Zumbro River Watershed Total Maximum Daily Loads for Turbidity Impairments

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List of Acronyms/Abbreviations

ac	acre
AUID	assessment unit identification number
BMP(s)	best management practice(s)
cm	centimeters
CR	County Road
Cr	Creek
CSAH	County State Aid Highway
EPA (U.S.)	Environmental Protection Agency
FNU	formazin nephelometric units
JD	Judicial Ditch
kg	kilograms
LA	load allocation
mg/L	milligrams per liter
MF	Middle Fork
mgd	million gallons per day
MN DOT	Minnesota Department of Transportation
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NA	not applicable
NBMF	North Branch Middle Fork
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
NTRU	nephelometric turbidity ratio units
NTU	nephelometric turbidity units
SBMF	South Branch Middle Fork
SF	South Fork
TMDL	total maximum daily load
TSS	total suspended solids
TT	transparency tube
USGS	United States Geological Survey
WLA	wasteload allocation
WWTP	wastewater treatment plant

TMDL Summary		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
Location	Zumbro River basin; southeast Minnesota	5
303(d) Listing Information	Total of 18 listings for turbidity; *see Table 1.*	4
Applicable Water Quality Standards/ Numeric Targets	*See Section 2.1*	6
Loading Capacity (expressed as daily load)	*See Section 3.4*	20
Wasteload Allocation	*See Section 3.4*	21
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Margin of Safety	Explicit MOS of ten percent used; *see Section 3.4*	23
Seasonal Variation	Load duration curve methodology accounts for seasonal variation; *see Section 3.6*	65
Reasonable Assurance	Information is presented regarding agricultural BMPs and their effectiveness. NPDES permits provide assurance for permitted sources to comply with WLAs. *See Section 6.0.*	74
Monitoring	A general overview of follow-up monitoring is included. *See Section 4.0.*	69
Implementation	A discussion of factors to consider for implementation is provided, as well as a rough approximation of the overall implementation cost to achieve the TMDL. (A separate more detailed implementation plan will be developed at a later date.) *See Section 5.0.*	71
Public Participation	• Public Comment period: October 24 to November 23, 2011 • Various public participation and outreach efforts were conducted; *see Section 7.0.*	76

Executive Summary

The Clean Water Act, Section 303(d), requires that every two years states publish a list of waters that do not meet water quality standards and do not support their designated uses. These waters are then considered to be “impaired”. Once a waterbody is placed on the impaired waters list, a Total Maximum Daily Load (TMDL) must be developed. The TMDL provides a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. It is the sum of the individual wasteload allocations (WLAs) for point or permitted sources, load allocations (LAs) for nonpoint or nonpermitted sources and natural background, plus a margin of safety (MOS).

The Minnesota Pollution Control Agency (MPCA) listed 17 stream reaches in the Zumbro River watershed as impaired for excess turbidity (a measure of cloudiness of water that affects aquatic life). All of these impairments are addressed in this study for the following reasons: 1) they share some common contributing sources; 2) it is more efficient from administrative and cost standpoints to address multiple impairments in the same effort rather than separately; and 3) a watershed-wide approach makes the most sense for addressing some of the long-standing nonpoint pollution issues in this region.

The Zumbro River watershed encompasses more than 900,000 acres of agricultural and urban lands that drain through the three forks of the Zumbro River. The watershed includes parts of Olmsted, Dodge, Goodhue, Rice, Wabasha, and Steele Counties, as well as the growing City of Rochester. The watershed is known for its diversity of landscape, ranging from deep fertile glacial-tills, to steep slopes and erodible loess soils of the bluff lands. Much of the watershed is in the Karst region, with exposed sedimentary bedrock and complex groundwater systems. The basin includes a variety of cold, cool and warm water streams, and numerous recreational waters. Land forms, land use and land management differ throughout the watershed. Land use is dominated by agricultural cropping and animal production. Point sources (permitted municipal and industrial dischargers) also exist in the watershed.

This study used a variety of methods to evaluate the current loading, contributions by the various pollutant sources, as well as the allowable pollutant loading capacity of the impaired reaches. These methods included the load duration curve approach for reaches impaired by turbidity. It is estimated that the overall magnitude of reduction needed to the meet the turbidity standard for each impaired reach is between 50 to 90 percent for high flows (0-10% flow duration), between 0 to 75 percent for moist conditions (10-40% flow duration), between 0 to 70 percent for mid-range flows (40-60% flow duration), between 0 and 50 percent for dry conditions (60-90% flow duration intervals), and low flows (90-100% flow duration) meet the turbidity standard throughout the study area under current conditions.

The primary contributing sources to the turbidity impairments in the watershed were found to be streambank/bed erosion, row cropland, impervious areas, inadequate buffers near streams and waterways, channelization of streams, and overgrazed pasture near streams and waterways. Minor contributions from algae to turbidity are more likely in reaches downstream of reservoirs or impoundments. A general strategy for implementation of nonpoint source-related actions to address the impairments is provided in this document (a more specific implementation plan will

be developed and will be available as a separate report). Nonpoint contributions are not regulated and, therefore, reductions will need to proceed on a voluntary basis. Allowable loadings from permitted point sources related to the turbidity TMDL are described in this TMDL report. These will be addressed through the MPCA's National Pollutant Discharge Elimination System (NPDES) permit programs.

1.0 INTRODUCTION

Section 303(d) of the Clean Water Act provides authority for completing Total Maximum Daily Loads (TMDLs) to achieve state water quality standards and/or designated uses.

A TMDL is a calculation of the maximum amount of pollutant that a waterbody can receive and still meet water quality standards and/or designated uses. It is the sum of the loads of a single pollutant from all contributing point and nonpoint sources. TMDLs are approved by the U.S. Environmental Protection Agency (EPA) based on the following elements:

1. They are designed to implement applicable water quality criteria;
2. Include a total allowable load as well as individual waste load allocations;
3. Consider the impacts of background pollutant contributions;
4. Consider critical environmental conditions;
5. Consider seasonal environmental variations;
6. Include a margin of safety;
7. Provide opportunity for public participation; and
8. Have a reasonable assurance that the TMDL can be met.

In general, the TMDL is developed according to the following relationship:

$$TMDL = WLA + LA + MOS + RC$$

Where:

WLA = wasteload allocation; the portion of the TMDL allocated to existing or future point sources of the relevant pollutant;

LA = load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources of the relevant pollutant. The load allocation may also encompass “natural background” contributions;

MOS = margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity (USEPA, 1999); and

RC = reserve capacity, an allocation for future growth. This is an MPCA-required element, if applicable, for TMDLs.

This TMDL report applies to 17 stream reaches in the Zumbro watershed as impaired for excess turbidity. These impairments are included in the 2008 303(d) list of impaired waters and are shown in Table 1 and Figure 1.

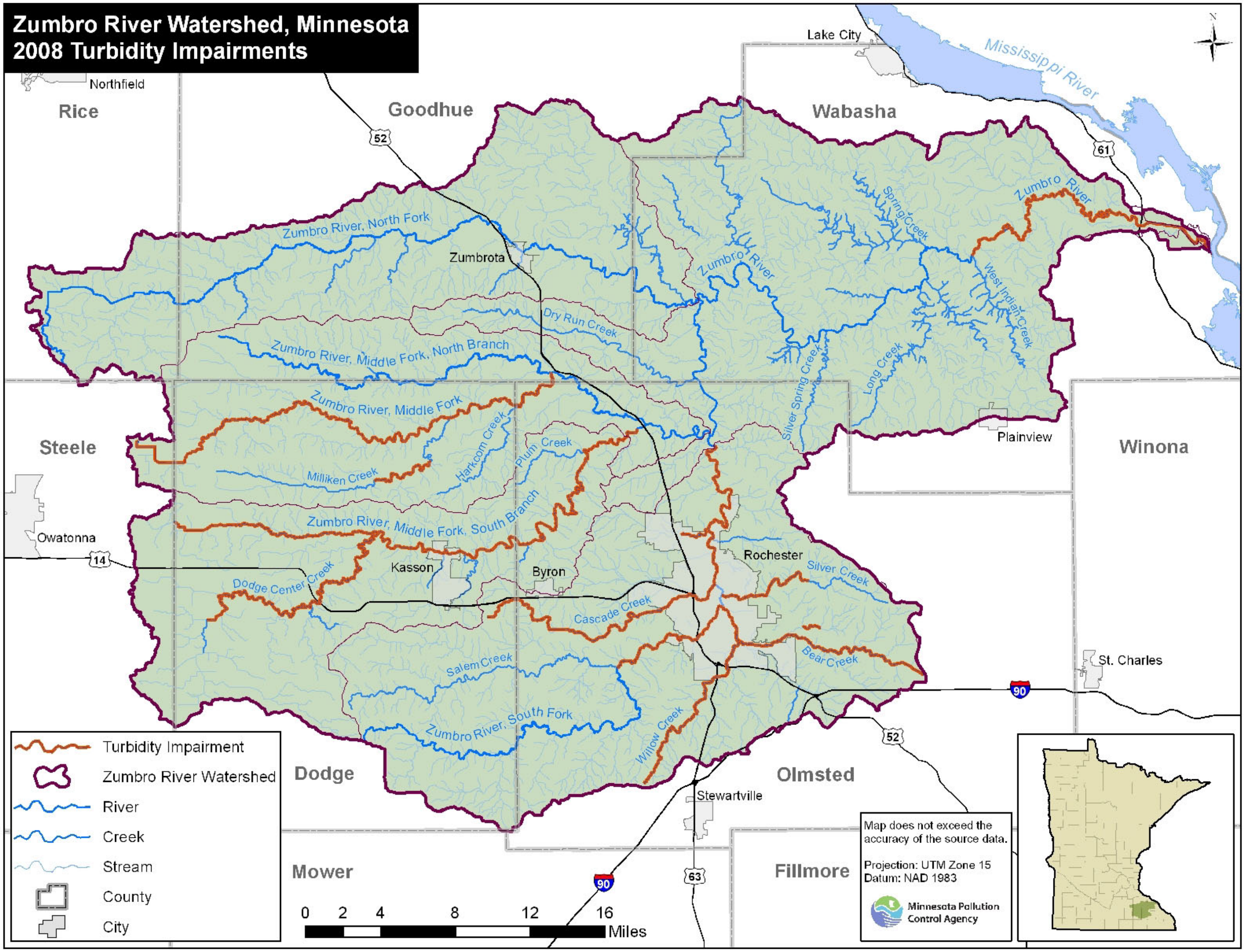
Table 1. Zumbro River watershed 303(d) impairments addressed in this report.

REACH	DESCRIPTION	YEAR LISTED	ASSESSMENT UNIT ID	AFFECTED USE	POLLUTANT OR STRESSOR
Silver Creek	Unnamed cr to Unnamed cr	06	07040004-552	Aquatic life	Turbidity
Silver Creek	Unnamed cr to Silver Lk (S Fk Zumbro R)	06	07040004-553	Aquatic life	Turbidity
Bear Creek Tributary	Unnamed cr to Unnamed cr	06	07040004-556	Aquatic life	Turbidity
Bear Creek	Headwaters to Willow Cr	08	07040004-539	Aquatic life	Turbidity
Willow Creek	Headwaters to Bear Cr	06	07040004-540	Aquatic life	Turbidity
Bear Creek	Willow Cr to S Fk Zumbro R	08	07040004-538	Aquatic life	Turbidity
Zumbro River, South Fork	Salem Cr to Bear Cr	06	07040004-536	Aquatic life	Turbidity
Cascade Creek	Headwaters to Unnamed cr	06	07040004-639	Aquatic life	Turbidity
Cascade Creek	Unnamed cr to S Fk Zumbro R	06	07040004-581	Aquatic life	Turbidity
Kings Run	Unnamed cr to Unnamed cr	08	07040004-601	Aquatic life	Turbidity
Zumbro River, South Fork	Cascade Cr to Zumbro Lk	02	07040004-507	Aquatic life	Turbidity
Dodge Center Creek	JD 1 to S Br M Fk Zumbro R	06	07040004-592	Aquatic life	Turbidity
Zumbro River, Middle Fork, South Branch	Headwaters to Dodge Center Cr	06	07040004-526	Aquatic life	Turbidity
Zumbro River, Middle Fork, South Branch	Dodge Center Cr to M Fk Zumbro R	06	07040004-525	Aquatic life	Turbidity
Milliken Creek	Unnamed cr to Unnamed cr	06	07040004-554	Aquatic life	Turbidity
Zumbro River, Middle Fork	Headwaters to N Br M Fk Zumbro R	08	07040004-522	Aquatic life	Turbidity
Zumbro River	West Indian Cr to Mississippi R	98	07040004-501	Aquatic life	Turbidity

The MPCA’s projected schedule for TMDL completions, as indicated on Minnesota’s 303(d) impaired waters list, implicitly reflects Minnesota’s priority ranking of this TMDL. The project was scheduled to be completed in 2009. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

In this report, the background information relevant to all impairments is provided in Section 2.0, followed by the TMDL technical elements provided in Section 3.0. For follow-up monitoring, implementation, reasonable assurance and public participation all impairments are addressed together in Sections 4.0 through 7.0.

Figure 1. Zumbro River watershed 303(d) impairments.



2.0 BACKGROUND INFORMATION

2.1 Applicable Water Quality Standards

A discussion of water classes in Minnesota and the standards for those classes is provided below in order to define the regulatory context and environmental endpoint of the TMDLs addressed in this report.

All waters of Minnesota are assigned classes based on their suitability for the following beneficial uses:

1. Domestic consumption
2. Aquatic life and recreation
3. Industrial consumption
4. Agriculture and wildlife
5. Aesthetic enjoyment and navigation
6. Other uses
7. Limited resource value

According to Minn. Rules Ch. 7050.0470, all of the impaired waters covered in this TMDL are classified as Class 2B, 3C, 4A, 4B, 5 and 6. West Indian Creek is also classified as Class 1B, 2A and 3B. Relative to aquatic life and recreation the designated beneficial uses for 2A and 2B waters are as follows:

> Class 2A waters. The quality of Class 2A surface waters shall be such as to permit the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface waters is also protected as a source of drinking water.
> Class 2B waters. The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable.

Turbidity

Turbidity in water is caused by suspended sediment, organic material, dissolved salts and stains that scatter light in the water column making the water appear cloudy. Excess turbidity can degrade aesthetic qualities of water bodies, increase the cost of treatment for drinking or food processing uses and can harm aquatic life. Aquatic organisms may have trouble finding food, gill function may be affected and spawning beds may be covered. In addition, sediment-laden water can hold more heat than sediment-poor water, and thus turbidity can affect a stream's thermal regime.

Minn. Rules Ch. 7050.0222, turbidity water quality standard for Class 2B and 2C waters is 25 nephelometric turbidity units (NTUs). The designated use that this standard protects is aquatic life. Impairment assessment procedures for turbidity are provided in the guidance manual for determination of impairment (MPCA, 2007). Essentially, listings occur when greater than ten percent of data points collected within the previous ten-year period exceed the 25 NTU standard (or equivalent values for total suspended solids or transparency tube data).

<u>Total Suspended Solids</u>

The MPCA is proposing to replace the current turbidity water quality standard with a standard that uses total suspended solids (TSS) criteria. In addition to the change from turbidity to TSS, the proposed criteria vary regionally, and the standard includes explicit language regarding its application (the TSS criteria may be exceeded no more than 10% of the time over the months April-September). The proposed change, if adopted, could go into effect near the end of 2012.

Current listed stream reaches will remain on the impaired waters list. There will not be a broad reassessment of all turbidity listings if the TSS standard is adopted. The MPCA is currently transitioning to a system in which all major watersheds in the state will be assessed on a ten-year cycle. This new assessment process relies heavily on biological data (fish and invertebrates) for making aquatic life use support decisions. Thus, in general, assessment against the TSS standard will follow this cycle and will be one of multiple components considered in a weight of evidence process. It is possible that some turbidity listings may remain for several years before re-assessment occurs. In the Zumbro River watershed, this assessment will begin in 2014.

In most cases, the differences between TMDL allocations based on the turbidity standard versus those that would be based on the new TSS standard, will not be significant. This is especially true in situations in which very high levels of TSS reduction from nonpoint sources are required (i.e. Zumbro watershed). In these situations, implementation of practices to reduce sediment loading should continue unchanged until the next assessment cycle and subsequent TMDL computations.

2.2 General Watershed Characteristics

The Zumbro River watershed encompasses more than 900,000 acres of agricultural and urban lands that drain through the three forks of the Zumbro River. The watershed includes parts of Olmsted, Dodge, Goodhue, Rice, Wabasha, and Steele Counties, as well as the growing City of Rochester. The watershed is known for its diversity of landscape, ranging from deep fertile glacial-tills, to steep slopes and erodible loess soils of the bluff lands. Much of the watershed is in the Karst region, with exposed sedimentary bedrock and complex groundwater systems. The basin includes a variety of cold, cool and warm water streams, and numerous recreational waters. Land forms, land use and land management differ throughout the watershed. Land use is dominated by agricultural cropping and animal production. Point sources (permitted municipal and industrial dischargers) also exist in the watershed.

Although each fork of river has not gone through significant channelization, other alterations to the waterbody have occurred in the form of dams, which are located at several locations along several river segments. These include a large main stem dam at Lake Zumbro and another significant dam structure at Lake Shady upstream of where the Middle Fork of the Zumbro River enters Lake Zumbro. There is a dam on the South Branch Middle Fork of the Zumbro River at Mantorville. Smaller dams and large regional flood control basins exist upstream of the City of Rochester in the South Fork Zumbro watershed. Significant dam structures also exist at Mazeppa and Zumbro Falls.

The land use of the Zumbro Watershed has seen many changes since it was settled by European immigrants in the 1800s. Although not as drastically as the initial clearing of forests and plowing of prairie, land use continues to change as populations grow and resource demands increase. Much like when the area was settled, agriculture continues to dominate the use of lands within the Zumbro River Watershed. However, the form of agriculture is much different than it would have been even 50 years ago. Today, nearly 70% of the watershed is in cultivated land (approximately 630,000 acres) and another 12% in hay and pasture (116,700 acres). Agricultural lands exist throughout the watershed with the exception of the steep slopes in the eastern watershed. The streams and river valleys of the watershed are home to most of the watershed's remaining forests, covering nearly 11% of the watershed or 100,000 acres. More than 5% of the watershed consists of urban development. There are 22 cities located within the watershed ranging from small towns with populations in the hundreds to larger communities having populations in the thousands.

The Department of Soil, Water, and Climate of the University of Minnesota has described the state's land area in terms of "agroecoregions", in which each agroecoregion is associated with a specific combination of soil types, landscape and climatic features, and land use (Hatch et al., 2001). The Zumbro watershed is primarily covered by five agroecoregions: the Rochester Plateau (in the eastern upland areas), Undulating Plains (southern and western portions of the watershed), Blufflands (along the lower valley of the main stem and north fork of the river), Level Plains (headwater portions of the middle fork and south fork subwatershed areas) and Alluvium & Outwash (the headwater portion of Dodge Center Creek and the main stem of the Zumbro River near Kellogg); see Appendix F. These agroecoregions are described as follows:

Alluvium and Outwash

This agroecoregion consists of either fine-textured alluvium or coarse-textured outwash. Soils are generally well drained, and are located on flat to moderately steep slopes. Soil series include Menahga, Hubbard, Mahtomedi, and Estherville. Water erosion potentials are moderate, while wind erosion potentials are high to severe. Stream water quality is generally good, and risk of phosphorus transport to streams is low to moderate.

Original vegetation was prairie, oak openings and barrens, jack pine barrens and openings, and aspen-birch. Roughly half of this agroecoregion is cropland, with another third in forest. Forested wetlands account for 8% of the land cover, while wetlands account for 3%. Dominant agricultural crops include corn, soybeans and hay (41%, 31%, and 20% of the area, respectively). About 11% of the state cattle population, 22% of the chicken broiler population, 12% of the turkey population, and 6% of the hog population is raised in this agroecoregion. Within this agroecoregion, statewide, cattle represent 79% of the animal units (A.U.s) raised, hogs represent 15% of the A.U.s, turkeys represent 5% of the A.U.s, and broilers represent only 0.5% of the A.U.s. Rates of phosphorus and nitrogen applied to cropland from manure and fertilizer average 23 lb/ac and 142 lb/ac, respectively.

Blufflands

This agroecoregion consists of fine textured soils (common series include Seaton and LaCrescent) located on very steep to extremely steep slopes. Soils are well drained. Sinkholes can occur near incised stream drainage networks. This agroecoregion has a very high density of intermittent streams, and a moderate density of permanent streams. Water erosion potentials are extreme, while wind erosion potentials are low. The risk of phosphorus transport to surface waters is moderate to high.

Original vegetation was oak openings and barrens and big woods. Two-thirds of this agroecoregion is in cropland, while one-third is forested. Corn, soybeans, and hay are grown on 47%, 24%, and 25% of the cropland, respectively. About 8% of the cattle, 1% of the turkeys, 3% of the hogs, and 1% of the broiler chickens produced statewide are raised in the Blufflands agroecoregion. Within the Blufflands, cattle account for 87% of the animal units (A.U.s) raised, hogs account for 12% of the A.U.s., and turkeys account for 0.4% of the A.U.s. Rates of phosphorus and nitrogen applied to cropland from manure and fertilizer average 23 lb/ac and 159 lb/ac, respectively.

Level Plains

Soils in this agroecoregion are generally fine textured, and common soils include the Maxfield, Skyberg, Clyde, and Sargeant series. Slopes are generally flat or moderately steep. Two-thirds of the soils are poorly drained, while the other third are well drained. This agroecoregion has a very high density of intermittent streams, and a moderate density of permanent streams. Water erosion potentials are high, while wind erosion potentials are low.

Original vegetation was prairie, and oak openings and barrens. Cropland accounts for 97% of the land use in the Level Plains, while forest covers only 2%. Corn and soybeans account for 49% and 44% of the cropland, respectively. Less than 2% of the hogs raised in Minnesota come from this agroecoregion. Rates of phosphorus and nitrogen applied to cropland from manure and fertilizer average 18 lb/ac and 123 lb/ac, respectively.

Rochester Plateau

This agroecoregion consists of fine textured loessial soils from the Seaton, Port Byron, and Mt. Carroll series developed over karstified limestones. It has a very high density of intermittent streams. Slopes are moderately steep to very steep, and soils are well drained. A relatively high density of sinkholes exists in this agroecoregion. Water erosion potentials are extreme, while wind erosion potentials are low. Stream water quality ranges from fair to poor. Phosphorus transport risks to surface waters are high to severe.

Original vegetation was oak openings and barrens, and prairie. Cropland accounts for 94% of the land use in the Rochester Plateau, while forest covers 5% of the area. Corn, soybeans, and hay account for 48%, 27%, and 21% of the cropland, respectively. This agroecoregion produces 5% of the cattle and 2% of the hogs grown in Minnesota. Within this agroecoregion, cattle account for 86% of the animal units (A.U.s) produced, while hogs account for 13% of the A.U.s. Rates of phosphorus and nitrogen applied to cropland from manure and fertilizer average 23 lb/ac and 159 lb/ac, respectively.

Undulating Plains

Soils in this agroecoregion are fine textured, including the Racine, Tripoli, Maxfield, and Oran series. A very high density of intermittent streams exists. Soils are located primarily on moderately steep slopes, with one-fourth of the slopes being flat. Two-thirds of the soils are well drained, with one-third being poorly drained. Water erosion potentials are high, while wind erosion potentials are low. Stream water quality is generally poor. Risks of phosphorus transport to surface waters are moderate.

Original vegetation was prairie, oak openings and barrens, and brush prairie. Cropland accounts for 96% of the land use in this agroecoregion, while forest covers only 2%. Corn and soybeans are grown on 49% and 41% of the cropland, respectively. Hay is grown on 8% of the cropland. Animal production in this agroecoregion accounts for 2% of the cattle and 3% of the hogs grown statewide. Within this agroecoregion, cattle account for 66% of the animal units (A.U.s) produced, while hogs account for 33% of the A.U.s. Rates of phosphorus and nitrogen applied to cropland from manure and fertilizer average 19 lb/ac and 138 lb/ac, respectively.

