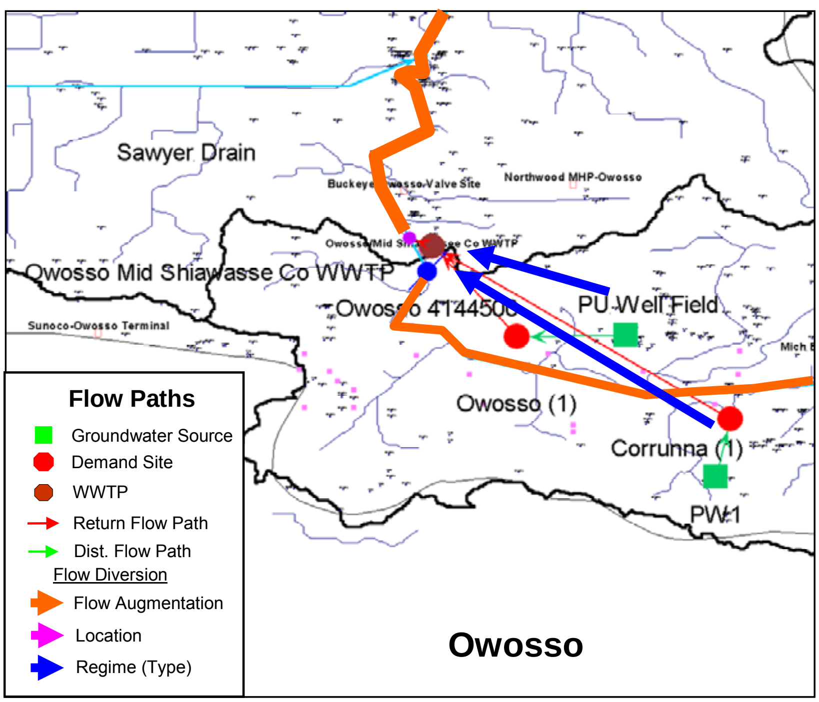

Figure 3.1-14b Groundwater is withdrawn, diverted and returned to Shiawassee River at the Owosso WWTP. The Owosso WWTP collects, treats, and returns ~ 4.0 Mgd (6.17 cfs) to the Shiawassee River.

Table 3.1-9 Annualized Diverted Flow Volumes (Return Flow - Wastewater) in the Shiawassee Watershed by USGS Gage Catchment

Facility	City	County	Annualized Flow (Mgd)	Annualized Flow (cfs)	USGS Gage Catchment	Mean Annual Discharge (cfs)*	Diverted Flow Volumes (%)	Cumulative Diverted Flow Volumes (%)
Holly STP	Holly	Oakland	0.873	1.35	**Linden**	60.26	2.24%	
						Total:	**2.24%**	**2.24%**
Linden WWTP	Linden	Genesee	4.500	6.94	**Byron**	272.32	2.55%	
Brighton STP	Brighton	Livingston	0.679	1.05	"	"	0.38%	
Howell STP	Howell	Livingston	1.800	2.78	"	"	1.02%	
Byron WWTF	Byron	Shiawassee	0.039	0.06	"	"	0.02%	
						Total:	**3.98%**	**4.47%**
Durand WWTF	Durand	Shiawassee	0.619	0.96	**Owosso**	388.81	0.25%	
Owosso WWTP	Owosso	Shiawassee	4.059	6.26	"	"	1.61%	
						Total:	**1.86%**	**4.99%**
Chesaning STP	Chesaning	Saginaw	0.579	0.89	**Fergus**	415.05	0.22%	
						Total:	**0.22%**	**4.89%**
Merrill STP	Merrill	Saginaw	0.099	0.15	**n/a**	n/a	n/a	n/a
Richland Township STP	Richland	Saginaw	0.169	0.26	**n/a**	n/a	n/a	n/a
St. Charles STP	St. Charles	Saginaw	0.189	0.29	**n/a**	n/a	n/a	n/a
		Total:	13.605	21.52				

*Mean Annual Discharge for common water years 1963 - 1983

Flow Diversions greater than 1 %

In summary, the groundwater Diversion Ratio (D_{GW}) for the Shiawassee watershed (V_{DIVg}/V_{GW}) is 0.76 or 76%. The surface water Diversion Ratio (D_{SW}) is 1.0 or 100%. The Diversion Ratio (D) for all water withdrawals in the Shiawassee watershed is 0.79 or 79%.

The Pathway Alteration Metric (PAM) for receiving waters is the volume of diverted water that travels along altered flow paths relative to the total volume of the receiving waters.

$$PAM = (V_{DIVg} + V_{DIVs}) / V_{receiving\ waters}$$

For the Shiawassee watershed, the receiving water Pathway Alteration Metric is 0.0724 or 7.24 % (Table 3.1-10). This value is probably low, as data are not available to assess potential flow path diversions due to agricultural drainage tile and other modifications that alter flow paths on the landscape.

Table 3.1-10 Estimated Diverted Flow Path Volumes (Total) and Pathway Alteration Metric for the Shiawassee Watershed

Flow Path Diversion Volumes	GW (cfs)	SW (cfs)	Total (cfs)	PAM
Private Household	2.67	0.00	2.67	0.0064
Irrigation	3.09	2.78	5.86	0.0141
Public Supply	15.05	0.00	15.05	0.0363
Wastewater (wastewater – public supply)	6.47	0.00	6.47	0.0156
Stormwater	n/a	n/a	n/a	n/a
	27.27	**2.78**	**30.05**	**0.0724**

Based on sensitivity analyses of the instream hydrologic assessment tools, it is not likely that changes in hydrology due to flow path diversion will be detected by instream tools, especially if withdrawal or return flow volumes are relatively low when compared to total flow volumes. However, flow path diversions could be locally important, especially in stream reaches that are in close proximity to (and downstream from) outfalls.

Dams and Channelization: In-stream modifications can greatly affect the fundamental characteristics of flow. Landscape tools do not consider these modifications, and the in-stream tools do not explicitly consider them in their analyses of gage records. There are two types of instream modifications that were quantified: 1) dams and impoundments and 2) channelization and/or channel straightening.

Dams and impoundments store and retain water and can therefore affect flow regime. The impact on flow regime will be a function of the size of the impoundment relative to the size of the river, and whether or not outflows from the impoundment are controlled or regulated. Other hydrologic impacts can include changes in channel morphology and channel slope (both upstream and downstream), change in sediment load, and altered time-dependent flows in cases where water is stored and released for flood control and/or power generation.

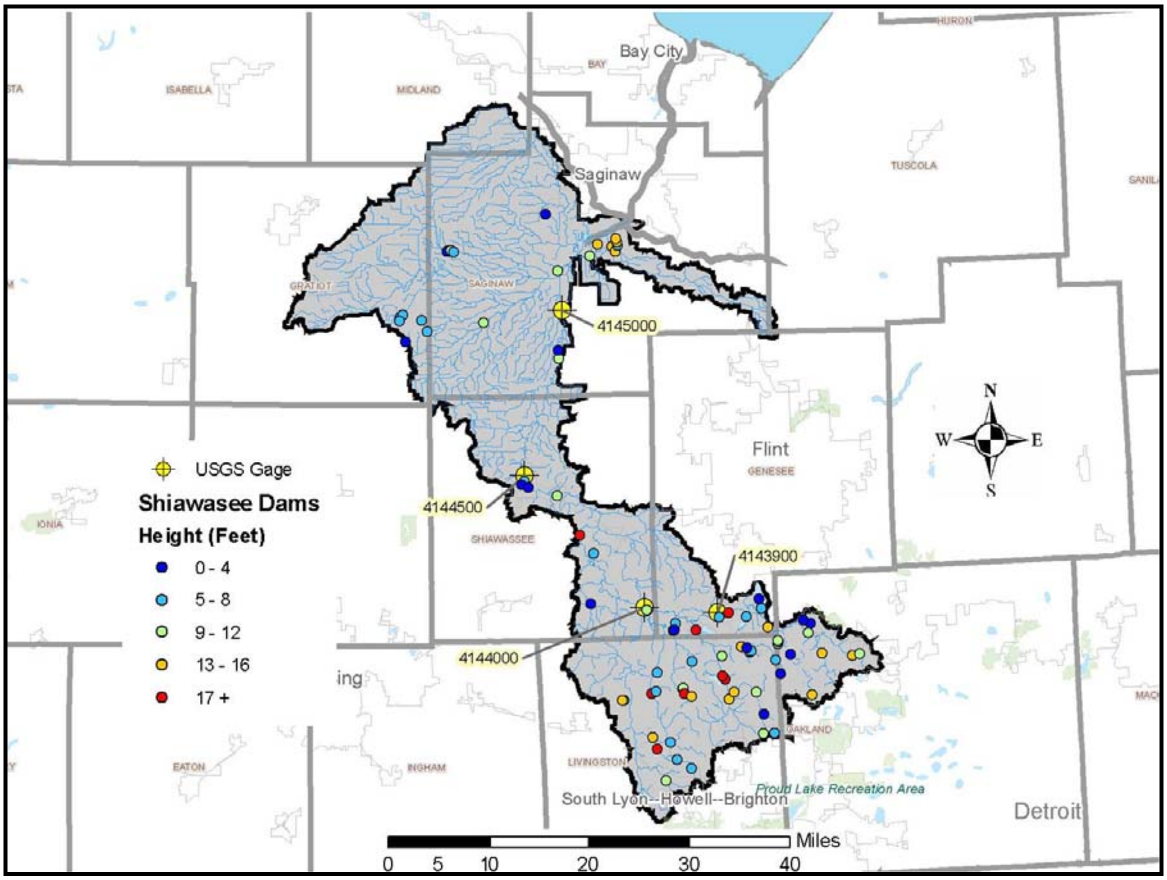

Figure 3.1-15 Location of dams in the Shiawassee watershed. Most of the dams are located in the southern portion of the watershed.

There are 85 dams total listed in the 2003 Michigan DEQ dams database within the Shiawassee watershed. More than 60% of those dams are located in the southern portion of the watershed, where topography (narrow stream valleys and floodplains) facilitate the creation of small ponds, lakes, and reservoirs (Figure 3.1-15 Dam heights range from 3 to 22 feet (Figure 3.1-16). At maximum capacity, these dams have the potential to impound more than 8500 acres of surface water retaining more than 62,325 acre-feet (76,876,756 cubic meters) of water in the watershed. However, none of the dams are currently being used for power production. Even though more than half of the dams have water control/release structures, virtually all of the dams in the Shiawassee watershed can be considered to be free flowing "run-of-the-river" dams where flows are not regulated. Even though there are certainly significant water quality, thermal, and ecological impacts associated with these dams, the hydrological impact of these dams on flow regime may only be measurable at a catchment level, but not at subwatershed or watershed scales.

