Ox Creek TMDL Development --
Linkage Analysis

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Prepared for

U.S. Environmental Protection Agency -- Region 5
Michigan Department of Environmental Quality

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Acronyms and Abbreviations

CWA	Clean Water Act
ESB	equilibrium partitioning sediment benchmark
ESBTU	equilibrium partitioning sediment benchmark toxicity unit
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FCV	final chronic value
GIS	Geographic Information System
IC	impervious cover
LA	load allocation
LSPC	Loading Simulation Program C++
LTA	long-term average
MDEQ	Michigan Department of Environmental Quality
MS4	Municipal Separate Storm Sewer System
NCDC	National Climatic Data Center
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
OIALW	Other Indigenous Aquatic Life and Wildlife Designated Use
PAHs	polynuclear aromatic hydrocarbons
PEC	probable effect concentration
SETP	Sediment Erosion Transport Predictor
SSC	suspended sediment concentration
TMDL	Total Maximum Daily Load
TOC	total organic carbon
TSS	total suspended solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WC&SA	Watershed Characterization and Source Assessment
WLA	waste load allocation
WSA	Wadeable Streams Assessment

Executive Summary

Ox Creek is a warm water stream located in southwest Michigan. The creek flows through Benton Harbor where it joins the Paw Paw River. Ox Creek appears on Michigan's §303(d) list as a result of biological impairments *(LeSage and Smith, 2010)*. Possible causes of non-attainment of the designated use have been listed as: sedimentation/siltation, oil and grease, chromium (total), lead, solids (suspended / bedload), and cause unknown. Sources identified by MDEQ for the aforementioned causes are stream bank modifications / destabilization, impervious surface / parking lot runoff, and urban runoff / storm sewers.

The poor macroinvertebrate community could also be attributed to a lack of suitable habitat for colonization (due to past channel alterations and siltation). In addition, high storm water flows likely bring additional pollutant and sediment loads to the stream that further degrades the habitat. The complexity of water quality concerns in the Ox Creek watershed has resulted in several investigations that have included biological assessments, sediment sampling, total suspended solids and flow monitoring, and water chemistry sampling.

An essential component of TMDL development is establishing a relationship between numeric indicators intended to measure attainment of designated uses and source loads. The linkage analysis examines connections between water quality targets, available data, and potential sources. A detailed evaluation of available information serves as the starting point for this linkage analysis (presented in Sections 3 through 7).

TMDL development for impaired streams based on biological monitoring data requires identification of a pollutant that is adversely affecting the aquatic community (macroinvertebrates in the case of Ox Creek). The macroinvertebrate community structure data coupled with qualitative observations indicates that siltation due to excess sediment loads is contributing to biological impairments in Ox Creek. Total suspended solids (TSS) targets are identified for use in the Ox Creek TMDL (presented in Section 8).

In order to relate source information to water quality monitoring results, the Ox Creek watershed was partitioned into nine subwatershed units. This facilitates an integrated evaluation of all information at a monitoring site scale. The subwatershed framework is needed because different factors appear to influence the biology at each location. Individual subwatershed assessments are presented in Section 9. An overall examination of Ox Creek's response to watershed loading is the last component of the linkage analysis (presented in Section 10).

1. Overview

Ox Creek is on Michigan's §303(d) list as a result of biological impairments *(LeSage and Smith, 2010)*. The biological impairments were determined by a poor macroinvertebrate community. The AUID for Ox Creek is 040500012509-02 and is not meeting the *"Other Indigenous Aquatic Life and Wildlife Designated Use"* (OIALW). Possible causes of non-attainment of the designated use have been listed as: sedimentation/siltation, oil and grease, chromium (total), lead, solids (suspended / bedload), and cause unknown. Possible sources identified in the §303(d) listing by MDEQ for the sedimentation/siltation and solids (suspended/bedload) causes include; stream bank modifications / destabilization, impervious surface / parking lot runoff, and urban runoff / storm sewers. The possible sources identified for the remaining toxic causes are listed as contaminated sediments, industrial point source discharges, municipal point source discharges, and unspecified urban stormwater.

Although MDEQ has identified possible causes and sources of causes for non-attainment for Ox Creek, the cause and sources of what is contributing to the biological impairment remains in question. The purpose of the Linkage Analysis report is to analyze available information and data to determine the cause(s) and sources that are contributing to the biological impairment for Ox Creek and to identify a target for the TMDL. The focus of the linkage analysis is to:

- identify key indicators through a stressor identification process;
- interpret watershed loadings and receiving water responses to those loadings; and
- describe logic used to develop TMDL targets and allocations.

Because TMDL requirements under the Clean Water Act (CWA) require that a pollutant be the cause of the impairment, this document identifies the pollutant to which the TMDL will be written.

Urban development introduces contaminants (human waste, pesticides, industrial chemicals) to the watershed where the development occurs. Impervious surfaces and artificial drainage systems speed the delivery of contaminants to streams, while bypassing soil filtration and local riparian processes that can mitigate the effects of these contaminants, and disrupting the timing and volume of hydrologic patterns. Aquatic habitats where biota live are degraded by sedimentation, channel incision, floodplain disconnection, substrate alteration and elimination of reach diversity. These compounding changes ultimately lead to an alteration of invertebrate community structure and function. Because the effects of urbanization on stream ecosystems are complex, multilayered, and interacting, modeling these effects presents many unique challenges, including: addressing and quantifying processes at multiple scales, representing major interrelated simultaneously acting dynamics at the system level, incorporating uncertainty resulting from imperfect knowledge, imperfect data, and environmental variability, and integrating multiple sources of available information about the system into the modeling construct. The complexity of water quality concerns in the Ox Creek watershed resulted in several investigations, which included biological assessments, sediment sampling, TSS and flow monitoring, and water chemistry sampling.

Developing TMDLs requires a combination of technical analysis, practical understanding of important watershed processes, and interpretation of watershed loadings and receiving water responses to those loadings. An essential component of TMDL development is establishing a relationship between numeric indicators intended to measure attainment of designated uses and pollutant source loads. The linkage analysis examines connections between water quality targets, available data, and potential sources.

2. Potential Stressors

Biological assessments are useful in detecting aquatic life impairment. Although biological assessments are critical tools for evaluating the condition of aquatic life uses, they do not identify the cause or causes of impairment. EPA developed the *"Stressor Identification Guidance Document"* to assist water resource managers in identifying stressors or combinations of stressors that cause biological impairment *(USEPA, 2000)*. Elements of the stressor identification process have been used to evaluate and identify the primary stressors of the benthic community in other TMDLs. Examples include Eagleville Brook, Connecticut and Accotink Creek, Virginia.

Basically, the stressor identification process involves critically reviewing available information, forming possible stressor scenarios that might explain the impairment, analyzing those scenarios, and producing conclusions about which stressor or stressors are causing the impairment *(USEPA, 2000)*. Stressor identification typically consists of three steps *(Figure 2-1)* that include: 1) listing candidate causes; 2) analyzing evidence; and 3) characterizing causes.

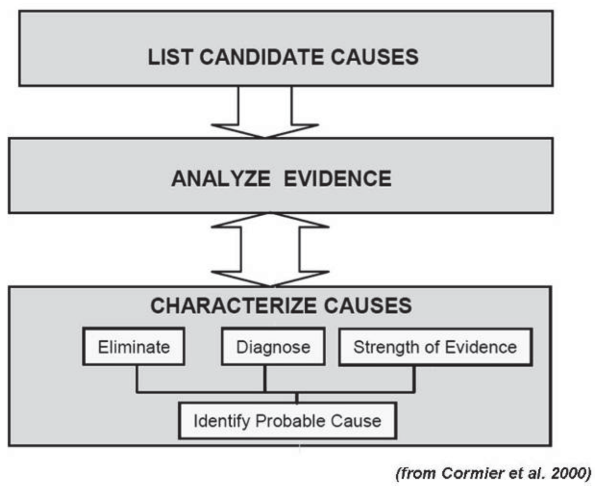


Figure 2-1. Overview of stressor identification process.

2.1 Candidate Causes

The first step in the stressor identification process is to develop a list of candidate causes (or stressors) that will be evaluated. This is accomplished by carefully describing the effect that is prompting the analysis (e.g., unexplained absence of mayflies, stoneflies, and caddisflies). Following a description of the biological concern, available information relevant to the situation is gathered and potential causes identified.

Evidence may come from the area of interest, other similar situations, or knowledge of biological processes or mechanisms. A key piece of information to be documented is a careful description of the effect that prompted the evaluation. Whenever possible, the impairment should be described in terms of its nature, magnitude, and spatial and temporal extent. Making inferences about causes is easier when the impairment is defined in terms of a specific effect, or response that is quantified as a count (e.g., abundance of isopods, snails, and leeches).

With respect to Ox Creek, example metrics that may help characterize the biological impairment include:

- altered community structure such as the absence, reduction, or dominance of a particular taxon (e.g., increase of tolerant species);
- loss of species or shifts in abundance;
- response of indicators designed to monitor or detect biological, community, or ecological condition, such as an index of biotic integrity.

In addition to describing the impairment, it is useful to prepare a background statement articulating the steps taken that revealed the biological impairment. In Michigan, Procedure 51 for wadeable streams describes the process for conducting biological field evaluations and for determining impairment conditions *(MDEQ 1990; Creal et al., 1996).* If conditions are below expectations, it is important to discuss how the quality or condition of the stream compares to other streams.

Outputs of the initial step are a *"candidate causes"* list. A conceptual model that shows cause and effect relationships may also be included. Conceptual models provide a good way to communicate hypotheses and assumptions about how and why effects are occurring. Models can also show where different causes may interact.

The Ox Creek TMDL Development Watershed Characterization and Source Assessment (WC&SA) report presents background information and describes possible causes of non-attainment *(Tetra Tech, 2010).* These include:

- Increased sedimentation
- Impaired in-stream habitat
- High storm water flows
- Presence of toxic pollutants

In some watersheds nutrients, dissolved oxygen, and pH may also be potential stressors. However, data collected in Ox Creek does not suggest these parameters to be a concern (based on the low percentage of surface dependent macroinvertebrates and lack of nuisance vegetation).

2.2 Available Evidence

The second step, analyzing evidence, involves evaluating the information related to each of the potential causes. Virtually everything that is known about an impaired aquatic ecosystem is potentially useful in this step. The WC&SA described biological studies and water quality investigations conducted on Ox Creek. This report summarized results for parameters and factors that could contribute to the impairment of biological communities in Ox Creek. Key findings from the WC&SA are highlighted in Table 2-1 as they relate to candidate causes.

Major problems reflected in the bioassessment data are associated with macroinvertebrate communities. These aquatic organisms are good indicators of stream health. Macroinvertebrate communities tend to be more sensitive to habitat alterations, to changes in substrate composition from siltation, or to the presence of toxic compounds. Overall, data suggests that increased sedimentation, degraded habitat, high storm water flows, and toxics are the highest concerns relative to biological impairments in Ox Creek.

Table 2-1. Potential stressors contributing to biological impairments.

Stressor	Importance	Key WC&SA Findings
Increased Sedimentation	**Most Probable**	Physical observations and water quality data coupled with bioassessment information provide strong evidence that siltation is a significant source of stress to biological communities in Ox Creek. In addition to siltation, suspended solids serve as a potential transport mechanism for toxic pollutants.
Impaired In-stream Habitat	**Possible**	
High Storm Water Flows	**Most Probable**	An analysis of flow data indicates that the *"flashiness"* of Ox Creek is in the upper quartile of all Michigan streams in the same size category.
Toxics	**Possible**	Monitoring data show Ox Creek to have elevated levels of heavy metals in bottom sediments (e.g., arsenic, chromium, copper, lead, zinc), and polynuclear aromatic hydrocarbons (PAHs) in the water column and sediment *(Lipsey, 2007)*.

Sections 3 through 7 of this Linkage Analysis expand on data and information presented in the WC&SA. These sections begin with a detailed analysis of the bioassessment information (Section 3). The discussion includes an examination of factors such as community structure, which could provide evidence that prioritizes those stressors of greater concern. Similarly, the other sections (4 through 7) build on the WC&SA analyses and explore ways to strengthen the connections between monitoring data and impairment causes.

2.3 Characterizing Causes

In the third step (characterize causes) the evidence is used to eliminate, to diagnose, and to compare the strength of evidence in order to identify a probable cause(s). The input information includes a description of the effects to be explained, the set of potential causes, and the evidence relevant to the characterization. Evidence is brought in and analyzed as needed until sufficient confidence in the causal characterization is reached. Section 9 completes the stressor identification process by using evidence presented in Section 3 through 7 in the context of individual subwatersheds.

3. Bioassessment Information

Ox Creek contains a mix of pools, runs, and riffles that were targeted for biological assessment with a focus on benthic macroinvertebrates. Benthic macroinvertebrates live throughout the stream bed, attaching to rocks and woody debris and burrowing in sandy stream bottoms and among the debris, roots, and grasses that collect and grow along the water's edge. Biologists have been studying the health and composition of benthic macroinvertebrate communities in streams for decades. As a result, benthic macroinvertebrates are widely used to determine biological condition. These organisms can be found in all streams, even in the smallest streams that cannot support fish.

Macroinvertebrate community data provide the most significant basis for identifying non-attainment of the aquatic life designated use in Ox Creek. Because they are relatively stationary and cannot escape pollution, macroinvertebrate communities integrate the effects of stressors over time (i.e., pollution-tolerant species will survive in degraded conditions, and pollution-intolerant species will die). These communities are also critically important to fish because most game and non-game species require a good supply of benthic macroinvertebrates as food. Studies in Ox Creek indicate that impairment of the macroinvertebrate community is due to loss of sensitive taxa and compositional shift toward more tolerant generalist taxa. The end result is a very simplified community structure and altered functional resiliency.

This section summarizes the results of macroinvertebrate studies in Ox Creek, as well as presents information on an approach used to support national studies.

3.1 Procedure 51

The Great Lakes and Environmental Assessment Section (GLEAS) Procedure 51 for wadeable streams was used to evaluate conditions at each site *(MDEQ, 1990; Creal et al, 1996)*. This section provides a closer examination of specific metrics used in Procedure 51. In particular, the question *"What aspects of Procedure 51 can be used to help identify potential stressors?"* is explored. In addition, several other biological assessment methods are reviewed relative to potential approaches that could be used to expand the utility of Ox Creek biological data.

Procedure 51 uses metrics that rate macroinvertebrate communities from excellent (+5 to +9) to poor (-5 to -9). Scores from +4 to -4 are rated acceptable. Negative scores in the acceptable range are considered tending towards a poor rating, while positive scores in the acceptable range are tending towards an excellent rating. The individual Procedure 51 metrics are described in Table 3-1 along with their expected response to declining stream conditions.

Table 3-1. Procedure 51 macroinvertebrate metrics.

	Metric	Description	Expected Response to Disturbance
1	Total Number of Taxa.	Taxa richness has historically been a key component in most all evaluations of macroinvertebrate subsample. The underlying reason is the basic ecological principle that healthy, stable biological communities have high species diversity. Increases in number of taxa are well documented to correspond with increasing water quality and habitat suitability. Small, pristine headwater streams may, however, be exceptions and show low taxa richness.	Decrease
2	Total Number of Mayfly Taxa.	Mayflies are an important component of a high quality stream biota. As a group, they are decidedly pollution sensitive and are often the first group to disappear with the onset of perturbation. Thus, the number of taxa present is a good indicator of environmental conditions.	Decrease
3	Total Number of Caddisfly Taxa.	Caddisflies are often a predominant component of the macroinvertebrate fauna in larger, relatively unimpacted streams and rivers but are also important in small headwater streams. Through tending to be slightly more pollution tolerant as a group than mayflies, caddisflies display a wide range of tolerance and habitat selection among species. However, few species are extremely pollution tolerant and, as such, the number of taxa present can be a good indicator of environmental conditions.	Decrease
4	Total Number of Stonefly Taxa.	Stoneflies are one of the most sensitive groups of aquatic insects. The presence of one or more taxa is often used to indicate very good environmental quality. Small increases or small declines in overall numbers of different stonefly taxa is thus very critical for correct evaluation of stream quality.	Decrease
5	Percent Mayfly Composition.	As with the number of mayfly taxa, the percent abundance of mayflies in the total invertebrate sample can change dramatically and rapidly to minor environmental disturbances or fluctuations.	Decrease
6	Percent Caddisfly Composition.	As with the number of caddisfly taxa, percent abundance of caddisflies is strongly related to stream size with greater proportions found in larger order streams. Optimal habitat and availability of appropriate food type seem to be the main constraints for large populations of caddisflies.	Decrease
7	Percent Contribution of the Dominant Taxon.	The abundance of the numerically dominant taxon is an indication of community balance. A community dominated by relatively few taxa for example, would indicate environmental stress, as would a community composed of several taxa but numerically dominated by only one or two taxa.	Increase
8	Percent Isopods, Snails, and Leeches.	These three taxa, when compared as a combined percentage of the invertebrate community, can give an indication of the severity of environmental perturbation present. These organisms show a high tolerance to a variety of physical and chemical parameters. High percentages of these organisms at a sample site are very good evidence for stream degradation.	Increase
9	Percent Surface Dependent.	This metric is the ration of the number of macroinvertebrates which obtain oxygen via a generally direct atmospheric exchange, usually at the air/water interface, to the total number of organisms collected. High numbers or percentages of surface breathers may indicate large diurnal dissolved oxygen shifts or other biological or chemical oxygen demanding constraints. Areas subject to elevated temperatures, low or erratic flows may also show disproportionately high percentages of surface dependent macroinvertebrates.	Increase

Biological assessment scores for Ox Creek were reported by Lipsey (2007) and have been summarized in the *"Ox Creek TMDL Development -- Watershed Characterization and Source Assessment Report" (Tetra Tech, 2010)*. Scores for Blue Creek were included in both reports. Blue Creek is the adjacent watershed located just north of the headwaters of Ox Creek. Macroinvertebrate scores in Blue Creek were acceptable and offer a potential opportunity to serve as a reference site for evaluating Ox Creek data since waterbodies with an acceptable score are determined to be supporting the other indigenous aquatic life and wildlife use, similarity in physical and chemical characteristics, and because of their close proximity. In addition, data from Pipestone Creek and Hickory Creek were examined. These streams are located in the Benton Harbor area and also support the other indigenous aquatic life and wildlife use.

Table 3-2 summarizes results for individual metrics at each station *(Lipsey, 2007; Rockafellow, 2002)*. Generally, all Ox Creek stations scored less than average on metrics 2 through 6 due to insufficient numbers of mayfly, stonefly, and caddisfly taxa (one exception was the 2006 bioassessment at Crystal Avenue, where Metric 2 scored *"Average"*). These taxa are relatively intolerant (i.e., typically the first organisms to disappear). In addition, most sites scored less than average on metrics 7 and 8. Metric 7 (percent contribution of dominant taxa) reflects community balance (e.g., a community dominated by relatively few taxa typically indicate environmental stress). Similarly, metric 8 (percent isopods, snails, and leeches) reflect the presence of a high number of pollution tolerant organisms.

Figure 3-1 through Figure 3-4 present a graphic display of key individual P51 metrics, notably the relative percentages of mayflies, caddisflies, dominant taxa, and intolerant taxa (i.e., isopods, snails, and leeches). The *"Above Average"* on each graph corresponds to an individual metric score of +1. This means that the community based on that metric is performing better than the average condition at excellent sites in that ecoregion *(Creal, et al, 1996)*. Conversely, the *"Poor"* corresponds to an individual metric score of -1; meaning that the site is outside of (minus) two standard deviations from the average condition at excellent sites *(Creal, et al, 1996)*.

The mayfly and caddisfly composition in Ox Creek is virtually non-existent compared to Blue, Pipestone, and Hickory Creeks (Figure 3-1 and Figure 3-2). The absence of these pollution intolerant organisms clearly supports inclusion of all potential stressors listed in Table 2-1 (increased sedimentation, impaired in-stream habitat, high storm water flows, toxics, and low dissolved oxygen). Any of these stressors individually would result in a significant decrease in mayflies and caddisflies.

The relatively high percentage of dominant taxa at all Ox Creek sites (Figure 3-3) is also indicative of degraded conditions. However, the dominant taxa vary between sites as shown in Table 3-3. This supports the importance of the individual subwatershed assessments, which more closely examine site-specific factors (as presented in Section 9). Figure 3-4 also confirms the importance of the individual subwatershed assessments. For example, the Yore-Stouffer Drain at Meadowbrook Road has a higher percentage of isopods, snails, and leeches than other Ox Creek sites.

Differences between these sites need to be examined for factors that could contribute to biological impairments. A compositional shift from sensitive species towards more tolerant species, such as isopods, snails and leeches, is indicative of degraded habitat and / or water quality conditions. Evaluating these trends in each subwatershed allows for evaluation of localized factors that could contribute to biological impairments in a specific reach. Subwatershed assessments that evaluate local trends are included in Section 9 of this document.

Table 3-2. Procedure 51 macroinvertebrate data summary.

Stream	Location	Year	Procedure 51 Metric								
			1	2	3	4	5	6	7	8	9
Yore-Stouffer Drain	Meadowbrook	2006	13	**0**	**1**	**0**	**0.00**	**0.31**	**50.00**	**63.52**	1.26
Ox Creek	Crystal Ave	2001	16	**0**	**0**	**0**	**0.00**	**0.00**	35.00	4.00	7.00
		2006	18	2	**0**	**0**	**0.78**	**0.00**	**44.53**	**14.84**	1.95
	Britain Ave	2006	13	**0**	**0**	**0**	**0.00**	**0.00**	**48.01**	**20.58**	0.72
	Water St	2006	20	**1**	**0**	**0**	**0.37**	**0.00**	**52.24**	8.96	3.73
	5th Ave	2001	16	**0**	**0**	**0**	**0.00**	**0.00**	29.00	**22.00**	8.00
Potential Reference Sites											
Blue Creek	Park	2006	18	**1**	3	**0**	7.01	8.23	25.91	**12.20**	0.61
	Territorial	2001	19	2	3	**0**	21.00	14.00	20.00	6.00	3.00
	Euclid	2006	27	3	4	1	6.53	30.24	26.46	5.15	1.72
Pipestone Creek	Naomi *(east)*	2006	23	**0**	2	**0**	**0.00**	29.93	29.93	**17.88**	6.93
	Old Pipestone	2001	26	**1**	2	**0**	**3**	19	23	3	4
	Naomi *(west)*	2006	22	2	3	**0**	5.03	11.32	31.45	**18.24**	0.63
	Hillandale Rd	2001	21	2	2	**0**	15	11	20	3	4
Hickory Creek	Snow	2006	20	**1**	**1**	**0**	**1.17**	**1.17**	**44.28**	**48.39**	7.33
	Stevensville Rd	2001	21	2	3	**0**	13	8	30	**11**	3
	Maiden Lane	2001	18	2	4	**0**	17	9	29	**16**	2
	Cleveland	2006	23	2	6	**0**	7.96	19.38	24.91	**12.46**	16.26

Note on cell shading:

- (light green cell) Light green cell indicates that the macroinvertebrate community is performing better than the average condition typically found in this ecoregion (above two standard deviations).
- (light diagonal cell) Light diagonal cell in **bold** indicates that the macroinvertebrate community is performing less than the average condition typically found in this ecoregion (below two standard deviations).

Table 3-3. Dominant taxa at Ox Creek 2006 macroinvertebrate sites.

Site	Dominant Taxa	Percentage
Yore-Stouffer Drain at Meadowbrook Road	Physidae (Gastropods)	50.0
Ox Creek at Crystal Avenue	Amphipoda (scuds)	44.5
Ox Creek at Britain Avenue	Oligochaeta (worms)	48.0
Ox Creek at Water Street	Oligochaeta (worms)	52.2

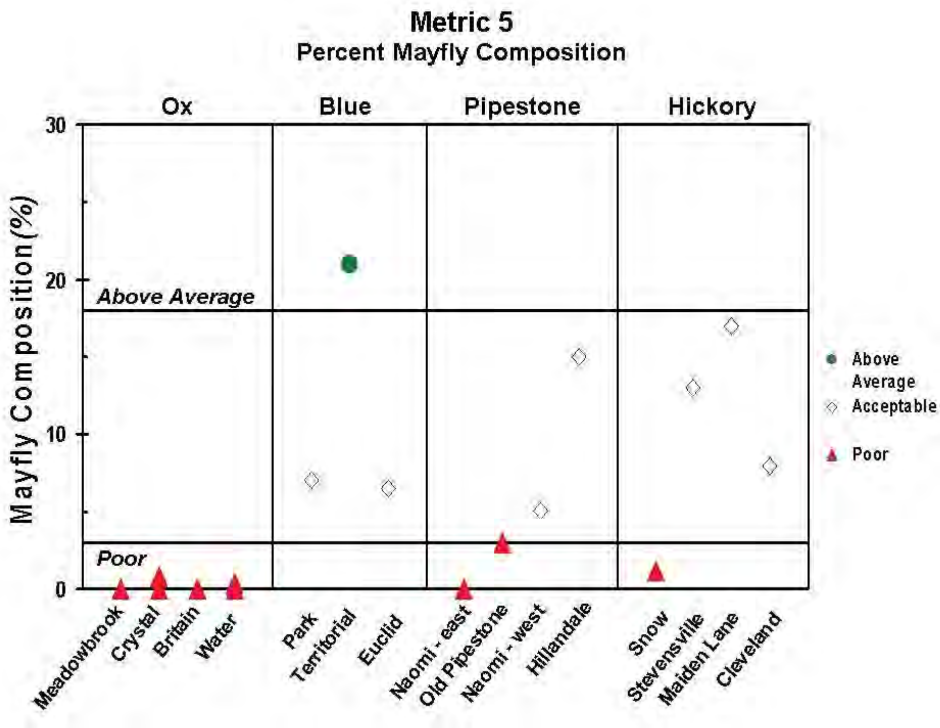


Figure 3-1. Mayfly composition in Ox Creek compared to Blue, Pipestone, and Hickory Creeks.

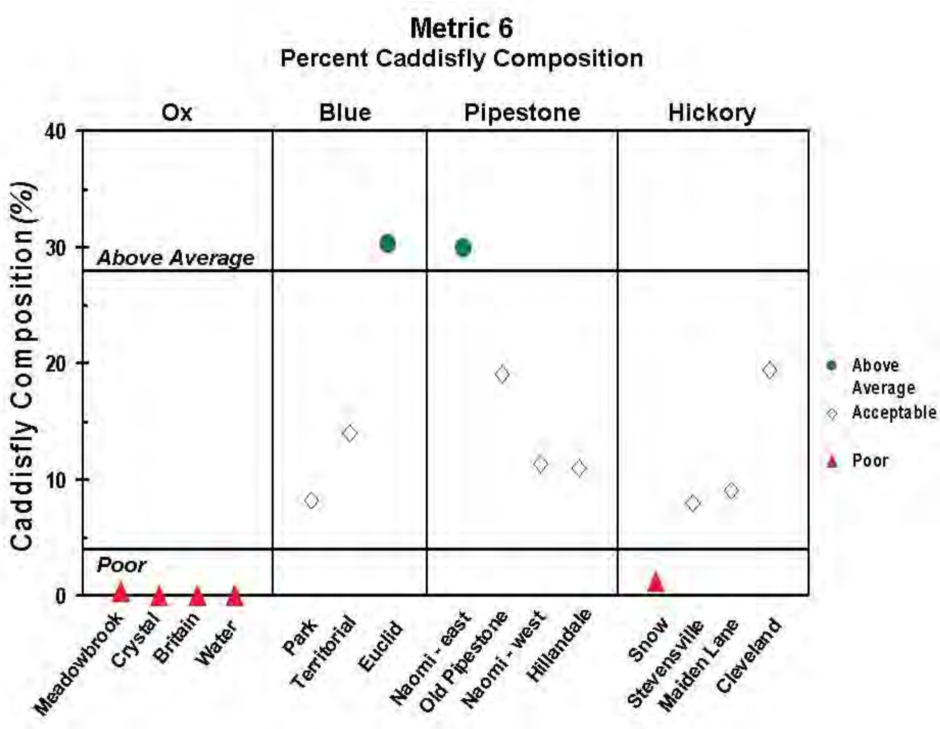


Figure 3-2. Caddisfly composition in Ox Creek compared to Blue, Pipestone, and Hickory Creeks.

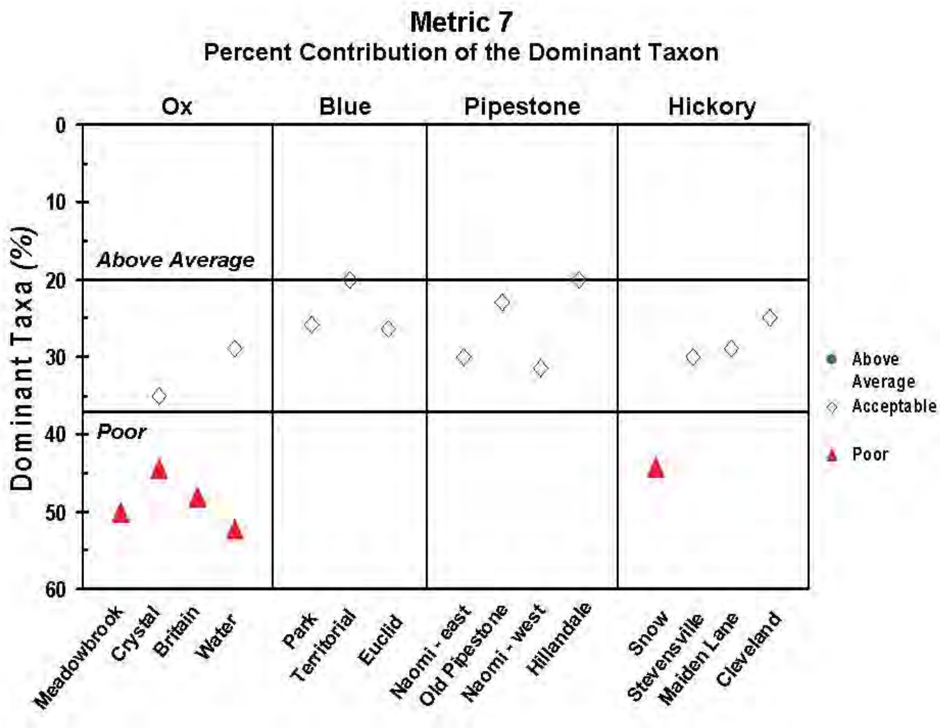


Figure 3-3. Dominant taxa percentage in Ox Creek compared to Blue, Pipestone, and Hickory Creeks.

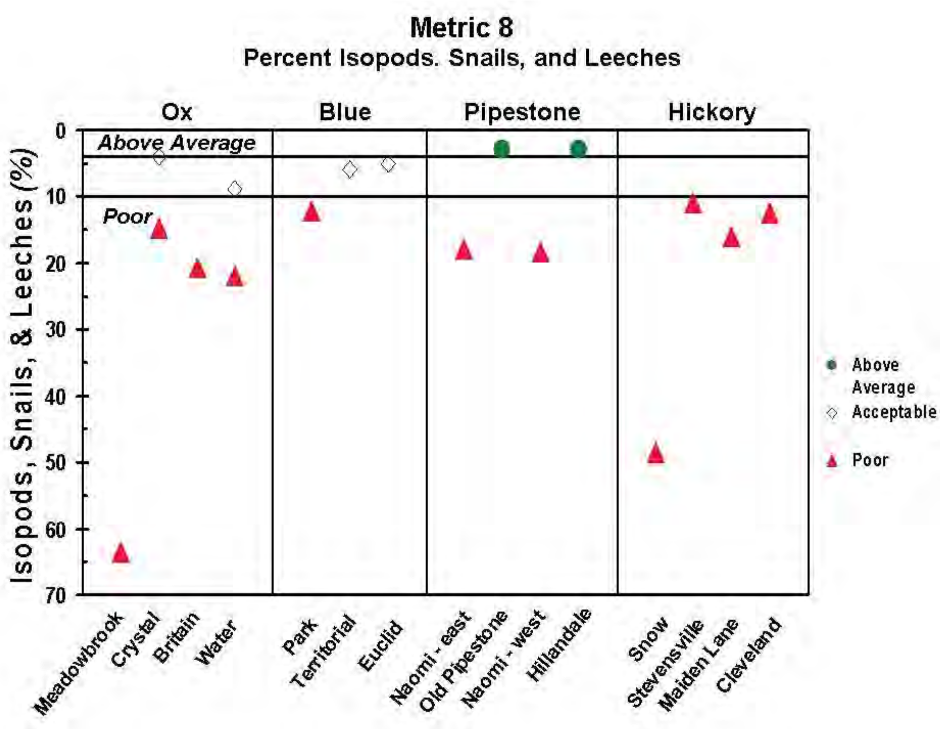


Figure 3-4. Isopod, snails, and leeches percentage in Ox Creek, Blue, Pipestone, and Hickory Creeks.

3.2 National Wadeable Stream Assessment

In December 2006, the USEPA published the *"Wadeable Streams Assessment"* (WSA) *(USEPA, 2006)*. One major purpose of this effort was to describe the biological condition of streams across the U.S. using direct measures of aquatic life. The WSA focused on the use of benthic macroinvertebrates (e.g., aquatic larval stages of insects, crustaceans, worms, mollusks) as the biological indicator of a stream's ecological condition. As indicated in the Procedure 51 discussion, macroinvertebrates possess the inherent capacity to integrate the effects of the stressors to which they are exposed, in combination and over time. Stream macroinvertebrates generally cannot move very quickly or very far; therefore, they are affected by, and may recover from, a number of changes in physical conditions (e.g., habitat loss), chemical conditions (e.g., excess nutrients), and biological conditions (e.g., the presence of invasive or non-native species). Some types of macroinvertebrates are affected by these conditions more than others.

Ecologists evaluate the biological condition of water resources, including wadeable streams, by analyzing key characteristics of the communities of organisms that live in these waterbodies. These characteristics include the composition and relative abundance of key groups or taxa. Specifically, the WSA used two measures: the Macroinvertebrate Index (MMI) of Biotic Condition and the Observed/Expected (O/E) Ratio of Taxa Loss. Several metrics were used to determine the Macroinvertebrate Index. Factors considered include taxonomic richness, habit and trophic composition, sensitivity to human disturbance, and other biotic aspects that reflect "naturalness." The metrics used to develop the Macro-invertebrate Index for the WSA covered six different characteristics of macroinvertebrate assemblages that are commonly used to evaluate biological condition including:

- Habit metric (based on % Burrower taxa)
- Feeding Group Metric (based on Scraper richness)
- Richness metric (based on Ephemeroptera richness)
- Composition metric (based on % EPT taxa)
- Diversity metric (based on Shannon-Weiner diversity)
- Pollution Tolerance metric (based on intolerant richness)

Table 3-4 elaborates on the importance of each metric with information provided in the Wadeable Streams Assessment Report.

Table 3-4. Key metrics that assess the influence macroinvertebrate assemblages.

Metric	**Description** (*from EPA Wadeable Streams Assessment, 2006)*
Habit	Benthic macroinvertebrates are characterized by certain habits, including how they move and where they live. For example, some taxa burrow under the streambed sediment, whereas others cling to rocks and debris within the stream channel. A stream that naturally includes a diversity of habitat types will support animals with diverse habits. However, if a stream becomes laden with silt, the macroinvertebrates that cling, crawl, and swim will be replaced by those that burrow.
Feeding Group	Many macroinvertebrates have specialized strategies to capture and process food from their aquatic environment. As a stream degrades from its natural condition, the distribution of animals among the different feeding groups will change. For example, as a stream loses its canopy (a source of leaves and shading), the aquatic community will shift from a more diverse food chain to one of predominantly algal-feeding animals that are tolerant of warm water.
Taxonomic Richness	This characteristic represents the number of distinct taxa, or groups of organisms, identified within a sample. Many different kinds of distinct taxa, particularly those that belong to pollution-sensitive insect groups, indicate a variety of physical habitats and food sources and an environment exposed to generally lower levels of stress.
Taxonomic Composition	Ecologists calculate composition metrics by identifying the different taxa groups, determining which taxa in the sample are ecologically important, and comparing the relative abundance of organisms in those taxa to the whole sample. Healthy stream systems have organisms from across many different taxa groups, whereas unhealthy stream systems are often dominated by a high abundance of organisms in a small number of taxa that are tolerant of pollution.
Taxonomic Diversity	Diversity looks at all taxa groups and distribution of organisms among those groups. Healthy streams should have a high level of diversity throughout the assemblage.
Pollution Tolerance	Each macroinvertebrate taxa can tolerate a specific range of stream contamination, which is referred to as their pollution tolerance. Once this level is exceeded, the taxa are no longer present in that area of the stream. Highly sensitive taxa, or those with a low pollution tolerance, are found only in streams with good water quality.

In terms of Ox Creek, several WSA metrics potentially add to the *"weight of evidence"* with respect to bioassessment data and potential stressors. For instance, the habit metric (based on % burrower) taxa can be used to connect excess siltation to low bioassessment scores. Figure 3-5 shows the relationship between burrowers (% of individuals) and Macroinvertebrate Index (MMI) scores for WSA sites sampled in EPA Region 5.

Although the correlation coefficient is not high, there is a decrease in MMI scores as the percentage of burrowers increases. Conversely, the relative abundance of scrapers also provides an indication of potential stressors. High levels of sediment, and organic or nutrient pollution cause declines in the percentage of scrapers. In Ox Creek burrowers accounted for as high as 53% percent of individuals collected while scrapers accounted for 2% to 10% of all individuals collected. The dominance of burrowers and low scraper populations in Ox Creek are likely related to increased sedimentation and degraded habitats.

The WSA sites located in the Southern Michigan – Northern Indiana Till Plains (SMNITP) Ecoregion are identified in Table 3-5. Because these sites are in the same Ecoregion as Ox Creek, it is useful to examine this subset of the WSA data including several key statistics (e.g., MMI score, percent burrowers, percent dominant taxa). Figure 3-5 through Figure 3-10 provides a visual display of several measures for both the EPA Region 5 WSA sites and the SMNITP WSA sites. In addition, Table 3-6 presents raw data for one southwest Michigan SMNITP WSA location: Cedar Creek (OWW04440-0504) in the Black – Macatawa watershed. As evident, this site supports a diverse community of macroinvertebrates, including populations of EPT species. Furthermore, when scored with Procedure 51 metrics, this location is rated as*"Acceptable"*.

Table 3-5. WSA sites sampled in the SMNITP Ecoregion.

Stream	State	HUC	MMI	% Burrower	Dominant Taxa	
					%	*Taxa*
NNT Plunge Creek	IN	05120104	11.3	27.6	32.5	Psychodidae-Psychoda
No Name	MI	04050001	18.5	20.7	25.9	Chironomidae-Tvetenia
Cedar Creek	MI	04050002	40.3	20.8	13.8	Asellidae-Caecidotea
Wanadoga Creek	MI	04050003	18.7	20.0	52.1	Caenidae-Caenis
Stegman Creek	MI	04050006	36.6	9.5	22.4	Simuliidae-Simulium
S.B. White River	MI	04060101	48.4	21.2	23.1	Branchiobdellidae-na
Cedar Creek	MI	04060101	73.2	8.7	16.7	Elmidae-Optioservus
Bottom Creek	MI	04080204	24.9	10.0	51.3	Chironomidae-Cladotanytarsus
Hemmingway and Whipple Drain	MI	04080204	26.4	25.6	23.2	Chironomidae-Microtendipes
Raisin River	MI	04100002	68.0	13.5	16.4	Elmidae-Stenelmis
W.F. St. Joseph River	MI	04100003	49.7	24.1	12.6	Chironomidae-Parakiefferiella

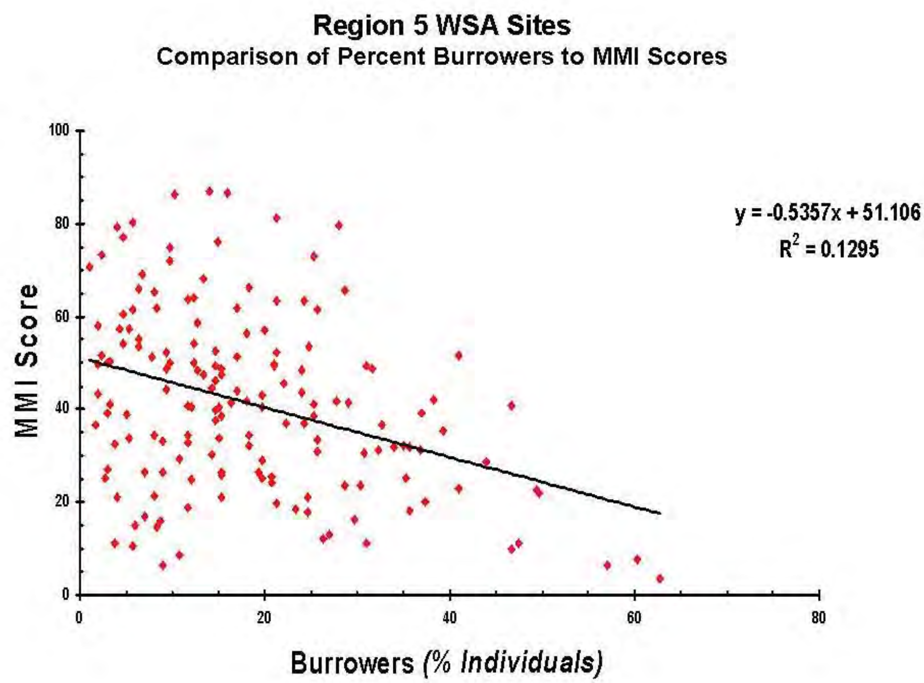


Figure 3-5. Relationship between burrowers and macroinvertebrate index score -- Region 5 WSA sites.

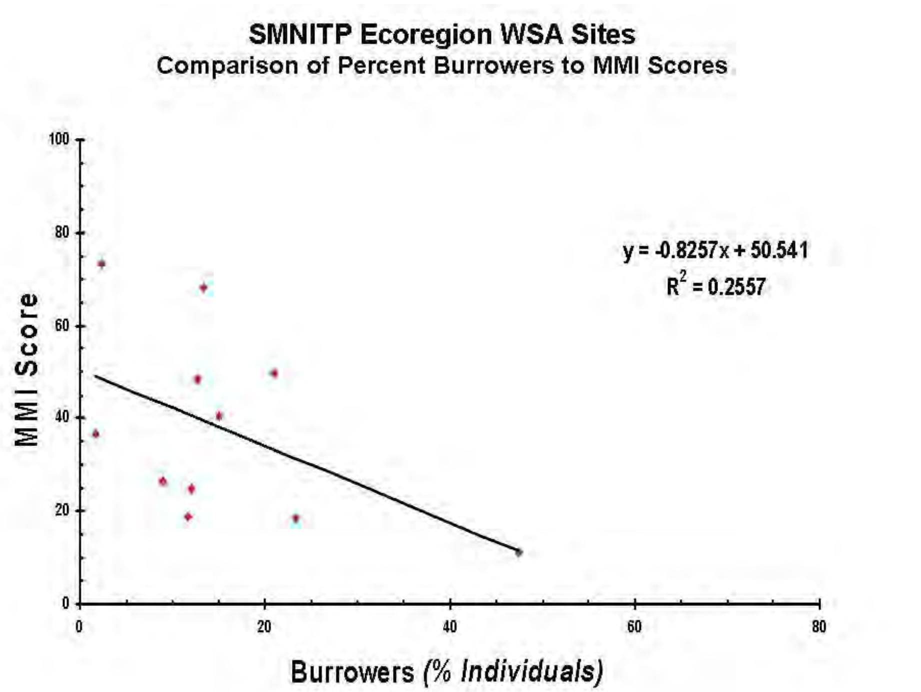


Figure 3-6. Relationship between burrowers and macroinvertebrate index score -- SMNITP WSA sites.

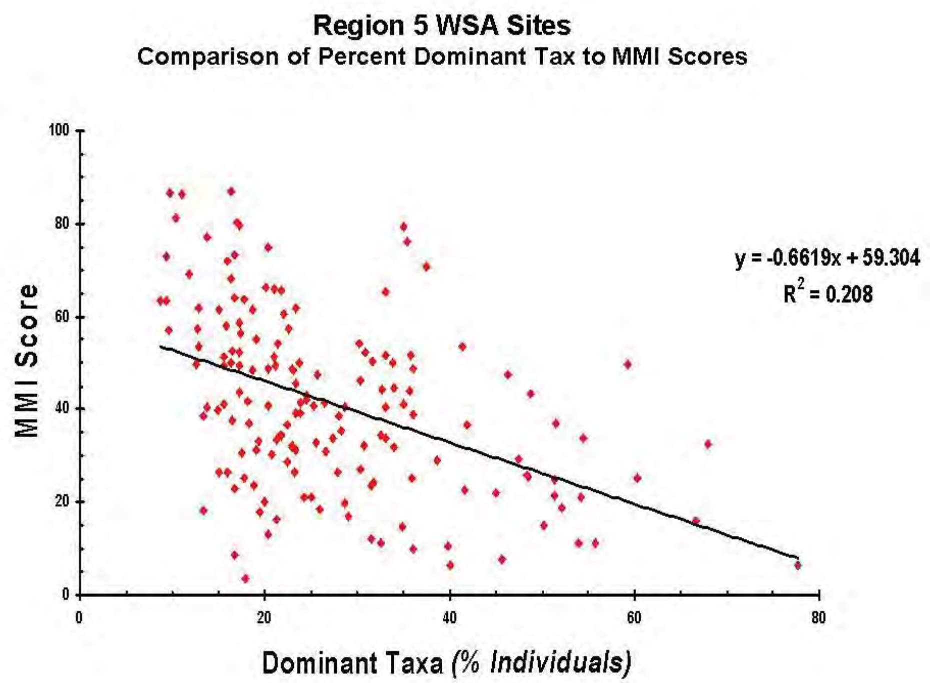


Figure 3-7. Dominant taxa and macroinvertebrate index score relationship -- Region 5 WSA sites.

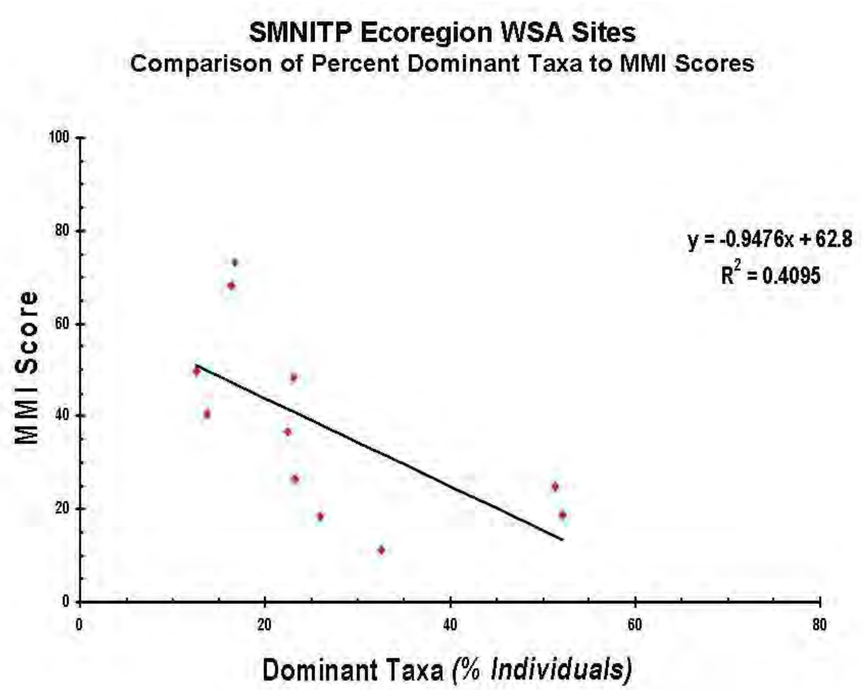


Figure 3-8. Dominant taxa and macroinvertebrate index score relationship -- SMNITP WSA sites.

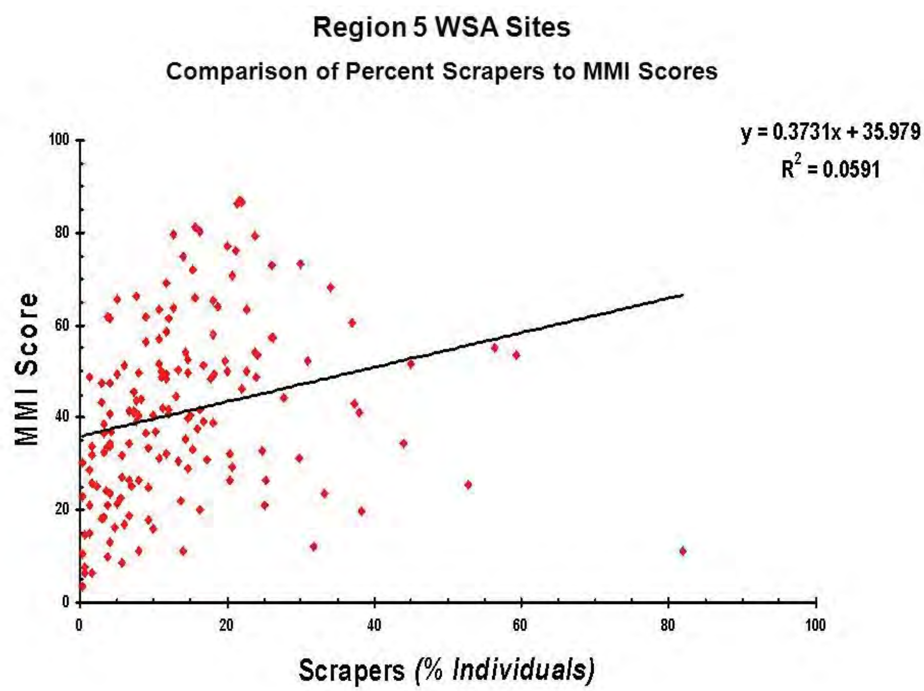


Figure 3-9. Relationship between scrapers and macroinvertebrate index score -- Region 5 WSA sites.

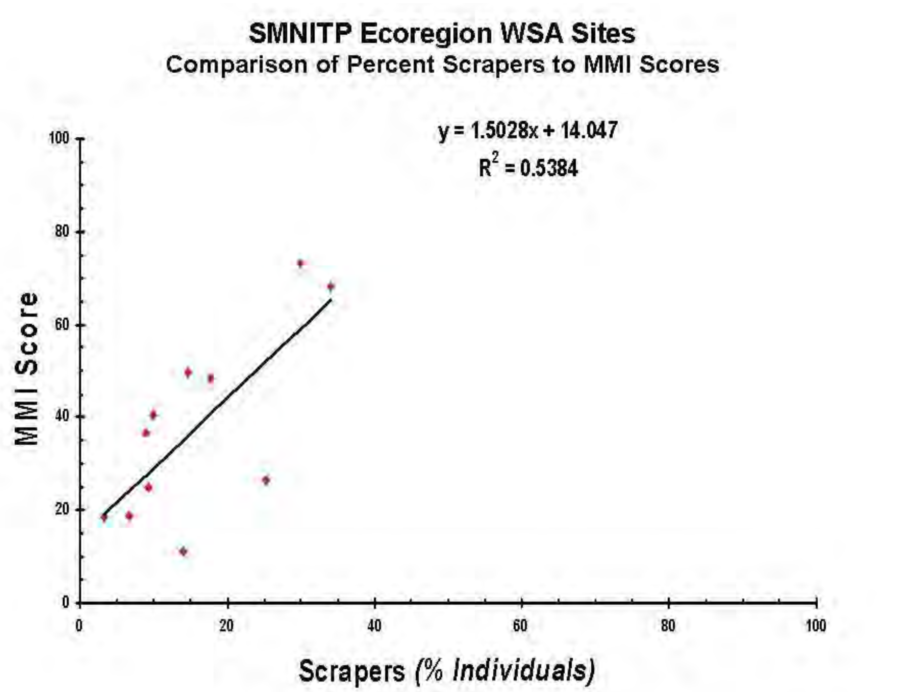


Figure 3-10. Relationship between scrapers and macroinvertebrate index score -- SMNITP WSA sites.

Table 3-6. WSA data collected at Cedar Creek (Black – Macatawa Watershed).

Site: OWW04440-0504		**Cedar Creek**	**HUC: 04050002** *(Black – Macatawa)*			
Order	Family	Genus	Count	Habit	Pollution Tolerance Value	Functional Feeding Group
Class: *Oligochaeta*						
ENCHYTRAEIDA	ENCHYTRAEIDAE	NA	4	BU	9	CG
HAPLOTAXIDA	TUBIFICIDAE	NA	13	CN	9	CG
Class: *Arachnida*						
TROMBIDIFORMES	HYGROBATIDAE	NA	16		8	PR
Class: *Insecta*						
COLEOPTERA	ELMIDAE	DUBIRAPHIA	6	CN	4.8	CG,SC
		MACRONYCHUS	2	CN	4.5	CG,SC
DIPTERA	CERATOPOGONIDAE	BEZZIA	1	SP	6	CG,PR
	CHIRONOMIDAE	BRILLIA	2	BU	4.6	SH
		CLADOTANYTARSUS	2	CB	6	CF,CG
		CONCHAPELOPIA	4	SP	7.3	PR
		CRICOTOPUS	3	BU,CN,SP	6.9	CG,SH
		NA	13	BU	6.2	CG,CF
		ODONTOMESA	2	SP	5	CG
		ORTHOCLADIUS	3	SP	4.4	CG
		PARAKIEFFERIELLA	6	SP	2	CG
		PARAMETRIOCNEMUS	8	SP	3.9	CG
		PARATANYTARSUS	4	CN	7	CG
		POLYPEDILUM	12	CB,CN	5.5	SH
		RHEOCRICOTOPUS	11	SP	5.3	CG
		RHEOTANYTARSUS	6	CN	6	CF
		SAETHERIA	3	BU	4.9	CG
		STEMPELLINELLA	40	CB,CN	2	CG
		STENOCHIRONOMUS	4	BU	4.6	CG,SH
		TANYTARSUS	26	CN	2.2	CF
		THIENEMANNIELLA	1	SP	4.4	CG
		TVETENIA	8	SP	5	CG
		XYLOTOPUS	2	BU	4	SH
		ZAVRELIA	1	SW	6	CG
		ZAVRELIMYIA	1	SP	8.5	PR
	EMPIDIDAE	HEMERODROMIA	1	SP	6	PR
	SIMULIIDAE	SIMULIUM	2	CN	5.7	CF
	TABANIDAE	CHRYSOPS	1	SP	8	PR
	TIPULIDAE	LIMONIA	1	BU	4	SH
		PSEUDOLIMNOPHILA	1	BU	7	PR
		TIPULA	6	BU	4	SH
EPHEMEROPTERA	BAETIDAE	NA	7	SW	4.2	CG
		STENACRON	22	CN	4.4	CG
		STENONEMA	22	CN	3.4	SC
	LEPTOPHLEBIIDAE	PARALEPTOPHLEBIA	16	SW	1	CG
HEMIPTERA	CORIXIDAE	SIGARA	2	SW		PI
ODONATA	AESHNIDAE	BOYERIA	4	CN	5.7	PR
	CALOPTERYGIDAE	CALOPTERYX	9	CB	5	PR
	GOMPHIDAE	GOMPHUS	6	BU	1.8	PR
PLECOPTERA	TAENIOPTERYGIDAE	TAENIOPTERYX	1	CN,SP	2.3	SH
TRICHOPTERA	HYDROPSYCHIDAE	CHEUMATOPSYCHE	26	CN	5.5	CF
	HYDROPSYCHIDAE	HYDROPSYCHE	2	CN	3	CF,PR
	LEPIDOSTOMATIDAE	LEPIDOSTOMA	1	CB	3	SH
	POLYCENTROPODIDAE	NYCTIOPHYLAX	2	CN	3.8	PR
	PSYCHOMYIIDAE	LYPE	9	BU	2.8	SC
Class: *Malacostraca*						
AMPHIPODA	GAMMARIDAE	GAMMARUS	50	SP	5.7	CG,SH
DECAPODA	CAMBARIDAE	NA	1	SP	6	CG
ISOPODA	ASELLIDAE	CAECIDOTEA	64	SP	8	CG
Class: *Bivalvia*						
VENEROIDA	PISIDIIDAE	PISIDIUM	16	BU	8	CF
		SPHAERIUM	1	BU	8	CF,CG
Class: *Gastropoda*						
BASOMMATOPHORA	PHYSIDAE	NA	7	CB	7.6	SC
NEOTAENIOGLOSSA	HYDROBIIDAE	NA	4	CB	5.3	SC
Phylum: *Nematoda*						
NA	NA	NA	2			SH
Codes & Abbreviations	**Habit:**	BU: Burrower, CB: Climber, CN: Clinger, SP: Sprawler; SW: Swimmer; SK: Skater				
	Feeding Group:	CF: Collecter – Filterer; CG: Collecter – Gatherer; F: Facultative PI: Piercer; PR: Predator; SC: Scraper; SH: Shredder				

4. Habitat Data

Habitat evaluations are important in determining the nature and degree of abiotic constraints on the biological potential. Habitat evaluations are accomplished through stream characterization based on selected physical measurements and descriptive watershed features *(MDEQ, 2008)*. The habitat metrics measure a wide range of physical characteristics, which are important to the optimum development and stability of biological communities *(MDEQ, 1990)*.