3.0 TURBIDITY & TMDLS

3.1 Surface Water Quality Conditions

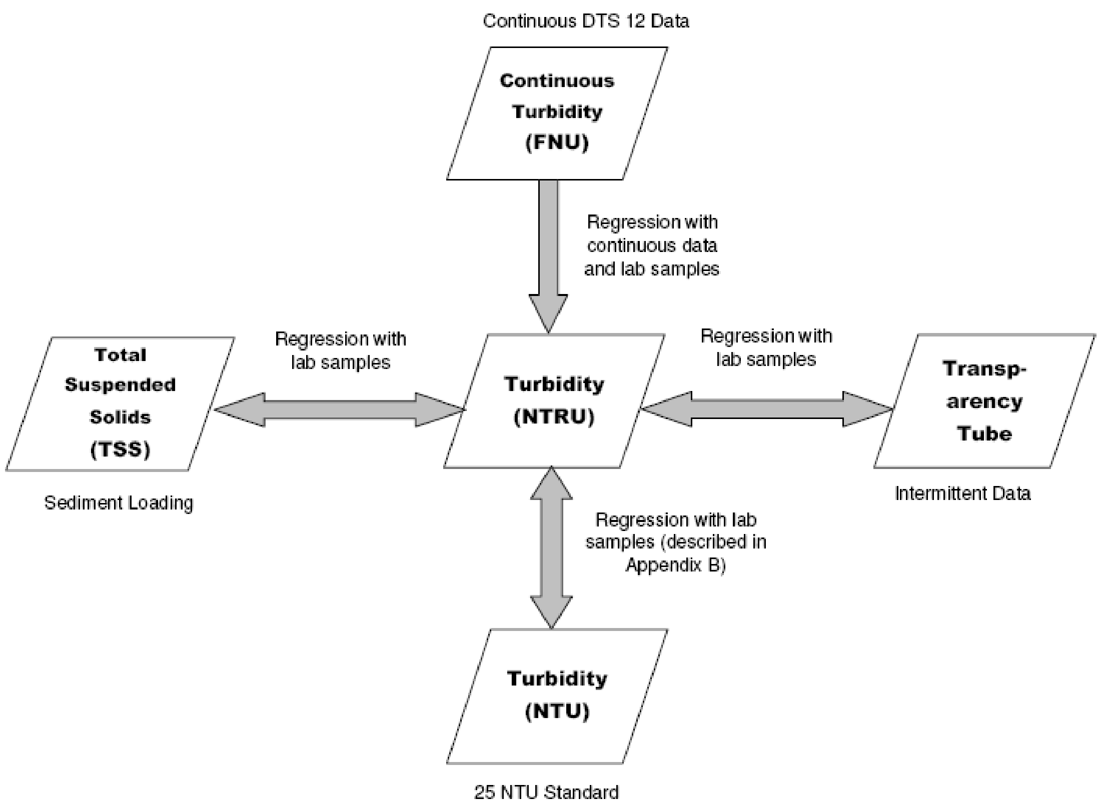
Turbidity in streams is derived from suspended sediments, organic material, dissolved salts and stains. This analysis will focus primarily on the suspended sediment and organic material components, as they appear to be the primary factors of turbidity in this watershed. In order to evaluate and establish loads the surrogate measure of total suspended solids (TSS) is used. This parameter shows a good correlation with turbidity, based on regressions done on the monitoring data for each of the impaired stream reaches for this project. Table 2 shows how the turbidity standard of 25 NTU is equivalent to TSS concentrations that range from 48 to 92 mg/L for these datasets, after applying the conversion factor described in Appendix C to each of the turbidity-TSS regression equations.

Turbidity is a parameter that has a significant amount of variability associated with the measurement values reported. Unlike many water quality parameters which are a measurement of mass of constituents in a volume of water, turbidity is a measure of the optical properties of a water sample which causes light to be scattered and absorbed (Federal Water Pollution Control Administration, 1968). Differences in the constituents' response to light contribute to the variability in turbidity readings. Adding to this variability, differences between turbidity meter types can result in different turbidity values being measured for the same water samples.

The MPCA's Turbidity TMDL Protocol (MPCA, 2007) identified the need to use the turbidity reporting units/categories adopted by the United States Geological Survey (USGS) to differentiate data sets by type of turbidity meter. The MPCA began using the reporting categories for data being entered into STORET in 2005. The protocol identified a list of options/recommendations to use/follow when a project has one or more types of turbidity data. The difficulty of selecting a "method" from this list of options became apparent fairly quickly for various reasons in developing the TMDLs in Minnesota. In the past, water samples had been analyzed by laboratories measuring turbidity as NTU, while more recent samples collected within the Zumbro River watershed have been analyzed by the MDH Lab measuring turbidity as NTRU. Fortunately, both turbidimeters had previously been used to test some of the same samples as part of the Minnesota River Turbidity TMDL project. Appendix C describes and fully documents the statistical relationship between the paired data to provide a "conversion" factor for estimating NTU values from measured NTRU values for use in this project given the absence of paired measurements with each meter.

Water quality duration curves were developed for each of the impaired reaches based on the most complete turbidity (or turbidity surrogate) dataset available. Continuous turbidity probe measurements typically provided the most complete dataset at most of the impaired stream reaches, followed by lab turbidity samples and transparency tube readings. Lab turbidity samples were typically collected at stream monitoring sites coincidental with the continuous turbidity measurements, while duration curves developed with transparency tube readings did not typically have coincidental lab turbidity samples. Table 2 shows that the water quality duration curves for nine of the seventeen turbidity-impaired reaches are based on continuous turbidity data and continuous flow data. Turbidity probes (DTS-12s, manufactured by Forest Technology Services (FTS)) installed at gauge locations along these reaches recorded turbidity data (in FNU units) at 15 minute intervals. To compare these turbidity data to the target of 25 NTU, two conversions were used. The pairs of turbidity data where the date and time of an automated, 'continuous' measurement matched the date and time of a sample sent to a laboratory were used to construct a linear FNU – NTRU relationship on a site by site basis. The conversion equation from Appendix C was then applied to convert NTRU measurements to NTUs. The NTRU turbidity equivalent to the 25 NTU turbidity standard is 39 NTRU based on a regression of all pairs of laboratory turbidity (NTU and NTRU) samples collected in a previous study (as described in Appendix C). The relationships between turbidity measurement units and TSS are shown in Figure 2. Appendix D contains a detailed description of the process used for all conversions of the data.

Figure 2. Data Relationships Diagram.



Similarly a regression of paired laboratory data was used to compare TSS to turbidity in NTRU units, based on the best-fit regression model. For stream reaches that had only transparency tube data available, the TSS equivalent from an adjacent AUID was used in the load duration curve development (the TSS equivalent is noted in the text of each AUID subsection of section 3.4). These regressions may also be found in Appendix D.

For the impaired stream reaches that did not have a flow gauge site or where the downstream tributary area did not correspond directly with a flow gauge site, Table 2 shows the flow gauge site that was used to develop the duration curves. The estimated loadings were adjusted based on ratio of the drainage area for the impaired reach to the tributary area of the flow gauge used (shown in Table 2).

Section 3.4 discusses the TMDL allocations for TSS loading for each of the individual impaired reaches. As described in Section 2.1, each stream reach is listed as impaired for turbidity when greater than ten percent of the data points collected in the previous ten-year period exceed the 25 NTU standard. The calculated Total Maximum Daily Load (TMDL) of TSS that serves as the loading capacity for each reach is based on the TSS concentration equivalent to the 25 NTU standard as the upper limit for an allowable load of sediment.

Table 2. Relationships between turbidity and total suspended solids.

						Equivalent to 25 NTU				
Report Section	App. F Site #	Reach	Description	River AUID	Duration Curve Data Source	Turbidity (FNU)	(NTRU)	TSS (mg/L)	Transparency Tube (cm)	Flow Gauge Used
3.4.1	2	Silver Creek	Unnamed cr to Unnamed cr	07040004 -552	Continuous Turbidity and Lab Samples	52	39	67		Silver Creek @ CR 155 bridge
3.4.2		Silver Creek	Unnamed cr - Silver Lk (SF Zumbro)	07040004 -553	Transparency Tube				15	Silver Creek @ CR 155 bridge
3.4.3		Bear Creek Tributary	Unnamed cr to Unnamed cr	07040004 -556	Transparency Tube				15	Bear Creek @ US 14
3.4.4		Bear Creek	Headwaters to Willow Cr	07040004 -539	Transparency Tube				15	Bear Creek @ US 14
3.4.5		Willow Creek	Headwaters to Bear Cr	07040004 -540	Transparency Tube				15	Bear Creek @ US 14
3.4.6	1	Bear Creek	Willow Cr to SF Zumbro R	07040004 -538	Continuous Turbidity and Lab Samples	71	39	72		Bear Creek @ US 14
3.4.7	3	Zumbro River, South Fork	Salem Cr to Bear Cr	07040004 -536	Continuous Turbidity and Lab Samples	57	39	70		SF Zumbro @ Hwy 14
3.4.8		Cascade Creek	Headwaters to Unnamed cr	07040004 -639	Transparency Tube				15	Cascade Creek @ 7th St NW
3.4.9	4	Cascade Creek	Unnamed Cr to SF Zumbro R	07040004 -581	Continuous Turbidity and Lab Samples	66	39	62		Cascade Creek @ 7th St NW
3.4.10		Kings Run	Unnamed Cr to Unnamed Cr	07040004 -601	Transparency Tube				15	SF Zumbro @ 90th St
3.4.11	5	Zumbro River, South Fork	Cascade Cr to Zumbro Lk	07040004 -507	Continuous Turbidity and Lab Samples	46	39	69		SF Zumbro @ 90th St
3.4.12		Dodge Center Creek	JD 1 to SBMF Zumbro R	07040004 -592	Transparency Tube				15	SBMF Zumbro @ 272nd St, Mantorville
3.4.13		Zumbro River, Middle Fork, South Branch	Headwaters to Dodge Center Cr	07040004 -526	Transparency Tube				15	SBMF Zumbro @ 272nd St, Mantorville
3.4.14	7	Zumbro River, Middle Fork, South Branch	Dodge Center Cr to MF Zumbro R	07040004 -525	Continuous Turbidity and Lab Samples	74	39	70		SBMF Zumbro @ 272nd St, Mantorville
3.4.15		Milliken Creek	Unnamed cr to Unnamed cr	07040004 -554	Continuous Turbidity and Lab Samples	47	39	48		Milliken Creek @ CSAH 9
3.4.16	6	Zumbro River, Middle Fork	Headwaters to NBMF Zumbro R	07040004 -522	Continuous Turbidity and Lab Samples	57	39	71		MF Zumbro @ CSAH 3, Pine Island
3.4.17	12	Zumbro River	West Indian Cr to Mississippi R	07040004 -501	Continuous Turbidity and Lab Samples	51	39	92		Zumbro R. @ Kellogg

Notes: 1. In-stream continuous turbidity measured with DTS-12 instrument, in FNU
2. Laboratory samples sent to Minnesota Department of Health, St. Paul (MDH), Hach 2100AN turbidimeter measured in NTRU
3. See Appendix D for data conversion methods and regressions.

3.2 Turbidity Sources and Current Contribution

Conclusions regarding turbidity sources and current loading are based largely on analysis/interpretation of the available data and information. Various sources of information are used in the analysis including water quality data collected and other MPCA information, soil and land use information, and a memorandum that details the results of several Zumbro watershed stream surveys (included as Appendix E).

A simplified turbidity conceptual model is presented in Figure 3 that shows several possible candidate sources. This figure illustrates both potential sources and pathways for sediment and phosphorus. Phosphorus is included since it can contribute to turbidity through production of algae during lower flow periods or in low-gradient/low-velocity portions of the streams or in lakes/ponds and reservoirs. Both “external” and “internal” sources are illustrated in this figure. Most point and nonpoint sources are typically considered external in that they are located in the watershed outside of the stream or river channel yet contribute TSS and turbidity in some manner. TSS contribution from point sources is more easily quantified, while the effects due to nonpoint sources are harder to define and measure. Internal sources typically encompass processes that occur within the channel (including the bed and banks) or the floodplain of a waterway, stream, or river. Such processes include channel and floodplain erosion or scour, and bank slumping. Algae growth and decay could be considered an internal process though the phosphorus that drives its production is generally from external sources. The components of this conceptual model, as they pertain to this watershed, are evaluated below. Following these component descriptions, Figure 3 identifies which nonpoint turbidity sources are likely contributors for each impaired reach based on the best available information.

Feedlots with pollution hazards

Feedlots near streams and watercourses with pollution hazards can contribute to excess turbidity via soil and phosphorus runoff. Overall, this source appears to represent a relatively low contribution in this watershed. However, on a site-specific basis some of these facilities may be a contributor to the problem and should be addressed.

Livestock in riparian zone

Livestock overgrazing in riparian areas can contribute to excess turbidity via soil and phosphorus runoff directly from devegetated areas, resuspending of sediments by walking in the stream, and by destabilizing the banks leading to increased bank erosion or slumping. While it does not appear that overgrazing in riparian pastures is a widespread chronic problem in the watershed this source contributes significant loadings per unit area and should be further identified and addressed.

Row cropland

Row cropland can contribute to excess turbidity via sheet/rill erosion of soil either overland or via surface tile intakes, wind-eroded soil settling in ditches that are then flushed during rain events, destabilization of banks (if inadequate buffers) leading to increased bank erosion, and also drainage alterations on cropped land can lead to increased flows which can then cause bank/bed erosion. Based on the National Land Cover Data (NLCD) 2001 land use coverage, row cropland includes both corn and soybean crops. The most recent crop survey statistics indicate corn and soybeans are grown on much of the harvested cropland in the watershed. Much of the poorly drained row cropland in the watershed has been tiled to improve drainage.

Inadequate Buffers

It is evident from field observation and aerial photos that cropping and livestock grazing activities are in many cases adjacent to intermittent and permanent waterways. Runoff may enter streams directly and is not slowed to allow sediments to filter out. During heavy rainfall and flooding events streams may rise to cover cropland and pastures, increasing soil loss and sediment loading directly to the stream.

Poorly vegetated ravines and gullies

It is evident from field observation and aerial photos that poorly vegetated ravines and ephemeral gullies are adjacent to intermittent and permanent waterways and classic gully erosion is occurring in other poorly vegetated areas of the watershed that receive concentrated flow. Runoff from these sources may enter streams directly and is not slowed to allow sediments to filter out. In some situations, these sources of sediment result from livestock overgrazing.

Ditches/channelization

Ditches and/or straightened stream segments can be turbidity sources. Such watercourses are shorter than the natural channel and, thus, steeper in gradient. As such they generally exhibit higher velocities and higher peak flows. Changes in gradient can result in head-cutting. Also, their geometry is such that there is limited access to the floodplain. Downcutting can occur, exacerbating the entrenchment of the watercourse and thus further keeping and concentrating flow energy in the channel. Straightened channels also exhibit a continuous tendency to revert to a meandering condition. The net result is increased potential for bank erosion. Temporary release of sediments also occurs during ditch and pond cleaning/dredging. Tiling exacerbates the condition by increasing the volume and peak rate of runoff to the system.

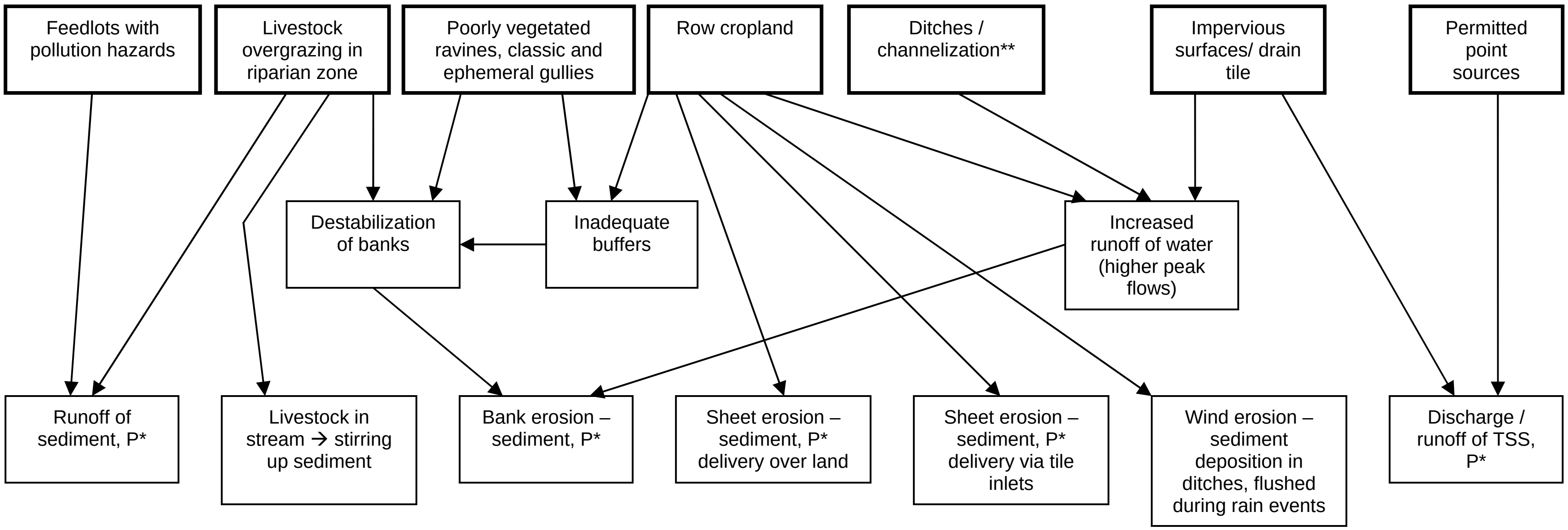
A full assessment of the influence of ditches/channelization/tiling in terms of turbidity is difficult and there are no specific monitoring data that provide a breakdown of contributions for upland erosion versus these near-channel sources. Engstrom (2007) reported that 68, 82 and 89 percent of TSS loading from snowmelt runoff samples originated from riverine sources of sediment in the Cottonwood River, Watonwan River, and Blue Earth River watersheds, respectively, based on a sediment fingerprinting study conducted in the Minnesota River basin. While these results may not be applicable to the entire Zumbro River watershed, they may translate well to the western lobe (Dodge and

Goodhue counties). Sediment fingerprinting in the Root River watershed is underway and will translate well to the Zumbro River watershed, including the eastern lobe (the blufflands).

Impervious surfaces

Impervious surfaces (roads, parking lots, roofs, etc.) can contribute to excess turbidity directly via sediment and phosphorus delivery and indirectly via increased runoff of water leading to increased bank/bed erosion. The Zumbro River watershed includes one large urban area (City of Rochester) and many smaller municipalities. Rochester completed a nondegradation review in 2007 that documented significant mitigation of the increase in impervious surfaces via stormwater management practices. The land use for the Municipal Separate Storm Sewer Systems (MS4s) is detailed in Appendix B.

Figure 3. Simplified turbidity conceptual model of candidate sources and potential pathways.



* Phosphorus (P) can contribute to turbidity through production of algal blooms during lower flow periods or in low-gradient/low-velocity portions of stream.

** Ditches / channelization also can cause sediment delivery via:

- bank erosion as watercourses revert to original meandering
- scour erosion at side-inlets
- steeper gradient can cause headward erosion and downcutting (nickpoints may form; channel erodes nickpoint resulting in upstream scour)
- ditch cleaning / dredging

Point sources

Point sources, for the purpose of this TMDL, are those facilities/entities that discharge or potentially discharge solids to surface water and require a NPDES permit from the MPCA. In this watershed the point source categories are: wastewater treatment facilities, construction activities, municipal (for Rochester urbanized area) and industrial stormwater sources. NPDES permitted discharges for cooling water and industrial wastewater are included in the 'wastewater treatment facilities' category.

Each of the wastewater treatment facilities in the watershed have calendar month average effluent TSS limits ranging from 20 to 45 mg/L TSS. By design of their respective permits, these facilities (listed in Appendix A) help to attain and maintain the turbidity water quality standard in their receiving waters.

Regarding construction, the MPCA issues permits for any construction activities disturbing one acre or more of soil; or less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre; or less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. Although stormwater runoff at construction sites that do not have adequate runoff controls can be significant on a per acre basis (MPCA Stormwater web page, 2006), the number of projects per year in this predominantly rural watershed is relatively small. Therefore, this source appears to be a very minor turbidity source.

Regarding MS4-permitted stormwater runoff, approximately 34,000 acres (53 square miles) from the city of Rochester and surrounding urbanized areas drains to the South Fork of the Zumbro River (AUID 07040004-507) and its tributaries. Table 2 shows that discharge to the South Fork of the Zumbro River should meet the 25 NTU turbidity standard as long as the TSS concentration in the stormwater runoff from the MS4 area remains at or below 69 mg/L on average. However, the total TSS loading from MS4 areas must also be considered. The MS4 wasteload allocations presented in the tables of Section 3.4 are based on the TSS concentration that corresponds to a turbidity reading of 25 NTU in each reach, and the flow rates that correspond with each flow zone for each of the impaired reaches in the Zumbro River watershed.

Regarding industrial stormwater sources, there are thirteen water discharge permit holders in the watershed according to the MPCA's DELTA database. These are mainly gravel pits, and do not appear to represent a TSS loading concern in this watershed if facilities are discharging at permitted TSS limits and design flows. (For the purpose of the TMDL this source is lumped with construction stormwater into a categorical WLA.)

3.3 Methodology for Load Allocations, Wasteload Allocations and Margins of Safety

The TMDLs developed for the stream reaches in this report consist of three main components: WLA, LA, and MOS as defined in Section 1.0. The WLA includes three sub-categories: permitted wastewater facilities with TSS limits, the MS4 permitted stormwater source category, and a construction plus industrial permitted stormwater category. The LA, reported as a single category, includes the nonpoint sources described in the previous section. The third component, MOS, is the part of the allocation that accounts for uncertainty that the allocations will result in attainment of water quality standards.

The three components (WLA, LA, and MOS) were calculated as total daily load of TSS. As described in Section 3.1 this parameter is used as a surrogate for turbidity based on a good correlation between the two. While it is noted that nutrients (i.e., phosphorus) may impact suspended solids concentrations (and thus turbidity) at some stream reaches at certain times of the year, there is not sufficient data to establish a correlation between nutrients, algae and turbidity upon which to base loading allocations. However, water quality data and field observations suggest that algal turbidity has a very limited impact on overall turbidity in the Zumbro River watershed. Regarding implementation though, it should be noted that reducing the delivery of sediment will also reduce the delivery of nutrients and nutrient reduction should be considered when sediment reduction practices are implemented.

The methodology to derive and express the TSS load components is the duration curve approach, described in Appendix D. For each impaired reach and flow condition, the total loading capacity or “TMDL” was divided into its component WLA, LA, and MOS. It should be noted that this method implicitly assumes that observed stream flows and flow regimes must remain constant over time. The process for computing each component of the TMDL is described below.

3.3.1 Wasteload Allocation

Load duration curves were developed to establish these TMDLs at levels necessary to attain and maintain applicable water quality standards. The nature of the NPDES permits written for the various categories of point source dischargers, appropriate measures for achieving compliance with the TSS wasteload allocation are described as follows.

Industrial & Municipal Wastewater Treatment Facilities: Individual WLAs
All wastewater treatment facilities (municipal and industrial) in the Zumbro River watershed are permitted to discharge TSS at a concentration (20-45 mg/l) that is below the lowest surrogate (48 mg/l) used in computing TMDLs for the seventeen impaired reaches and therefore serve to attain and maintain the turbidity water quality standard. Wasteload allocations for wastewater treatment facilities are mass-based, but expanding and new dischargers permitted at or below the lowest TSS surrogate (48 mg/l) will be added to the wasteload allocation via the NPDES permit public notice process (see Section 3.7). Potential impacts (including volume) of new or expanding discharges to low flow conditions in the watershed will be addressed via anti-degradation rules. Permitted wastewater treatment facilities and their wasteload allocations are listed in Appendix A.

Construction Stormwater: Categorical WLA
Given the transient nature of construction work, these loads are difficult to quantify. Construction storm water activities are required to meet the conditions of the Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

Industrial Stormwater: Categorical WLA
Given the lack of design flows and concentration limits, these loads are difficult to quantify. Industrial storm water activities are required to meet the conditions of the industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

Municipal Separate Storm Sewer Systems (MS4s): Categorical WLAs
MS4s are apart from the preceding three categories of point source dischargers in that they have the potential to encompass large land areas and thus generate significant runoff to surface waters during high flow conditions; thus they have the potential to change over time the flow duration characteristics of a given stream reach. They have no design flows or numeric loading limits. Their compliance with the provisions of the TMDL will be based on implementation of performance measures as part of a phased approach in pursuit of water quality goals.