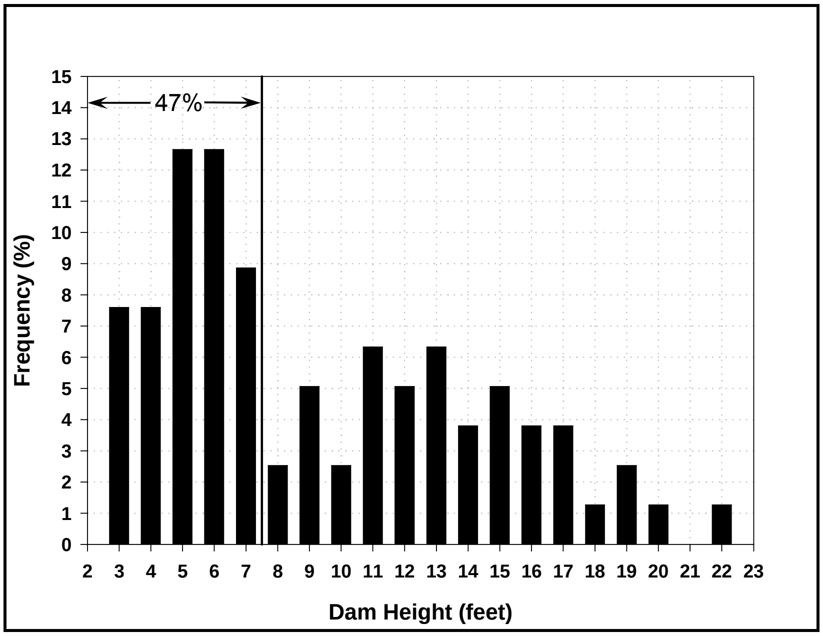

Figure 3.1-16 Dam height frequency plot for Shiawassee watershed dams. 47% of dams in the Shiawassee watershed are 7 feet high or less.

Table 3.1-11 summarizes uses and ownership of dams in the Shiawassee watershed. More than half of the dams are publicly owned by Federal, State, or Local entities. Dominant use of these impoundments is for recreation. Only one impoundment is used for water supply purposes and that is for private commercial use.

Table 3.1-11 Summary of Dams in the Shiawassee Watershed

Use	Dams (total #)	Ownership	Dams (total #)
Recreation	48	Public	34
Recreation/Other	4	Federal	*6*
Retired Hydro	4	State	*10*
Water Supply	1	Local	*18*
Other	16	Private	51
No Data	12	Total	85

Channelization and channel straightening modifies the natural stream channel to more efficiently convey water off the landscape into the drainage network. These modifications have the potential to significantly alter flow regimes in surface waters and directly affect groundwater recharge in a watershed. Loss of in-stream habitat, increased sediment load, and degraded water quality typically result from in-stream modifications. In the Shiawassee watershed, conversion of forests and woody wetlands to agriculture in areas with poorly-drained soils has led to significant hydromodifications to the landscape and the associated drainage network. Tiled fields and deeply incised agricultural drainage channels are common throughout the northern portion of the watershed.

Using existing stream reach classifications and newly developed geospatial algorithms that quantify the degree of channel straightening, more than 30% of the channels in the northern portion of the basin have been significantly modified either by widening and deepening and/or straightening of natural stream channels. Associated with these modifications is the installation field drain tiles that intercept shallow ground and surface waters and redirect these waters into adjacent agricultural drainage channels.

Table 3.1-12 illustrates how in-stream channelization varies by USGS stream gage drainage area in the Shiawassee watershed. The Linden and Byron gages are located in the southern (upstream) portion of the watershed, and the Owosso and Fergus gages are located in the central and northern (downstream) portions of the watershed. Table 3.1-12 also summarizes the relative density of dams and impoundments by drainage area.

Table 3.1-12 In-Stream Modifications summarized by USGS Gage Drainage Areas

Location Name	Dams (total #)	In-stream (% channelized)	Incremental Drainage Area	Acres/Dam
4143900 Linden	18	2.45%	53568	2976
4144000 Byron	30	13.16%	180032	6001
4144500 Owosso	8	28.41%	110720	13840
4145000 Fergus	2	36.75%	63360	31680
Ungaged Area	18	> 40% estimated	334820	18601

(green)	Natural channels with higher proportion of dams/impoundments
(yellow)	Modified channels with lower proportion of dams/impoundments

To summarize, there are a total of 85 dams and/or impoundments in the Shiawassee watershed, virtually all which can be considered to be free flowing “run-of-the-river” dams. Approximately 47% of these dams are 7 feet or less in height (low-head dams). More than 60% of the Shiawassee watershed dams are located in the southern (upstream) portion of the watershed, and more than half of these dams are publicly owned by Federal, State, or Local entities. These impoundments are used primarily for recreational purposes. Even though there are potentially significant water quality, thermal, and ecological impacts associated with these dams, they are free flowing “run of the river” dams that minimize impacts to hydrology. The hydrologic impacts of these dams can not be detected at subwatershed and watershed scales. In-stream channel modifications may have significant hydrologic impacts in the northern portion of the watershed, especially in agricultural areas where drainage efficiencies are maximized.

Assessment of Hydrologic Alterations

Indicators of Hydrologic Alteration:

Single period IHA analyses were run using the entire period of record for four gages in the Shiawassee watershed. The single period analysis is used to detect trends rather than to detect changes attributable to a specific event in time (two period analyses). Table 3.1-13 lists the metrics that were calculated by the IHA tool for the Shiawassee watershed. The project team selected metrics based on potential sensitivity, potential to indicate longer-term trends, and potential to detect altered flows. Results were normalized by watershed area so that comparisons between subwatersheds could be made.

Table 3.1-13 Selected IHA Metrics for the Shiawassee Watershed

Magnitude	Attribute
Ordinary monthly conditions	Monthly mean flows
Max and Min extremes	Annual 3 day min Annual 3 day max
Dry and wet season magnitudes	Annual 90 day min Annual 90 day max
Frequency of extreme low flow and flood events	# of extreme low flow events / yr # of 2-yr flood events / yr
Duration of extreme low flow and high flow pulses	# extreme low flow days per year # high flow days per year

Note: The extreme low flows were defined as 15% of all low flows. Only one flood was defined with return interval of at least 2 years. This eliminated the large flood suite of metrics.

Over the available period of record, results of the IHA analyses show that there is a slight increase in monthly flows in the late summer and fall months at three of the gages (Table 3.1-14). The magnitude of minimum (low) flows increases slightly at three of the gages. Low flow frequency decreased slightly at the downstream gages (Owosso and Fergus), and the high flow cumulative duration increased slightly at three of the gage sites.

Table 3.1-14 IHA Metrics vs. USGS Stream Gage (Upstream to Downstream)

Location	Magnitude					Frequency and Duration			
Gage ID	Monthly Mean Flows	Low Flows 3-day min	High Flows 3-day max	90-day Min	90-day Max	# Low Flows/yr	# 2-Yr Flood/yr	Low Flow Days	High Flow Days
4143900 Shiawassee@Linden	↑	↑	-	↑	-	-	-	-	↑
4144000 Shiawassee@Byron	-	-	-	-	-	-	-	-	-
4144500 Shiawassee@Owosso	↑	-	-	↑	-	↓	-	↓	↑
4145000 Shiawassee@Fergus	↑	↑	-	↑	-	↓	-	↓	↑

Note: The 4144000 Shiawassee @ Byron record ends in 1983 and given the relatively short time period that this site was active, the data show no trend in any metric.

A two period IHA analysis was also performed using data from the Owosso and Fergus gages which have the longest periods of record. The two period analysis yielded similar results to the one period analysis reported above.

To summarize, the degree and direction of change to the metrics (e.g., higher flow magnitudes, longer high flows, and fewer/shorter low flows) are consistent with generally increased precipitation in the watershed. With respect to anthropogenic hydromodifications, the IHA metrics used here do not appear to be sensitive to local changes in land use/land cover and/or in-stream channel modifications. This may be due to the limited period of record that is available (many of the land use/land cover changes occurred prior to the period of record).

Q-P Ratio: Regional climatic effects may mask the effects of land cover change and/or in-stream channel modifications on flow regime. The project team evaluated whether changes in precipitation could explain changes in monthly flow magnitude in the Shiawassee watershed. The team calculated a monthly Flow (Q) / Precipitation (P) ratio to normalize the effects of increased precipitation in order to more clearly isolate the impacts of land cover change and/or in-stream channel modifications on flow regimes. These analyses were performed using flow data from the Shiawassee River at Owosso - USGS gage 4144500 using data from 1931 to 1996.

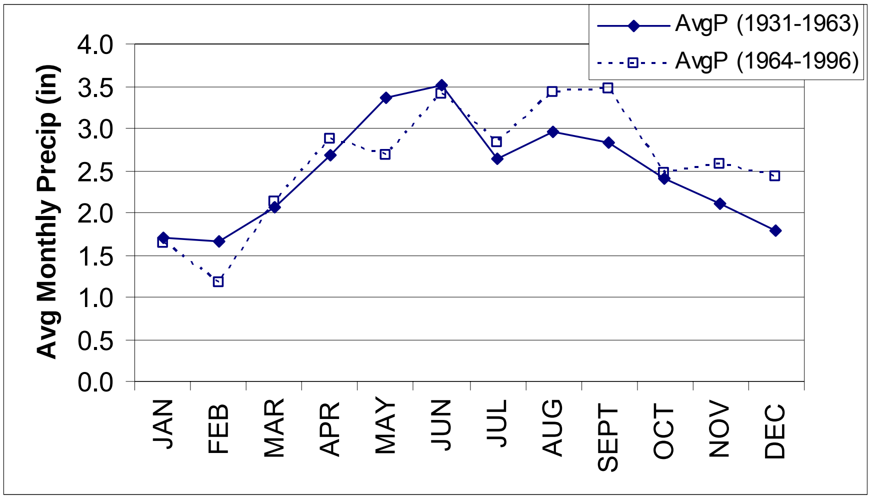

Figure 3.1-17 Two-period analysis of average monthly precipitation for the Shiawassee watershed.

Between 1931 and 1996, there has been a slight increase in average annual precipitation. A two-period analysis of average monthly precipitation shows that these increases occurred primarily in the late summer and extend through the fall (July through December) (Figure 3.1-17).

