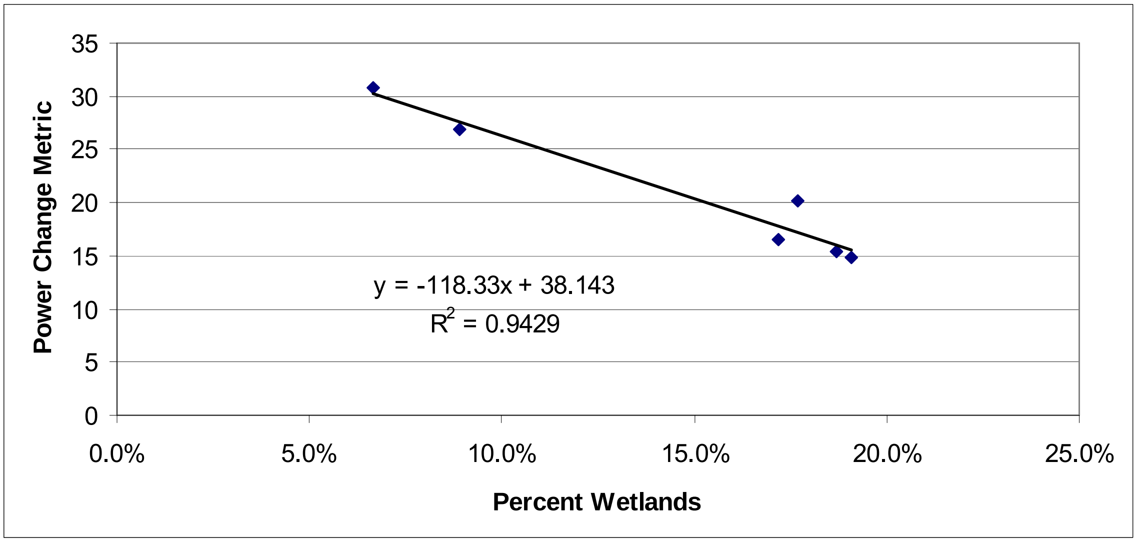

Figure 3.4-23 Relationship between percent wetlands and power change metric values for gaged watersheds.

To conclude, changes in stream power seem to be related to changes seen in gage derived high flow magnitude metrics. Modeling changes in stream power may be a “quick and dirty” substitute for estimating land cover change’s effect on high flow parameters when using gage data is not possible. Changes in MLR-FDC’s low flow magnitude metrics seem to be related to changes seen in gage derived low flow magnitude metrics. Modeling land cover change in MLR-FDC’s may be a way to model estimated changes in low flow characteristics when using gage data is not viable.

4. SYNTHESIS

4.1 Watershed assessment tools

4.1.1 Stream Power Tool Synthesis

The project team modeled stream power change for all stream reaches within the four demonstration watersheds. Both percent change and the power change metric were calculated for gaged subwatersheds and at selected demonstration subwatersheds in the St. Joseph and the Paw Paw watersheds (See section 2.1.1 for a more detailed description of methodology.) In the Shiawassee and Paw Paw watersheds a future land use scenario, based on MI LTM 2040, was used to evaluate how future changes in land cover might affect the stream power. In the Milwaukee watershed, a hypothetical scenario was run to evaluate how restoration of all potentially restorable wetlands (PRWs) would affect stream power.

Stream power change from presettlement to current conditions varied greatly within and among the demonstration watersheds (Figure 4.1-1). The highest percent change was generally in the Milwaukee subwatersheds with an average percent change of 150%. The St. Joseph subwatersheds had an average percent change of 111% with the East Branch of the West Fork removed from analysis (122% if not removed). The Paw Paw and Shiawassee subwatersheds had stream power changes of 90 and 78%, respectively. The percent stream power change is generally higher in downstream reaches than in headwater reaches.

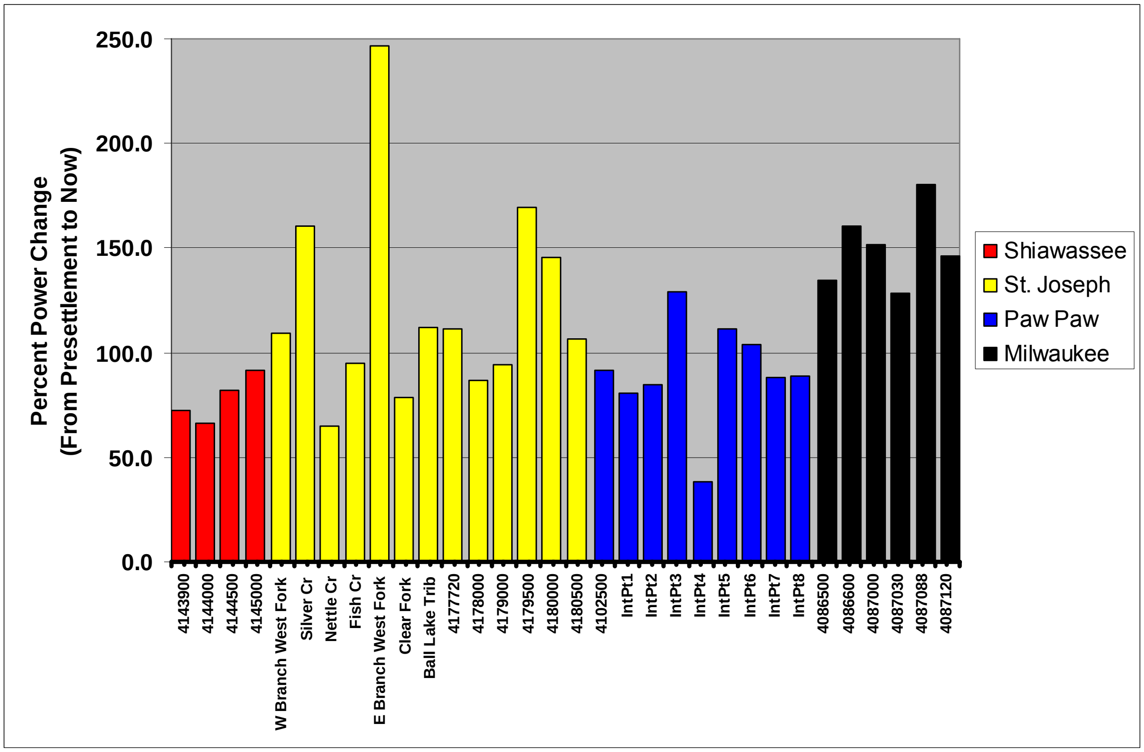

Figure 4.1-1 Selected Subwatershed's Percent Power Change by Demonstration Watershed.