Methodology

The methodology for developing the WLAs was as follows:

- The permitted wastewater and water treatment facility WLAs were determined based on their permitted discharge design flow rates and their permitted TSS concentration limits or their permitted daily loading rates, whichever were higher. Appendix A includes permitted loading rates for all permitted wastewater facilities in the watershed. The tables in Section 3.4 include the overall wastewater allocations for each impaired reach. The TSS concentration limit is 30 mg/L for most treatment facilities, and estimated at 5 mg/L for cooling water and groundwater discharges. Several stabilization pond wastewater treatment plants with a TSS concentration limit of 45mg/L exist within the Zumbro River watershed. Permitted daily loading rates for these ponds were calculated by multiplying the average daily discharge volume, which is six inches of pond water depth, by the 45mg/L concentration limit. However, these ponds do not discharge continuously.
- Construction stormwater and industrial stormwater are lumped together into a categorical WLA based on an approximation of the land area covered by those activities. To account for these sources, for which the MPCA does not have readily accessible acreage data, as well as reserve capacity (to allow for the potential of higher rates of construction and additional industrial facilities), this TMDL assumes 0.1 percent of the land area for a combined construction and industrial stormwater category. The allocation to this category is made after the MOS is subtracted from the total loading capacity. That remaining capacity is divided up between construction and industrial stormwater, permitted MS4s and all of the nonpoint sources (the LA) based on the percent land area covered. See Appendix B for MS4 details.
- As indicated above the allocation for communities subject to MS4 NPDES stormwater permit requirements is made after the MOS is subtracted from the total loading capacity. The allocation for the MS4 is based on the percentage of the land area in the impaired reach watershed that the MS4 permit covers. For this TMDL the permitted MS4 categorical area includes the City of Rochester, Federal Medical Center, Rochester Community and Technical College, roads and land owned by Olmsted County and MN DOT, and surrounding urbanized portions of Cascade, Haverhill, Marion, and Rochester Townships. Area considered as part of the MS4 urbanized area included the non-agricultural portions of planned 2020 Rochester land use, and urbanized township areas as defined by the 2000 Census. The MS4 wasteload allocations can be exchanged within the jurisdictional boundaries of the MS4s because they are based on the TSS concentration (from Table 2) that corresponds to a turbidity reading of 25 NTU for each of the impaired reaches (the downstream receiving waters). As a result, the areal TSS loading rate allocated for urban or urbanizing areas will be the same regardless of whether the contributing area is subject to the WLA (MS4) or LA portion of the TMDL. See Table 3 for a list of the MS4s areas.
- In two instances (both of the Silver Creek reaches), the loading capacity in the low flow zone is very small due to the occurrence of very low flows in the long-

term flow records. Because these values approach zero, it is not useful to compute numeric allocations. To account for these unique situations only, the WLAs are expressed as equations rather than absolute numbers, according to the methodology described in this section:

Loading Capacity = (stream flow) * (stream's TSS equivalent to 25 ntu)
MOS = (loading capacity) * 10%
MS4 WLA = (MS4% in AUID watershed) * (loading capacity)
Construction and industrial stormwater wasteload allocation =
(0.01%) * (loading capacity)

3.3.2 Margin of Safety

- The purpose of the MOS is to account for uncertainty that the allocations will result in attainment of water quality standards. For this TMDL an explicit ten percent (10%) MOS is applied. This percent is derived from the statistics used to estimate water quality standard (25 NTU) TSS equivalents for the impaired reaches (see Appendix D, Table D1: the average r-squared values are > 0.90; 10% rounds down to 0.90). This is expected to provide an adequate accounting of uncertainty, especially given that wastewater treatment facilities have generally demonstrated consistent meeting of TSS discharge limits and in the case of wastewater facilities with pond systems, discharge only during spring and fall windows (i.e., before June 15 and after September 15). Also, the mechanisms for soil loss from agricultural sources and the factors that affect this have been extensively studied over the decades and are well understood. Agricultural BMPs have been targeted for soil loss prevention (see section 5.0 and Appendix F). Follow-up effectiveness monitoring will provide a means to evaluate installed BMPs in terms of compliance with WLAs and LAs and progress or achievement of the TMDL. The MOS cannot be used as reserve capacity.

Table 3. MS4s and Associated Areas

MS4 Jurisdiction	NPDES Permit Tracking #	Area (Square Miles)
Cascade Township	MS400071	4.16
Federal Medical Center	MS400175	0.17
Haverhill Township	MS400137	1.22
Marion Township	MS400145	3.18
Olmsted County	MS400064	0.85
Rochester Community & Technical College	MS400256	0.16
Rochester	MS400116	36.36
Rochester Township	MS400152	2.81
Right-of-Way **	MS400180	4.41
TOTAL		53.30

** Right-of-Way area includes State, County, and Local road and highway jurisdictions. Right-of-Way Permit # listed is for MN DOT Outstate District - Rochester

- For the impaired reaches in which the allocation for the dry and low flow zones required use of an alternative method of calculation, an implicit MOS was used. An implicit MOS means that conservative assumptions were built into the TMDL and/or allocations. In this instance the reaches are expected to meet the TMDL because the permitted point source dischargers are limited to discharge concentrations below the TSS target, thereby providing additional capacity. In addition, there is little or no overland runoff or MS4 discharge and the stream flow is primarily being fed by ground water at these low flows, which is believed to convey very little TSS. An additional conservative assumption relates to reaches with discharges from wastewater facilities with pond systems that discharge only in spring and fall, as indicated above: for a significant portion of the year much of the WLA is not being used.

3.3.3 Load Allocations

- Once the WLA and MOS were determined for a given reach and flow zone, the remaining loading capacity was considered LA. The LA includes nonpoint pollution sources that are not subject to NPDES permit requirements, as well as “natural background” sources such as low levels of soil/sediment erosion from both upland areas and the stream channel. The nonpoint pollution sources were described previously and include upland and riparian erosion and bank/bed erosion, as well as the other sources.

3.4 TMDL Allocations for Individual Impaired Reaches

In the sections below TMDL allocations are provided for the individual impaired reaches (indicated in Figure 1). Calculations for the TMDL, LA, WLA and MOS consider the total drainage area represented by the end of the listed reach. Water quality duration curves which integrate flow and the measured turbidity to illustrate the loading capacity across the flow record, as well as comparisons to the loading capacity using collected water quality data and TSS equivalents are also included in each section (see explanation in Appendix D). The TSS equivalent used in calculations is from Table 2. TSS equivalents are based on data from each flow gauge, not necessarily each individual impaired reach because laboratory samples were not gathered for all reaches (some reaches had field measurements—transparency tube readings—only). Duration curves that integrate flow and the transparency tube equivalent to the turbidity standard are provided in the sections that discuss the reaches that were listed based on transparency tube readings.

Discussion of TSS load reduction targets is included for each reach. It should be noted that these numbers describe the magnitude of the load exceedance that occurs during specific flow conditions (typically very high and high flows). Continuous turbidity data collected during the course of this project can be used in the implementation planning process to further examine percent exceedance and magnitude of exceedance of the turbidity standard for these stream reaches.

3.4.1 Silver Creek; Unnamed Cr to Unnamed Cr (AUID: 07040004-552)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The drainage area to the downstream end of this impaired reach is about 18 square miles. This drainage area mainly exists within the Rochester Plateau, Blufflands, and Undulating Plains agroecoregions, with a small region of Alluvium & Outwash, entirely within Olmsted County. Primary sources and causal factors contributing to sediment loading within this area are streambank erosion, row cropland, and inadequate buffers near streams and intermittent waterways. Frequent bank erosion was noted in the 2007 survey of Silver Creek (see Appendix E) and it appears that the stream is eroding a narrower, deeper channel.

One cooling water discharge exists within the land area that drains to this listed reach (Appendix A). There are no wastewater treatment facilities. There is just over one square mile of urbanized land area subject to NPDES MS4 regulations that drains to this reach (6.8% of the watershed area).

Table 4 provides the average total suspended solids loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 67 mg/L (from Table 2). The loading capacities for the five flow zones were developed using flow data from 2007-2008 from the gauge site identified in the MPCA STORET database as S001-572, Silver Creek @ CR 155 Bridge.

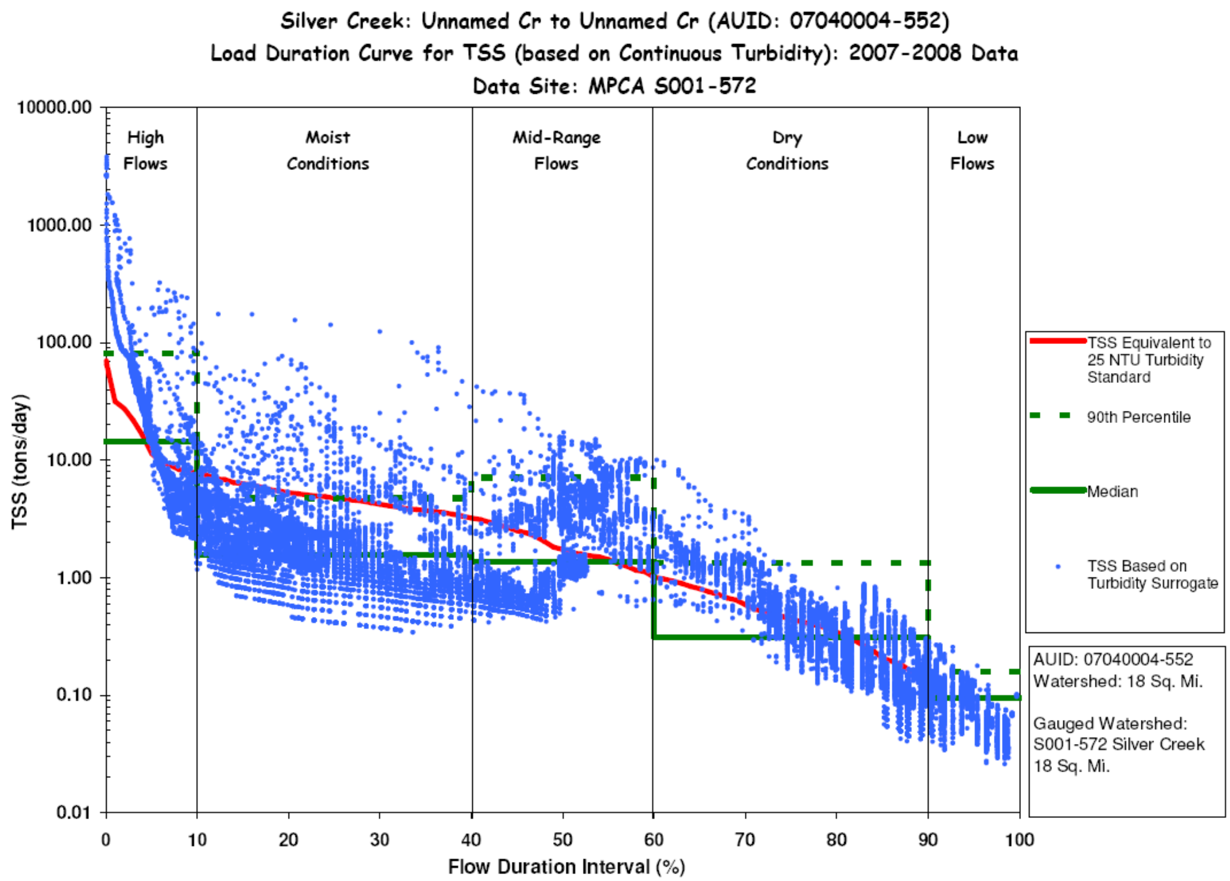
The water quality duration curve (Figure 4) for the available dataset indicates exceedance of the target during high and mid-range flows and also during dry conditions. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 65 percent at high flows, 70 percent at mid-range flows, and 30 percent during dry conditions. The highest turbidity is observed to occur during the highest flow and it is also evident that mid-range flows are almost as turbid.

Table 4. Total suspended solids loading capacities and allocations (AUID: 07040004-552).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	11.35	4.75	1.74	0.44	<0.001
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	<0.001	<0.001	<0.001	<0.001	**
Communities Subject to MS4 NPDES Requirements	0.70	0.29	0.11	0.03	**
Construction and Industrial Stormwater	0.01	0.004	0.002	<0.001	**
Load Allocation	9.50	3.97	1.46	0.37	**
Margin of Safety	1.13	0.47	0.17	0.04	Implicit
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	<0.1%	<0.1%	<0.1%	0.1%	**
Communities Subject to MS4 NPDES Requirements	6.2%	6.2%	6.2%	6.2%	**
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	**
Load Allocation	84%	84%	84%	84%	**
Margin of Safety	10%	10%	10%	10%	Implicit

* The facility is listed in Appendix A.
** See Section 3.3 for allocations for these specific categories in this flow zone.

Figure 4. Load Duration Curve (AUID: 07040004-552).



3.4.2 Silver Creek; Unnamed Cr to Silver Lk S Fk Zumbro R. (AUID: 07040004-553)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The drainage area to the downstream end of this impaired reach is about 19 square miles, only slightly larger than the area draining to AUID 07040004-552. The drainage area of the listed stream mainly exists within the Rochester Plateau and Blufflands agroecoregions with smaller regions of Undulating Plains and Alluvium & Outwash, entirely within Olmsted County. Primary sources and causal factors contributing to sediment loading within this area are streambank erosion (observed), row cropland, and inadequate buffers near streams and intermittent waterways, as well as impervious area from urbanization on the outskirts of Rochester.

One cooling water discharge exists within the land area that drains to this listed reach (Appendix A). There are no wastewater treatment facilities. Most of the urbanized area subject to NPDES MS4 regulations is in the downstream portion of the land that drains to this reach, a total of about two and one half square miles (12.5% of watershed area).

Table 5 provides the average total suspended solids loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 67 mg/L (from Table 2). The TSS concentration and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the gauge site identified in the MPCA STORET database as S001-572, Silver Creek @ CR 155 Bridge.

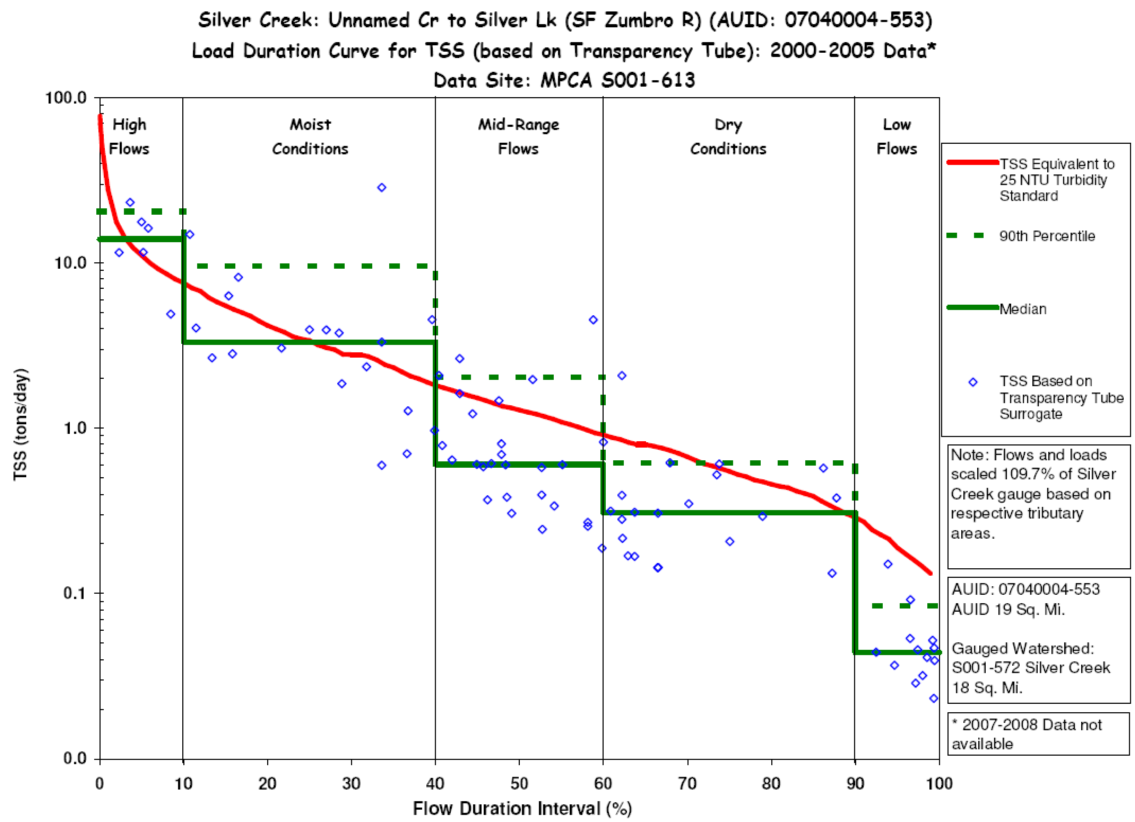
Table 5. Total suspended solids loading capacities and allocations (AUID: 07040004-553).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	12.45	5.21	1.91	0.49	<0.001
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	<0.001	<0.001	<0.001	<0.001	**
Communities Subject to MS4 NPDES Requirements	1.40	0.59	0.21	0.05	**
Construction and Industrial Stormwater	0.01	0.005	0.002	0.0004	**
Load Allocation	9.80	4.10	1.50	0.38	**
Margin of Safety	1.25	0.52	0.19	0.05	Implicit
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	<0.1%	<0.1%	<0.1%	0.11%	**
Communities Subject to MS4 NPDES Requirements	11.2%	11.2%	11.2%	11.2%	**
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	**
Load Allocation	79%	79%	79%	79%	**
Margin of Safety	10%	10%	10%	10%	Implicit

* The facility is listed in Appendix A.
** See Section 3.3 for allocations for these specific categories in this flow zone.

The transparency tube reading duration curve (Figure 5) for the available dataset indicates exceedance of the target during all flow regimes except low flow. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by 50 percent at high flows, 40 percent during moist conditions 20 percent at mid-range flows, and 10 percent during dry conditions. Note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings correspond to higher turbidity. Since the drainage area of this impaired segment overlaps the drainage area of the previous (AUID -552), it would be expected that the highest turbidity is observed to occur during the highest flow, which is the case. With far fewer measurements in the data set it is not possible to distinguish the same high-turbidity pattern during mid-range flows.

Figure 5. Load Duration Curve (AUID: 07040004-553).



3.4.3 Bear Creek Tributary; Unnamed Cr to Unnamed Cr (AUID: 07040004-556)

This reach was added to the Section 303(d) Clean Water Act impaired waters list in 2006. The drainage area to the downstream end of this reach is about 4.5 square miles. The drainage area of the listed stream exists within the Undulating Plains, Blufflands, and Rochester Plateau, entirely within Olmsted County. Primary sources and causal factors contributing to sediment loading within this area are streambank erosion, row cropland, and inadequate buffers near streams and intermittent waterways.

There are no wastewater treatment facilities within the land area that drains to this listed reach. There is no land area subject to MS4 regulations that drains to the listed reach.

Table 6 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 71 mg/L (from Table

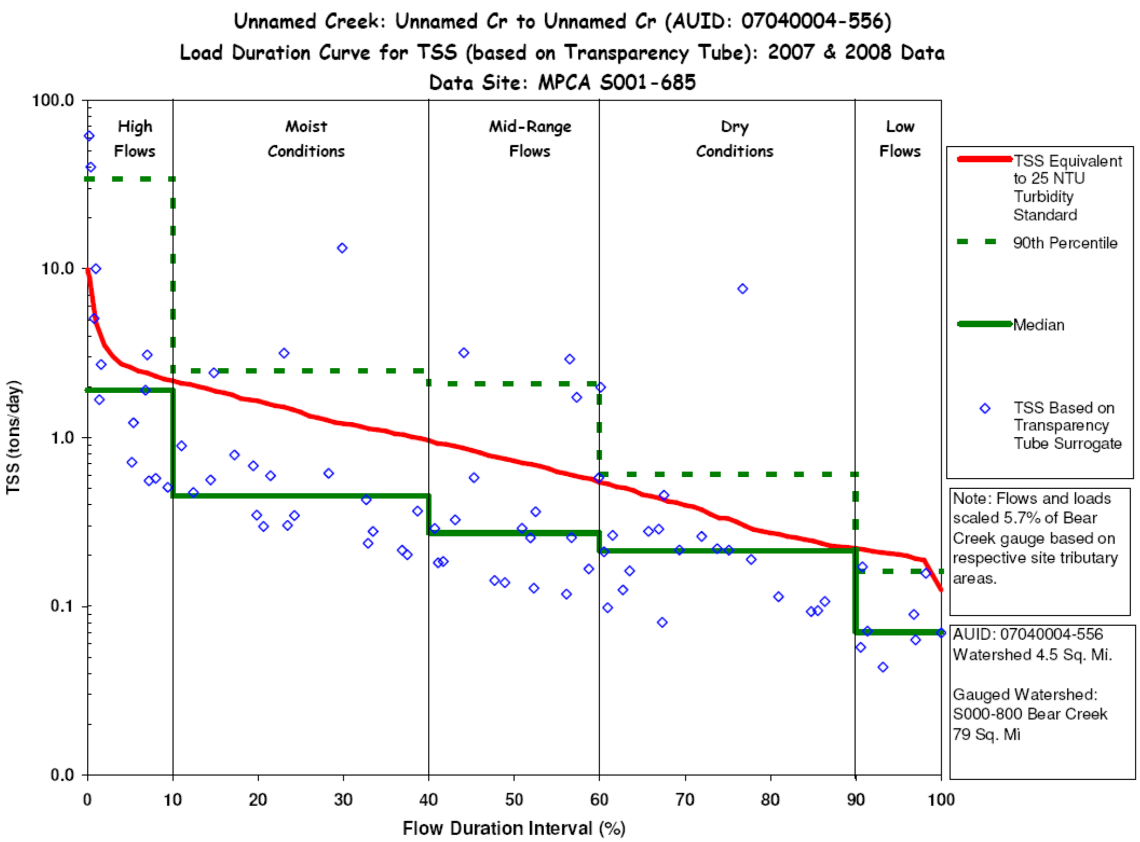
2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on Bear Creek at US 14 in Rochester (MPCA STORET S000-800).

Table 6. Total suspended solids loading capacities and allocations (AUID: 07040004-556).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	2.78	1.50	0.77	0.35	0.22
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.003	0.001	0.001	0.0003	0.0002
Load Allocation	2.50	1.35	0.69	0.32	0.19
Margin of Safety	0.28	0.15	0.08	0.04	0.02
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	90%	90%	90%	90%	90%
Margin of Safety	10%	10%	10%	10%	10%

The transparency tube duration curve (figure 6) for the available dataset indicates exceedance of the target in all flow ranges except low flows (90-100% flow duration interval). The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by 80 percent at high flows, 20 percent during moist conditions, 30 percent at mid-range flows, and 50 percent during dry conditions. Note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings correspond to higher turbidity.

Figure 6. Load Duration Curve (AUID: 07040004-556).



3.4.4 Bear Creek; Headwaters to Willow Cr (AUID: 07040004-539)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The drainage area to the downstream end of this reach is about 48 square miles. The drainage area of the listed stream exists mainly within the Rochester Plateau agroecoregion, with smaller areas in the Undulating Plains, Alluvium & Outwash, and Blufflands ecoregions, entirely within Olmsted County. Primary sources and causal factors contributing to sediment loading within this area are streambank erosion, row cropland, and inadequate buffers near streams and intermittent waterways. As detailed in Appendix E, a stream survey of this reach of Bear Creek revealed that streambanks were generally stable in 2007, but could be prone to erosion during high flow due to the sand streambed.

There are no wastewater treatment facilities within the land area that drains to this listed reach. Approximately 3.6 square miles of land area subject to MS4 regulations drains to this listed reach (7.6% of watershed area). If additional development is undertaken within this drainage area, the impervious surface may have a moderate effect in adding additional turbidity.