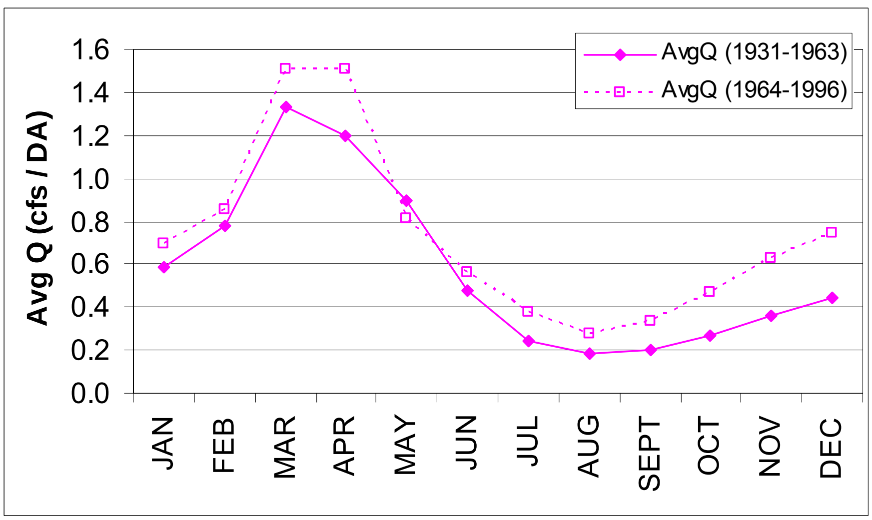

Figure 3.1-18 Two-period analysis of average monthly yield for the Shiawassee watershed.

A two-period analysis of yield (Q) - the volume of water flowing off the landscape - shows increases in all months (except for the month of May) in the Shiawassee watershed. The average annual Q for the 1931 to 1963 period is 0.58 and the average annual Q for the 1964 to 1996 period is 0.73 (Figure 3.1-18)

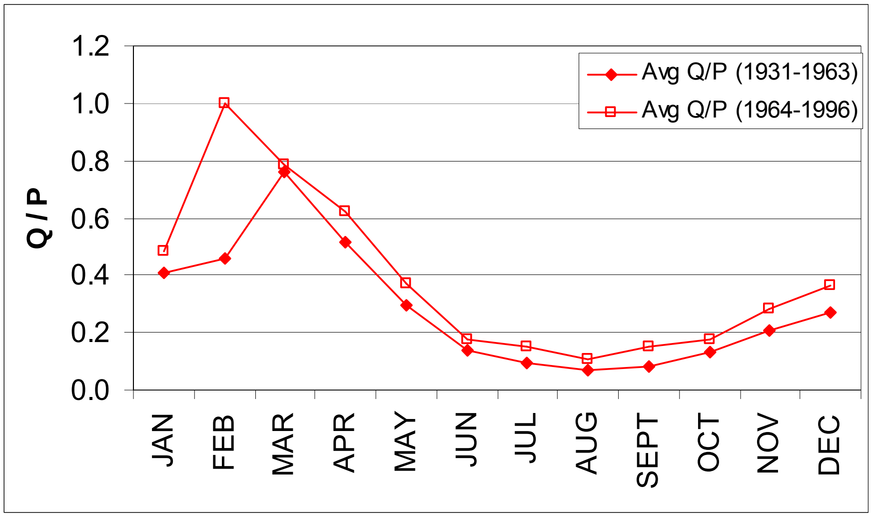

Figure 3.1-19 Two-period analysis of the monthly Q/P ratio for the Shiawassee watershed.

The Q/P ratio is a measure that normalizes the watershed yield by precipitation. Changes in Q/P over time indicate that some factor other than precipitation volume is changing the amount of water running off of the landscape and/or through the river network. Monthly comparisons show that the Q/P ratio has increased every month (except March) as shown in the two period analyses (Figure 3.1-19). Average annual Q/P also increased from 0.28 to 0.39 from the 1931-1963 period to the 1964-1996 period. These results suggest that water is moving off the landscape more efficiently now than in the past for a given precipitation event.

R-B Flashiness Index: The R-B Flashiness index is a metric used to quantify the frequency and rapidity of short term changes in streamflow. Daily streamflow was used to calculate the RBI value for each year. In the Shiawassee River, the R-B Index values were compared at each gage by water year where there were continuous data at all gages (Water Years 1968-1983). Annual values were plotted over time to identify long term trends in flashiness (Figure 3.1-20).

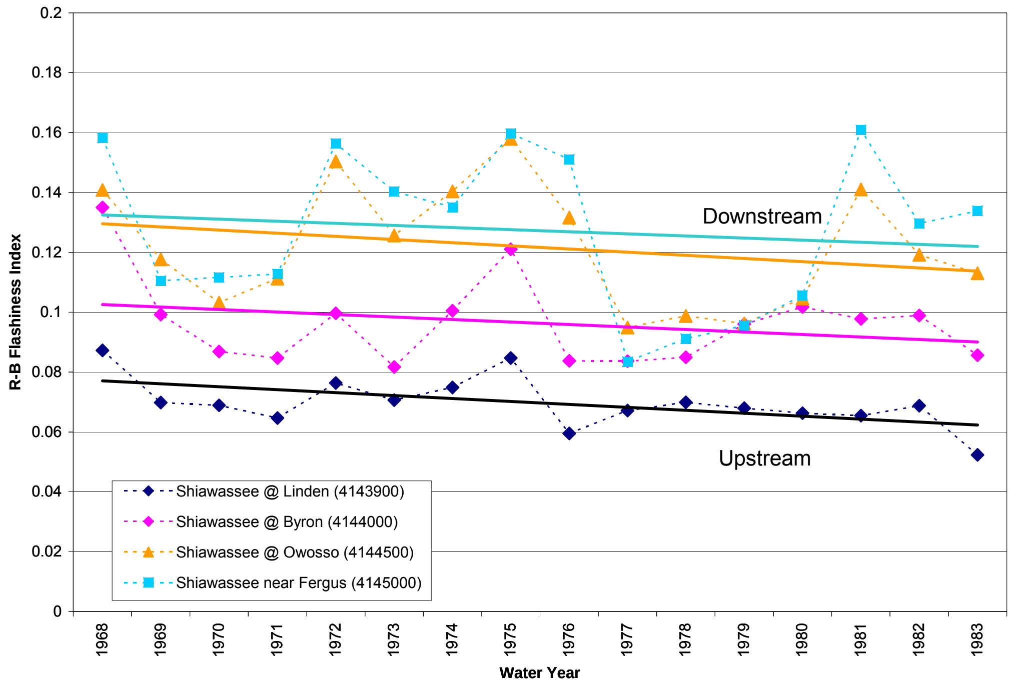

Figure 3.1-20 Plot of R-B index values (with linear trendline) for water years 1968-1983 at four gage sites in Shiawassee. R-B index values decrease in a downstream direction.

Based on results from gages in Midwest states, Richards et al (1995) observed that headwater streams are generally flashier than downstream reaches. The pattern observed within the Shiawassee watershed is not consistent with this observation. For the common period of record, flashiness index values are higher at downstream gages than at upstream gages (Figure 3.1-20).

Lower flashiness values in the southern (upstream) portion of the watershed are likely due to the following factors:

1) Higher groundwater flows into headwater streams (i.e. increased baseflow);
2) More natural stream channels (3 to 13% instream modified vs. 28 to >40% instream modified downstream); and
3) More natural landcover (deciduous/mixed forests and forested wetlands) and less agricultural land use than in the northern (downstream) portion of the watershed.

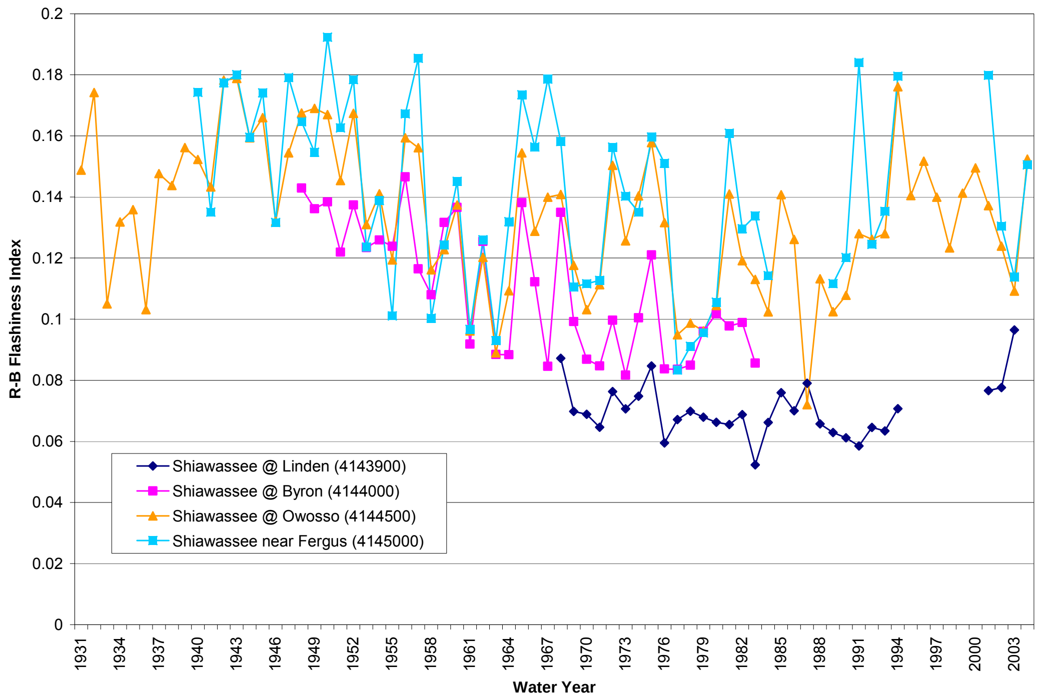

Figure 3.1-21 Plot of R-B index values for entire period of record at four gage sites in the Shiawassee watershed.

When the entire period of record – instead of just the common water years – is used for all four sites, flashiness generally decreases until the mid 1970's, and then (with the exception of the upstream-most site (Shiawassee @ Linden), the R-B Index generally increases (Figure 3.1-21). These trends may be related to regional changes in precipitation.

Baseflow Index Analyses: For this study, daily baseflow values were estimated using the BFLOW separation algorithm (Neff et al (2005) to calculate average annual baseflow for the period of record at each gage. BFLOW was used because it is among the more conservative baseflow separation algorithms.

The calculation produced one baseflow index value (based on BLFOW estimates) for each year in the period of record for each of the four gages in the Shiawassee watershed. All BFLOW index values are normalized by catchment area to compare among sites. Gages are sequenced upstream (left) to downstream (right). Base flow contributions are greatest in the upstream portion of the watershed and generally decrease in a downstream direction (Figure 3.1-22). This is likely because of high groundwater input to upstream reaches relative to downstream reaches.