Procedure 51 uses qualitative metrics that rate habitat based on substrate, in-stream cover, channel morphology, bank structural features, and riparian vegetation. The habitat assessment process involves rating the sum total of the 10 metrics as *Excellent, Good, Marginal,* or *Poor* based on Michigan Department of Environmental Quality (MDEQ) assessment scores. Habitat scores greater than 154 are considered excellent, 105 to 154 is considered good, 56 to 104 is marginal, and habitat scores less than 56 are characterized as poor. Specific individual metrics are summarized in Table 4-1.

Table 4-1. Procedure 51 habitat metrics.

Metric	Description	Expected Response to Disturbance
1	Epifaunal Substrate / Available Cover	Decrease
2	Embeddedness (Riffle / Run)	Increase
	Pool Substrate (Glide / Pool)	
3	Velocity/Depth Regime (Riffle / Run)	Decrease
	Pool Variability (Glide / Pool)	
4	Sediment Deposition	Decrease
5	a. Flow Status – Maintained Flow Volume	Decrease
	b. Flow Status – *“Flashiness”*	Increase
6	Channel Alteration	Decrease
7	Frequency of Riffles or Bends (Riffle / Run)	Decrease
	Channel Sinuosity (Glide / Pool)	
8	Bank Stability	Decrease
9	Vegetative Protection	Decrease
10	Riparian Vegetation Zone Width	Decrease

Habitat scores for Ox Creek were reported by Lipsey (2007). Table 4-2 summarizes results for individual metrics at each station. Scores for Blue Creek were also included for reasons identified in the bioassessment discussion. Based on the habitat assessment, sediment deposition and siltation are major problems in Ox Creek (metric 4). This is consistent with the bioassessment information, as mayflies and caddisflies are not typically found in silt laden streams. The lack of diversity (or high percentages of dominant taxa) is also indicative of siltation problems. Less than average conditions for metrics 1 and 3 at Britain Avenue are likely the result of flashy flows monitored at that location.

Table 4-2. Procedure 51 habitat metrics summary.

Stream	Location	Year	Substrate & In-stream Cover			Channel Morphology				Riparian & Bank Structure		
			1	2	3	4	5	6	7	8	9	10
Blue Creek	Park	2006	15	11	9	8	20	18	17	18	20	20
	Territorial	2001	11	10	10					16	16	
	Euclid	2006	15	10	13	6	16	13	11	14	15	11
Yore – Stouffer Drain	Meadowbrook	2006	6	10	11	10	14	**5**	**6**	18	12	**4**
Ox Creek	Crystal Avenue	2001	8	10	10					10	14	
		2006	6	6	8	**5**	15	13	13	18	14	10
	Britain Avenue	2006	**5**	7	**5**	**3**	14	15	10	12	17	17
	Water Street	2006	7	10	16	6	15	8	**2**	18	12	**4**
	5th Avenue	2001	8	10	11					20	20	

Note on cell shading:

Light green cell indicates that the habitat is better than the average condition typically found in this ecoregion

Light diagonal cell in **bold** indicates that the habitat is less than the average condition typically found in this ecoregion.

5. Flow

Hydrology plays an important role in evaluating water quality. The hydrology of the Ox Creek watershed is driven by local climate conditions. This includes situations that often result in *"flashy"* flows, where the stream responds to and recovers from precipitation events relatively quickly. Flooding periodically occurs in areas of the watershed, flowing over roads and encroaching on streamside properties. In addition, ditching and channelizing has been used throughout this region to drain areas where soils are too wet for settlement and agriculture.

5.1 Ox Creek Data Analysis

Recorders that report water levels at short time intervals (i.e., 15 minutes) can be used to examine the *"flashiness"* of a stream. These devices, often referred to as level loggers, were deployed on Ox Creek at Britain Avenue in 2007 and 2008 by the MDEQ *(Figure 5-1)*. The 2007 information shows that during storm events across the Ox Creek watershed, water levels can rise over four feet in a very short period of time. Similar patterns were also observed in 2008 *(Figure 5-2)*. In addition to water volume excesses due to storm water and flooding, natural dry weather periods (e.g., the lack of sufficient water) can make water quantity a factor that affects water quality.

5.1.1 Flow Estimates Based on Level Logger Data

In order to use available water quality data to calculate pollutant loads, level logger data must be converted to flow estimates. This is typically accomplished through a rating curve or stage - discharge relation. A common approach is to plot stage height versus discharge, which generally results in a parabolic curve. In conjunction with the Ox Creek TSS monitoring effort, MDEQ staff made several measurements of stream discharge associated with water level (or stage height). These MDEQ flow measurements can be used to develop a stage - discharge relationship for Ox Creek at Britain Avenue.

Water levels recorded by MDEQ staff in conjunction with instantaneous flow monitoring were also expressed as *"tape down"* measurements. This is the *"tape"* distance measured from a fixed point on a bridge *"down"* to the water surface. Table 5-1 summarizes the flow survey results for the Britain Avenue site. Because MDEQ flow measurements include a cross-sectional diagram of this location *(Figure 5-3)*, a stage value that reflects water depth is included in Table 5-1. This provides a direct cross-reference to the level logger data, which is expressed as stream depth.

MDEQ Hydrologic Studies staff prepared a rating curve at the Britain Avenue site based on USGS methodologies. Rating curve equations require flow estimates that cover the full range of expected conditions. MDEQ flow measurements were taken at lower, stable flow conditions. In order to develop a stage - discharge rating curve that covers the expected range of conditions, estimates are needed for higher flows. MDEQ staff determined these high flow estimates using channel geometry measurements (i.e., width, depth, shape) at each site in conjunction with Manning's equation.

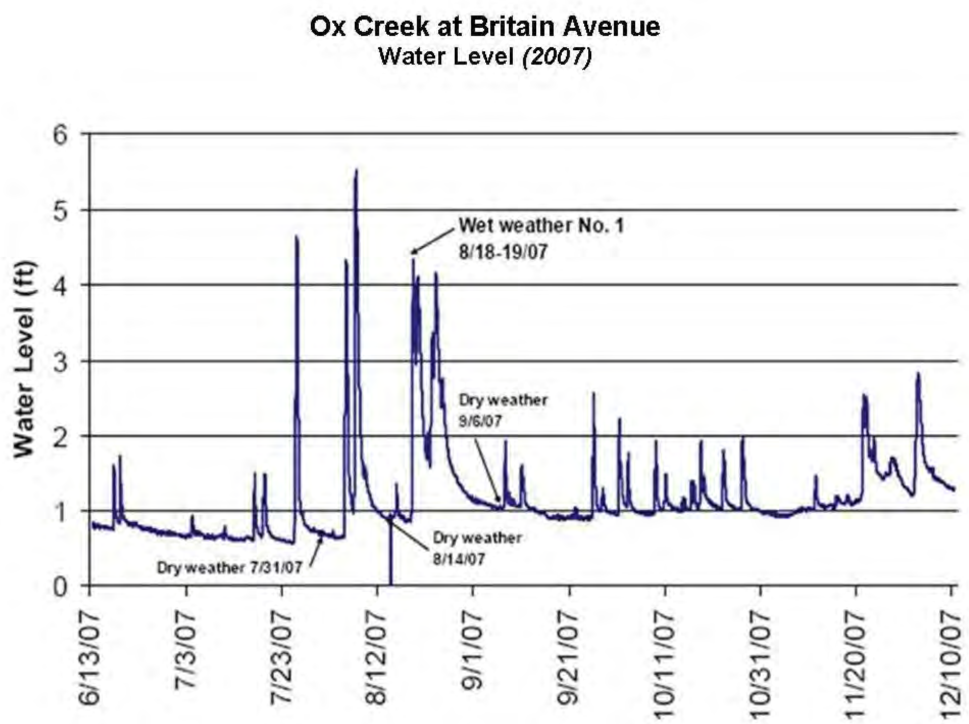


Figure 5-1. Level logger data collected in Ox Creek at Britain Avenue -- 2007.

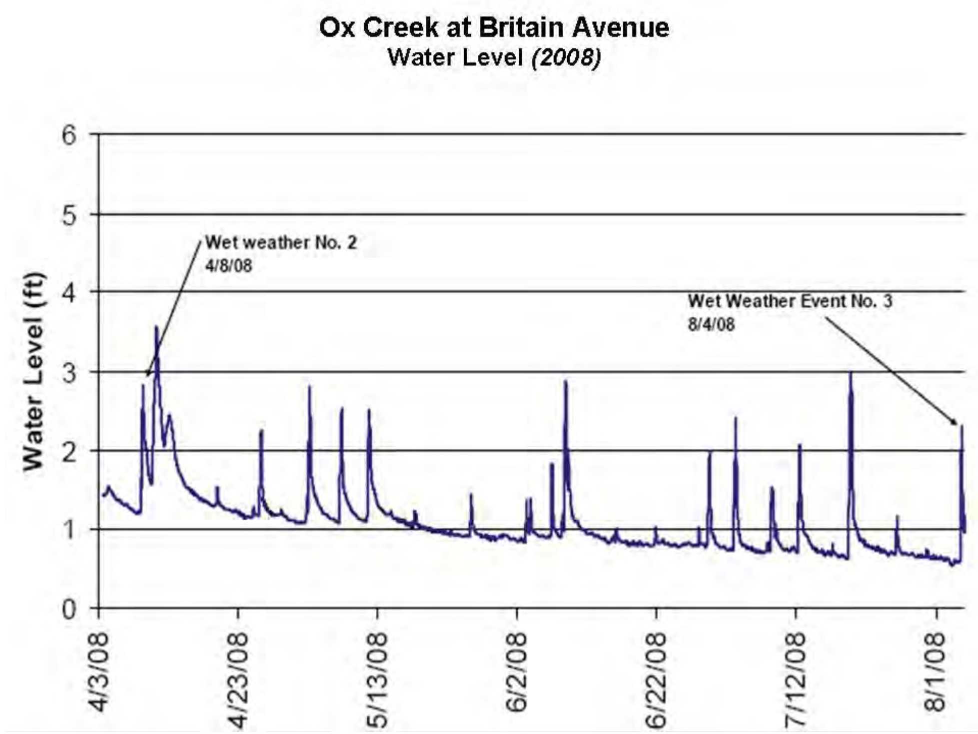


Figure 5-2. Level logger data collected in Ox Creek at Britain Avenue -- 2008.

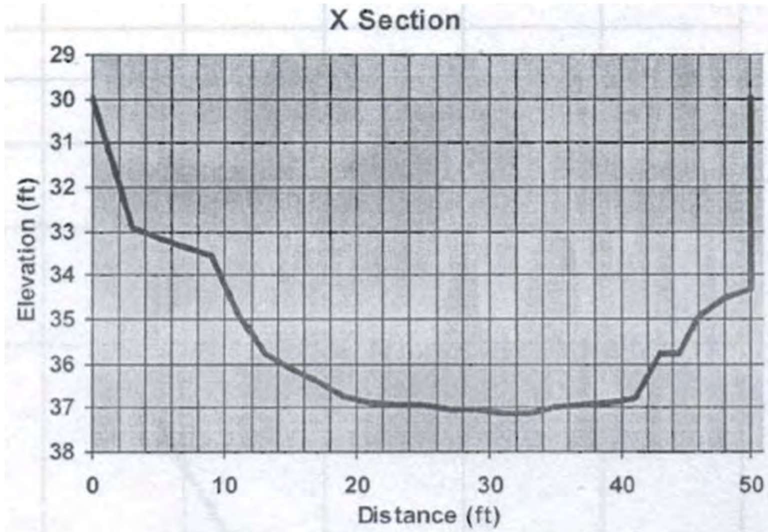


Figure 5-3. Flow measurement site cross-section -- *Britain Avenue*.

Table 5-1. Measurements used to develop rating curve for Ox Creek at Britain Avenue.

Site	Area (mi^2)	Date	Tape Down (ft)	Stage (ft)	Discharge (cfs)
Ox Creek at Britain Avenue	14.68	7/9/2007	35.96	1.14	15.4
		9/6/2007	36.15	0.95	6.98
		1/10/2008	35.77	1.33	26.8
		*	33.92	3.18	234
		*	29.98	7.12	506
Note:	* Discharge estimate based on MDEQ Hydrologic Studies procedure using Manning's equation.				

The resultant stage – discharge rating curve for Ox Creek at Britain Avenue (shown in Figure 5-4) is the equation:

$$\text{Flow} = 10.837 * \text{Stage}^{(2.2106)}$$

is used to convert the level logger data to flow estimates for Ox Creek at Britain Avenue. Flows for Ox Creek at Britain Avenue calculated using the stage - discharge rating curve are shown in Figure 5-5 for 2007 and in Figure 5-6 for 2008. Precipitation at the Benton Harbor Airport is also depicted with the flows to illustrate how Ox Creek responds to runoff events. In addition, dates associated with TSS monitoring by MDEQ are also highlighted in these figures. *"Tape Down"* measurements were collected to describe flows at other points in the Ox Creek watershed during TSS sampling surveys. A discussion on how *"tape down"* measurements were used to calculate flow estimates at other sites in Ox Creek can be found in Section 5.1.2.

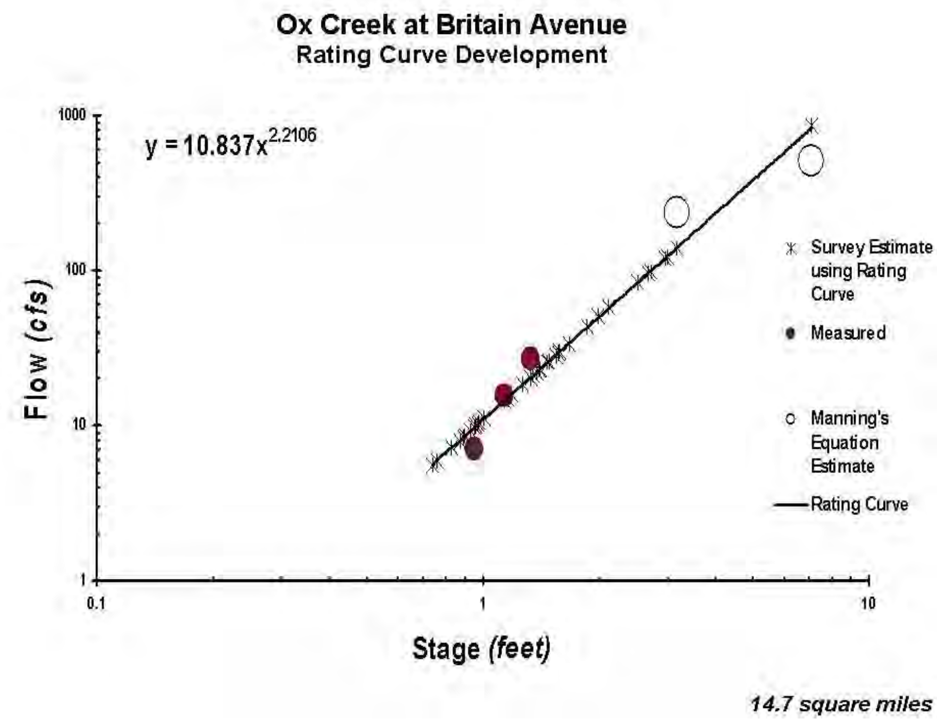


Figure 5-4. Stage – discharge rating curve -- *Ox Creek at Britain Avenue*.

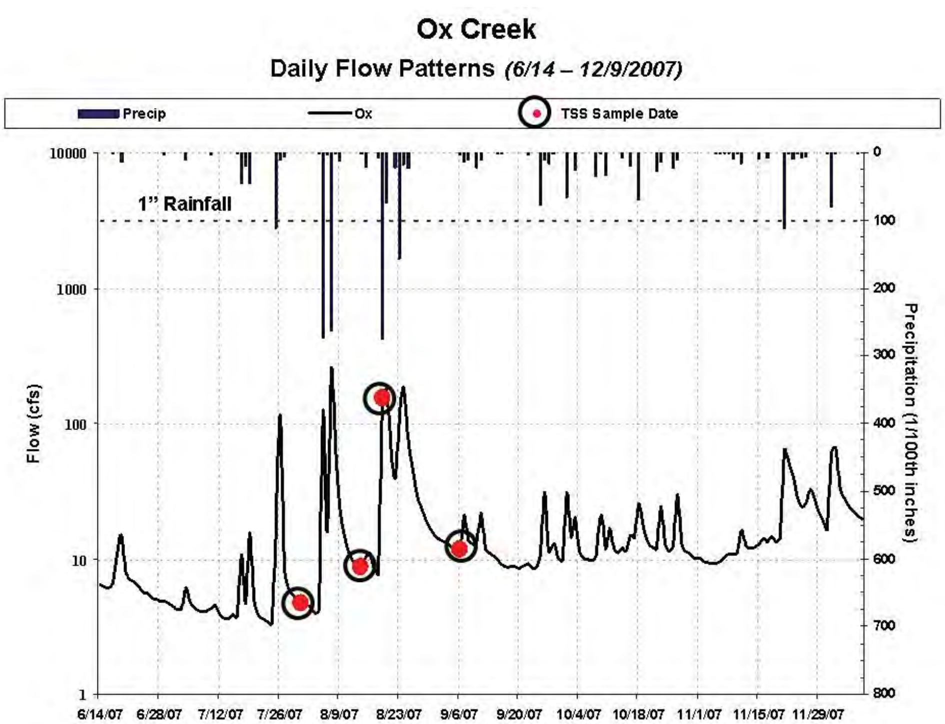


Figure 5-5. Ox Creek daily average flows -- 2007.

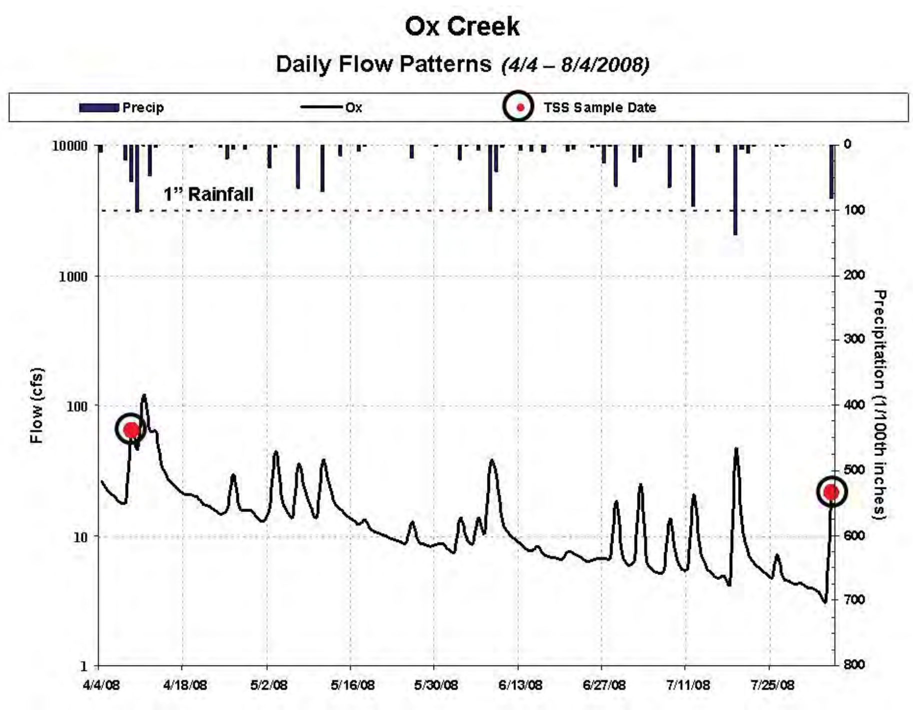


Figure 5-6. Ox Creek daily average flows -- 2008.

5.1.2 Flow Estimates Based on Tape Down Measurements

"Tape down" measurements at other Ox Creek sites were converted to flow estimates using the same procedure described for the level logger data. Rating curves were developed for each site from MDEQ field measurements coupled with high flow estimates based on Manning's equation. Table 5-2 and Table 5-3 summarize the information used to develop rating curves.

Table 5-2. Information used to develop stage-discharge rating curves -- *Yore-Stouffer Drain*.

Site	Area *(mi^2)*	Date	Tape Down *(ft)*	Stage *(ft)*	Discharge *(cfs)*
Yore-Stouffer Drain at Blue Creek Road	3.36	7/12/2007	4.39	0.56	0.076
		7/19/2007	4.35	0.60	0.092
		9/6/2007	4.01	0.94	0.329
		5/22/2008	3.56	1.39	1.02
Yore-Stouffer Drain at Yore Avenue	4.09	7/12/2007	8.35	0.20	0.097
		7/19/2007	8.07	0.48	0.489
		9/6/2007	7.89	0.66	0.837
		5/22/2008	7.74	0.81	1.18
Yore-Stouffer Drain at Meadowbrook Road	6.83	7/12/2007	9.06	0.54	1.18
		9/6/2007	8.99	0.61	1.37
		*	6.10	3.50	24.4
Note: * Estimate based on MDEQ procedure using Manning's equation.					

Table 5-3. Information used to develop stage-discharge rating curves -- *Ox Creek*.

Site	Area *(mi 2)*	Date	Tape Down *(ft)*	Stage *(ft)*	Discharge *(cfs)*
Ox Creek at Crystal Avenue	4.06	7/12/2007	15.90	1.10	1.95
		7/19/2007	15.93	1.07	1.83
		9/6/2007	15.94	1.06	1.79
		*	13.88	3.12	21.4
Ox Creek at Empire Avenue	13.28	7/19/2007	9.55	1.95	14.2
		1/10/2008	9.17	2.33	23.2
		*	7.16	4.34	127
Ox Creek at Water Street	16.34	7/19/2007	11.98	2.52	18.3
		9/6/2007	12.48	2.02	10.1
		*	11.66	2.84	24.4
		*	7.98	6.52	337
		*	6.09	8.41	658
Note: * Estimate based on MDEQ procedure using Manning's equation.					

Figure 5-7 through Figure 5-12 show the resultant rating curve for each site. Each graph identifies the stage height and flow associated with actual measurements, as well as stage height and flow estimates based on Manning's equation. Flow estimates from *"tape down"* measurements during the TSS survey are also displayed to describe the range of flow conditions to which the rating curves are applied. Figure 5-13 provides a broader view of flow variability across the Ox Creek watershed using stream discharge estimates based on *"tape down"* measurements and rating curves.

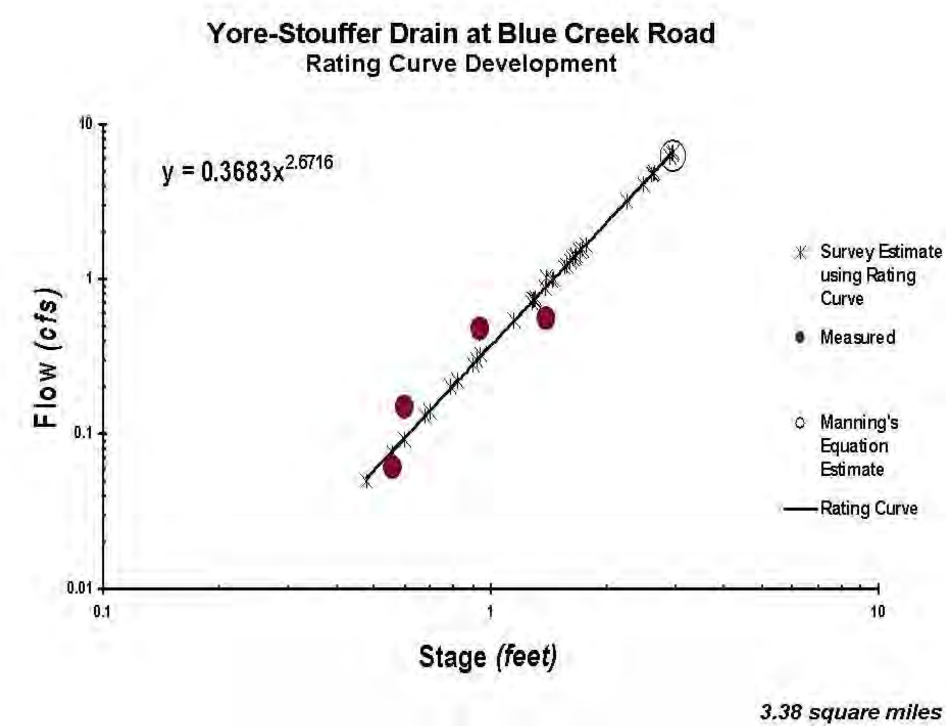


Figure 5-7. Stage – discharge rating curve -- *Yore-Stouffer Drain at Blue Creek Road*.

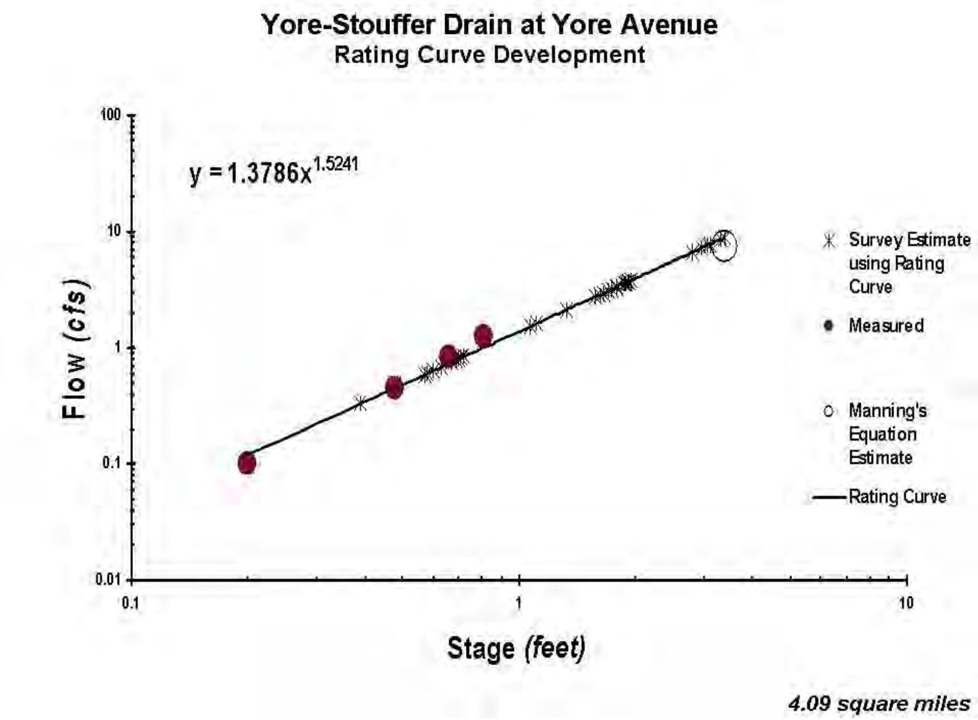


Figure 5-8. Stage – discharge rating curve -- *Yore-Stouffer Drain at Yore Avenue*.

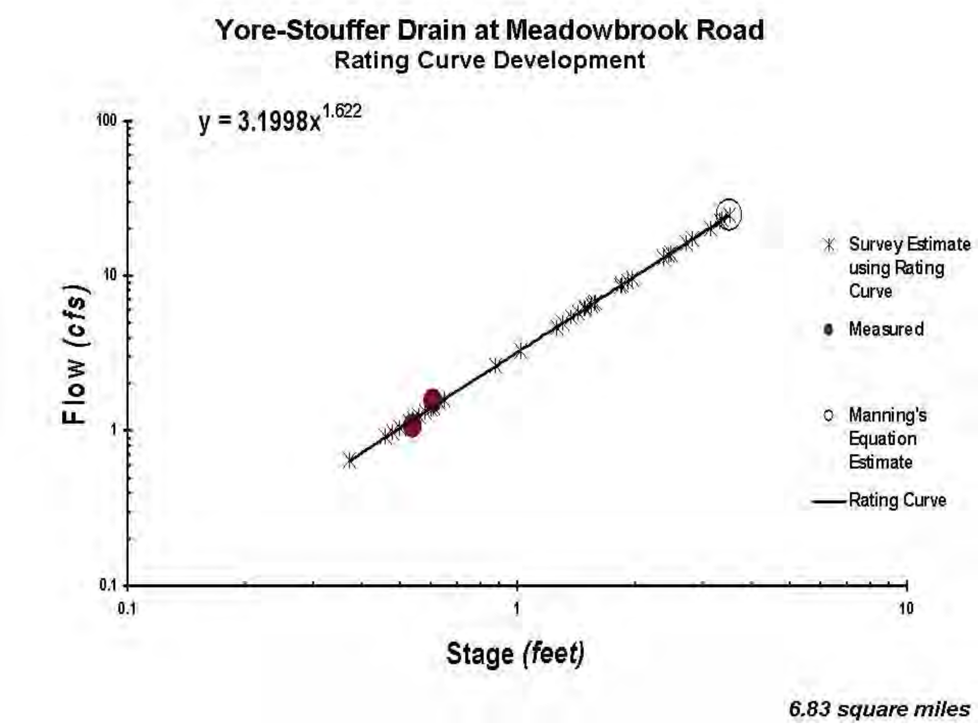


Figure 5-9. Stage – discharge rating curve -- *Yore-Stouffer Drain at Meadowbrook Road*.

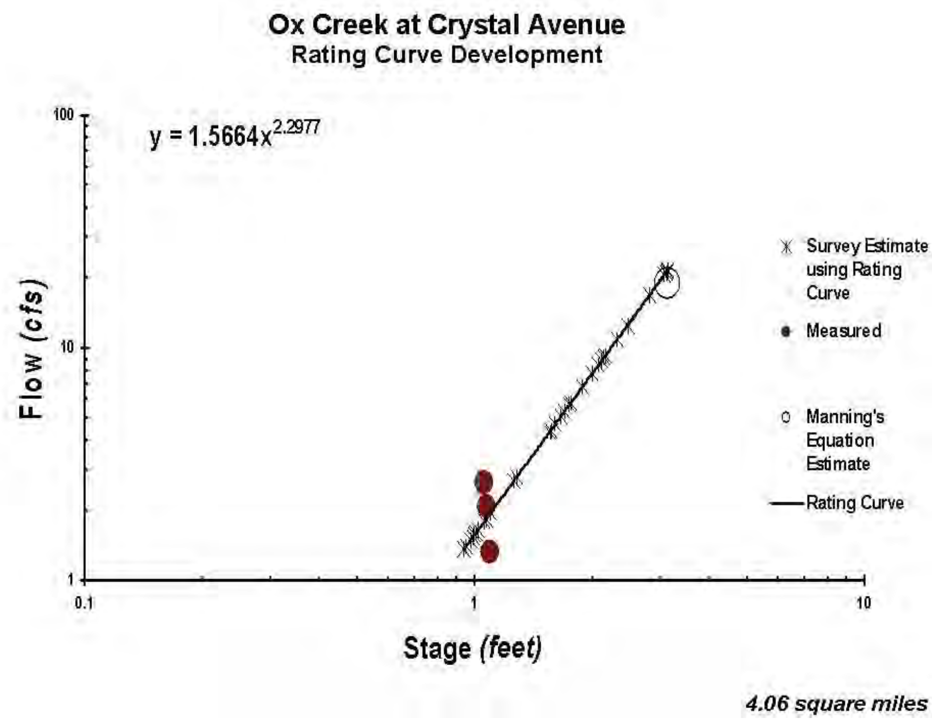


Figure 5-10. Stage – discharge rating curve -- *Ox Creek at Crystal Avenue*.

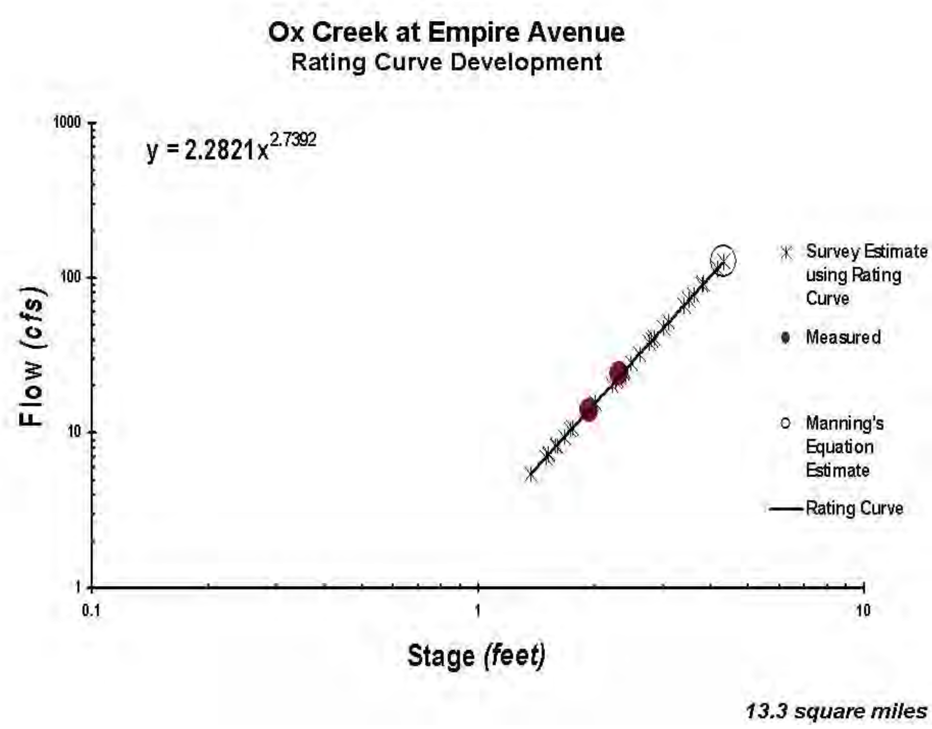


Figure 5-11. Stage – discharge rating curve -- *Ox Creek at Empire Avenue*.

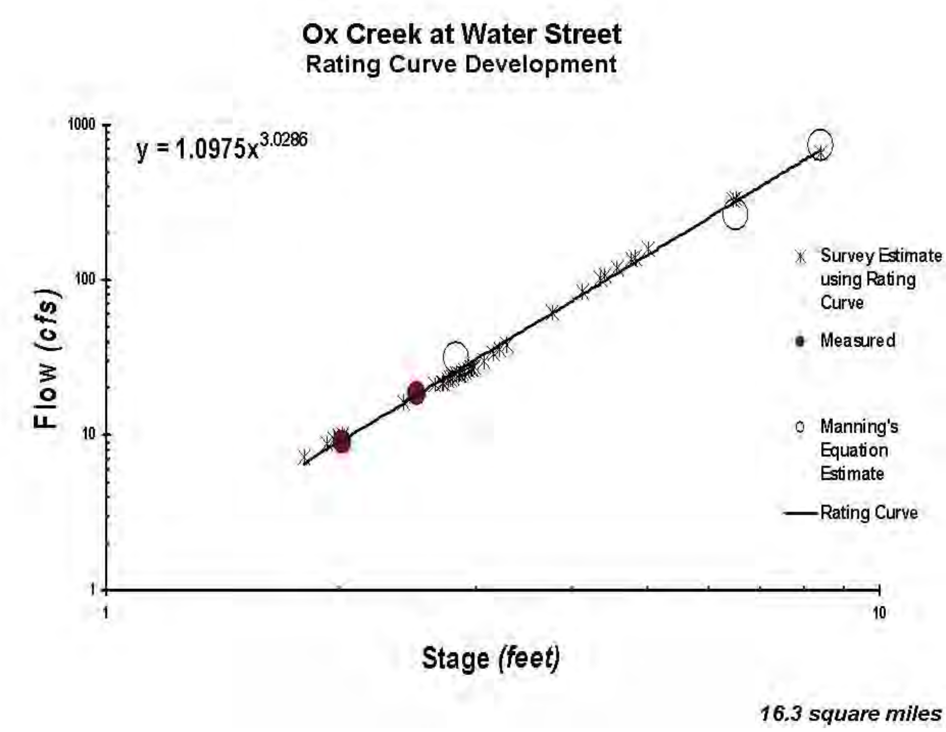


Figure 5-12. Stage – discharge rating curve -- *Ox Creek at Water Street*.

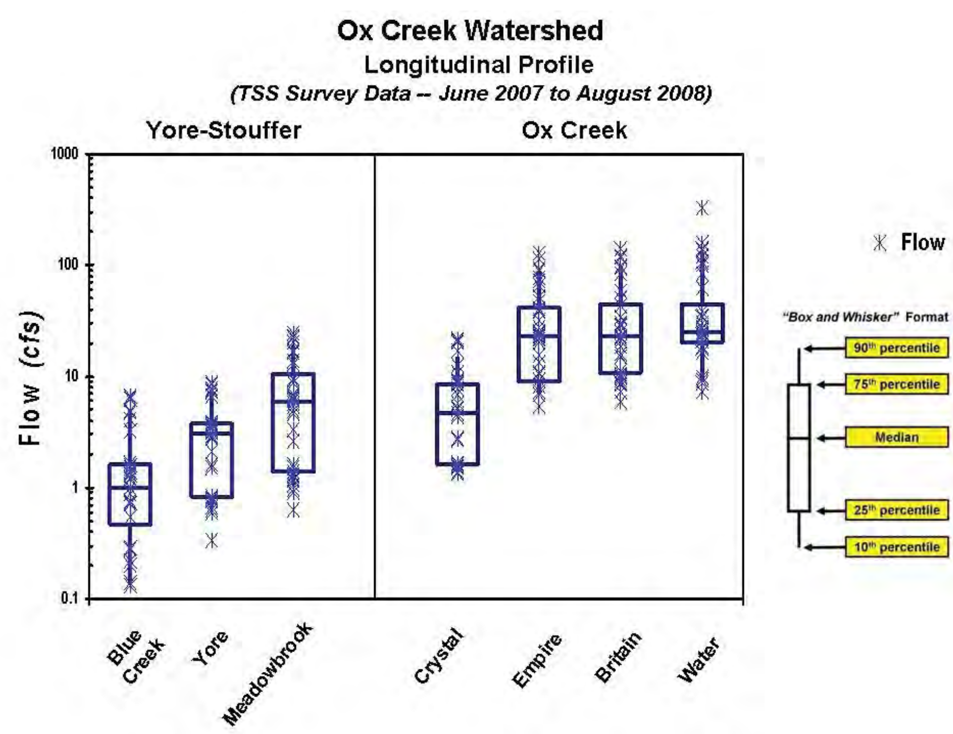


Figure 5-13. Longitudinal profile of Ox Creek flows during TSS survey dates.

5.1.3 Temporal and Spatial Variability

The intent of the linkage analysis is to bring available information together in a way that integrates concerns with watershed processes and potential causes of observed problems. With respect to flow conditions, a deeper examination is needed to look at hydrologic responses in terms of subwatershed characteristics and subsequent effects on stream biology. The longitudinal profile shown in Figure 5-13 represents a starting point. However, information shown in this graph must be put into the context of variable conditions that occur in Ox Creek, both temporal (e.g., response to storm events) and spatial (e.g., account for land use patterns).

"Tape down" measurements from the TSS survey included three dry weather events and three wet weather events. Table 5-4 summarizes average flows for the dry weather events and average flows for individual wet weather events at subwatershed outlet locations in Ox Creek. Subwatersheds were described in the WC&SA report.

Average flows for seven of the eight subwatersheds are based on *"tape down"* measurements and rating curves described in Section 5.1.2. Average flows for the eighth subwatershed (D) were estimated through a water balance approach using individual measurements from subwatershed F (the next downstream subwatershed) and subwatershed E (the additional flow to subwatershed F above its confluence with the outlet of subwatershed D). Figure 5-14 depicts the schematic relationship of each subwatershed and monitoring points used in estimating flow at the outlet of subwatershed D.

Table 5-4. Average event-based subwatershed flows.

Event	Average Subwatershed Outlet Flow *(cfs)*							
	Yore – Stouffer Drain				*Ox Creek*			
	A	B	C	D	E	F	G	H
Dry	0.18	0.61	1.12	5.42	1.53	6.95	7.18	8.81
Wet #1	2.87	4.86	12.51	45.34	10.13	55.47	59.54	89.83
Wet #2	1.25	3.08	5.91	20.32	4.88	25.20	25.96	26.02
Wet #3	0.75	0.81	1.12	7.27	1.45	8.72	9.86	12.46

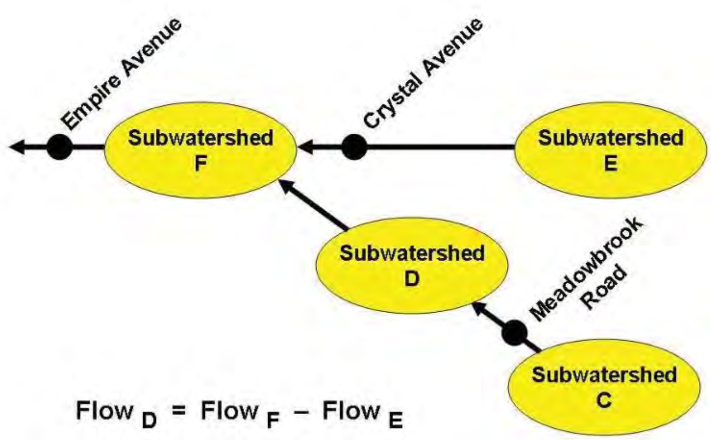


Figure 5-14. Schematic for estimating subwatershed D flows.

Figure 5-13 and Table 5-4 describe the spatial variability of flows in the Ox Creek watershed. Table 5-4 provides additional information with respect to specific wet weather events. Stream response for each storm is another factor to consider in evaluating Ox Creek hydrology. Figure 5-15 through Figure 5-17 show individual measurements at each TSS monitoring site based on *"tape down"* and rating curve information. A graph of hourly precipitation for the same storm is shown in each figure.

Wet weather event #1 *(Figure 5-15)* reflects the largest of the three storms monitored during the TSS survey. This event shows the strongest hydrologic response. Flows were relatively low at the onset of sampling. In contrast to events #2 and #3, wet weather event #1 also consisted of several hourly intervals where precipitation intensity exceeded 0.2 inch per hour between 2am and 8am on the morning of August 19th. Flows continued to rise at all sampling sites until noon.

Estimated flows appear to be fairly constant in wet weather events #2 and #3. In the case of wet weather event # 2 *(Figure 5-16)*, most precipitation fell in a one hour period shortly after the start of TSS sampling. With respect to wet weather event #3 *(Figure 5-17)*, the majority of the rainfall at Benton Harbor occurred more than 12 hours before the first sample was taken. The contrasting patterns of all three storms could have an effect on differences in TSS sample results.

One noteworthy observation follows the analysis of temporal and spatial variability. In particular, there is a significant increase in flow associated with subwatershed unit D. This subwatershed unit contains a relatively large percentage of medium- and high-intensity developed land *(Table 5-5)*. The higher percentage of impervious surfaces in this subwatershed unit is likely responsible for the increased flows observed during storm events over the Ox Creek watershed.

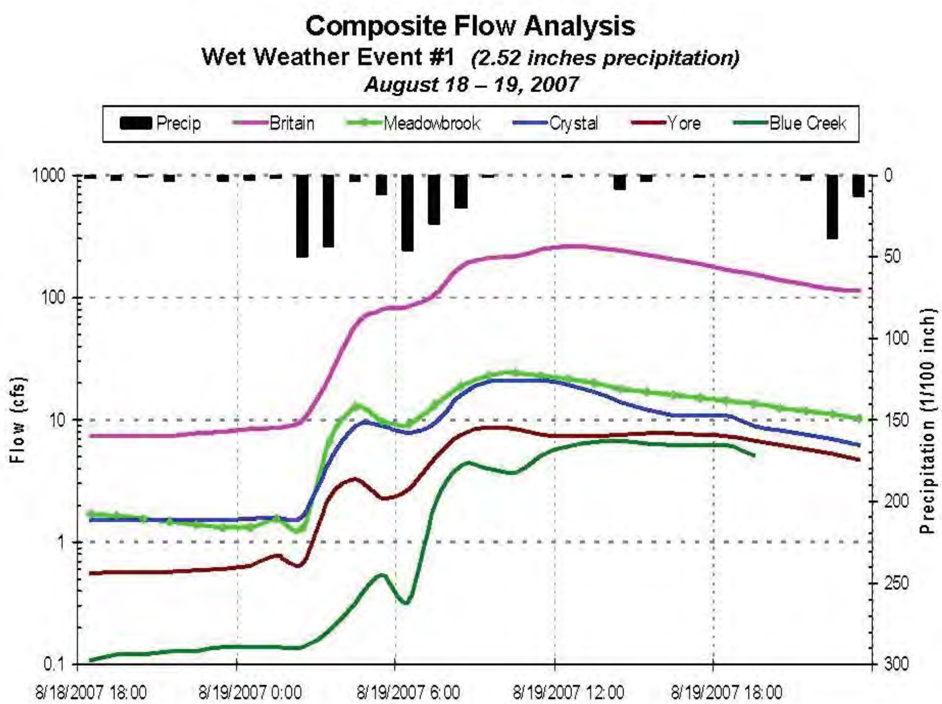


Figure 5-15. Estimated streamflow and precipitation for wet weather event #1.

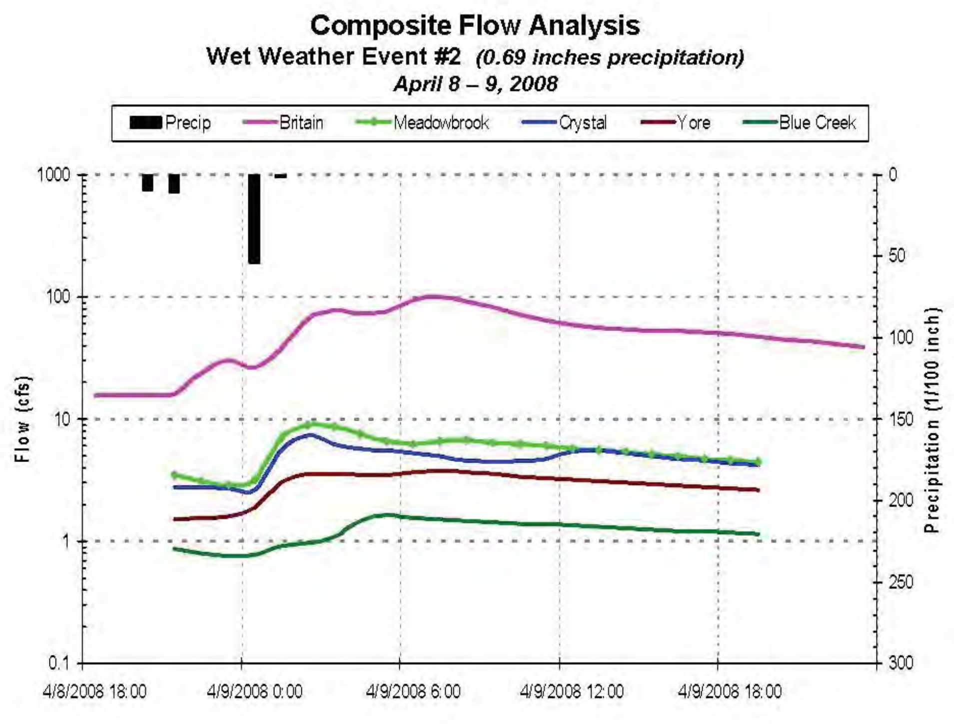


Figure 5-16. Estimated streamflow and precipitation for wet weather event #2.

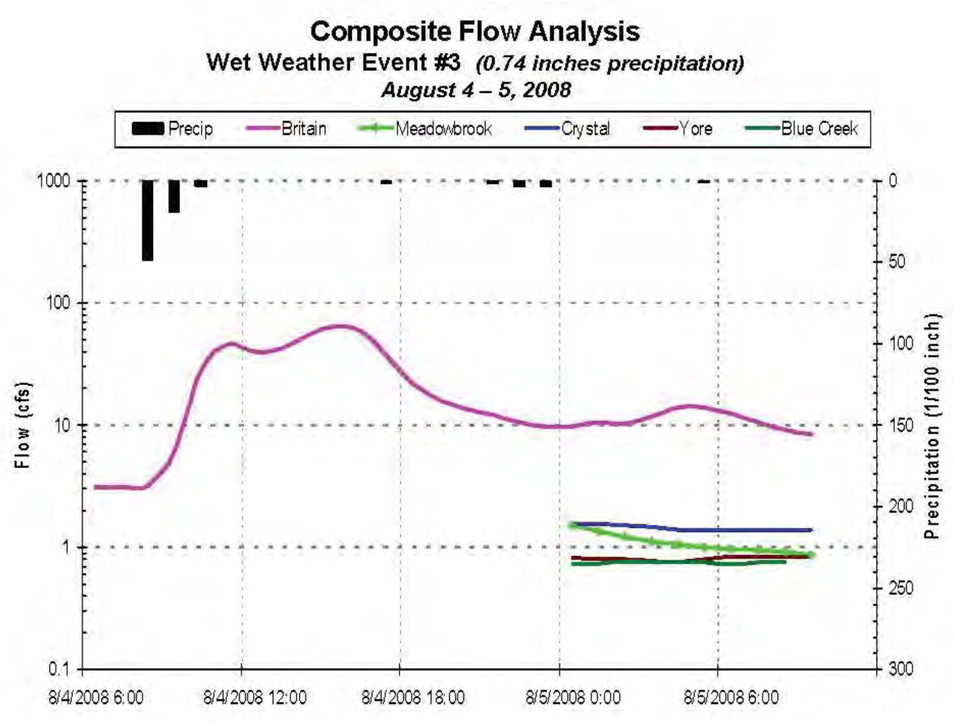


Figure 5-17. Estimated streamflow and precipitation for wet weather event #3.

Table 5-5. Ox Creek watershed land use summary *(percentage)*.

Land Use / Land Cover	Subwatershed Unit ID								
	A	B	C	D	E	F	G	H	I
Developed, Open	3%	6%	19%	25%	24%	34%	54%	39%	19%
Developed, Low-Intensity	4%	4%	17%	17%	10%	25%	29%	35%	27%
Developed, Medium-Intensity	0%	0%	4%	28%	4%	20%	8%	17%	32%
Developed, High Intensity	--	--	3%	17%	2%	10%	0%	5%	20%
Forest	7%	3%	9%	8%	11%	6%	4%	2%	--
Pasture / Grassland	19%	36%	10%	1%	13%	--	1%	0%	--
Cultivated Crops	61%	48%	33%	1%	32%	--	0%	--	--
Wetlands	6%	3%	5%	3%	4%	5%	4%	2%	2%
Subwatershed Size *(acres)*	2,150	465	1,755	805	2,600	725	895	1,060	104

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

5.2 Area Hydrologic Patterns

5.2.1 USGS Gages Considered

Limited flow data makes it difficult to describe the full range of hydrologic conditions the Ox Creek watershed may experience. An analysis of Ox Creek data relative to long-term flow information is needed. A screening level evaluation was described in the WC&SA report, which examined USGS gage sites located within 30 miles of the Ox Creek watershed *(Table 5-6 and Figure 5-18)*. The Galien River was identified as a potential site for comparison with Ox Creek. This was based on a correlation between daily average flows between the Galien River USGS gage and level logger flow estimates from Ox Creek at Britain Avenue.

Two other USGS gages considered in the screening level analysis include the South and Middle Branches of the Black River. Although the correlation of daily average flows was not as strong as the Galien River, these gages provide additional insight regarding hydrologic patterns in the area. Both are located approximately the same distance from Ox Creek as the Galien River; both are similar in drainage area size to the Galien.

Table 5-6. USGS stream gaging sites within 30 miles of Ox Creek watershed.

Gage ID	Area ($mi.^2$)	Location
04096015	80.7	Galien River near Sawyer
04101800	255	Dowagiac River at Sumnerville
04102500	390	Paw Paw River at Riverside
04102531	14.7	Ox Creek at Benton Harbor *(Britain Avenue)*
04102700	83.6	South Branch Black River near Bangor
04102776	83.0	Middle Branch Black River near South Haven

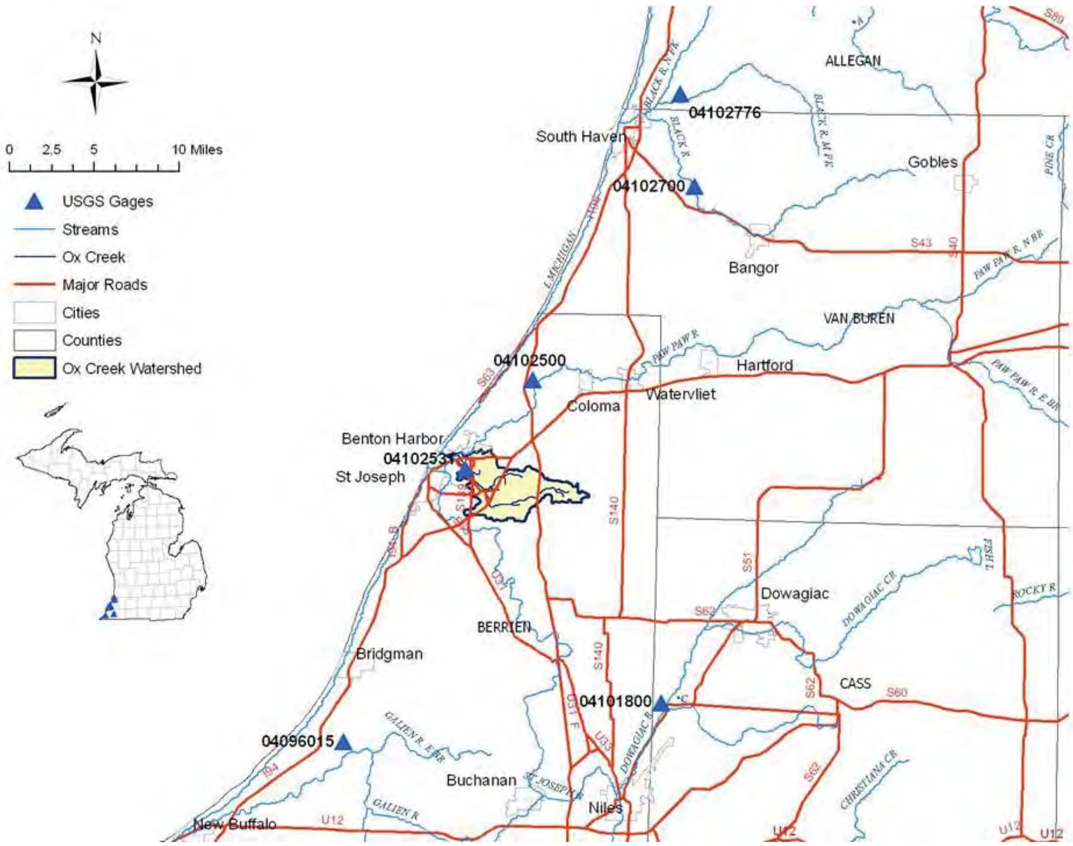


Figure 5-18. Location of USGS stream gaging sites in the general proximity of Ox Creek.

Table 5-7 provides basic summary statistics for all three stations. The 1995-2010 timeframe is used to compare annual average flows between the sites. This represents the only period where daily data was collected concurrently at all three sites. This approach ensures that the comparison between these sites is not influenced by year-to-year variation in meteorological conditions (e.g., differences in annual precipitation and temperature). With respect to the analyzing the hydrology of Ox Creek, several patterns are of particular interest. These include flow duration curves, seasonal variation, and the relative proportion of base flow to total flow.

Table 5-7. Summary statistics for USGS gages considered.

Gage ID	Location	Area *(mi.^{2})*	Average Annual Flow *(cfs/mi.^{2})*	Annual Runoff *(in.)*		
				Total	*Base*	*Surface*
04096015	Galien River near Sawyer	80.7	1.105	15.0	*9.6*	*5.4*
04102700	S.B. Black River near Bangor	83.6	1.184	16.1	*12.0*	*4.1*
04102776	M.B. Black River near South Haven	83.0	1.209	16.4	*13.1*	*3.3*

5.2.2 Flow Duration Curves

Flow duration curves are an important component of the overall hydrologic analysis. Duration curves provide a quantitative summary that describes the full range of flow conditions, both magnitude and frequency of occurrence. Figure 5-19 depicts flow duration curves for the Galien, South Branch Black, and Middle Branch Black Rivers. These curves are expressed as unit area flows (i.e., cfs / square mile) in order to provide a meaningful comparison between sites. Similar to values presented in Table 5-7, these curves are derived from daily average flows between 1995 and 2010.