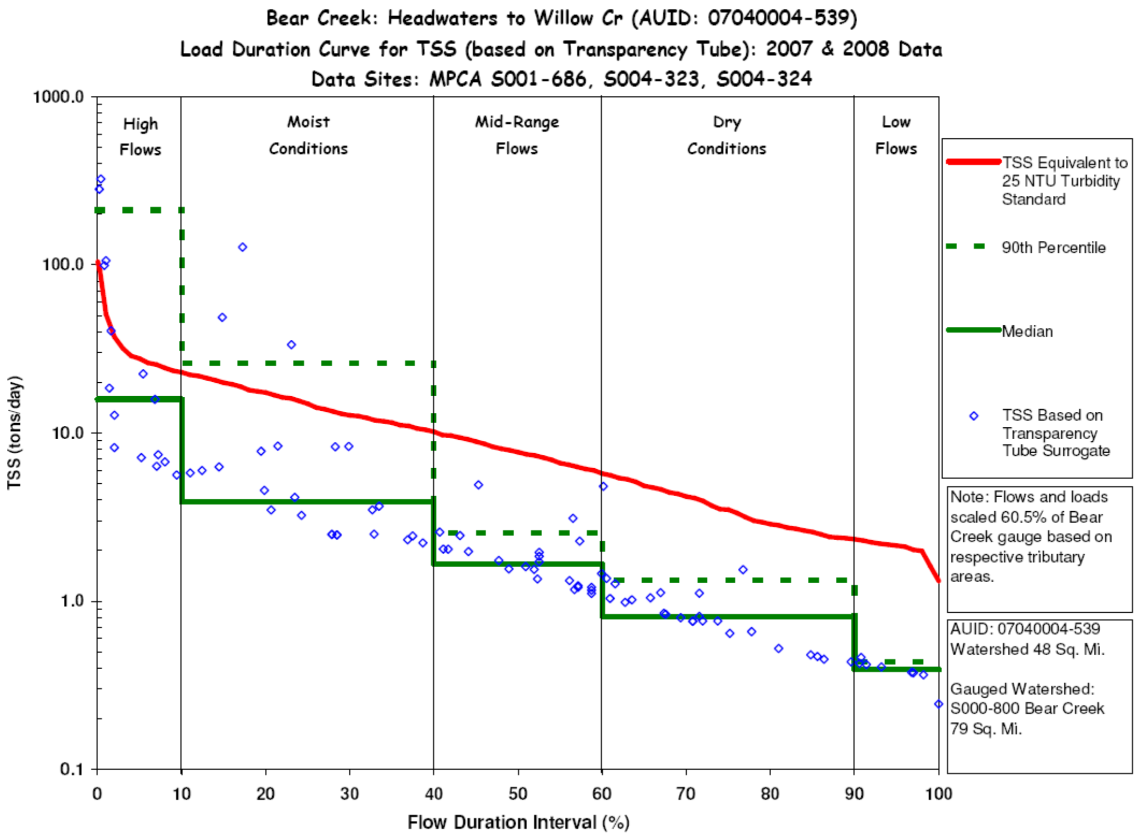
Table 7 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 71 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on Bear Creek at US 14 in Rochester (MPCA STORET S000-800).

Table 7. Total suspended solids loading capacities and allocations (AUID: 07040004-539).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	29.35	15.83	8.15	3.71	2.27
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	2.00	1.08	0.56	0.25	0.15
Construction and Industrial Stormwater	0.03	0.01	0.007	0.003	0.002
Load Allocation	24.39	13.15	6.78	3.08	1.89
Margin of Safety	2.93	1.58	0.82	0.37	0.23
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	6.8%	6.8%	6.8%	6.8%	6.8%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	83%	83%	83%	83%	83%
Margin of Safety	10%	10%	10%	10%	10%

The transparency tube duration curve (Figure 7) for the available dataset indicates exceedance of the target during high flow. Note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings correspond to higher turbidity. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 70 percent at high flows. The cluster of transparency tube readings at 60 cm in the dry conditions and low flow regimes indicates that water clarity often met or exceeded 60cm (the maximum tube measurement). Load reduction should be targeted to high flows in this impaired reach.

Figure 7. Load Duration Curve (AUID: 07040004-539).



3.4.5 Willow Creek; Headwaters to Bear Cr (AUID: 07040004-540)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The drainage area to the downstream end of this reach is about 29 square miles. The drainage area of the listed stream exists mainly within the Rochester Plateau agroecoregion, with smaller areas in the Alluvium & Outwash, Undulating Plains and Level Plains ecoregions, entirely within Olmsted County. Primary sources and causal factors contributing to sediment loading within this area are streambank erosion, impervious surfaces, row cropland, and inadequate buffers near streams and intermittent waterways.

There is one industrial wastewater discharger within the land area that drains to this listed reach (Appendix A), and there are about 9 square miles of land area subject to MS4 regulations that drain to this listed reach (31.8% of watershed area). If further development is undertaken within this drainage area, as is likely along the Highway 63 corridor from Rochester to the Rochester airport, the impervious surface may have a moderate effect in adding additional turbidity.

Table 8 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 71 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on Bear Creek at US 14 in Rochester, MPCA STORET S000-800.

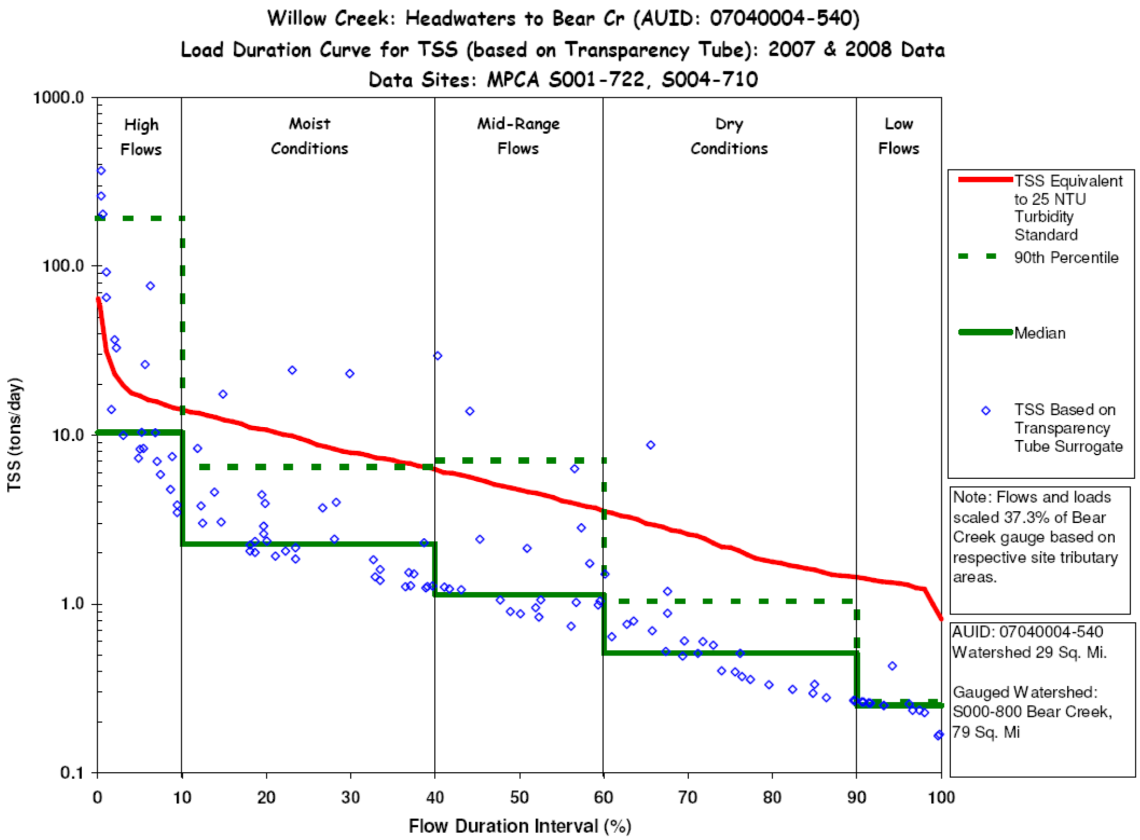
Table 8. Total suspended solids loading capacities and allocations (AUID: 07040004-540).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	18.11	9.77	5.03	2.29	1.40
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.02	0.02	0.02	0.02	0.02
Communities Subject to MS4 NPDES Requirements	5.17	2.79	1.43	0.65	0.39
Construction and Industrial Stormwater	0.02	0.01	0.005	0.002	0.001
Load Allocation	11.09	5.98	3.07	1.39	0.85
Margin of Safety	1.81	0.98	0.50	0.23	0.14
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.1%	0.2%	0.4%	0.9%	1.5%
Communities Subject to MS4 NPDES Requirements	28.6%	28.5%	28.5%	28.3%	28.1%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	61%	61%	61%	61%	60%
Margin of Safety	10%	10%	10%	10%	10%

* The facility is listed in Appendix A.

The transparency tube duration curve (Figure 8) for the available dataset indicates exceedance of the target during the high flow and moist conditions flow regimes. Note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings correspond to higher turbidity. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 80 percent at high flows and 35 percent during moist conditions. The cluster of transparency tube readings at 60 cm in the dry conditions and low flow regimes indicates that water clarity often met or exceeded 60cm (the maximum tube measurement).

Figure 8. Load Duration Curve (AUID: 07040004-540).



3.4.6 Bear Creek; Willow Cr to S Fk Zumbro R. (AUID: 07040004-538)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2008. The drainage area to the downstream end of this reach is about 82 square miles. The drainage area of the listed stream exists mainly within the Rochester Plateau agroecoregion, with smaller areas in the Alluvium & Outwash, Undulating Plains, and minimal area within the Blufflands and Level Plains agroecoregions, entirely within Olmsted County. Primary sources and causal factors contributing to sediment loading within this area are streambank erosion, impervious surfaces, row cropland, and inadequate buffers near streams and intermittent waterways.

There is one industrial wastewater discharger within the land area that drains to this listed reach (Appendix A), the same that is in the watershed draining to AUID 07040004-539. There are about 17 square miles of land area subject to NPDES MS4 regulations that drain to this listed reach (20.9% of watershed area) including much of southeastern Rochester.

Table 9 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 71 mg/L (from Table

2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on Bear Creek at US 14 in Rochester, MPCA STORET S000-800.

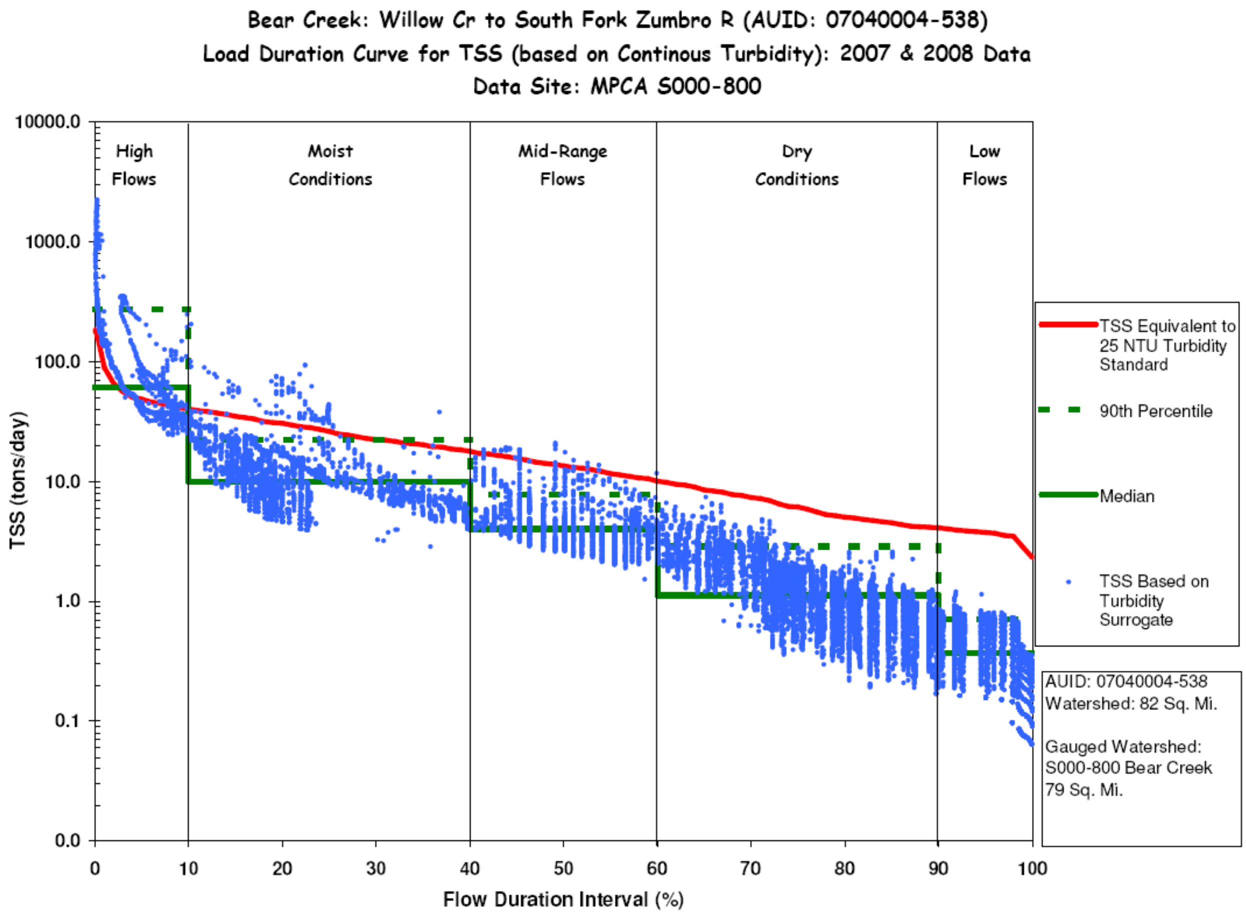
Table 9. Total suspended solids loading capacities and allocations (AUID: 07040004-538).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	50.37	27.17	13.99	6.37	3.90
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.02	0.02	0.02	0.02	0.02
Communities Subject to MS4 NPDES Requirements	9.48	5.11	2.63	1.20	0.73
Construction and Industrial Stormwater	0.05	0.02	0.013	0.006	0.003
Load Allocation	35.79	19.30	9.93	4.51	2.76
Margin of Safety	5.04	2.72	1.40	0.64	0.39
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	<0.1%	<0.1%	0.1%	0.3%	1%
Communities Subject to MS4 NPDES Requirements	18.8%	18.8%	18.8%	18.8%	18.7%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	71%	71%	71%	71%	71%
Margin of Safety	10%	10%	10%	10%	10%

* The facility is listed in Appendix A.

The water quality duration curve (Figure 9) for the available dataset indicates exceedance of the target during high flows. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 60 percent at high flows. The highest turbidity is observed to occur during the highest flow, which is expected because the tributaries to this impaired reach, Bear Creek and Willow Creek (AUIDs 0704004-539 and -540) exhibit the same trend. Unnamed Creek (AUID 0704004-556) shows turbidity impairment across much more of the flow duration interval, perhaps because more erosion is taking place in the steeper upstream portions of the Bear Creek watershed.

Figure 9. Load Duration Curve (AUID: 07040004-538).



3.4.7 Zumbro River, South Fork; Salem Cr to Bear Cr (AUID: 07040004-536)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The drainage area to the downstream end of this reach is about 156 square miles. The drainage area of the listed stream exists mainly within several agroecoregions, from the Level and Undulating Plains in the West transitioning to the Rochester Plateau and Blufflands near Rochester, with Alluvium & Outwash agroecoregion adjacent to the stream. The land area draining to this impaired reach is split roughly between Dodge County on the west and Olmsted County in the East. Primary sources and causal factors contributing to sediment loading within this area are row cropland, inadequate buffers near streams and intermittent waterways, streambed erosion, and impervious surfaces from the urbanized area. The 2007 stream survey showed that this impaired reach of the South Fork Zumbro River has not changed significantly over the last 14 years (Appendix E). The gravel streambed may minimize internal erosion in lower flows but would be mobile in high flows and thus susceptible to increased flows. Some of the flatter plains land in the western half of the watershed has been tiled to improve drainage of farm fields in poorly drained soils and would be expected to add flow volume in the stream.

There are two cooling water dischargers within the land area that drains to this listed reach (Appendix A). Approximately 7 square miles of land area subject to NPDES MS4 regulations drains to this listed reach, incorporating a large portion of southwestern Rochester. Other than this area the land area draining to this impaired reach is agricultural.

Table 10 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 70 mg/L (from Table 2). The relatively large area subject to MS4 regulations takes up a corresponding portion of the WLA. The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on the South Fork of the Zumbro River at US 14 in Rochester, MPCA STORET S004-385.

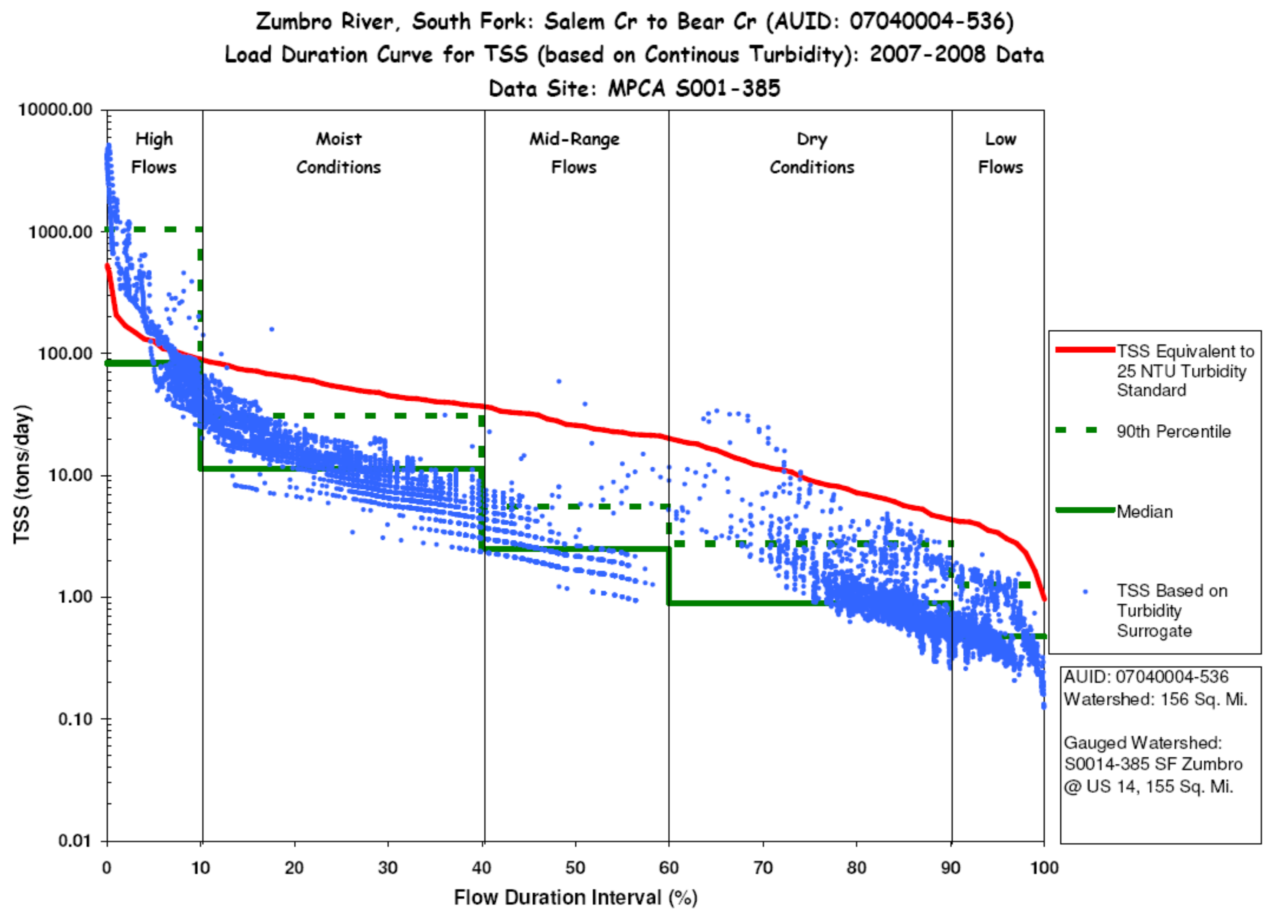
Table 10. Total suspended solids loading capacities and allocations (AUID: 07040004-536).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	128.04	53.48	25.98	9.18	3.43
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.04	0.04	0.04	0.04	0.04
Communities Subject to MS4 NPDES Requirements	4.95	2.07	1.00	0.35	0.13
Construction and Industrial Stormwater	0.12	0.05	0.023	0.008	0.003
Load Allocation	110.12	45.98	22.31	7.86	2.91
Margin of Safety	12.80	5.35	2.60	0.92	0.34
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	<0.1%	<0.1%	0.2%	0.4%	1%
Communities Subject to MS4 NPDES Requirements	3.9%	3.9%	3.9%	3.8%	3.8%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	86%	86%	86%	86%	85%
Margin of Safety	10%	10%	10%	10%	10%

* The facilities are listed in Appendix A.

The water quality duration curve (Figure 10) for the available dataset indicates exceedance of the target only during high flows. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 70 percent at high flows. The highest turbidity is observed to occur during the highest flow, which may be a result of streambed gravel mobility during these high flows.

Figure 10. Load Duration Curve (AUID: 07040004-536).



3.4.8 Cascade Creek; Headwaters to Unnamed Cr (AUID: 07040004-639)

This reach was added to the Section 303(d) Clean Water Act impaired waters list in 2006. The drainage area to the downstream end of this reach is about 20 square miles. The drainage area of the listed stream exists mainly within the Rochester Plateau, also within the Undulating Plains, Blufflands, and Level Plains agroecoregions. The majority of the land area draining to this impaired reach is within Olmsted County, except for the western, upper portion which is in Dodge County. Primary sources and causal factors contributing to sediment loading within this area are row cropland, inadequate buffers near streams and intermittent waterways, and runoff from impervious surfaces.

There are no wastewater treatment facilities within the land area that drains to this listed reach. Approximately 1.6 square miles of land area subject to MS4 regulations drains to the listed reach (8.1% of watershed area).

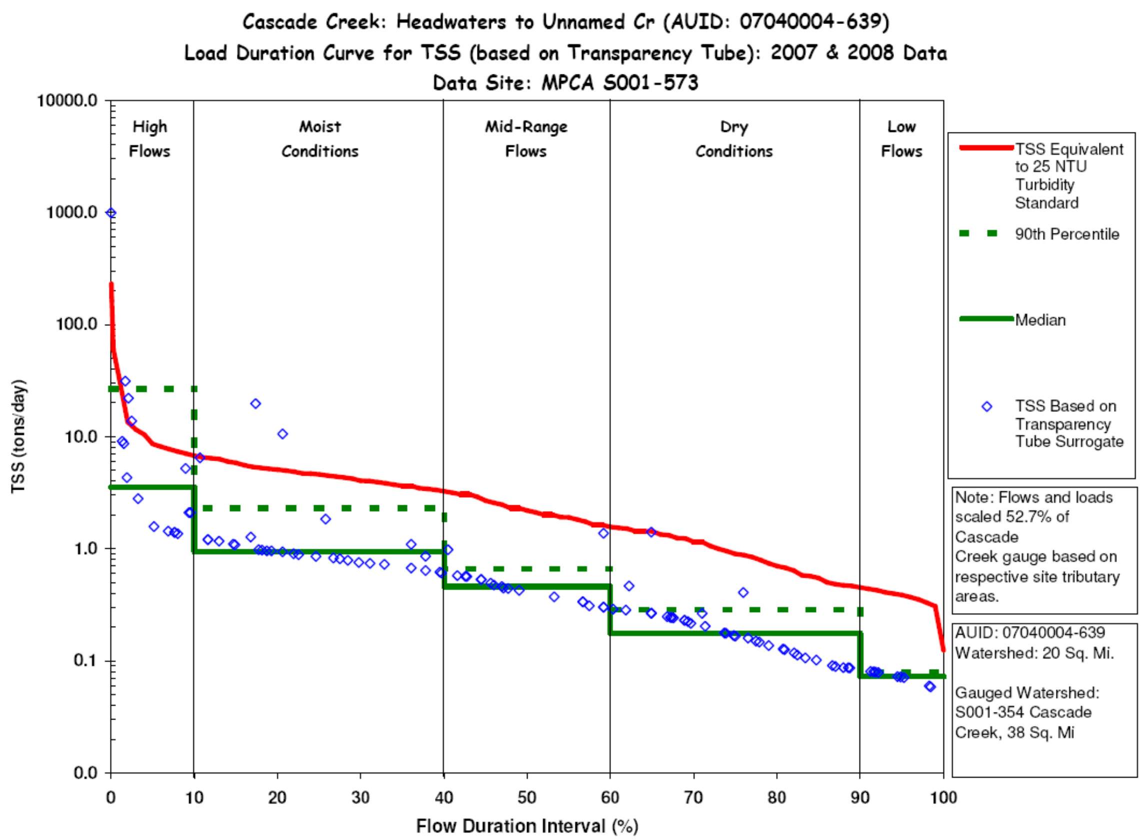
Table 11 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 62 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on Cascade Creek at 7th St NW in Rochester, MPCA STORET S001-354.