Stream power metric values, considering current land cover, also varied within and among demonstration watersheds (Figure 4.1-2). Metric values, averaged across selected subwatersheds within, were highest in the St. Joseph and Milwaukee watersheds with values of 22 and 21 respectively. The values were lowest in the Shiawassee and Paw Paw watersheds with values of 10.5 and 9, respectively.

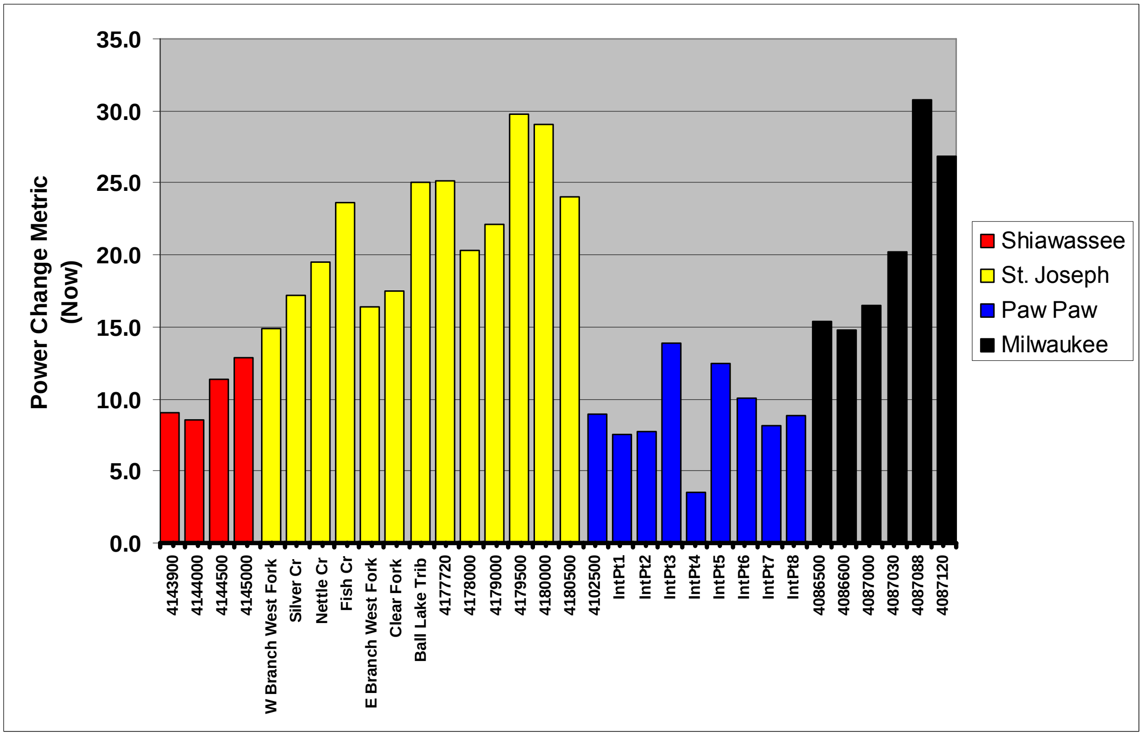

Figure 4.1-2 Selected Subwatershed's Power Change Metric by Demonstration Watershed.

Comparison of percent power change with the power change metric yields a potential change ratio (PCR) that is a measure of the normalized difference in stream power between presettlement conditions and conditions for the worst case scenario, i.e.

$$\mathbf{PCR} = \frac{\underline{(\mathbf{Ppp} - \mathbf{Pps})}}{\mathbf{Pps}}$$

Where (Ppp) is worse case stream power and (Pps) is presettlement stream power. This ratio represents the relative length of the line upon which we are plotting (or calculating) the Power Change Metric. Within each watershed or subwatershed, the potential change ratios are constant as they are controlled by fundamental differences in CN numbers, watershed surface area, drainage pattern, and slope between presettlement and worse case scenarios – parameters that are fixed for each scenario.

Based on this ratio, a PCR metric can be calculated that measures the relative "responsiveness" of a watershed (or subwatershed) to changes in stream power ((Figure 4.1-3). The PCR metric is calculated by adding 1 to the PCR ratio.

A PCR metric value of one (1) means that there are no differences between presettlement conditions and the worse case scenario. When PCR metric values are greater than one, stream power is greater in the worse case scenario than in the presettlement scenario. Higher PCR metric values mean greater potential differences in stream power between the two end-member scenarios.

For example, a PCR metric of 10 means that worse case stream power (Ppp) is 10 times the presettlement stream (Pps). A value of 2 means that worse case stream power is only 2 times presettlement power. Watersheds with relatively low potential differences in stream power might be more susceptible to hydrologic modifications and more responsive to hydrologic improvements. In other words, assuming that the stream power metric is an appropriate measure of hydrologic change, then one would get more bang for their hydrologic restoration buck in watersheds where minor changes in stream power yield major changes in the power change metric.

Figure 4.1-3 illustrates maximum potential differences in stream power for each of the pilot watersheds. On average, maximum potential stream power is ~12 times the presettlement stream power in the Paw Paw watershed, and ~5 times the presettlement stream power in the St. Joseph watershed. This difference may be due to fundamental differences in the soils, geology, and hydrology between the two watersheds. These data suggest that the St. Joseph watershed would yield the greatest change in the power change metric for a given percent change in stream power.