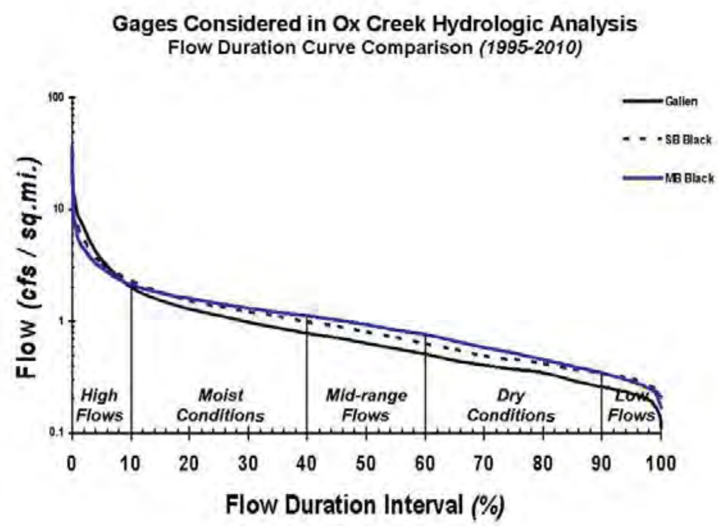


Figure 5-19. Flow duration curves for USGS gages considered.

Flow duration curves basically represent a cumulative frequency distribution. Duration curves can also be used to put the Ox Creek level logger data into perspective relative to a longer time frame and the full range of seasons. Figure 5-20 compares a duration curve using all Ox Creek level logger flows to one derived from Galien River flows measured on the same days. Both are displayed with the Galien River duration curve developed using the full range of flows (1995 – 2010). The Ox Creek level logger was deployed from mid June to early December in 2007 and from early April to early August in 2008. For this reason, the Ox Creek recorded data set may have missed a number of high flow events (confirmed by the discrepancy between the two Galien River curves; one reflects only the 2007 and 2008 periods, while the other is based on the entire period of record). One way to more closely examine this possibility is to plot Ox Creek level logger flows against flow duration intervals derived from the Galien River data set.

Figure 5-21 displays this information and shows that level logger measurements are clustered in the *"Dry Conditions"* zone. The width of each zone represents the percentage of that particular condition. For instance, *"Dry Conditions"* represents 30 percent of the all daily average flow values used to develop the Galien River duration curve. However, nearly 40 percent of all Ox Creek values are in this zone (instead of the observed 30 percent of all Galien River measurements). Conversely, the number of level logger measurements in the *"High Flow"* zone are less than would be expected based on Galien River data; only five percent versus the 10 percent observed in the Galien (i.e., the width of the *"High Flow"* zone). This suggests that some high flow events were not recorded by the level logger in the Ox Creek watershed. Although the level logger information is still quite valuable, the overall Ox Creek hydrologic analysis must be augmented with long term flow information using the Galien River gage.

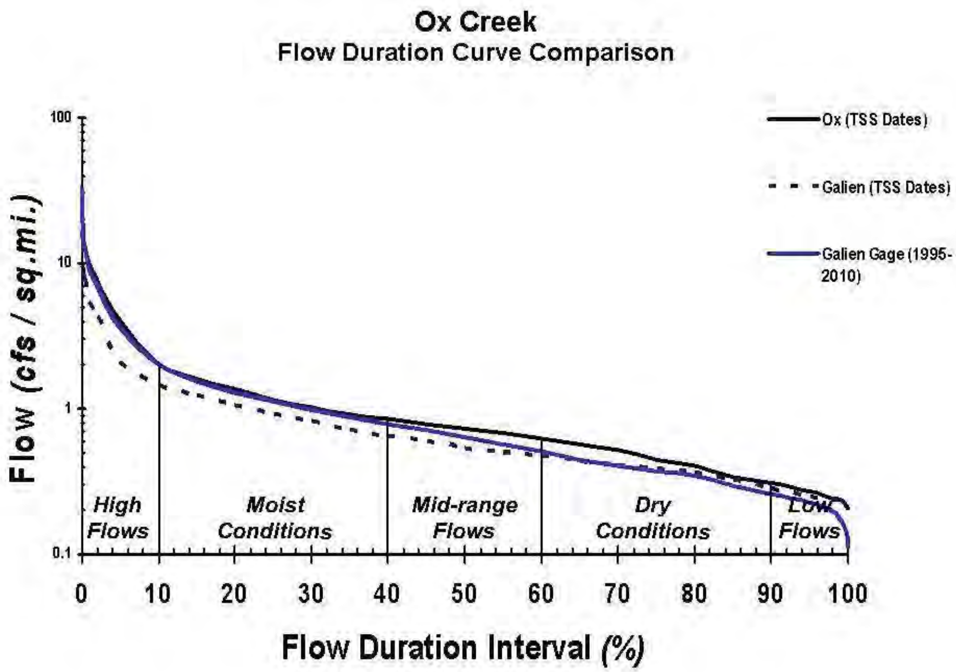


Figure 5-20. Flow duration curves for Ox Creek and Galien River.

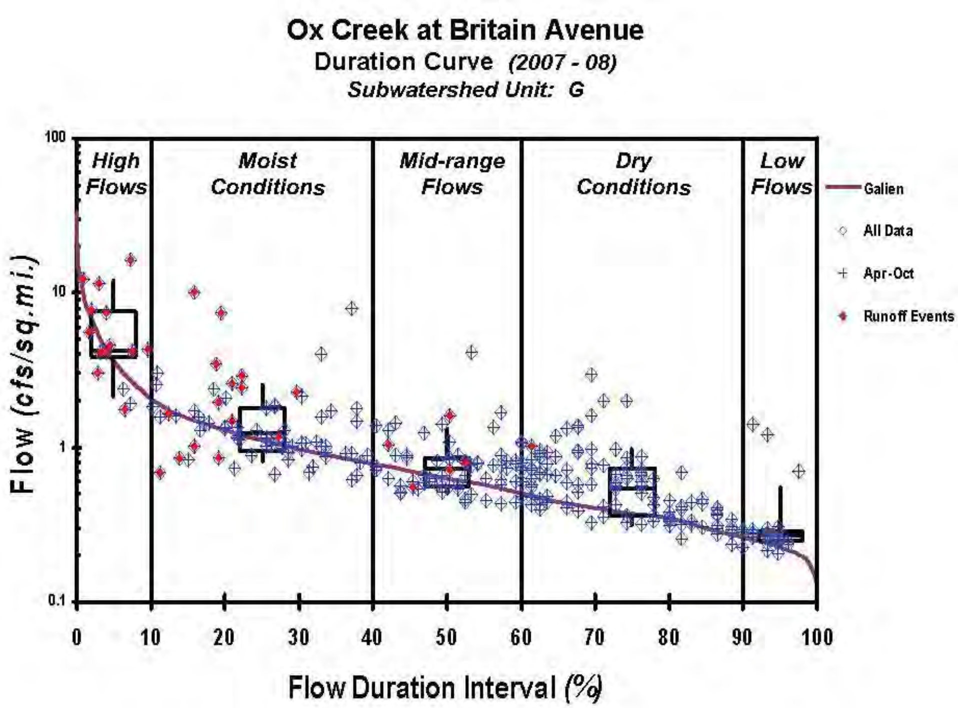


Figure 5-21. Ox Creek level logger flows using Galien River duration curve.

5.2.3 Seasonal Variation

One important part of the hydrologic analysis for the Ox Creek area is to examine seasonal patterns. Figure 5-22 through Figure 5-24 depict seasonal variation in unit area flows for the Galien, S.B. Black, and M.B. Black Rivers. Another useful aspect to seasonal variation in flows is to evaluate runoff patterns relative to precipitation.

Table 5-8 provides a monthly summary of average monthly precipitation measured at the Benton Harbor airport from 1995 to 2010. This timeframe corresponds to the same period used for the flow data analysis. In order to compare seasonal precipitation patterns to flow information, Table 5-8 includes monthly average runoff from the Galien, South Branch Black, and Middle Branch Black Rivers. Table 5-8 also summarizes the average runoff for all three gage locations as a percentage of the monthly precipitation.

As shown, the lowest volume of precipitation occurred in February and March. Interestingly, March also corresponds to the greatest runoff at all sites. It is likely that runoff in March is elevated due to the absence of mature vegetation and saturated soils due to spring melt. This presumption is supported by the fact that August corresponds to the greatest amount of precipitation, yet least amount of runoff. As opposed to March, vegetation is mature in August and likely slows, absorbs and soaks up precipitation, minimizing runoff.

Table 5-8. Seasonal precipitation and runoff patterns.

	Monthly Precipitation and Runoff *(in.)*											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Precipitation	2.62	1.83	2.06	3.14	3.75	3.33	3.12	4.32	3.80	3.26	2.86	2.67
Galien River	1.88	1.88	2.06	1.55	1.68	1.13	0.66	0.57	0.63	0.78	0.97	1.36
S.B. Black River	1.75	1.81	2.55	2.11	1.47	1.15	0.75	0.60	0.79	0.96	1.24	1.77
M.B. Black River	1.71	1.74	2.21	1.77	1.68	1.69	0.75	0.58	0.71	0.90	1.20	1.52
Average Ratio *Runoff / Precipitation*	68%	99%	110%	58%	43%	40%	23%	14%	19%	27%	40%	58%

5.2.4 Base Flow Distribution and Flashiness

A general understanding of the processes that deliver water to the stream is another key element of the hydrologic analysis. Specifically, water associated with base flow has different quality characteristics than water associated with surface runoff. For example, excessive surface water runoff can lead to the detachment of soil particles. If the runoff volume is high enough and soils are exposed, surface erosion occurs. Runoff flowing rain events can be one of the most significant delivery mechanisms of sediment and other nonpoint source pollutants.

Development of duration curves requires the assessment of hydrologic information. Other analytical methods can use the same stream flow data to examine general watershed runoff patterns. Hydrograph analysis has proven to be a useful technique for a variety of water resource investigations. For example, streamflow hydrographs can be separated into base-flow and surface runoff components *(Sloto and Crouse, 1996)*. The base-flow component is traditionally associated with groundwater discharge and the surface-runoff component with precipitation that enters the stream as overland flow. This information is included in Table 5-7 for the Galien, S.B. Black, and M.B. Black Rivers.

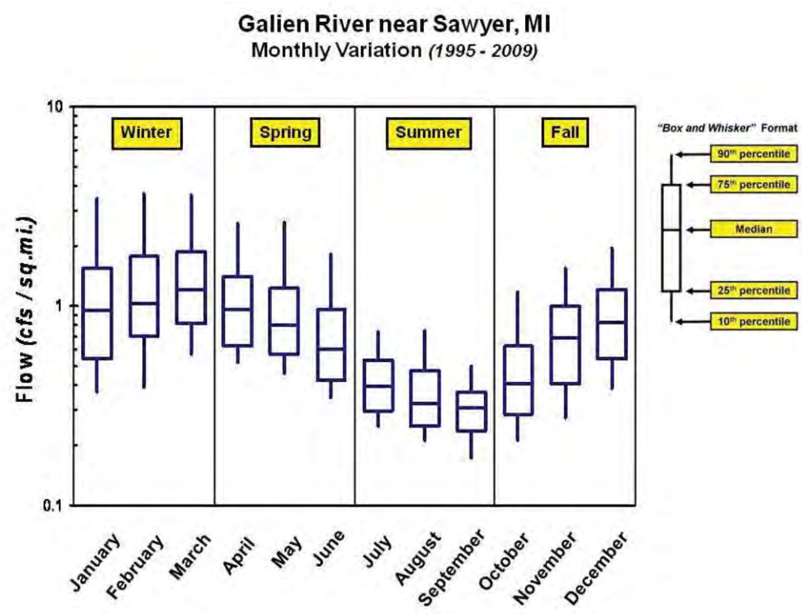


Figure 5-22. Seasonal variation of Galien River flows.

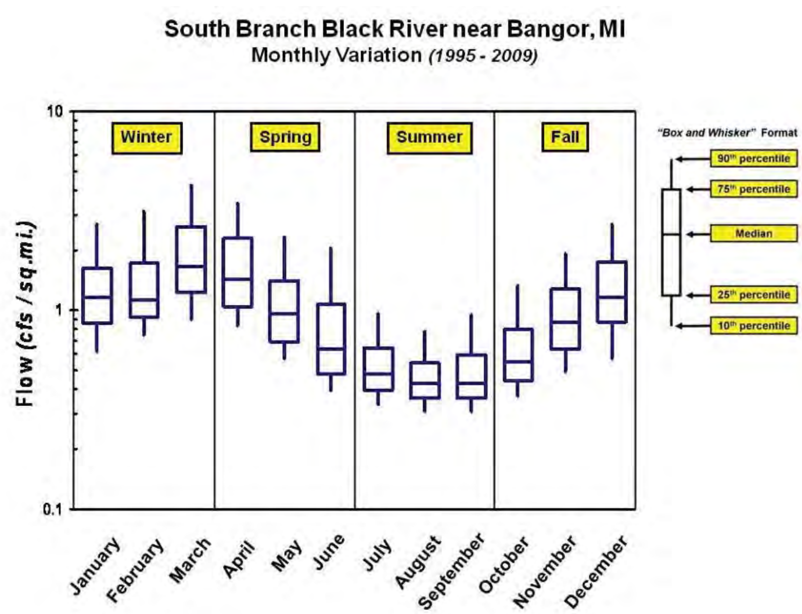


Figure 5-23. Seasonal variation of S.B. Black River flows.

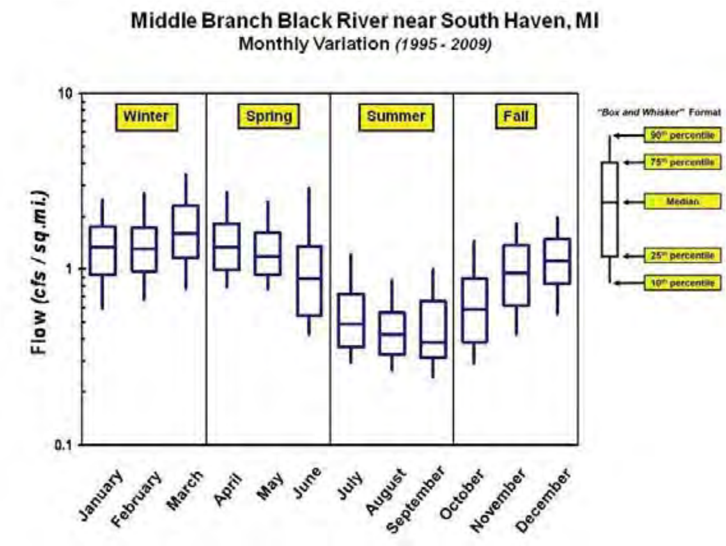


Figure 5-24. Seasonal variation of M.B. Black River flows.

Another important hydrologic measure that is closely related to base-flow and surface-runoff patterns is *"flashiness"*. *"Flashiness"* is an important component of a stream's hydrologic regime *(Baker, et al, 2004)*. *"Flashiness"* is often a common cause of stream channel instability *(Fongers, et al, 2007)*. *"Flashiness"* affects habitat stability and conditions that influence the suitability of a stream to support aquatic life. Increased stream *"flashiness"* results in increased habitat disturbance. Stable flow regimes (or low stream *"flashiness"*) support the establishment of healthy macroinvertebrate populations, while *"flashy"* flows (e.g., those associated with urban runoff) can disrupt community structure.

For example, swimmers, crawlers, and clingers (particularly EPT) are typically *"washed out"* from *"flashy"* systems due to increased stream velocities and flow volumes. Rocks that serve as good habitat for EPT and support diverse macroinvertebrate communities are scoured in *"flashy"* systems. Oligochaetes (pollution tolerant worms) tend to become more established in *"flashy"* systems, as they can burrow into the substrate. In addition, periphyton that serves as a food source for scrapers is stripped out of *"flashy"* systems.

The Richards-Baker (R-B) Flashiness Index has been used with mean daily stream flows to quantify this component of stream hydrology. The index is calculated by dividing the path length of flow oscillations for a time interval by the total discharge during that time interval. The index has low inter-annual variability, relative to most flow regime indicators, with greater power to detect trends *(Baker, et al, 2004)*. A greater R-B Flashiness Index is associated with a greater potential for an expected response of stream habitat disturbance. R-B Index scores range from 0 to 2, with 0 being that the stream flow is absolutely constant and increases in flashiness as the R-B Index approaches 2.

Fongers, et. al. (2007) provides a context to incorporate *"flashiness"* into the linkage analysis based on an examination of gaged streams and rivers across Michigan. Their study included a summary of R-B Flashiness Index quartile rankings for Michigan watersheds by drainage area size *(Figure 5-25)*. The R-B Flashiness Index can be calculated using daily average flow information for the Galien, S.B. Black, and M.B. Black Rivers, as well as for Ox Creek using the level logger data *(Table 5-9)*. To ensure consistency, the calculations are based on the same dates that flows were recorded in Ox Creek.

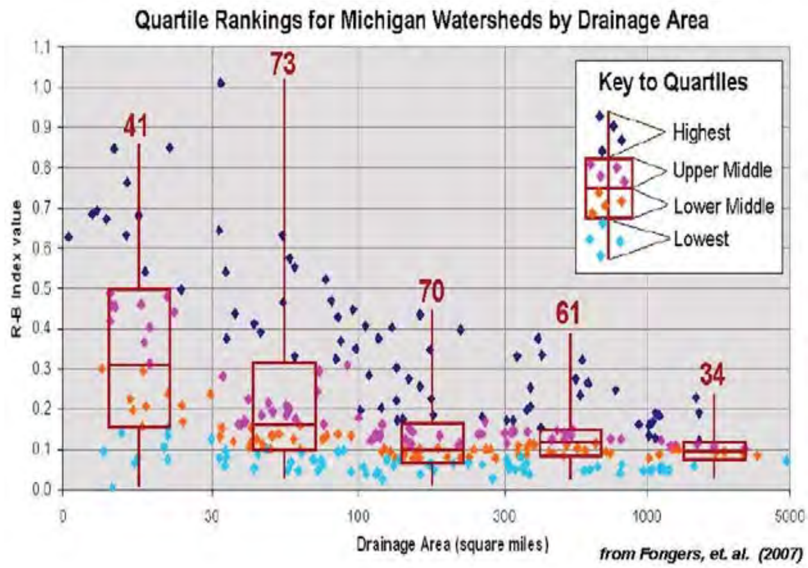


Figure 5-25. R-B flashiness index quartile rankings for Michigan rivers and streams.

As noted in Table 5-9, the R-B Flashiness Index for Ox Creek at Britain Avenue is 0.52. This is consistent with general observations presented in the 2007 DEQ report (Lipsey, 2007), and places it in the upper quartile of R-B Flashiness Indices for Michigan's watersheds of the same size *(Figure 5-25)*. In addition to these sites, the R-B Flashiness Index was calculated for several other Michigan locations where bioassessment, flow, and suspended sediment data have been collected. These sites all have acceptable macroinvertebrate populations based on Michigan's Procedure 51 rapid bioassessment protocols. It appears that in addition to TSS, flow conditions are adversely affecting macroinvertebrate populations in Ox Creek below its confluence with Yore-Stouffer Drain. The R-B Index values for Michigan watersheds range from 0.006 to 1.009 (as watershed size decreases, flashiness increases). For watershed sizes 0 to 30 square miles, the range is 0.006 to 0.848, with the mean 0.365. Table 5-9 shows that Ox Creek, having a R-B Index value of 0.52 and watershed size of 14.7 square miles, is flashy.

Table 5-9. R-B flashiness index for Ox Creek and selected Michigan sites.

Gage ID	Drainage Area *(mi^2)*	R-B Flashiness Index	Site Name
04102531	14.7	0.52	Ox Creek at Benton Harbor *(Britain Avenue)*
04096015	80.7	0.28	Galien River near Sawyer
04102700	83.6	0.15	South Branch Black River near Bangor
04102776	83.0	0.13	Middle Branch Black River near South Haven
04102320	195	0.11	Paw Paw River near Paw Paw
04102420	311	0.07	Paw Paw River near Hartford
04096340	144	0.06	St. Joseph River at Clarendon
04096312	20.6	0.09	Sand Creek
04096272	42.4	0.17	Beebe Creek
04096325	10.9	0.13	Soap Creek

5.3 Rainfall - Runoff Patterns in Ox Creek

The overall assessment of water quality can be strengthened by examining potential relationships between source areas and rainfall – runoff patterns. Models are particularly useful tools to evaluate the effect that different land uses may have on a particular receiving water. In the case of Ox Creek, principles behind the Loading Simulation Program C++ (LSPC) can be used in conjunction with Benton Harbor precipitation data to examine the effect of land use on runoff. Rainfall – runoff analysis in LSPC is based on algorithms from the Hydrologic Simulation Program FORTRAN (HSPF), a widely used model approved by USEPA to support TMDL development.

5.3.1 Hydrologic Response

A technique being used in conjunction with rainfall – runoff modeling is the use of Hydrologic Response Units (HRUs). The concept of HRUs is based upon the principles that areas with similar sets of characteristics can be expected to respond similarly to the same weather conditions. A brief overview of the hydrologic cycle is presented in Figure 5-26 to help illustrate major processes involved in developing a rainfall-runoff model and HRUs. This diagram shows those processes and factors found in each subwatershed that exert an effect on hydrologic response to precipitation events. For example, the type of vegetation (e.g., forest, pasture, urban grass, etc.) affects the amount of precipitation that is retained and never reaches the land surface. Precipitation intercepted by vegetation is either consumed by the plants and released through transpiration, or is returned to the atmosphere via evaporation.

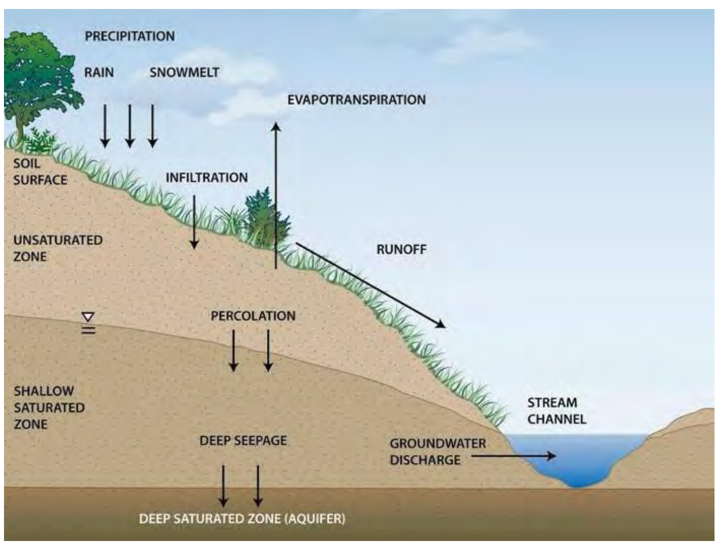


Figure 5-26. Key processes in the hydrologic cycle.

Soil characteristics also play a major role in hydrologic response. For instance, precipitation that is not intercepted by vegetation falls to the surface and either infiltrates into the soil or flows across the surface. The amount of water that enters the soil is a function of its infiltration rate. Higher infiltration rates produce more water in the various soil layers (either the upper unsaturated zone, or the lower shallow saturated zone and groundwater components that result in higher base flow to the stream). In addition to land use, soil group, and slope, other factors can affect the development of hydrologic response units in any given watershed. These include: proximity to the stream channel, connected impervious surfaces, and alterations to the drainage system (e.g., ditches associated with road networks or agricultural fields).

In defining HRUs, land use categories typically include: forest, pasture, cultivated crops, wetlands, high density residential, low density residential, and commercial. Information from local sources can be used to refine land use groups. Soil groups used in identifying HRUs generally include traditional classifications such as A, B, C, and D. Slope categories can be divided into two classes: low (e.g., 0% - 10%) and high (e.g., >10%). The HRU approach simplifies selection of model parameters by providing a clear physical basis for assignment of values. Existing Geographic Information System (GIS) data layers are commonly used to construct project-specific HRUs. These serve as a foundation for subsequent modeling analyses. A rainfall – runoff model can then be used to compare unit area flows associated with each HRU or land use category.

The most significant factor affecting storm water runoff in the Ox Creek watershed is impervious cover (IC). Although impervious cover has not been measured in Ox Creek, land use information can help make IC estimates. The WC&SA report provided summary information by subwatershed from 15 GIS land use categories. Many of these categories are associated with undeveloped land (e.g., forest, pasture, crops, wetlands) that have little or no impervious cover. The categories of greatest interest with respect to IC are developed lands. One way to examine the potential effect of storm water runoff on Ox Creek is through a screening analysis using impervious cover assumptions for different developed land uses *(Table 5-10)*.

Table 5-10. Effect of impervious cover assumptions for developed land uses on runoff.

Land Use / Land Cover	Impervious Cover *(assumed %)*	Runoff Volume *(inches / year)*	R-B Flashiness Index
Undeveloped	0%	11.3	0.17
Developed, Open	5%	12.3	0.32
Developed, Low-Intensity	25%	16.2	0.81
Developed, Medium-Intensity	50%	21.2	1.17
Developed, High-Intensity	75%	26.2	1.39
Note: Assumed values solely for purposes of illustrating potential effect of stormwater runoff under different levels of development.			

A screening analysis can describe the effect of land use on runoff by comparing flow duration curves for locations draining areas representative of different IC levels, as shown in Figure 5-27. The results illustrated in this screening analysis graph are the results of LSPC model runs based on assumptions in Table 5-10 coupled with Benton Harbor precipitation data from 1995 to 2010.

The *"Undeveloped"* curve provides a baseline (e.g., no impervious cover). Figure 5-27 highlights the effect of increased IC on flow duration, magnitude and distribution. The flows for the *"High-Intensity"* area show higher peak flows as well as lower base flows, compared to flows under *"Undeveloped"* conditions. In addition to flow duration curves, the effect of IC on storm water runoff is summarized in Table 5-10 through changes in runoff volume and *"flashiness"*. Understanding these patterns helps planners target different land uses with appropriate types of BMPs, which is particularly useful in stormwater management.

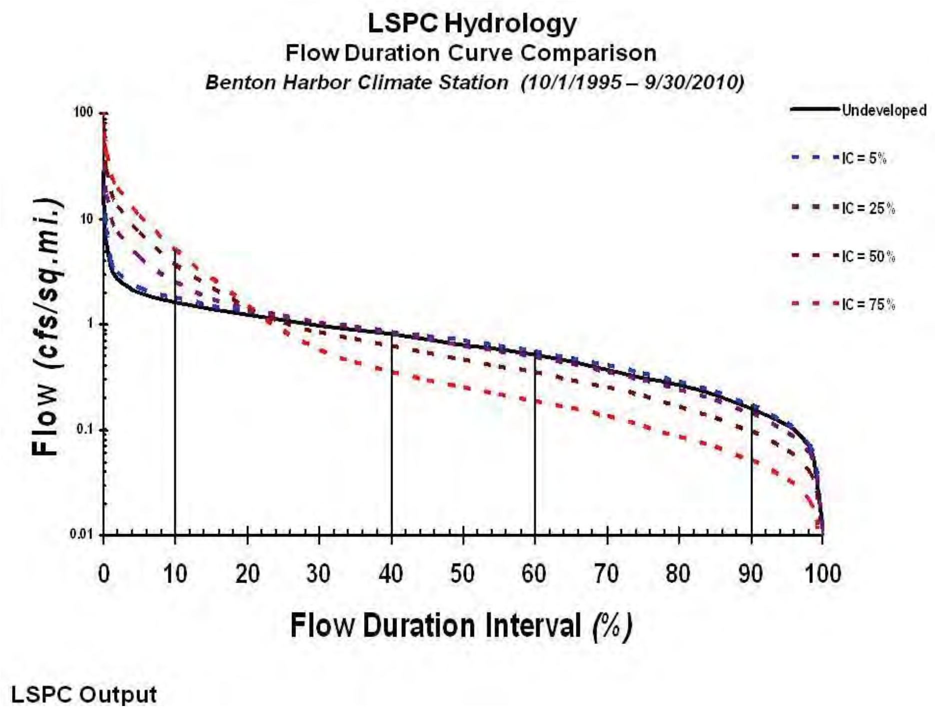


Figure 5-27. Effect of impervious cover (IC) on flow duration curve.

5.3.2 Ox Creek Storm Events

The wet-weather survey information was used to assess rainfall – runoff patterns in the Ox Creek watershed. A key part of this analysis is to examine where significant amounts of water are being delivered to Ox Creek. Flow information collected during the TSS survey can be used to develop a water volume analysis; somewhat analogous to a pollutant loading analysis (e.g., TSS).

The LSPC screening analysis describes the critical importance of land use and IC in terms of their effect on flow patterns and hydrologic response. In particular, the amount of impervious cover can have a dramatic effect on the flow duration curve, runoff volume, and stream *"flashiness"*. Given the amount and type of data available, however, the use of LSPC in this setting is best suited for comparing the relative change in daily average flows based on a multi-year simulation (e.g., 1995-2010). In order to examine wet-weather event patterns using the level logger data and *"tape down"* measurements, a different approach is needed; one that ensures continuity across the entire Ox Creek watershed.

As discussed in Section 5.2.4, stream discharge consists of two major components: base flow and surface runoff. The base flow component has traditionally been associated with ground water discharge and the surface runoff component with precipitation that enters the stream as overland runoff (Sloto and Crouse, 1996). Discharge estimates derived using the Ox Creek Britain Avenue level logger can be separated into these two components using a technique developed by the USGS. The Ox Creek Britain Avenue base flow component can be equally apportioned across the watershed using drainage area weighting. This assumption ensures continuity in developing a water balance using the wet-weather survey information.

The surface runoff component at each site is a function of land use, particularly impervious cover. A major focus of storm water management plan development is the amount (or volume) of runoff. Flow volume, as a function of IC can be calculated using the following equation, adapted from *"Urban Runoff Quality Management"* (ASCE / WEF, 1998):

$$Qv = C * P * (A/12)$$

where:

C = runoff coefficient

$= 0.858*i^3 - 0.78*i^2 + 0.774*i + 0.04$

i = watershed imperviousness ratio *(percentage divided by 100)*

P = amount of precipitation occurring in a 24-hour period *(inches)*

A = drainage area *(acres)*

This relationship can be used to estimate stormwater volumes at each site. Again, the Ox Creek Britain Avenue surface runoff component can be apportioned across the watershed through drainage area weighting (similar to the base flow component). A runoff coefficient (C) can be calculated for each subwatershed to account for the effect of impervious surfaces. This coefficient is based on subwatershed land use information (presented in the WC&SA report) and IC assumptions for each developed land use category *(Table 5-10)*. The adjustment at each site is made based on the ratio of the runoff coefficient (C) for that subwatershed to the runoff coefficient (C) for the Ox Creek Britain Avenue site.

The results of these calculations are summarized in Table 5-11. In addition to each volume component, the subwatershed size, cumulative IC, and runoff coefficient is included in the summary table. These volume estimates provide continuity across the watershed (benchmarked to the Ox Creek level logger flows -- Unit G). These volumes have been combined with "*tape down*" measurements at each site to ensure that stream reach-by-reach water amounts are balance (which is critical to subsequent pollutant loading calculations). This method also preserves hydrograph patterns observed at each site using "*tape down*" measurements.

Table 5-11. Ox Creek wet-weather survey event subwatershed runoff volumes.

Unit	**Cumulative**		**Runoff Coeff. (C)**	**Water Volume** *(acre-feet)*					
				8/19/2007			**4/9/2008**		
	Area *(acres)*	**IC** *(%)*		*Base*	*Surface*	**Total**	*Base*	*Surface*	**Total**
A	2,150	1%	0.049	3.42	28.33	**31.75**	7.77	8.91	**16.68**
B	2,615	1%	0.050	4.16	34.67	**38.84**	9.45	10.91	**20.36**
C	4,370	4%	0.073	6.96	84.70	**91.65**	15.79	26.64	**42.44**
D	5,175	9%	0.102	8.24	140.41	**148.65**	18.70	44.17	**62.88**
E	2,600	7%	0.091	4.14	62.93	**67.07**	9.40	19.80	**29.20**
F	8,500	10%	0.108	13.53	244.73	**258.26**	30.72	76.99	**107.71**
G	9,395	10%	0.111	14.96	277.29	**292.24**	33.96	87.23	**121.19**
H	10,455	11%	0.119	16.64	331.65	**348.30**	37.79	104.34	**142.12**
I	10,559	12%	0.121	16.81	339.73	**356.54**	38.16	106.88	**145.04**

6. Water Column

Studies to investigate potential causes of biological impairments included water column measurements. MDEQ surveys of the macroinvertebrate populations noted heavy siltation. For this reason, an emphasis was placed on collecting total suspended solids data, both under dry conditions and during wet-weather events. Samples were also analyzed for metals and toxic organic compounds. This section of the Linkage Analysis summarizes those results. Because of the focus on suspended sediment, sampling efforts conducted by the USGS at locations where waterbodies meet the other indigenous aquatic life and wildlife designated use are also discussed.

6.1 Ox Creek Total Suspended Solids Sampling

A study was initiated by MDEQ in 2007 and continued in 2008 that focused on total suspended solids monitoring at seven sites (Limno Tech, 2008). These sites are listed in Table 6-1 with locations shown in Figure 6-1. Sampling was conducted that consisted of both wet and dry weather events. Water level recorders were deployed at the Britain Avenue site to enable development of stream flow estimates. In addition, *"tape down"* measurements (i.e., the distance from an identified reference point at each monitoring location to the water surface) were recorded at the time of each sample collection.

Table 6-1. Ox Creek TSS Sampling sites.

Location	MDEQ Site ID
Yore – Stouffer Drain at Blue Creek Road	#05
Yore – Stouffer Drain at Yore Avenue	#06
Yore – Stouffer Drain at Meadowbrook Road	#01
Ox Creek at Crystal Avenue	#02
Ox Creek at Empire Avenue	#03
Ox Creek at Britain Avenue	#07
Ox Creek at Water Street	#04

Table 6-2 summarizes the dates sampled for each type of event (wet or dry). In addition, the 24-hour precipitation reported by the National Weather Service for the Benton Harbor airport is included for each wet weather sampling event. Because hydrology plays an important role in evaluating water quality, Ox Creek flows associated with TSS sample events are shown in Figure 6-2. This graph provides a context for TSS sampling events relative to hydrologic conditions.

Figure 6-3 presents a summary of the TSS monitoring data. Information is depicted in the longitudinal direction moving from upstream to downstream (left to right). Two horizontal lines are included to put TSS concentrations into some perspective. These are drawn at 25 mg/L and 300 mg/L, which will be discussed under *"Targets Development"* (Section 8).

The highest TSS values were reported for the Yore-Stouffer Drain at the Yore Avenue site (the largest occurred during the second wet weather sampling event in April 2008). This particular site, located in the upper reaches of the Yore-Stouffer Drain, is in the agricultural portion of the watershed. This site, along with the Blue Creek Road site, also exhibited a high degree of variability, as evidenced by the range of sample values shown in Figure 6-3.

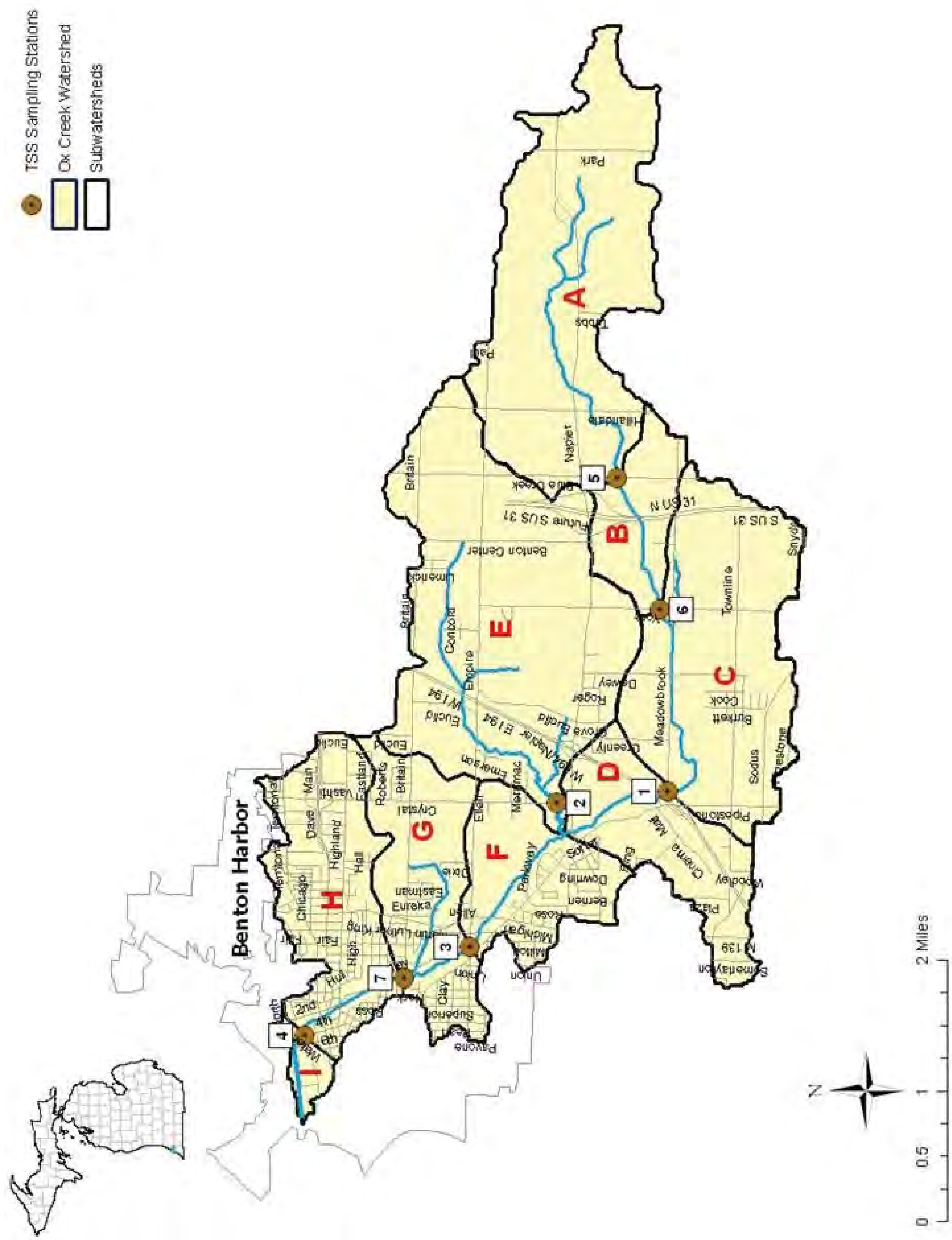


Figure 6-1. Location of Ox Creek TSS monitoring sites.

Table 6-2. Dates associated with each TSS sampling event.

Sample Date	Event	24-hour Precipitation (inches)
7/31/2007	Dry	0
8/14/2007	Dry	0
8/18-19/2007	Wet	2.52
9/6/2007	Dry	0
4/8-9/2008	Wet	0.69
8/4-5/2008	Wet	0.74

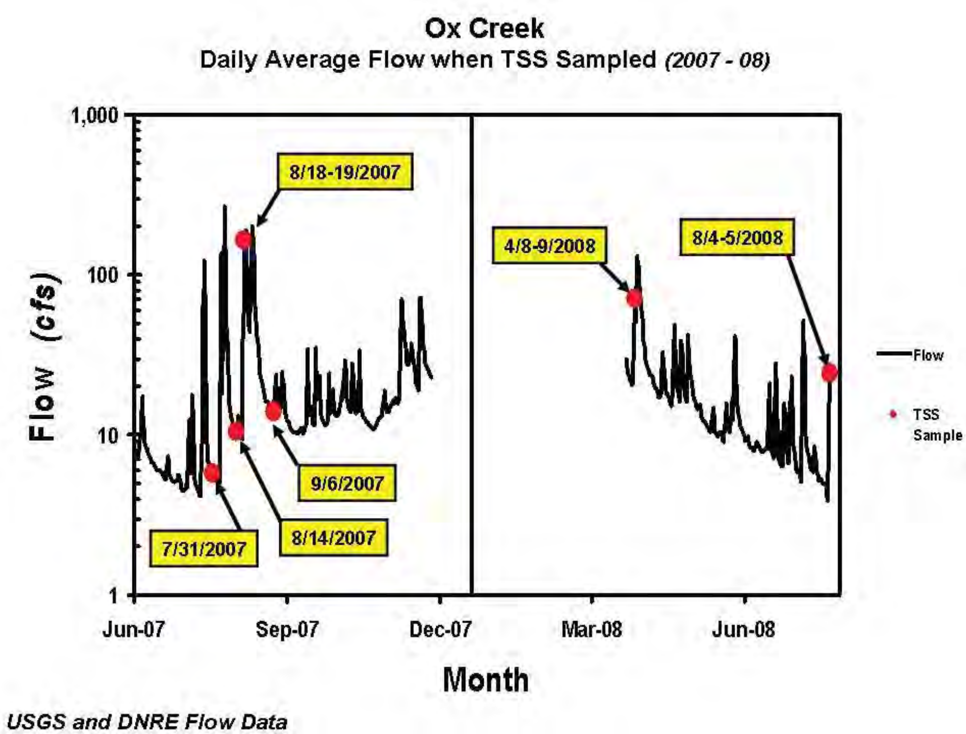


Figure 6-2. Ox Creek flow and TSS sample dates.

One way to examine the TSS data is through an analysis of its relationship to flow. As discussed earlier, *"tape down"* measurements can be expressed as water level; this provides an indication of flow. Figure 6-4 depicts TSS data for the Yore Avenue site as a function of water level. The general pattern indicates that TSS concentrations increase with rising water level (and flow). However, two areas of the graph are highlighted where exceptions to the general pattern occur. First, the two largest TSS values (noted by the upper circle) did not correspond to the highest water levels. Second, the smallest TSS values did not necessarily occur at the lowest water level (noted by the lower circle). These anomalies may be related to several factors such as the intensity of the precipitation event, the season of occurrence, and the timing of the individual TSS sample relative to the onset of the storm.

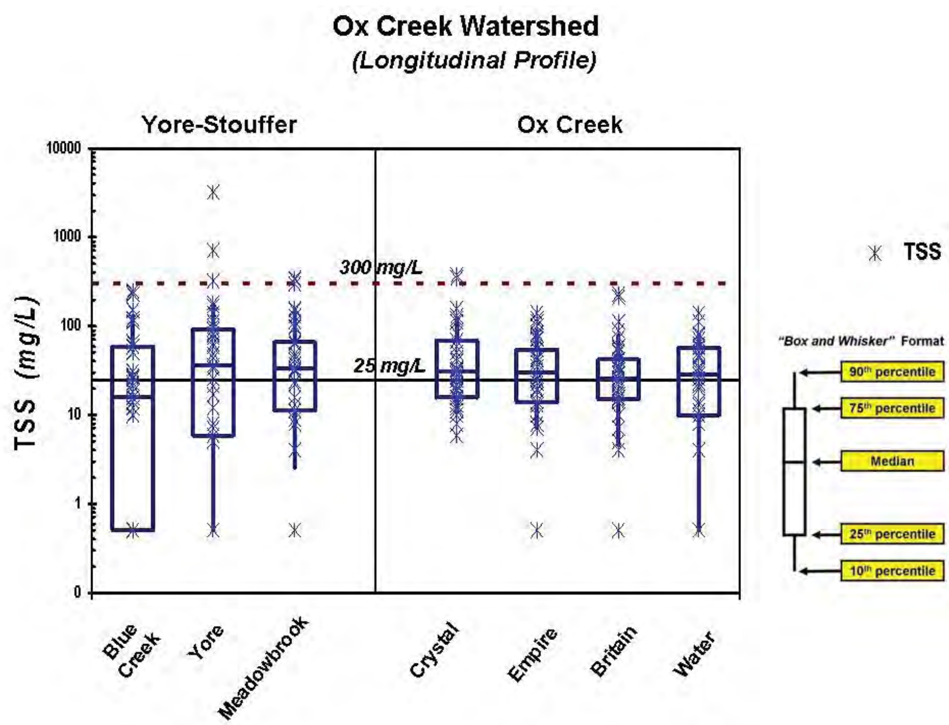


Figure 6-3. Longitudinal profile of TSS monitoring data.

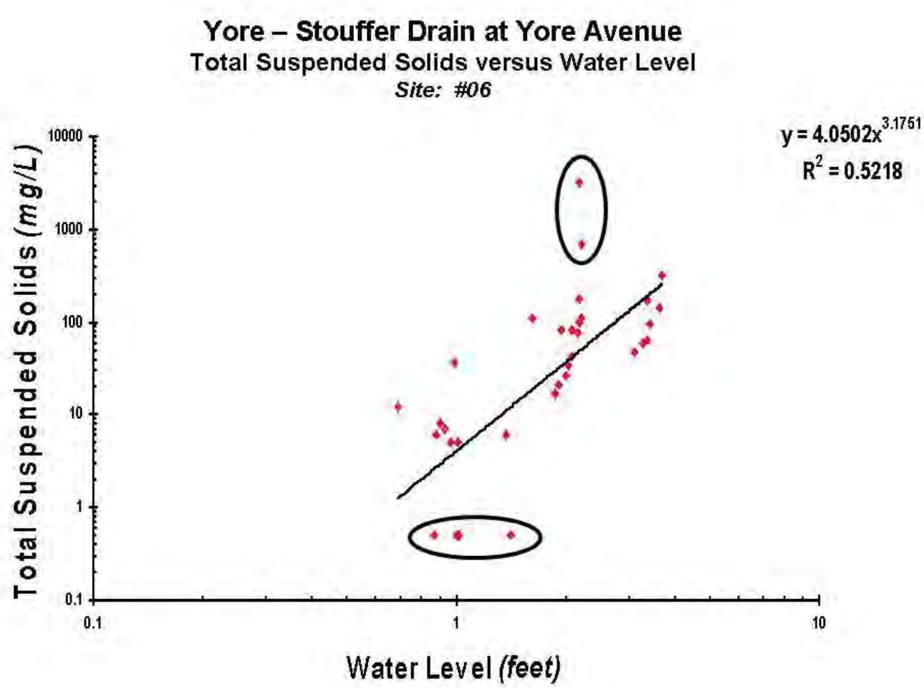


Figure 6-4. TSS as a function of water level -- Yore Avenue site.

6.2 USGS Suspended Sediment Monitoring

The USGS has collected suspended sediment concentration (SSC) data at a number of sites across the country. One such location sampled was the South Branch Black River at the gaging site identified in Section 5.2.1. In addition to the USGS SSC data, MDEQ has collected biological information on the S.B. Black River. Biological data indicates that this stream meets the other indigenous aquatic life and wildlife use. Thus, information from this stream can be used to describe daily fluctuations in SSC values over the course of several years at a location that achieves an acceptable score using Michigan's rapid bioassessment protocols.

Using a time series analysis of individual data points, elevated SSC values on the S.B. Black River are generally associated with higher flow conditions *(Figure 6-5).* This graph also indicates that suspended sediment varies both by season and from year-to-year. Although this SSC data was collected in the 1980's, land use in the area draining to this site has not changed significantly. Cultivated crops, woods, and pasture exert the greatest influence at this site.

Understanding the variability associated with water quality conditions is a key part of the overall assessment process. This can be especially important in the linkage analysis, where factors that affect variability are considered (e.g., flow conditions, seasonality). The USGS information can be used to provide information on suspended sediment concentrations for a southwest Michigan stream that achieves bioassessment targets for protection of aquatic life. Characteristics of particular interest include average and median values, the magnitude of high concentration events, and the frequency at which high concentration events occur.

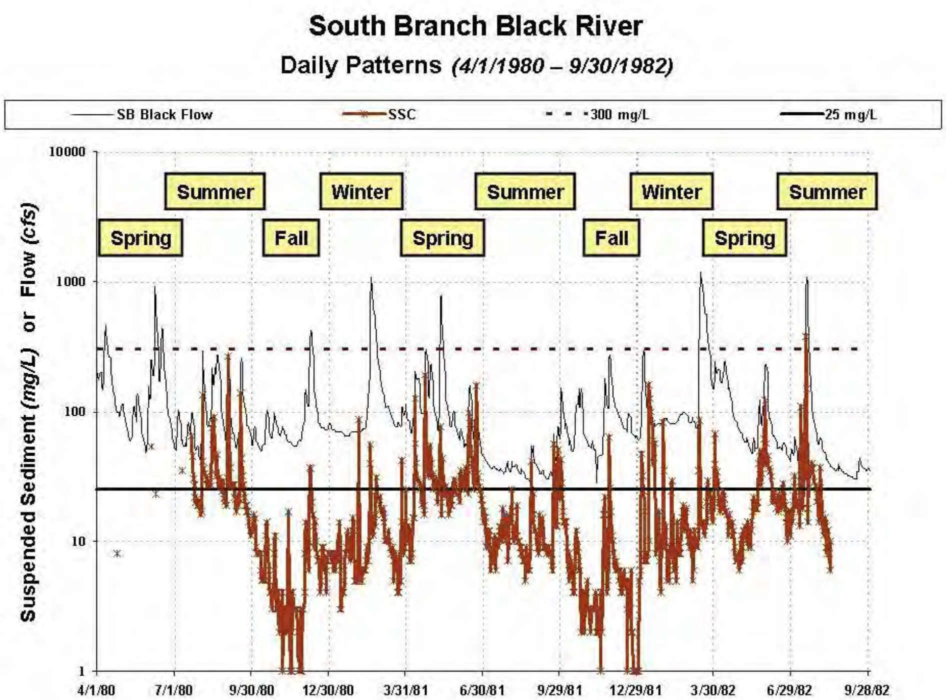


Figure 6-5. Temporal variability of suspended sediment and flow -- S.B. Black River.

As mentioned earlier, an important part of the linkage analysis is to examine factors that influence variability. Leopold (1994) and others have documented the relationship between flow and sediment loads. Figure 6-6 depicts this relationship for the South Branch Black River. Although there is a correlation between suspended sediment loads and flow in the South Branch Black River, the r^2=0.584 indicates that other factors contribute to the variability of suspended sediment load versus flow, such as seasonality.

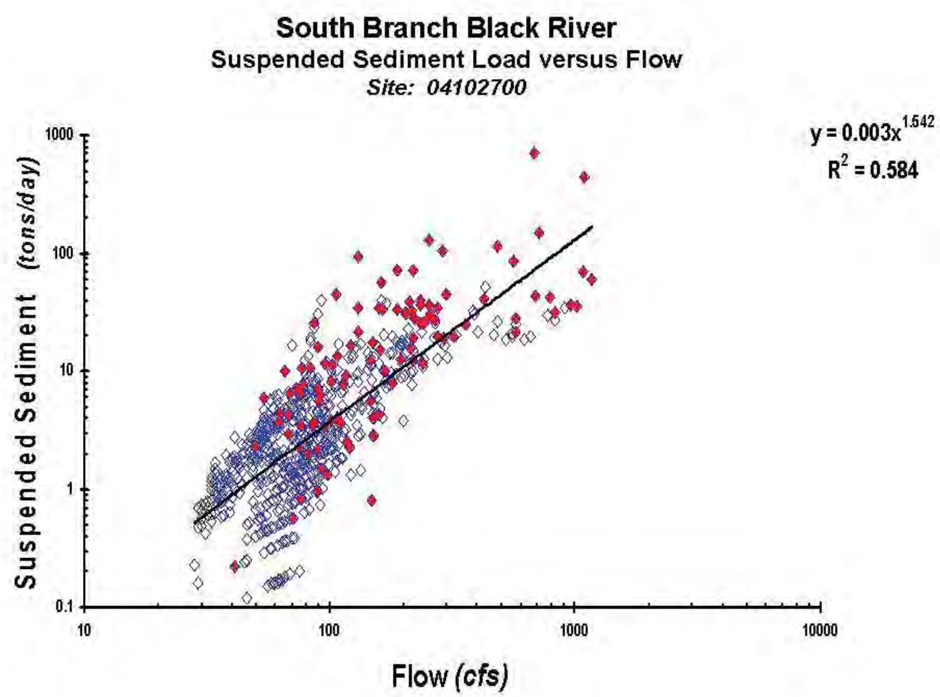


Figure 6-6. Flow versus suspended sediment load -- S.B. Black River *(year-round)*.

Figure 6-7 presents information that describes the seasonal variation of SSC values for the S.B. Black River. Definite patterns are apparent. For instance, winter SSC values are affected by snow, ice, and freeze-thaw conditions. Concentrations in the spring show a general increase, likely attributed to saturated soil conditions following the winter thaw, as well as the effect of rains on bare ground. Summer values appear to be fairly consistent, largely affected by the variability associated with thunderstorms on unsaturated soils. It is interesting to note that this consistency is reflected by a stronger correlation between suspended sediment load and flow for summer samples *(Figure 6-8).*

The S.B. Black River SSC data provides some insight regarding suspended sediment patterns on a stream that meets Michigan's other indigenous aquatic life and wildlife use. SSC data has also been collected at other sites in Michigan, which have acceptable macroinvertebrate populations based on Procedure 51. This information is summarized in Figure 6-9 for comparison to the Ox Creek data. Site names, drainage areas, and R-B Flashiness Index scores for these locations were presented earlier in Table 5-9.

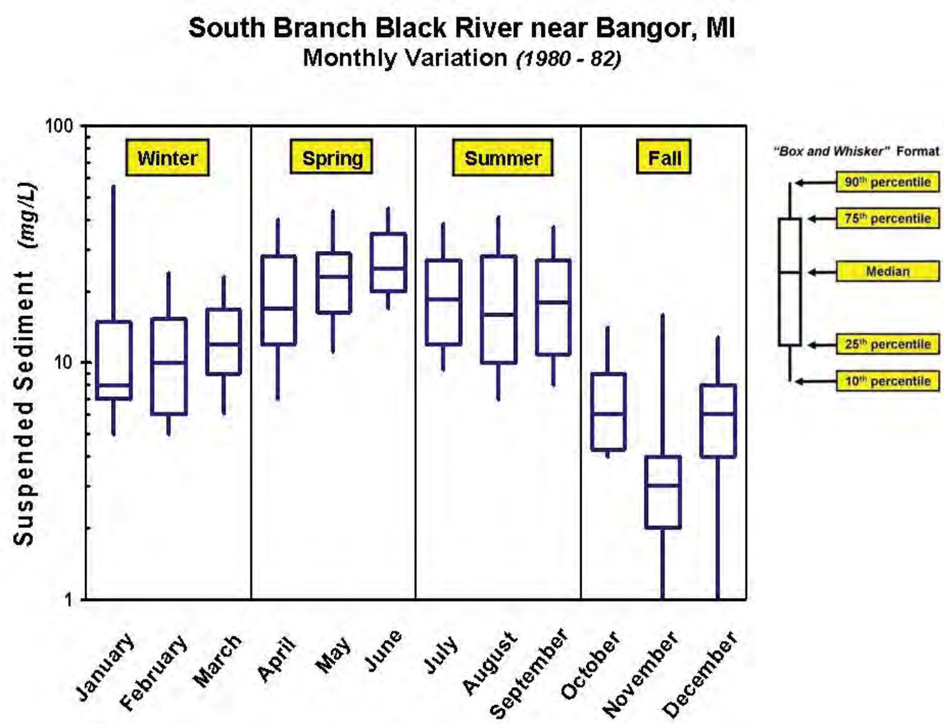


Figure 6-7. Suspended sediment seasonal variation -- S.B. Black River.

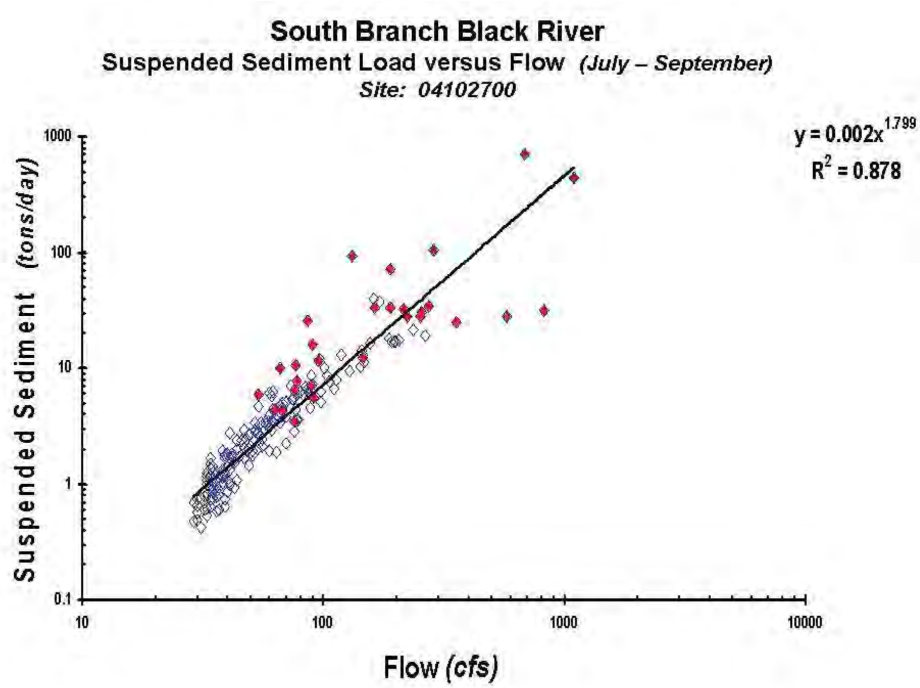


Figure 6-8. Flow versus suspended sediment load -- S.B. Black River *(summer)*.