Table 11. Total suspended solids loading capacities and allocations (AUID: 07040004-639).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	7.93	4.17	1.95	0.81	0.33
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	0.58	0.30	0.14	0.06	0.02
Construction and Industrial Stormwater	0.01	0.004	0.002	0.001	0.0003
Load Allocation	6.55	3.44	1.61	0.67	0.27
Margin of Safety	0.79	0.42	0.20	0.08	0.03
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	7.3%	7.3%	7.3%	7.3%	7.3%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	83%	83%	83%	83%	83%
Margin of Safety	10%	10%	10%	10%	10%

The transparency tube duration curve (Figure 11) for the available dataset indicates exceedance of the target only during the high flow zone. Note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings correspond to higher turbidity. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 60 percent at high flows. The cluster of transparency tube readings at 60 cm in all of the flow zones less than high flows indicates that water clarity almost always met or exceeded the maximum tube measurement of 60cm, thus the turbidity was low much of the time. This corresponds well with the stream survey done in 2007 on this reach (Appendix E) which showed that the streambed is mainly well-embedded gravel and cobbles and thus less susceptible to streambed erosion at less than high flows.

Figure 11. Load Duration Curve (AUID: 07040004-639).



3.4.9 Cascade Creek; Unnamed Cr to S Fk Zumbro R. (AUID: 07040004-581)

This reach was added to the Section 303(d) Clean Water Act impaired waters list in 2006. The drainage area to the downstream end of this reach is about 39 square miles. The drainage area of the listed stream exists mainly within the Rochester Plateau and to a lesser extent within the Blufflands agroecoregions, with minor areas classified as Level Plains, Undulating Plains, Alluvium & Outwash, and steeper Alluvium agroecoregions. The majority of the land area draining to this impaired reach is within Olmsted County, except for the far western portion which is in Dodge County. Primary sources and causal factors contributing to sediment loading within this area are row cropland, inadequate buffers near streams and intermittent waterways, and runoff from impervious surfaces. Algae growth on the streambed was observed (See Appendix E).

There are no wastewater treatment facilities within the land area that drains to this listed reach, but minor TSS contributions are assumed to be made from one cooling water discharge, one groundwater remediation system, and seasonal discharges from a swimming pool (Appendix A). There are approximately 9 square miles of land area subject to NPDES MS4 regulations that drain to the listed reach (24.1% of watershed area) comprising western Rochester and surrounding urbanized area along the Highway 14 corridor. The portion of the WLA allotted to the MS4 area is correspondingly a significant portion of the total loading capacity.

Table 14 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 62 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on Cascade Creek at 7th St NW in Rochester, MPCA STORET S001-354.

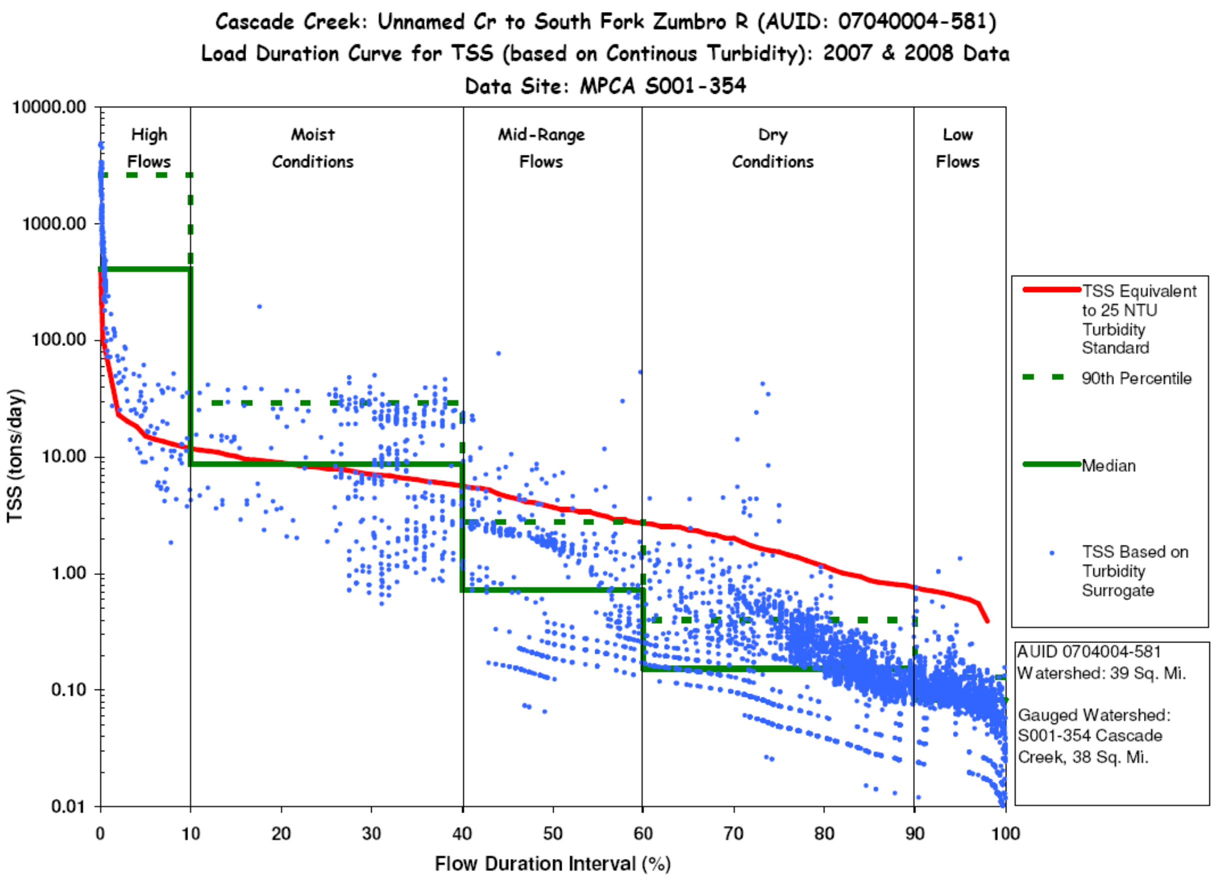
Table 12. Total suspended solids loading capacities and allocations (AUID: 07040004-581).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	15.19	7.99	3.74	1.55	0.63
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.005	0.005	0.005	0.005	0.005
Communities Subject to MS4 NPDES Requirements	3.29	1.73	0.81	0.33	0.14
Construction and Industrial Stormwater	0.01	0.01	0.003	0.001	0.001
Load Allocation	10.37	5.45	2.55	1.05	0.43
Margin of Safety	1.52	0.80	0.37	0.15	0.06
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	<0.1%	<0.1%	0.1%	0.3%	0.7%
Communities Subject to MS4 NPDES Requirements	21.6%	21.6%	21.6%	21.6%	21.5%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	68%	68%	68%	68%	68%
Margin of Safety	10%	10%	10%	10%	10%

* The facilities are listed in Appendix A.

The water quality duration curve (Figure 12) for the available dataset indicates exceedance of the target during high flow and moist conditions. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 75 percent at high flows and during moist conditions. This duration curve shows more variability than can be seen in Fig 3.10 for the upstream 07040004-639 AUID sub-area. This may be due to a larger percentage of urbanized and impervious area in the drainage to this downstream reach (07040004-581), more erosion from steeper hillsides (i.e. Steeper Alluvium), or simply higher resolution (continuous) monitoring data. This impaired reach is similar to its tributary impaired reach in that very low turbidities were observed during lower flows. The 2007 survey indicates that Cascade Creek is moderately susceptible to channel evolution. Following high flows in August of 2007 the channel at the 7th Street NW bridge shifted such that a new gravel bar was formed under the weighted wire stage measuring device.

Figure 12. Load Duration Curve (AUID: 07040004-581).



3.4.10 Kings Run; Unnamed Cr to Unnamed Cr (AUID: 07040004-601)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2008. The drainage area to the downstream end of this reach is about 13 square miles. The drainage area of the listed stream exists within the Blufflands, Undulating Plains, Alluvium & Outwash, and Rochester Plateau agroecoregions. The entirety of the land area draining to this impaired reach is within Olmsted County. Primary sources and causal factors contributing to sediment loading within this area are runoff from impervious surfaces, inadequate buffers near streams and intermittent waterways, and streambank and bed erosion.

There are no wastewater treatment facilities within the land area that drains to this listed reach. There are approximately 8 square miles of land area subject to NPDES MS4 regulations that drain to the listed reach (60.1%) comprising the suburban areas of northwestern Rochester along Highway 52 and surrounding urbanized areas. The portion of the WLA allotted to the MS4 area is correspondingly a significant portion of the total loading capacity, more than half.

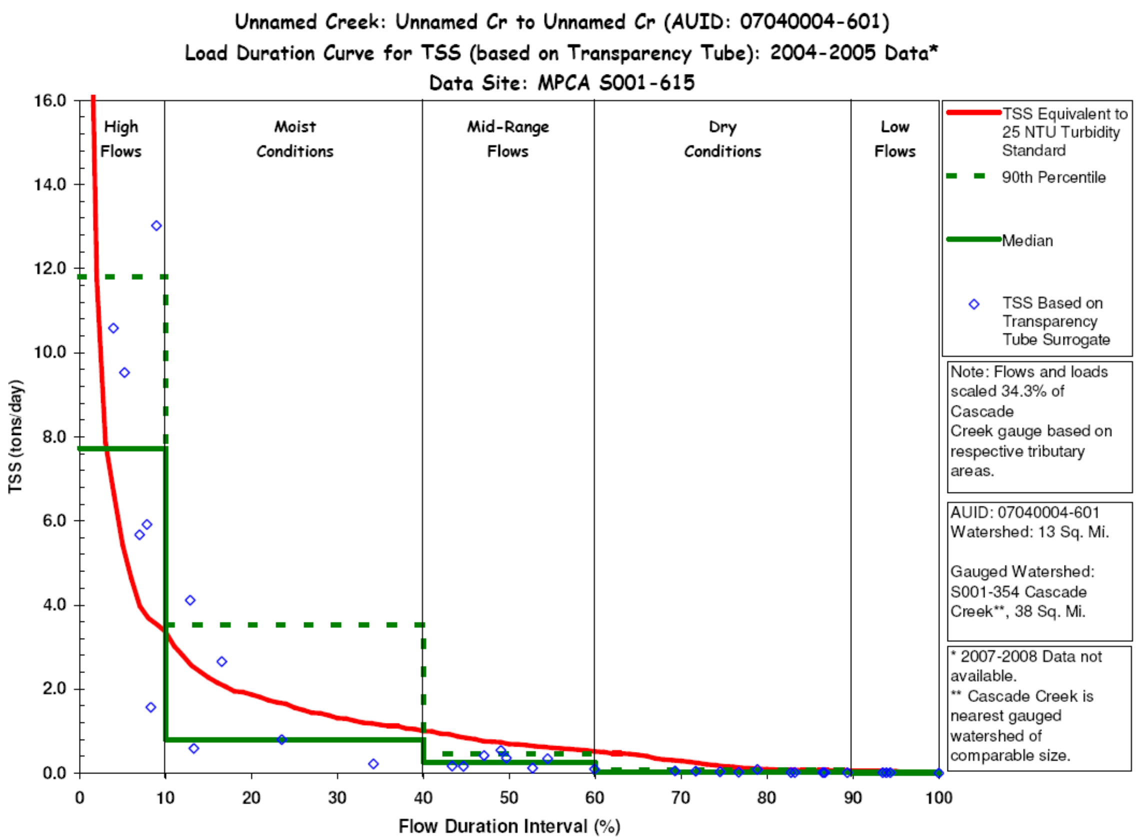
Table 13 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 69 mg/L (from Table 2, see AUID 07040004-507), taken from the nearest downstream continuous monitoring, at 90th St on the South Fork of the Zumbro River (AUID -507, MPCA STORET S003-802). Loading capacities for the five flow zones were developed using flow data from 2004-2005 from the flow gauge on Cascade Creek at 7th St NW in Rochester, MPCA STORET S001-354. The flow duration characteristics from this adjacent watershed is likely a better representation of the (ungauged) flow in Kings Run impaired reach -601 because the Cascade Creek watershed, which encompasses about three times as much area, more closely approximates the Kings Run watershed than does the South Fork Zumbro River watershed (-507) as a whole, which contains roughly 30 times as much area and a wider variety of land uses and regions.

Table 13. Total suspended solids loading capacities and allocations (AUID: 07040004-601).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	7.35	3.04	1.30	0.72	0.48
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	3.97	1.64	0.70	0.39	0.26
Construction and Industrial Stormwater	0.01	0.003	0.001	0.001	0.0004
Load Allocation	2.63	1.09	0.47	0.26	0.17
Margin of Safety	0.73	0.30	0.13	0.07	0.05
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	54.1%	54.1%	54.1%	54.1%	54.1%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	36%	36%	36%	36%	36%
Margin of Safety	10%	10%	10%	10%	10%

The transparency tube duration curve (Figure 13) for the available dataset indicates exceedance of the target during high flow and moist conditions. Note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings correspond to higher turbidity. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 45 percent both at high flows and during moist conditions. Low turbidity and high water clarity are indicated during low flows and dry conditions. The transparency tube data consists of 33 readings taken in 2004 and 2005; the STORET database did not contain 2007-2008 transparency tube information.

Figure 13. Load Duration Curve (AUID: 07040004-601).



3.4.11 Zumbro River, South Fork; Cascade Cr to Zumbro Lk (AUID: 07040004-507)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2002. The total land area draining to the downstream end of this reach is about 343 square miles including the entire City of Rochester and areas draining to the impaired reaches of Silver Creek, Bear Creek, upstream portion of the South Fork of the Zumbro, Cascade Creek and Unnamed Creek. Approximately one-third of the drainage area is in the Undulating Plains agroecoregion, another one-third is classified as Rochester Plateau, and the remaining area is split between Blufflands, Level Plains, Alluvium & Outwash, with a small area of Steeper Alluvium. The western quarter of the area draining to the impaired reach is in Dodge County while the remainder is in Olmsted County.

Primary sources and causal factors contributing to sediment loading within this area are streambank and bed erosion, row cropland, inadequate buffers near streams and intermittent waterways and runoff from impervious surfaces. Growth in the Rochester area has likely increased storm runoff leading to higher peak flows. Higher peak flows have been mitigated to some extent through BMP implementation by the MS4s in the watershed. According to analysis based on the 2007 stream survey of this reach (see Appendix E) the South Fork Zumbro River has in general a high risk for surface erosion due to farmland and a high risk of adverse impacts from increases in flow. At the surveyed location the channel has gotten wider and shallower since 1994.

Multiple public and private wastewater facilities, permitted industrial wastewater dischargers (including gravel pits), and cooling water users discharge to this impaired reach (Appendix A). All of the land area subject to NPDES MS4 regulations in the Zumbro River watershed is within the drainage area of this impaired reach, approximately 53 square miles or approximately 15.6% of the drainage area for this reach.

Table 14 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 69 mg/L (from Table 2), as calculated from continuous turbidity data from a station at 90^{th} St, identified as MPCA STORET S003-802. However, there was not a flow gauge installed at the same site, so flows for determining loading capacities for the five flow zones were developed using flow data from the USGS flow gauge at 37^{th} St, (STORET S000-333). The instantaneous and daily stream flow passing the 90^{th} St monitoring point was estimated by scaling up the recorded flow at 37^{th} St up by the ratio (1.13 or 113%) of the respective tributary areas of the 90^{th} St monitoring point and the 37^{th} St gauge. Scaling the flow in this way does not affect the flow duration interval because it is expressed as a percent, but the loading capacity is affected because it is based on the actual flow.

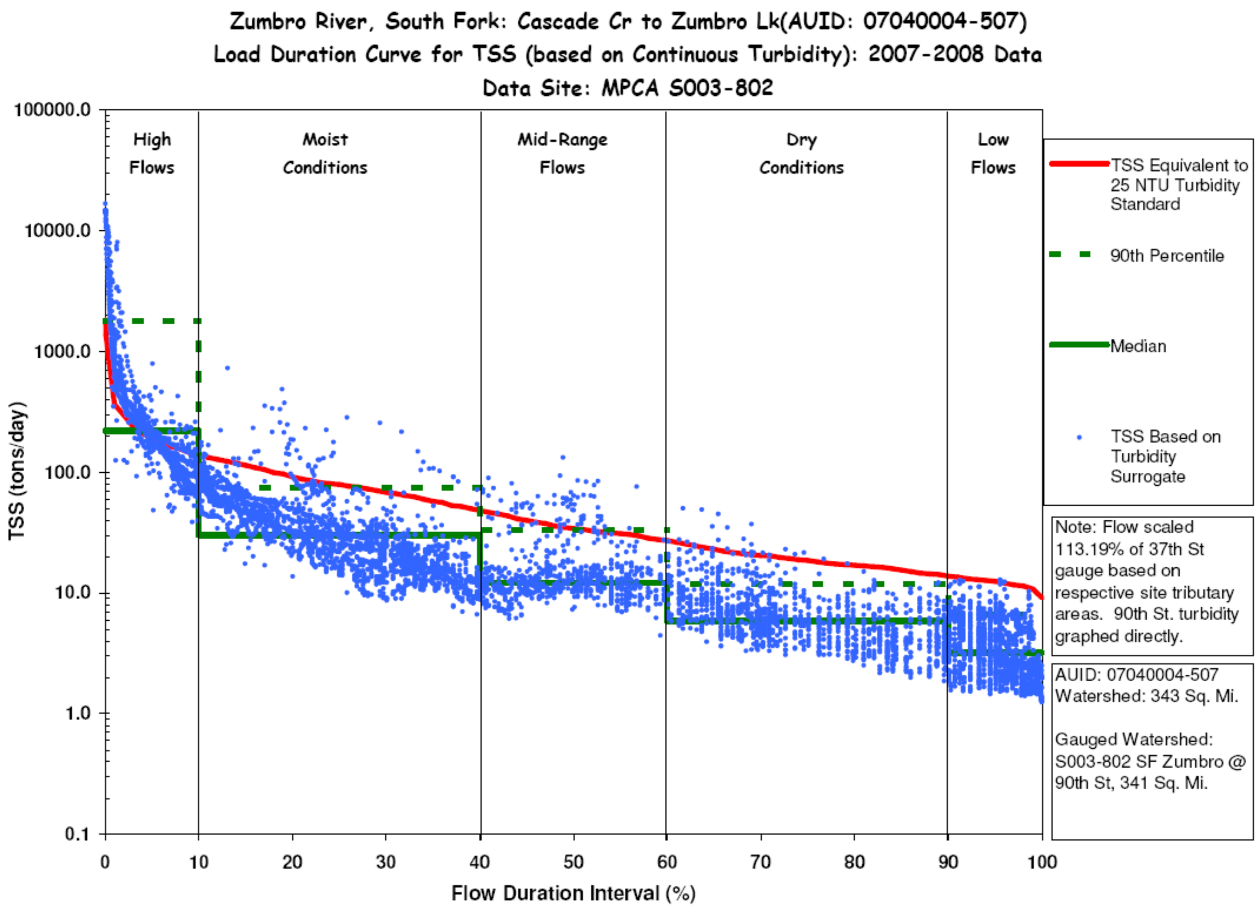
The water quality duration curve (Figure 14) for the available dataset indicates exceedance of the target during high flow conditions. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 70 percent at high flows. During high flows all tributaries are contributing excess turbidity to this reach of the South Fork of the Zumbro River.

Table 14. Total suspended solids loading capacities and allocations (AUID: 07040004-507).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	192.42	79.57	34.04	18.72	12.55
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	5.21	5.21	5.21	5.21	5.21
Communities Subject to MS4 NPDES Requirements	26.17	10.34	3.96	1.81	0.95
Construction and Industrial Stormwater	0.17	0.07	0.025	0.012	0.006
Load Allocation	141.63	55.99	21.44	9.81	5.13
Margin of Safety	19.24	7.96	3.40	1.87	1.26
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	3%	7%	15%	28%	42%
Communities Subject to MS4 NPDES Requirements	13.6%	13.0%	11.6%	9.7%	7.6%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.06%	0.05%
Load Allocation	74%	70%	63%	52%	41%
Margin of Safety	10%	10%	10%	10%	10%

* The facilities are listed in Appendix A.

Figure 14. Load Duration Curve (AUID: 07040004-507).



3.4.12 Dodge Center Creek; JD1 to S Br M Fk Zumbro R (AUID: 07040004-592)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The drainage area to the downstream end of this reach is about 91 square miles. The drainage area of the listed stream exists mainly within the Level Plains agroecoregion, with smaller areas in the Alluvium & Outwash, Undulating Plains, and Rolling Moraine agroecoregions. The majority of the area is within Dodge County, with a small portion in Steele County. Primary sources and causal factors contributing to sediment loading within this area are row cropland, inadequate buffers near streams and intermittent waterways, streambank erosion, and ditching/channelization. Large areas of poorly drained soils in the Plains and Alluvium regions in the western part of the drainage area have been tiled to increase agricultural production. It is evident from aerial photography that many streams have been straightened or ditches constructed to drain the land, increasing flow to the impaired reach.

There is one industrial wastewater discharger and three wastewater treatment plants within the land area that drains to this listed reach (Appendix A). There is no land area subject to NPDES MS4 regulations that drains to this listed reach.

Table 15 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 70 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007 from the flow gauge on the Middle Fork of the South Branch of the Zumbro River at 272nd Street near Mantorville, MPCA STORET S001-729. Continuous flow data was taken at 272nd St in 2007 and 2008 but along the impaired reach transparency tube readings were only available for 2007.

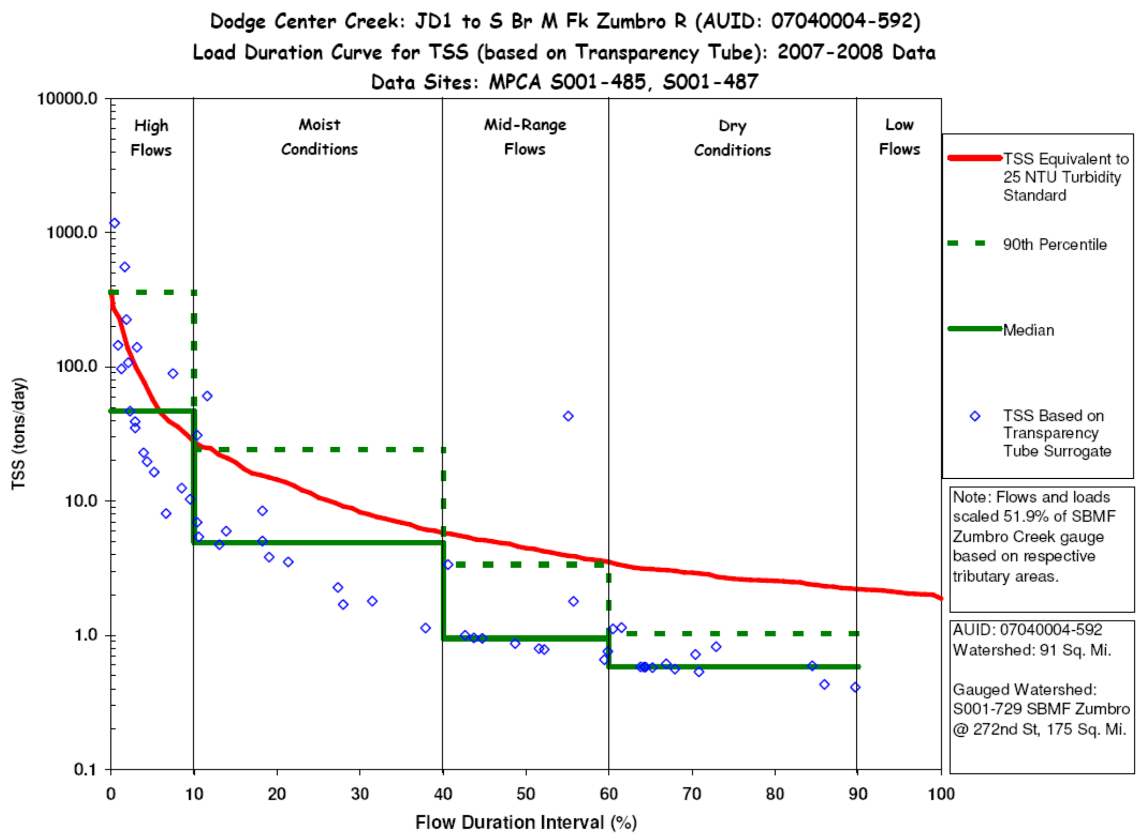
Table 15. Total suspended solids loading capacities and allocations (AUID: 07040004-592).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	59.34	10.98	4.62	2.73	2.16
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.25	0.25	0.25	0.25	0.25
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.05	0.01	0.004	0.002	0.002
Load Allocation	53.10	9.63	3.90	2.21	1.69
Margin of Safety	5.93	1.10	0.46	0.27	0.22
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.4%	2%	5%	9%	12%
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.08%	0.1%
Load Allocation	89%	88%	85%	81%	78%
Margin of Safety	10%	10%	10%	10%	10%

* The facilities are listed in Appendix A.