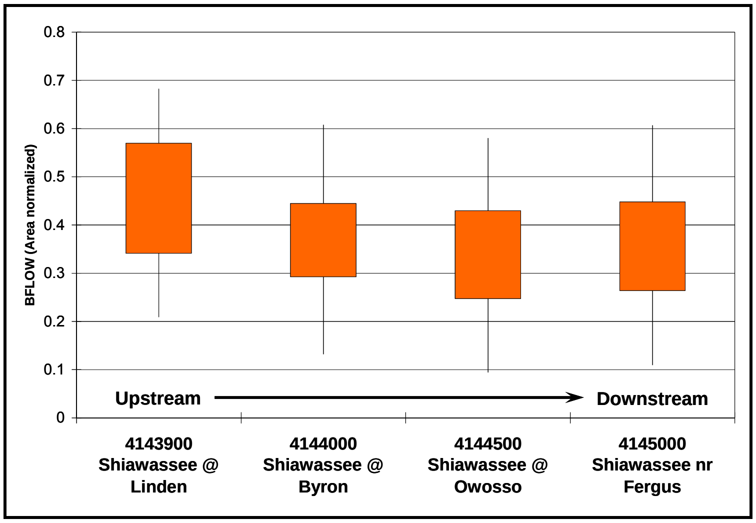

Figure 3.1-22 Box and whisker plot showing mean and range of calculated average annual base flows normalized by catchment area for four gages in the Shiawassee watershed over the period of record. Baseflow generally decreases in a downstream direction in the Shiawassee watershed.

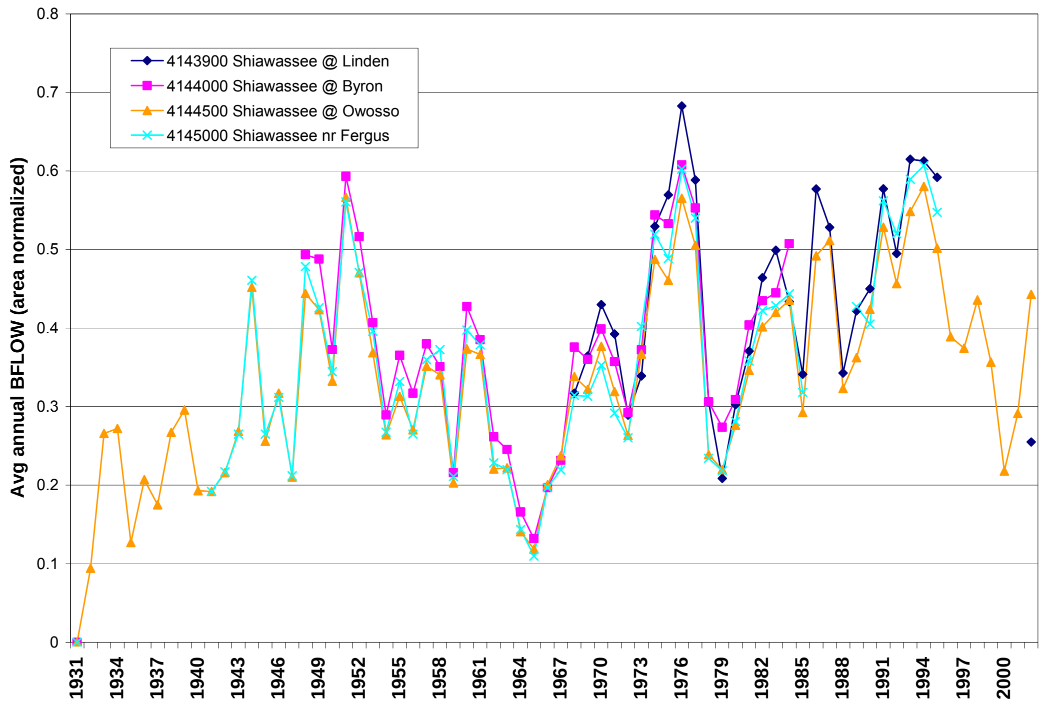

Figure 3.1-23 Plot of annual average BFLOW values normalized to catchment area for water years 1931-2004 at four gage sites in Shiawassee. BFLOW generally increases through time and is strongly influenced by precipitation and overall streamflow.

Annual values over the period of record are plotted for each gage over the period of record in Figure 3.1-23. Within the Shiawassee watershed, baseflow appears to have increased at three out of four sites. The only site that does not appear to increase (stays fairly constant) is the Shiawassee @ Byron (4144000). At this site, the period of record did not include years after

1983, which are considered to be years of high precipitation relative to previous years. The baseflow separation algorithms usually produce higher estimates in years of high precipitation – when total streamflow is high, the proportion attributed to baseflow is also high.

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3.2 St. Joseph River, Michigan, Ohio, and Indiana

Location: The St. Joseph River watershed drains 1,094 square miles of the Maumee River basin, a tributary to western Lake Erie. The headwaters of the St. Joseph River originate in Michigan, and the river flows through Ohio and Indiana before its confluence with the St. Mary's River near Ft. Wayne, Indiana (Figure 3.2-1).

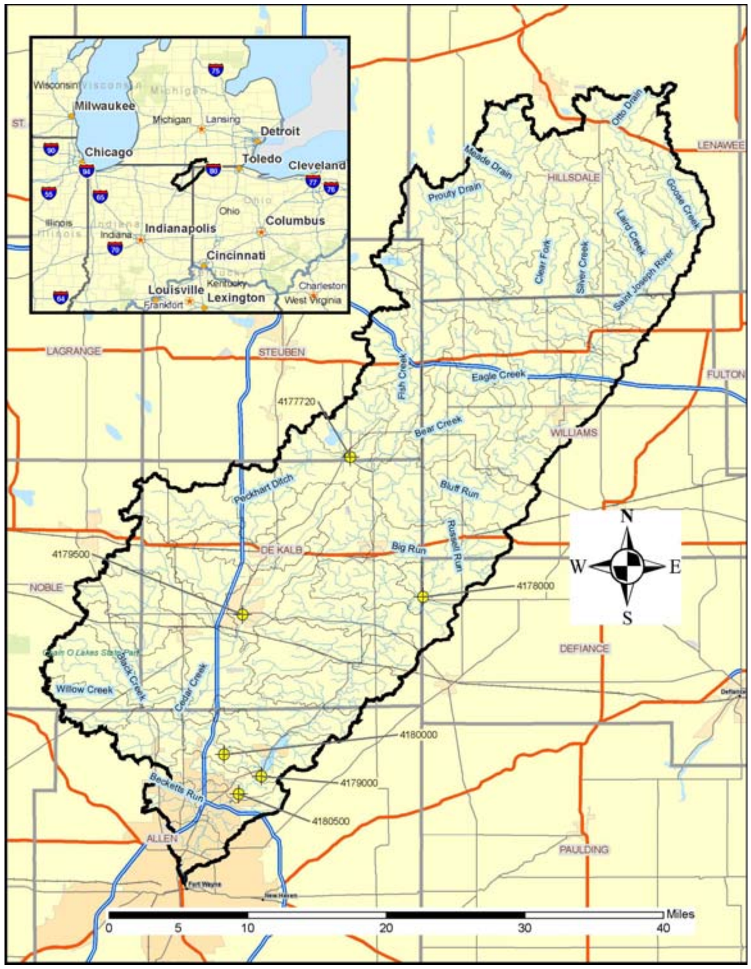

Figure 3.2-1 Location of the St. Joseph River watershed and USGS gages

Geology: The watershed is characterized by fine end and ground moraine with medium and coarse end moraine and ice contact deposits, especially in the headwaters. These coarse textured deposits result in groundwater contributions to headwater streams. Natural lakes are also present in the northern portion of the watershed. The mainstem of the St. Joseph River flows through fine–textured ground moraine and outwash channels.

Data availability: There are seven USGS streamflow gages in the St. Joseph River watershed that are either currently recording daily streamflows or have recorded them until recently (Table 3.2-1). For this study, we analyzed streamflow data for the six sites that had more than 20 years of data.

Table 3.2-1 USGS stream gages with recent daily streamflow records

Gage ID	Site name	Period of record
4177720	Fish Creek @ Hamilton	1969-2004
4178100	Fish Creek @ Artic	1998-2007
4178000	St Joseph River near Newville	1946-2004
4179000	St Joseph River @ Cedarville	1900-1982
4179500	Cedar Creek @ Auburn	1943-1973
4180000	Cedar Creek near Cedarville	1946-2004
4180500	St Joseph River near Fort Wayne	1941-2004

St. Joseph River subwatersheds and analysis sites: Within the St. Joseph River watershed, we analyzed hydrologic data and summarized extent of anthropogenic changes within the upstream catchment at thirteen sites. Six sites were at the locations of gages that had sufficient data to evaluate trends to selected hydrologic statistics. Seven additional sites were in the headwaters region and were of particular interest to The Nature Conservancy and others due to known or expected changes to biological or habitat conditions that may be linked to hydrologic changes. The locations of USGS gages and the other sites of interest, including their contributing catchments, are shown in Figure 3.2-2.

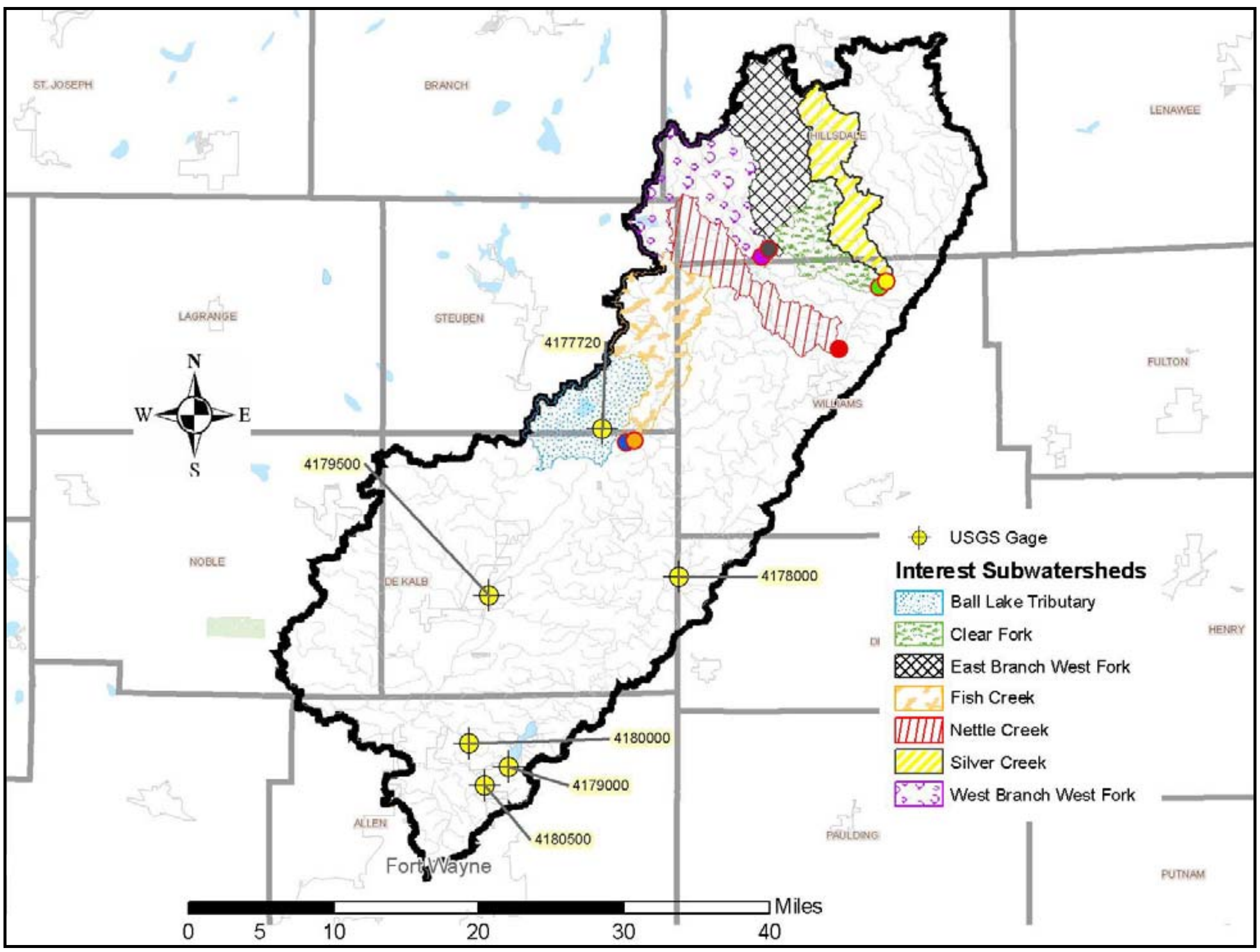

Figure 3.2-2 Locations of analysis sites within the St. Joseph River watershed

Land cover: Current land cover in the watershed is predominately row crop agriculture (Figure 3.2-3). Urban and developed land only comprises a small proportion of watershed land cover. Forest and pasture exist in the northern portion of the watershed. Remaining wetland cover primarily exists in the floodplain.