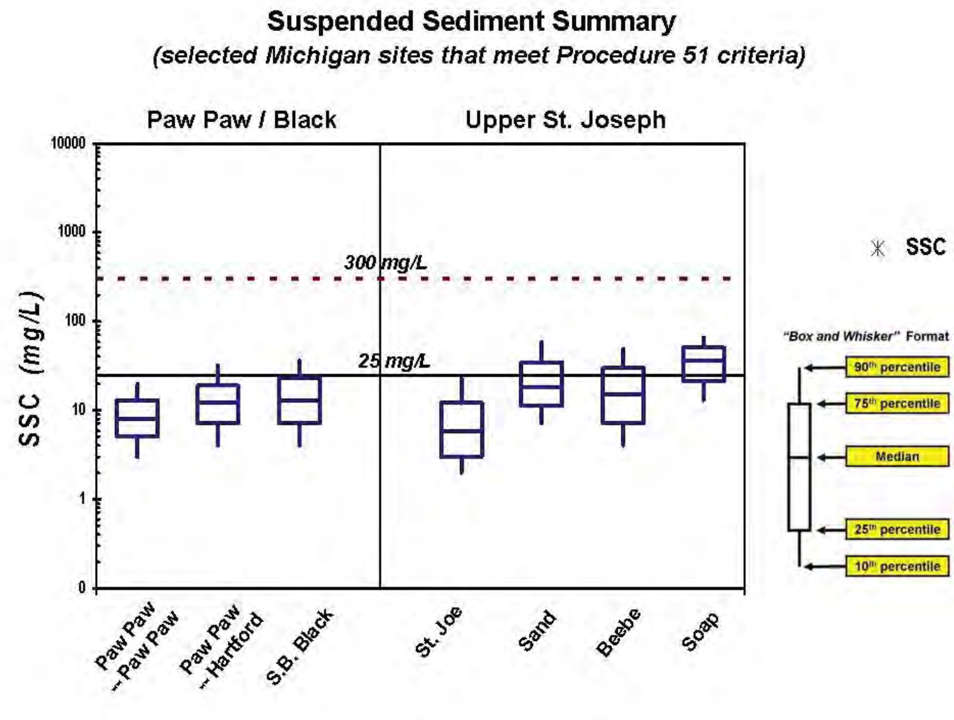


Figure 6-9. SSC summary from selected Michigan sites.

6.3 Hydrology and Water Quality Relationships

The primary benefit of flow duration curves in TMDL development is to provide insight regarding patterns associated with hydrology and water quality concerns. The duration curve approach is particularly applicable because water quality is often a function of stream flow. For instance, sediment concentrations typically increase with rising flows as a result of factors such as channel scour from higher velocities. Other parameters, such as chloride, may be more concentrated at low flows and more diluted by increased water volumes at higher flows.

The use of duration curves in water quality assessment creates a framework that enables data to be characterized by flow conditions. The method provides a visual display of the relationship between stream flow and water quality. This concept is illustrated by using sediment data collected at one of the gages identified in Table 5-6: the S.B. Black River near Bangor, Michigan. In the case of Figure 6-10, sediment concentrations are the greatest under high flow conditions. The display also shows that the highest levels are generally associated with runoff events (as indicated by the shaded diamonds). These events are days when surface runoff constitutes more than half of the daily average flow, as determined through hydrograph separation.

Level logger data from the Ox Creek Britain Avenue site provides information that can be used to estimate flows and loads. Using the relationship described in the hydrology discussion between this location and the Galien River gage, a flow duration curve can be developed for Ox Creek at Britain Avenue. This provides a starting point to view TSS loads as they may be related to flows. Figure 6-11 shows a load duration curve for TSS data at Britain Avenue developed from the combined information.

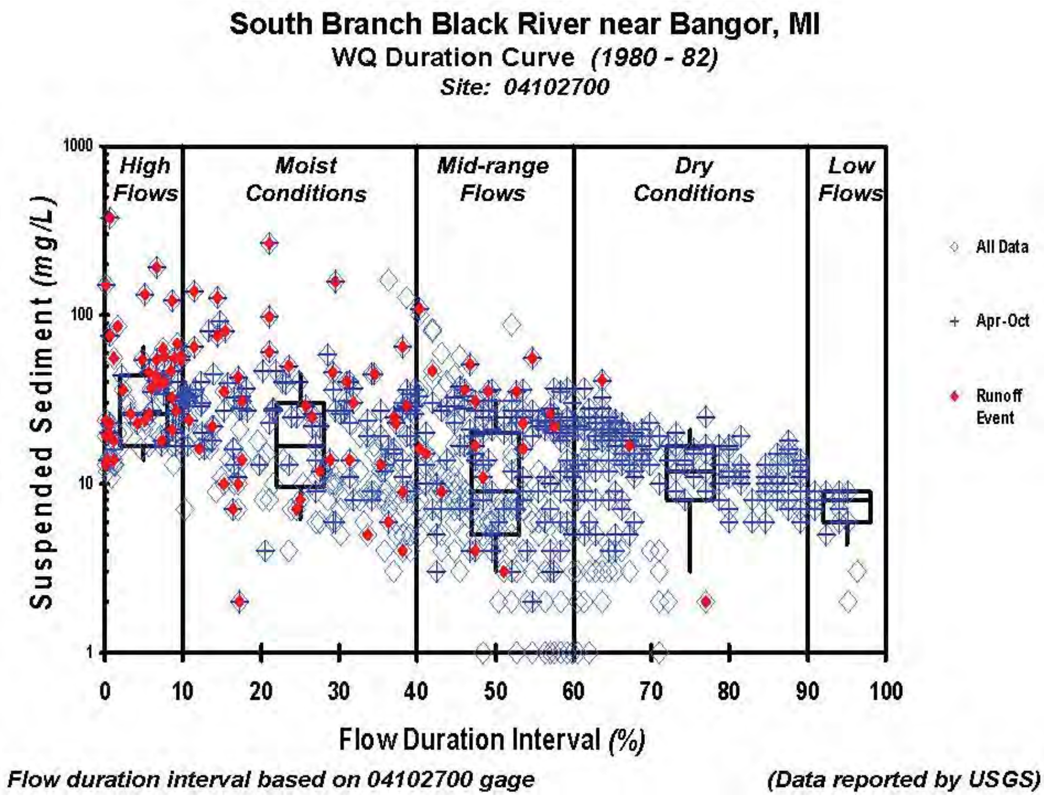


Figure 6-10. Relationship between flow and sediment using duration curve framework.

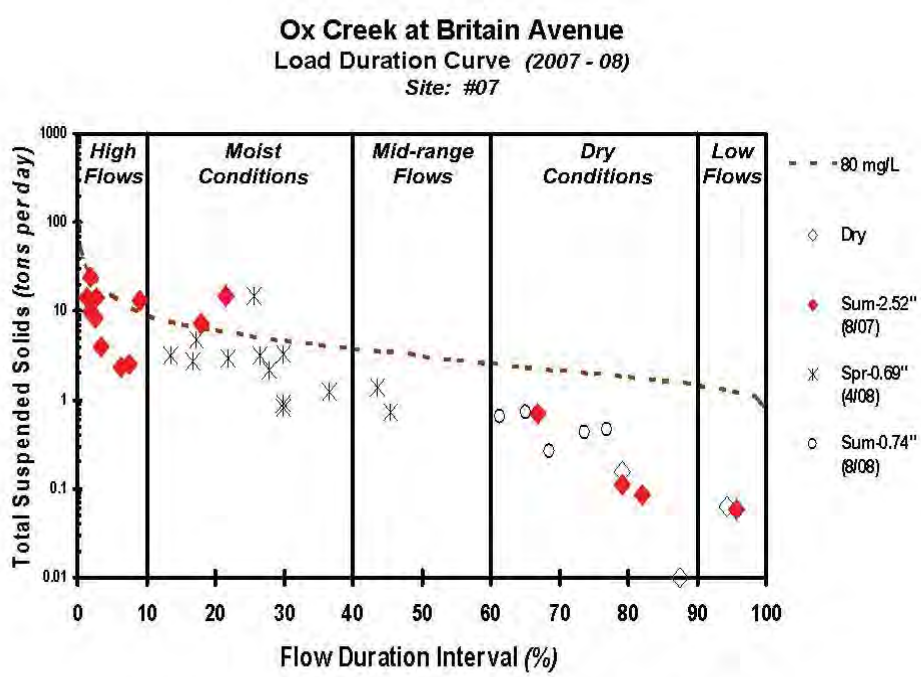


Figure 6-11. Load duration curve for TSS at Britain Avenue.

The TSS data in Figure 6-11 is displayed according to the flow duration interval associated with each sample point. In addition, data is separated by each sample event. The first wet weather event occurred in August (summer) as the result of a 2.52 inch storm (noted as Sum-2.52" in Figure 6-11). A significant number of these samples were collected under high flow conditions and included the largest TSS loads. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation (noted as Spr-0.69" in Figure 6-11). However, it did result in greater loads than the third event that occurred in the summer as the result of a 0.74 inch storm (noted as Sum-0.74" in Figure 6-11). This may reflect seasonal factors as the second storm occurred in April, prior to the emergence of vegetation on agricultural lands that would provide a greater potential for precipitation to be absorbed.

6.4 Water Chemistry Sampling

Several samples collected as part of the TSS monitoring effort were analyzed for metals and toxic organic compounds in the water column. These analyses were conducted at all locations shown in Table 6-3 except at the Yore – Stouffer Drain at Blue Creek Road (station # 05). Each site was tested six times for toxic pollutants in the water column; once for each of the three dry weather events and once for the first flush of each of the wet weather events.

In many cases, sample results indicated that the pollutant was not detected. Table 6-3 provides an overview of the occurrence for the same compounds shown in the discussion on sediment quality. These results are presented in terms of the number of times the pollutant was detected. In addition to reporting the frequency of occurrence in the six samples at each site, results were compared to Michigan's chronic water quality criteria listed in the Ox Creek WC&SA (if a value was available for that pollutant). It should be noted that Michigan's water quality criteria for several metals are based on calculations that require hardness values. For Ox Creek, a hardness value of 260 mg/L was used, which is the long-term average concentration for the St. Joseph River.

While Table 6-3 presents information on the frequency of occurrence, Table 6-4 provides an indication of magnitude. Table 6-4 summarizes the median of values detected for each compound at the sites sampled. Some general observations in reviewing the data merit discussion. Although arsenic was detected on all occasions at each site, the levels measured were significantly below the chronic criteria. Zinc, on the other hand, approached the criteria on one sample event at the Empire Road site (#03). The Yore - Stouffer Drain at Meadowbrook Road (#01) exceeded the chronic criteria for two pollutants: fluoranthene and phenanthrene. The Empire Avenue exceeded the chronic criteria for fluoranthene on one occasion.

Table 6-3. Occurrence of toxic pollutants in the water column during TSS survey.

Parameter	Site					
	Yore #06	*Meadowbrook* #01	*Crystal* #02	*Empire* #03	*Britain* #07	*Water* #04
Arsenic	**6**	**6**	**6**	**6**	**6**	**6**
Cadmium	---	---	---	---	---	---
Chromium	**1**	**3**	**1**	**3**	**3**	**2**
Lead	---	**2**	**2**	**2**	**4**	**3**
Zinc	---	**2**	**1**	**5**	**6**	**5**
Benzo(a)anthracene	---	**1 ****	---	**1 ****	---	---
Benzo(a)pyrene	---	**1 ****	---	**1 ****	---	---
Chrysene	---	**2 ****	---	**1 ****	---	---
Fluoranthene	---	**2**	---	**1**	**1**	---
Phenanthrene	---	**2**	---	**1**	---	---
Pyrene	---	**2 ****	---	**1 ****	---	---

Notes: Testing at each site consisted of six possible samples.
"---" means that parameter was tested for, but was not detected at that site.
Shaded cell indicates at least one sample exceeded the chronic criteria.
** indicates that no numeric criteria available for that parameter.

Table 6-4. Median concentration of toxic pollutants in the water column during TSS survey.

Parameter	Units	Site					
		Yore #06	*Meadowbrook* #01	*Crystal* #02	*Empire* #03	*Britain* #07	*Water* #04
Arsenic	*(µg/L)*	2.15	2.60	2.30	1.90	1.85	1.60
Cadmium	*(µg/L)*	---	---	---	---	---	---
Chromium	*(µg/L)*	1.20	1.70	1.10	1.50	1.30	1.20
Lead	*(µg/L)*	---	6.95	1.65	7.35	2.40	3.80
Zinc	*(µg/L)*	---	52	14	34	18	20
Benzo(a)anthracene	*(µg/L)*	---	3.90	---	1.00	---	---
Benzo(a)pyrene	*(µg/L)*	---	8.00	---	2.50	---	---
Chrysene	*(µg/L)*	---	7.95	---	1.90	---	---
Fluoranthene	*(µg/L)*	---	15.45	---	3.20	1.00	---
Phenanthrene	*(µg/L)*	---	7.00	---	1.30	---	---
Pyrene	*(µg/L)*	---	99.65	---	2.00	---	---

Notes: Testing at each site consisted of six possible samples.
"---" indicates compound not detected at site.

7. Sediment Quality

Investigations have been conducted to evaluate sediment quality in Ox Creek. Data from these sampling efforts was examined in the WC&SA report. Sediment samples were tested for a number of metals and PAH parameters; several were detected. A preliminary assessment was conducted on those compounds detected most frequently in sediment samples collected in 2001 and 2006, specifically arsenic, cadmium, chromium, lead, zinc, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene.

No numeric bottom sediment quality criteria have been promulgated in Michigan. This poses some challenges with respect to TMDL development for those toxic pollutants that exceed bottom sediment probable effect concentration (PEC) values, but do not exceed water quality criteria based on water column sampling. However, contaminated sediment and flow have been identified as stressors that affect macroinvertebrate populations in Ox Creek; the basis for placing this stream on Michigan's §303(d) list. PAHs and certain metals have a strong tendency to adsorb to fine particulate matter (USEPA, 1985). As a result, fine sediment often serves as the primary carrier for these pollutants to receiving waters.

Michigan has developed TMDLs using TSS as a target. Implementation efforts to reduce sediment loads through reducing storm water runoff will reduce transport of these toxic pollutants of concern to other areas in Ox Creek.

7.1 Key Parameters

The WC&SA summarized information regarding potential sources of PAHs and metals in Ox Creek. Most are related to storm water runoff originating from transportation systems (either originating from vehicle exhaust or petroleum products). These include roads, parking lots, driveways, gas stations, truck stops, etc. Galvanized metal rooftops, gutters, and downspouts are also sources of zinc. Outdoor storage of scrap metal can also contribute to metals in surface water.

Basically, many of these PAHs and metals originate from the same source areas. In addition, sediment and storm water runoff serve as the main delivery mechanism to receiving streams. A framework that identifies key parameters can help focus efforts to address those stressors associated with toxic pollutants in Ox Creek. A starting point is to identify those parameters that exceeded water column criteria values; namely fluoranthene and phenanthrene.

The WC&SA used several studies and research papers to provide a frame of reference for screening bottom sediment data. The PEC can be used in conjunction with MDEQ's bottom sediment sample results to identify key metals of potential concern in Ox Creek (the PEC is the concentration above which adverse effects are expected to occur more often than not). This includes cadmium, lead, and zinc.

Results of the WC&SA screening evaluation are presented in Figure 7-1 through Figure 7-5 for the key metals and PAHs. These graphs present a longitudinal profile of the data in order to examine patterns moving from the headwater areas of Ox Creek to the lower reaches (or left to right). Different symbols are used to represent each survey conducted [e.g., MDEQ, Prism, Earth Tech (ET) 0-6" samples, and ET 18-24" samples].

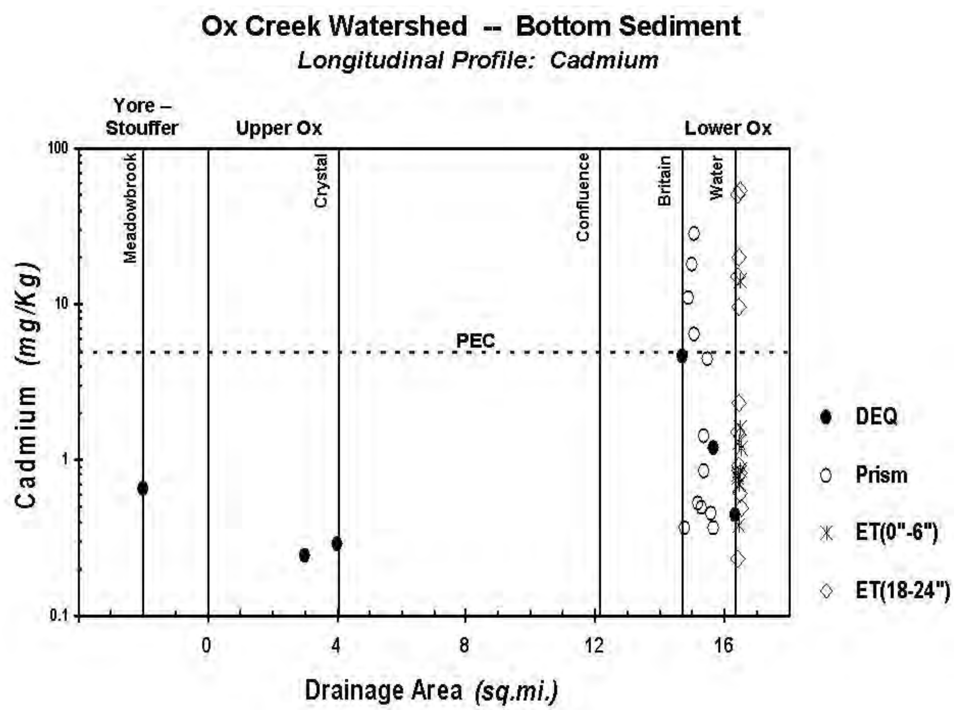


Figure 7-1. Ox Creek sediment sampling results -- cadmium.

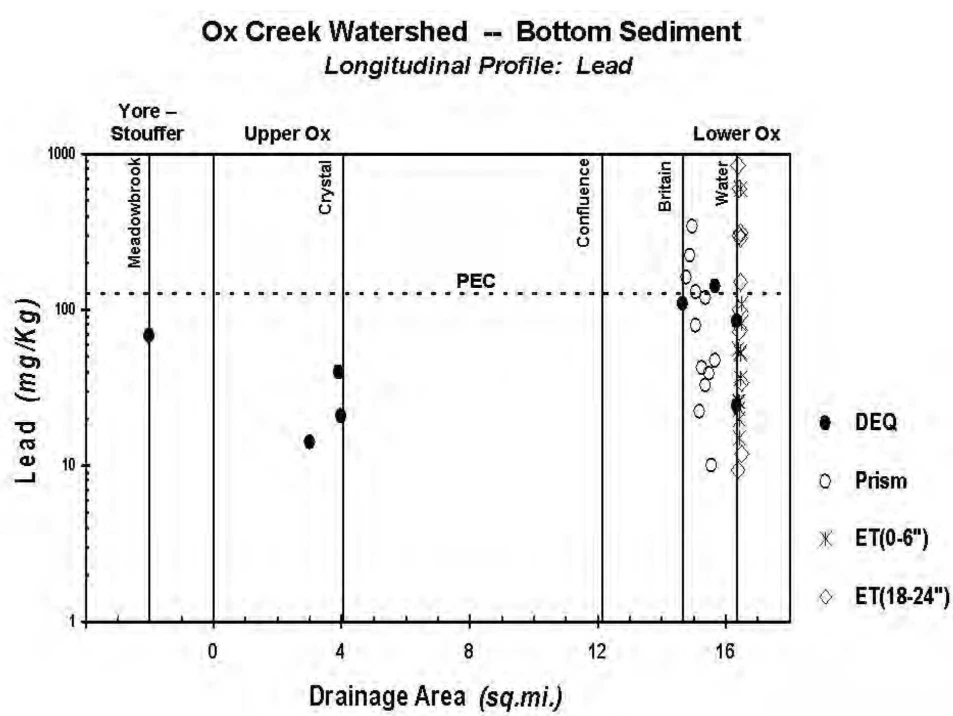


Figure 7-2. Ox Creek sediment sampling results -- lead.

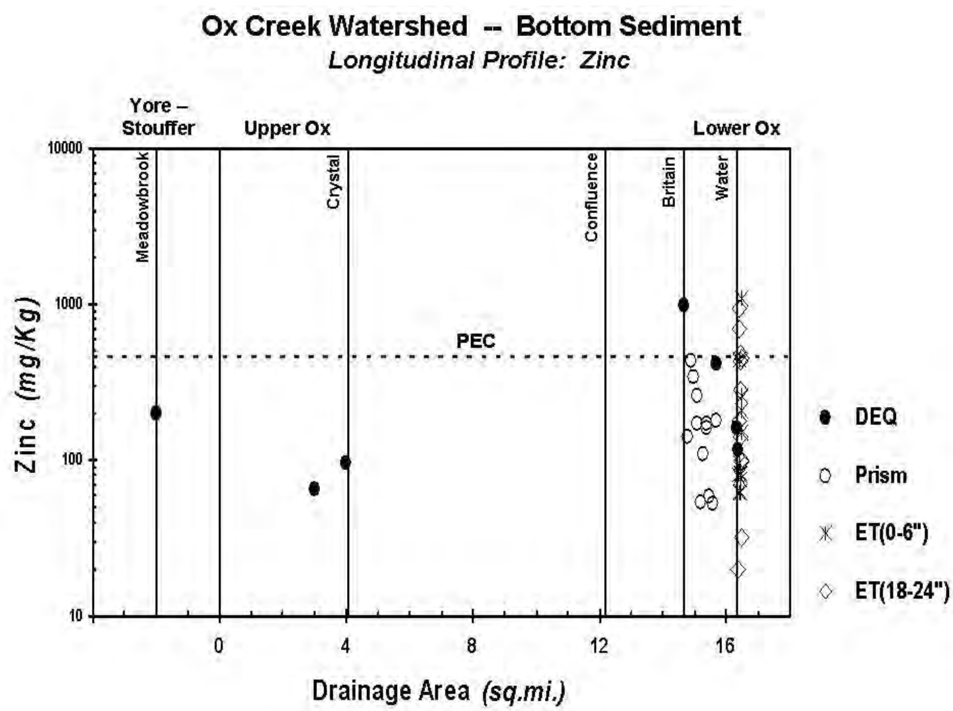


Figure 7-3. Ox Creek sediment sampling results -- zinc.

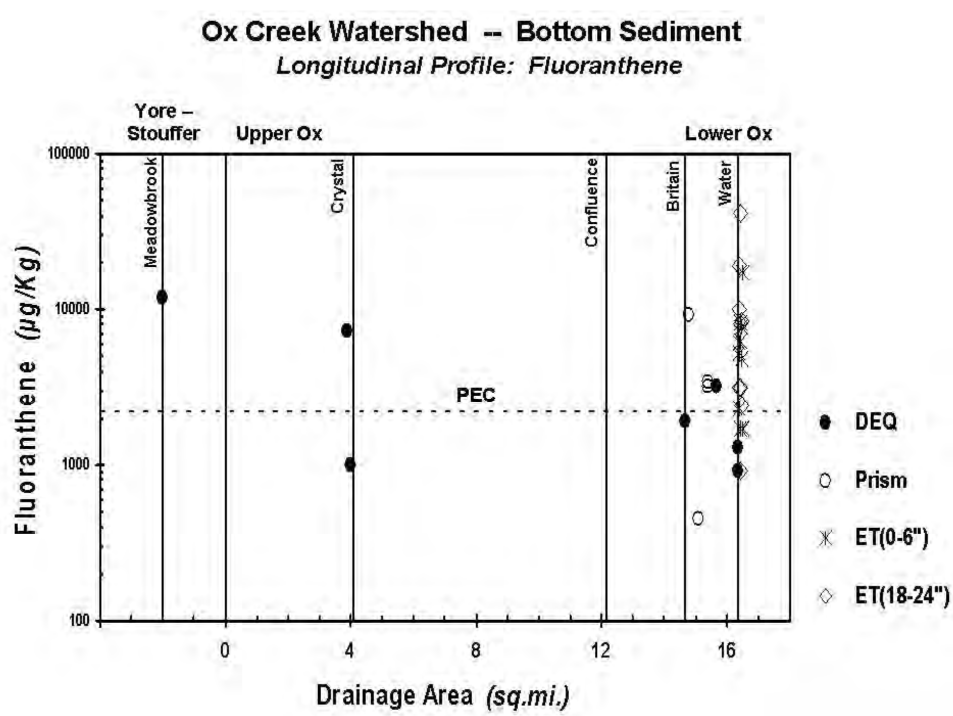


Figure 7-4. Ox Creek sediment sampling results -- fluoranthene.

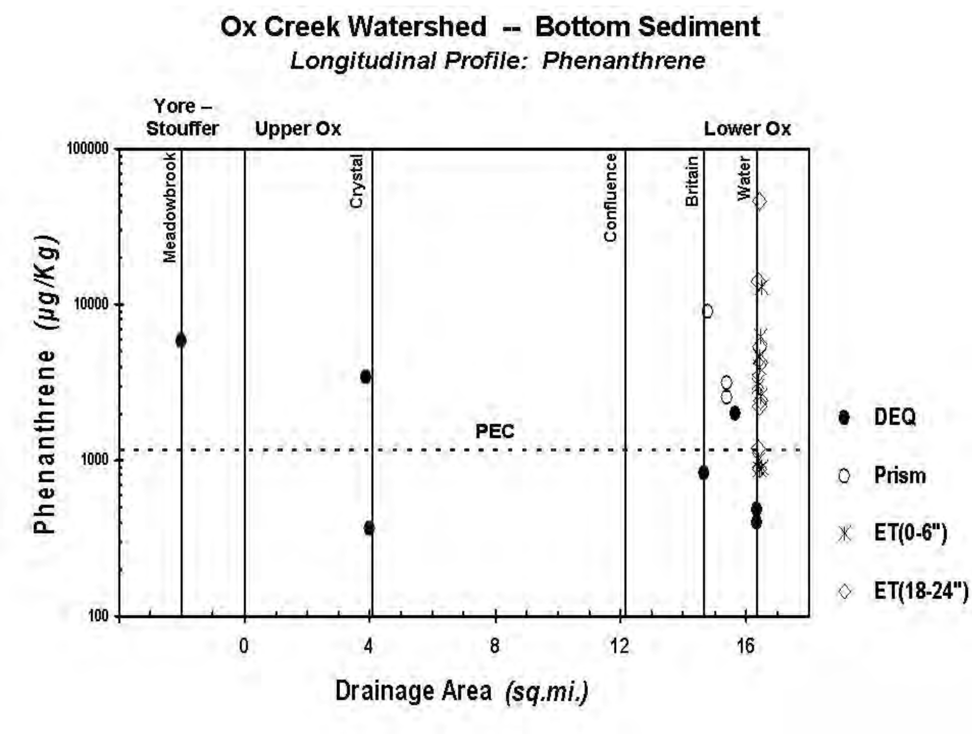


Figure 7-5. Ox Creek sediment sampling results -- phenanthrene.

7.2 Sediment Toxicity

The biological availability of toxic compounds in contaminated sediments can vary due to differences in the type and chemical composition of the material. Procedures have been developed to calculate equilibrium partitioning sediment benchmarks (ESBs) for mixtures of PAHs (USEPA, 2003; Ohio EPA, 2010). Equilibrium partitioning is a methodology that accounts for this variability when evaluating the potential toxicity of contaminated sediments. The approach supports the derivation of benchmarks that are causally linked to the specific chemicals, are applicable across a range of sediment types, and are appropriately protective of benthic organisms. ESBs can complement other sediment assessment tools.

These procedures examine bottom sediment quality levels of up to 34 PAH compounds. Normalized PAH concentrations are calculated based on the fraction of organic carbon in the bottom sediment using either measurements or estimates of total organic carbon (TOC). Next, an ESB toxicity unit (ESBTU) is determined using the normalized concentrations and final chronic values (FCVs) from EPA's *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures* (USEPA, 2003). EPA determined these FCVs using the National Water Quality Criteria Guidelines as the toxicity endpoint for ESBTUs. These values are intended to be the chemical concentrations in water that are protective of aquatic life uses.

The ESBTUs for all PAH chemicals are summed to identify one value, ∑ESBTU. The ESB methodology assumes that the *"total PAH"* includes 34 compounds. However, an uncertainty factor may need to be applied because some analyses include fewer than the 34 compounds, commonly either 13 or 23. If the adjusted ∑ESBTU is less than 1, it is likely that the sediment will not be toxic to aquatic life. If the adjusted ∑ESBTU is greater than 1, the sediment may be toxic to benthic organisms. The ∑ESBTU value can be used to also identify a general level of risk (e.g., limited, some possible, some probable, or probable).

In the case of Ox Creek, the ∑ESBTUs were calculated using less than the required 34 PAH compounds. It is important to point out that because of the uncertainty associated with using less than 34 compounds, the resultant ∑ESBTU should not be considered as an ESB nor used in important sediment management decisions. However, uncertainty factors applied to the ∑ESBTU do add value to the assessment of bottom sediment quality. For example, the results can be used to determine if additional chemical analyses are needed or to prioritize areas within the watershed that may be of concern due to potential risk the benthic organisms.

As indicated above, TOC measurements or estimates are needed to calculate normalized PAH concentrations. Because TOC data was not available for Ox Creek, a value of one percent was used; a common assumption in the absence of site-specific TOC information. Results for Ox Creek are summarized in Table 7-1. The results of this sediment toxicity screening analysis indicate that subwatershed unit C (Yore-Stouffer Drain at Meadowbrook Road) is the area of greatest concern with respect to PAHs.

Table 7-1. ESBTU calculation summary for Ox Creek PAH data.

Unit	Location	∑ESBTU *(at 1% TOC)*			Total PAHs *(ppm)*
		34 PAHs	23 PAHs	13 PAHs	
C	Yore – Stouffer at Meadowbrook Rd.	0.74 *Limited Risk*	3.07 *Some Probable Risk*	8.53 *Probable Risk*	58.0
E	Ox Creek upstream of Crystal Avenue	0.45 *Limited Risk*	1.84 *Some Possible Risk*	5.12 *Probable Risk*	35.9
G	Ox Creek at Britain Avenue	0.14 *Limited Risk*	0.59 *Limited Risk*	1.65 *Some Possible Risk*	11.7
	Unnamed tributary to Ox Creek at M-139	0.29 *Limited Risk*	1.19 *Some Possible Risk*	3.32 *Some Probable Risk*	23.0
H	Ox Creek at Highland Avenue	0.27 *Limited Risk*	1.10 *Some Possible Risk*	3.05 *Some Probable Risk*	20.6

Although there is uncertainty associated with using 13 PAH compounds, this screening analysis of sediment toxicity shows potential risk to aquatic organisms in Ox Creek. Part of that risk to be considered includes an evaluation of the adverse effects that may occur when contaminated bottom sediment is resuspended as TSS back into the water column during high flow events, as illustrated in Figure 7-6.

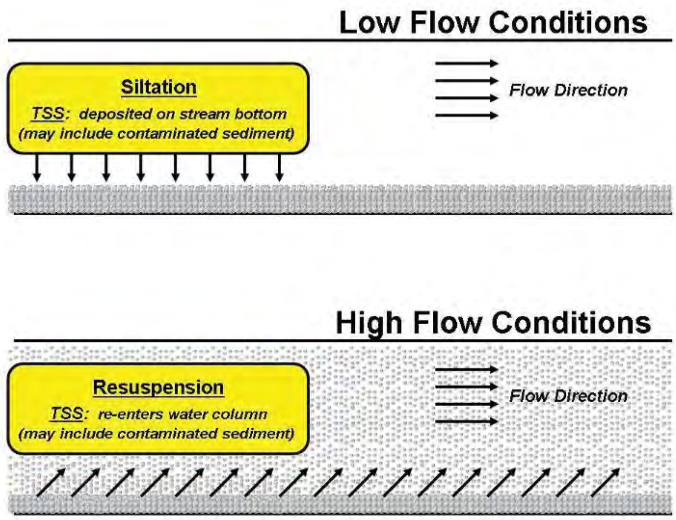


Figure 7-6. Deposition and resuspension of TSS.

8. Target Development

Several TMDLs developed by the MDEQ used TSS as a secondary numeric target to address aquatic life impairments (Goodwin, 2007; Wuycheck, 2004). The primary target has been restoration of biological communities to achieve an acceptable score using a biological monitoring protocol. Use of TSS as a secondary target is intended to help guide proper control of excessive sediment loads from runoff. This indicator can also address problems associated with runoff discharge rates and volumes that lead to channel instability, stream bank erosion, and increased TSS concentrations. In addition, the use of TSS as a secondary numeric target connects a measurable in-stream parameter to hydrologic changes in the watershed, which can result in habitat changes that are adversely affecting biological communities.

The numeric value used in past MDEQ TMDLs has been a mean annual TSS concentration of 80 mg/L for wet weather events. This TSS target was based on a review of existing conditions and published literature on the effects of TSS to aquatic life. Vohs et al., (1993) indicated that a chemically inert long-term average (LTA) TSS concentration of 100 mg/L appears to separate those streams with a fish population from those with significantly reduced populations. Gammon (1970) demonstrated decreases in the standing crop of both fishes and macroinvertebrates in river reaches continuously receiving LTA TSS loadings above 40 mg/L. The European Inland Fisheries Advisory Commission stated that, in the absence of other pollution, a fishery would not be harmed at LTA TSS concentrations less than 25 mg/L (EIFAC, 1980).

Alabaster and Lloyd (1982) provided the following long-term average water quality goals for TSS in order to protect fish communities:

Optimum = < 25 mg/L LTA
Good to Moderate = > 25 to 80 mg/L LTA
Less than Moderate = > 80 to 400 mg/L LTA
Poor = > 400 mg/L LTA

The past use of numeric TSS targets helped create a TMDL framework that can identify possible steps to restore biological communities to an acceptable condition. However, the way in which these targets are expressed leaves questions regarding how to compare the values to in-stream monitoring data in terms of TMDL development and implementation. For example, the mean annual TSS concentration for wet weather events is difficult to interpret relative to §303(d) requirements to identify a maximum daily load.

The 25 mg/L long-term average TSS is supported in the literature as a level where fisheries would not be harmed. In order to clarify how the target is to be interpreted, this value is applied in the Ox Creek TMDL as a long-term annual average. A long-term annual average is defined as the mean value calculated from measurements collected over several years covering a representative range of flow conditions (e.g., high, moist, mid, dry, low) determined using techniques, such as a duration curve analysis. This is consistent with other statistics used in water resource management, which are intended to take into account natural fluctuations in conditions (e.g., day-to-day, week-to-week, month-to-month, year-to-year, wet versus dry, etc).

USEPA has also long recognized the need to use multiple averaging periods for parameters that exhibit variability, such as TSS. For example, National Pollutant Discharge Elimination System (NPDES) permits typically include both monthly and weekly average limits for TSS. Both USEPA's *"An Approach for Using Load Duration Curves in the Development of TMDLs"* and

"Options for Expressing Daily Loads in TMDLs" describe methods to develop targets that reflect multiple averaging periods (e.g., annual average, daily maximum, etc), particularly when a daily maximum value is needed to meet regulatory requirements. These techniques are particularly applicable for pollutants such as sediment, which can vary with weather, season, and flow conditions.

An innovative approach used by MDEQ to support the Bear Creek TMDL provides information that relates to development of TSS targets, particularly identifying a daily maximum value. Specifically, the Sediment Erosion Transport Predictor (SETP) method represents functions of watershed characteristics, soils, and flow regimes. The technique is simply a graph showing the relationship between solids and flow.

The purpose of this section is to present information on the SETP method and to describe the rationale on its use towards development of TSS targets for use in the Ox Creek TMDL. In particular, a maximum daily average target value of 300 mg/L TSS is supported by *"multiple lines of evidence"*. These include the original data analysis conducted in the development of the SETP method, validation of the SETP framework through an evaluation of sites with both bioassessment information and either TSS or SSC data collected by the USGS, and a comparison of Ox Creek data relative to the TSS targets.

In summary, the approach used to identify TSS targets for Ox Creek builds on literature values used in earlier Michigan TMDLs that are protective of aquatic life uses. These values are combined with multiple averaging period methods in order to provide a greater level of clarity that describes how the targets are to be interpreted.

8.1 SETP Framework

The initial basis for the maximum daily average 300 mg/L value is a Michigan MDEQ report (Feldpausch, 1996) that described TSS targets in conjunction with the SETP method. The 1996 MDEQ report pooled data from different sources in order to analyze a wider range of suspended solids information. This included both TSS data collected by MDEQ and SSC data collected by the USGS. Feldpausch pointed out that pooling information from various sources is a common practice in science and engineering (the use of state-wide averages, reference streams in biological assessments, and reference watersheds for stream flow calculations being a few examples).

Data was normalized by computing stream flow ratios, in order to compare separate but similar data sets. Feldpausch computed these flow ratios by taking the stream flow at the sampling time and dividing it by the annual average flow. The combined data set (both TSS and SSC) was used by Feldpausch to develop a ratio of solids concentration versus flow ratio river comparison plot *(Figure 8-1)*. The approach enables comparison of stream solids conditions between different rivers and streams.

The use of flow ratios in the SETP framework highlights the importance of stream hydrology. Feldpausch noted that the watershed response to changes in flow conditions affects stream sediment and biology. Flow ratios below five reflect good, stable stream conditions. In contrast, flow ratios approaching and exceeding ten are generally indicative of *"flashy"* systems. *"Flashiness"* is an indicator of the frequency and rapidity of short-term changes in stream flow, particularly during runoff events (Baker, et.al, 2004). Increased *"flashiness"* is typically associated with unstable watersheds and degraded habitat that adversely affects aquatic life.

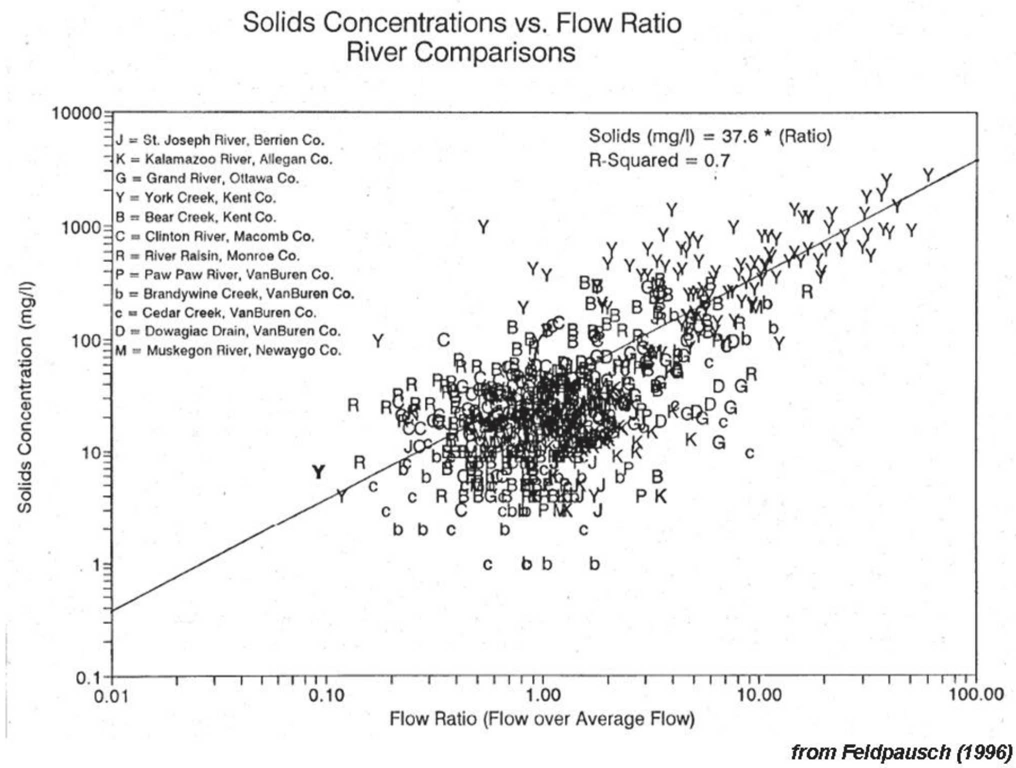


Figure 8-1. SETP state-wide application *(from Feldpausch, 1996)*.

Most of the watersheds used by Feldpausch are located in the Southern Michigan Northern Indiana Till Plains (SMNITP) ecoregion; the same as Ox Creek. In analyzing the data, Feldpausch noted that several trends became apparent. For flow ratios up to five, suspended solids values were consistently low or below 70 mg/L. Between flow ratios of five and ten, suspended solids values were generally less that 300 mg/L. Based on this analysis, Feldpausch determined that concentrations of 70 mg/L and 300 mg/L became suspended solids cutoff zones. These zone delineations were chosen qualitatively based on the visual frequency and concentration of the data scatter.

Feldpausch noted that 70 mg/L suspended solids concentration approximates a long-term value commonly used to identify streams where biological communities could become adversely affected (Alabaster and Lloyd, 1982). The short-term (or daily maximum) 300 mg/L suspended solids concentration was determined by examining data from York Creek in Kent County, known to be an extremely sedimented stream affected by unnatural flow fluctuations due to excessive urban runoff. Feldpausch used York Creek and its suspended sediment data as an indicator stream for watershed planning.

Application of the technique results in a graph showing the relationship between solids and flow. Specifically, Feldpausch used the information to designate three sedimentation zones (green, yellow, and red); these correspond to good, fair, and poor quality stream conditions *(Figure 8-2)*. The cutoff between the yellow and red zone (i.e., fair and poor) was 300 mg/L TSS. Data from York Creek stream plotted in the *"red zone"*. TSS data from Bear Creek plotted in the *"yellow zone"*, which was consistent with biological assessment information.

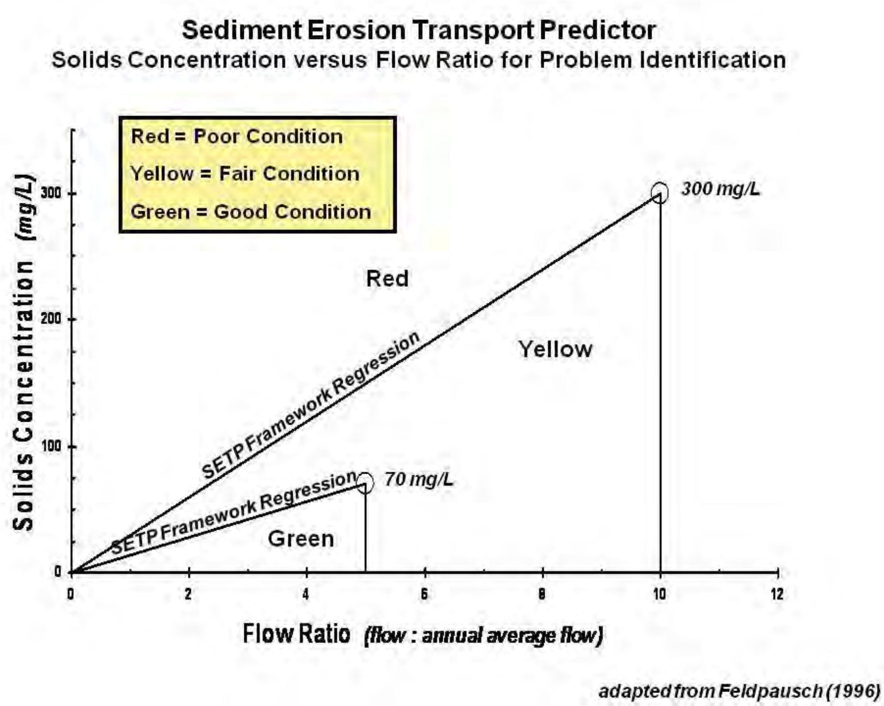


Figure 8-2. SETP application for stream sedimentation comparisons.

8.2 Technical Approach

A technical approach can be developed by building on the SETP framework to analyze sites with both bioassessment information and either TSS or SSC data. An evaluation of locations with bioassessment information is needed because the §303(d) listing of Ox Creek is based on aquatic life use impairments as measured through macroinvertebrate index scores.

The use of dynamic sediment or TSS targets that vary with flow has been used in other TMDL efforts. For example, the Deep Creek, Montana TMDL described in USEPA's sediment protocol used a target that was set based on the slope of the regression curve by plotting flow against total suspended sediment load (USEPA, 1999). This approach acknowledges the fact that sediment concentrations vary substantially as a function of flow, which better reflects system dynamics than a static target. This same relationship between flow and sediment concentrations is a foundation of the SETP framework, as evidenced by Figure 8-1.

Literature cited in previous MDEQ efforts to use TSS targets include both the European Inland Fisheries Advisory Commission (EIFAC, 1980) and Alabaster and Lloyd (1978) reports. A common value identified in both documents is a long-term average of 25 mg/L TSS as a level where fisheries would not be harmed. Development of SETP identified 300 mg/L as a short-term (or acute) value, above which streams are known to suffer from extreme sedimentation. York Creek was cited as an example. A technical approach that builds on the SETP framework can be used to validate the appropriateness of 25 mg/L as a long-term annual average and 300 mg/L as a daily maximum average TSS target for use in the Ox Creek TMDL.

As discussed in the introduction to the *"Target Development"* section, USEPA recommends that TMDL targets include a daily time step in order to satisfy Clean Water Act §303(d) legal requirements. The SETP framework moves in that direction by incorporating flow ratios (e.g., flow on the sampling date divided by the annual average flow). However, neither the 70 mg/L nor the 300 mg/L values identified by Feldpausch were placed in the context of a specific averaging period.

Both USEPA's *"An Approach for Using Load Duration Curves in the Development of TMDLs"* and *"Options for Expressing Daily Loads in TMDLs"* describe methods to develop targets that reflect multiple averaging periods (e.g., annual average, daily maximum, etc). These techniques are particularly applicable for pollutants such as sediment, which can vary with weather, season, and flow conditions. The approach used to identify TSS targets for Ox Creek builds on literature values used in earlier Michigan TMDLs that are protective of aquatic life uses. These values are combined with multiple averaging period methods in order to provide a greater level of clarity that describes how the targets are to be interpreted.

8.2.1 Multiple Averaging Periods

The use of multiple averaging periods is demonstrated through the following example, at a location where both suspended sediment and bioassessment information have been collected. As discussed earlier in Section 6.2, the USGS has collected SSC data at a number of sites across the country. Water quality at a location over time can be described using common descriptive characteristics, such as the monthly or annual average concentration, the standard deviation, and the coefficient of variation. The coefficient of variation is a statistical measure of the relative variability of a data set. It is defined as the ratio of the standard deviation to the mean. Another way to describe water quality patterns is by constructing a frequency-concentration plot of the data. Figure 8-3 depicts S.B. Black River suspended sediment information using a frequency-concentration plot of the data.

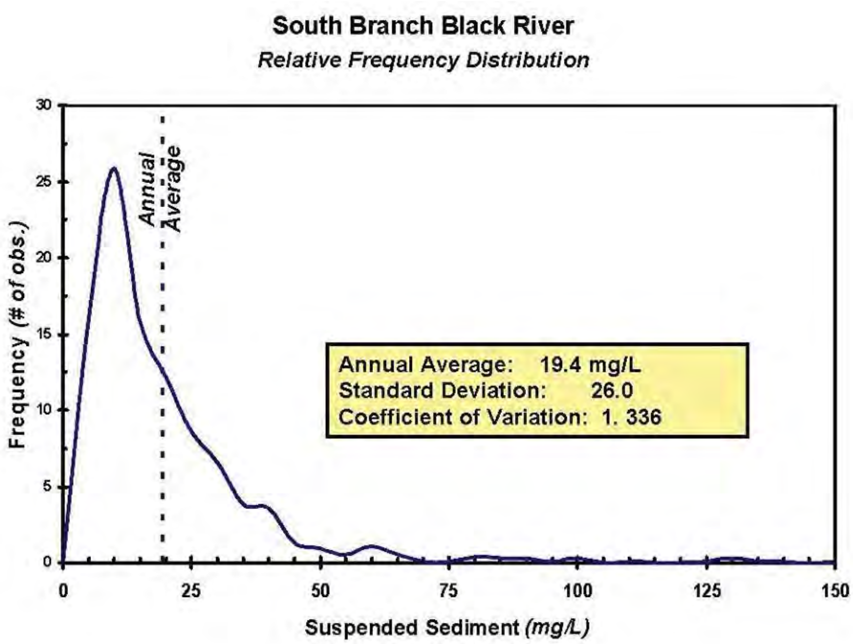


Figure 8-3. Frequency-concentration plot of S.B. Black River suspended sediment data.

On the basis of the frequency-concentration curve shape, data can be characterized in terms of a particular type of statistical distribution. Choices often include a normal distribution (bell-shaped), log-normal distribution (positively skewed), or other variations on the log-normal distribution. EPA's *"Technical Support Document for Water Quality-Based Toxics Control"* (USEPA, 1991), also referred to as the TSD, uses log-normal distributions to determine maximum daily and monthly average effluent limits, based on achieving a long-term average target and an understanding of variability.

Using a statistical framework, such as a log-normal distribution, a set of values covering the entire range can be projected from the data. Correspondingly, concentrations can be determined based on a specified probability of occurrence (e.g., a 1-day recurrence interval that represents the daily maximum). Thus, the TSD provides an approach to identify a maximum daily concentration based on a coefficient of variation and the assumption of a log-normal distribution. The equation for determining the maximum daily concentration (MDC) is described in the TSD (USEPA, 1991) and in *"Options for Expressing Daily Loads in TMDLs"* (USEPA, June 2007) as follows:

$$MDC = LTA * e^{[z\sigma - 0.5\sigma^2]}$$

where:

	MDC:	maximum daily concentration
	LTA:	long-term average
	z:	z-score associated with target recurrence interval
	σ^2:	$\ln(CV^2 + 1)$
	CV:	coefficient of variation

Details regarding the mathematics used to derive this equation are described in the TSD. The z-score is sometimes called the *"standard score"* for normal distributions because it provides a useful way to compare sets of data with different means and standard deviations. The z-score for an item (or a particular recurrence interval) indicates how far and in what direction that item deviates from its distribution's mean (expressed in units of its distribution's standard deviation). For instance, a z-score of +1.0 indicates that item (or recurrence interval) is one standard deviation in the positive direction from the mean. Z-scores are published in basic statistical reference tables and are often included as a spreadsheet function [e.g., NORMSINV(y) in Excel©].

Using this relationship, the TSD constructed a table of LTA to MDC multipliers for several recurrence interval / coefficient of variation combinations. Table 8-1 provides a summary of these multiplier values to determine a maximum daily concentration (e.g., based on a 365-day averaging period). This averaging period is also expressed as a recurrence interval in order to identify the appropriate z-score for use in the TSD equation.

A daily maximum concentration is represented by a 365-day averaging period, which equates to a recurrence interval of 99.7% [e.g., (365/366)% or (k/k+1)% where k is the number of averaging period days] and corresponding z-score of 2.778. In the case of the S.B. Black River, where the coefficient of variation for a parameter is 1.336 *(Figure 8-3)*, the multiplier to convert the long-term average to a maximum daily concentration is 9.97 (*Note:* key boxes for this combination are shaded in Table 8-1).

Table 8-1. Multipliers -- Long-term average to maximum daily concentration.

Averaging Period *(days)*	Recurrence Interval	Z-Score	Coefficient of Variation					
			0.2	**1.0**	**1.2**	**1.336**	**1.4**	**1.6**
365	**99.7%**	**2.778**	1.70	7.15	8.83	9.97	10.5	12.13

The TSD provides an approach that considers patterns and variability in a consistent manner. The method is based on the assumption that water quality data follow a log-normal distribution. Identification of a maximum daily concentration is based on the recurrence interval associated with the long-term averaging period and a coefficient of variation that reflects the data. Figure 8-4 graphically illustrates a *"log probability plot"* of the TSD equation using the S.B. Black River data. The x-axis is expressed as the z-score of a normal probability distribution and concentrations are displayed on a logarithmic scale. A probability plot is one method that can be used to check the assumption of log-normality. If data follow the pattern of a log-normal distribution, they will fall approximately along a straight line, as shown in Figure 8-4.

Using the approach described in the TSD, the maximum daily suspended sediment concentration for the S.B. Black River is determined through a four-step process, as follows:

1) Display the observed TSS or SSC data using a probability plot to ensure that the assumption of a log-normal distribution is valid *(Figure 8-4)*.
2) Use Excel© to calculate a mean, standard deviation, and coefficient of variation for the TSS or SSC data.
3) Establish the averaging period to determine the corresponding z-score based on a recurrence interval of (k/k+1), or 99.7% for a 365-day averaging period.
4) Determine the appropriate multiplier using the z-score to convert the LTA concentration to a maximum daily concentration

Thus, the maximum daily concentration for the S.B. Black River is 194 mg/L *(Figure 8-4)*. Determination of this value is based on an annual average of 19.4 mg/L with a coefficient of variation of 1.336 using procedures described in the TSD and the USEPA document *"Options for Expressing Daily Loads in TMDLs"*.

8.2.2 Flow Duration, Frequency, and Ratios

Leopold (1994) and others have documented the relationship between flow and sediment loads. This relationship forms the basis for sediment rating curves; it was also a supporting principle behind the SETP framework. Based on this general relationship, a flow duration curve can be used to identify a flow value associated with the maximum daily average sediment concentration calculated using the above approach. Figure 8-5 depicts the flow duration curve for the S.B. Black River. By definition, the flow duration curve is a cumulative frequency distribution. This enables determination of the recurrence interval associated with a 1-day maximum daily average flow (e.g., one divided by 365, or 0.274%), as shown in Figure 8-5. For the S.B. Black River, this corresponds to a flow value of 899 cubic feet per second (cfs).

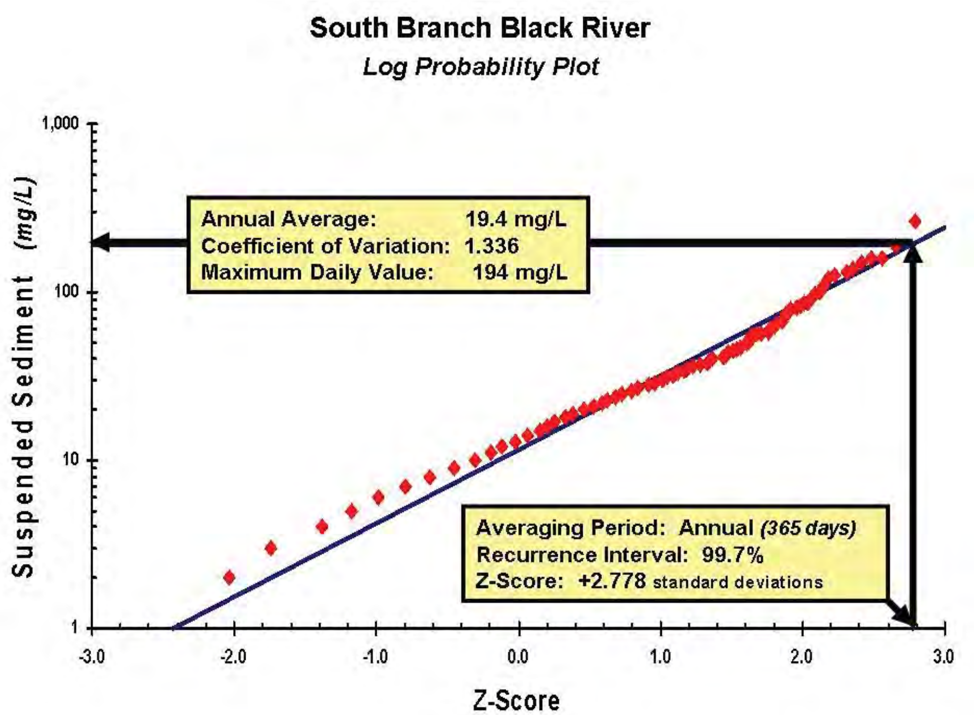


Figure 8-4. Log probability display of S.B. Black River suspended sediment data.