The transparency tube duration curve (Figure 15) for the available dataset indicates exceedance of the target during high flow and moist conditions. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 75 percent at high flows and 45 percent during moist conditions.

Figure 15. Load Duration Curve (AUID: 07040004-592).



3.4.13 Zumbro River, South Branch, Middle Fork; Headwaters to Dodge Center Creek (AUID: 07040004-526)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The drainage area to the downstream end of this reach is about 42 square miles. The headwaters of this reach include Rice Lake in eastern Steele County. The drainage area of the listed stream exists mainly within the Level Plains and Rolling Moraine agroecoregion, with a smaller portion of Undulating Plains. The majority of the area is within Dodge County, with a small portion in Steele County. Primary sources and causal factors contributing to sediment loading within this area are row cropland, inadequate buffers near streams and intermittent waterways, streambank erosion, and ditching/channelization. As with the Dodge Center Creek watershed, agricultural tiling and ditching have been put in place in the western portions of the area draining to this impaired reach.

There are no wastewater treatment plants, and no land area subject to NPDES MS4 regulations that drains to this listed reach.

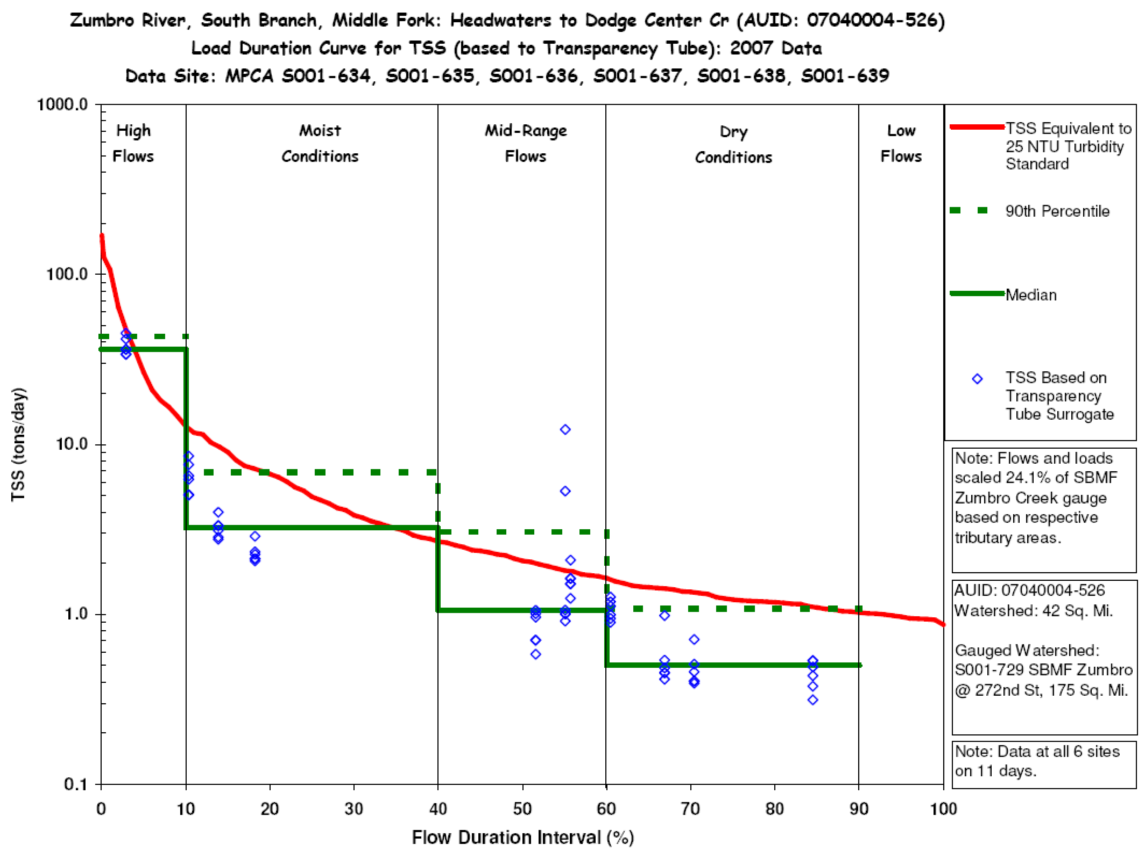
Table 16 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 70 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on the Middle Fork of the South Branch of the Zumbro River at 272nd Street near Mantorville, MPCA STORET S001-729. Continuous flow data was taken in 2007 and 2008 at 272nd Street but along the impaired reach transparency tube readings were only available for 2007.

Table 16. Total suspended solids loading capacities and allocations (AUID: 07040004-526).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	27.51	5.09	2.14	1.27	1.00
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.02	0.005	0.002	0.001	0.001
Load Allocation	24.74	4.58	1.92	1.14	0.90
Margin of Safety	2.75	0.51	0.21	0.13	0.10
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	90%	90%	90%	90%	90%
Margin of Safety	10%	10%	10%	10%	10%

The transparency tube duration curve (Figure 16) for the available dataset indicates exceedance of the target only in the mid-range flow zone. Note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings correspond to higher turbidity. However, the (recent) data set is limited to 11 dates in 2007, at each of 6 sites, and is likely not a good representation of the stream turbidity over time. Transparency tube readings at two of the sites on just one day (June 21) caused the 25 NTU turbidity target to be exceeded in the mid-range flow regime. Further investigation on this reach would provide better understanding of the timing and magnitude of water quality standard exceedances. It is notable that the average transparency tube reading increased from 23 cm to 30 cm between the site (S001-634) nearest Rice Lake to the site furthest downstream (S001-639), indicating that algal turbidity may impact this reach.

Figure 16. Load Duration Curve (AUID: 07040004-526).



3.4.14 Zumbro River, South Branch, Middle Fork; Dodge Center Creek to M Fk Zumbro R. (AUID: 07040004-525)

This reach was added to the Section 303(d) Clean Water Act impaired waters list in 2006. The drainage area to the downstream end of this reach is about 207 square miles. The agroecoregions of drainage area of the listed stream varies from Rolling Moraine and Level Plains in the west through Undulating Plains to Blufflands and the Rochester Plateau in the east, with Alluvium & Outwash areas in the far west and along the river. The land area draining to this impaired reach is split between Steele, Dodge, and Olmsted counties, with the majority in Dodge County. Primary sources and causal factors contributing to sediment loading within this area are row cropland, stream bank erosion, and inadequate buffers near streams and intermittent waterways.

There are six small municipal wastewater treatment facilities and one industrial combined wastewater and cooling water discharge within the land area that drains to this listed reach (Appendix A). There is no land area subject to NPDES MS4 regulations that drains to the listed reach.

Table 17 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 70 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge on the Middle Fork of the South Branch of the Zumbro River at 272nd Street near Mantorville, MPCA STORET S001-729. Continuous flow data were collected in 2007 and 2008, however reliable continuous turbidity data is only available for 2008.

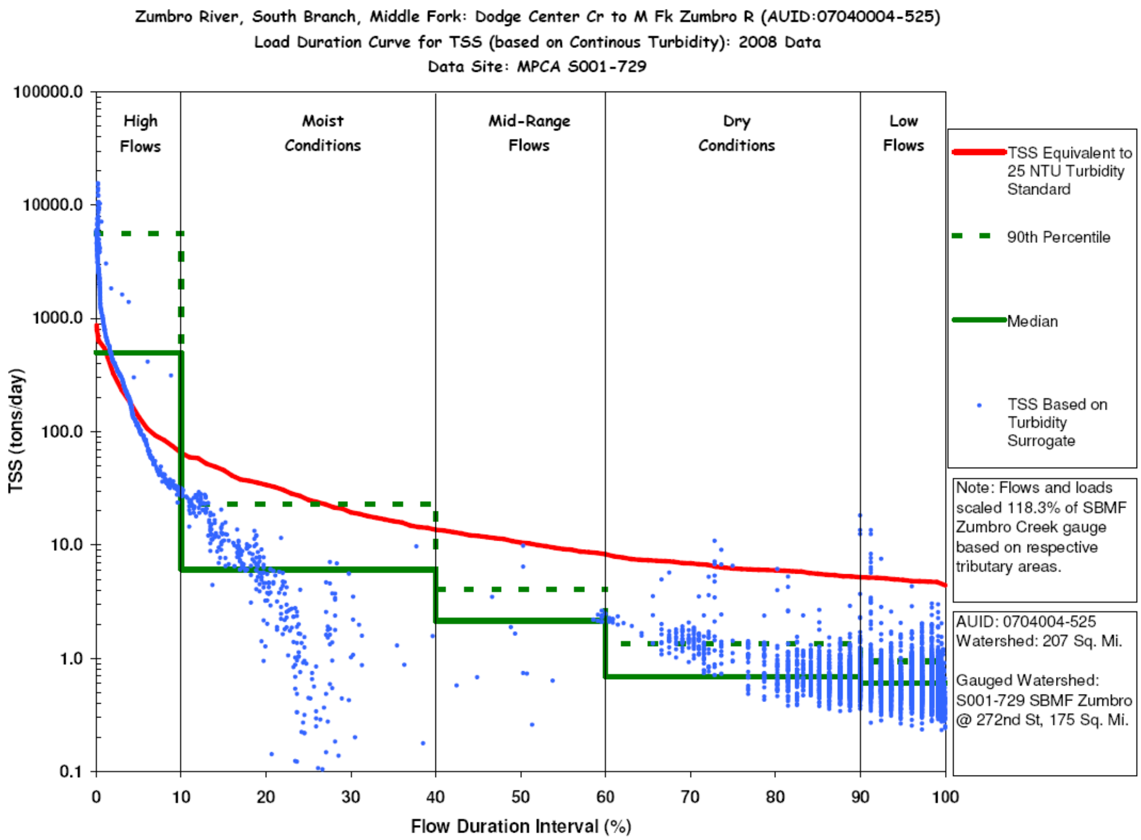
The water quality duration curve (Figure 17) for the available dataset indicates exceedance of the target during high flow conditions. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 85 percent at high flows. During the 2007 stream survey in this reach (Appendix E) tall eroding banks were observed and it is indicated that the stream has a very high risk of additional streambank erosion at high flows. Tiling and channelization in the upper watershed may contribute to increased flow and additional bank erosion. It is evident from the graph that very little data was available at mid-range flows.

Table 17. Total suspended solids loading capacities and allocations (AUID: 07040004-525).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	143.60	26.57	11.17	6.61	5.23
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	0.57	0.57	0.57	0.57	0.57
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.13	0.02	0.009	0.005	0.004
Load Allocation	128.53	23.32	9.47	5.37	4.13
Margin of Safety	14.36	2.66	1.12	0.66	0.52
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	0.4%	2%	5%	9%	11%
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.08%	0.1%
Load Allocation	90%	88%	85%	81%	79%
Margin of Safety	10%	10%	10%	10%	10%

* The facilities are listed in Appendix A.

Figure 17. Load Duration Curve (AUID: 07040004-525).



3.4.15 Milliken Creek; Unnamed Cr to Unnamed Cr (AUID: 07040004-554)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2006. The total land area draining to the downstream end of this reach is about 28 square miles. The majority of the drainage area is in the Level Plains agroecoregion with the balance in the Undulating Plains agroecoregion, all in Dodge County.

Primary sources and causal factors contributing to sediment loading within this area are streambank and bed erosion, row cropland, inadequate buffers near streams and intermittent waterways and livestock overgrazing in the riparian zone.

There are no wastewater treatment plants in this impaired reach, nor is any area subject to NPDES MS4 regulations within its drainage area. In this rural zone TSS loading comes almost exclusively from natural sources and agricultural activities

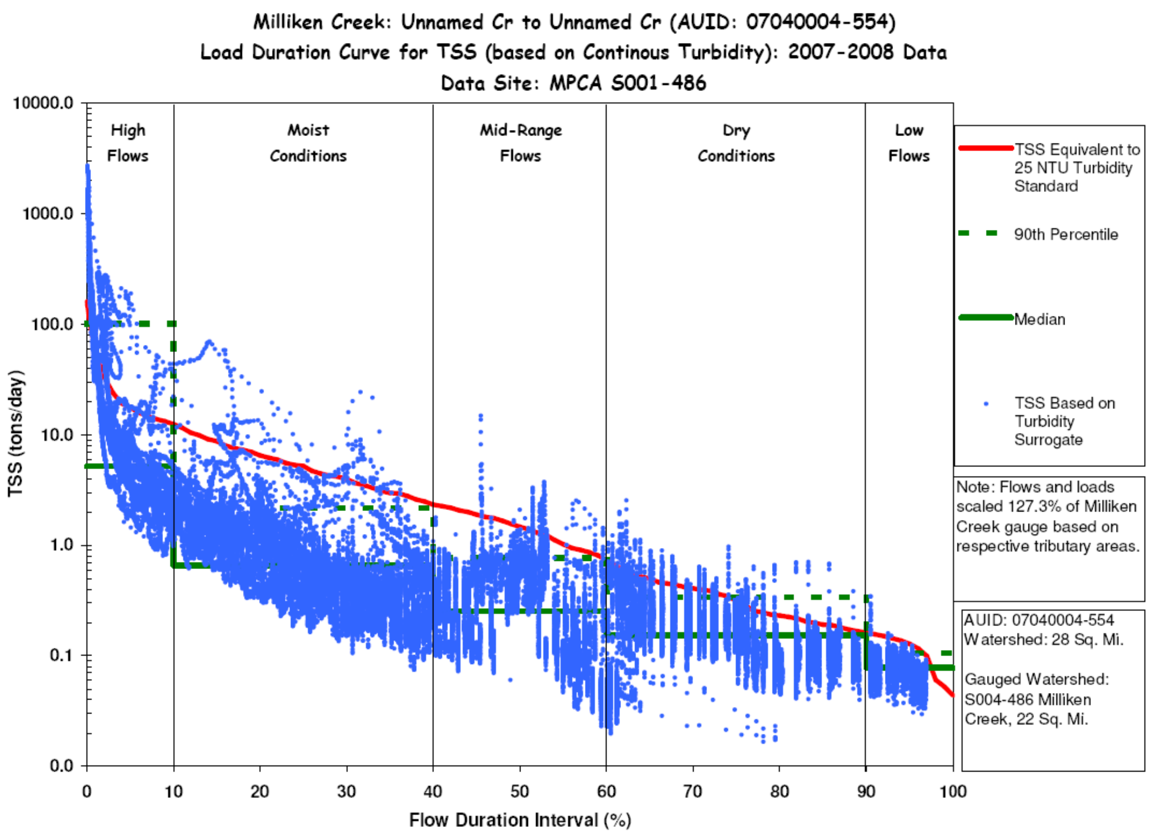
Table 18 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 48 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge at the County State Aid Highway (CSAH) 9 bridge, MPCA STORET S004-486.

Table 18. Total suspended solids loading capacities and allocations (AUID: 07040004-554).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	17.39	5.11	1.44	0.31	0.13
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.02	0.005	0.001	0.0003	0.0001
Load Allocation	15.64	4.60	1.29	0.27	0.11
Margin of Safety	1.74	0.51	0.14	0.03	0.01
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	NA	NA	NA	NA	NA
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	90%	90%	90%	90%	90%
Margin of Safety	10%	10%	10%	10%	10%

The data in each flow zone exhibits a high degree of variability, but on average the water quality duration curve (Figure 18) for the available dataset indicates exceedance of the target during high flow conditions. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 55 percent at high flows.

Figure 18. Load Duration Curve (AUID: 07040004-554).



3.4.16 Zumbro River, Middle Fork; Headwaters to N Br M Fk Zumbro R (AUID: 07040004-522)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 2008. The total land area draining to the downstream end of this reach is about 129 square miles. The majority of the drainage area is in the Level Plains or Undulating Plains agroecoregions, with areas of Rolling Moraine in the west, Rochester Plateau in the east and Alluvium & Outwash along the lower portion of the river.

Primary sources and causal factors contributing to sediment loading within this area are streambank erosion, row cropland, inadequate buffers near streams and intermittent waterways and livestock overgrazing in the riparian zone. Instability and eroding banks were observed along the impaired reach during the 2007 survey (Appendix E). Drainage tile has been installed in much of the poorly drained soil area in the Plains agroecoregions, speeding the delivery of water to the river.

There is one wastewater treatment plant in this impaired reach and one permitted industrial discharger (Appendix A). There is no area subject to NPDES MS4 regulations within the drainage area.

Table 19 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 71 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge at County State Aid Highway (CSAH) 3 in Pine Island, MPCA STORET S004-382.

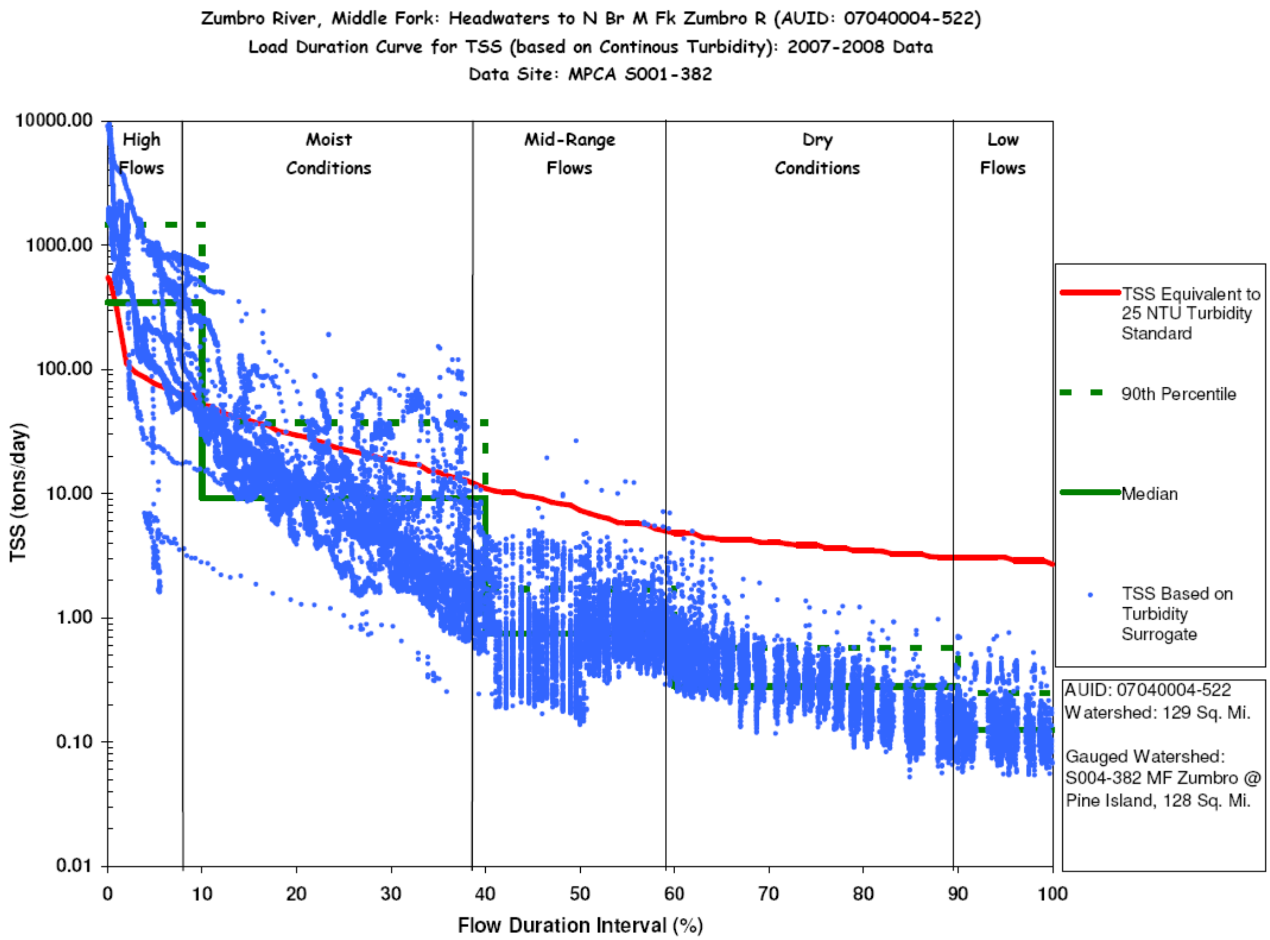
Table 19. Total suspended solids loading capacities and allocations (AUID: 07040004-522).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	77.03	22.83	7.38	3.89	3.09
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.35	0.35	0.35	0.35	0.35
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.07	0.02	0.006	0.003	0.002
Load Allocation	68.91	20.18	6.29	3.15	2.43
Margin of Safety	7.70	2.28	0.74	0.39	0.31
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.5%	2%	5%	9%	11%
Communities Subject to MS4 NPDES Requirements	NA	NA	NA	NA	NA
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.08%	0.1%
Load Allocation	89%	88%	85%	81%	79%
Margin of Safety	10%	10%	10%	10%	10%

* The facilities are listed in Appendix A.

The water quality duration curve (Figure 19) for the available dataset indicates exceedance of the target during high flow and moist conditions. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 90 percent at high flows and 5 percent for the moist conditions flow zone.

Figure 19. Load Duration Curve (AUID: 07040004-522).



3.4.17 Zumbro River; West Indian Cr to Mississippi R. (AUID: 07040004-501)

This reach was added to the Section 303(d) Clean Water Act Impaired waters list in 1998. Since it is the furthest reach downstream before the Mississippi River, the drainage area encompasses the entire Zumbro River watershed, about 1422 square miles. The south-western half (approximately) of the watershed is covered by the drainage areas of turbidity-impaired streams described in sections 3.4.1 to 3.4.16. Although land area in the north-eastern half of the Zumbro watershed is not covered by impairment classifications at the minor watershed level, sources of turbidity and suspended sediment from that area also affect this final reach of the Zumbro River. Table 20 lists the agroecoregions within this watershed, with the general trend being that the eastern portion of the watershed is steeper than the western, plains-like portion.

Primary sources and causal factors contributing to sediment loading within this area are streambank and bed erosion, row cropland, inadequate buffers near streams and intermittent waterways, impervious urbanized area, ditches and channelization, livestock overgrazing in the riparian zone, and algae. Instability and eroding banks were observed along the impaired reach (main stem of the Zumbro River) during the 2007 survey (Appendix E). The sandy, silty riverbed and banks observed several miles upstream of the town of Kellogg are susceptible to erosion due to the small particle size. It is likely that sand, gravel, and sediments are flushed downstream and settle out in the lower-gradient portions of the lower river reach. During high flows these sediments can be remobilized.

Table 20. Zumbro River ecoregions, AUID 07040004-501

Agroecoregion	% of Area
Rochester Plateau	34%
Undulating Plains	21%
Blufflands	19%
Level Plains	13%
Alluvium & Outwash	7%
Rolling Moraine	3%
Steeper Alluvium	2%
Total	100%

There are numerous wastewater treatment plants, including pond systems with seasonal discharges, in this impaired reach as well as several permitted industrial wastewater dischargers and several cooling water users (Appendix A). There are about 53 square miles of area subject to NPDES MS4 regulations within the drainage area for this impaired reach (3.8% of watershed area), which includes Rochester and urbanized portions of the surrounding townships.