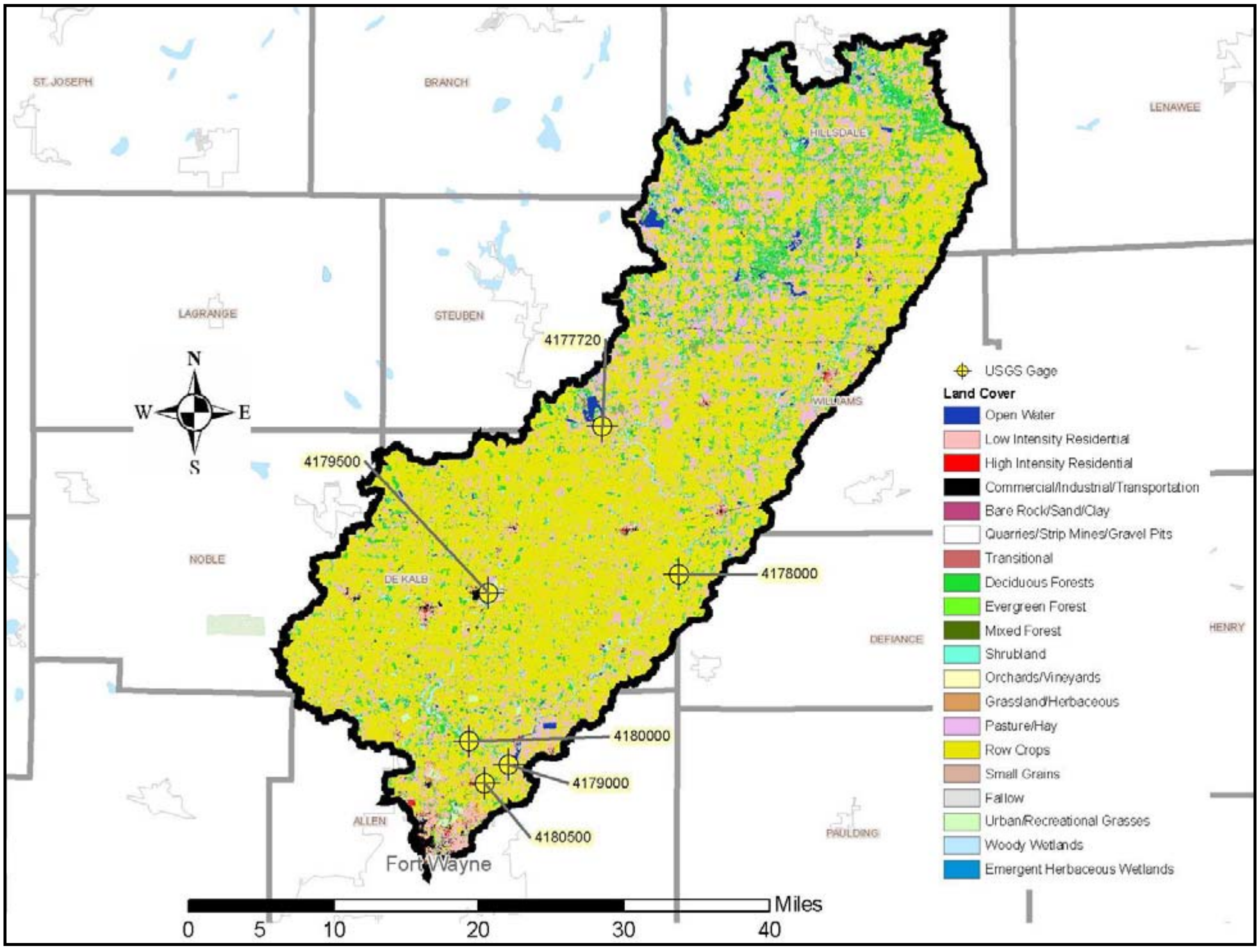

Figure 3.2-3 Recent land cover within the St. Joseph River watershed

There was no GIS layer of presettlement vegetation for the entire St. Joseph River watershed. Based on soil and topography and existing remnants of native vegetation, it is likely that deciduous forest and woody wetlands were common in the watershed prior to European settlement. In order to run the stream power tool and estimate change to stream power since presettlement conditions, data on locations of hydric soils were used to estimate the extent of woody wetlands under presettlement conditions; areas without hydric soils were assumed to be deciduous forest under presettlement conditions.

Results of watershed assessment tools

Stream power tool:

Differences in stream power can be presented in two ways (For a full discussion of the tool see section 2.1.1 of this report):

1) Using land cover from presettlement and recent time periods, change in stream power can be calculated and compared using a percent power change calculation, i.e.,

$$\textbf{Percent Power Change} = \frac{\textbf{Recent Stream Power} - \textbf{Presettlement Stream Power}}{\textbf{Presettlement Stream Power}}$$

Figure 3.2-4 illustrates percent power change from presettlement to current conditions for the gaged subwatersheds and selected subwatersheds in the St. Joseph watershed. In all gaged and selected subwatersheds, stream power increased between 65 and 247% (Figure 3.2-4).

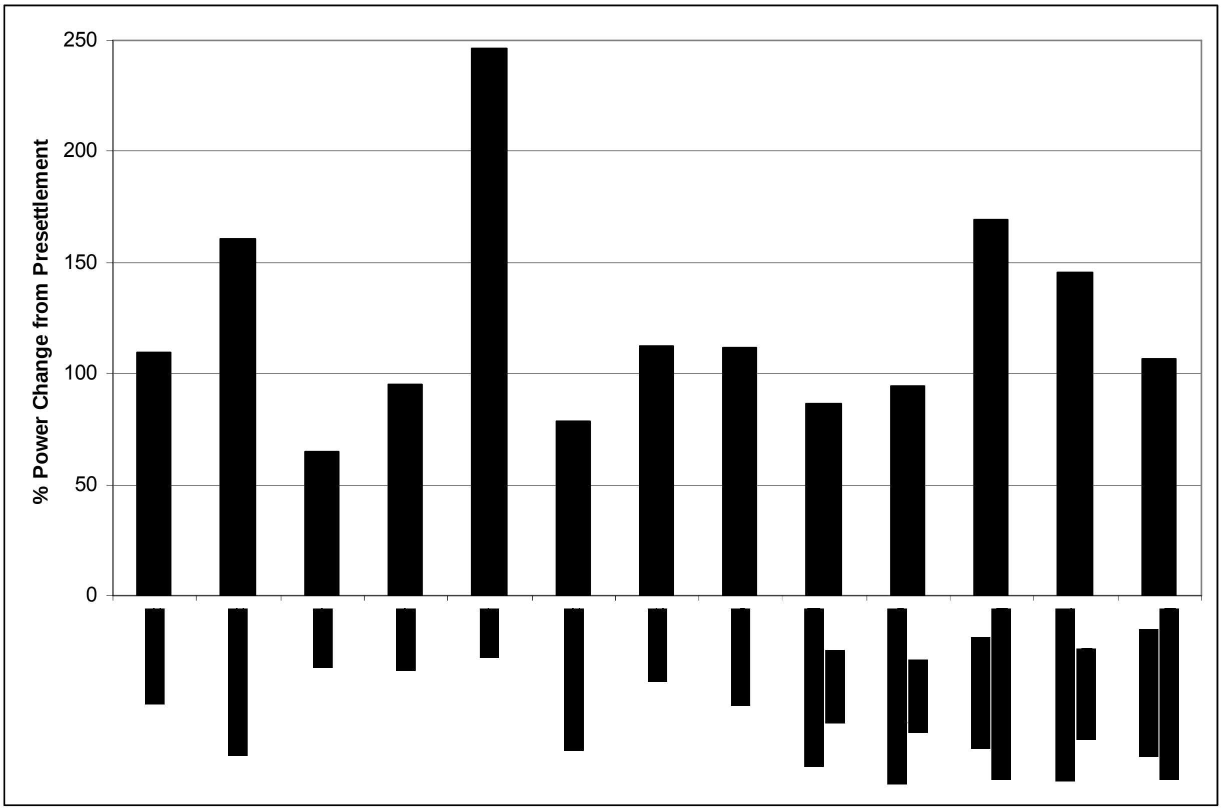

Figure 3.2-4 Percent change in stream power at St. Joseph River sites

2) Calculating the maximum stream power change possible for each stream reach and compare the actual change (from presettlement conditions) to the maximum possible change (under hypothetical "paved paradise" conditions). This power change metric provides a quantitative way to estimate hydrologic degradation (or improvement) relative to maximum possible degradation.

$$\textbf{Power Change Metric} = \frac{\textbf{Recent Stream Power} - \textbf{Presettlement Stream Power}}{\textbf{Paved Paradise Power} - \textbf{Presettlement Power}}$$

Figure 3.2-5 illustrates the power change metric for the gaged subwatersheds and other selected subwatersheds in the St. Joseph Watershed. This analysis suggests that patterns of landcover change have led to moderately high power change metric values, with values ranging from 15 to 30 in many reaches of the St. Joseph watershed (Figure 3.2-5). Another way of stating this result is that, depending on the reach, stream power has increased between 15 and

30% of the maximum possible increase. Figure 3.2-6 shows the current degree of stream power change relative to the potential change for all reaches in the St. Joseph River.