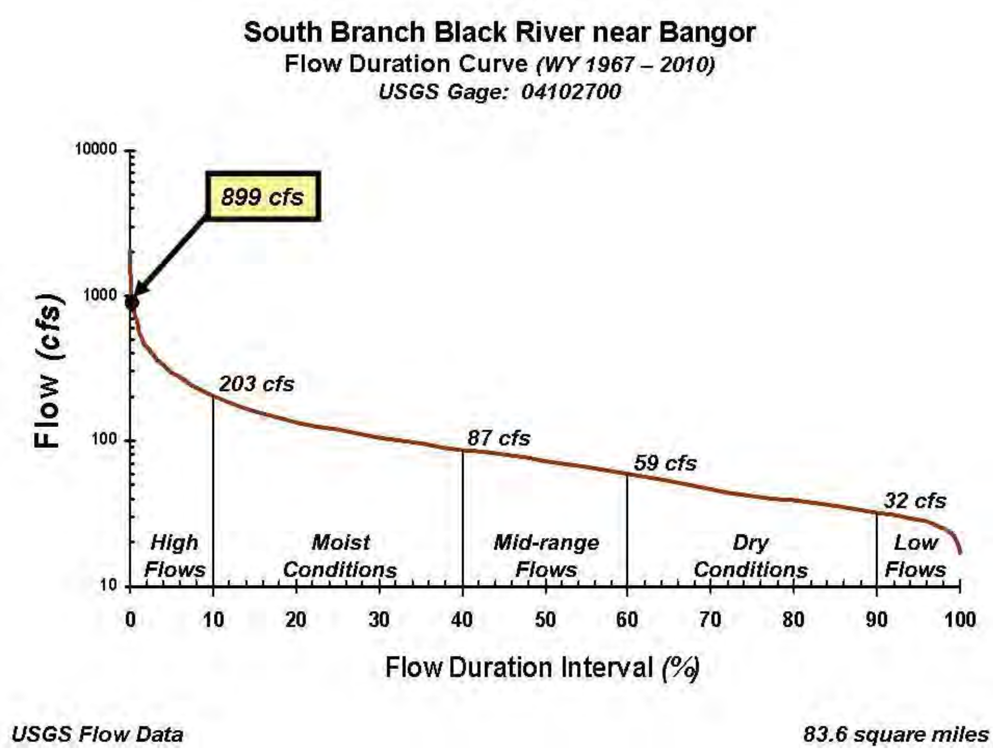


Figure 8-5. S.B. Black River flow duration curve.

The annual average flow for the S.B. Black River is 104 cfs. Thus, the flow ratio for the S.B. Black River 1-day maximum daily average flow is 8.65 (i.e., 899 cfs divided by 104 cfs). Figure 8-6 shows the S.B. Black River maximum daily average concentration based on the USEPA methodology presented by using the SETP framework. Figure 8-6 also displays several other key points of the S.B. Black River data using the SETP framework. This includes the median and annual average SSC values. The concentration associated with a flow of 520 cfs (or flow ratio of 5) is also shown in Figure 8-6. This value was determined using the flow duration interval for 520 cfs (i.e., the 1.3 percentile) applied to the frequency distribution of the SSC data *(Figure 8-4)*. It is interesting to note that these points all fall within the *"yellow zone"*.

In order to provide a context for flow ratios, it is useful to identify where specific values plot on a flow duration curve. Figure 8-7 depicts the unit area flow duration curve for the S.B. Black River. This is developed by simply dividing all values along the flow duration curve by the drainage area at the gage location. Unit area flow duration curves enable a meaningful comparison of hydrologic characteristics between watersheds of different sizes (basically a technique that normalizes the information).

For the S.B. Black River, the unit area annual average flow is 1.24 cfs / square mile (or the annual average flow of 104 cfs divided by the drainage area of 83.6 square miles). This annual average flow corresponds to a flow duration interval (FDI) of 30.9%. As indicated earlier, a flow ratio of 5 for the S.B. Black River corresponds to a FDI of 1.3%. A flow ratio of 10 for the S.B. Black River corresponds to a FDI of 0.2%.

The text box in Figure 8-7 summarizes flow ratio, flow duration interval statistics, and the R-B Flashiness Index.

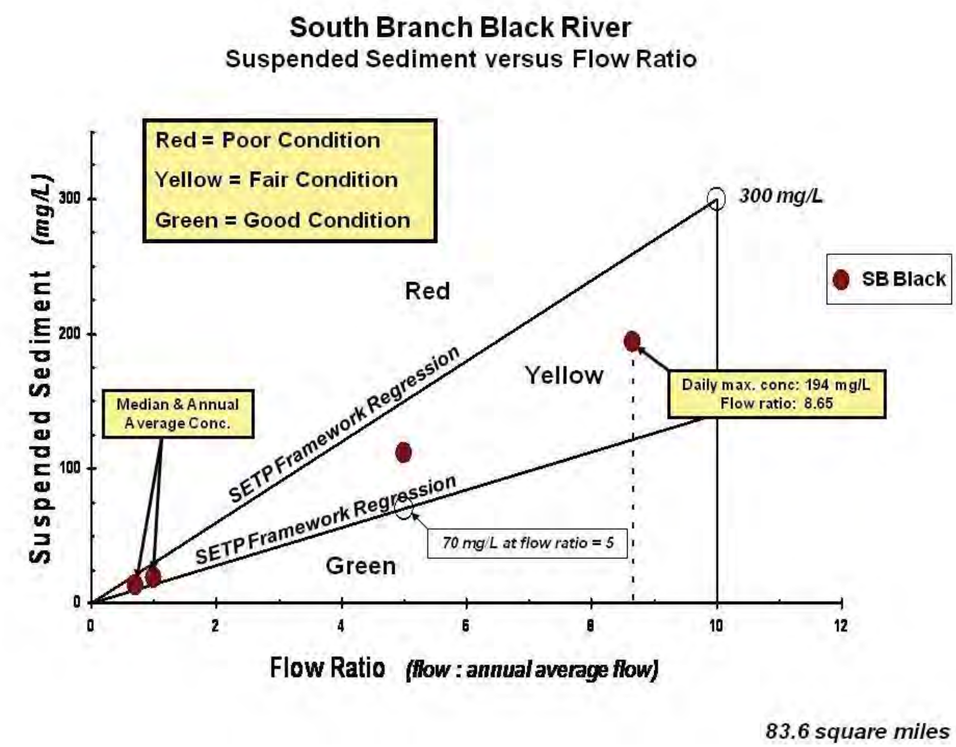


Figure 8-6. S.B. Black River SSC information using SETP framework.

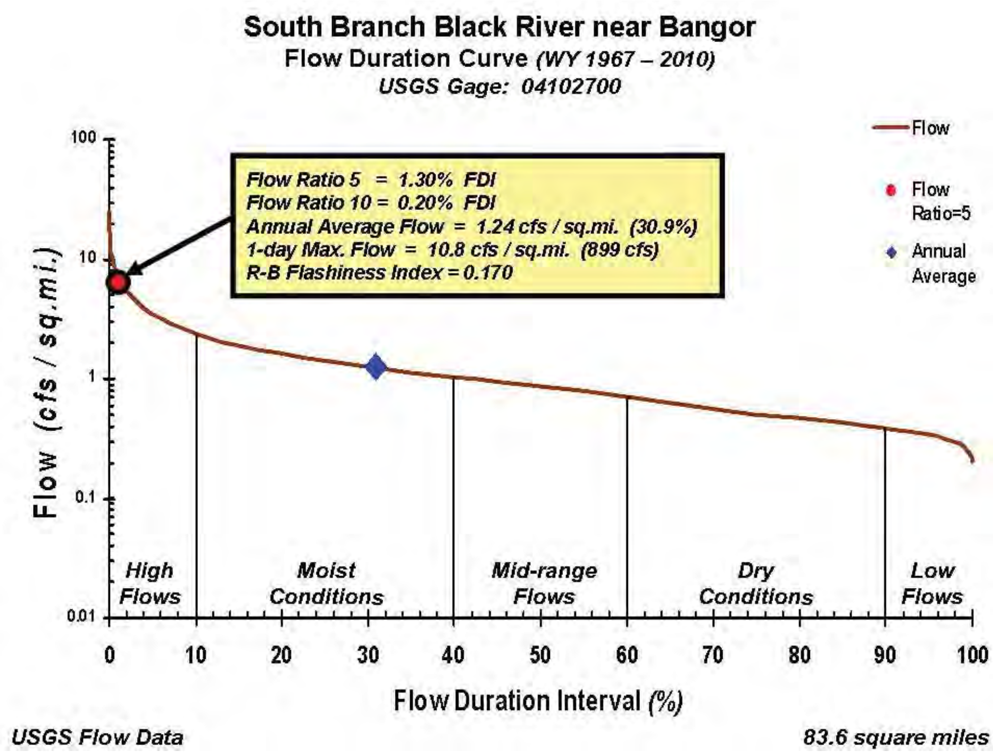


Figure 8-7. S.B. Black River unit area flow duration curve.

8.3 Validation Process

The previous section describes the technical approach used to validate the appropriateness of 25 mg/L as a long-term average and 300 mg/L maximum daily average TSS targets at one location. The approach builds on USEPA guidance for incorporating flow into the TMDL process through the use of duration curves. The validation process couples the use of duration curves with the SETP framework developed by MDEQ. Application of the technical approach was illustrated through use of data from the S.B. Black River as an example *(Figure 8-6)*. In addition to the S.B. Black River, other sites examined in the validation process were two on the Paw Paw River and four in the upper St. Joseph River watershed *(Table 8-2)*.

This summary table includes median, annual average, and daily maximum SSC values for each site. The daily maximum was determined by using the USEPA method to develop targets that reflect multiple averaging periods described in the Technical Approach section. Because the variability of TSS and SSC data affects the determination of daily maximum values, the coefficient of variation is included in Table 8-2.

Michigan's rapid bioassessment protocol scores at each location are also included in Table 8-2. Scores at these sites used in the validation process ranged from acceptable (-4 to +4) to excellent (+5 to +9). As noted in the S.B. Black River example, the data points all fall within the *"yellow zone"*; this is consistent with the bioassessment information for this site.

Table 8-2. Summary of suspended sediment concentrations for selected sites.

Site	Area (mi^2)	Suspended Sediment (mg/L)				P51 Bioassessment	
		Median	Annual Average	Daily Max.	Coeff. of Variation	Date	Score
South Branch Black River	83.6	13.0	19.4	194	1.34	8/14/2007	5
						8/20/2002	2 / 5 *
Paw Paw River near Paw Paw	195	8.0	10.1	73	1.01	8/1/2006	1
						7/18/2001	4
Paw Paw River near Hartford	311	12.0	16.4	130	1.09	8/1/2006	4 / 6 *
						7/18/2001	4 / 6 *
St. Joseph River at Clarendon	144	6.0	9.6	76	1.08	2000	6 / 7 *
Sand Creek	20.6	18.0	26.1	146	0.81	8/9/2005	1
						2000	2
Beebe Creek	42.4	15.0	21.7	145	0.94	2000	5
Soap Creek	10.9	36.0	38.0	142	0.56	2000	0

Note: * denotes that SSC station was located between two bioassessment sites. Both P51 scores reported.

Results of the SETP analyses used in the validation process are presented in a project Technical Memorandum *(Tetra Tech, 2011).* These results confirm the utility of the SETP framework with respect to identifying condition zones (e.g., green, yellow, red) that are reasonably consistent with bioassessment scores. In order to provide a broader hydrologic context for each site, the technical memorandum also presented the corresponding unit area flow duration curves for the SSC sample locations. Each curve also includes a text box with key hydrologic summary statistics for the site.

There was one instance (Sand Creek) where the daily maximum was just over the line delineating the yellow and red zones. Feldpausch noted that MDEQ tests have shown that traditional TSS analyses typically underestimate the actual sediment mass present. By nature of the procedure, sand particles are often not included in the analytical results. Because the data reported for this particular site are SSC values, TSS measurements at the Sand Creek location would likely be lower (and would plot in the *"yellow zone"* below the delineation line).

One interesting observation is that the SETP flow ratio is significantly affected by the hydrology at each site. This is evident from the x-axis location of the maximum daily values in the SETP graphs (highlighted by the dashed line). In addition to its effect on SSC values, hydrology can also be a major factor that affects aquatic communities (thus influencing bioassessment scores). Stable flow regimes support the establishment of healthy macroinvertebrate populations, while *"flashy"* flows (e.g., those associated with urban runoff) can disrupt community structure.

Alternative approaches could be examined that take advantage of the positive aspects of the SETP framework and that also account for different hydrologic settings, including use of the R-B Flashiness Index. An in-depth assessment of the full set of SSC and flow data did highlight one other interesting observation, particularly at two sites (Beebe Creek and Soap Creek). The relationship between elevated flow and SSC values at these locations was not strong. This is apparently due to the physical characteristics of these watersheds (e.g., the dominant influence of ponds and wetlands that exert a major stabilizing effect on the hydrology at these sites).

Feldpausch recognized the importance of a framework that could be used with TSS data because of the need to compare information with other MDEQ sampling efforts (e.g., Michigan's fixed station monitoring program, site-specific investigations, etc). Taking this into consideration and based on the available data, this visual analysis supports the use of 300 mg/L TSS as a maximum daily target.

8.4 Ox Creek Analysis

The next step in evaluating the utility of SETP as a tool to identify TSS targets is to apply the framework to Ox Creek data. As discussed in the WC&SA report, flow and TSS data for Ox Creek is somewhat limited when compared to the amount of data used in the SSC validation analysis. However, it is possible to use the available TSS survey information, *"tape down"* measurements, and level logger records to develop a screening evaluation of the SETP method as it applies to Ox Creek. This is accomplished through a linked regression approach.

The first part of the analysis involved developing flow estimates at each location where Michigan's rapid bioassessment protocol was conducted. A relationship was established between stream discharge information from the Galien River USGS gage and flow estimates derived for Ox Creek at Britain Avenue using the level logger records from June 2007 to August 2008. This relationship was used to extend the period of record for Ox Creek. This step ensured that all seasons were considered over a longer time frame.

The extended Ox Creek at Britain Avenue flow record was then used to develop corresponding estimates for other bioassessment sites (notably Ox Creek at Crystal Avenue, Ox Creek at Water Street, and Yore-Stouffer drain at Meadowbrook Road). This was accomplished through use of flow estimates derived from *"tape down"* measurements made during the TSS survey.

The second part of the linked regression analysis involves using the TSS survey data to develop a frequency distribution, which characterizes the information at each bioassessment site. Table 8-3 summarizes the results of the frequency analysis. The frequency distribution was used to estimate a maximum daily average concentration in the same way that the SSC analysis was developed; based on the USEPA method to develop targets for multiple averaging periods (described in the Technical Approach section).

In order to develop the SETP graphs, a duration curve was developed for each site using the process described above to estimate flows. As with the SSC analysis, the flow and the duration curve interval (or frequency of occurrence) was identified at each of four points: the median flow, the annual average flow, the value associated with five times the annual average flow, and the one-day maximum. Each value was divided by the annual average flow to determine the x-axis plotting position in the SETP method. The frequency of occurrence value from the duration curve was also used to identify a corresponding averaging period. This averaging period was then linked to the TSS frequency distribution developed from the Ox Creek survey data to identify the appropriate y-axis value in the SETP graph.

Table 8-3. Summary of TSS concentrations for Ox Creek bioassessment sites.

Site	Area (mi²)	Total Suspended Solids (mg/L)				P51 Bioassessment	
		Median	Average	Daily Max.	Coeff. of Variation	Date	Score
Ox Creek at Water Street *	16.34	29.0	36.6	245	0.95	7/19/2006	-5
						6/26/2001	-6
Ox Creek at Britain Avenue	14.68	26.0	40.2	368	1.24	7/19/2006	-6
Ox Creek at Crystal Avenue	4.06	31.0	61.6	619	1.34	7/18/2006	-3
						6/26/2001	-5
Yore – Stouffer Drain at Meadowbrook Road	6.83	33.0	66.5	663	1.34	7/18/2006	-6

Note: * 2001 bioassessment conducted at 5th Avenue *(just downstream of Water Street)*.

This approach is based on two assumptions: that there is a direct relationship between flow and TSS; and that the frequency distribution derived from the TSS surveys is reasonably representative of longer term conditions in the Ox Creek watershed. The intent of this analysis is to evaluate the applicability of TSS target values to Ox Creek using the SETP method. With this objective in mind, these are reasonable assumptions given the data limitations.

Results of the screening analysis are presented in Figure 8-8 through Figure 8-13. The maximum daily average concentration at the Britain Avenue site is above the TSS target *(Figure 8-8)*. In addition, the flow ratio for the 1-day recurrence interval at this site is nearly 16. This value is significantly above the threshold presented by Feldpausch; indicative of a *"flashy"* system. As discussed earlier, the R-B Flashiness Index for this location is 0.52, which places it in the highest quartile for Michigan watersheds of comparable size.

It should also be noted that two SETP graphs were prepared for both the Ox Creek at Crystal Avenue, and the Yore-Stouffer Drain at Meadowbrook Road sites *(Figure 8-10 through Figure 8-13)*. Challenges exist in developing relationships between the Britain Avenue level logger flow estimates and the *"tape down"* measurements at the Crystal Avenue and Meadowbrook Road sites. These challenges include the significant change in land use that occurs in the downstream direction from these sites (e.g., the influence of Orchards Mall on the Britain Avenue site). For this reason, a separate set of flow estimates was developed at the Crystal Avenue and Meadowbrook Road sites based solely on the Galien River gage. This also provides a way to demonstrate the sensitivity of the SETP method to flow assumptions.

Finally, the daily maximum average concentration for Ox Creek at Water Street is below the TSS target. This site is immediately downstream of Britain Avenue and is affected by the same *"flashy"* flows, as evidenced by the very high flow ratio associated with the daily maximum concentration.

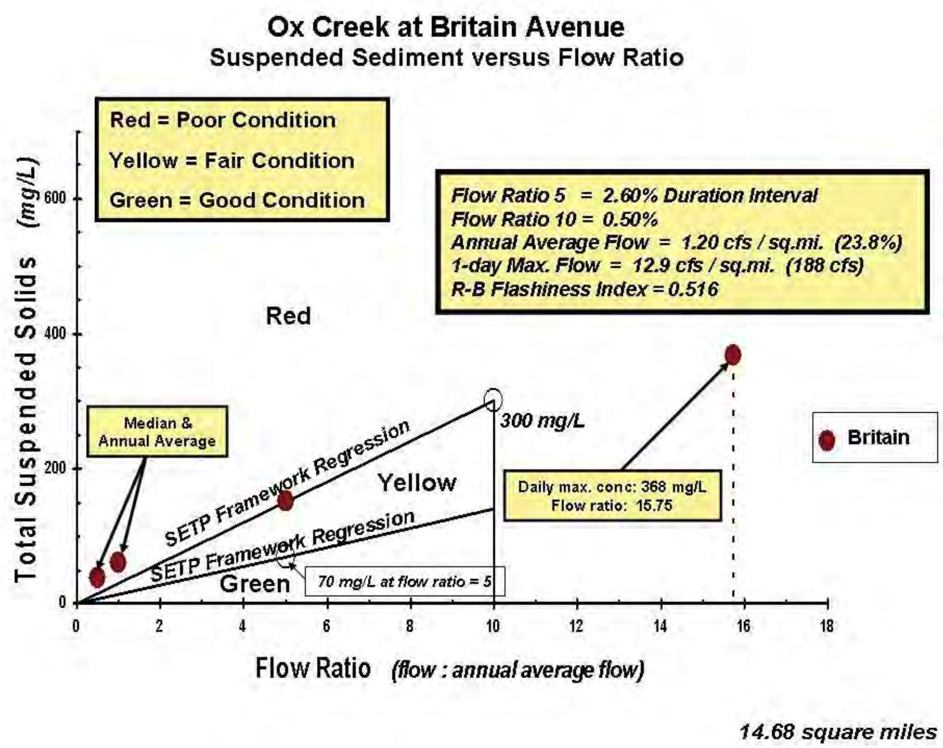


Figure 8-8. Ox Creek at Britain Avenue TSS information using SETP framework.

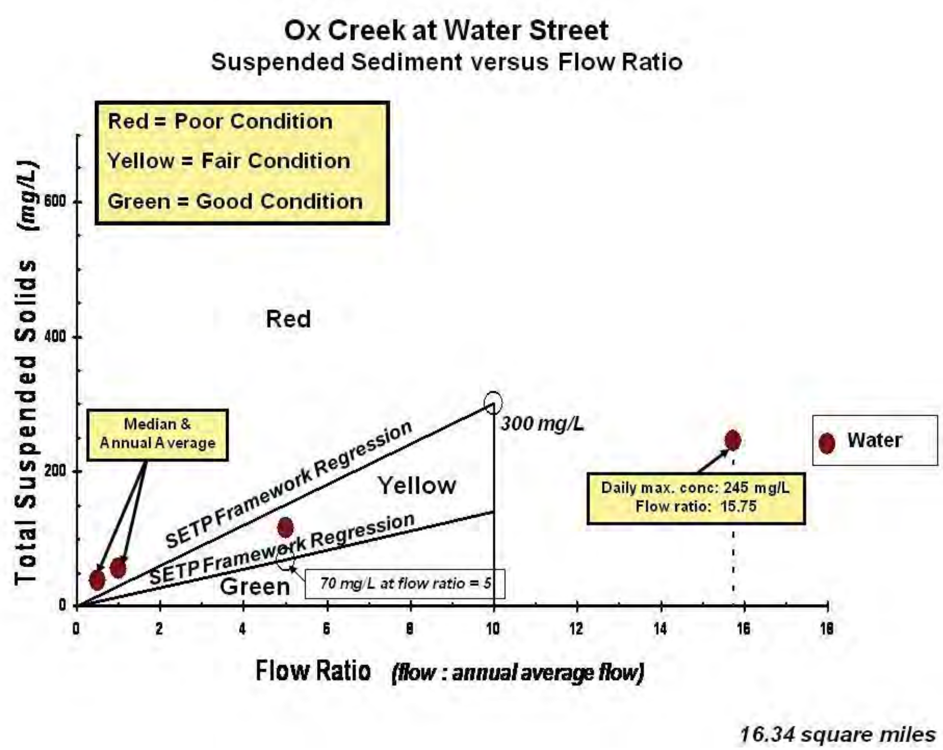


Figure 8-9. Ox Creek at Water Street TSS information using SETP framework.

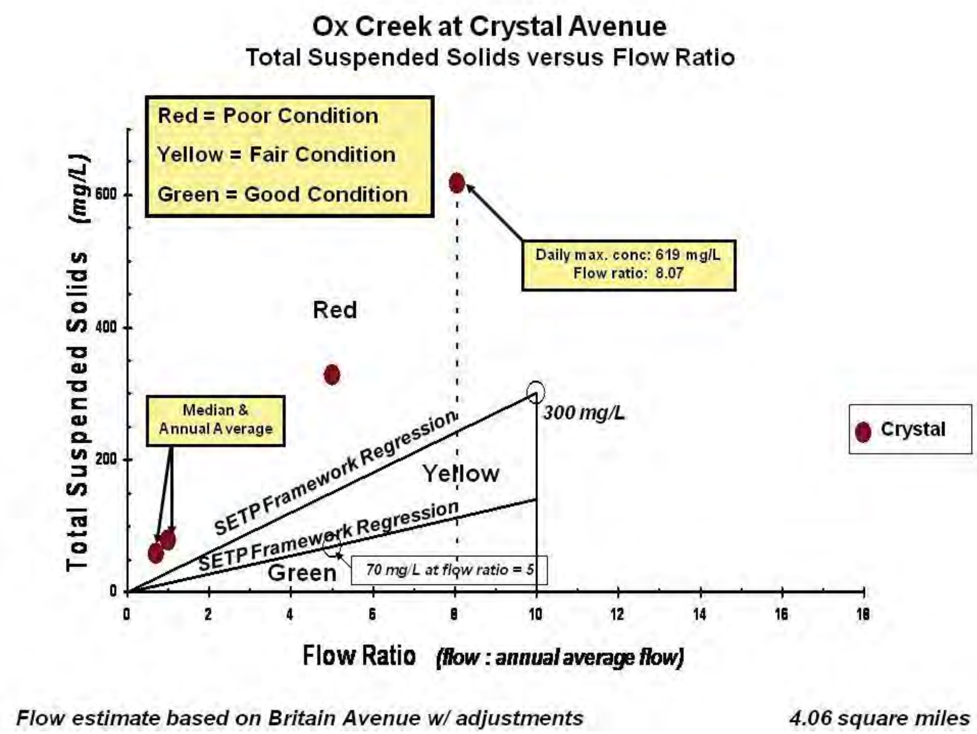


Figure 8-10. Ox Creek at Crystal Avenue TSS information using SETP framework *(Britain flows)*.

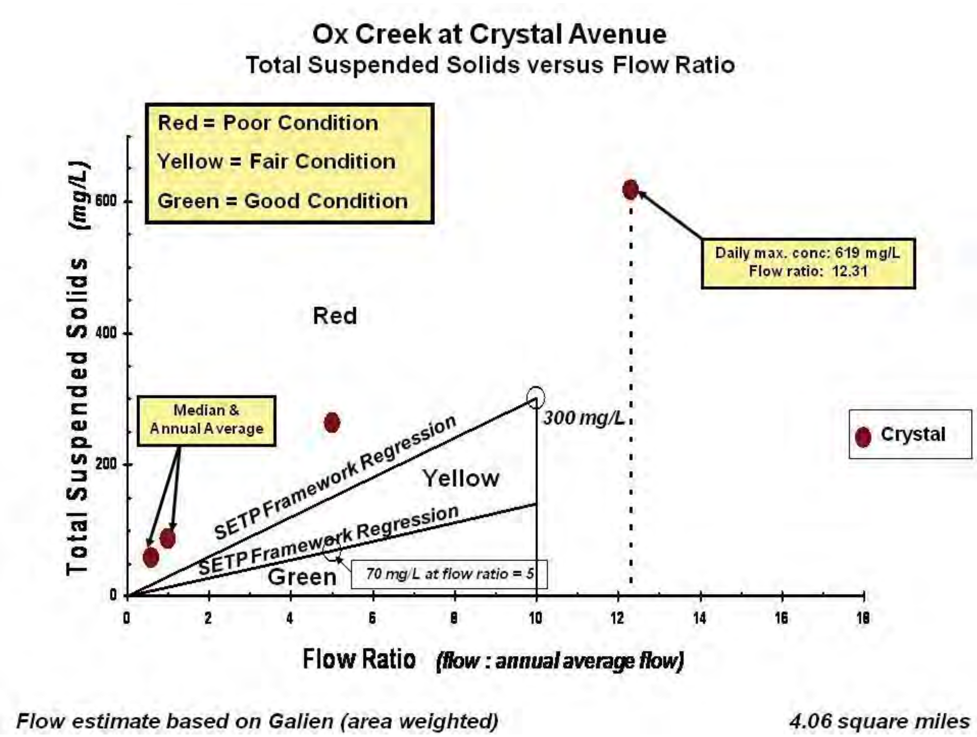


Figure 8-11. Ox Creek at Crystal Avenue TSS information using SETP framework *(Galien flows)*.

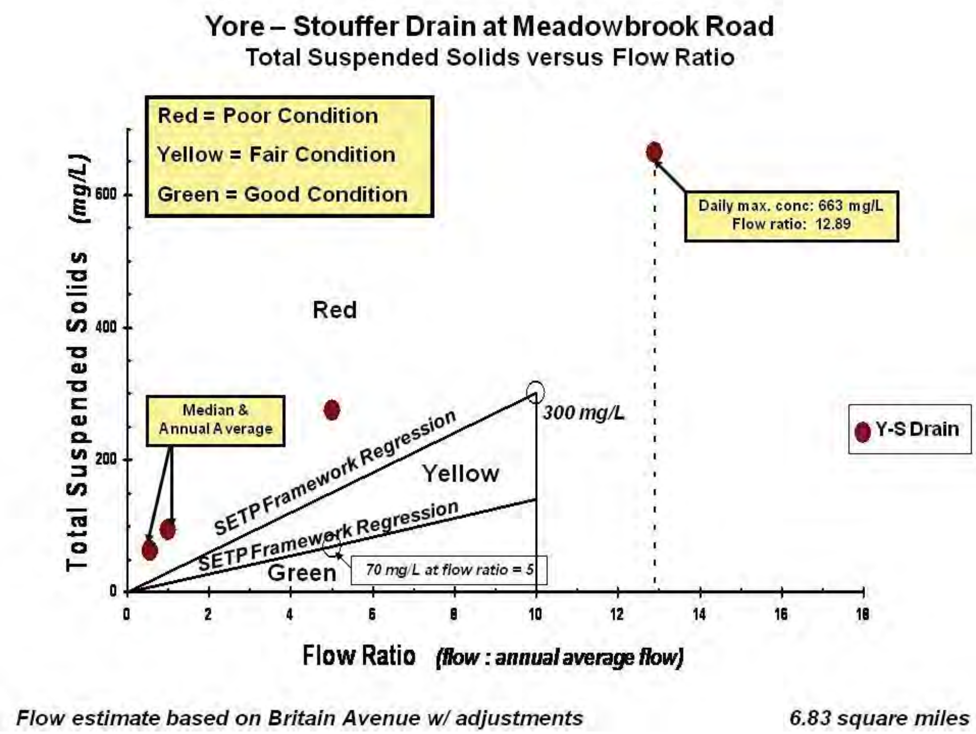


Figure 8-12. Yore-Stouffer at Meadowbrook Road TSS information with SETP framework *(Britain flows)*.

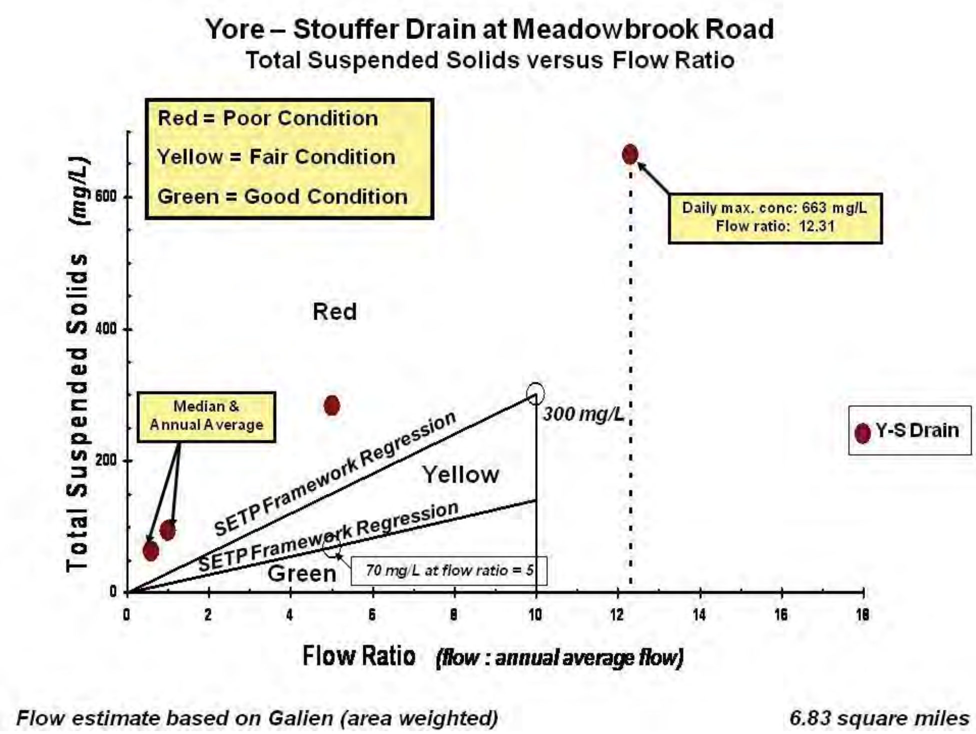


Figure 8-13. Yore-Stouffer at Meadowbrook Road TSS information with SETP framework *(Galien flows)*.

8.5 Summary

Based on available information for suspended solids in southern Michigan, the following TSS targets are used to develop the Ox Creek TMDL:

- 25 mg/L long-term annual average TSS
- 300 mg/L maximum daily average TSS

These numeric targets are intended to address aquatic life use impairments responsible for Ox Creek being placed on Michigan's §303(d) list. These targets are supported by multiple lines of evidence. The literature supports the long-term annual average 25 mg/L TSS as a level where fisheries would not be harmed. The 300 mg/L maximum daily average TSS is based on MDEQ studies supporting development of SETP. The SETP effort included a qualitative analysis of the visual frequency and concentration of data scatter with information from 12 different Lower Michigan streams and rivers. The analysis identified 300 mg/L TSS as a general level above which the stream sedimentation condition was degraded.

The appropriateness of these targets was validated by applying the SETP framework to sites with both bioassessment information and either TSS or SSC data. The concurrent evaluation of bioassessment information is needed because the §303(d) listing of Ox Creek is based on aquatic life use impairments. Validation results indicate that, with one exception, sites with acceptable biology are placed in either the green or yellow zone under the SETP framework. This confirms the appropriateness of the TSS targets for addressing aquatic life use impairments. The one exception would likely have placed in the yellow zone when accounting for differences between TSS and SSC monitoring techniques.

Following validation, the targets and methodology were applied to Ox Creek flow and TSS data. The analysis showed that Ox Creek generally exceeded the threshold levels of 25 mg/L and 300 mg/L, placing results in the red zone; consistent with bioassessment scores using P51.

9. Subwatershed Analysis

The Watershed Characterization and Source Assessment (WC&SA) partitioned the Ox Creek drainage into subwatershed units. The approach provides a framework that relates source information to water quality monitoring results. The use of subwatershed units also helps connect potential cause information to documented effects on a reach-by-reach basis. The ability to summarize information at different spatial scales strengthens the overall TMDL development process and enables more effective targeting of implementation efforts.

A total of nine subwatershed units were identified *(Table 9-1 and Figure 9-1)*. These subwatershed boundaries are defined in a way that builds on locations sampled by MDEQ. The WC&SA report identified point sources in the Ox Creek watershed, as well as remediation (Part 201) and leaking underground storage tank (Part 213) sites, which may affect water quality in Ox Creek. The WC&SA report also summarized basic characteristics for each subwatershed group, including size, land use / land cover and source areas located within each subwatershed.

Storm water sources play a significant role in affecting water quality in Ox Creek. For that reason, an understanding of factors that affect storm water runoff within each subwatershed unit is an important part of the linkage analysis. This section presents information that examines the bioassessment and water quality data from each subwatershed unit in the context of source and land use information that appear to affect sample results.

Table 9-1. Ox Creek subwatersheds.

Subbasin ID	Name	Area	
		(acres)	*(sq.mi.)*
Unit A	Yore – Stouffer Headwaters	2,150	3.36
Unit B	Upper Yore – Stouffer	465	0.73
Unit C	Middle Yore – Stouffer	1,755	2.74
Unit D	Lower Yore – Stouffer	805	1.26
Unit E	Ox Headwaters	2,600	4.06
Unit F	Upper Ox	725	1.13
Unit G	Middle Ox	895	1.40
Unit H	Lower Ox	1,060	1.66
Unit I	Ox Outlet	104	0.16
TOTAL		10,559	16.50

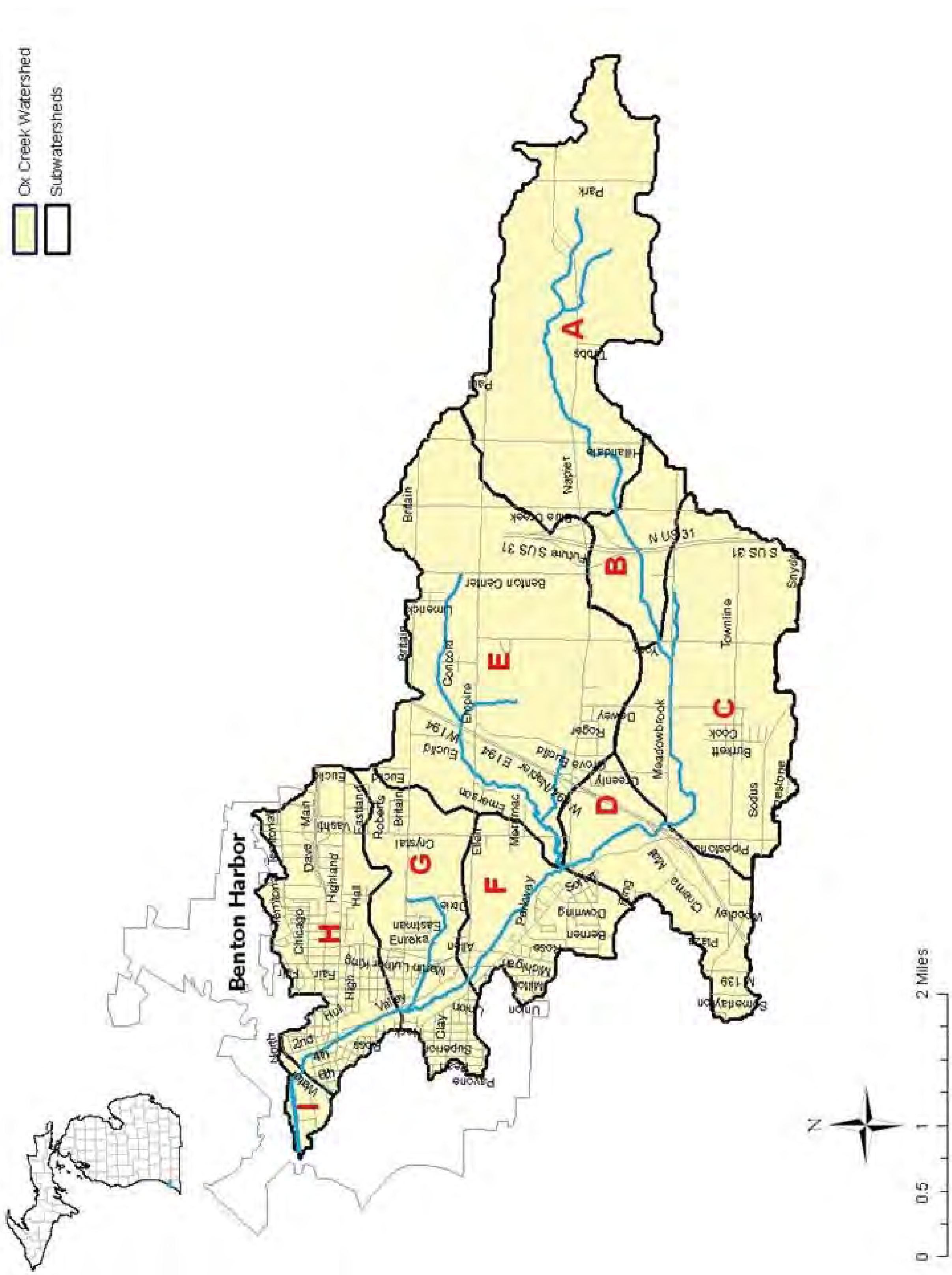


Figure 9-1. Ox Creek subwatersheds.

9.1 Unit A -- Yore - Stouffer Headwaters

The Yore – Stouffer Headwaters unit consists of the land area draining to the Yore – Stouffer Drain upstream of Blue Creek Road *(Figure 9-2)*. Figure 9-3 shows a ground view of the unit A outlet taken at the Blue Creek Road monitoring site. There are no point source, Part 201, or Part 213 facilities in this unit. Land use in this unit, shown in Figure 9-4, is dominated by cultivated crops (61%) with a noticeable amount as pasture / hay (16%). Table 9-2 presents a summary of land use in unit A.

This particular subwatershed unit is largely agricultural and contains relatively little developed land within its drainage area. Water quality data collected at the outlet of unit A (Blue Creek Road) was limited to TSS sampling because of the lack of point sources or other activities that would likely contribute toxics or heavy metals. With the exception of storm events, sampling results at this location indicate relatively low TSS levels compared to other Ox Creek sites.

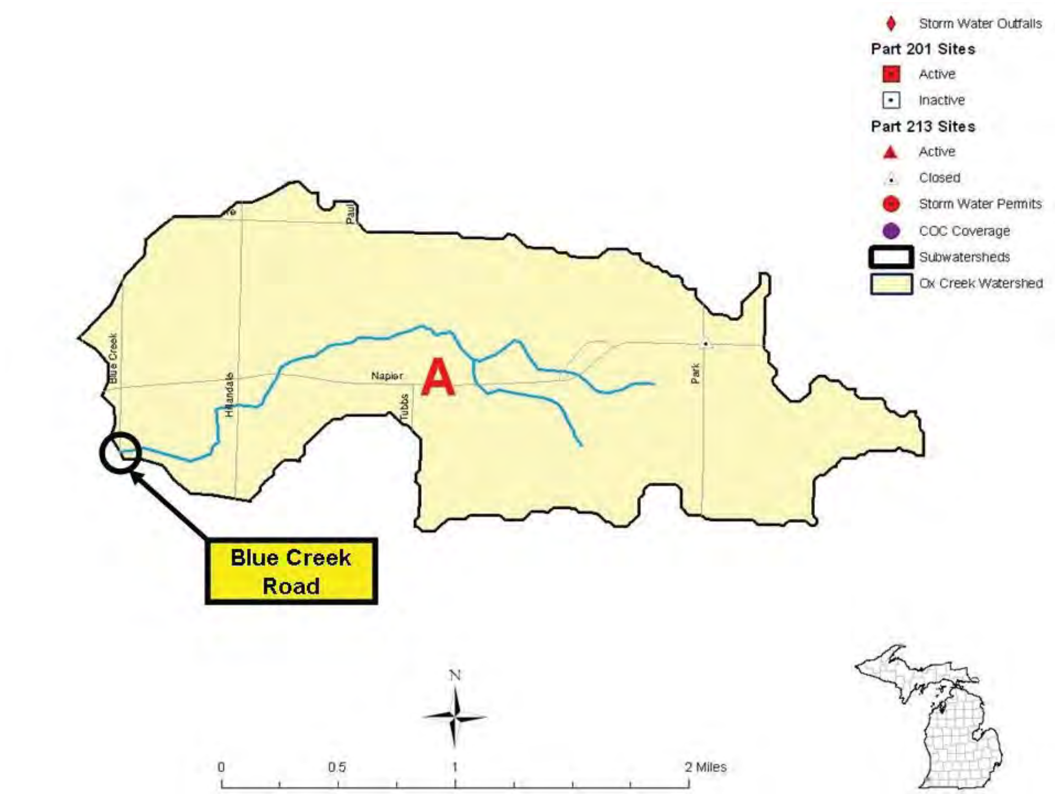


Figure 9-2. Unit A -- Yore - Stouffer Headwaters location.

Figure 9-3. Yore - Stouffer Drain at Blue Creek Road.

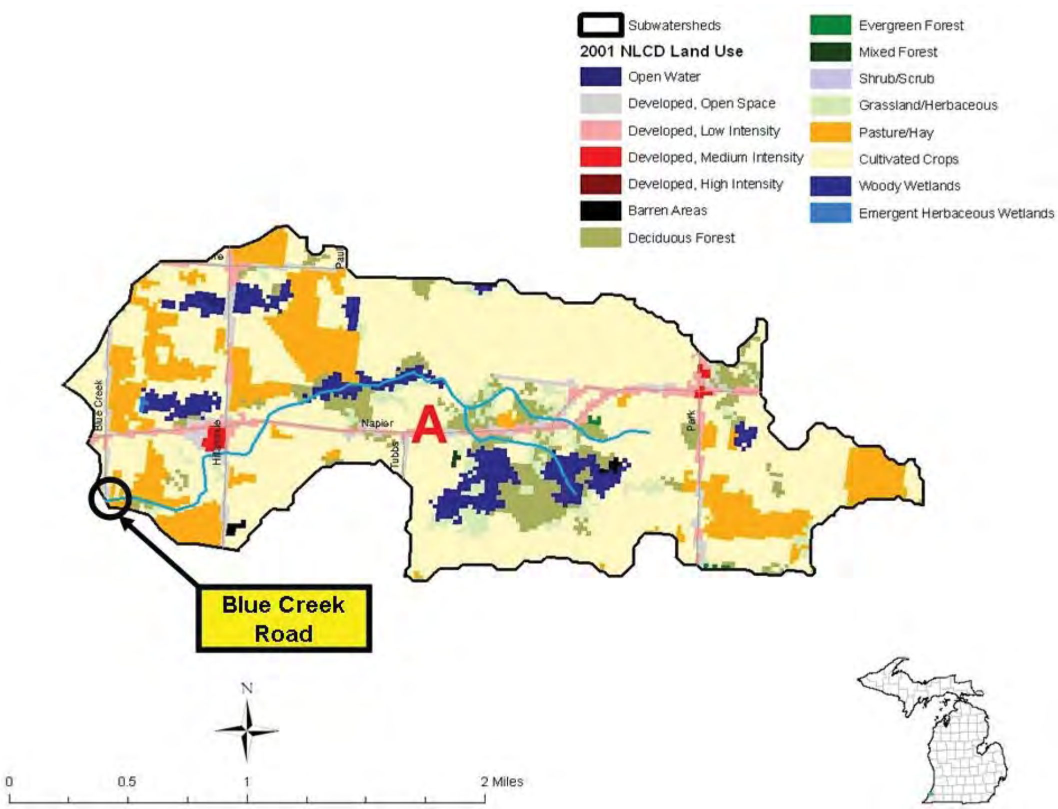


Figure 9-4. Unit A -- Yore - Stouffer Headwaters land use.

Table 9-2. Yore - Stouffer Headwaters land use summary.

Land Use / Land Cover	Size	
	(acres)	*(percentage)*
Open Water	2	0%
Developed, Open	64	3%
Developed, Low-Intensity	77	4%
Developed, Medium-Intensity	8	0%
Developed, High Intensity	0	--
Barren Land	4	0%
Deciduous Forest	152	7%
Evergreen Forest	3	0%
Mixed forest	1	0%
Shrub/Scrub	0	--
Grassland/Herbaceous	74	3%
Pasture/Hay	329	16%
Cultivated Crops	1,301	61%
Woody Wetlands	134	6%
Emergent Herbaceous Wetlands	1	0%
TOTAL	2,150	100%

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

A useful way to examine the TSS data is through an analysis of its relationship to flow. Figure 9-5 uses the survey information to depict TSS data for the Blue Creek Road site as a function of water level. The general pattern indicates that TSS concentrations increase with rising water level (and flow). Figure 9-6 through Figure 9-8 present time series displays of the data for the wet-weather events: the August 18-19, 2007 storm (2.52 inches); the April 8-9, 2008 storm (0.69 inches), and the August 4-5, 2008 storm (0.74 inches).

Although below daily maximum targets, the TSS response for the first two events was associated with the onset of intense precipitation. These peaks likely resulted from a *"first flush effect"*; the effect where sediment accumulated on surfaces and exposed soils, in gullies or other areas susceptible to erosion is quickly washed away. Both storms also resulted in a second TSS peak approximately five hours after the event. These subsequent peaks could be the result of delayed watershed loading. In the case of the first event, the second peak was associated with intense precipitation. The first wet-weather event also resulted in a third peak that appears to correspond with the highest estimated flows.

Figure 9-7 and Figure 9-8 also point to another noteworthy observation. Both storms resulted in relatively minor changes in stream flow (both storms were also less than 1 inch precipitation). This subwatershed unit is largely pervious land suggesting a threshold magnitude storm is needed to produce runoff. The elevated TSS levels in the second storm supports *"first flush"* generated sediment associated with surface and gully erosion. This was not observed in the third storm (likely because monitoring was not initiated until 12 hours after the intense precipitation).

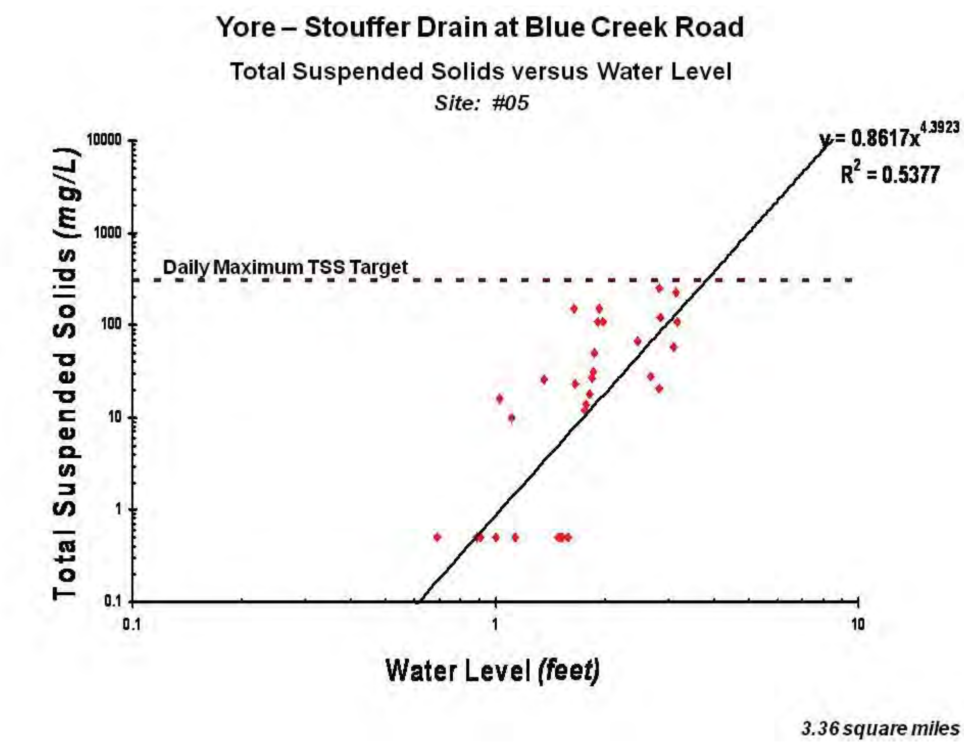


Figure 9-5. TSS as a function of water level -- Blue Creek Road site.

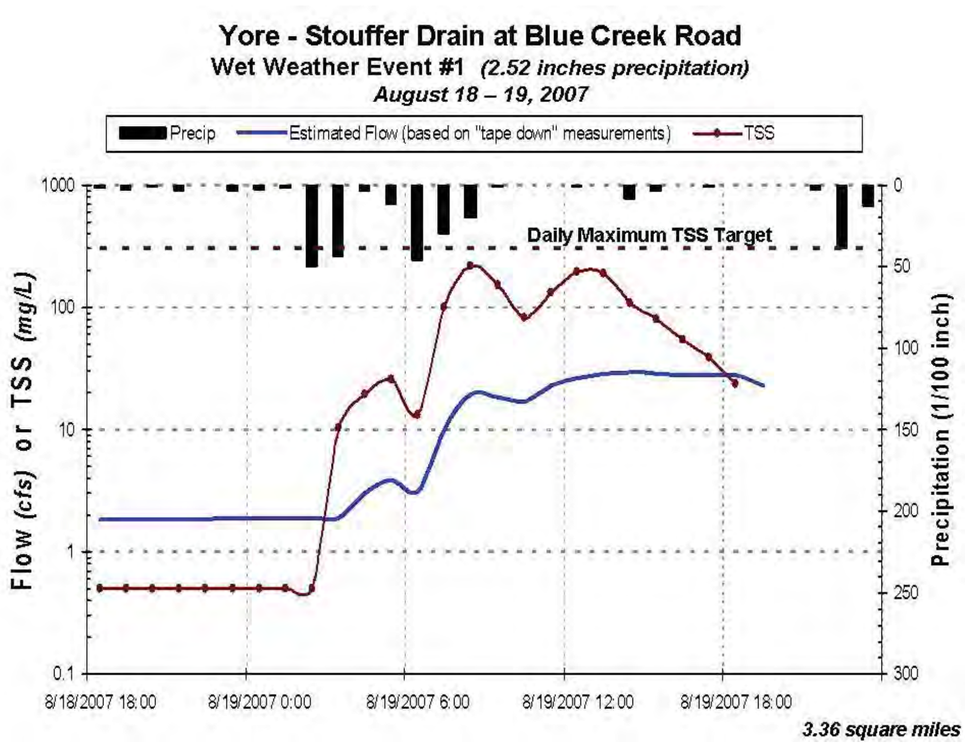


Figure 9-6. TSS, flow, and precipitation for wet weather event #1 -- Blue Creek Road.

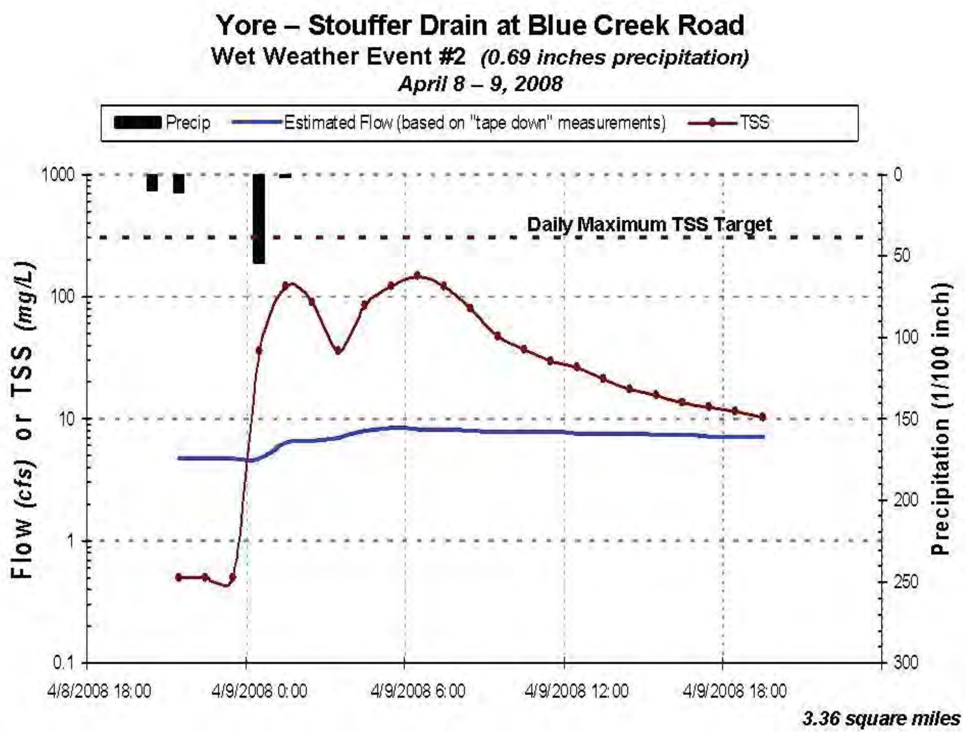


Figure 9-7. TSS, flow, and precipitation for wet weather event #2 -- Blue Creek Road.

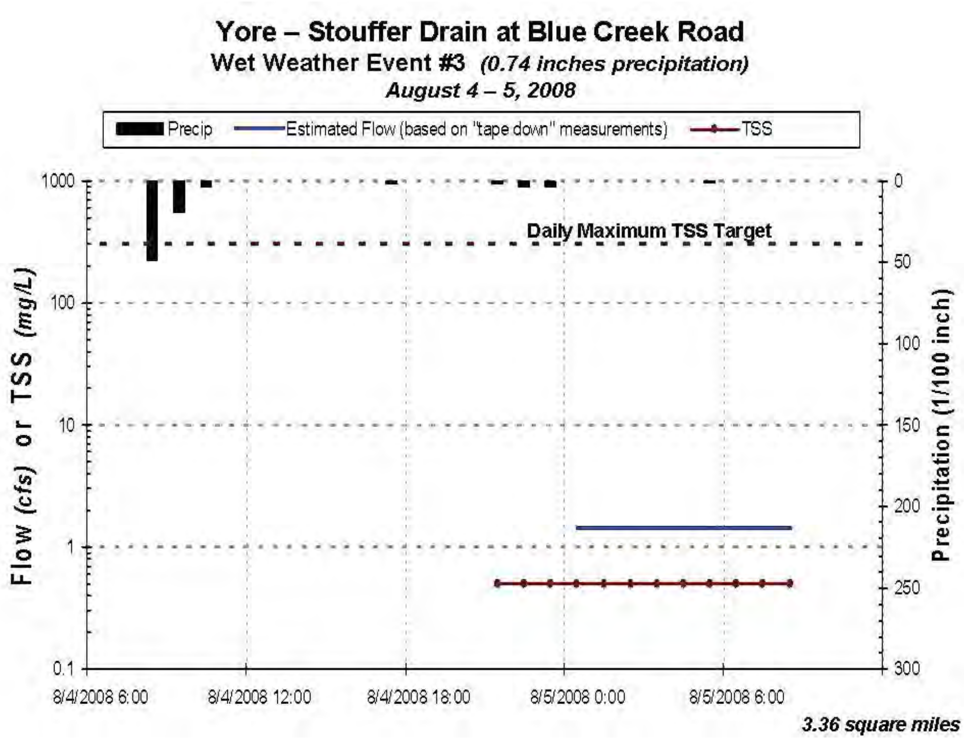


Figure 9-8. TSS, flow, and precipitation for wet weather event #3 -- Blue Creek Road.

Another way to view this information is through the use of a duration curve framework *(Figure 9-9)*. Data is also separated by each sample event. The first wet weather event occurred in August (summer) as the result of a 2.52 inch storm (noted as Sum-2.52" in Figure 9-9). A significant number of these samples were collected under high flow conditions and included the largest TSS loads. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation (noted as Spr-0.69" in Figure 9-9). However, it did result in greater loads than the third event that occurred in the summer as the result of a 0.74 inch storm (noted as Sum-0.74" in Figure 9-9). This may reflect seasonal factors as the second storm occurred in April, prior to the emergence of vegetation on agricultural lands.