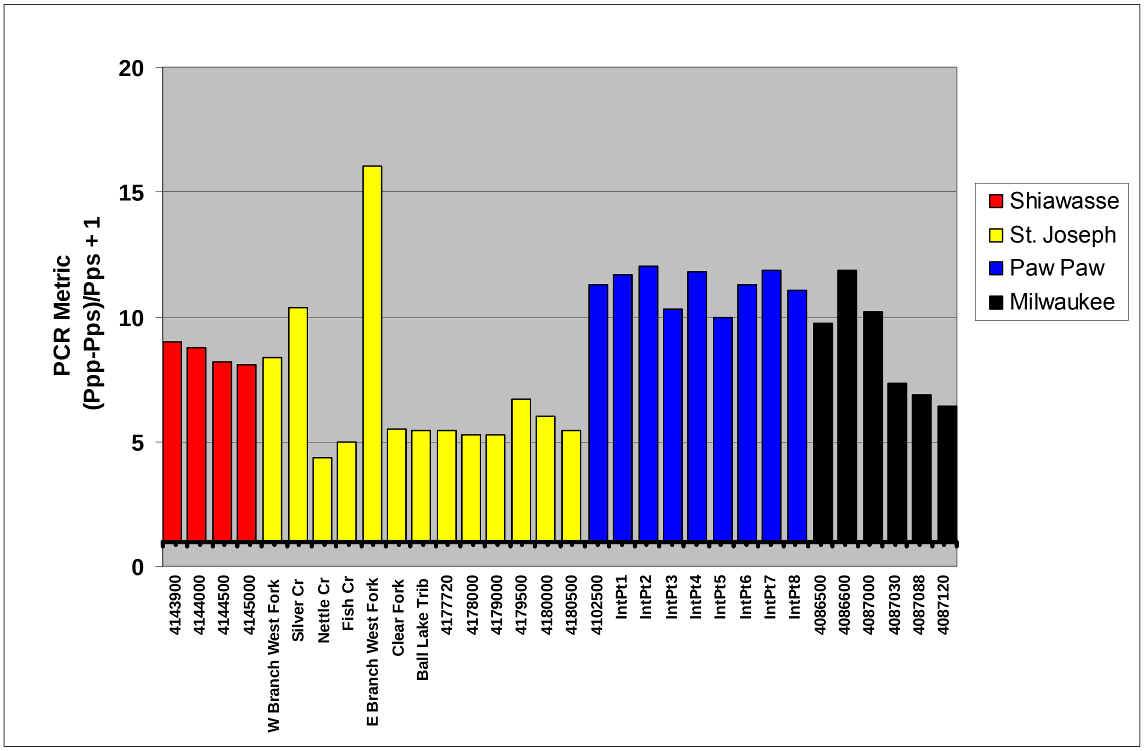

Figure 4.1-3 Plot of the PCR metric which measures the maximum potential for stream power alteration within the four pilot watersheds. Larger values indicate greater potential differences in stream power between worse case and presettlement scenarios.

Stream power percent change was also assessed under the modeled future scenario using MI LTM 2040 in the Shiawassee and Paw Paw watersheds. Percent change in the Shiawassee watershed under 2040 modeled conditions ranged from 125 to 150% from presettlement, or increased 55 to 77% over current percent change, with the largest change occurring in the most headwater analysis subwatershed, USGS 4143900, Linden (Figure 4.1-4). Percent change in the Paw Paw watershed under 2040 modeled conditions ranged from 120 to 210% from presettlement or increased 80 to 100% over current percent change (Figure 4.1-5).

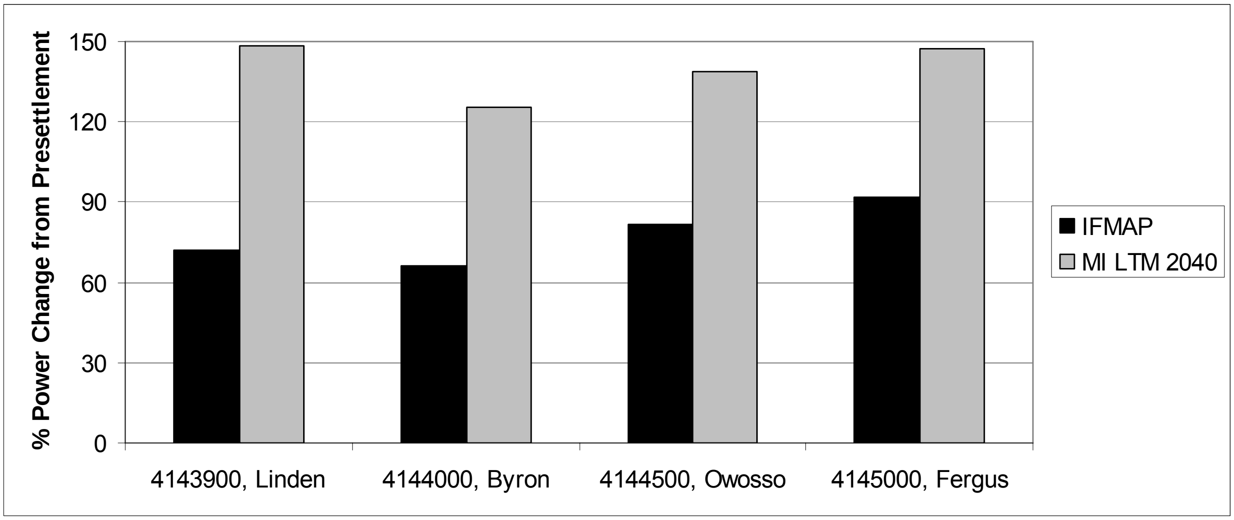

Figure 4.1-4 Percent Power Change from Presettlement in Gaged Subwatersheds in the Shiawassee River Watershed Under Current Land Cover (IFMAP) and Future Land Cover (Mi LTM 2040) Scenarios.