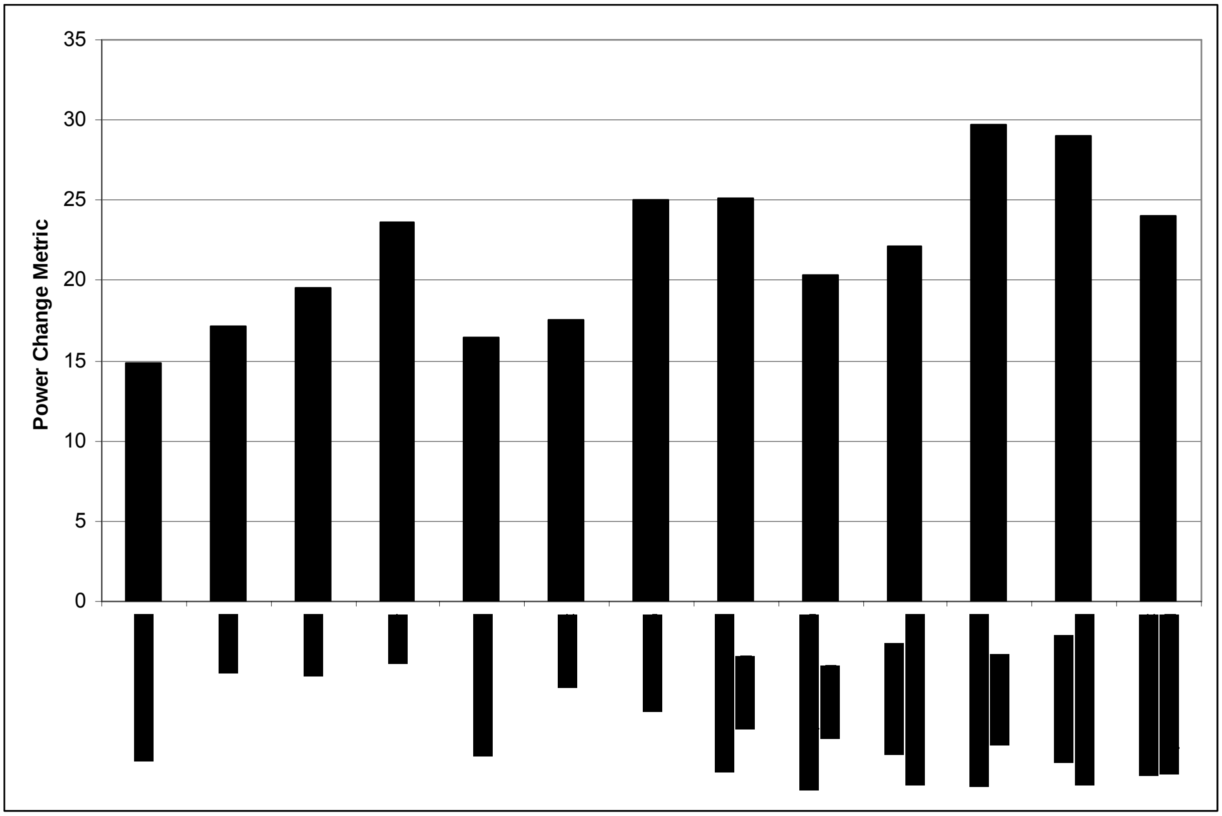

Figure 3.2-5 Change to stream power change metric at St. Joseph River sites

Increases in stream power may increase bank and stream bed scour, which could increase erosion and sediment load. Increases in stream power may also increase the stream's capacity to move sediment, and may reduce deposition of fine materials in the channel.

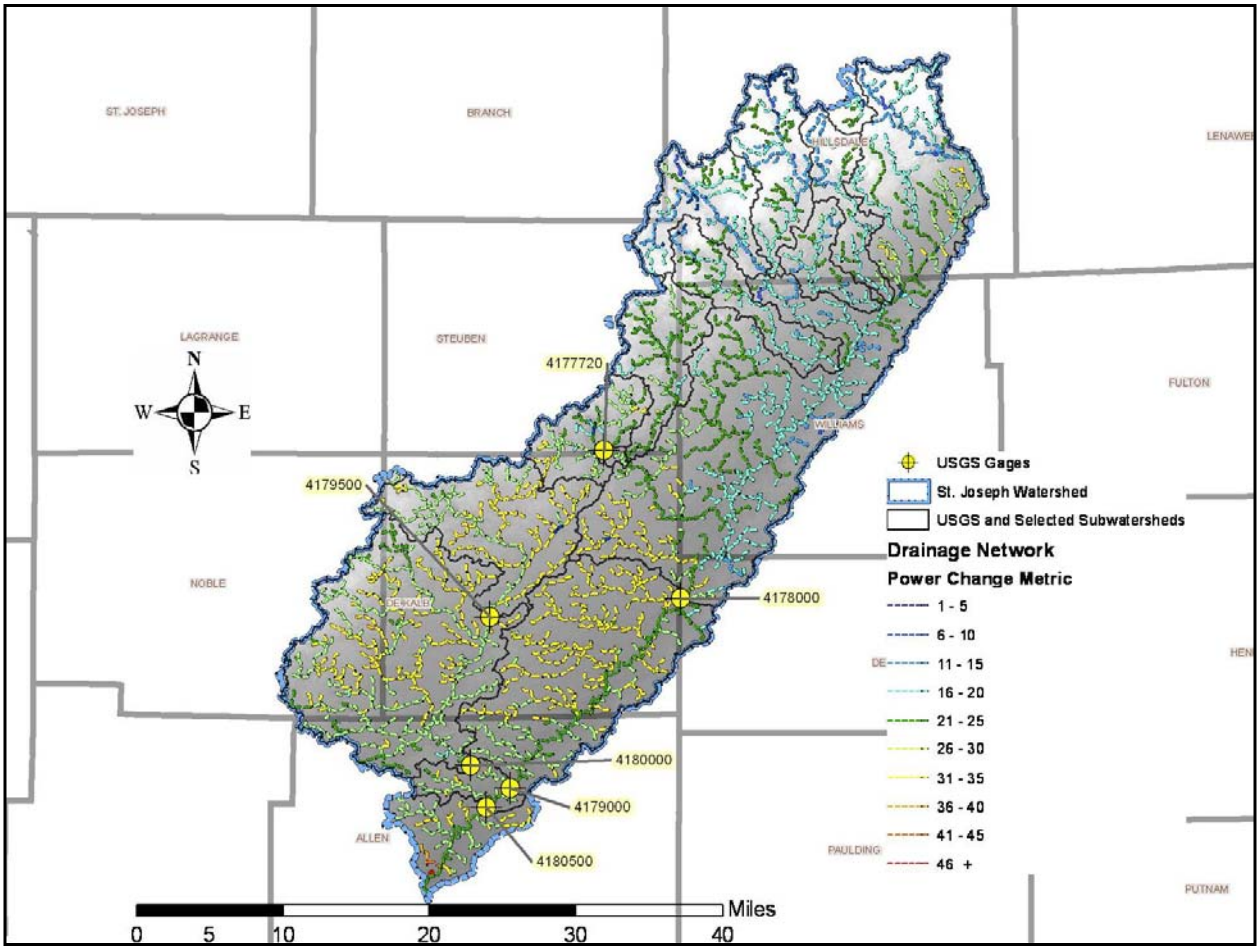

Figure 3.2-6 Stream power change metric for all reaches within the St. Joseph River watershed

Flow Duration Curve models: Multiple linear regression models can be used to predict values of specific flow exceedance frequencies (i.e., Q05, Q10, Q25, Q50, Q75, Q90, and Q95). In the St. Joseph River, these models were used to predict flow exceedance frequencies using recent land cover as model inputs. Two different regression models, built from Michigan statewide data and Illinois statewide data, were used. Even though the St. Joseph River is not in Illinois, the watershed conditions (i.e., land cover, surficial geology) in Illinois are similar to conditions in the St. Joseph River, making it appropriate to apply the Illinois models to the St. Joseph River subwatersheds. The results of these models are shown in Figures 3.2-7 and 3.2-8.

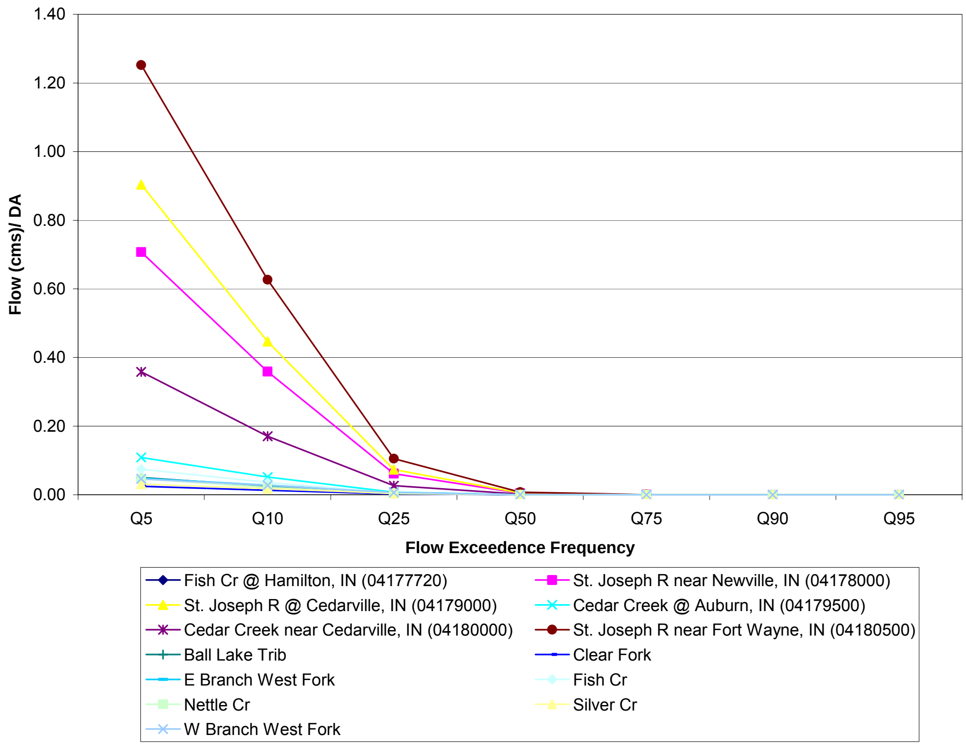

Figure 3.2-7 Flow duration curve model results - St Joseph River (MI state models)

- Low flow yields are extremely low at all sites.
- Median flow yields are similar among sites.
- High flow yields vary among sites, but sites with small drainage areas have lower yields than sites with larger drainage areas. This result could also reflect the limitations of the model to predict extreme flows and flows for sites with small drainage areas.