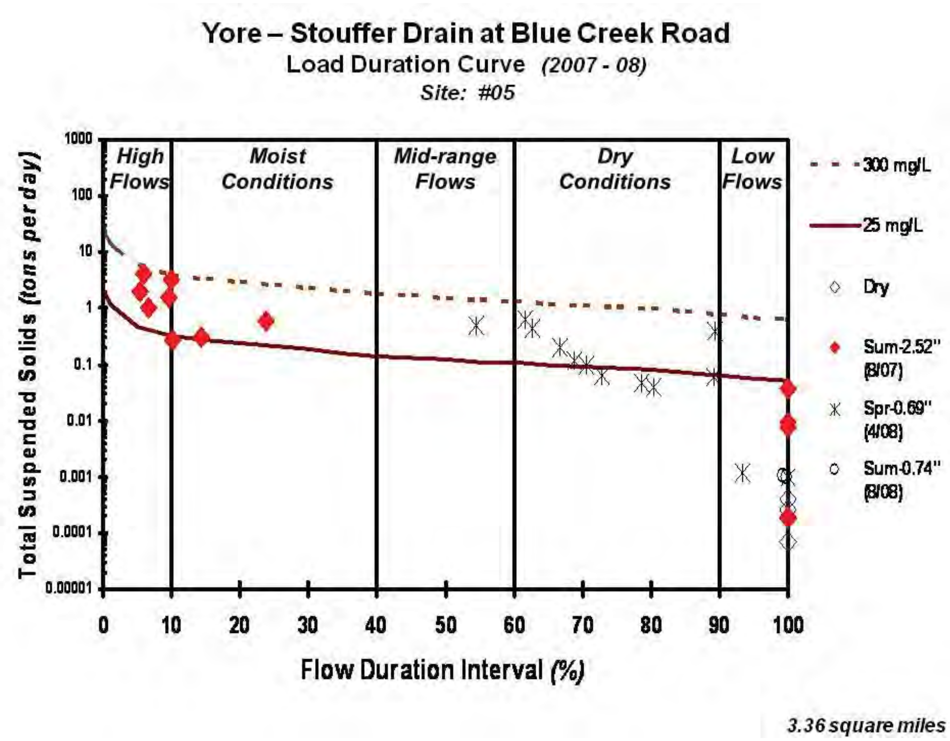


Figure 9-9. Load duration curve for TSS at Blue Creek Road.

9.2 *Unit B -- Upper Yore – Stouffer*

Unit B, the Upper Yore – Stouffer unit consists of the land area draining to the Yore – Stouffer Drain between Blue Creek Road and Yore Avenue *(Figure 9-10)*. Figure 9-11 shows a ground view of the unit B outlet taken at the Yore Avenue monitoring site. There are no point source, Part 201, or Part 213 facilities in this unit. Land use in this unit, as shown in Figure 9-12 and summarized in Table 9-3, is dominated by cultivated crops (48%) with a noticeable amount as pasture / hay (28%).

This drainage area is largely dominated by agricultural lands, and contains relatively little developed land. However, highway US-31 divides the subwatershed. Runoff from vehicles as well as the highway and surrounding development may be a potential source of pollutants. Of particular interest, major construction on this highway recently occurred in 2007; corresponding with monitoring activities. Water quality data collected at the outlet of unit B (Yore Avenue) consisted of water column TSS and toxics sampling. No heavy metals or toxics were detected at this location. However, sample results for TSS included several of the highest levels in the entire Ox Creek watershed.

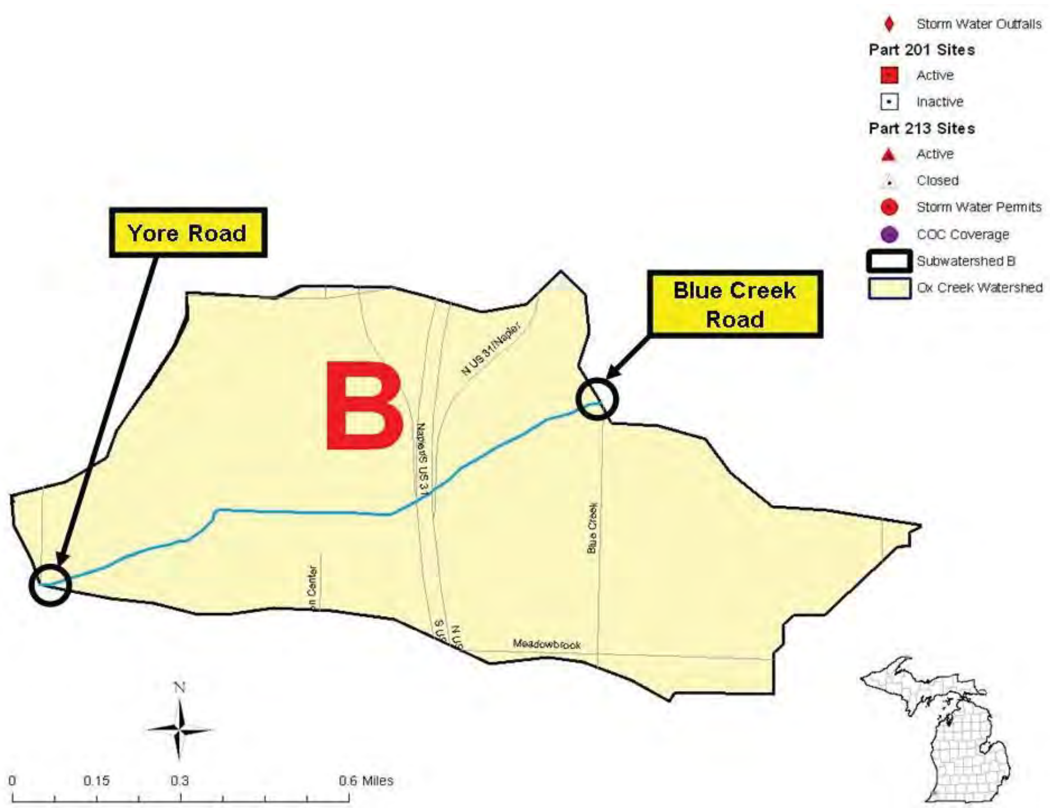


Figure 9-10. Unit B -- Upper Yore - Stouffer location.

Figure 9-11. Yore - Stouffer Drain at Yore Avenue.

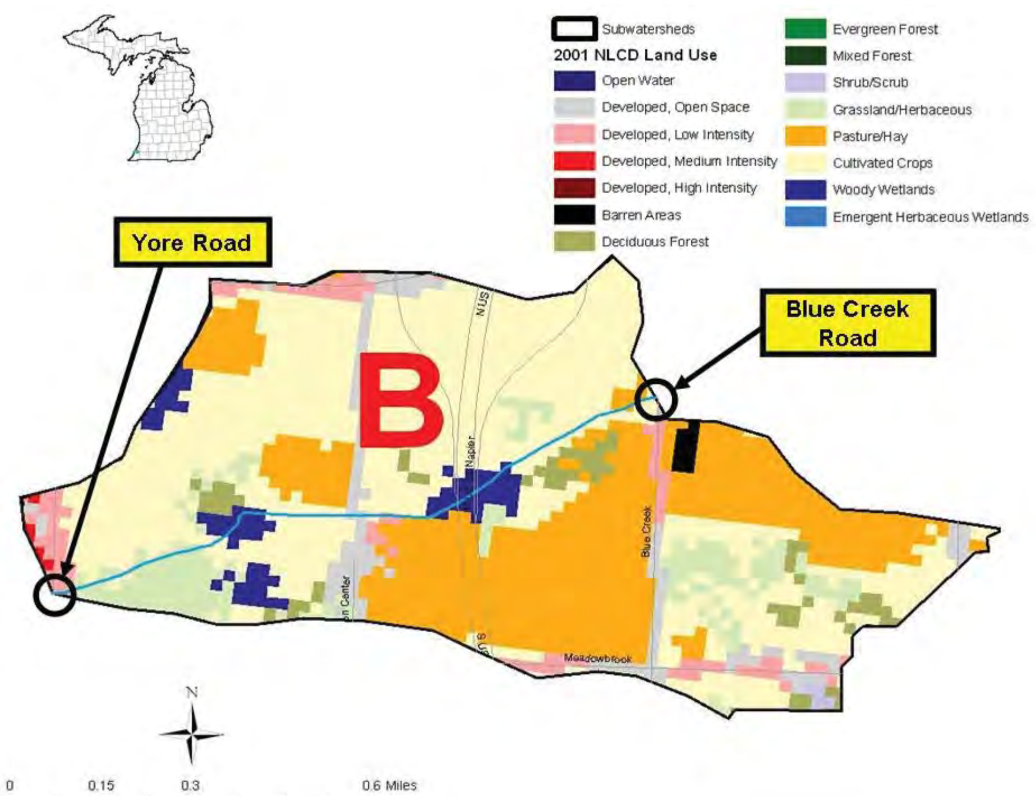


Figure 9-12. Unit B -- Upper Yore - Stouffer land use.

Table 9-3. Upper Yore - Stouffer land use summary.

Land Use / Land Cover	Size	
	(acres)	*(percentage)*
Open Water	0	--
Developed, Open	26	6%
Developed, Low-Intensity	20	4%
Developed, Medium-Intensity	1	0%
Developed, High Intensity	0	--
Barren Land	2	0%
Deciduous Forest	15	3%
Evergreen Forest	0	--
Mixed forest	0	--
Shrub/Scrub	1	0%
Grassland/Herbaceous	36	8%
Pasture/Hay	128	28%
Cultivated Crops	220	48%
Woody Wetlands	16	3%
Emergent Herbaceous Wetlands	0	--
TOTAL	465	100%

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

Examining TSS data and its relationship to flow can be useful. Figure 9-13 presents TSS data for the Yore Avenue site as a function of water level. The general pattern shows that TSS increases with rising water level (and flow). One exception to the general pattern occurred as the two largest TSS values (noted by the upper circle) did not correspond to the highest water levels. These anomalies may be related to several factors such as the intensity of the precipitation event, the season (and vegetation coverage) of occurrence, and the timing of the individual TSS sample relative to the onset of the storm. Figure 9-14 through Figure 9-16 present time series displays of the data for the wet-weather events: the August 18-19, 2007 storm (2.52 inches); the April 8-9, 2008 storm (0.69 inches), and the August 4-5, 2008 storm (0.74 inches).

The highest TSS levels were associated with the onset of intense precipitation and / or greatest in stream flow. Interestingly, the spring storm resulted in a greater sediment load compared to the summer event. This could be associated with seasonal factors (e.g. lack of mature vegetative coverage, particularly in agricultural fields, during spring months). The residual effect of highway construction activities on US-31 may also have contributed to the higher concentrations.

Figure 9-15 and Figure 9-16 also point to another noteworthy observation. Both storms resulted in relatively minor changes in stream flow (both storms were also less than 1 inch precipitation). This subwatershed unit is largely pervious land suggesting a threshold magnitude storm is needed to produce runoff. The elevated TSS levels in the second storm supports *"first flush"* generated sediment associated with surface and gully erosion. This was not observed in the third storm (likely because monitoring was not initiated until 12 hours after the intense precipitation).

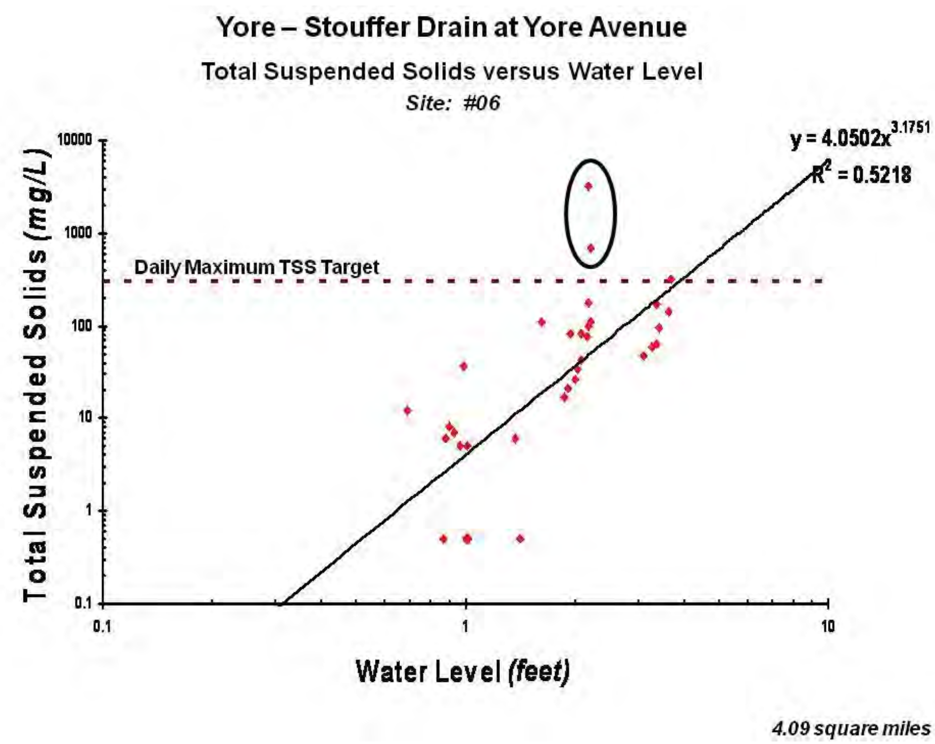


Figure 9-13. TSS as a function of water level -- Yore Avenue site.

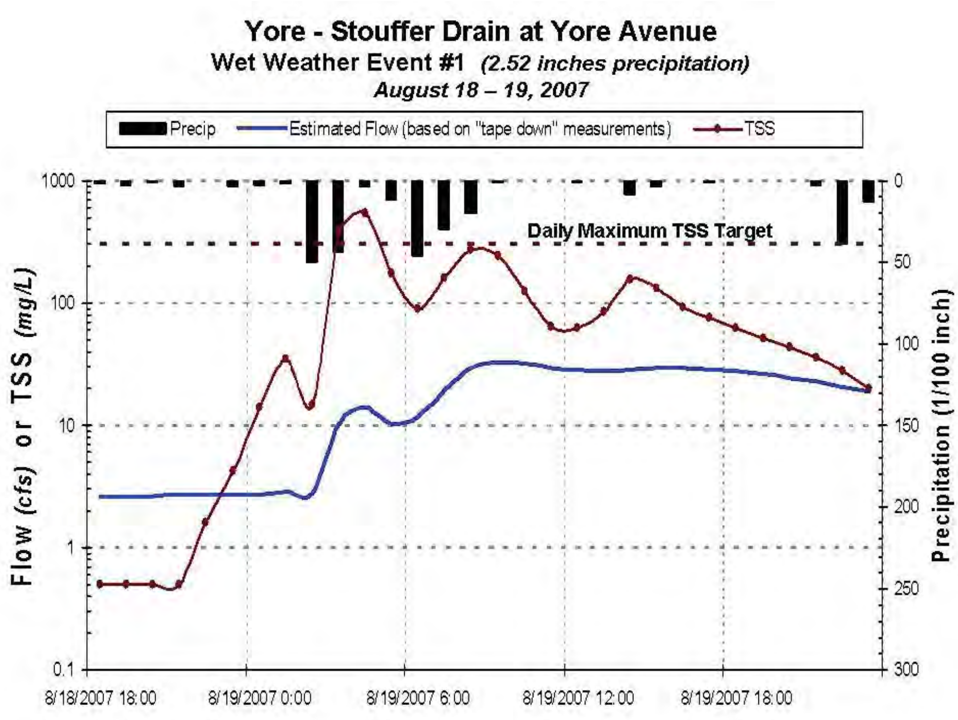


Figure 9-14. TSS, flow, and precipitation for wet weather event #1 -- Yore Avenue.

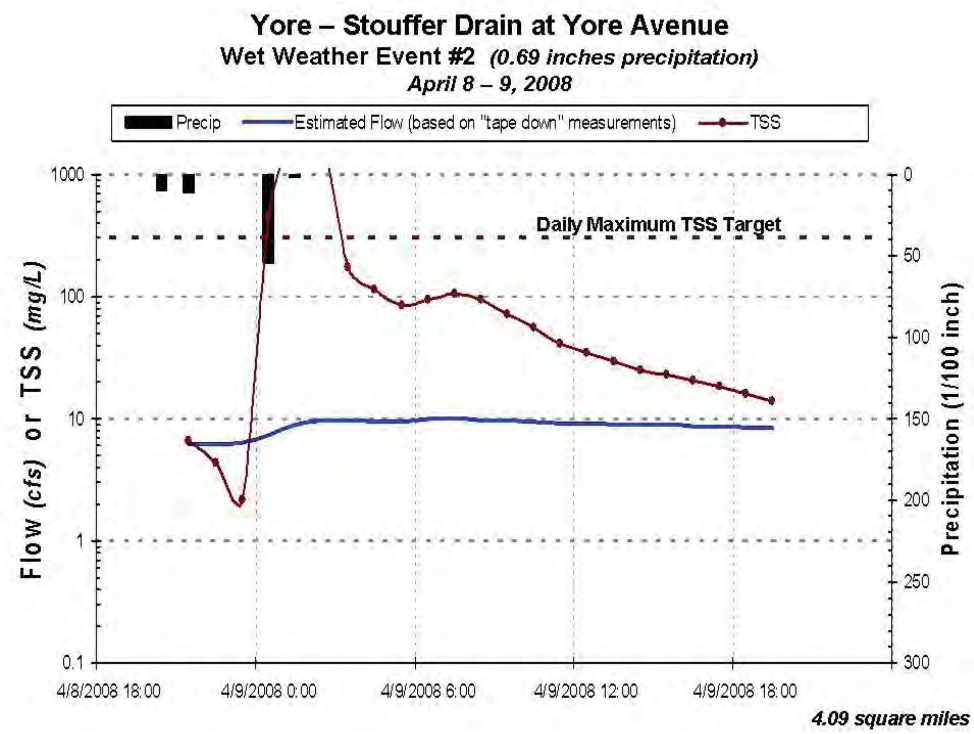


Figure 9-15. TSS, flow, and precipitation for wet weather event #2 -- Yore Avenue.

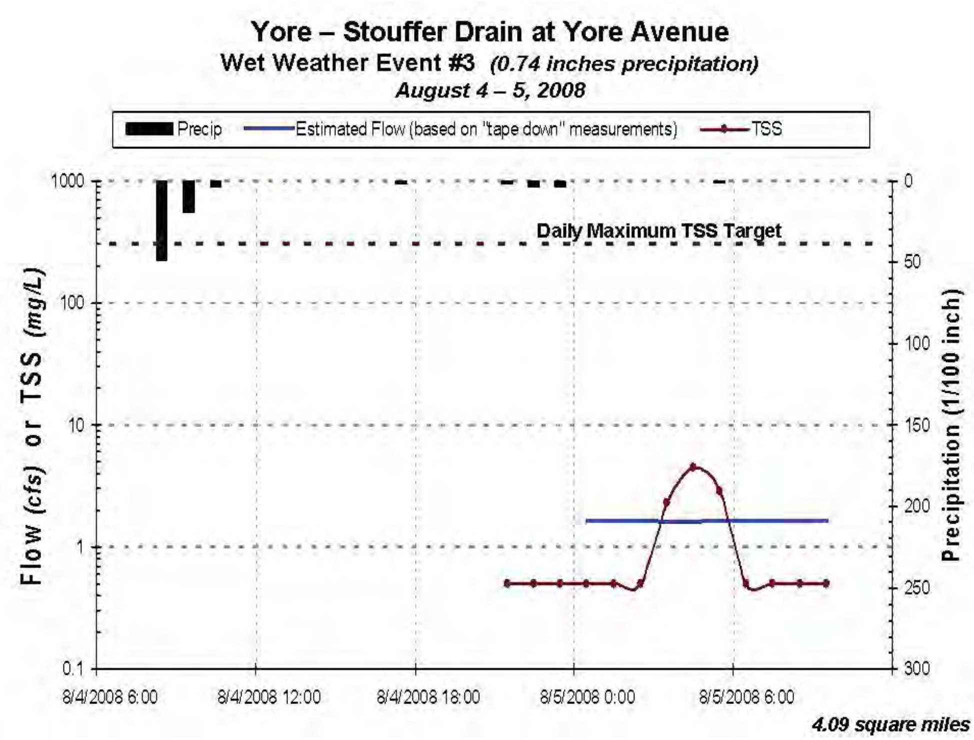


Figure 9-16. TSS, flow, and precipitation for wet weather event #3 -- Yore Avenue.

The load duration curve framework *(Figure 9-17)* presents another way to view the relationship between stream flow and water column response. Load duration curves allow data to be paired with specific flow regimes, which can be used to identify periods of concern. For example, data collected during higher flow regimes is most often correlated to greater TSS concentrations.

Duration curves also allow data to be separated by sampling event where trends can be evaluated by, and between, events. The first wet weather event occurred in August (summer) as the result of a 2.52 inch storm (noted as Sum-2.52" in Figure 9-17). A significant number of these samples were collected under high flow conditions and included the largest TSS loads. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation (noted as Spr-0.69" in Figure 9-17). However, it did result in greater loads than the third event that occurred in the summer as the result of a 0.74 inch storm (noted as Sum-0.74" in Figure 9-17). This may reflect seasonal factors as the second storm occurred in April, prior to the emergence of vegetation on agricultural lands. Finally, in all cases, the higher flows were associated with greater TSS concentrations, likely a result of surface and / or gully erosion.

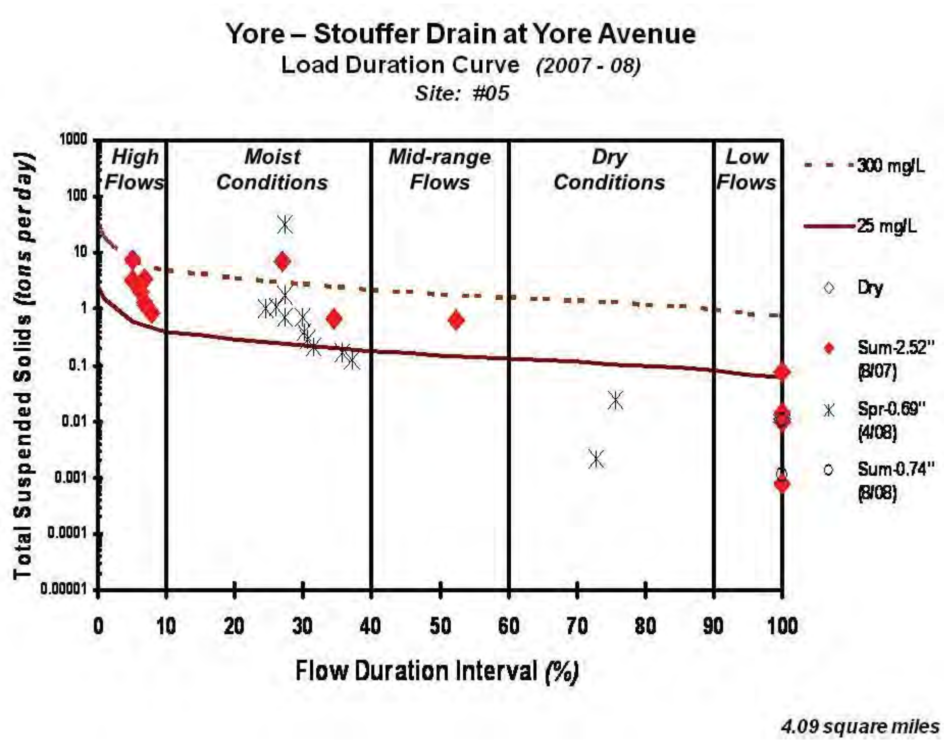


Figure 9-17. Load duration curve for TSS at Yore Avenue.

9.3 Unit C -- Middle Yore – Stouffer

The Middle Yore – Stouffer unit consists of the land area draining to the Yore – Stouffer Drain between Yore Avenue and Meadowbrook Road *(Figure 9-18)*. Figure 9-19 shows a ground view of the unit C outlet taken at the Meadowbrook Road monitoring site. There are five industrial facilities located in unit C that are covered under storm water permits, while two MS4 jurisdictions include lands in this unit. Two active Part 201 sites are located in unit C. Three active Part 213 facilities and seven closed sites lie within unit C. Major land uses in this unit, shown in Figure 9-20, include cultivated crops (33%), as well as low, medium, and high intensity development (24%). Highway US-31 also runs through the eastern edge of this unit. Table 9-4 presents a summary of land uses in unit C.

Subwatershed unit C is a transition area in terms of sources and land use. This is reflected in the water quality data collected at the outlet of unit C (Meadowbrook Road). Sample results for TSS show elevated levels during storm events indicating the potential for sediment and siltation to influence biological communities at this site. Water column samples also indicate relatively high concentrations of several PAHs, notably fluoranthene and phenanthrene. These compounds were also detected at relatively high levels in bottom sediment samples.

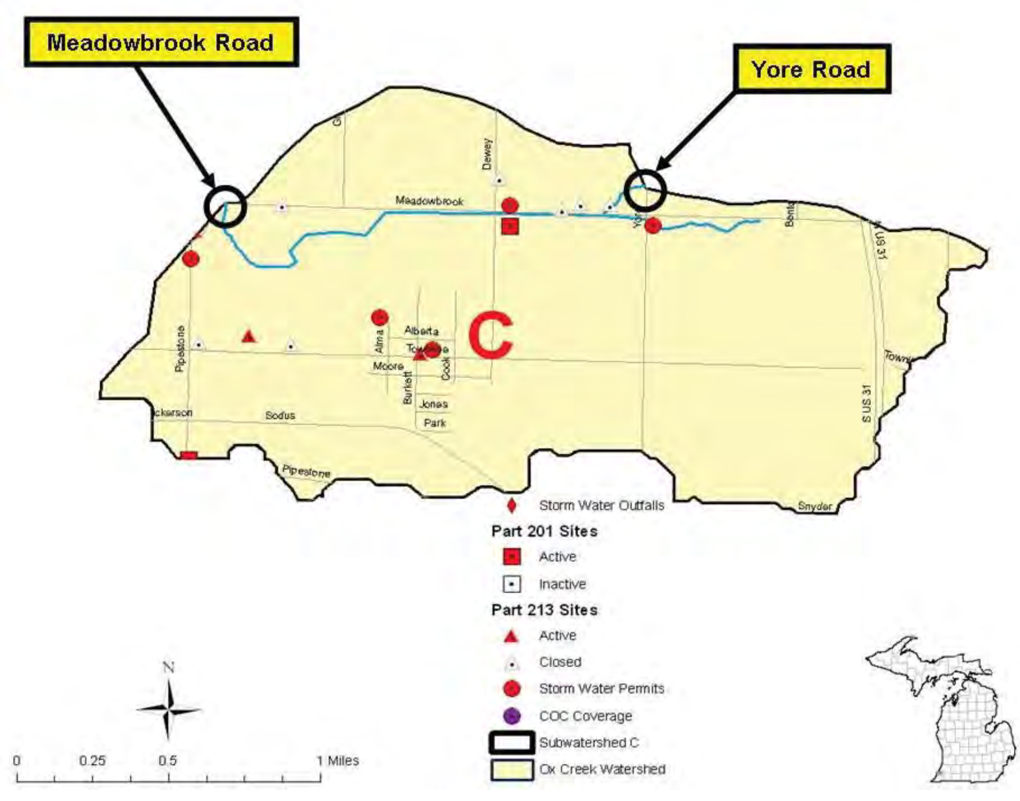


Figure 9-18. Unit C -- Middle Yore - Stouffer location.

Figure 9-19. Yore - Stouffer Drain at Meadowbrook Road.

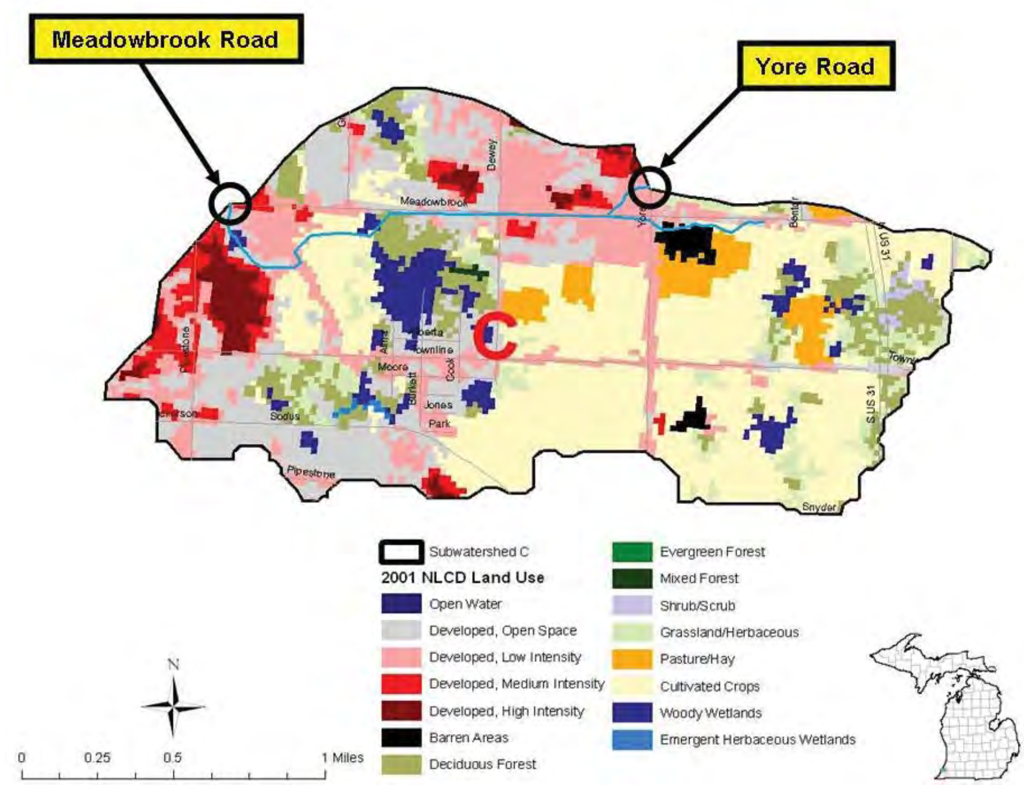


Figure 9-20. Unit C -- Middle Yore - Stouffer land use.

Table 9-4. Middle Yore - Stouffer land use summary.

Land Use / Land Cover	Size (acres)	Size (percentage)
Open Water	0	--
Developed, Open	332	19%
Developed, Low-Intensity	290	17%
Developed, Medium-Intensity	67	4%
Developed, High Intensity	49	3%
Barren Land	17	1%
Deciduous Forest	145	8%
Evergreen Forest	0	--
Mixed forest	2	0%
Shrub/Scrub	8	0%
Grassland/Herbaceous	110	6%
Pasture/Hay	63	4%
Cultivated Crops	590	33%
Woody Wetlands	80	5%
Emergent Herbaceous Wetlands	2	0%
TOTAL	1,755	100%

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

Biological and habitat assessments have been conducted at Meadowbrook Road *(Table 3-2 and Table 4-2)*. The most recent biological evaluation conducted at this location was completed in 2006. Table 9-5 summarizes the dominant taxa that were present in this survey. Because healthy streams typically support macroinvertebrate populations from the Ephemeroptera, Plecoptera, or Tricoptera (EPT) orders (more commonly known as mayflies, stoneflies, and caddisflies), if present, these taxa are also included in Table 9-5.

Table 9-5. Key taxa at Middle Yore - Stouffer macroinvertebrate site.

Yore – Stouffer at Meadowbrook Road		Taxa	Percentage
Dominant Taxa	2006	Sphaeriidae (clams)	19.2
		Planorbidae	9.7
		Oligochaeta (worms)	8.2
EPT Taxa	2006	Hydropsychidae	0.3

Key findings from the 2006 bioassessment are shown in Table 9-6. Overall, the habitat at this location was identified as marginal and moderately impaired. Relative to results typical of this ecoregion, disturbances at this location included channel alterations, changes in channel sinuosity/frequency of riffles or bends, and width of riparian vegetation were identified in this location. Habitat assessments are crucial since both the quality and quantity of available habitat affect the structure and composition of resident biological communities (Barbour, 1999). The biological response to any of the disturbances indentified in this location is expected to be negative.

The macroinvertebrate community at this location was rated as poor (-6) in 2006. This result was related to several factors including: a reduced number of total taxa observed (13 taxa in total); the dominance of isopods, snails and leeches (64% of all individuals); and the absence / reduction in mayfly, caddisfly and stonefly populations. a large population of sphaeriidae (clams) was also identified at this site, composing nearly 20 percent of all individuals collected. Oligochaets (worms) were found to comprise eight percent of all individuals identified. These taxa are both classified as burrowers; generally considered tolerant of varying water quality conditions. As burrowers, these organisms can succeed in environments experiencing excessive sedimentation. In general, burrowers accounted for 27 percent of all individuals collected at this location

Table 9-6. Habitat and biological assessment notes observed at Meadowbrook Road *(Lipsey, 2007)*.

Location	Notes
Meadowbrook Road	• Glide / pool habitat rated as marginal. • Epifaunal substrate limited to overhanging vegetation. • Large amount of fine sediment and sand deposits • Little pool variability due to the deposition. • Debris could be found in the shrubs more than three feet above the surface of the water; banks were stable. • Stream has obviously been altered and straightened in the past. • Bank vegetation was limited to grasses. • Only 13 taxa were found. Sixty percent of the individuals found were snails, isopods, and leeches, which are taxa that are more tolerant of degraded conditions. • No mayfly or stonefly taxa were found, and only one individual caddisfly was found. • Poor macroinvertebrate community can most likely be attributed to a lack of suitable habitat for colonization and high storm water flows that bring additional sediment load and silt to further degrade the habitat.

A useful way to examine the TSS data is through an analysis of its relationship to flow. Figure 9-21 uses the survey information to depict TSS data for the Meadowbrook Road site as a function of water level. The general pattern indicates that TSS concentrations increase with rising water level (and flow). One area of interest is highlighted where an exception to the general pattern occurs. In particular, the highest TSS values (noted by the upper circle) did not correspond to the highest water levels. These anomalies may be related to several factors such as the intensity of the precipitation event, the season of occurrence, and the timing of the individual TSS sample relative to the onset of the storm. Figure 9-22 through Figure 9-24 present time series displays of the data for the wet-weather events: the August 18-19, 2007 storm (2.52 inches); the April 8-9, 2008 storm (0.69 inches), and the August 4-5, 2008 storm (0.74 inches).

The highest TSS levels appear to be associated with the onset of intense precipitation. Interestingly, both the water column response and hydrographs from the two events closely reflect precipitation inputs, where precipitation and increasing flows resulted in increased TSS concentrations. Water column response to precipitation may reflect seasonal factors as the second storm occurred in April, prior to the emergence of vegetation on agricultural lands resulted in higher TSS loading.

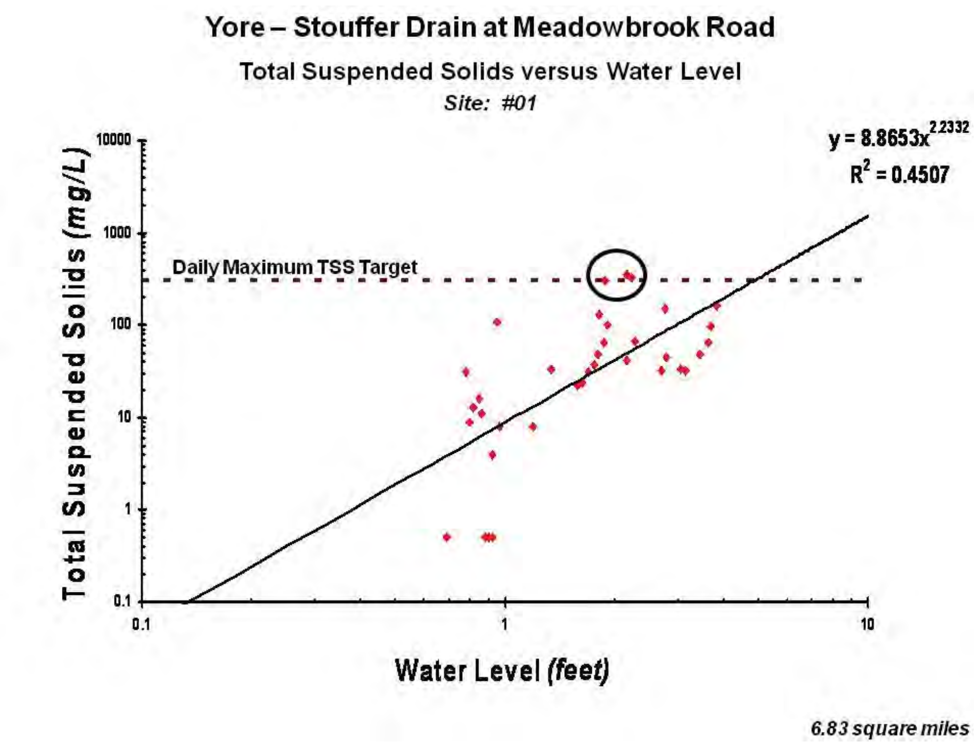


Figure 9-21. TSS as a function of water level -- Meadowbrook Road site.

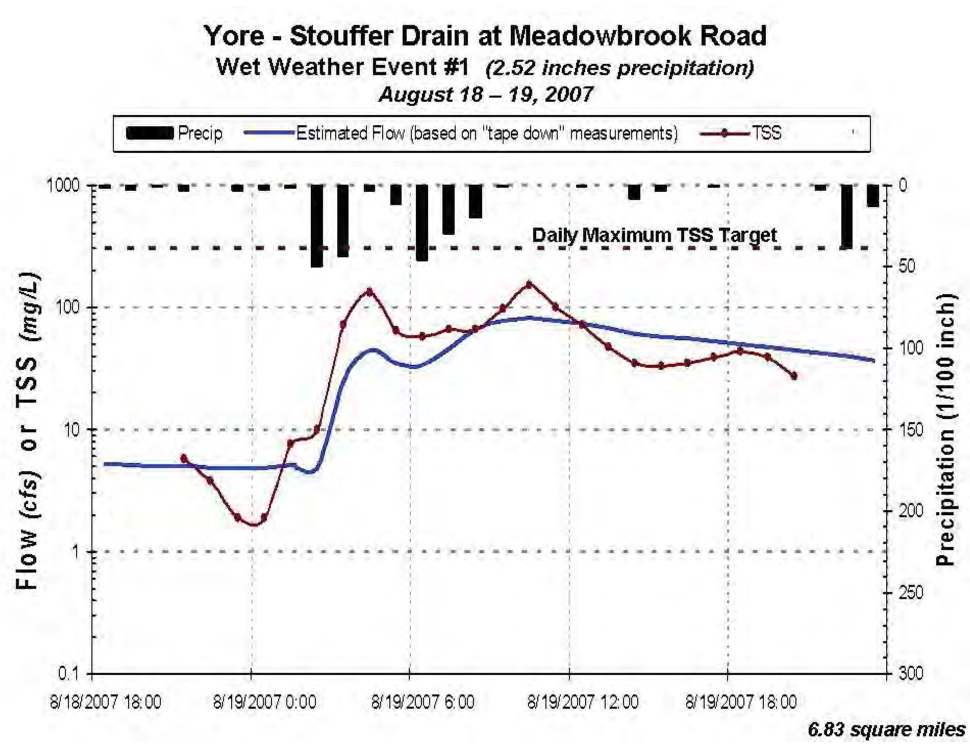


Figure 9-22. TSS, flow, and precipitation for wet weather event #1 -- Meadowbrook Road.

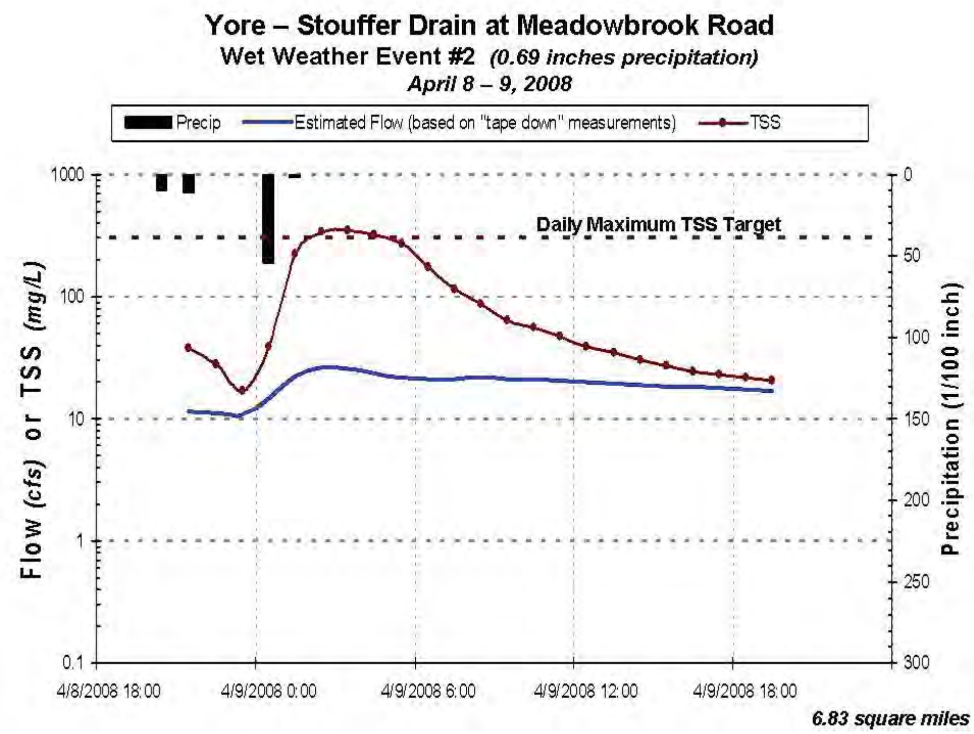


Figure 9-23. TSS, flow, and precipitation for wet weather event #2 -- Meadowbrook Road.

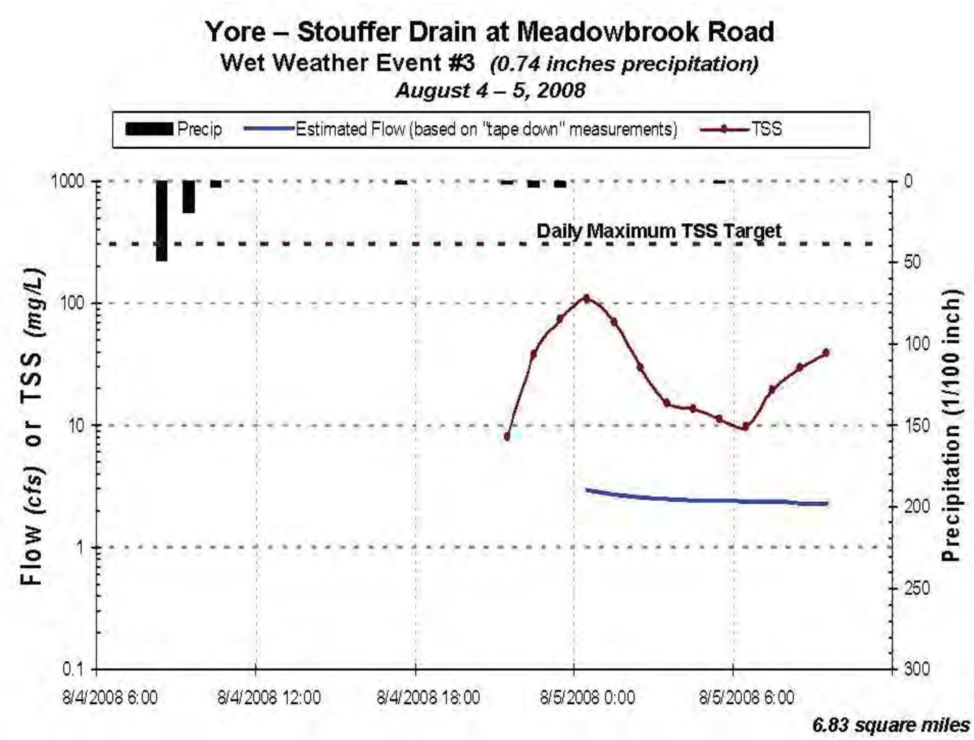


Figure 9-24. TSS, flow, and precipitation for wet weather event #3 -- Meadowbrook Road.

Another way to view this information is through a duration curve *(Figure 9-25)*. The first wet weather event occurred as the result of a 2.52 inch storm *(Sum-2.52" in Figure 9-25)*. Many of these samples were collected under high flow conditions. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation *(Spr-0.69" in Figure 9-25)*. Interestingly, the second storm (spring storm), although having minimal effect on in-stream flow estimates, resulted in an exceedance of the daily maximum TSS target. The second event also resulted in greater loads than the third event that occurred as the result of a 0.74 inch storm *(Sum-0.74" in Figure 9-25)*. This may reflect seasonal factors as the second storm occurred in April, prior to the emergence of vegetation on agricultural lands.

Despite these seasonal variations, a relationship can be drawn between water level and TSS. Particularly, as shown in Figure 9-25, storms that occur during periods of higher stream flows are more likely to contribute significantly to TSS loading. This is likely related to surface and gully erosion, as well as sediment delivery across poorly vegetative riparian areas. As noted in the habitat assessment, sections of the stream in this subwatershed have been altered and straightened. With this alteration and loss in sinuosity, increasing flows have greater likelihood of channel scour, contributing to sediment loads.

Data collected at the Meadowbrook Road site had the highest water column PAH concentrations in the entire Ox Creek drainage. The concern of PAHs in this subwatershed is particular concern due to high vehicular traffic (e.g., I-94 and Pipestone Road), as well as other transportation related development including truck stops and gas stations. Once released into the environment, these compounds adsorb to sediment and wash into receiving waters during runoff events. Often, this sediment and associated contaminates, settle and accumulate on the stream bed. This is confirmed by the high PAH levels in bottom sediment samples collected at this location.

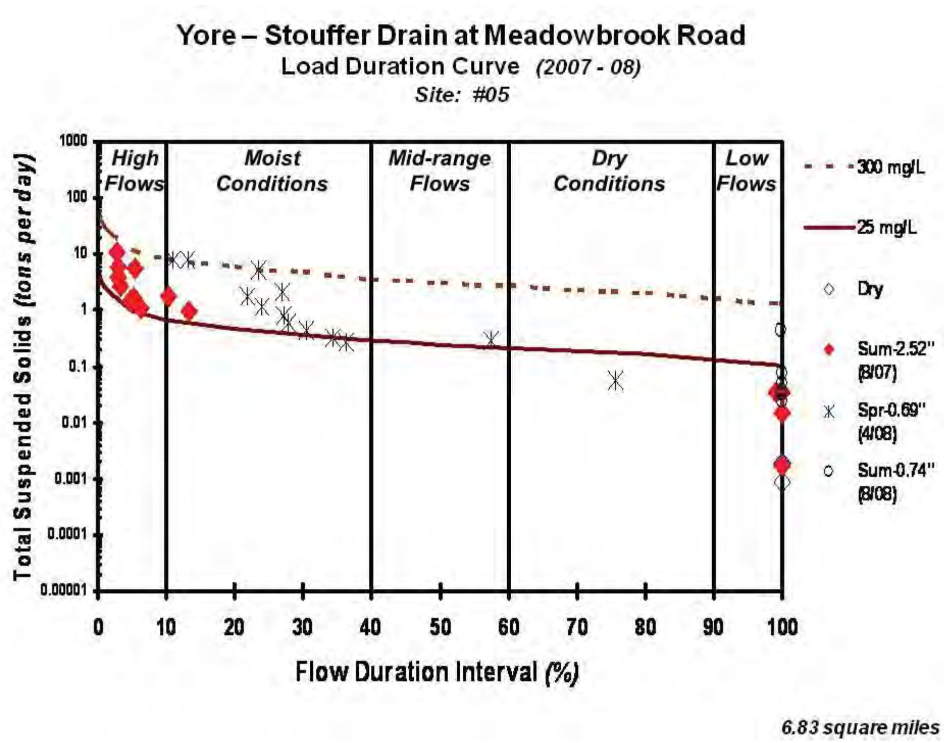


Figure 9-25. Load duration curve for TSS at Meadowbrook Road.

9.4 Unit D -- Lower Yore – Stouffer

The Lower Yore – Stouffer unit consists of the land area draining to the Yore – Stouffer Drain between Meadowbrook Road and the confluence with Ox Creek *(Figure 9-26)*. Figure 9-27 shows a ground view of the unit D outlet taken at the Napier Avenue just above the confluence with Ox Creek. There are no point source or Part 201 facilities located in unit D. Three MS4 jurisdictions include lands in this unit. Four active Part 213 facilities and four closed sites lie within unit D. Features of interest in this unit include the development around the I-94 interchange at Pipestone Road and the Orchards Mall area. Land use in this unit, shown in Figure 9-28, is dominated by low, medium, and high intensity development (62%) followed by developed open land (25%). Table 9-7 presents a summary of land uses in unit D.

No data was collected at the outlet of subwatershed unit D (the Yore-Stouffer Drain at Meadowbrook Road was the most downstream site monitored). However, this subwatershed unit contains a relatively large amount of impervious surfaces, which clearly affects the hydrology of Ox Creek. This is particularly evident when looking at the wet-weather outlet flows for this subwatershed unit that was presented in Table 5-4. For this reason, unit D was identified as a separate subwatershed for analysis purposes due to the significant change in land use.

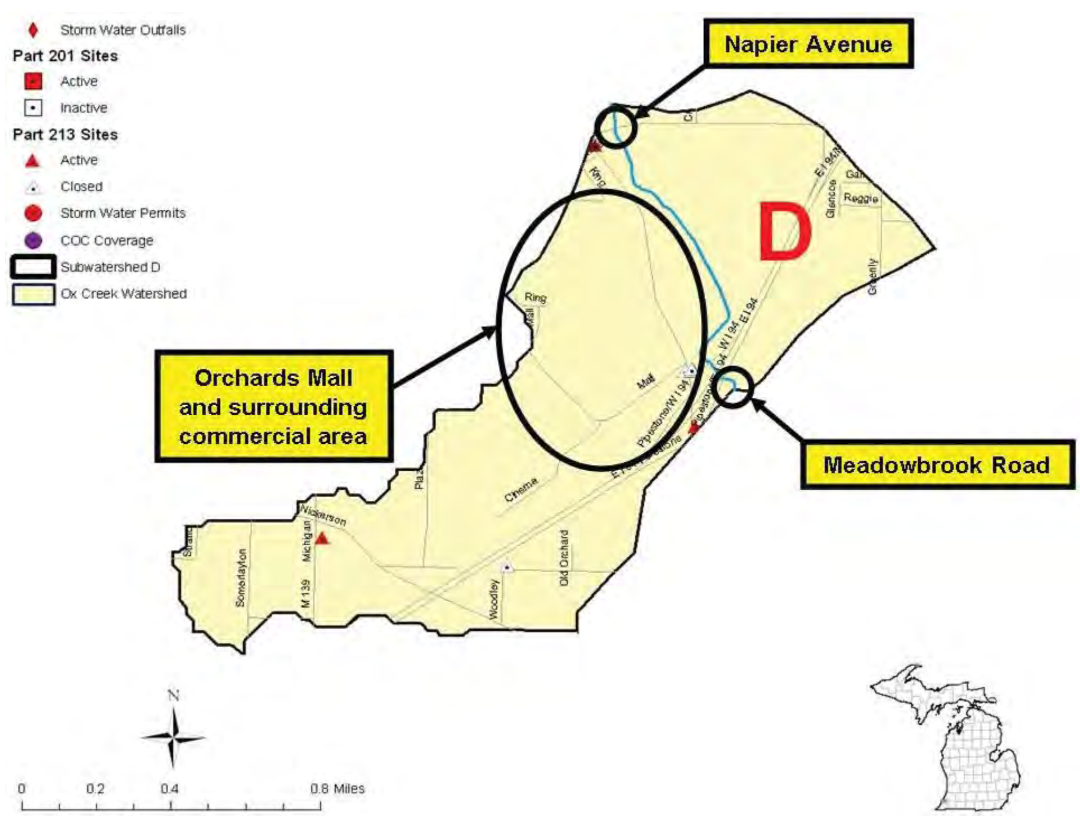


Figure 9-26. Unit D -- Lower Yore - Stouffer location.

Figure 9-27. Yore - Stouffer Drain above Ox Creek.

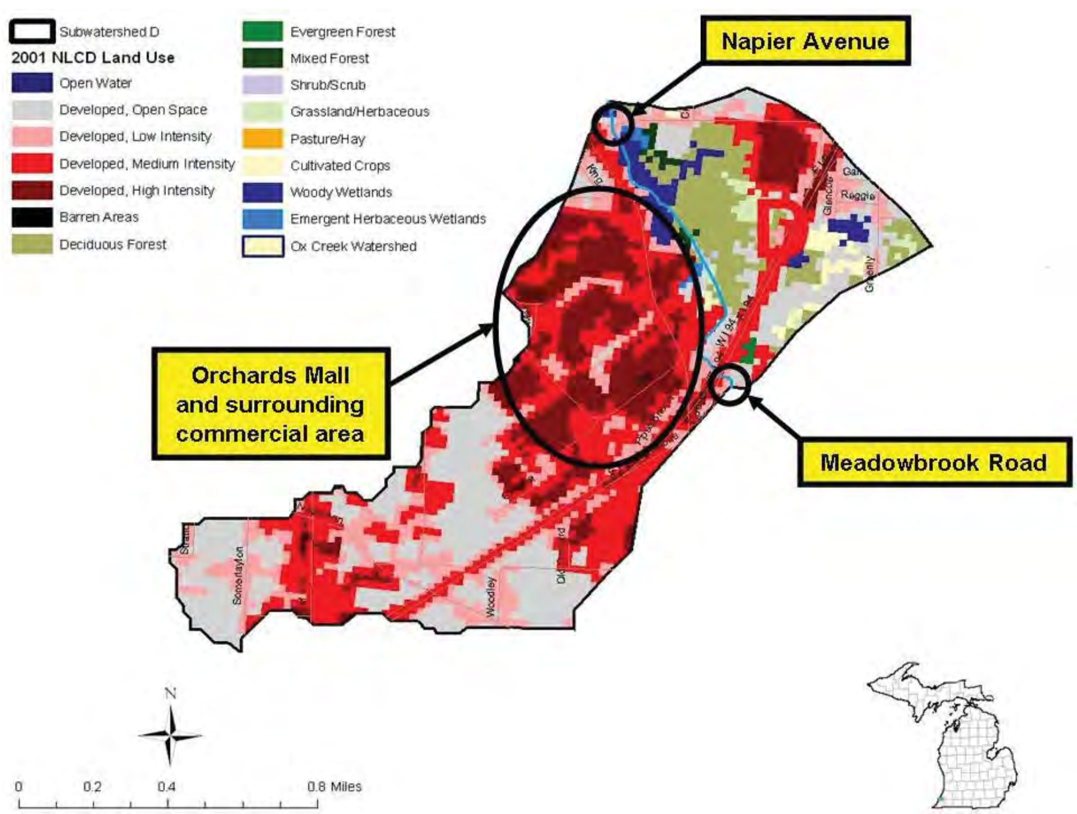


Figure 9-28. Unit D -- Lower Yore - Stouffer land use.

Table 9-7. Lower Yore - Stouffer land use summary.

Land Use / Land Cover	Size	
	(acres)	*(percentage)*
Open Water	0	--
Developed, Open	201	25%
Developed, Low-Intensity	137	17%
Developed, Medium-Intensity	217	28%
Developed, High Intensity	137	17%
Barren Land	0	--
Deciduous Forest	61	8%
Evergreen Forest	1	0%
Mixed forest	4	0%
Shrub/Scrub	1	0%
Grassland/Herbaceous	10	1%
Pasture/Hay	0	--
Cultivated Crops	12	1%
Woody Wetlands	21	3%
Emergent Herbaceous Wetlands	3	0%
TOTAL	805	100%

Note: "--" means that land use not present in the subwatershed unit

"0%" means land use present in subwatershed unit, but in amount less than 0.5%

9.5 Unit E -- Ox Headwaters

The Ox Headwaters unit consists of the land area draining to Ox Creek from its source to its confluence with the Yore – Stouffer Drain just below Crystal Avenue *(Figure 9-29)*. Figure 9-30 shows a ground view of the unit E outlet taken at the Crystal Avenue monitoring site. There is one facility located in unit E that is covered under a COC for the discharge of non-contact cooling water and one facility covered under an industrial storm water permit, while three MS4 jurisdictions include lands in this unit. No active Part 201 sites are located in unit E. Two active Part 213 facilities and two closed sites lie within unit E. Land uses in this unit, shown in Figure 9-31, include a mix of cultivated crops (32%) and pasture / hay (11%), as well as low, medium, and high intensity development (16%). Additionally, I-94 runs through the unit. Table 9-8 presents a summary of land uses in unit E.