Table 21 provides the average TSS loading capacities for this reach to meet the water quality standard, as well as the component WLAs, LAs, and MOS. The TSS concentration equivalent to 25 NTU used for these calculations was 92 mg/L (from Table 2). The TSS equivalent to 25 NTU and loading capacities for the five flow zones were developed using flow data from 2007-2008 from the flow gauge at Highway 61 in Kellogg, MPCA STORET S004-384.

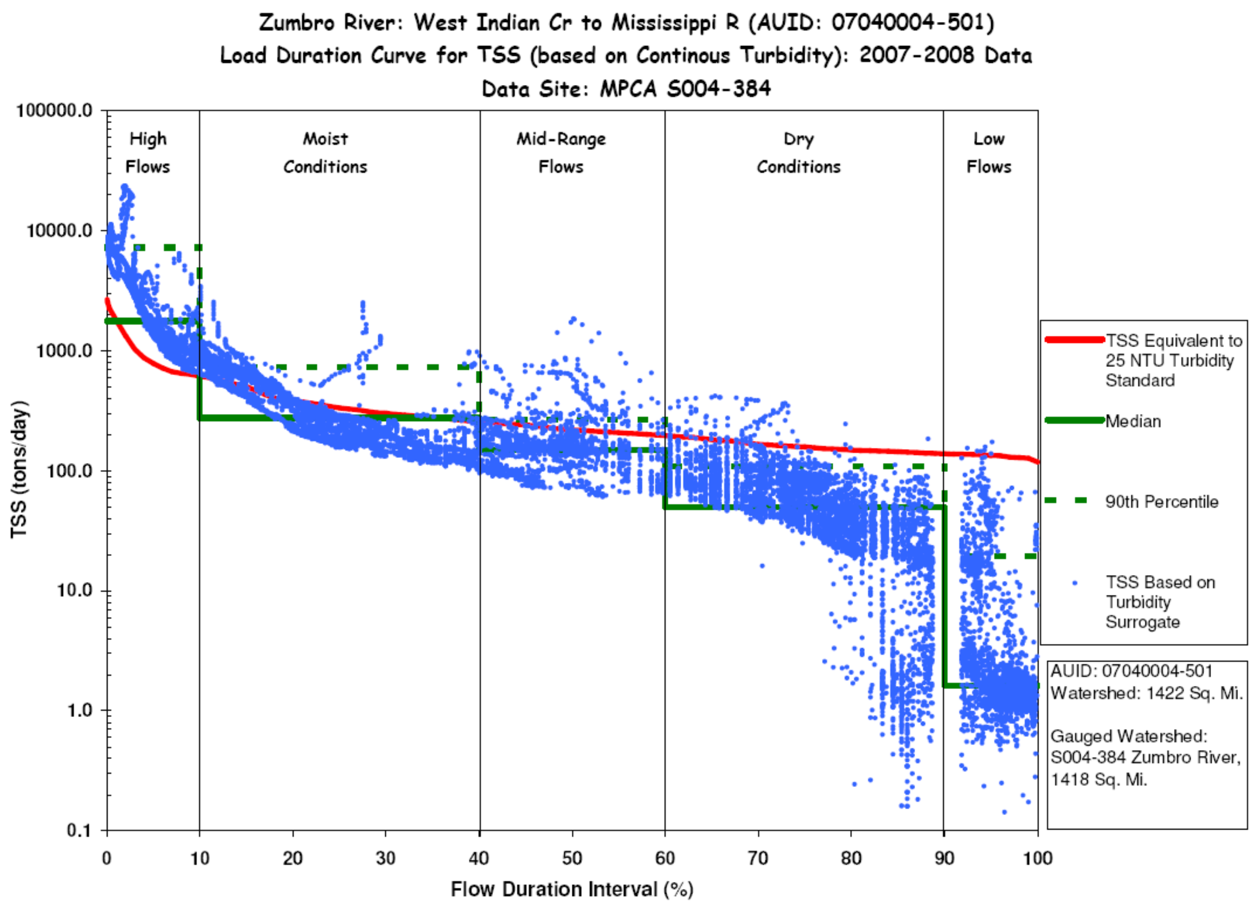
Table 21. Total suspended solids loading capacities and allocations (AUID: 07040004-501).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY LOADING CAPACITY	785.57	334.55	219.07	158.11	134.56
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	6.72	6.72	6.72	6.72	6.72
Communities Subject to MS4 NPDES Requirements	26.51	11.15	7.21	5.13	4.33
Construction and Industrial Stormwater	0.70	0.29	0.190	0.136	0.114
Load Allocation	673.08	282.94	183.04	130.31	109.94
Margin of Safety	78.56	33.45	21.91	15.81	13.46
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	1%	2%	3%	4%	5%
Communities Subject to MS4 NPDES Requirements	3.4%	3.3%	3.3%	3.2%	3.2%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.09%	0.1%
Load Allocation	86%	85%	84%	82%	82%
Margin of Safety	10%	10%	10%	10%	10%

* The facilities are listed in Appendix A.

The water quality duration curve (Figure 20) for the available dataset indicates exceedance of the target during high flows, moist conditions, and mid-range flows. The allowable TSS load (based on the 25 NTU turbidity standard) is exceeded by approximately 75 percent at high flows, 25 percent for the moist conditions flow zone, and 10 percent for the mid-range flows. In the high flow zone it appears that turbidity always exceeded the standard. During dry conditions and low flows very low turbidities were recorded.

Figure 20. Load Duration Curve (AUID: 07040004-501).



3.5 Overall Conclusions from Turbidity-Related Monitoring and Required Load Reductions

Some of the conclusions to be drawn from the project monitoring experience, data and assessments discussed in Sections 3.1, 3.2 and Sections 3.4.1 through 3.4.17 are the following:

- Based on the available data the turbidity impairments in the watershed appear to be “significant” when viewed across the entire sampling season. A significant portion of the wet-weather turbidity readings are above the standard; however, some site differences do exist.
- Primary sources contributing TSS within this watershed are likely streambank/bed erosion, row cropland, impervious areas, inadequate buffers near streams and waterways, channelization of streams, ravine and gully erosion, and overgrazed pasture near streams and waterways (see Table 22). Depending on the flow conditions and landscape of the various subwatershed areas, each one of these primary sources may be equally likely to contribute significant amounts of TSS in the watershed. See Appendix E for detail regarding likely sediment sources in each subwatershed. Minor contributions from algae to turbidity are more likely in reaches downstream of reservoirs or impoundments.
- In most of the studied stream reaches, water quality standard exceedances typically occur during high flow conditions and flood events. For a number of the streams, there is no load reduction required to meet the loading capacity for moderate and low flow conditions. Streams that exhibit regular water quality standard exceedance during moderate and low flow conditions are notable going forward to implementation planning.

Table 22. Possible Sediment Loading Sources (summary; not quantitative).

				Internal Sources				External Sources			
Section	Reach	Description	River ID# (AUID) 07040004 -	Bank Erosion (App. E)	Channel Erosion (Appendix E)	Algae Growth & Death	Ravines, Gullies, Ditch & Stream Channelization	Row Cropland	Inadequate Buffer Strip	Impervious Surfaces	Livestock in Riparian Zone
3.4.1	Silver Creek	Unnamed cr to Unnamed cr	552	X	X		X	X	X	X	X
3.4.2	Silver Creek	Unnamed cr to Silver Lk (S Fk Zumbro R)	553	X	X		X	X	X	X	X
3.4.3	Bear Creek tributary	Unnamed cr to Unnamed cr	556	X			X	X	X		X
3.4.4	Bear Creek	Headwaters to Willow Cr	539	X			X	X	X	X	X
3.4.5	Willow Creek	Headwaters to Bear Cr	540	X			X	X	X	X	X
3.4.6	Bear Creek	Willow Cr to S Fk Zumbro R	538	X			X	X	X	X	X
3.4.7	Zumbro River, South Fork	Salem Cr to Bear Cr	536				X	X	X	X	X
3.4.8	Cascade Creek	Headwaters to Unnamed cr	639				X	X	X	X	X
3.4.9	Cascade Creek	Unnamed cr to S Fk Zumbro R	581			X	X	X	X	X	X
3.4.10	Kings Run	Unnamed cr to Unnamed cr	601	X	X		X		X	X	X
3.4.11	Zumbro River, South Fork	Cascade Cr to Zumbro Lk	507	X	X		X	X	X	X	X
3.4.12	Dodge Center Creek	JD 1 to S Br M Fk Zumbro R	592	X			X	X	X		X
3.4.13	Zumbro River, Middle Fork, South Branch	Headwaters to Dodge Center Cr	526	X		X	X	X	X		X
3.4.14	Zumbro River, Middle Fork, South Branch	Dodge Center Cr to M Fk Zumbro R	525	X			X	X	X		X
3.4.15	Milliken Creek	Unnamed cr to Unnamed cr	554		X		X	X	X		X
3.4.16	Zumbro River, Middle Fork	Headwaters to N Br M Fk Zumbro R	522	X			X	X	X		X
3.4.17	Zumbro River	West Indian Cr to Mississippi R	501	X	X	X	X	X	X	X	X

3.6 Critical Conditions and Seasonal Variation

EPA states that the critical condition *"…can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence"* (USEPA, 1999). Turbidity levels are generally at their worst following significant storm events during the spring and summer months. Seasonal variation is somewhat more difficult to generalize given reach-specific differences. Regardless, such conditions and variation are fully captured in the duration curve methodology used in this TMDL.

3.7 Future Growth

All WLAs and LAs are based on 2007-2008 stream flow rates and the allowable loadings implicitly assume that flow rates and flow regimes will stay the same in the future.

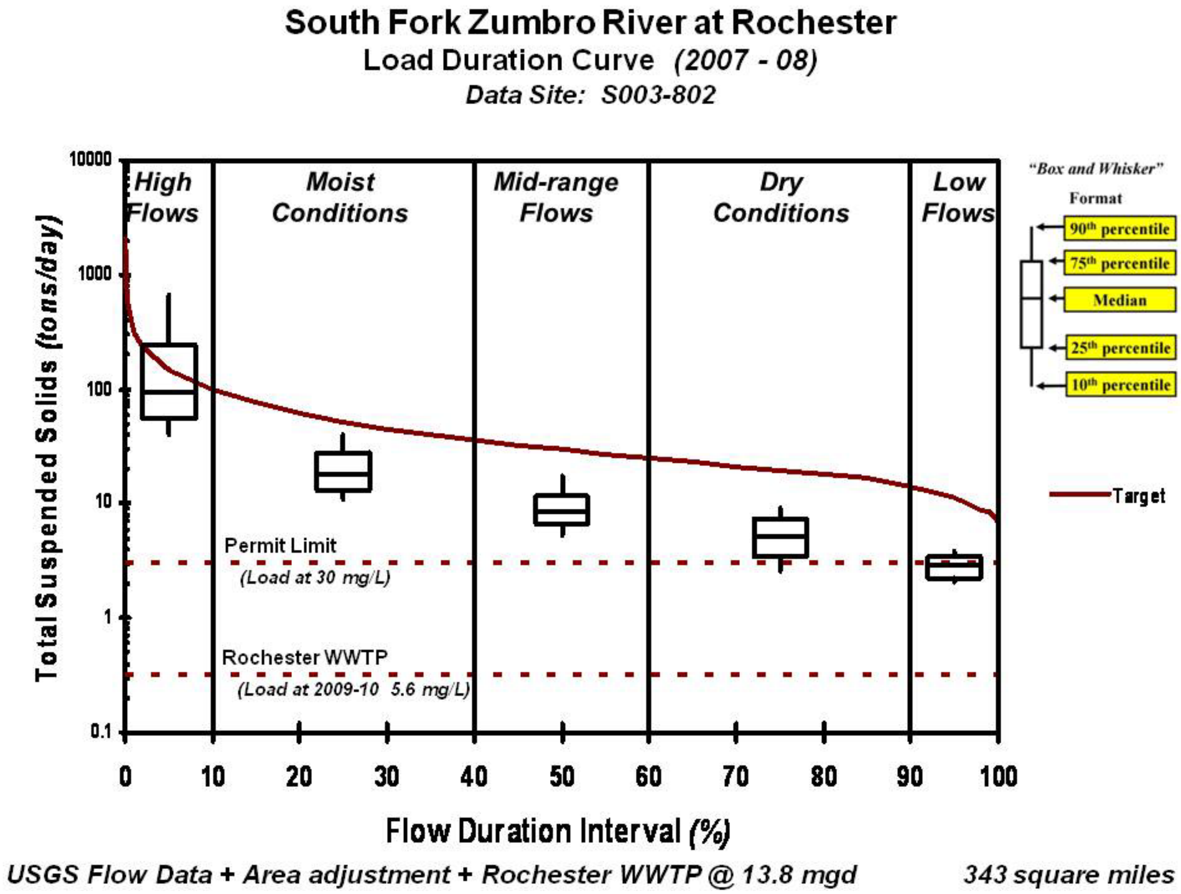
The increase in impervious areas in the form of roads, parking lots, buildings, and landscape changes due to growing population will contribute additional runoff and TSS loading as previously discussed. This effect was partially accounted for by considering Rochester's planned land use for 2020 as part of the current MS4 allotment (see Appendices B and D for details).

The allocations for nonpoint sources are for all current *and* future sources. This means that any expansion of nonpoint sources will need to comply with the LA provided in this report. Additional nonpoint sources (e.g., shifting grassland to row cropland) could very well make meeting the TMDL more difficult over time. Therefore, continued efforts over time to prevent soil/sediment delivery to the stream will be critical.

Regarding population changes and contributions from industrial wastewater discharges, flows at some wastewater treatment facilities are likely to increase over time with increases in the population they serve. This is not likely to have an impact on any of the impaired reaches provided discharge limits are met. This is because increased flows from wastewater treatment facilities add to the overall loading capacity by increasing river flows.

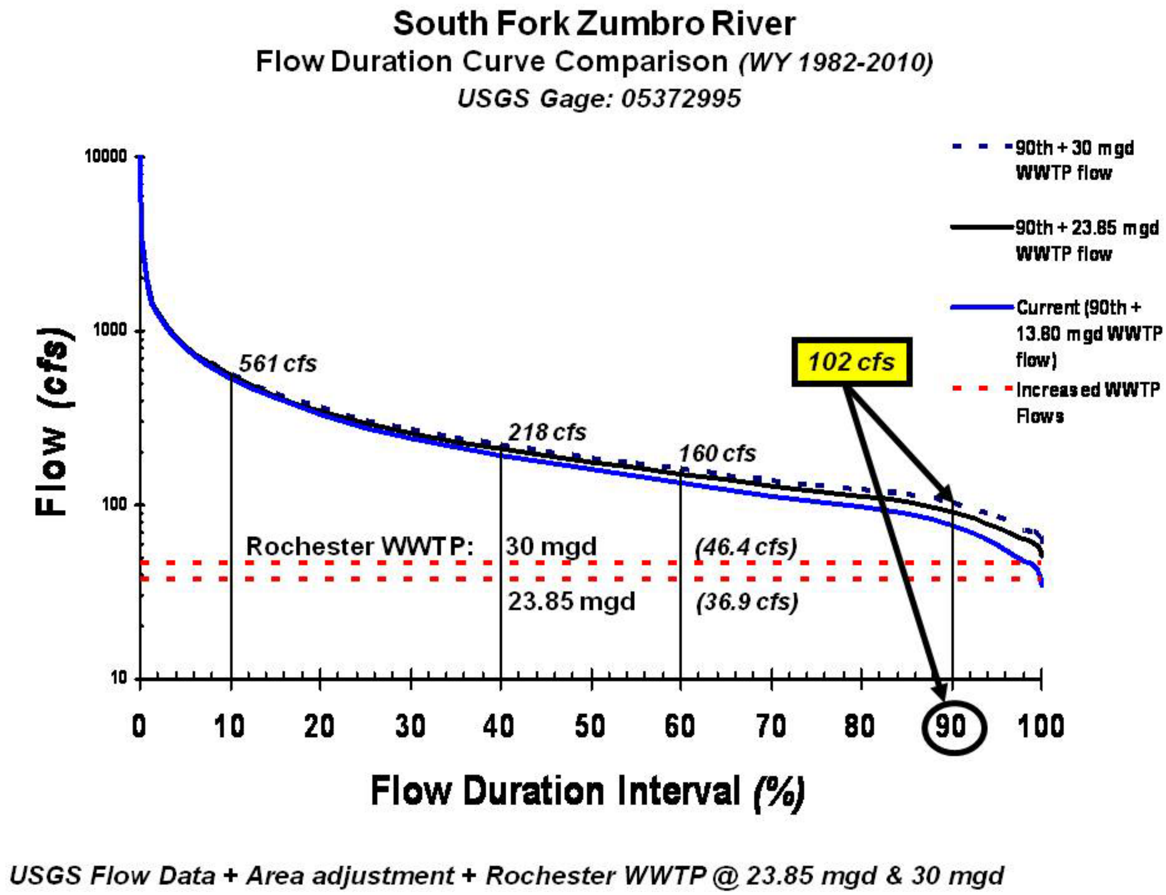
As discussed in Section 3, MPCA used the Load Duration Curve (LDC) method to determine the loads required to attain water quality standards. The LDC method uses river flows to determine the allowable loads of TSS. A comparison between the in-stream TSS targets (see Table 2) and technology-driven TSS effluent limits contained in MPCA NPDES permits shows that the effluent limits are below the in-stream targets. Thus, as demonstrated by Tetratech (Cleland, 2011), discharges from these facilities provide assimilative capacity beyond that which is required to offset their respective TSS loads (Figure 21 below). Although facilities are discharging below the in-stream targets, they are still discharging the pollutant of concern (TSS), and therefore individual wasteload allocations are required (wasteload allocations are listed in Appendix A; derivation methodology is described in section 3.3).

Figure 21. South Fork Zumbro River at Rochester Flow Duration Characteristics.



The NPDES wasteload allocations in this TMDL are based upon current discharges. For a new or expanding (non-stormwater) NPDES-permitted facility in the watershed, permit limits will maintain discharge effluent at a concentration below the respective in-stream TSS concentration target. A new or expanding facility will increase both load and flow, as described above and illustrated in Figure 22 below. This effect will be most pronounced in lower flows, when conventional point sources have the greatest impact. The increased flow will effectively increase the overall assimilative capacity of the river, as the flow increase will be larger proportionally than the load increase.

Figure 22. NPDES expanding discharge scenarios.



3.7.1 New and Expanding Discharges:

The analysis summarized above demonstrates that current discharges can be expanded and new NPDES discharges can be added while maintaining water quality standards, provided the permitted NPDES effluent concentrations remain below the in-stream targets. Given this circumstance, a streamlined process for updating TMDL wasteload allocations to incorporate new or expanding discharges will be employed. This process will apply to the non-stormwater facilities identified in Appendix A of the TMDL (in the case of expansion) and any new wastewater or cooling water discharge in the Zumbro River watershed:

1. A new or expanding discharger will file with the MPCA permit program a permit modification request or an application for a permit reissuance. The permit application information will include documentation of the current and proposed future flow volumes and TSS loads.

2. The MPCA permit program will notify the MPCA TMDL program upon receipt of the

request/application, and provide the appropriate information, including the proposed discharge volumes and the TSS loads.

3. TMDL Program staff will provide the permit writer with information on the TMDL wasteload allocation to be published with the permit's public notice.

4. The supporting documentation (fact sheet, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the TSS discharge requirements, noting that for TSS, the effluent limit is below the in-stream TSS target and the increased discharge will maintain the turbidity water quality standard. The public will have the opportunity to provide comments on the new proposed permit, including the TSS discharge and its relationship to the TMDL.

5. The MPCA TMDL program will notify the EPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheet (or other appropriate supporting documentation) and new TSS information to the MPCA TMDL program and the US EPA TMDL program.

6. EPA will transmit any comments to the MPCA Permits and TMDL programs during the public comment period, typically via e-mail. MPCA will consider any comments provided by EPA and by the public on the proposed permit action and wasteload allocation and respond accordingly; conferring with EPA if necessary.

7. If, following the review of comments, MPCA determines that the new or expanded TSS discharge, with a concentration below the in-stream target, is consistent with applicable water quality standards and the above analysis, MPCA will issue the permit with these conditions and send a copy of the final TSS information to the USEPA TMDL program. MPCA's final permit action, which has been through a public notice period, will constitute an update of the WLA only.

8. EPA will document the update to the WLA in the administrative record for the TMDL. Through this process EPA will maintain an up-to-date record of the applicable wasteload allocation for permitted facilities in the watershed.

4.0 MONITORING

The goals of monitoring are to (1) provide information for use support assessments, (2) evaluate progress toward water quality improvement (and associated targets provided in TMDLs), and (3) inform and guide implementation activities. Particularly important facets of monitoring when considering aquatic life use support are long-term collection of flow, turbidity, TSS and transparency data and periodic assessments of aquatic biota and associated habitat. Monitoring in the Zumbro River watershed provides a strong base of multi-purpose information, including that which supports these critical components.

Long-term stream gauges: the USGS has operated gauges at Kellogg (05374900), Zumbro Falls (05374000) and Rochester (05372995). They continue to maintain the Rochester site, while DNR now operates the gauge at Kellogg. The station at Zumbro Falls is a stage-only site. Together these records span back to the early 1900s, although none of the three are continuous over that period.

i. http://waterdata.usgs.gov/mn/nwis/uv?site_no=05374900 (Kellogg)
ii. http://waterdata.usgs.gov/mn/nwis/uv?site_no=05374000 (Zumbro Falls)
iii. http://waterdata.usgs.gov/nwis/uv?05372995 (Rochester)

Flood warning gauges: the DNR maintains flood warning gauges upstream of Rochester: Bear Creek (41051001), Cascade Creek (41064001), Silver Creek (41050001), South Fork Zumbro River (41061001). There is also one site upstream of Wanamingo (41010001), and a new site on the South Branch Middle Fork Zumbro River (41067002). These records span from the early 1990s to present. DNR Trails and Waterways/Division of Waters maintains a gauge on the Middle Fork Zumbro River upstream of Pine Island (41015001). This site was established in 2006. All of these records can be reviewed at the Cooperative Stream Gauging interface, maintained by MPCA and DNR: http://www.dnr.state.mn.us/waters/csg/index.html.

Long-term comprehensive monitoring stations: MPCA monitors sites at West Indian Creek (S004-452), Milliken Creek (S004-486), and the South Fork of the Zumbro River (S003-802). Regular monitoring includes grab sampling and continuous recording of turbidity and temperature. MPCA maintains the West Indian Creek and the Milliken Creek gauges. The site on the South Fork of the Zumbro River (S003-802) is just downstream of a USGS gauge (05372995) and very near the MPCA Milestone site (S000-268); it will provide a continuation of the Milestone sampling record (that site will no longer be monitored). At West Indian Creek, DNR performs annual surveys of fish and aquatic macroinvertebrates and scheduled surveys of stream geomorphology and habitat measures.

Citizen Stream Monitoring Program: 51 (as of April 2011) active volunteers in the Zumbro River watershed monitor stream transparency on a regular basis, at fixed sites.

MPCA load monitoring network: the Zumbro River at Kellogg (05374900 listed above) is sampled by MPCA staff on a regular basis, to allow for various load computations, including TSS. This sampling is long-term and will allow for trend analysis of overall sediment yield from the watershed.

Aquatic Biota Monitoring:

(1) DNR mussel survey: several watershed mussel surveys have been completed, the most recent was completed in 2010 (which included 77 sites).
(2) DNR fish surveys: a number of reaches in the Zumbro River watershed are assessed by DNR Fisheries. Reports for Middle Fork and the South Branch Middle Fork were completed in 2009. These assessments are long-term.
(3) Intensive Watershed Monitoring (IWM):
    a. MPCA staff will execute an intensive monitoring effort in the Zumbro River watershed every 10 years going forward, starting in 2012. This design will provide comprehensive assessment of various designated uses, including aquatic life (sampling of fish and aquatic macroinvertebrates), at approximately 90 sites distributed throughout the watershed. A primary goal of the IWM design is to allow for benchmarking and tracking progress toward improved water quality.