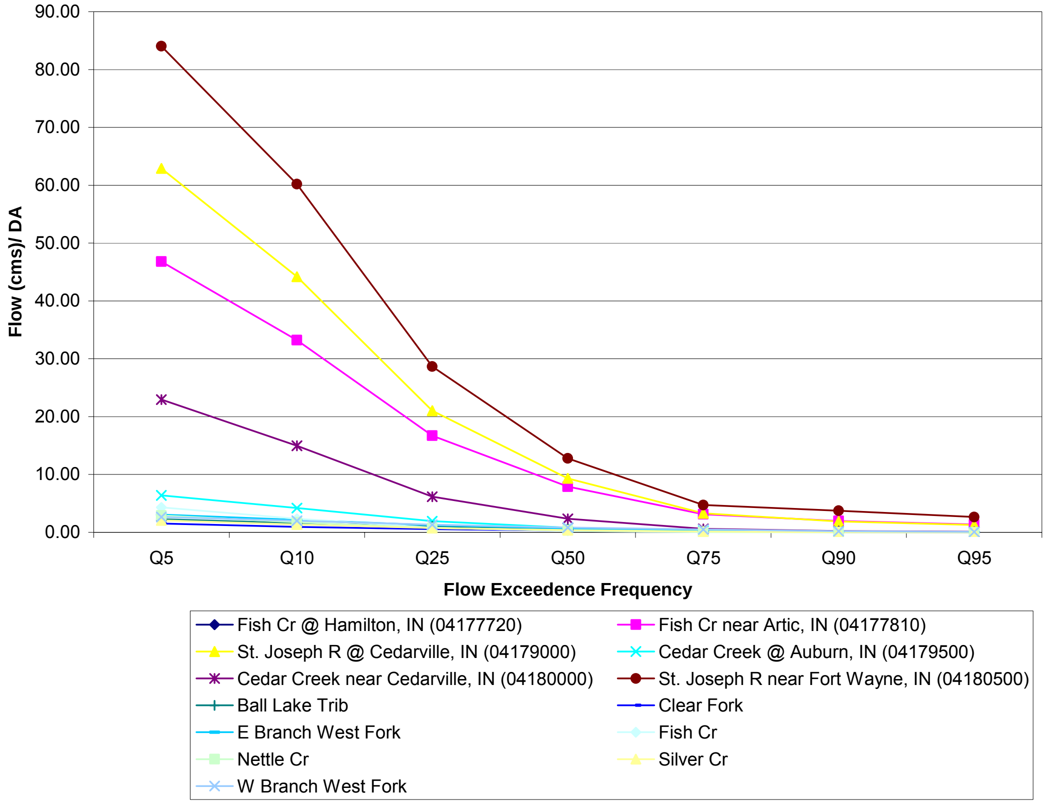

Figure 3.2-8 Flow duration curve model results - St Joseph River (IL state models)

When the Illinois model was used, the predicted flow magnitudes are higher at low, median, and high flows, but the patterns among sites are similar.

Dams and channel modifications: In addition to land cover modification, dams and channel modifications are two other examples of anthropogenic changes within the watershed (Figure 3.2-9). A summary of the dams and an estimate of the extent of channel modification (derived from visual inspection of stream hydrography to identify reaches that appeared unnaturally straightened) is shown in Table 3.2-2. Most dams in the watershed are small, recreational dams. Some have controlled outflows but many do not.

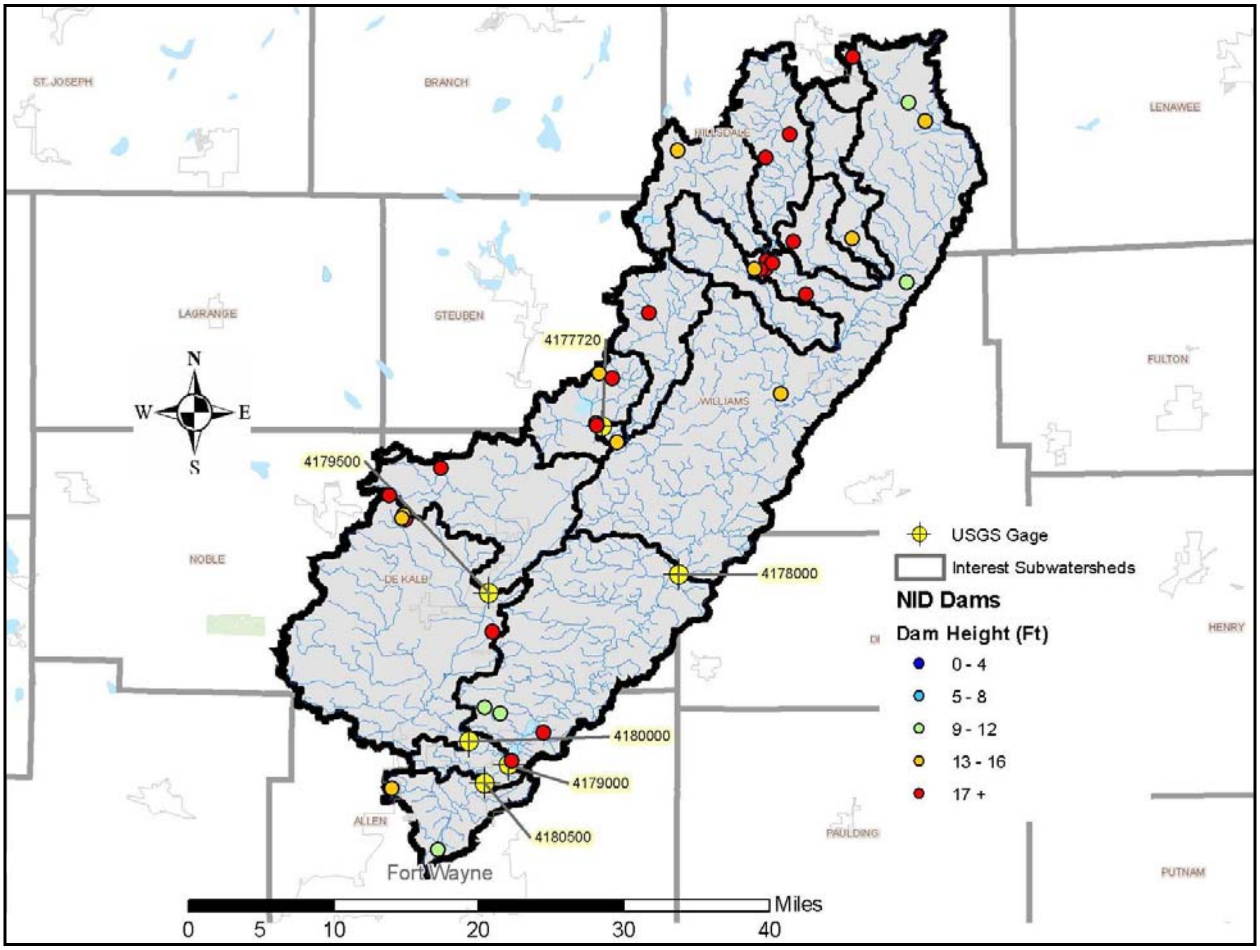

Figure 3.2-9 Location of dams within the St. Joseph River watershed

Table 3.2-2 Summary of dams and channel modifications within St. Joseph River subwatersheds

St. Joseph River subwatershed	**Watershed area** (km^2)	**Dams** (total#)	**Channel modification** (% of upstream streamlength modified)
Clear Fork	60.2	1	8%
Silver Creek	83.4	1	17%
Fish Creek @ Hamilton, IN (04177720)	94.4	4	46%
Nettle Creek	98.7	0	39%
Ball Lake Tributary	99.5	4	43%
Fish Creek	114.8	1	10%
W Branch West Fork	123.2	1	46%
E Branch West Fork	124.9	2	40%
Cedar Creek @ Auburn, IN (04179500)	222.3	2	73%
Cedar Creek near Cedarville, IN (04180000)	691.9	21	34%
St. Joseph R near Newville, IN (04178000)	1563.8	6	64%
St. Joseph R @ Cedarville, IN (04179000)	1960.1	25	40%
St. Joseph R near Fort Wayne, IN (04180500)	2695.3	31	44%

Hypotheses about affects of anthropogenic changes on flow metrics

The combination of land cover changes and instream modifications make it difficult to predict the hydrologic alterations associated with these anthropogenic changes and other changes that were not quantified in this study (e.g., dam management, water use). Despite these complexities, it is useful to hypothesize about the expected hydrologic responses to existing anthropogenic modifications in the watershed.

Land cover change: Loss of forest cover in a watershed, specifically a conversion to agricultural land cover, may decrease evapotranspiration and increase the volume of water that flows through the watershed. Field observations from other studies provides evidence that loss of forest cover often results in increased annual, peak and, summer (low) flows.

Channel modification: In general, channelization creates more efficient stream networks and more precipitation is routed to the stream channel rather than infiltrated or otherwise stored within the watershed. This can have the effect of increasing high flow magnitude, increasing low flow magnitude, and increasing responsiveness (rate of change) within the stream network. Subwatersheds with high degrees of channel modification may also be correlated with irrigation, which changes the water balance by adding water (usually from groundwater) to the drainage network. Over the long term, if groundwater is used for irrigation, drawdown will likely occur and the groundwater component of streamflow may be diminished. Hypotheses about anticipated changes to specific flow metrics as a result of channel modification are listed in Table 3.2-3.

Table 3.2-3 Hypothesized responses of flow metrics areas due to channel modification

Flow component	Flow metric	Anticipated change due to channelization	Explanation
Summer/Fall Magnitude	July, Aug, Sept, and Oct median flow	Increase (higher flows during dry season)	Channelization increases drainage efficiency. More precipitation is routed to the stream network, increasing dry-season flows.
Spring Magnitude	March, April, May, and June median flow	Increase (higher flows during wet season)	Channelization increases drainage efficiency. More precipitation is routed to the stream network.
High Flow (event) Magnitude	3-Day annual high flow	Increase (higher flows)	Efficient drainage concentrates flow and magnifies peakflow.
Rate of Change	Flashiness Index	Increase	Channelized reaches increase responsiveness of the stream network.

Results of hydrologic assessment tools

Indicators of Hydrologic Alteration: In the St. Joseph River, one- and two-period analyses were conducted. The one-period analysis is used to detect trends rather than to detect changes attributable to a specific event in time. The two-period analysis is useful when the period of record is sufficiently long to describe conditions before and after a discrete event (e.g., dam construction, change in dam operation) or to describe and compare historical and recent period 'snapshots'. In the St. Joseph River, six gages had sufficiently long periods of record to conduct a one-period analysis and three gages had two sufficiently long periods that were suitable for two-period analysis. When both one- and two-period analyses were conducted for the same gage site, we compared the results to determine if they were consistent with each other.

A summary of the results of the one-period analyses are shown in Table 3.2-4. Changes to monthly flow magnitudes were summarized into seasonal summaries by noting if the slopes of the line for 3 out of the 4 months in each season were positive or negative. If so, the seasonal changes were noted as 'increases' or 'decreases', respectively; if not, ‘no consistent change’ was noted. The one-period analysis was also used to identify changes to extreme high and low flow magnitudes.