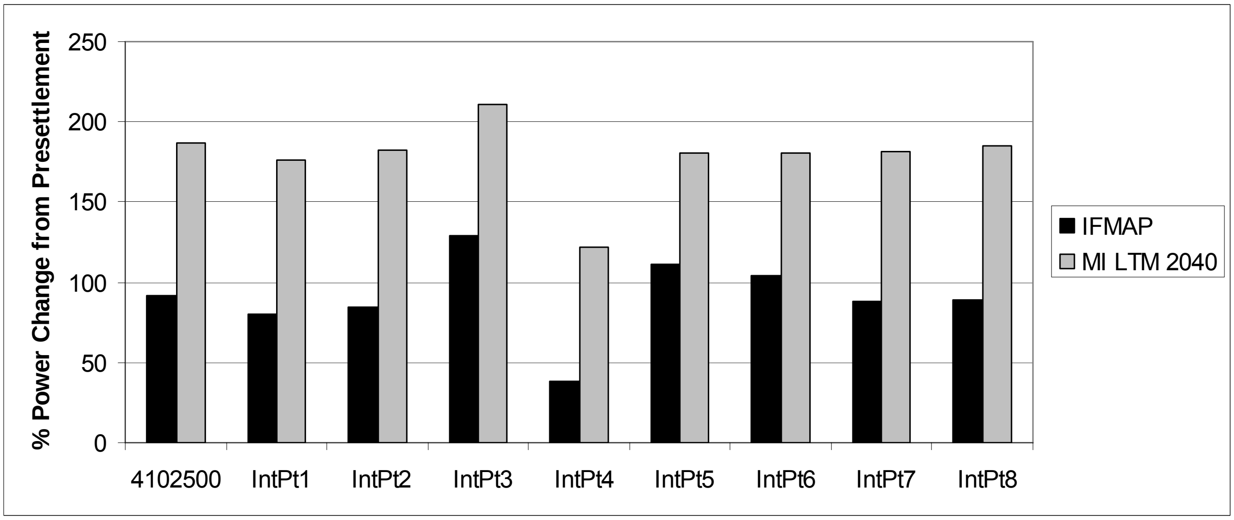

Figure 4.1-5 Percent Power Change from Presettlement in Selected Subwatersheds in the Paw Paw River Watershed Under Current Land Cover (IFMAP) and Future Land Cover (Mi LTM 2040) Scenarios.

The power change metric was also assessed under the modeled future scenario using MI LTM 2040 in the Shiawassee and Paw Paw watersheds. Estimated landcover alteration based on this scenario in the Shiawassee would lead to further power metric increases of 8 to 9.5 units over current conditions (Figure 4.1-6). Estimated landcover alteration based on this scenario in the Paw Paw watershed would lead to further power metric increases of 7.5 to 9.5 units (Figure 4.1-7.).

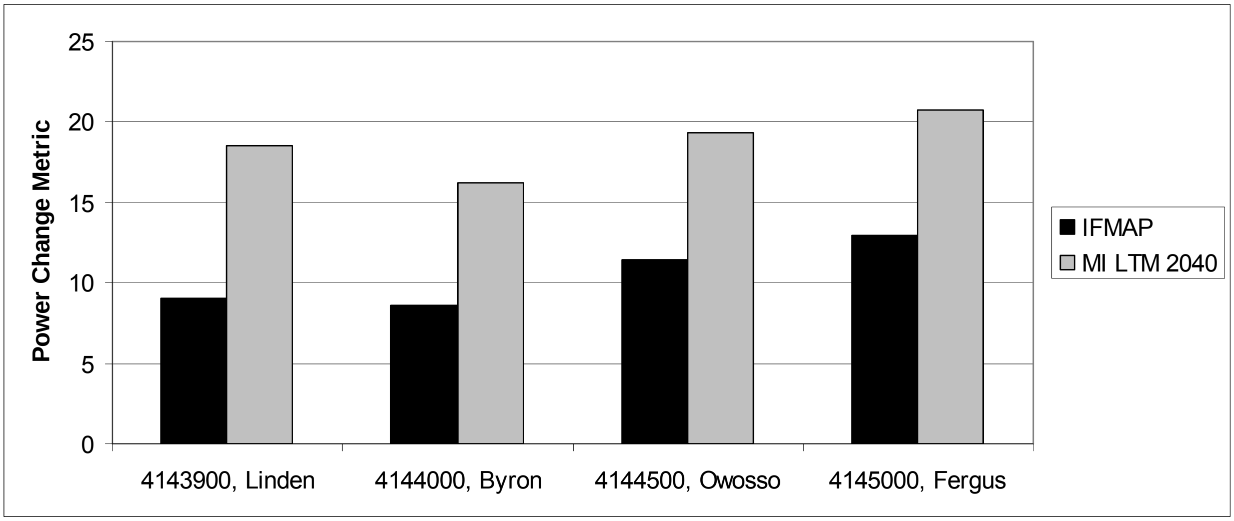

Figure 4.1-6 Power Change Metric in Gaged Subwatersheds in the Shiawassee River Watershed Under Current Land Cover (IFMAP) and Future Land Cover (MI LTM).

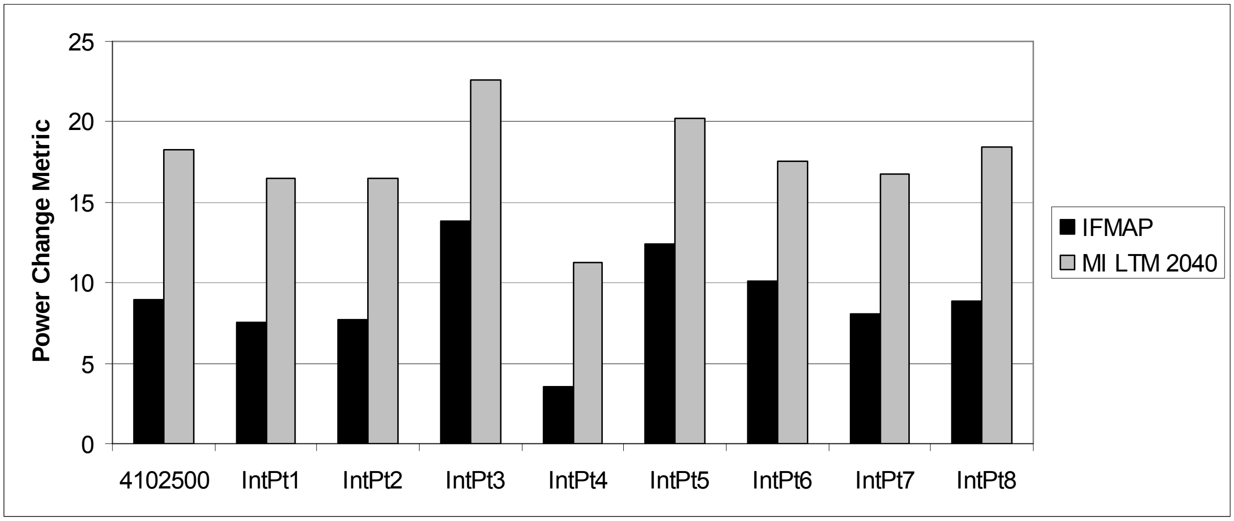

Figure 4.1-7 Power Change Metric in Gaged Subwatersheds in the Shiawassee River Watershed Under Current Land Cover (IFMAP) and Future Land Cover (MI LTM).