Subwatershed unit E is a transition area in terms of sources and land use. Water quality data collected above the outlet of unit E (Crystal Avenue) consisted of water column TSS and toxics sampling, as well as bottom sediment analyses. Sample results for TSS did show elevated levels during storm events indicating the potential for sediment and siltation to influence biological communities at this site. Although no heavy metals or toxics were detected in the water column at this location, bottom sediment samples indicate that the occurrence of heavy metals and PAHs.

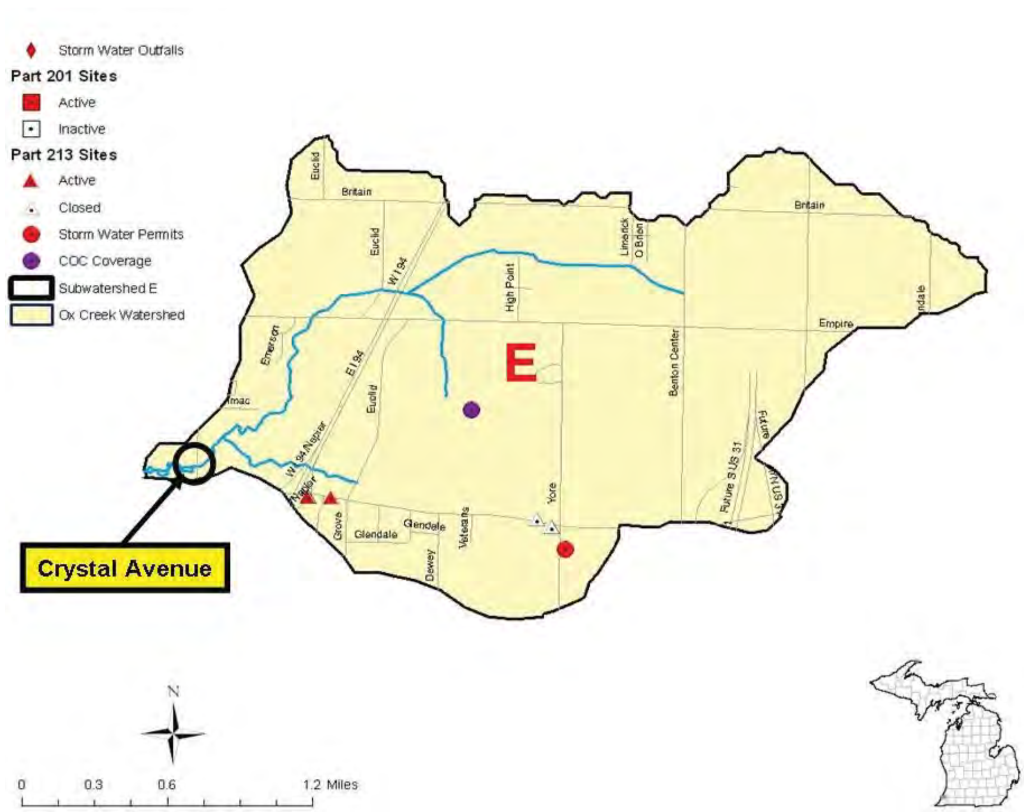


Figure 9-29. Unit E -- Ox Headwaters location.

Figure 9-30. Ox Creek at Crystal Avenue.

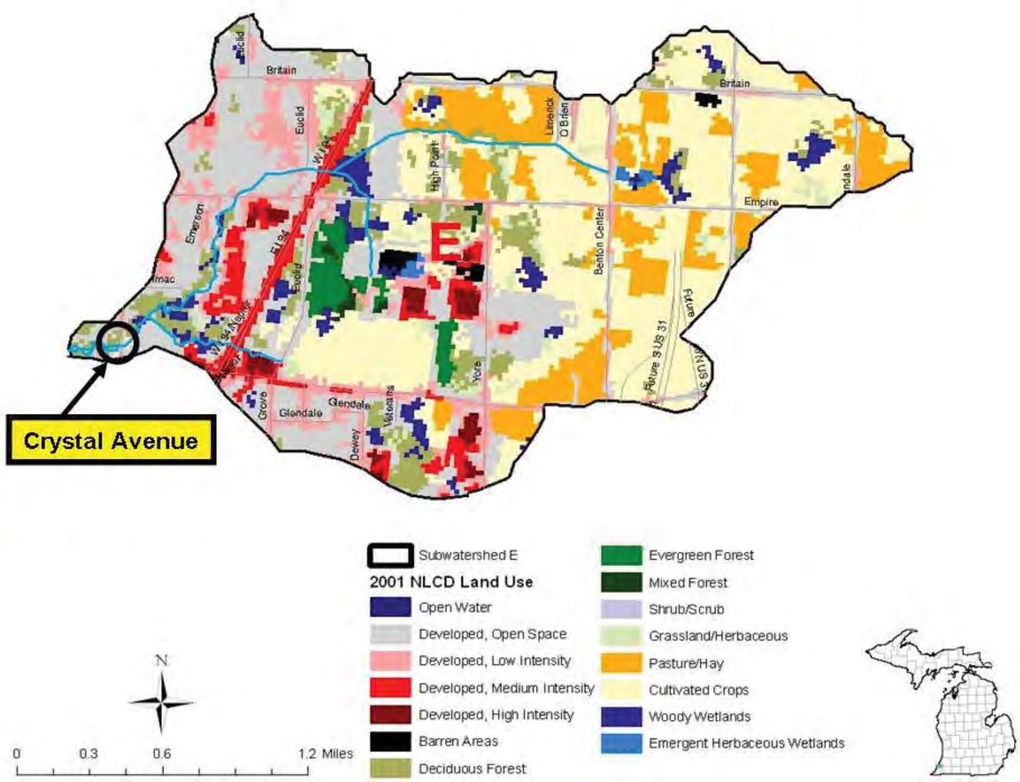


Figure 9-31. Unit E -- Ox Headwaters land use.

Table 9-8. Ox Headwaters land use summary.

Land Use / Land Cover	Size (acres)	Size (percentage)
Open Water	1	0%
Developed, Open	628	24%
Developed, Low-Intensity	256	10%
Developed, Medium-Intensity	114	4%
Developed, High Intensity	40	2%
Barren Land	15	1%
Deciduous Forest	200	8%
Evergreen Forest	48	2%
Mixed forest	10	0%
Grassland/Herbaceous	45	2%
Pasture/Hay	292	11%
Cultivated Crops	847	32%
Woody Wetlands	95	4%
Emergent Herbaceous Wetlands	9	0%
TOTAL	2,600	100%

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

Biological and habitat assessments have been conducted at Crystal Avenue *(Table 3-2 and Table 4-2)*. The most recent biological evaluation conducted at this location was completed in 2006. Table 9-9 summarizes the dominant taxa that were present in both this and the 2001 surveys. Because healthy streams typically support macroinvertebrate populations from the EPT orders, if present, these taxa are also included in Table 9-9.

Table 9-9. Key taxa at Ox Headwaters macroinvertebrate site.

Ox Creek at Crystal Avenue		Taxa	Percentage
Dominant Taxa	2006	Amphipoda *(scuds)*	44.5
		Oligochaeta	17.2
		Chironomidae	11.7
	2001	Chironomidae	35.0
		Decopoda *(crayfish)*	15.0
		Amphipoda *(scuds)*	10.0
		Aeshnidae *(dragonfly order)*	10.0
		Calopterygidae *(damselfly order)*	10.0
EPT Taxa	2006	Baetidae *(mayfly order)*	0.4
		Heptageniidae *(mayfly order)*	0.4

A summary of key findings from the 2006 assessment is shown in Table 9-10. Overall, the habitat score at this location was marginal in 2006. The evaluation identified channel morphology and specifically, sediment deposition as likely disturbances. Correspondingly, the macroinvertebrate score ranged from poor (-5) to acceptable (-3) in 2001 and 2006, respectively. The acceptable rating was associated with a higher number of taxa (18) than that observed in 2001 (16). However, intolerant EPT species were still nearly absent with less than one percent of individuals collected in 2006 belonging to those taxa. Interestingly, between 2001 and 2006, the predator group declined from 33% to 4% of all individuals collected. A high number of tolerant taxa were identified in both years including oligochaeta and chironomidae. These taxa are generally considered tolerant of a broad range of water quality and are frequently associated with sedimentation, as they are preferred burrowers.

Table 9-10. Ox Headwaters biological assessment notes *(Lipsey, 2007)*.

Location	Notes
Crystal Avenue	• Glide / pool habitat rated as good. • Station located upstream of old check dam remnants that historically formed a small pond in the cemetery. • Only epifaunal substrate available was aquatic vegetation. • Large amount of sediment deposited in pools and aquatic vegetation. This sediment may be remnants of sediment collected in the pond. The stream water levels rose two feet after a 1.25 inch precipitation event. • Riparian zone has been altered as it is located in a cemetery; however, wetland vegetation was abundant in immediate riparian area. • Macroinvertebrate community scored acceptable (in 2006) [and poor (in 2001)].

Examining TSS data and its relationship to flow can be extremely useful, for example, Figure 9-32 uses the survey information to depict TSS data for the Crystal Avenue site as a function of water level. A strong pattern indicates that TSS concentrations increase with rising water level (and flow). As similar to other units, one area of interest is highlighted where an exception to the general pattern occurs. In particular, the two largest TSS values (noted by the upper circle) did not correspond to the highest water levels. These anomalies may be related to several factors such as the intensity of the precipitation event, the season of occurrence, and the timing of the individual TSS sample relative to the onset of the storm.

Figure 9-33 through Figure 9-35 present time series displays of the data for the wet-weather events: the August 18-19, 2007 storm (2.52 inches); the April 8-9, 2008 storm (0.69 inches), and the August 4-5, 2008 storm (0.74 inches). The highest TSS levels appear to be associated with the onset of intense precipitation. Interestingly, both the water column response and hydrographs from the first two wet-weather events closely reflect precipitation inputs, where precipitation and increasing flows resulted in increased TSS concentrations. Water column response to precipitation may reflect seasonal factors as the second storm occurred in April, prior to the emergence of vegetation on agricultural lands resulted in higher TSS loading.

Figure 9-34 and Figure 9-35 also point to another noteworthy observation. Both storms resulted in relatively minor changes in stream flow (both storms were also less than 1 inch precipitation). The elevated TSS levels in the second storm supports *“first flush”* generated sediment associated with surface and gully erosion. This was not observed in the third storm (likely because monitoring was not initiated until 12 hours after the intense precipitation).

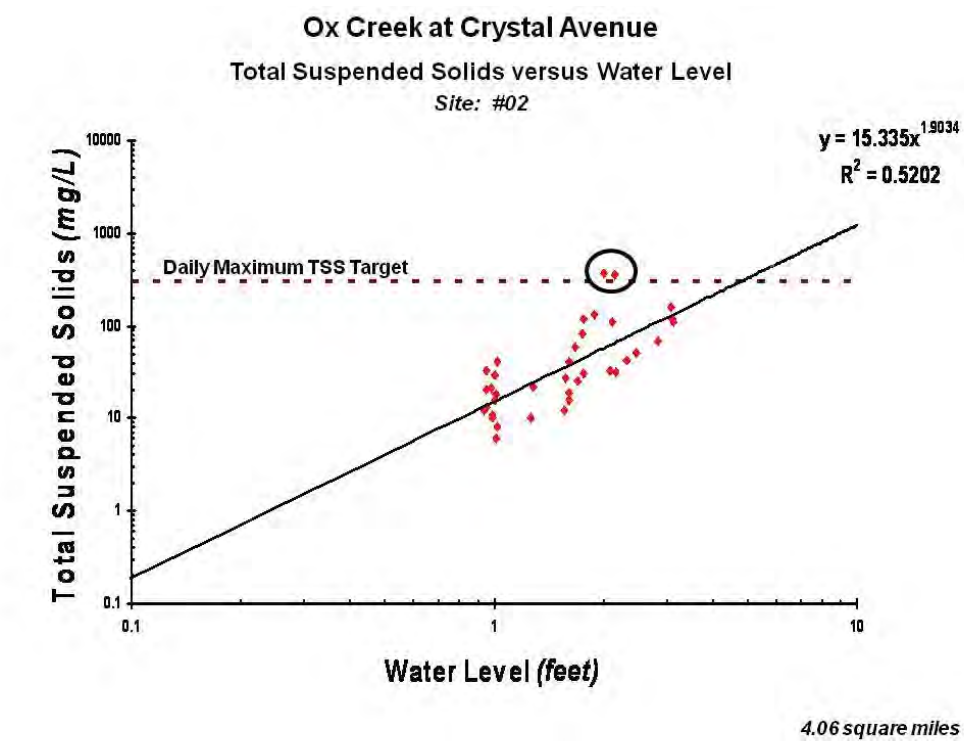


Figure 9-32. TSS as a function of water level -- Crystal Avenue site.

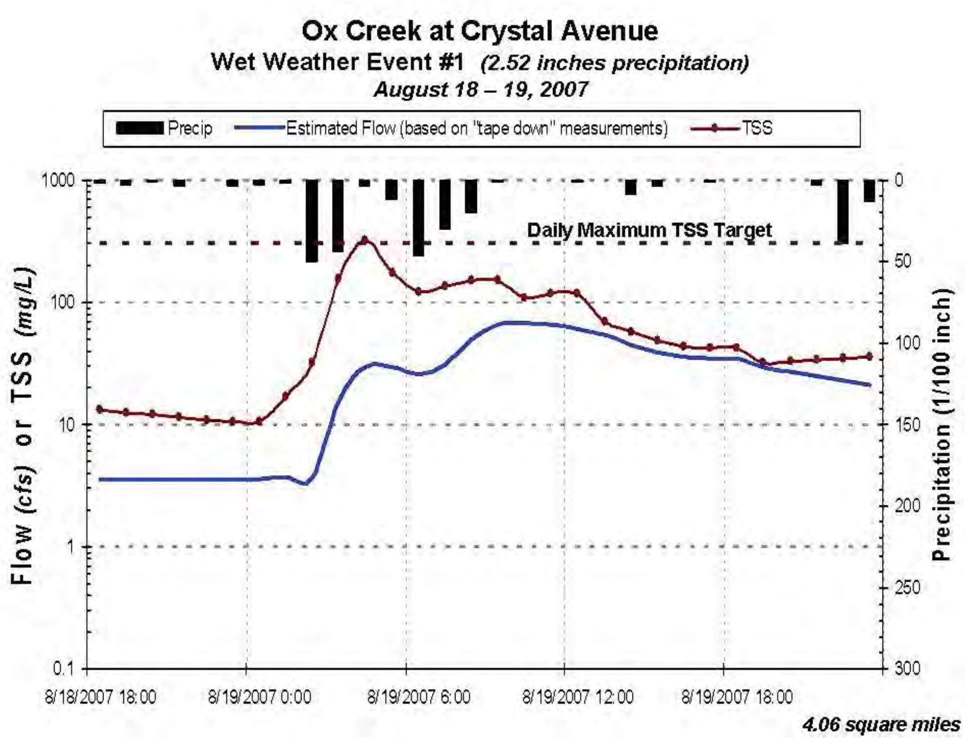


Figure 9-33. TSS, flow, and precipitation for wet weather event #1 -- Crystal Avenue.

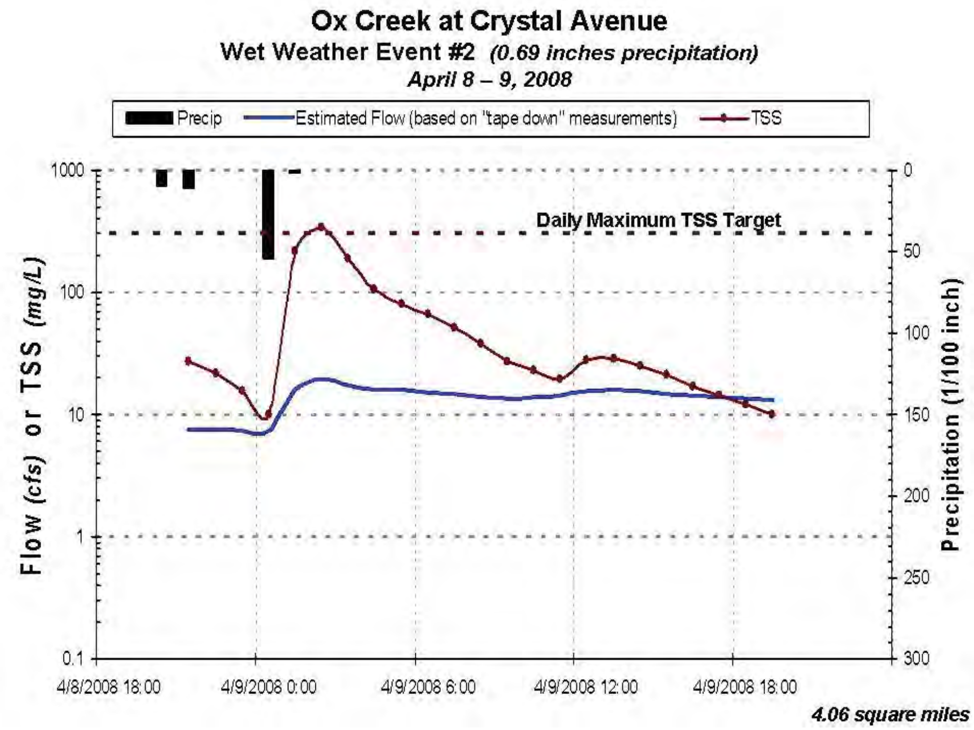


Figure 9-34. TSS, flow, and precipitation for wet weather event #2 -- Crystal Avenue.

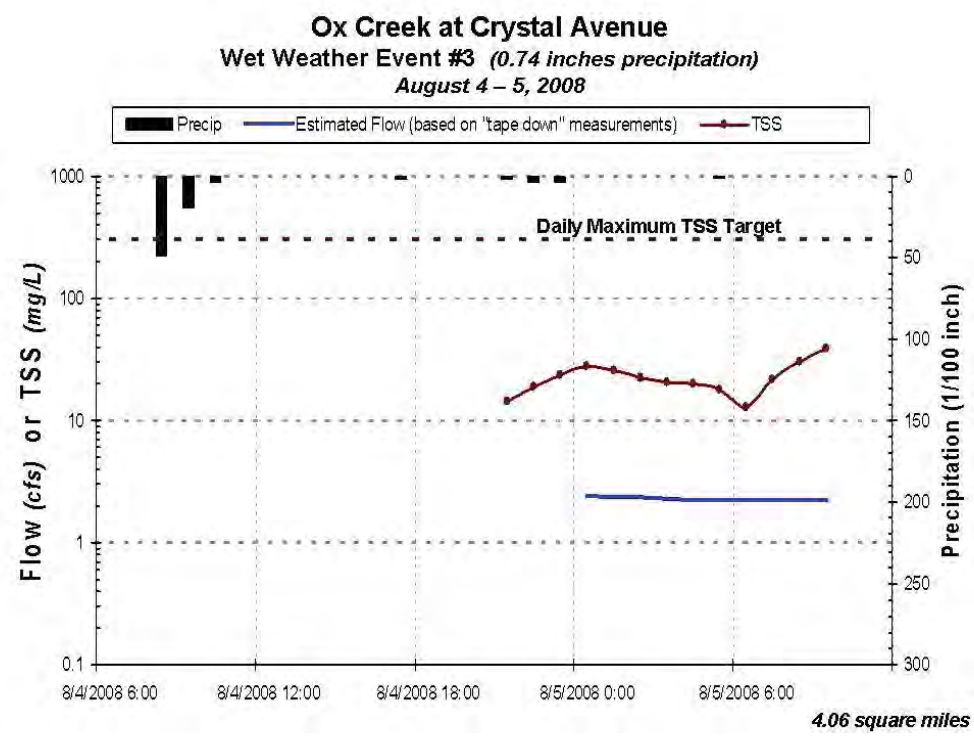


Figure 9-35. TSS, flow, and precipitation for wet weather event #3 -- Crystal Avenue.

Another way to view this information is through the use of a duration curve framework *(Figure 9-36)*. Data is also separated by each sample event. The first wet weather event occurred in August (summer) as the result of a 2.52 inch storm (noted as Sum-2.52" in Figure 9-36). A significant number of these samples were collected under high flow conditions and included the largest TSS loads. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation (noted as Spr-0.69" in Figure 9-36). However, it did result in greater loads than the third event that occurred in the summer as the result of a 0.74 inch storm (noted as Sum-0.74" in Figure 9-36). This may reflect seasonal factors as the second storm occurred in April, prior to the emergence of vegetation on agricultural lands.

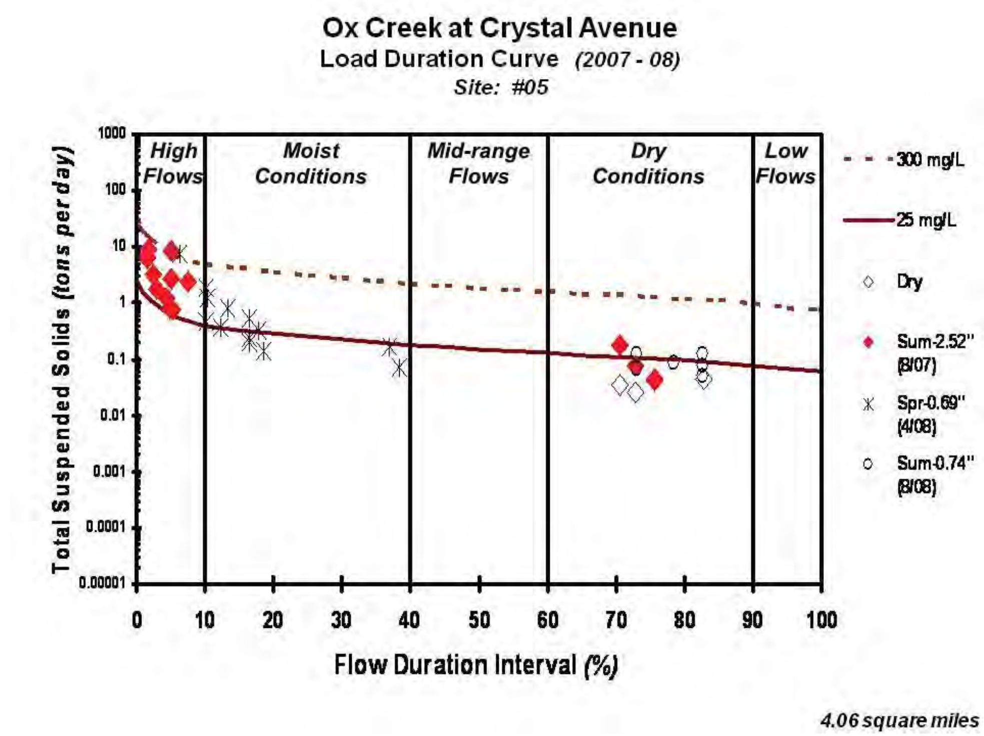


Figure 9-36. Load duration curve for TSS at Crystal Avenue.

9.6 Unit F -- Upper Ox

The Upper Ox unit consists of the land area draining to Ox Creek from its confluence with the Yore – Stouffer Drain just below Crystal Avenue to Empire Avenue *(Figure 9-37)*. Figure 9-38 shows a ground view of the unit F outlet taken at the Empire Avenue monitoring site. There is one facility located in unit F that is covered under a COC for the discharge of non-contact cooling water and four facilities covered under an industrial storm water permit, while one MS4 jurisdiction (Benton Harbor) includes lands in this unit. No active Part 201 sites are located in unit F. Four active Part 213 facilities and three closed sites lie within unit F. Land use in this unit, shown in Figure 9-39, is dominated by low, medium, and high intensity development (55%) followed by developed open land (34%). The riparian area along this reach of Ox Creek is largely woody wetlands (5% of the entire subwatershed unit). Table 9-11 presents a summary of land uses in unit F.

Subwatershed unit F contains a relatively large amount of impervious surface, which likely affects the hydrology of Ox Creek. Sample results for TSS did show elevated levels during storm events indicating the potential for sediment and siltation to influence biological communities at this site.

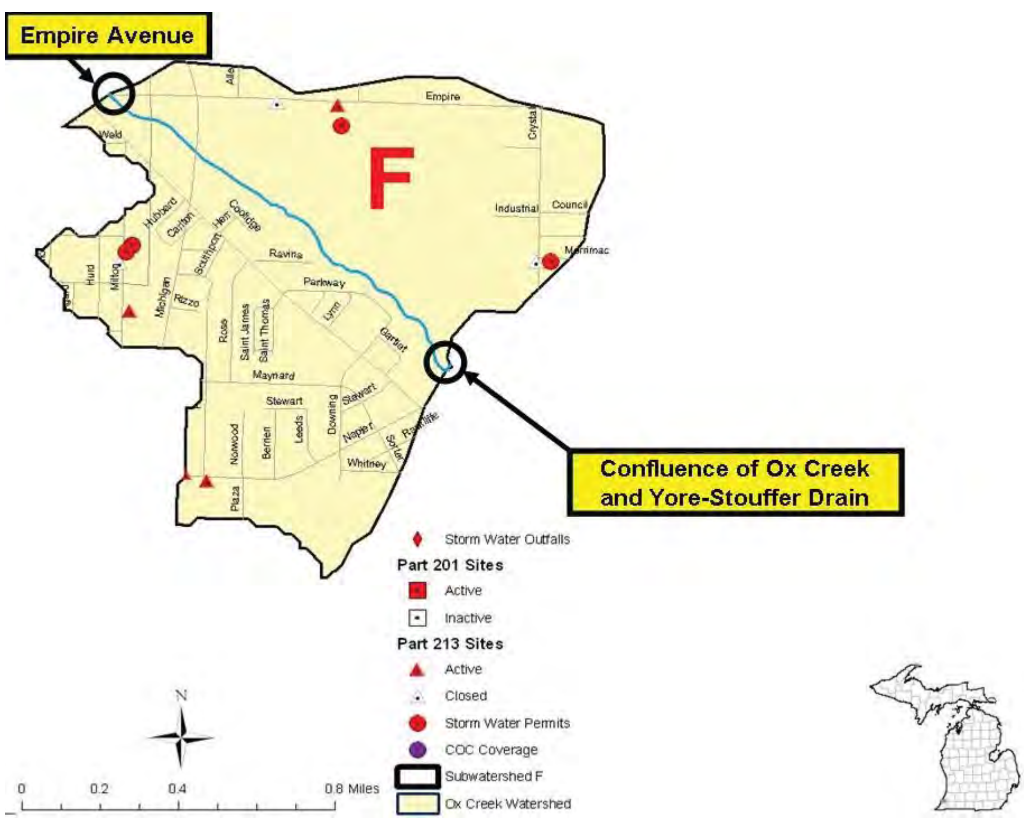


Figure 9-37. Unit F -- Upper Ox location.

Figure 9-38. Ox Creek at Empire Avenue.

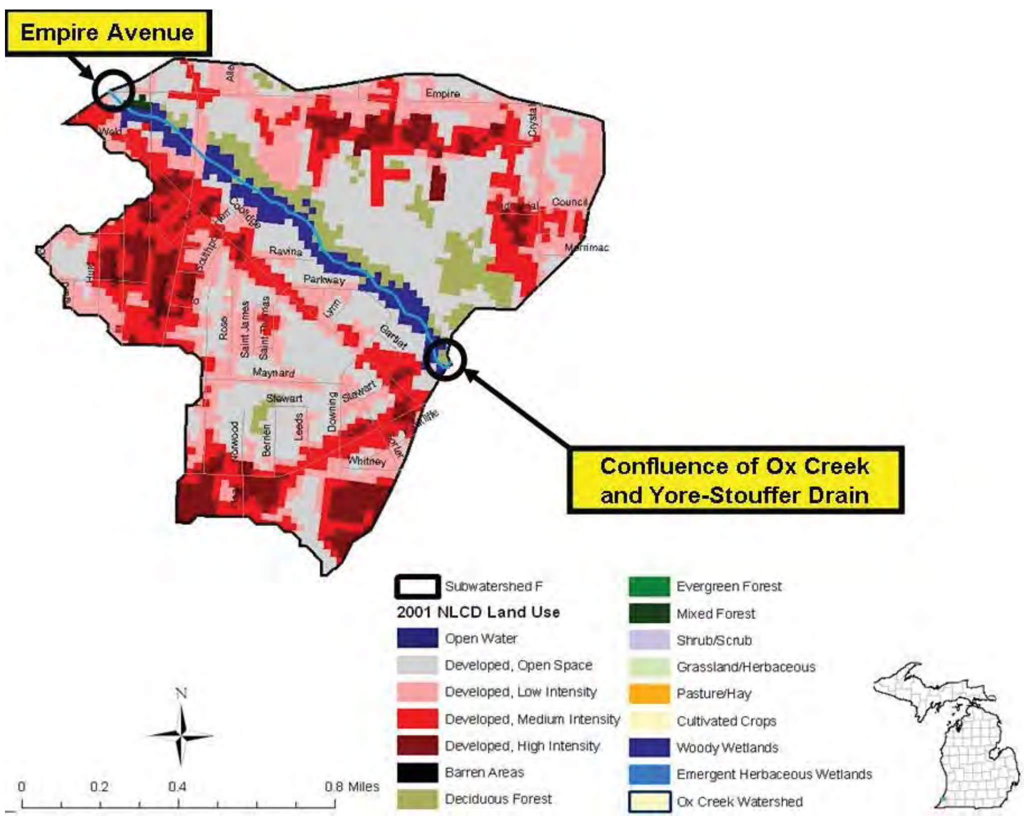


Figure 9-39. Unit F -- Upper Ox land use.

Table 9-11. Upper Ox land use summary.

Land Use / Land Cover	Size	
	(acres)	*(percentage)*
Open Water	0	--
Developed, Open	240	34%
Developed, Low-Intensity	183	25%
Developed, Medium-Intensity	145	20%
Developed, High Intensity	75	10%
Barren Land	0	--
Deciduous Forest	46	6%
Evergreen Forest	0	--
Mixed forest	1	0%
Shrub/Scrub	0	--
Grassland/Herbaceous	0	--
Pasture/Hay	0	--
Cultivated Crops	0	--
Woody Wetlands	35	5%
Emergent Herbaceous Wetlands	0	--
TOTAL	725	100%

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

A useful way to examine the TSS data is through an analysis of its relationship to flow. Figure 9-40 uses the survey information to depict TSS data for the Empire Avenue site as a function of water level. The general pattern indicates that TSS concentrations increase with rising water level (and flow). Figure 9-41 and Figure 9-42 present time series displays of the data for two wet-weather events: the August 18-19, 2007 storm (2.52 inches) and the April 8-9, 2008 storm (0.69 inches). In both cases, the highest TSS levels for those events were associated with the onset of intense precipitation.

Another way to view this information is through the use of a duration curve framework (Figure 9-43). Data is also separated by each sample event. The first wet weather event occurred in August (summer) as the result of a 2.52 inch storm (noted as Sum-2.52" in Figure 9-43). A significant number of these samples were collected under high flow conditions and included the largest TSS loads. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation (noted as Spr-0.69" in Figure 9-43). However, it did result in greater loads than the third event that occurred in the summer as the result of a 0.74 inch storm (noted as Sum-0.74" in Figure 9-43).

Water column concentrations for select toxicants were measured at the Empire Avenue location. Fluoranthene, a PAH, was found to exceed the chronic water quality standard. This location is downstream from the Meadowbrook Road site, where water column concentrations were greater than those measured at Empire Avenue.

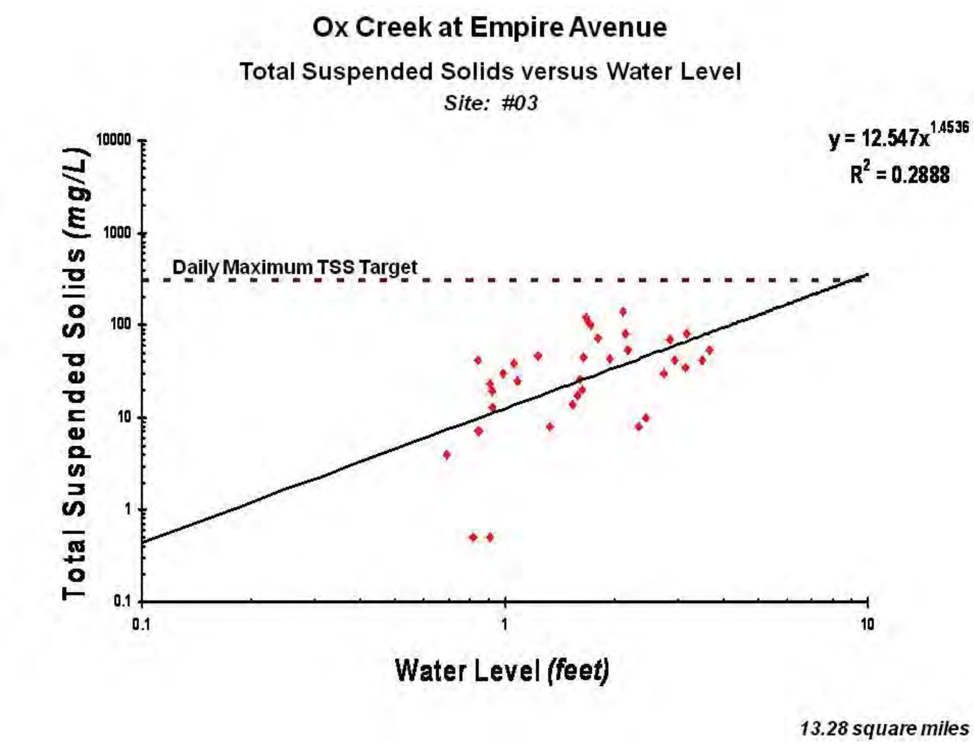


Figure 9-40. TSS as a function of water level -- Empire Avenue site.

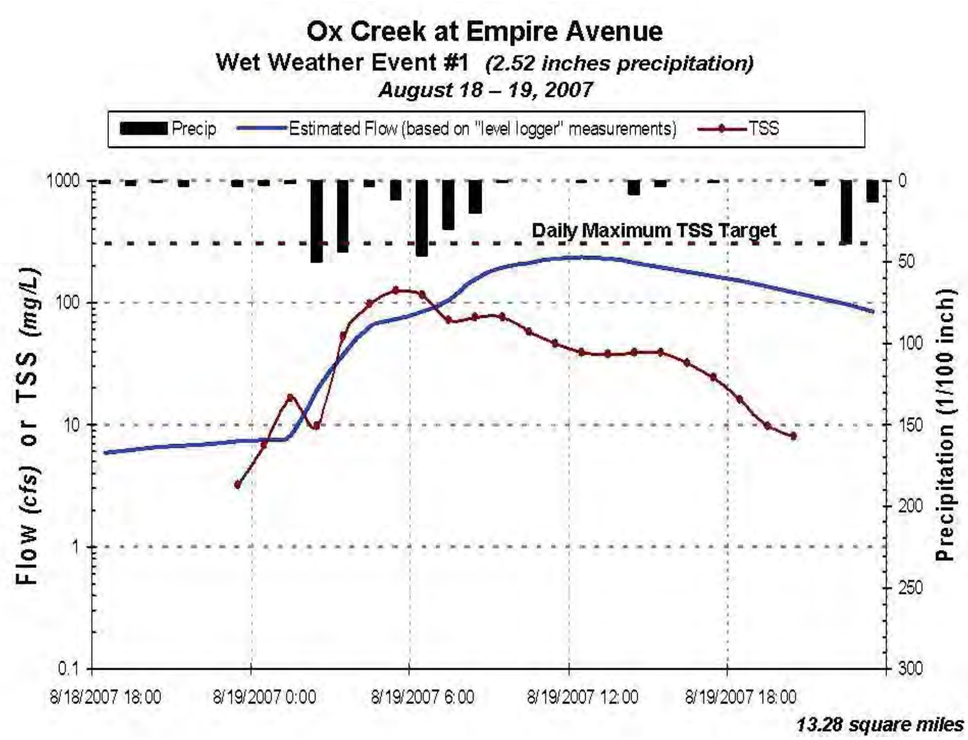


Figure 9-41. TSS, flow, and precipitation for wet weather event #1 -- Empire Avenue.

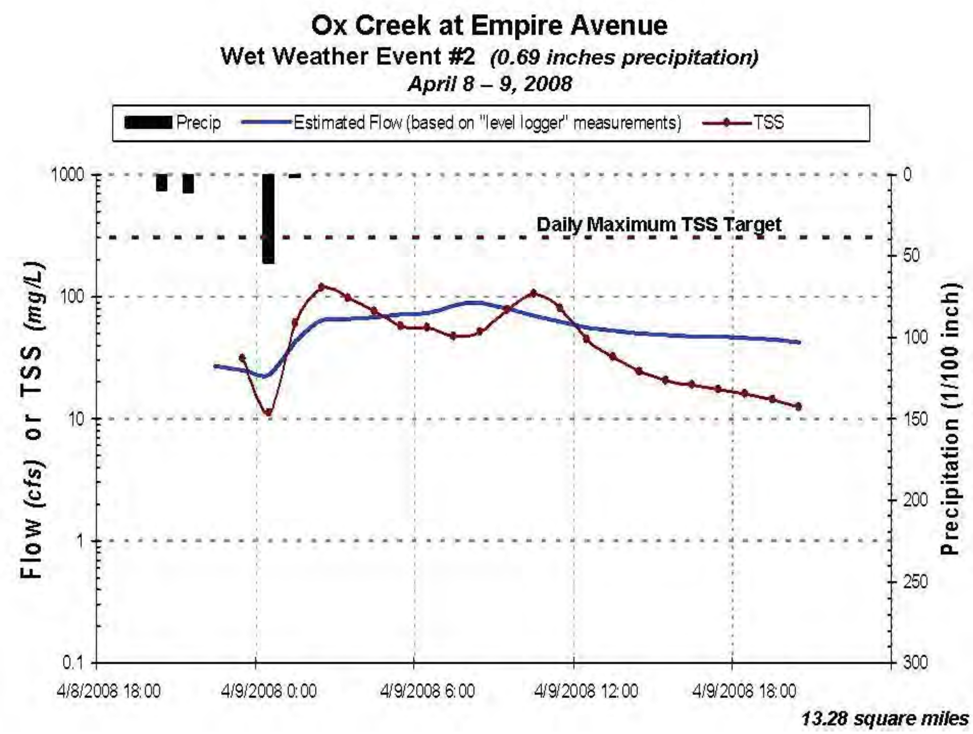


Figure 9-42. TSS, flow, and precipitation for wet weather event #2 -- Empire Avenue.

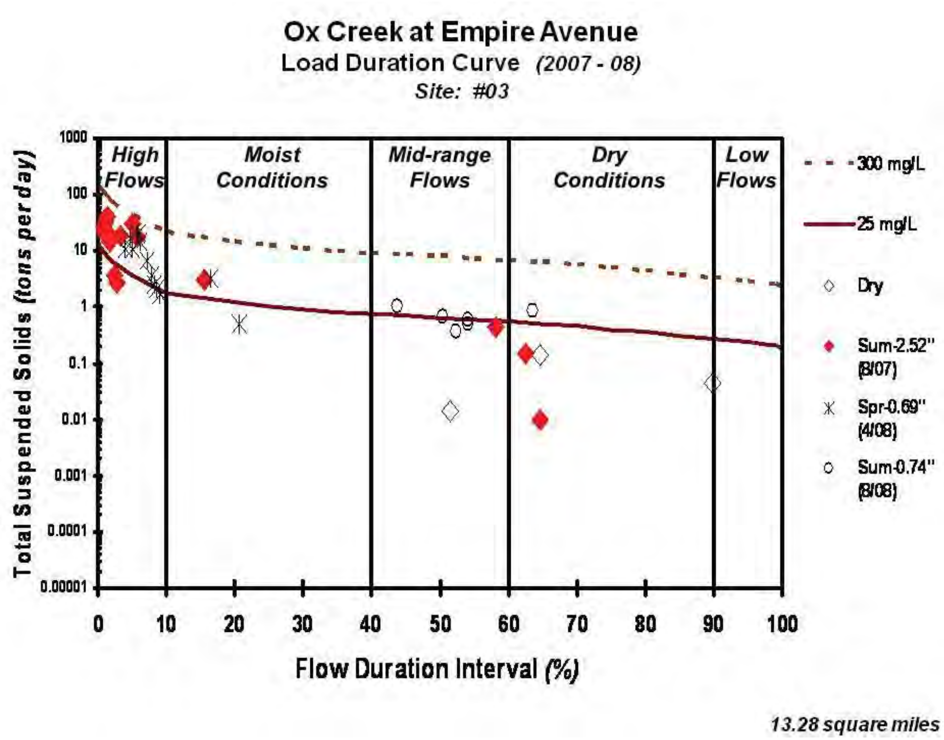


Figure 9-43. Load duration curve for TSS at Empire Avenue.

9.7 Unit G -- Middle Ox

The Middle Ox unit consists of the land area draining to Ox Creek from Empire Avenue to Britain Avenue *(Figure 9-44)*. Figure 9-45 shows a ground view of the unit G outlet taken at the Britain Avenue monitoring site. There are no point sources located in unit G, although one MS4 jurisdiction (Benton Harbor) includes lands in this unit. One active Part 201 sites is located in unit G. Four active Part 213 facilities and one closed site lie within unit G. Land use in this unit, shown in Figure 9-46, is dominated by low, medium, and high intensity development (37%) and by developed open land (54%). Similar to unit F, the riparian area along this reach of Ox Creek is largely woody wetlands (4% of the entire subwatershed unit). Table 9-12 presents a summary of land uses in unit G.

Subwatershed unit G contains a relatively large amount of impervious surface, which likely affects the hydrology of Ox Creek. Sample results for TSS did show elevated levels during storm events indicating the potential for sediment and siltation to influence biological communities at this site.

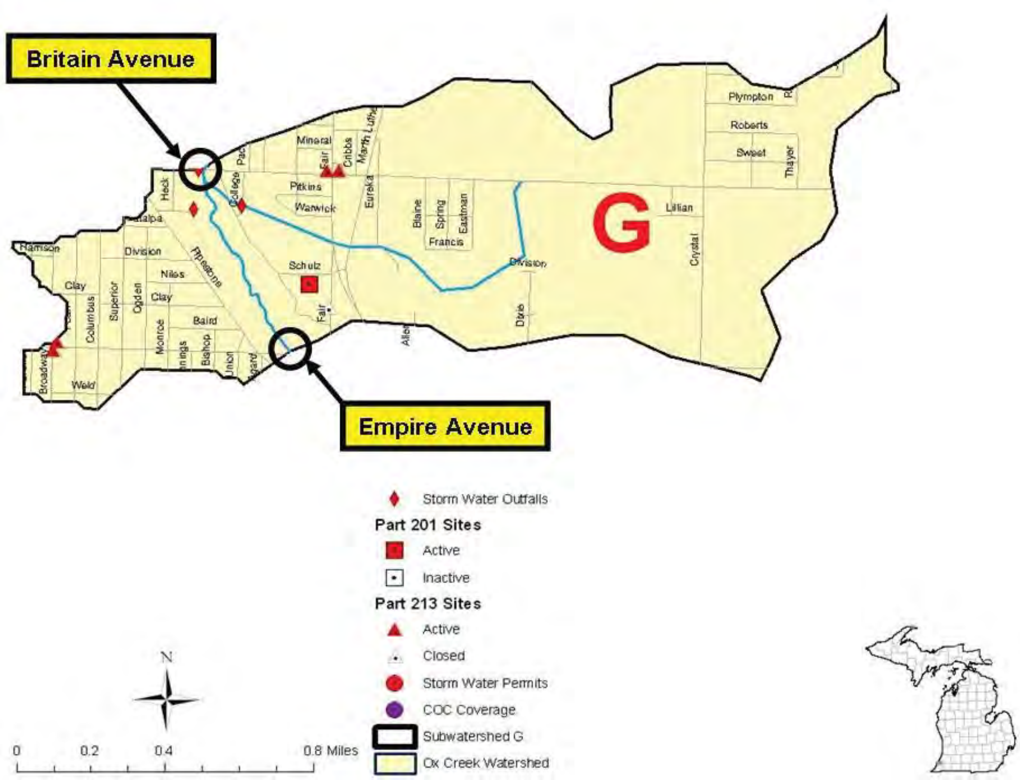


Figure 9-44. Unit G -- Middle Ox location.

Figure 9-45. Ox Creek at Britain Avenue.

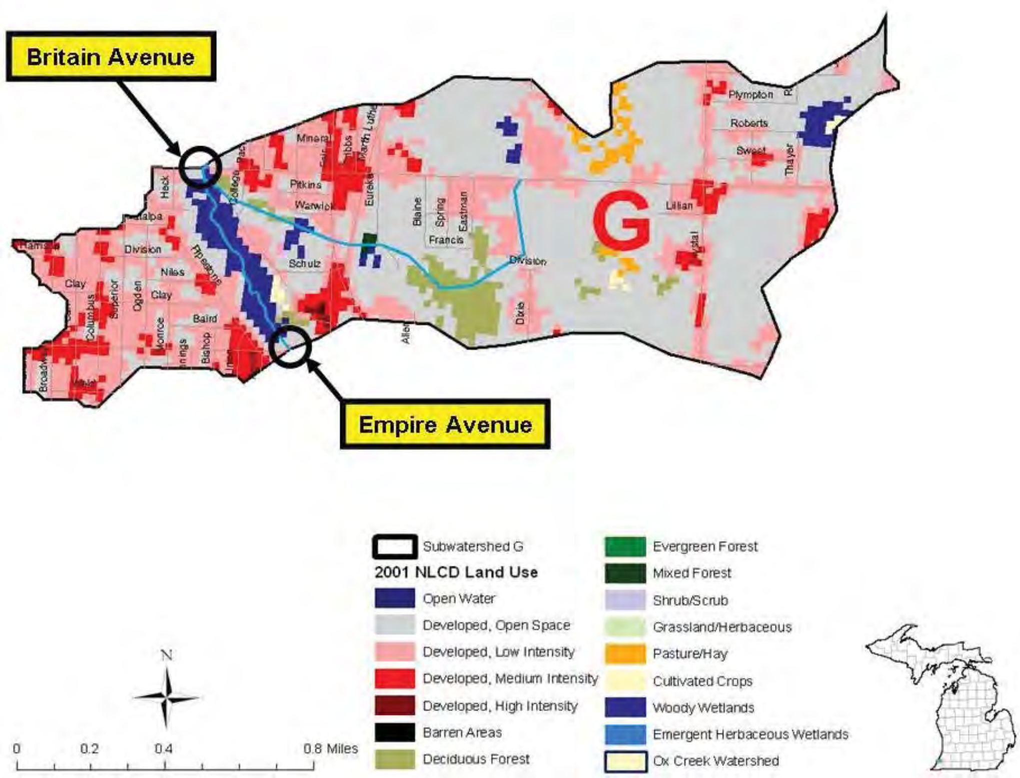


Figure 9-46. Unit G -- Middle Ox land use.

Table 9-12. Middle Ox land use summary.

Land Use / Land Cover	Size (acres)	Size (percentage)
Open Water	0	--
Developed, Open	475	54%
Developed, Low-Intensity	260	29%
Developed, Medium-Intensity	72	8%
Developed, High Intensity	1	0%
Barren Land	0	--
Deciduous Forest	32	4%
Evergreen Forest	0	--
Mixed forest	1	0%
Shrub/Scrub	0	--
Grassland/Herbaceous	0	--
Pasture/Hay	11	1%
Cultivated Crops	4	0%
Woody Wetlands	39	4%
Emergent Herbaceous Wetlands	0	--
TOTAL	895	100%

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

Biological and habitat assessments have been conducted at Britain Avenue *(Table 3-2 and Table 4-2)*. The most recent biological evaluation conducted at this location was completed in 2006. Table 9-13 summarizes the dominant taxa that were present in this 2001 survey. Because healthy streams typically support macroinvertebrate populations from the EPT orders, if present, these taxa are also included in Table 9-13.

Table 9-13. Key taxa at Middle Ox macroinvertebrate site.

Ox Creek at Britain Road		Taxa	Percentage
Dominant Taxa	2006	Oligochaeta (worms)	42.8
		Amphipoda (scuds)	19.8
		Isopoda (sowbugs)	9.2
EPT Taxa	2006	*None Present*	

A summary of key findings from the 2006 assessment is shown in Table 9-14. Overall, the habitat score at this location was marginal. When compared to average sites in this ecoregion, identified disturbances at this location included degraded epifaunal substrate; degraded velocity / depth regime and pool variability; and increased sediment deposition. Interestingly, the pool habitat was absent due to sedimentation.

Table 9-14. Middle Ox biological assessment notes *(Lipsey, 2007)*.

Location	Notes
Britain Avenue	• Glide / pool habitat rated as good. • Station had a large amount of woody debris, but it was unavailable as epifaunal substrate due to large amount of siltation and sediment deposition covering the debris. • Pools also absent due to the sediment deposition. • Bank scour was evident, but the banks were fairly stable. • Only 13 taxa were found and none were taxa that are sensitive to environmental perturbations (i.e., mayflies, stoneflies, or caddisflies). • Poor macroinvertebrate community can most likely be attributed to lack of suitable habitat for colonization and high storm water flows that bring additional silt and sediment load to further degrade the habitat.

The macroinvertebrate community was rated as poor (-6), associated with a decreased number of taxa (13 in total) and dominance of tolerant species such as oligochaeta (over 42 percent of total identified individuals). Burrowers, such as the oligochaeta taxa, accounted for 49 percent of all individuals identified at this location. Less tolerant EPT species were not found at this site. This shift from intolerant to tolerant species is indicative of a degraded habitat. Furthermore, the dominance of burrowers indicates degradation associated with sedimentation.

A useful way to examine the TSS data is through an analysis of its relationship to flow. Figure 9-47 uses the survey information to depict TSS data for the Britain Avenue site as a function of water level. The general pattern indicates that TSS concentrations increase with rising water level (and flow). One area of interest is highlighted where an exception to the general pattern occurs. In particular, the two largest TSS values (noted by the upper circle) did not correspond to the highest water levels. These anomalies may be related to several factors such as the intensity of the precipitation event, the season of occurrence, and the timing of the individual TSS sample relative to the onset of the storm.

Figure 9-48 through Figure 9-50 present time series displays of the data for the wet-weather events: the August 18-19, 2007 storm (2.52 inches); the April 8-9, 2008 storm (0.69 inches), and the August 4-5, 2008 storm (0.74 inches). Figure 9-49 and Figure 9-50 also point to another noteworthy observation. Both events resulted in higher stream flows. Both storms were also less than 1 inch precipitation, but did not produce significantly higher flow rates at upstream sites. The noticeable response at Britain Avenue reflects the increased impervious cover between this location and the upstream sites. The elevated TSS levels in the first and second wet-weather events appear to be in response to *"first flush"* generated sediment. This was not observed in the third storm (likely because monitoring was not initiated until 12 hours after the intense precipitation).

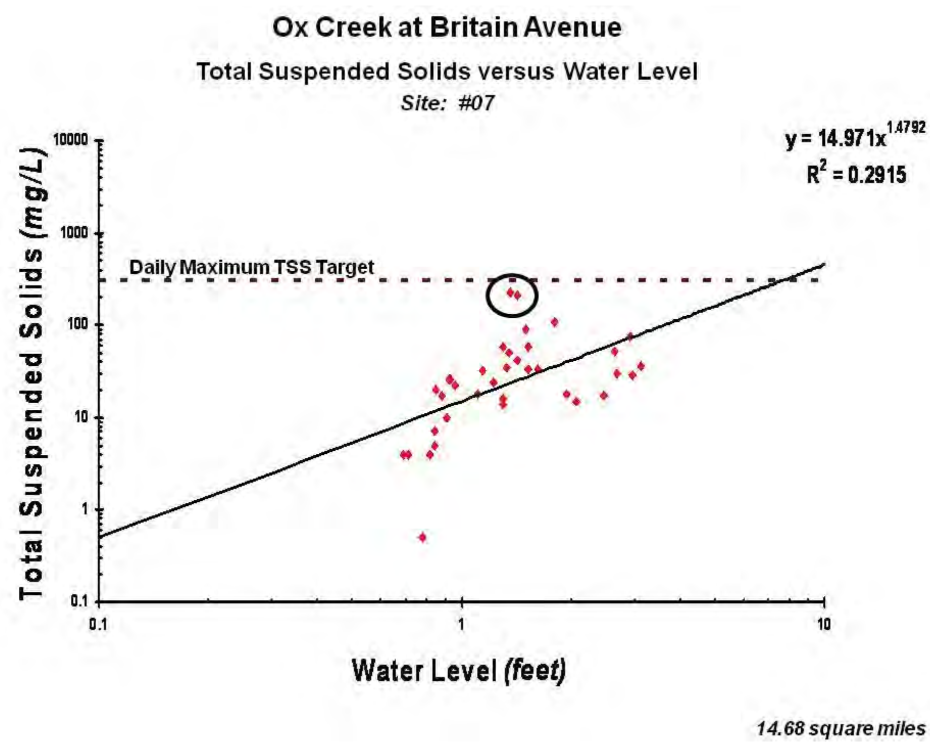


Figure 9-47. TSS as a function of water level -- Britain Avenue site.

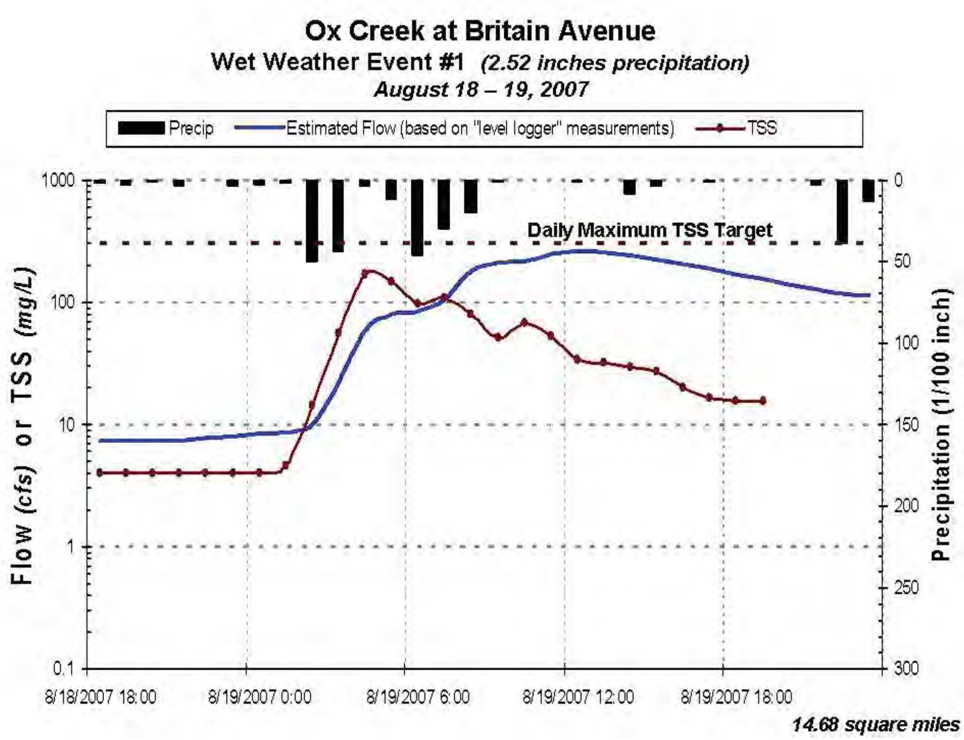


Figure 9-48. TSS, flow, and precipitation for wet weather event #1 -- Britain Avenue.

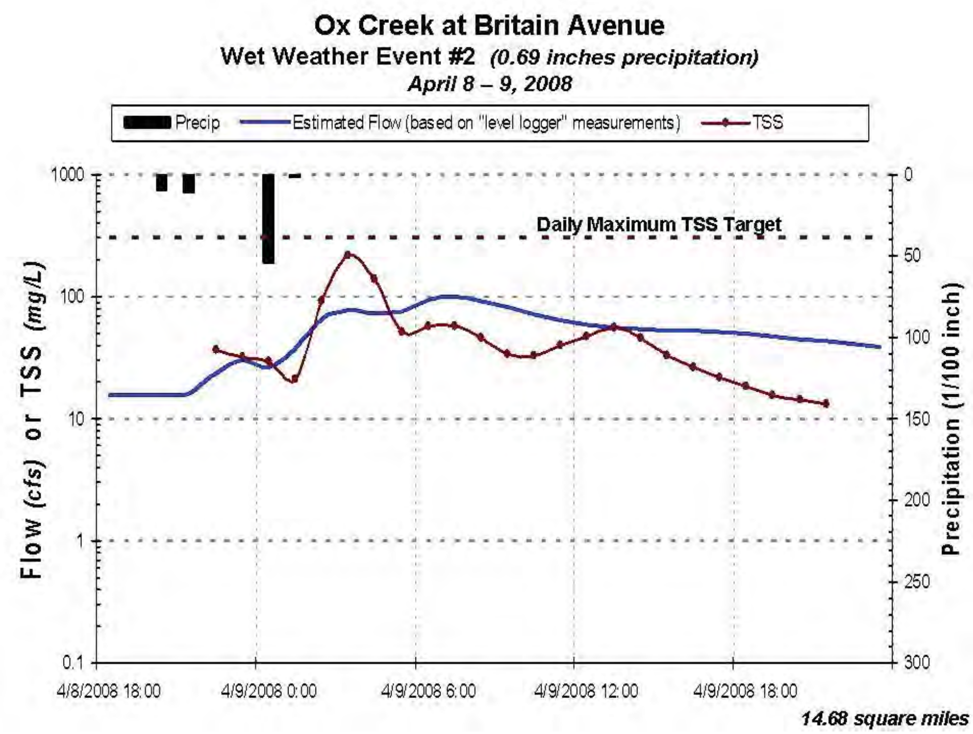


Figure 9-49. TSS, flow, and precipitation for wet weather event #2 -- Britain Avenue.