Table 3.2-4 Summary of changes to flow metrics at six USGS gages within the St. Joseph River

		Summary of changes to seasonal magnitude			**Changes to flow events**	
Gage ID	**Period of analysis**	***Winter***	***Spring***	***Summer/ Fall***	***Low flows*** (7-day min)	***High flows*** (3-day max)
Fish Cr @ Hamilton, IN (04177720)	1969-2004	no consistent change	no consistent change	increase	increase	increase
St. Joseph R near Newville, IN (04178000)	1998-2007	no consistent change	no consistent change	increase	increase	increase
St. Joseph R @ Cedarville, IN (04179000)	1946-2004	increase	increase	increase	increase	increase
Cedar Creek @ Auburn, IN (04179500)	1900-1982	no consistent change	decrease	increase	no change	decrease
Cedar Creek near Cedarville, IN (04180000)	1943-1973	increase	no consistent change	increase	increase	increase
St. Joseph R near Fort Wayne, IN (04180500)	1946-2004	increase	decrease	increase	increase	increase

Summer and fall (dry season) flows increased at all sites. Depending on the site, winter flows either did not change (three sites) and or increased (three sites). Spring (wet season) flows did not change, decreased or increased.

Magnitude of low flow events either increased (5 sites) or did not change (1 site). Magnitude of high flow events increased at 5 sites and decreased at one site. Generally, the changes to high and low flow events were consistent with seasonal changes. In other words, if low flow event magnitudes decreased, dry season (summer) magnitudes decreased also (and vice versa). If high flow event magnitudes increased, wet season (summer) magnitudes often, but not always, increased also.

Flashiness Index: The R-B Flashiness index (RBI) is a metric used to quantify the frequency and rapidity of short term changes in streamflow. Daily streamflow was used to calculate the RBI value for each year. Annual values were plotted over time to identify long term trends in flashiness (Figure 3.2-10).

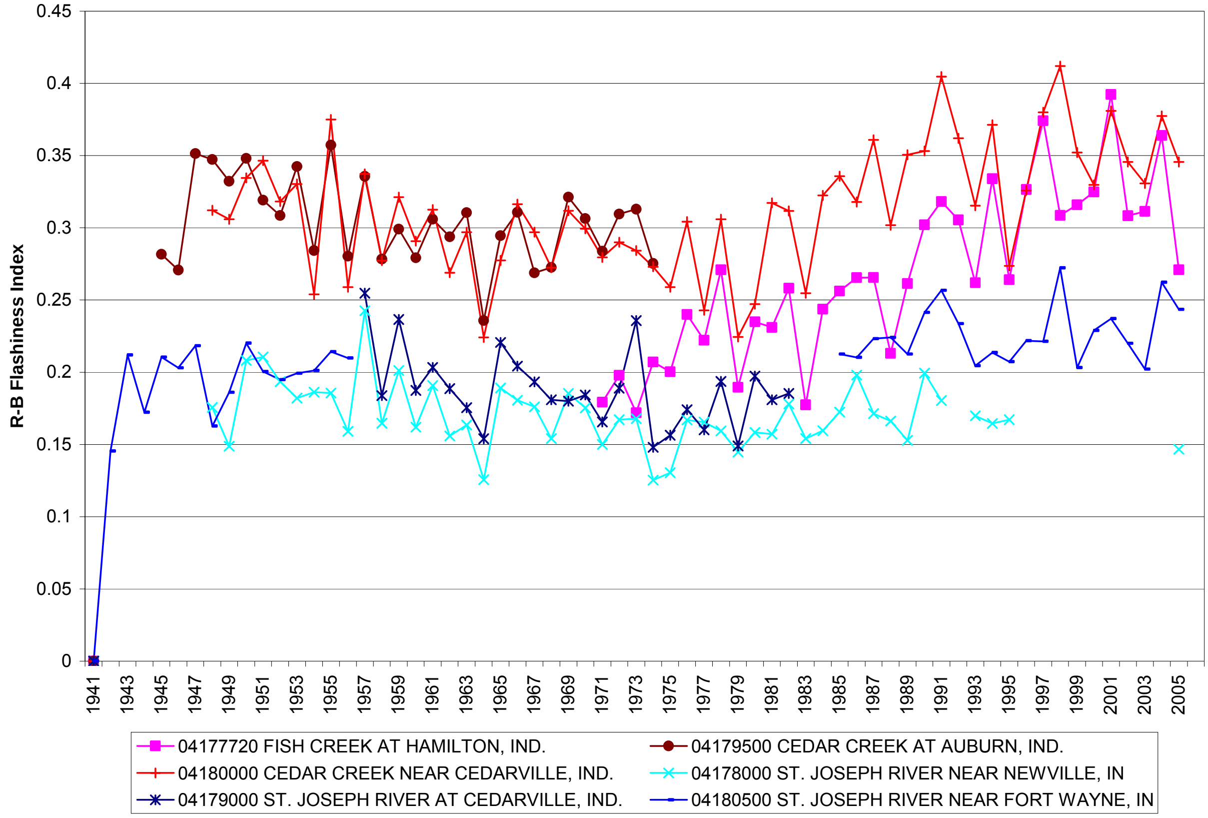

Figure 3.2-10 Annual Richards-Baker Flashiness Index values at USGS gage sites

Within the St. Joseph River, period of record varied by site. Generally, there were no trends in flashiness before about 1970. After 1970, flashiness at several sites appeared to increase over time, especially at Fish Creek @ Hamilton and Cedar Creek near Cedarville.

Baseflow Index: Estimates of the baseflow component of streamflow were calculated for all stream gages within the US portion of the Great Lakes basin by Neff et al (2005). The baseflow index values can be used to identify potential changes to the groundwater component of streamflow over time (Figure 3.2-11).

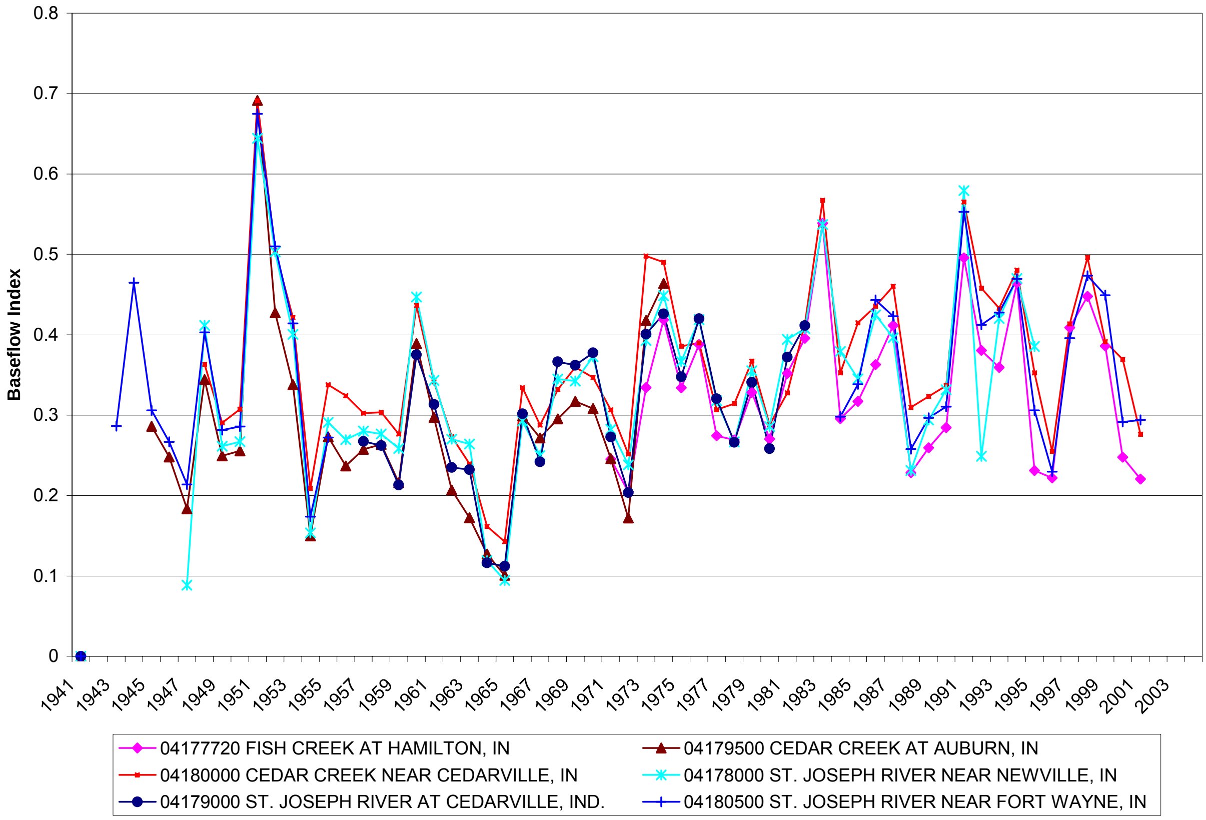

Figure 3.2-11 Annual Baseflow Index values at USGS gage sites

In the St. Joseph River, there were no obvious trends in baseflow index over time. Nor were there notable differences in baseflow index values among sites.

Summary of hydrologic changes: In summary, most subwatersheds included in this assessment experienced similar hydrologic changes:

- Increased flow magnitude during most seasons, especially during summer / fall and winter.
- Increased flow magnitude during extreme high and extreme low events (as measured by increases in annual 7-day min and 3-day max).
- Increased flashiness, especially since 1970.
- Increased stream power throughout the watershed, as a result of increased runoff (surface water flows).

These results are consistent with the hypothesized effects of land cover change and channelization on flow conditions, which were increased flow magnitudes and increased flashiness. The results of the tools were generally consistent with each other.

Watershed and instream restoration

Results from these analyses are consistent with field observations that streamflow magnitudes and flashiness has increased in many reaches of the St. Joseph River watershed and that these increases likely contribute to habitat changes, including bank and bed scour. Both in-channel and in-catchment restorations could be used to address these changes. The Nature

Conservancy will be applying the results of this assessment (and conducting some additional assessment using the stream power tool) to select target reaches for restoration using 1) channel restoration techniques and 2) forest and wetland restoration within catchment.

Possible rules for targeting restoration could include:

- Subwatersheds with least hydrologic alteration where alteration is focused in a few reaches.
- Highly altered upstream reaches.
- Reaches that have species of concern or potential to support species of concern.
- Opportunities to implement forest or wetland restoration.

The Conservancy will develop and apply several forest and wetland restoration scenarios using stream power tool to identify locations for restoration that have greatest benefit to stream power in targeted reaches.

3.3 Paw Paw River, Michigan

Location: The Paw Paw River is a major westward flowing tributary of the St. Joseph River that drains approximately 445 square miles of southwestern Michigan near Benton Harbor (Figure 3.3-1). The watershed is well known for containing a diverse landscape including large fens, state designated trout streams, and several rare species including the Eastern Box Turtle.