Many subwatersheds of the St. Joseph watershed show higher stream power change as a percent and as a power change metric than subwatersheds of the Milwaukee watershed. Given the urbanization that has occurred within the Milwaukee watershed this result seems surprising. One possible explanation would be data quality. At the time of analysis SSURGO soils were not available for the St. Joseph but were for the Milwaukee and thus STATSGO soils were used in the St. Joseph stream power analysis. In the STATSGO dataset there were obvious differences among soil types among state lines that were not explainable by geomorphic properties of the area. Further, NLCD 1992 was the best quality land cover dataset available that covered the entire St. Joseph watershed while there were at least two land cover datasets available for the Milwaukee watershed that were more recent (WISCLAND, 1998; US EPA Natural Resource Grant #97565801).

Agricultural land covers often have very high run off. Depending on the soil type they may have higher curve numbers and associated higher runoff than high intensity residential, or even commercial land covers (Table 4.1-1). 82% of the St. Joseph was classified as some form of agriculture in NLCD 1992 while a WISCLAND to NLCD cross-walk shows only 39% of the Milwaukee watershed is classified as agriculture. 17% of the Milwaukee is classified as urban while only 2% of the St. Joseph is considered urban. It is likely that the higher proportion of agriculture in the St. Joseph may be the reason the percent power change and power change metrics are higher in many of the subwatersheds in the St. Joseph than in the Milwaukee (although the fact that different resolution soils layers were used in the stream power analysis for the Milwaukee and St. Joseph should be kept in mind.)

Table 4.1-1 NLCD and corresponding TR-55 categories of land cover/land use and associated curve numbers based on soil hydrologic group.

NLCD Description	NLCD Code	TR55 Code	TR55 Class	TR55 Description	Soil Hydrologic Group						
					A	B	C	D	A/D	B/D	C/D
Open Water	11	4	Impervious areas:	Paved parking lots, roofs, driveways, etc (excluding rig	98	98	98	98	98	98	98
Perennial Ice/Snow	12	4	Impervious areas:	Paved parking lots, roofs, driveways, etc (excluding rig	98	98	98	98	98	98	98
Low Intensity Residential	21	14	Residential districts by average lot size	1/4 acre (0.25 acres)	61	75	83	87	74	81	85
High Intensity Residential	22	13	Residential districts by average lot size	1/8 acre or less (town houses) (0.13 acres)	77	85	90	92	85	89	91
Commercial/Industrial/Transporta	23	12	Urban districts:	Industrial	81	88	91	93	87	91	92
Bare Rock/Sand/Clay	31	20	Fallow	Bare soil	77	86	91	94	86	90	93
Quarries/Strip Mines/Gravel Pits	32	7	Streets and roads:	Gravel (including right-of-way)	76	85	89	91	84	88	90
Transitional	33	19	Developing urban areas	Newly graded areas (pervious areas only, no vegetation)	77	86	91	94	86	90	93
Deciduous Forest	41	65	Woods		30	55	70	77	54	66	74
Evergreen Forest	42	65	Woods		30	55	70	77	54	66	74
Mixed Forest	43	65	Woods		30	55	70	77	54	66	74
Shrubland	51	58	Brush, brush-weed mixture with brush the major element		35	56	70	77	56	67	74
Orchards/Vineyards/Other	61	61	Woods, grass combination (orchard or tree farm)		43	65	76	82	63	74	79
Grasslands/Herbaceous	71	68	Herbaceous, mixture of grass, weeds, and low-growing brush, with brush the mino		71	71	81	89	80	80	85
Pasture/Hay	81	54	Pasture, grassland, or range, continuous forage for graving		49	69	79	84	67	77	82
Row Crops	82	24	Row crops	Straight row (SR)	67	78	85	89	78	84	87
Small Grains	83	36	Small grain	SR	63	75	83	87	75	81	85
Fallow	84	22	Fallow	Crop residue cover (CR)	74	83	88	90	82	87	89
Urban/Recreational Grasses	85	2	Open space (lawns, parks, golf courses, cemeteries, etc.)	Fair condition (grass cover 50% to 75%)	49	69	79	84	67	77	82
Woody Wetlands	91	63	Woods		45	66	77	83	64	75	80
Emergent Herbaceous Wetlands	92	4	Impervious areas:	Paved parking lots, roofs, driveways, etc (excluding rig	98	98	98	98	98	98	98

In summary,

- Stream power and CN surface tools link land cover/land changes use to hydrology
- Stream power tool uses a flow accumulation approach to sum discharge in the watershed. These discharges are additive and cumulative. These properties are incorporated into the stream power calculation and can be used to assess:
    - Cumulative downstream impacts (or improvements) resulting from changes in land cover/land use
    - Effects of individual tributary flows on main stem flows
    - Effects of wetland restoration on hydrology
- Stream power metrics quantify hydrologic change in a systematic way.
    - Quantify degree of hydrologic alteration from presettlement conditions at multiple scales – from an individual stream reach/catchment to an 8-digit HUC watershed.
    - Quantify degree of hydrologic alteration in response to potential changes in land cover/landscape (what if scenarios)
- Allows comparison among stream reaches within the same watershed.
- Runs as an extension in ArcGIS and provides geographic specificity.
- Uses data that are generally publicly available.

The stream power tool is scaleable and can be used to evaluate how potential landcover changes have affected (or could potentially affect) hydrologic and hydraulic conditions in a watershed, subwatershed, catchment, or individual stream reach.

4.1.2 Water Use/Pathway Assessments

The project team considered the potential effects of water use and flow path changes on hydrology as water moves across and through watershed landscapes. Potential effects include flow augmentation of receiving waters and/or flow depletion of source waters, which may have significant water resource and/or ecological impacts. The diversion of Great Lakes water outside of the basin has received considerable attention, but the diversion of Great Lakes water within and between watersheds has not been evaluated with respect to potential impacts and/or restoration opportunities.