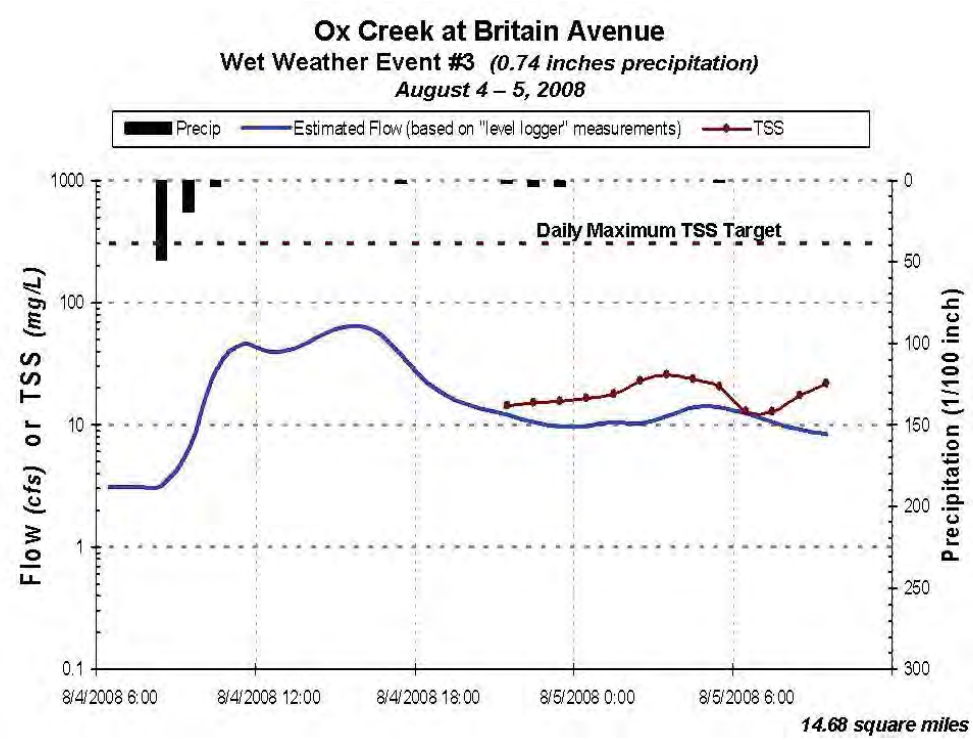


Figure 9-50. TSS, flow, and precipitation for wet weather event #3 -- Britain Avenue.

Another way to view this information is through the use of a duration curve framework (Figure 9-51). Data is also separated by each sample event. The first wet weather event occurred in August (summer) as the result of a 2.52 inch storm (noted as Sum-2.52” in Figure 9-51). A significant number of these samples were collected under high flow conditions and included the largest TSS loads. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation (noted as Spr-0.69” in Figure 9-51). However, it did result in greater loads than the third event that occurred in the summer as the result of a 0.74 inch storm (noted as Sum-0.74” in Figure 9-51).

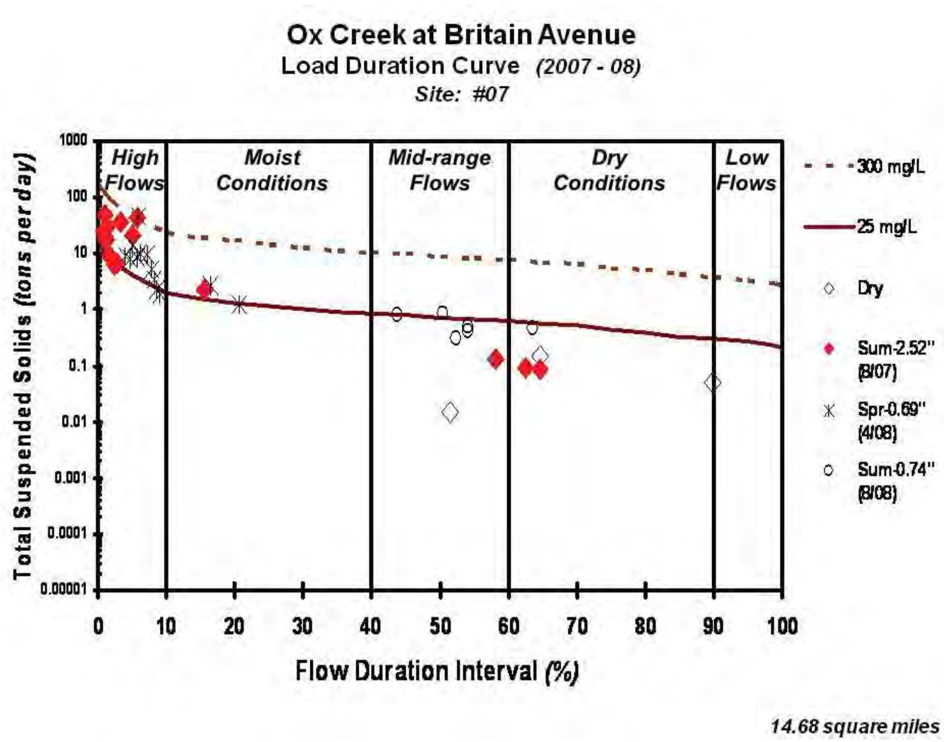


Figure 9-51. Load duration curve for TSS at Britain Avenue.

9.8 *Unit H -- Lower Ox*

The Lower Ox unit consists of the land area draining to Ox Creek from Britain Avenue to Water Street *(Figure 9-52)*. Figure 9-53 shows a ground view of the unit H outlet taken at the Water Street monitoring site. There is one facility located in unit H that is covered under a COC for the discharge of non-contact cooling water and two facilities covered under an industrial storm water permit, while one MS4 jurisdiction (Benton Harbor) includes lands in this unit. Five active Part 201 sites are located in unit H. Six active Part 213 facilities and eleven closed sites lie within unit H. Features of interest include the high intensity development in downtown Benton Harbor at the lower end of this subwatershed unit. Land use in this unit, shown in Figure 9-54, is dominated by low, medium, and high intensity development (57%) and by developed open land (39%). Table 9-15 presents a summary of land uses in unit H.

Subwatershed unit H contains a relatively large amount of impervious surface, which likely affects the hydrology of Ox Creek. Sample results for TSS did show elevated levels during storm events indicating the potential for sediment and siltation to influence biological communities at this site.

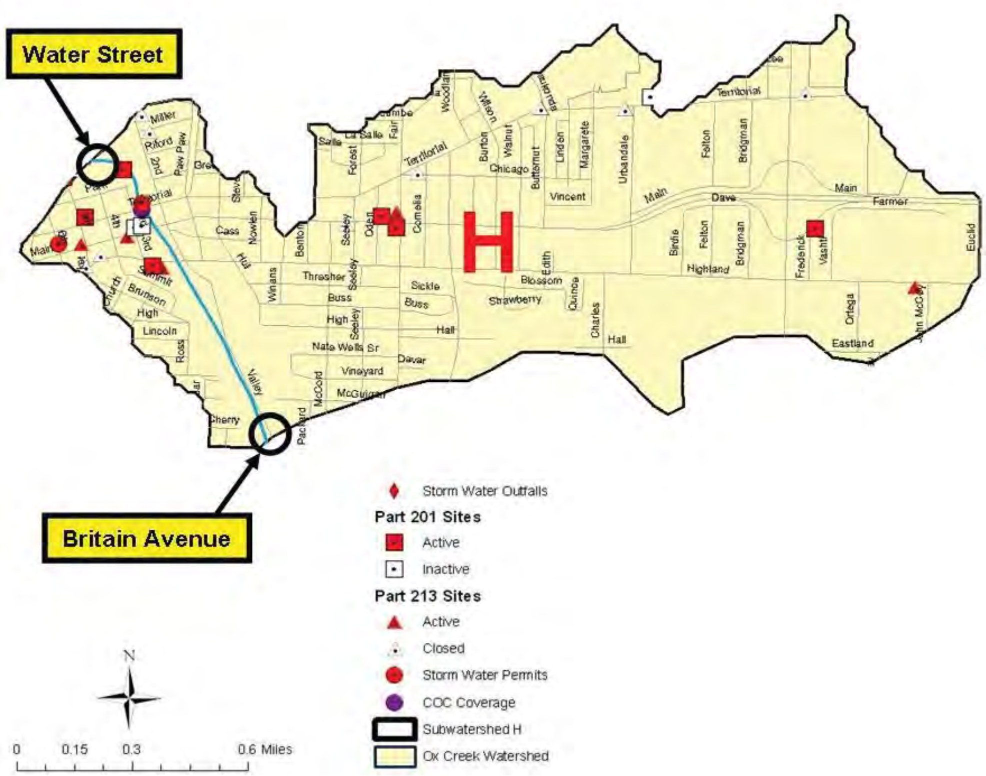


Figure 9-52. Unit H -- Lower Ox location.

Figure 9-53. Ox Creek at Water Street.

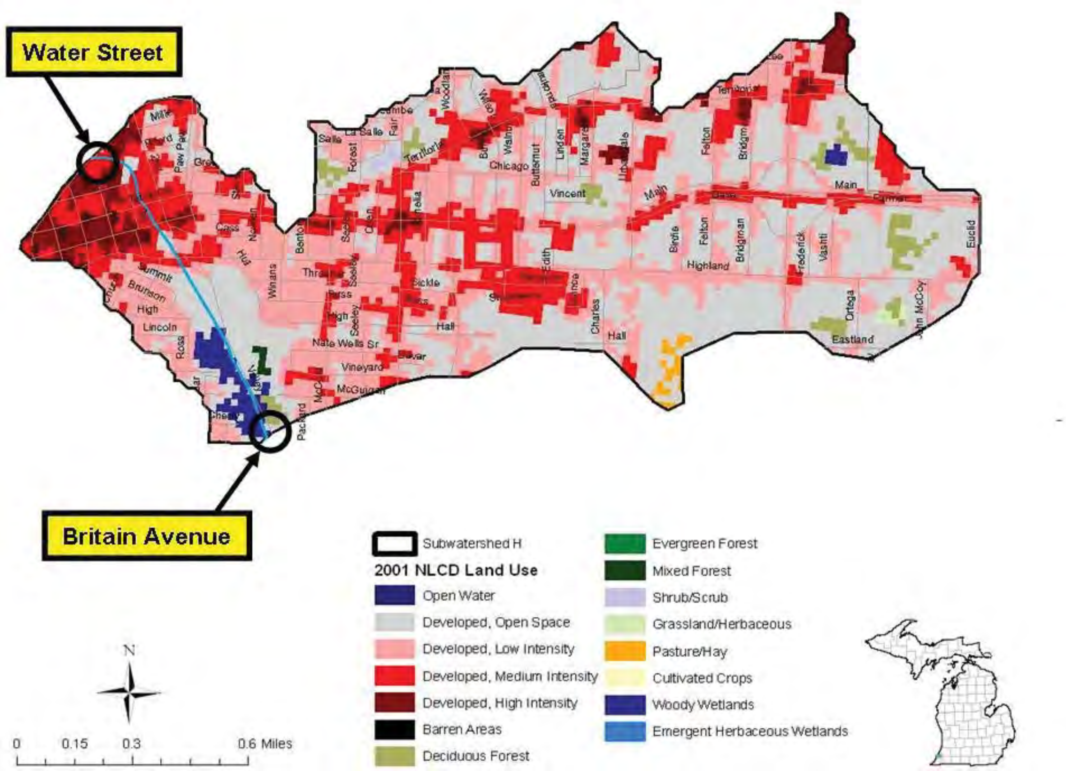


Figure 9-54. Unit H -- Lower Ox land use.

Table 9-15. Lower Ox land use summary.

Land Use / Land Cover	Size (acres)	Size (percentage)
Open Water	0	--
Developed, Open	410	39%
Developed, Low-Intensity	370	35%
Developed, Medium-Intensity	185	17%
Developed, High Intensity	49	5%
Barren Land	0	--
Deciduous Forest	21	2%
Evergreen Forest	0	--
Mixed forest	1	0%
Shrub/Scrub	1	0%
Grassland/Herbaceous	2	0%
Pasture/Hay	5	0%
Cultivated Crops	0	--
Woody Wetlands	16	2%
Emergent Herbaceous Wetlands	0	--
TOTAL	1,060	100%

Note: "--" means that land use not present in the subwatershed unit
"0%" means land use present in subwatershed unit, but in amount less than 0.5%

Biological and habitat assessments have been conducted at Crystal Avenue *(Table 3-2 and Table 4-2)*. The most recent biological evaluation conducted at this location was completed in 2006. Table 9-16 summarizes the dominant taxa that were present in both this and the 2001 surveys. Because healthy streams typically support macroinvertebrate populations from the EPT orders, if present, these taxa are also included in Table 9-16.

Table 9-16. Key taxa at Lower Ox macroinvertebrate site.

Ox Creek at Waters Street		Taxa	Percentage
Dominant Taxa	2006	Oligochaeta (worms)	44.0
		Chironomidae	11.0
		Planorbidae	5.0
EPT Taxa	2006	Heptageniidae	0.3

A summary of key findings from the 2006 assessment is shown in Table 9-17. Overall, the habitat score at this location was marginal. When compared to average sites in this ecoregion, identified disturbances at this location included a reduced riparian vegetation zone and reduced frequency of riffles/bends and channel sinuosity.

Table 9-17. Lower Ox biological assessment notes *(Lipsey, 2007)*.

Location	Notes
Water Street	• Glide / pool habitat rated as marginal. • Lack of epifaunal substrate. • Heavy deposits of sand were observed throughout the stream channel. • Bank scour was not evident due to rip rap stabilizing the stream banks. • Stream channel has been altered dramatically as it enters the downtown Benton Harbor area. • Poor macroinvertebrate community can most likely be attributed to a lack of suitable habitat for colonization and high storm water flows that bring additional silt and sediment load to further degrade the habitat.

The macroinvertebrate community was rated as poor (-5), affected by the dominance of tolerant species such as oligochaeta (over 44% of total identified individuals) and reduction in EPT. This shift from intolerant to tolerant species is indicative of a degraded habitat and, furthermore, the dominance of burrowers indicates degradation associate with sedimentation.

A useful way to examine the TSS data is through an analysis of its relationship to flow. Figure 9-55 uses the survey information to depict TSS data for the Water Street site as a function of water level. The general pattern indicates that TSS concentrations increase with rising water level (and flow). One area of interest is highlighted where an exception to the general pattern occurs. In particular, the two largest TSS values (noted by the upper circle) did not correspond to the highest water levels. These anomalies may be related to several factors such as the intensity of the precipitation event, the season of occurrence, and the timing of the individual TSS sample relative to the onset of the storm. Figure 9-56 and Figure 9-57 present time series displays of the data for two wet-weather events: the August 18-19, 2007 storm (2.52 inches) and the April 8-9, 2008 storm (0.69 inches). In both cases, the highest TSS levels for those events were associated with the onset of intense precipitation.

Another way to view this information is through the use of a duration curve framework (Figure 9-58). Data is also separated by each sample event. The first wet weather event occurred in August (summer) as the result of a 2.52 inch storm (noted as Sum-2.52” in Figure 9-58). A significant number of these samples were collected under high flow conditions and included the largest TSS loads. The second wet weather event occurred in the spring and, at 0.69 inches, was the smallest in terms of measured precipitation (noted as Spr-0.69” in Figure 9-58). However, it did result in greater loads than the third event that occurred in the summer as the result of a 0.74 inch storm (noted as Sum-0.74” in Figure 9-58).

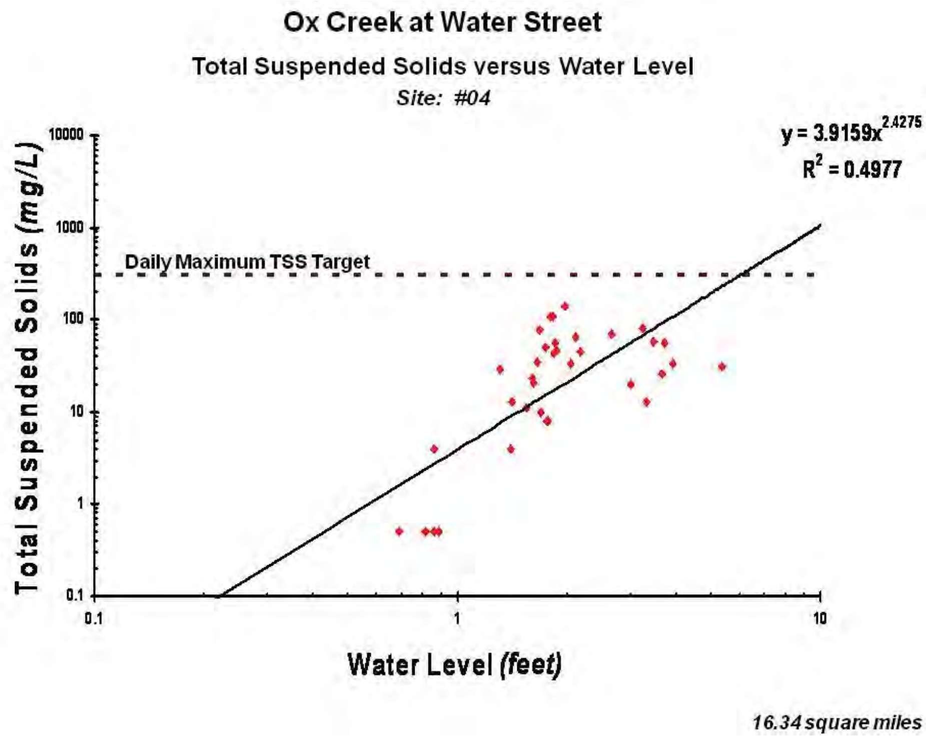


Figure 9-55. TSS as a function of water level -- Water Street site.

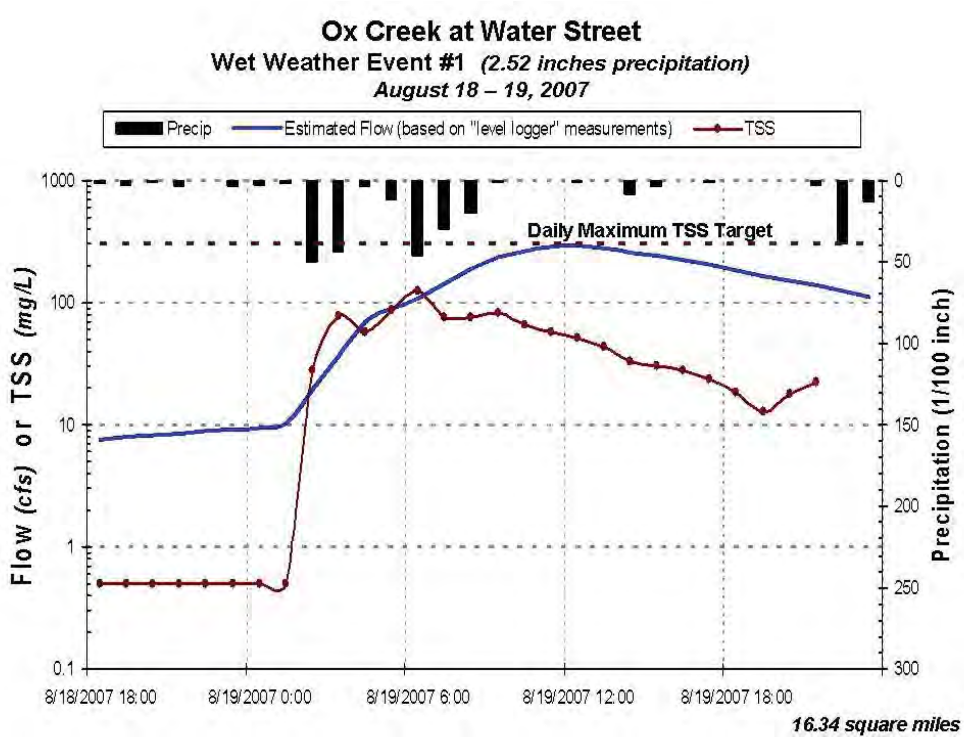


Figure 9-56. TSS, flow, and precipitation for wet weather event #1 -- Water Street.

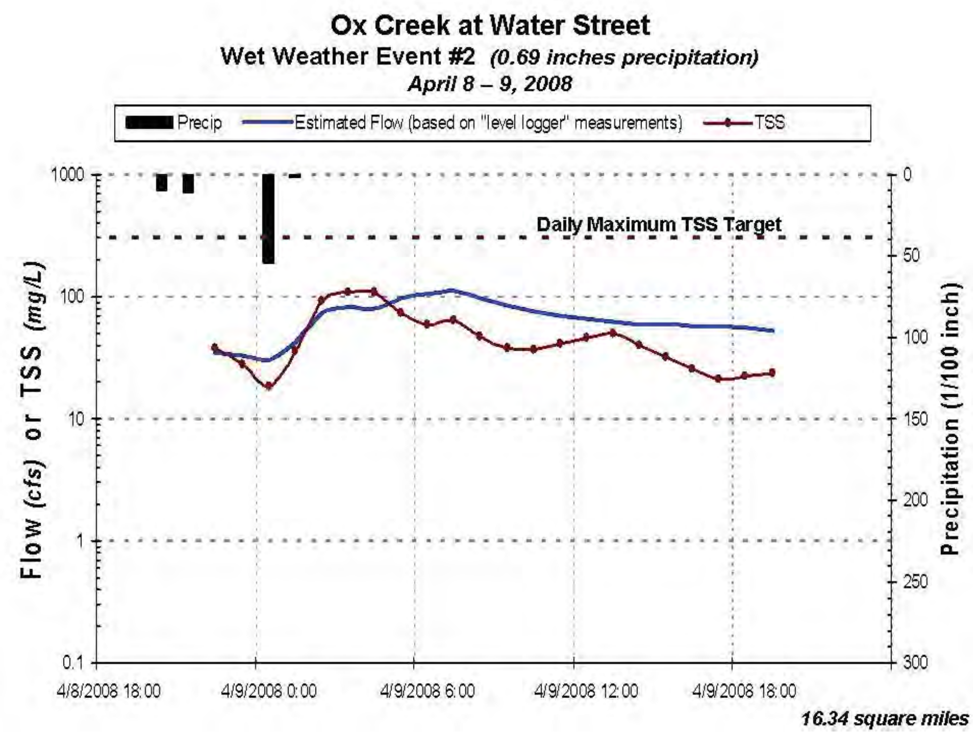


Figure 9-57. TSS, flow, and precipitation for wet weather event #2 -- Water Street.

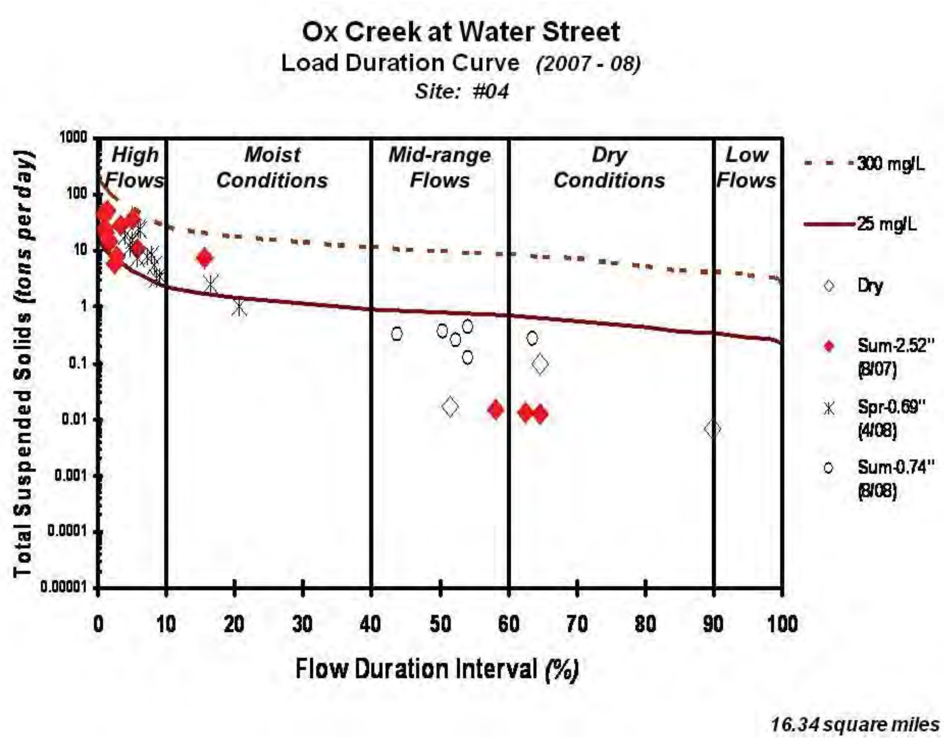


Figure 9-58. Load duration curve for TSS at Water Street.

10. Watershed Loading and Response

Biological data collected at several sites in the Ox Creek drainage resulted in the stream being placed on MDEQ's §303(d) non-attainment list; the result of not achieving the Michigan other indigenous aquatic life and wildlife designated use. Biological assessments are indicative of the adverse effects of pollution. However, the specific pollutant(s) and source(s) are not known based on biological assessments alone. For this reason, MDEQ initiated efforts to collect information on other potential stressors including flow, TSS, and toxic pollutants. A detailed evaluation of this information served as the starting point for this linkage analysis (presented in Sections 3 through 7).

10.1 Indicators and Relationships

TMDL development for impaired streams based on biological monitoring data requires identification of a pollutant(s) that is adversely affecting the aquatic community (macroinvertebrates in the case of Ox Creek). An important part of the linkage analysis is to examine the relationship between various key indicators (e.g., bioassessment, habitat, flow, TSS, water quality). This is a major consideration in identifying the pollutant(s) that will be the focus of any given TMDL. Figure 10-1 shows the relationship of the biological impairment to major processes of concern in Ox Creek. This diagram provides a framework for connecting information on the biological impairment to other key indicators at a watershed scale.

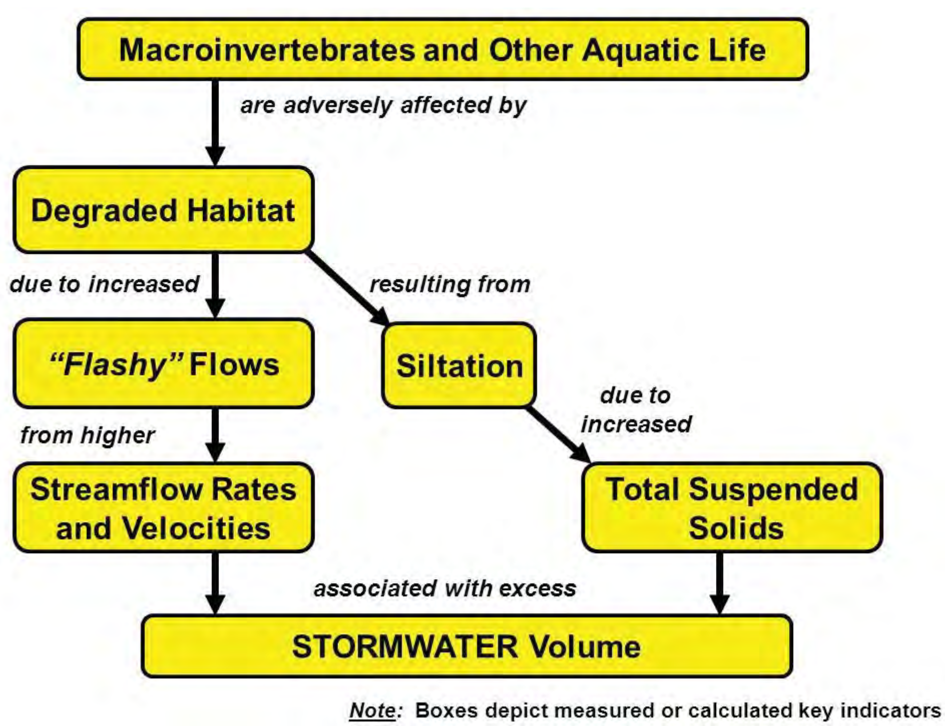
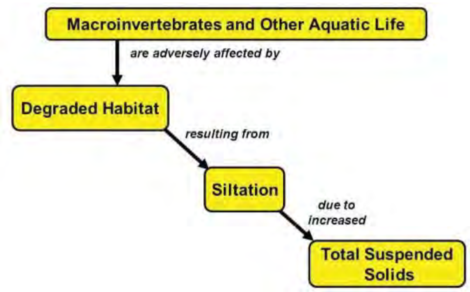


Figure 10-1. Relationship between key indicators in Ox Creek linkage analysis.

10.2 Total Suspended Solids Targets

The relationship between macroinvertebrates and key indicators shown in Figure 10-1 revolves around two critical paths. The first critical path (represented by the right side of the diagram) proceeds through total suspended solids. The macroinvertebrate community structure data coupled with qualitative habitat observations indicate that siltation due to excess total suspended solids loads is a cause of biological impairments in Ox Creek.



Because of this critical relationship and because total suspended solids is a pollutant, TSS targets have been identified that are used to develop the Ox Creek TMDL. The approach used to define TSS targets for the Ox Creek TMDL builds on literature values used in earlier Michigan TMDLs that are protective of aquatic life uses. These values are combined with multiple averaging period methods in order to provide a greater level of clarity that describes how the targets are to be interpreted (presented in Section 8). Based on available information for suspended solids in southern Michigan, the following TSS targets are used to develop the Ox Creek TMDL:

- 25 mg/L long-term annual average TSS
- 300 mg/L maximum daily average TSS

These targets are supported by multiple lines of evidence. The literature supports the long-term annual average 25 mg/L TSS as a level where fisheries would not be harmed. The 300 mg/L maximum daily average TSS is based on MDEQ studies supporting development of SETP *(Figure 10-2)*. The SETP effort included a qualitative analysis of information from 12 different Lower Michigan streams and rivers. The analysis identified 300 mg/L TSS as a general level above which the stream sedimentation condition was degraded.

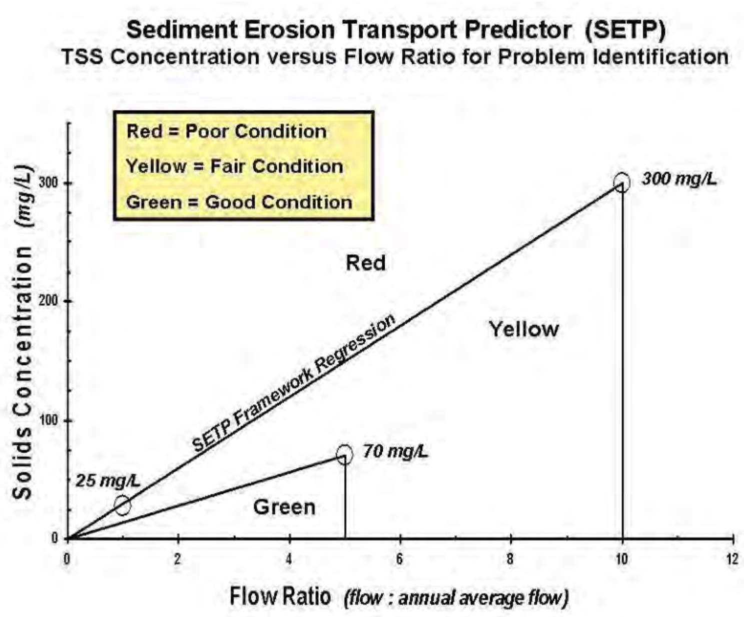


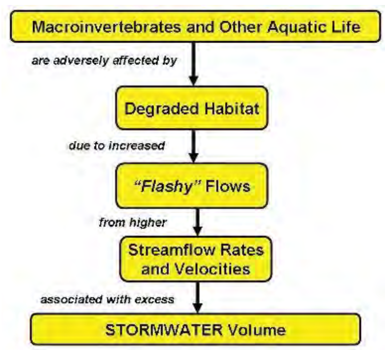
Figure 10-2. Sediment Erosion Transport Predictor *(SETP)* framework overview.

EPA's TSD (USEPA, 1991) describes a multiple averaging period method, which has been used to define the Ox Creek TMDL TSS targets. The approach is based on achieving a long-term average target that considers patterns and variability in a consistent manner. Multiple averaging periods provide a way to achieve both long-term program objectives and focus implementation efforts while avoiding short term problems.

The appropriateness of these targets was validated by applying the framework to sites with both bioassessment information and either TSS or SSC data. Validation involved ensuring that sites meeting the TSS targets were also in either acceptable or above average condition based on bioassessment data. Using the best available information, the validation process demonstrates that these TMDL targets should lead to attainment of Michigan's water quality standards. Following validation, the targets and methodology were applied to Ox Creek flow and TSS data. The analysis showed that Ox Creek generally exceeded threshold levels; consistent with bioassessment scores.

10.3 Flashiness and Stormwater Volume

The second critical path (represented by the left side of the diagram) emphasizes the need to also consider storm water volume. As discussed in Sections 6 and 8, flow rates affect TSS concentrations. Hydrology can also be a major factor that affects aquatic communities (thus influencing bioassessment scores). Stable flow regimes support the establishment of healthy macroinvertebrate populations. *"Flashy"* flows (e.g., due to urban runoff) disrupt aquatic community structure and increase the transport of TSS loads that cause downstream siltation problems.



For example, swimmers, crawlers, and clingers (particularly EPT) are typically *"washed out"* from *"flashy"* systems due to increased stream velocities and flow volumes. Rocks that serve as good habitat for EPT and support diverse macroinvertebrate communities are scoured in *"flashy"* systems. Oligochaetes (pollution tolerant worms) tend to become more established in *"flashy"* systems, as they can burrow into the substrate. In addition, periphyton that serves as a food source for scrapers is stripped out of *"flashy"* systems.

"Flashiness" is an indicator of the frequency and rapidity of short-term changes in stream flow, particularly during runoff events (Baker, et.al, 2004). Increased *"flashiness"* is typically associated with unstable watersheds and degraded habitat that adversely affects aquatic life. Fongers, et. al. (2007) provides a context to incorporate *"flashiness"* into the stormwater assessment process based on an examination of gaged streams and rivers across Michigan. Their study included a summary of R-B Flashiness Index quartile rankings by drainage area size for Michigan watersheds *(Figure 10-3)*. The R-B Flashiness Index score for lower Ox Creek is 0.52, which places it in the highest quartile for Michigan watersheds of comparable size.

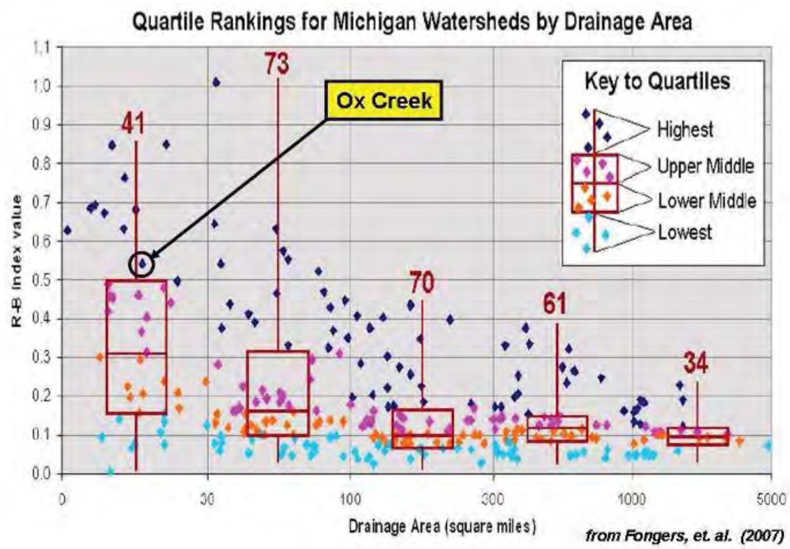


Figure 10-3. R-B flashiness index quartile rankings for Michigan rivers and streams.

10.4 Spatial Patterns

An examination of Ox Creek's overall response to watershed loading is a key part of the linkage analysis. This evaluation recognizes the varied nature of the drainage. Different land use patterns and source areas across the watershed contribute to the spatial variation summarized in Sections 3 through 7. In order to relate source information to water quality monitoring results, the Ox Creek drainage was partitioned into nine subwatershed units. This facilitates an integrated evaluation of all information at a monitoring site scale. The subwatershed framework is needed because different factors (e.g., land use, sources of sediment, amount of impervious cover, etc.) appear to influence the biological integrity, hydrology, and water quality patterns at each location. Individual subwatershed assessments are presented in Section 9.

Table 10-1 represents a summary of major considerations and concerns based on information presented in the preceding sections of this linkage analysis. As indicated in Table 10-1, specific concerns in the Ox Creek watershed vary by location. For example, the daily maximum TSS target is exceeded in the Yore-Stouffer Drain (Units B,C) and the headwater area of Ox Creek (Unit E). *"Flashy"* flows, which disrupt macroinvertebrate community structure, exert a much greater adverse effect on the lower portions of Ox Creek (Units F,G,H,I). *"Flashy"* flows also transport elevated TSS loads from the upper portion of the watershed, causing excess siltation in the downstream reaches of Ox Creek. The following paragraphs provide a brief synopsis of information in this table.

Table 10-1. Ox Creek watershed loading considerations and concerns.

Unit	Cumulative Land Use (acres)	Cumulative Land Use estimated % IC	Biology*** (dominant taxa)	Total Suspended Solids	Hydrology	PAHs & Heavy Metals
Yore – Stouffer Drain						
A	2,150	1%	n.a.	---	---	n.a.
B	2,615	1%	n.a.	TSS Targets exceeded	---	---
C	4,370	4%	*Physidae (Gastropods)*		---	WQS & PEC exceeded
D	5,175	9%	n.a.	n.a.	n.a.	n.a.
Ox Creek						
E	2,600	7%	*Amphipoda (scuds)*	TSS Targets exceeded	---	PEC exceeded
F	8,500	10%	n.a.	Siltation due to excess TSS loads	*"Flashy"* flows	WQS exceeded
G	9,395	10%	*Oligochaeta (worms)*			PEC exceeded
H	10,455	11%	*Oligochaeta (worms)*			
I	10,559	12%	n.a.			

Notes:
***: Dominant taxa used as an example indicator to illustrate the variation in biological stressors that exist across the Ox Creek watershed.
---: no identified concern
n.a.: not assessed

Cumulative land use is included in Table 10-1 with a focus on the estimated percentage of impervious cover (IC). Land use (and specifically IC) is one characteristic that clearly affects all aspects of watershed loading and response; particularly hydrology, water quality, and biology. It is a major controlling factor that determines the amount of storm water runoff. The summary information presented in Table 10-1 shows that the estimated percentage of impervious cover in the lower portions of Ox Creek (Units D, E, F, G, H, I) is significantly greater than in the upper subwatersheds (Units A, B, C). The increased percentage impervious surfaces subsequently cause *"flashy"* flows and generate excess stormwater volume.

Biology changes across the watershed. The variation in dominant taxa, shown in Table 10-1, is one way to illustrate the effect that different significant stressors may exert at each location. For example, physidae (or freshwater snails) are dominant in subwatershed unit C. This particular subwatershed is an area where TSS targets, as well as water quality criteria and PECs for several PAHs, are all exceeded. MDEQ's Procedure 51 specifically uses the percentage of isopods, snails, and leeches as a metric. As indicated earlier *(Table 3-1)*, these organisms show a high tolerance to a variety of both physical and chemical parameters. High percentages of these organisms at a sample site are strong evidence of stream degradation.

Amphipods are dominant in subwatershed unit E. Many species within the amphipod family are moderately tolerant of pollution. Subwatershed unit E is an area where TSS targets are exceeded. Yet another example of the biological variation in Ox Creek is the dominance of oligochaetes in subwatershed units G and H. These areas experience siltation problems due to excessive TSS loads transported from upstream sources. Oligochaetes are burrowing worms and are generally very pollution tolerant. Subwatersheds G and H coincide with stream reaches that are also adversely affected by *"flashy"* flows. Worms tend to be more established, as they can burrow into the substrate. Swimmers and clingers, particularly EPT, are typically *"washed out"* from *"flashy"* systems due to increased stream velocities and flow volumes.

Total Suspended Solids targets are exceeded in upper portions of the watershed; notably the Yore-Stouffer Drain (Units B,C) and the headwater area of Ox Creek (Unit E). An important part of the linkage analysis is to examine the effect of these TSS exceedances across the entire watershed, particularly their role in causing downstream siltation problems. This closer examination is best accomplished through a loading analysis.

Figure 10-4 and Figure 10-5 depict the loading of TSS in the Ox Creek watershed for two wet-weather surveys. These graphs integrate information presented in the analysis of individual subwatersheds (Section 9). Data from the third wet-weather survey was not included in this analysis, as sampling was initiated nearly 12 hours following intense precipitation. Consequently, peak sediment loads would not be represented for that event. Thus, including this data in the analysis would underestimate the overall effect of that storm on TSS in Ox Creek.

The TSS loads for both wet-weather events are shown in Figure 10-4 and Figure 10-5 as a longitudinal profile. The TSS exceedances occur in the two primary upstream tributaries: Yore-Stouffer Drain (Units B,C) and the Ox Creek headwater area (Unit E). The individual tributary loads form the total TSS load to the mainstem of Ox Creek below their confluence. Each tributary load is shown separately. The shaded box is the Yore-Stouffer TSS load (represented by the Meadowbrook Road site); the empty box is the Ox Creek headwaters TSS load (represented by the Crystal Avenue site). In order to depict the sum of these loads, the Yore-Stouffer Drain TSS load is also shown on top of the Ox Creek headwaters TSS load in each figure.

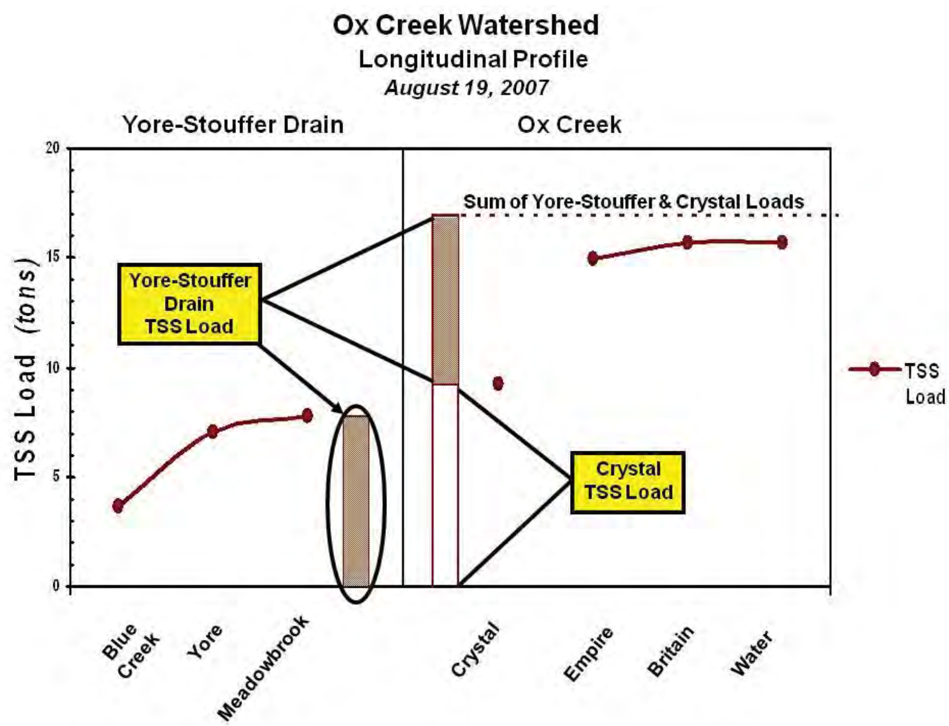


Figure 10-4. TSS loads in the Ox Creek watershed for wet weather event #1.

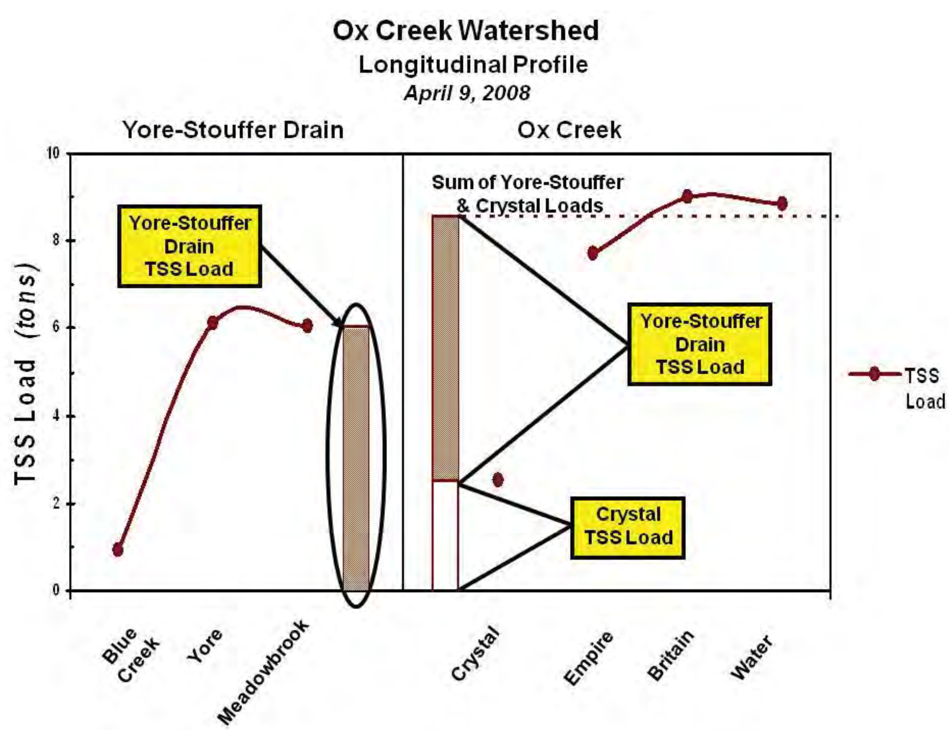


Figure 10-5. TSS loads in the Ox Creek watershed for wet weather event #2.

In both storm events, the sum of the tributary TSS loads either exceeded or comprised a significant majority of the TSS loads that were monitored downstream. This indicates that TMDL implementation efforts to meet the TSS targets in the upper subwatershed units should address sediment sources in these areas. This includes erosion from land surfaces where soil has been disturbed. Potential areas to be examined in this source category include:

- construction sites
- poorly managed agricultural fields
- riparian corridors in a degraded condition
- commercial areas with accumulated sediment on impervious surfaces that can be delivered to the stream (which could also be a source of PAHs and heavy metals)

In addition to these potential source areas, the role of ditches or gullies should also be evaluated as contributors of sediment and TSS to Ox Creek.

Implementation efforts to meet the TSS targets in the upper subwatershed units will also reduce downstream loads causing siltation problems. In summary, this highlights the importance of focusing on sediment reduction efforts in the upper portion of the watershed to address TSS problems that are causing biological impairments in Ox Creek.

Hydrology and flow rates affect TSS concentrations. Stable flow regimes also support the establishment of healthy macroinvertebrate populations. As indicated in Table 10-1, the primary concern regarding hydrology in Ox Creek is *"flashy"* flows in the lower subwatersheds (Units F,G,H,I). *"Flashy"* flows disrupt aquatic community structure and increase the transport of TSS loads that cause downstream siltation problems. As discussed earlier, the R-B Flashiness Index score for lower Ox Creek at Britain Avenue is 0.52, which places it in the highest quartile for Michigan watersheds of comparable size.

Table 10-1 provides an estimate the cumulative level of impervious surfaces at the outlet of each subwatershed unit. During storm events, rain falling on impervious surfaces produces higher volumes of runoff (due to the decreased ability of the subwatershed to infiltrate water). These higher volumes occur in shorter *"bursts"*, resulting in *"flashy"* flows. Not surprisingly, the problems with *"flashy"* flows in Ox Creek appear to coincide with those subwatershed units that have higher amounts of impervious surfaces.

Another important part of the linkage analysis is to use the data to examine where significant amounts of water are being delivered to Ox Creek. Flow information collected during the TSS survey can be used to develop a water volume analysis (somewhat analogous to the loading analysis for TSS). Figure 10-6 and Figure 10-7 depict the water volume in Ox Creek for the first two wet-weather surveys. These graphs integrate information presented in the discussion on flow (Section 5) and in the analysis of individual subwatersheds (Section 9).

Similar to the TSS loading analysis, individual tributary flow volumes are shown separately. Again, in order to depict the sum of the volumes, the Yore-Stouffer Drain at Meadowbrook volume is also shown on top of the Ox Creek at Crystal volume. In the case of both storm events, a significant volume of water is added to Ox Creek below these two sites. This is not surprising given the increased levels of impervious surfaces that occur in subwatersheds D, F, G, H, and I. This highlights the need to also focus on reducing flow volumes (i.e, quantity) in efforts to address biological impairments in Ox Creek.

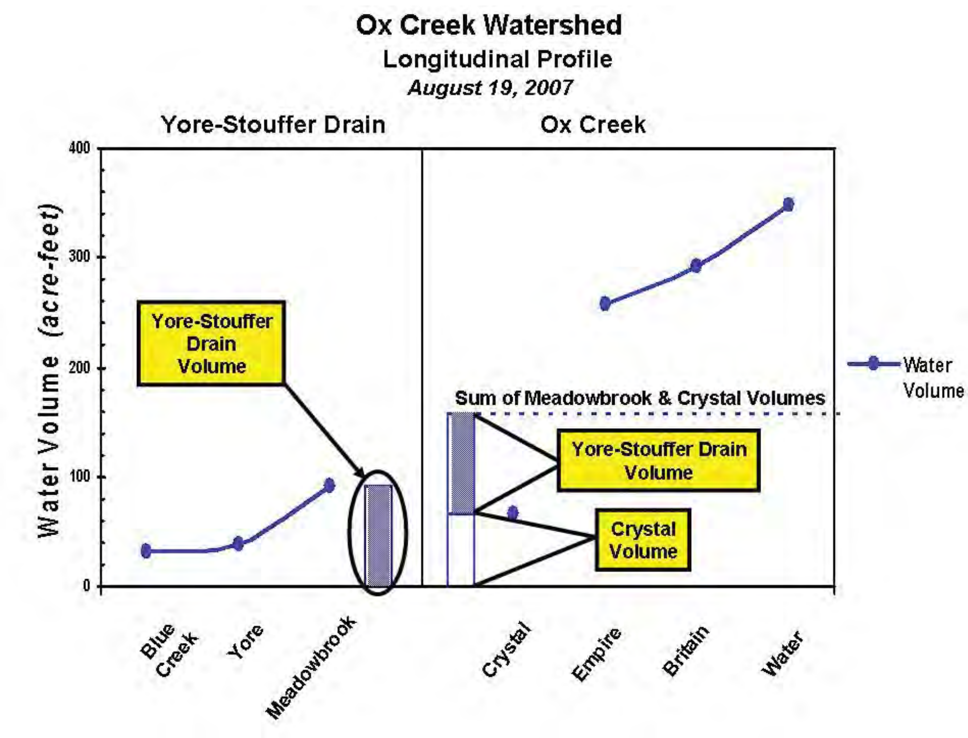


Figure 10-6. Water volume in the Ox Creek watershed for wet weather event #1.

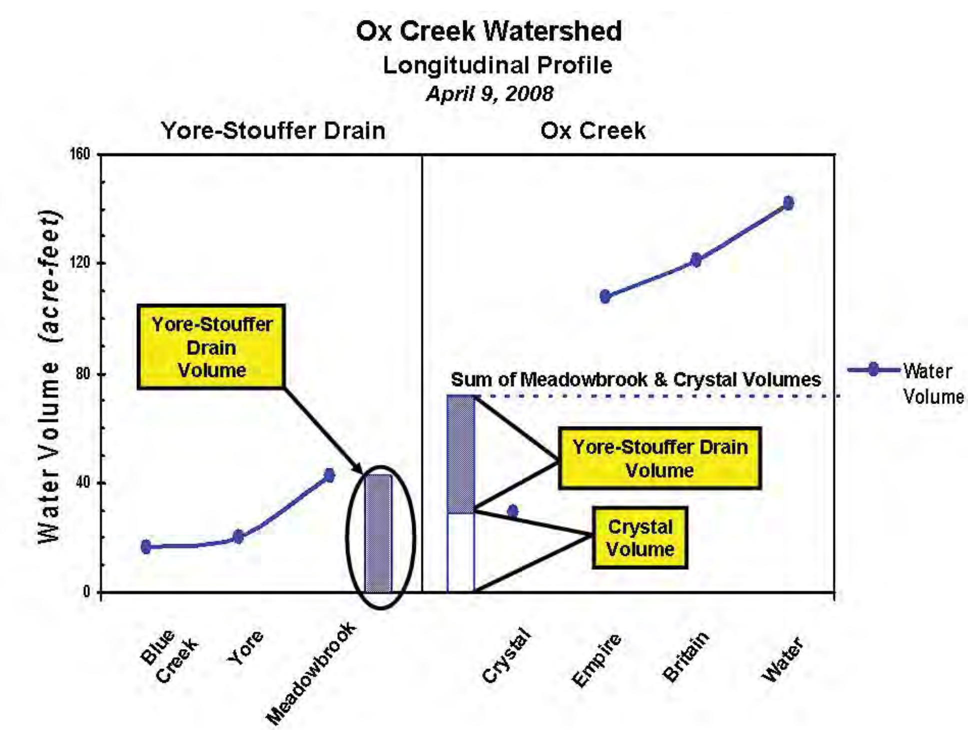


Figure 10-7. Water volume in the Ox Creek watershed for wet weather event #2.

PAHs and Heavy Metals have been detected in certain areas of the Ox Creek watershed at levels that exceed either water column criteria or bottom sediment PECs (presented in Sections 6 and 7). Table 10-1 identifies subwatersheds where the potential source(s) of PAHs and heavy metals should be further investigated.

10.5 Summary

The linkages described in Figure 10-1 reiterate the importance of TSS and flow to address biological impairments in Ox Creek. A summary of major considerations and concerns by location across the Ox Creek watershed is presented in Table 10-1. Combined, the linkages and the array of concerns point to the need for a range of different management strategies to address problems causing non-attainment of Michigan's other indigenous aquatic life and wildlife use in the Ox Creek watershed.

The watershed scale analysis of TSS loads highlights the need for erosion control in the upper portions of the watershed. The highest TSS concentrations observed during wet-weather events coincide with upper portions of the drainage that have a relatively lower percentage of urban development. Dominant sources include areas where soils are disturbed (e.g., construction activities including transportation projects, poorly managed agricultural fields). The major concern is where sediment accumulated on surfaces and exposed soils, in gullies or other areas susceptible to erosion and is quickly washed away. Sediment from these source areas can be transported to the stream through erosion processes. Areas adjacent to the stream provide the most direct delivery path of sediment to Ox Creek receiving waters. As a result, riparian management is typically associated with erosion control efforts.

Sediment loads originating in the upper portions of the Ox Creek watershed are transported to the lower reaches. This contributes to siltation problems downstream that degrades habitat. Thus, implementation of erosion control practices will also reduce TSS loads that contribute to downstream siltation problems. In addition, *"flashy"* flows that can disrupt macroinvertebrate community structure are also a problem in the lower reaches of Ox Creek. These *"flashy"* flows are associated with urban runoff. The watershed scale analysis of flow volumes further describes the concern. This assessment highlights the need for storm water management, particularly strategies that reduce flow volumes.

Water column concentrations for two PAH compounds (fluoranthene and phenanthrene) exceeded Michigan's WQS at two locations (subwatershed C and F) in the drainage. Although no numeric bottom sediment quality criteria have been promulgated in Michigan, several heavy metals and PAHs were detected above PEC sediment quality guidelines (MacDonald et.al., 2000) at several locations. PAHs and certain metals have a strong tendency to adsorb to fine particulate matter (as evidenced by their presence in bottom sediments). As a result, fine sediment often serves as the primary carrier for these pollutants to receiving waters. TSS reductions are needed in units where water column concentrations were exceeded. Implementation efforts to reduce sediment loads through reducing storm water runoff will reduce transport of these toxic pollutants of concern to other areas in Ox Creek.

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