The project team developed a conceptual framework that identifies and describes critical flow path parameters and elements that must be considered when identifying flow path linkages to potential hydrologic impairments (or improvements). For the purpose of this project, flow paths are considered to be the paths that connect source waters with receiving waters that is diverted for anthropogenic use (e.g. public/private water supply, commercial/industrial, and irrigation). There are four critical flow path elements that need to be considered: 1) source waters, 2) diverted flows, 3) return flows, and 4) receiving waters. Parameters associated with flow path elements include the location of water withdrawal and/or return flow, the type of source or receiving water, and the volume of water withdrawn from source waters and/or returned to receiving waters.

With few exceptions, water use and water supply information are typically reported by political subdivision and/or community – not by watershed or subwatershed. This reporting framework makes it difficult to attribute water use at watershed or subwatershed scales. The pathways assessment tool was not applied to the St Joseph watershed (MI, OH, IN) due to data incompatibility issues between three different State jurisdictions. Where possible, staff from local Nature Conservancy chapters assisted the project team by identifying data sources and/or by providing the data on water use and water supplies where available for the pilot watersheds.

Diversion Ratio

Flow-path hydrologic alterations can be quantified by the proportion of water diverted for anthropogenic use and returned to a location that is substantially different from where the source water was withdrawn. The Diversion Ratio (D) is a measure of the amount of water that is withdrawn and diverted along altered flow paths compared to the total amount of water withdrawn in a watershed. In other words, it is the proportion of water withdrawn that travels along altered flow paths. Calculated source water diversion ratios for each of the three pilot watersheds are summarized in Table 4.1.2-1.

Table 4.1.2-1 Calculated Source Water Diversion Ratios (D_{sw}) by Watershed

Diversion Ratio	Groundwater	Surface water	TOTAL
Shiawassee	0.760	1.000	0.790
Paw Paw	0.940	1.000	0.950
Milwaukee	0.930	0.000	0.125

The results of these analyses show that the groundwater flow path diversion ratios for the Paw Paw and Milwaukee River watersheds are very similar, with more than 90% of the groundwater withdrawals being returned to surface waters augmenting receiving water flows. In the Shiawassee watershed, more than 75% of the groundwater withdrawals are being diverted to surface waters augmenting receiving water flows. Due to the presence of shallow aquifers in the Shiawassee watershed, there is a higher proportion of shallow (self supply) groundwater wells where waters are returned to shallow aquifers via individual septic systems, which are not considered to be flow path diversions.

Surface water diversion ratios for the Shiawassee and Paw Paw River watersheds are identical where 100% of the surface water withdrawn is diverted and returned to a surface receiving water that is located some distance from the source water withdrawal point. Source waters are potentially depleted due to these surface water withdrawals and receiving water flows are locally augmented by return flows. In the Milwaukee River basin, the surface water diversion ratio is 0.0 as all Lake Michigan surface water withdrawals are returned directly to Lake Michigan by the MMSD Jones Island and South Shore wastewater treatment plants.

In the Shiawassee watershed, 79% of the total volume of water withdrawn is returned along altered flow paths. In the Paw Paw watershed, 95% of the total volume of water withdrawn is returned along altered flow paths. In the Milwaukee River watershed, only 12.5% of the total volume of water withdrawn is returned along altered flow paths. The low overall diversion ratio in the Milwaukee River watershed is due to large Lake Michigan surface water withdrawals that are returned directly to Lake Michigan within the MMSD service area (primarily the Milwaukee metropolitan area).

Pathway Alteration Metric

The impact of flow-path alterations on receiving waters is dependent on the volume (and location) of return flows relative to the total volume of source waters and the receiving waters. The Pathway Alteration Metric (PAM) is the volume of diverted water that travels along altered flow paths relative to the total volume of source water and/or receiving water in the watershed (detailed description in section 2.2.3 and Figure 2.2.3-1). Simply, PAM is a measure of the potential impact of diverted waters on either: 1) depletion or augmentation of source waters or 2) augmentation or depletion of receiving waters in a watershed.

Receiving water PAM values were calculated for three of the four pilot watersheds. PAM values were not calculated for the St. Joseph watershed due to data compatibility limitations. A comparison of receiving water PAM values for each of the pilot watersheds is illustrated in Figure 4.1.2-1.

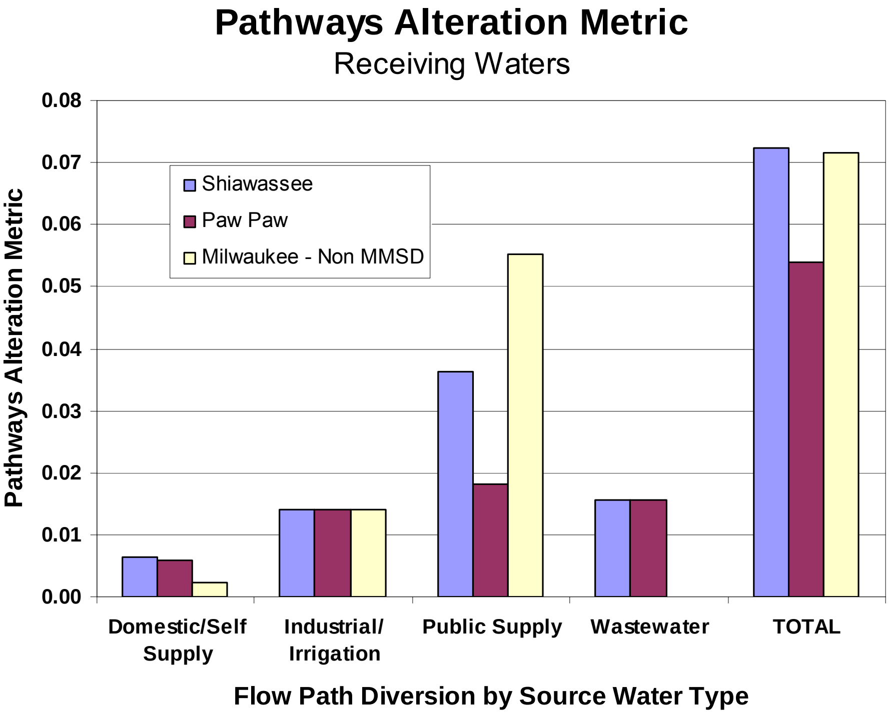

Figure 4.1.2-1 Pathways alteration metric for receiving waters broken out by source water type for three of the four pilot watersheds. Lake Michigan surface water and return flows in the Milwaukee metropolitan area not included in these plots.

Relative to receiving waters, PAM values are very low for domestic/self supply groundwater sources in all three pilot watersheds (Figure 4.3.1.-1). Industrial/irrigation and public wastewater sources are low as well. For example, wastewater flow volumes are estimated to be 1.56% of the total volume of receiving waters in the Shiawassee watershed and 1.57 % of the total volume of receiving waters in the Paw Paw watershed. Given the relatively low return flow volumes, hydrologic impacts are not measurable using existing in-stream hydrologic assessment tools.

In the Milwaukee River watershed, the primary source of return flow is the West Bend and Cedarburg WWTPs which are located upstream from the USGS Milwaukee stream gage near Cedarburg. Wastewater flow volumes are calculated to be 5.53% of the total volume of receiving waters for area of the Milwaukee River watershed not serviced by MMSD. Wastewater values are not included in the PAM calculation for the Milwaukee River watershed as public water supply volumes are approximately equal to the volume of treated wastewater in areas outside of the MMSD service area.

PAM values for public water supply source waters vary by watershed. The Paw Paw River watershed has the lowest PAM value at 0.0181 or 1.81% of total receiving water volume. The Shiawassee River watershed has a PAM value of 0.0363 or 3.63% total receiving water volume, and the Milwaukee River watershed has the highest PAM value of 0.0553 or 5.53% of total receiving water volume. The public supply PAM values are linked to population density and the number and size of incorporated areas with public water supplies.

Impacts and Opportunities

Potential impacts to the hydrologic regime include flow augmentation and flow depletion, which are influenced by the location of water withdrawal and/or return flows, the type of source or receiving water, and the volume of source water withdrawals and/or return flows to receiving waters. The magnitude of hydrologic impacts resulting from flow augmentation and/or depletion will be influenced, in part, by return flow volumes relative to receiving water volumes. High return flow volumes may result in significant hydrologic impacts, while the effects of low return flow volumes may be negligible.

Within the three pilot watersheds, the proportion of return flow volumes ranged from 1.81% to 5.53% of the total volume of receiving waters. These volumes are relatively small and may not be detectable (or measurable) at watershed or subwatershed scales. In fact, when these return flow volumes are considered at a subwatershed or catchment level, none of the in-stream hydrologic assessment tools had the resolution or sensitivity to detect flow augmentation (or depletion) due to these flow path diversions. It is likely that other scenarios exist where the potential for significant flow augmentation (or depletion) exists locally in Great Lakes watersheds. However, for the Shiawassee, Paw Paw, and Milwaukee River watersheds, the hydrologic impacts of altered flow paths appear to be negligible at watershed and subwatershed scales.

4.1.3 Flow Duration Curve Regression models

Four families of flow duration curve (FDC) models were used to estimate flows in the pilot watersheds. These models had been previously developed using data summaries from three Great Lakes States (Illinois, Michigan, and Wisconsin). These models are now being used by resource specialists in these states and similar models are in development for New York (Jana Steward, Great Lakes Aquatic Gap, personal communication). Predictors for exceedence flows used in these models fall into three basic categories: (1) general (drainage area, precipitation, slope), (2) landcover (agriculture, urban, forested wetland, open and wet, and total wetland), and (3) surficial geology (types and textures). While these models are generally good at predicting flows for current conditions they are mainly sensitive to anthropogenic disturbance through altered landcover. Exceptions might be interbasin transfers that effectively increase the drainage area or channelization that alters slope within the stream. However, this sensitivity to landcover has it limits. While the models contain predictors for wetlands and heavily altered landcover (agriculture, urban) other types of landcover are absent. Thus changes in landcovers that are not used as predictors will not affect the model output.

FDC models were applied at 39 sites including 17 gaged catchments in this study. Their application at gaged sites allowed for comparisons with IHA summaries of recorded flow data, flashiness and baseflow indices, and developing expectations based on alternative landcover scenarios (i.e., presettlement, potential future) where flow data are not available. Twenty-two catchments within the pilot watersheds were ungaged where application of FDC models allowed an assessment of the flow regime where alternative methods of assessing annual discharges (e.g., IHA analysis) would not have been possible.

Summaries from existing presettlement landcover maps allowed FDC models to estimate exceedence flows under “historic” conditions for 26 catchments within three of the pilot watersheds (Milwaukee, Paw Paw, and Shiawassee). Throughout these watersheds lands have become less forested and more agricultural and urbanized. Results of our analysis suggest that landcover change has influenced both high and low flow magnitudes. In general high flows were predicted to have declined in magnitude from presettlement to current conditions except in small catchments within highly urbanized areas (see Section 3. Watershed Results for specifics within each of the pilot watersheds).

An alternative landcover scenario was also used to assess potential changes in flow from current conditions using FDC models in the Paw Paw Pilot watershed for nine catchments. Results from this analysis suggest that further increases in urban and agricultural landcover will result in a leveling of the flow duration curve with lower high flow magnitudes and higher low flow magnitudes. These results are consistent with similar analysis conducted in Michigan on gaged streams which demonstrated lower high flow and higher low flow metrics during the later part of the 20th Century (Allan and Hinz 2004).

Summary of Flow Duration Curve model applications:

1. strength... application to non-gaged catchments where other data are not available.
2. strength... application to novel landcover conditions possible
3. weakness... models parameterized to historical data that is not always representative of the locations we are most interested in.
4. weakness... regional models fit the average condition within the area and may not be representative of the catchment of interest. Predictors that best fit the region may not be those we are most interested in for the problem being addressed (e.g., no wetland predictors for Paw Paw Watershed).

References

Allan, J.D., and L.C. Hinz Jr. 2004. An assessment of flows for rivers of the Great Lakes Basin. Final Report to the Great Lakes Protection Fund, Evanston, IL.

4.2 Hydrologic assessment tools

4.2.1 Indicators of Hydrologic Alteration

The project team completed one-period analyses for the 17 stream gages within the four demonstration watersheds where >20 years of continuous data were available. For eight gages that had especially long periods of record, the team also conducted two-period analyses to compare flow conditions during historical and recent period ‘snapshots’.

At the sites where both one- and two-period analyses were completed, the results were consistent with each other. In other words, if a specific flow statistic showed an increasing or decreasing trend over time using a one-period analysis, a two-period analysis showed that this flow statistic was higher or lower, respectively, in the recent period than in the historical period. This suggests that either the one- or two-period analysis could be used for a cursory diagnostic of how flow statistics have changed over time.

Analyses indicated that low flows – both seasonal (summer/fall) flows and annual low flow events – had increased over time in all four watersheds. There were no consistent trends in changes to high flows (high flow events and spring flows) among watersheds or among sites within the same watershed. If trends exist for high flows, they may be more difficult to detect because high flow statistics generally have high interannual variability. Many of the anthropogenic changes in these four watersheds, including conversion to developed and agricultural land cover and channel modification, could lead to increased low flows because they increase the 'efficiency' of the stream network. However, the land cover, water withdrawals and return flows, instream modification, and variations in precipitation and temperature all influence how a watershed processes precipitation. Despite the differences in land and water management among these watersheds, all four watersheds showed increased low flows. This suggests that regionwide climatic patterns may be contributing to these changes.

Of all the hydrologic assessment tools applied in this project, the IHA has the most options for describing changes to a variety of flow statistics. It calculates flow statistics that describe flow magnitude, timing, frequency and duration of flow events, and rate of change between flow events. It includes a lot of set-up options that enable the user to customize the analysis. Because daily flow data are required as input, the analyses can only be completed for sites and time periods where continuous daily flow data exist. No specific expertise is required to set up and run the analyses, although some expertise is required to interpret the output.

4.2.2 Richards-Baker Flashiness Index

The Flashiness index was calculated for all gage sites within the Milwaukee, Paw Paw, Shiawassee, and St. Joseph River watersheds. This index was useful for detecting differences in flashiness among watersheds, at different sites within watersheds, and over time. In general, flashiness was highest in the Milwaukee watershed and lowest in the Paw Paw watershed. Table 4.2.2-1 contains a summary of the differences in flashiness among sites within each watershed and changes over time.

Table 4.2.2-1 Summary of flashiness analysis in four demonstration watersheds

	Differences among sites within watershed	Change over time
Shiawassee	Flashiness higher at downstream sites than at upstream sites	Decrease in late 1960s – early 1980s Slight increase since early 1980s at sites where data exist
St. Joseph	Flashiness higher at upstream sites than at downstream sites	Increase since 1970s
Paw Paw	Only complete for one site	Decrease up to 1970s Increase since 1970s
Milwaukee	Flashiness higher at Menomonee subwatersheds than Milwaukee subwatersheds	Slight increase since 1970s

In general, flashiness increased in all watersheds since 1970s, although trends were weak. These increases results are consistent with the expectation that increases in anthropogenic land cover (developed and agricultural land) would increase flashiness.
This index was also useful for detecting differences among sites within the same watershed.

The flashiness index is simple to calculate using a spreadsheet provided by Richards and Baker. Because daily flow data are required as input, the index can only be calculated for sites and time periods where continuous data exist.

4.2.3 Flow/precipitation ratio

The ratio of flow yield to precipitation was calculated for one site in each of three demonstration watersheds (Milwaukee, Shiawassee, and Paw Paw). This ratio increased in summer and winter months in all three watersheds. In the Milwaukee and Shiawassee watersheds, the ratio increased in all months. In the Paw Paw, it increased in all months except March and September. These results are consistent with the expectation that increases in anthropogenic land cover (developed and agricultural land) with in a watershed may increase the volume of precipitation delivered to the stream channel as a consequence of the loss of storage in natural land cover types (wetlands and forest).

The Q/P ratio is a simple and potentially useful preliminary analysis to better understand whether changes in precipitation volume could explain changes in flow magnitudes. Because the results were consistent among all three watersheds, it does suggest that even though precipitation volume may not be able to fully explain increases in flow yield, some other regional factor (e.g., precipitation intensity, whether precipitation falls as rain or snow, temperature) may contribute to these changes. This tool also has a few weaknesses. The calculation is quick and simple, but it is a coarse analysis. The assumption is that the precipitation recorded at the gage represents precipitation falling throughout the watershed. If either the stream gage or precipitation gage are affected by lake effect precipitation or precipitation is highly variable locally, these results may not accurately reflect precipitation patterns throughout the watershed. Also, precipitation and flow data may not be available for many sites within a watershed and, even if they are, the period of record may not overlap.

4.2.4 Baseflow Separation Algorithms and Baseflow Index Models

The team evaluated trends in baseflow index for three of the four demonstration watersheds (Milwaukee, Shiawassee, and St. Joseph). In the St. Joseph River, there was no discernable trend over time, nor were there clear differences in baseflow index values among sites. There are slight increasing trends in baseflow index values at most sites within the Milwaukee and Shiawassee Rivers, especially since 1960. Within watersheds there was not much difference in baseflow index values among sites.

Two of three watersheds showed increasing trends in baseflow. Estimates of baseflow index strongly correlated with total flows. The trends in the baseflow index are consistent with increased total flows during period of record. Analysis of trends in baseflow index requires that baseflow separation algorithms be run and then these results summarized. The separation algorithms have already been completed for Great Lakes states and Ontario by Neff et al. (2005), but in places where these results do not exist, this requires a lot of processing. Given that this analysis does not provide much more information than analysis of trends in total flow, the effort is probably not worth it.

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5. SUMMARY AND LESSONS LEARNED

The project team has developed tools and metrics to assess hydrologic alterations resulting from anthropogenic changes to the watershed. These tools can be applied at multiple watershed and subwatershed scales. Three different types or classes of tools (and metrics) were developed during this project:

1) **Basinwide Screening** tool designed to identify areas with significant hydrologic impairments at regional (i.e. basinwide) scales.

2) **Watershed Assessment** tools and metrics designed to assess and measure the cumulative impact of changes on the land surface (land cover and flow path alterations) on watershed hydrology. These tools (stream power, CN surface/wetland water retention, pathways) are especially useful for scenario testing, comparing different types and combinations of restorative actions, and/or hypothetical “what-if” analyses. In general, these tools are spatially but not temporally explicit.

3) **Hydrologic Assessment** tools and metrics designed to assess and measure the in-stream impact of changes on the land surface (land cover, flow path and channel alterations) on the fundamental characteristics of flow, i.e. magnitude, frequency, timing, duration, and rate-of-change in Great Lakes watersheds. In general, these tools are temporally, but not spatially explicit and highly effective testing time-dependent hypotheses using site-specific data.