USGS sediment site at Kellogg: MPCA and USGS have partnered to provide monitoring of various sediment parameters (TSS, turbidity, suspended sediment concentration (SSC) and (in coming years) bedload) at the Zumbro River at Kellogg (05374900 listed above). This is a monitoring effort designed to understand various dimensions of sediment dynamics and movement in the river system.

Best Management Practice (BMP) implementation: the installation and maintenance of BMPs is tracked for the state by Soil and Water Conservation Districts using the state *ELink* reporting system. The Natural Resources Conservation Service uses the federal *Performance Results System*.

Future monitoring:

Together, these monitoring components will allow for tracking of water quality trends, load computation at various scales, and regular assessment of aquatic biota. There are sufficient data to execute trend analysis at some sites (preliminary trend work completed by MPCA has documented statistically significant decreasing trends in TSS concentration at the Milestone site (S000-368)). Flow patterns and trends can be analyzed using data from the USGS and DNR flow gauges. Overall watershed TSS yield will be closely tracked going forward. Volunteers will continue to monitor transparency at numerous sites in the watershed, allowing for potential trend analysis in coming years. Local government units record BMP implementation – information that can be paired with water quality trend analysis. In 2012, a more comprehensive assessment of aquatic life use support in the watershed will begin; this will provide further guidance in planning and project design. In 2022 intensive watershed monitoring will be repeated, thus providing a significant milestone in understanding progress toward water quality improvement. Field-scale monitoring could be a useful addition to monitoring work.

5.0 IMPLEMENTATION

This section provides an overview of implementation options and considerations to primarily address nonpoint sources of turbidity and suspended solids.

Point sources with required effluent monitoring will be addressed through NPDES permit programs within the MPCA. Construction stormwater activities are considered in compliance with provisions of the turbidity TMDLs if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix C of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit. Similarly, industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an Industrial Stormwater General Permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit, or meet local industrial stormwater requirements if they are more restrictive than requirements of the permit.

NPDES permits held by MS4s in the Zumbro Watershed must be consistent with the TMDL wasteload allocations (WLA) for appropriate tributaries. Because the TMDLs are expressed by load duration curves, compliance will be attained through implementation of a performance-based management approach. MS4s must demonstrate that their SWPPPs include prescribed activities/controls/schedules. MS4s may demonstrate progress towards the WLA based on an average annual basis. The performance-based approach can be discussed in detail in the TMDL Implementation Plan.

Future new and expanded municipal and/or industrial discharges will be permitted if their NPDES permits contain TSS effluent limits that are at least as restrictive as the applicable water quality standard.

Regarding the nonpoint sources of pollutants, a more detailed implementation plan addressing those sources will be developed following approval of this TMDL study. The State of Minnesota (Clean Water Fund) has funded development of an implementation plan for the Zumbro River watershed. It will be conceptualized and composed by the local watershed partnership (Zumbro Watershed Partnership), which includes a diverse cross-section of stakeholders. The plan will include strategies and tools specific to the various landscapes in the watershed.

A general reference for agricultural BMP implementation options is provided in Appendix F. The agro-ecoregion material included there was developed by Dr. David Mulla of the Department of Soil, Water, and Climate of the University of Minnesota. It was designed to provide options on an agroecoregion basis and is focused on turbidity impairments, though it appears to have applicability to other runoff-driven pollutants. The Zumbro River watershed is predominantly in the Rochester Plateau, Undulating

Plains, Blufflands, Level Plains and Alluvium & Outwash agroecoregions (see Appendix F and Table 20). The following narratives discuss these agroecoregions and provide summaries of appropriate BMPs for the range of agricultural-related water quality impacts that occur there.

Rochester Plateau
Major resource concerns in this agroecoregion are soil erosion by water, cattle and hog operation management, nutrient management from manure and fertilizer, and rapid leaching or seepage of pollutants to ground water in areas with karst topography and sinkholes. Soil erosion should be controlled by any or all of the following practices where applicable: conservation tillage, contour farming, strip cropping, terracing, grassed waterways, and sediment detention basins. Riparian buffer strips are recommended along streams. Best management practices for cattle include livestock exclusion from streams, and practices to reduce feedlot runoff.

Undulating Plains
Streams in this agroecoregion should be protected from sediment and phosphorus carried by runoff. Erosion control practices through conservation tillage are recommended. Steep lands can be further protected by permanent grass easements or riparian forest and grass buffer strips. Proper animal and manure management practices are important, including livestock exclusion from streams, improved pasture management, and injection of liquid manure.

Blufflands
On steep lands, practices to control water erosion are important. These include avoiding row crops on steep lands, or if they must be grown on steep lands, using a combination of conservation tillage, strip-cropping, and terracing. Buffers, along with practices that provide stable conveyances of flow, should be provided for ravines and gullies.

Level Plains
Practices to control soil erosion by water and sediment delivery to streams are important. These include conservation tillage, and grassed filter strips along streams. Tile intakes at the base of steep slopes should be replaced with French drains or blind inlets.

Alluvium and Outwash
Riparian forest and grass buffer strips are encouraged along streams and lake shorelines.

Appendix E details extensive field work completed to provide a foundational understanding of sediment sources in the watersheds of the impaired reaches (summarized in Table 22). This information, which includes Rosgen stream classifications, Bank Erosion Hazard Indices (BEHI) and sediment sieve results, will be studied and drawn upon during the implementation planning process.

Streambank erosion was identified as an important contributing source of sediment loading in the watershed. Local partner efforts to further examine stream channel stability have been funded and will provide important information to the implementation planning process.

Specific to improved pasture management the use of rotational grazing is an appropriate practice to be used in this watershed. In such a system, only one portion of the pasture is grazed at a time. This is accomplished by dividing the pasture into paddocks and by moving livestock from one paddock to another before the forage is overgrazed. Rotationally grazed pastures have several environmental advantages to tilled land or to continuously grazed pastures: they dramatically decrease soil erosion potential, require minimal pesticides and fertilizers, and decrease the amount of fecal coliform and nutrient runoff. Grazing management that encourages tall, vigorous growing vegetation will result in higher water infiltration into the soil, thus reducing runoff and soil losses. When grazing along streams, rotational grazing can be used as a tool to manage livestock activity for maintaining healthy stream bank vegetative cover while controlling unwanted plant species. Determining strategies for examining grazing in the Zumbro watershed will be part of the implementation planning process. *Managing Grazing in Stream Corridors* (http://www.mda.state.mn.us/news/publications/animals/livestockproduction/grazing.pdf) is a publication of the Minnesota Department of Agriculture.

The Clean Water Legacy Act requires that a TMDL include an overall approximation ("…a range of estimates") of the cost to implement a TMDL [Minn. Statutes 2007, section 114D.25]. At the direction of the *Group of 16* (G16), an interagency work group (Board of Water Resources, Department of Agriculture, Pollution Control Agency, Minnesota Association of Soil and Water Conservation Districts, Minnesota Association of Watershed Districts, Natural Resources and Conservation Service) assessed restoration costs for several TMDLs. The initial estimate for implementing the Zumbro River Turbidity TMDL ranged from approximately $140 to $170 million. This estimate will be refined when the detailed implementation plan is developed, following approval of the TMDL study.

6.0 REASONABLE ASSURANCE

Reasonable assurance that water quality and aquatic life use support in the Zumbro River watershed will be improved is formulated on the following points:

- Availability of reliable means of addressing pollutant loads (i.e. best management practices, NPDES permits);
- A means of prioritizing and focusing management;
- Development of a strategy for implementation;
- Availability of funding to execute projects;
- A system of tracking progress and monitoring water quality response.

Accordingly, the following summary provides reasonable assurance that implementation will occur and result in sediment load reductions in the Zumbro River watershed.

- The BMPs outlined in Section 5.0 have all been demonstrated to be effective in reducing transport of pollutants to surface water. Conservation tillage, contour farming, strip cropping, terracing, grassed waterways, sediment detention basins and riparian buffer strips are all proven means of holding topsoil and infiltrating water. This suite of practices is supported by the basic programs administered by the SWCDs and the NRCS. Local resource managers are well-trained in promoting, placing and installing these BMPs. Some watershed counties have shown significant levels of adoption of these practices. Thus, these BMPs constitute the standard means of addressing nonpoint source pollutant loads in the Zumbro River watershed.
- All municipal and industrial NPDES wastewater permits in the watersheds of the turbidity impaired reaches contain effluent TSS concentration limits that are more restrictive than applicable water quality standards. The MPCA's MS4 Permit requires MS4s to provide reasonable assurances that if an EPA-approved TMDL has been developed, they must review the adequacy of their Storm Water Pollution Prevention Program to meet the TMDL's WLA set for stormwater sources. If the Storm Water Pollution Prevention Program is not meeting the applicable requirements, schedules and objectives of the TMDL, the MS4 must modify their Storm Water Pollution Prevention Program, as appropriate, within 18 months after the TMDL is approved. The NPDES program is the means of addressing point source pollutant loads in the Zumbro River watershed.
- Various projects and tools provide means for identifying priority sediment sources and focusing implementation work in the watershed:
    - The Legislative Citizen Commission on Minnesota Resources (LCCMR) funded a local partner-led project that will provide guidance in focusing management efforts: *Prioritizing Critical Restoration Sites in the Zumbro Watershed*.
    - The State of Minnesota funded a shoreland mapping project to inventory land use in riparian areas in southeast Minnesota. The project is complete, and the results are available here: http://www.crwp.net/shoreland-mapping/. This information will be used in the implementation planning

process to examine riparian land use in the Zumbro River watershed, and prioritize potential BMP installation.
    - Light Detection and Ranging (LIDAR) data are available for all of southeast Minnesota, and being increasingly used by local government units to examine landscapes, understand water flow and dynamics, and accordingly prioritize BMP targeting.
    - A component of the implementation strategy development for the Zumbro River watershed (described below) is inventory and assessment of sediment retention basins in each watershed county. This information will be used by local government units to consider basin cleanouts and/or installation of new basins in priority locations.
    - Intensive Watershed Monitoring (IWM) will be initiated in the Zumbro River Watershed in 2012. Inherent in its design is geographic prioritization and focus. Encompassing site placement across the watershed will allow for a full examination of aquatic life use support, which will be the foundation for subsequent steps, ultimately leading to focused management efforts.
- The State of Minnesota (Clean Water Fund) has funded development of an implementation plan for the Zumbro River watershed. It will be conceptualized and composed by the local watershed partnership (Zumbro Watershed Partnership), which includes a diverse cross-section of stakeholders. The plan will include strategies and tools specific to the various landscapes in the watershed. It will make use of the prioritization and focus tools described above, and serve as a guide for funding projects to realize water quality improvements.
- On November 4, 2008, Minnesota voters approved the Clean Water, Land & Legacy Amendment to the constitution to:
    - protect drinking water sources;
    - protect, enhance, and restore wetlands, prairies, forests, and fish, game, and wildlife habitat;
    - preserve arts and cultural heritage;
    - support parks and trails;
    - and protect, enhance, and restore lakes, rivers, streams, and groundwater.

  This is a secure funding mechanism with the explicit purpose of supporting water quality improvement projects.
- Monitoring components in the Zumbro River watershed are diverse and constitute a sufficient means for focusing work, tracking progress and supporting adaptive management decisions (see Section 4.0).

Further, recent surveys by the Minnesota DNR documented “good” fish scores (index of biotic integrity) at various stations throughout the Middle Fork and South Branch Middle Fork Zumbro watersheds (DNR, 2009). Preliminary results of MPCA trend analysis have documented decreasing TSS concentrations at the South Fork Zumbro River Milestone site (S000-268). Together, these analyses provide reasonable assurance in that they suggest that aquatic life impairments are not ubiquitous in the watershed, and TSS concentrations at some monitoring stations may be decreasing.

7.0 PUBLIC PARTICIPATION

A "kickoff" stakeholder meeting for this project was held February 8, 2007 at the MPCA office in Rochester. Multiple stakeholder meetings for various purposes were held between that date and the public meeting on January 26, 2010 (more than 30 people attended – including point source managers and local farmers). A meeting log was kept throughout development of the Zumbro Watershed Turbidity TMDLs – it includes brief summaries of 29 meetings from 2007-2010; of those meetings, fourteen were open to the public, with circulated agendas. Most meetings were held at the Oronoco Community Center – an approximately central location with respect to the Zumbro River watershed.

In addition to meetings, "TMDL Updates" were sent via email in July 2007, November 2007 and October 2008. The updates were planned to fill gaps between meetings – to communicate information without requiring the time and travel of the various interested parties. These updates were included as part of the outreach/communication effort after a recommendation to do so came from the stakeholders at the kickoff meeting. Other updates were provided via email per request of the Minnesota Department of Agriculture and distributed at their discretion.

Stakeholder involvement was an important component of this TMDL. Public meetings were held on January 26, 2010 and November 17, 2011. The public comment period was noticed in the State Register, and was open from October 24, 2011 to November 23, 2011.

Figure 23. January 26, 2010 public meeting at Oronoco Community Center.

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APPENDICES

Appendix A. NPDES tabulation and summary by AUID

Table A1. Wastewater treatment facilities in the Zumbro River watershed.

Facility	NPDES Permit #	Design Flow mgd	TSS limit mg/L	WLA kg/day
Kenyon WWTP	MN0021628	0.357	30	40.5
Zumbrota WWTP	MN0025330	1.11	30	126.1
Bellechester WWTP (stabilization pond)	MN0022764	0.229[1]	45	39.0
Wanamingo WWTP	MNG550027	0.458	30	52.0
Pine Island WWTP	MN0024511	0.705	30	80.1
Mazeppa WWTP	MNG550015	0.0723	30	8.2
Hammond WWTP	MN0066940	0.023	30	2.6
Zumbro Falls WWTP (stabilization pond)	MN0051004	0.244[1]	45	41.6
Camp Victory WWTP	MN0067032	0.03	30	3.4
Kellogg WWTP (stabilization pond)	MNG580027	0.749[1]	45	127.5
Goodhue WWTP	MNG550005	0.099	30	11.2
West Concord WWTP	MN0025241	0.4732	30	53.7
Milestone Materials – Granger	MN0062791	2.3	30	261.2
Hayfield WWTP	MN0023612	0.41	45	69.8
Al-Corn Clean Fuel	MN0063002	0.19	30	21.6
Claremont WWTP	MN0022187	0.206	30	23.4
Dodge Center WWTP	MN0021016	0.973	30	110.5
Mantorville WWTP	MNG550013	0.232	30	26.3
Byron WWTP	MN0049239	1.4	30	159.0
Zumbro Ridge Estates Mobile Home Park	MN0038661	0.025	30	2.8
Hallmark Terrace, Inc. (stabilization pond)	MNG580070	0.166[1]	45	28.3
Milestone Materials - Goldberg	MN0062227	2.16	30	245.3
Kemps Milk Plant	MN0059803	0.105	--	2.0
Rochester Public Utilities - Silver Lake	MN0001139	88.6	***	***
Rochester WWTP / Water Reclamation	MN0024619	23.85	30	2708.5
Rochester Athletic Club	MN0062537	*	--	0.38
Kerry Bio-Science	MNG250047	0.06	--	1.14
Remediation System Pilot Testing	MNG790158	0.144	--	2.73
Seneca Foods Corp - Rochester	MN0000477	0.93	20	18.9
Kasson WWTP	MN0050725	0.968	30	109.9
AMPI Rochester - Cooling Water	MNG255051	0.64	--	12.1
Franklin Heating Station	MN0041271	1.364	--	2.8

Table A2. Wastewater treatment facilities and associated WLAs (AUID: 07040004-552).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Olmsted Waste-to-Energy Facility	MNG255076	0.025	--	0.5

Table A3. Wastewater treatment facilities and associated WLAs (AUID: 07040004-553).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Olmsted Waste-to-Energy Facility	MNG255076	0.025	--	0.5

Table A4. Wastewater treatment facilities and associated WLAs (AUID: 07040004-540).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Seneca Foods Corp - Rochester	MN0000477	0.93	20	18.9

Table A5. Wastewater treatment facilities and associated WLAs (AUID: 07040004-538).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Seneca Foods Corp - Rochester	MN0000477	0.93	20	18.9

Table A6. Wastewater treatment facilities and associated WLAs (AUID: 07040004-536).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
AMPI Rochester - Cooling Water	MNG255051	0.64	--	12.1
Franklin Heating Station	MN0041271	1.364	--	2.8

Table A7. Wastewater treatment facilities and associated WLAs (AUID: 07040004-581).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Rochester Athletic Club	MN0062537	*	--	0.38
Kerry Bio-Science	MNG250047	0.06	--	1.1
Remediation System Pilot Testing	MNG790158	0.144	--	2.7

* Indicates Seasonal Discharge

Table A8. Wastewater treatment facilities and associated WLAs (AUID: 07040004-507).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Zumbro Ridge Estates Mobile Home Park	MN0038661	0.025	30	2.8
Hallmark Terrace, Inc.	MNG580070	*	45	28.3
Milestone Materials - Goldberg	MN0062227	2.16	30	245.3
Kemps Milk Plant	MN0059803	0.105	--	2.0
Rochester Public Utilities - Silver Lake	MN0001139	88.6	**	1676.9
Rochester WWTP / Water Reclamation	MN0024619	23.85	30	2708.5
Rochester Athletic Club	MN0062537	*	--	0.38
Kerry Bio-Science	MNG250047	0.06	--	1.14
Remediation System Pilot Testing	MNG790158	0.144	--	2.73
Seneca Foods Corp - Rochester	MN0000477	0.93	20	18.9
AMPI Rochester - Cooling Water	MNG255051	0.64	--	12.1
Franklin Heating Station	MN0041271	1.364	--	2.8

* Indicates Seasonal Discharge
** Indicates river water recycling

Table A9. Wastewater treatment facilities and associated WLAs (AUID: 07040004-592).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Hayfield WWTP	MN0023612	0.41	45	69.8
Al-Corn Clean Fuel	MN0063002	0.19	30	21.6
Claremont WWTP	MN0022187	0.206	30	23.4
Dodge Center WWTP	MN0021016	0.973	30	110.5

Table A10. Wastewater treatment facilities and associated WLAs (AUID: 07040004-525).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Hayfield WWTP	MN0023612	0.41	45	69.8
Al-Corn Clean Fuel	MN0063002	0.19	30	21.6
Claremont WWTP	MN0022187	0.206	30	23.4
Dodge Center WWTP	MN0021016	0.973	30	110.5
Mantorville WWTP	MNG550013	0.232	30	26.3
Kasson WWTP	MN0050725	0.968	30	109.9
Byron WWTP	MN0049239	1.4	30	159.0

Table A11. Wastewater treatment facilities and associated WLAs (AUID: 07040004-522).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
West Concord WWTP	MN0025241	0.4732	30	53.7
Milestone Materials - Granger	MN0062791	2.3	30	261.2

Table A12. Wastewater treatment facilities and associated WLAs (AUID: 07040004-501).

Facility	NPDES Permit #	Discharge, mgd	TSS limit mg/L	WLA kg/day
Kenyon WWTP	MN0021628	0.357	30	40.5
Zumbrota WWTP	MN0025330	1.11	30	126.1
Bellechester WWTP	MN0022764	*	45	39.0
Wanamingo WWTP	MNG550027	0.458	30	52.0
Pine Island WWTP	MN0024511	0.705	30	80.1
Mazeppa WWTP	MNG550015	0.0723	30	8.2
Hammond WWTP	MN0066940	0.023	30	2.6
Zumbro Falls WWTP	MN0051004	*	45	41.6
Camp Victory WWTP	MN0067032	0.03	30	3.4
Kellogg WWTP	MNG580027	*	45	127.5
Goodhue WWTP	MNG550005	0.099	30	11.2
West Concord WWTP	MN0025241	0.4732	30	53.7
Milestone Materials - Granger	MN0062791	2.3	30	261.2
Hayfield WWTP	MN0023612	0.41	45	69.8
Al-Corn Clean Fuel	MN0063002	0.19	30	21.6
Claremont WWTP	MN0022187	0.206	30	23.4
Dodge Center WWTP	MN0021016	0.973	30	110.5
Mantorville WWTP	MNG550013	0.232	30	26.3
Byron WWTP	MN0049239	1.4	30	159.0
Zumbro Ridge Estates Mobile Home Park	MN0038661	0.025	30	2.8
Hallmark Terrace, Inc.	MNG580070	*	45	28.3
Milestone Materials - Goldberg	MN0062227	2.16	30	245.3
Kemps Milk Plant	MN0059803	0.105	--	2.0
Rochester Public Utilities - Silver Lake	MN0001139	88.6	**	1676.9
Rochester WWTP / Water Reclamation	MN0024619	23.85	30	2708.5
Rochester Athletic Club	MN0062537	*	--	0.38
Kerry Bio-Science	MNG250047	0.06	--	1.14
Remediation System Pilot Testing	MNG790158	0.144	--	2.73
Seneca Foods Corp - Rochester	MN0000477	0.93	20	18.9
Kasson WWTP	MN0050725	0.968	30	109.9
AMPI Rochester - Cooling Water	MNG255051	0.64	--	12.1
Franklin Heating Station	MN0041271	1.364	--	2.8

* Indicates Seasonal Discharge

** Indicates river water recycling

Appendix B. MS4 Information

WASTELOAD ALLOCATION BY MS4										
June 17, 2009										
Land Use/Land Cover	**Cascade Township**	**Federal Medical Center**	**Haverhill Township**	**Marion Township**	**Olmsted County**	**RCTC***	**Rochester**	**Rochester Township**	**Right-of-Way**	**TOTAL**
No Value	0.5	0.0	0.0	0.4	0.0	0.0	7.8	0.2	0.0	9.0
Commercial/Industrial	423.8	47.2	30.6	80.5	69.9	0.0	4,052.2	76.4	0.0	4,780.6
Golf Course	3.3	0.0	0.0	1.6	105.1	0.0	716.2	34.2	0.0	860.4
High Density Residential	65.1	0.0	6.8	12.6	44.6	0.0	1,389.3	18.3	0.0	1,536.7
Institutional	20.0	43.8	25.8	15.7	0.0	93.0	1,283.2	68.7	0.0	1,550.1
Low Density Residential	914.8	0.0	351.8	785.4	46.8	0.0	8,992.3	580.3	0.0	11,671.4
Medium Density Residential	61.0	0.0	31.8	54.6	28.6	0.0	724.8	21.4	0.0	922.2
Open Space	317.6	0.0	87.1	601.7	19.3	4.5	1,708.4	210.3	0.0	2,948.7
Open Space-C	120.8	8.8	160.7	170.2	0.0	0.5	2,765.0	186.9	0.0	3,412.9
Pits and Quarries	140.0	0.0	0.0	4.3	188.5	0.0	82.0	148.9	0.0	563.8
Right-of-Way	0.0	5.8	0.0	0.0	0.0	2.8	0.0	0.0	2,819.2	2,827.9
Row Crop Agriculture	33.6	0.0	0.0	9.6	0.0	0.0	98.6	25.1	0.0	166.8
Row Crop Agriculture-C	7.7	0.0	0.8	9.2	0.0	0.0	66.3	8.3	0.0	92.2
Very Low Density Residential	502.3	0.0	79.3	266.3	36.3	0.0	646.4	378.6	0.0	1,909.2
Water	53.1	0.5	6.3	22.0	3.1	0.0	736.4	38.5	0.0	859.8
TOTAL	2,663.6	106.1	780.9	2,034.1	542.1	100.8	23,268.7	1,796.1	2,819.2	34,111.7
*Rochester Community & Technical College										

Appendix C. Evaluation of "Paired" Turbidity Measurements from Two Turbidimeters for Use in Two TMDL Projects

December 13, 2007

Greg Johnson
Minnesota Pollution Control Agency
Regional Division
Watershed Section – Technical Assistance Unit

Background

Turbidity is a parameter that has a significant amount of variability associated with the measurement values reported. Unlike many water quality parameters which are a measurement of a mass of constituents in a volume of water, turbidity is a measure of the optical properties of a water sample which causes light to be scattered and absorbed (Federal Water Pollution Control Administration, 1968). The optical properties are affected by the biological, physical and chemical components in the water. Differences in the constituents' response to light contribute to this variability. Adding to this variability, differences between turbidity meter types can result in different turbidity values being measured for the same water samples. The USGS and others have published papers documenting the variation in turbidity measurements that can occur due to different sensor configurations, detector angle, and light wavelength used (Pavelich 2002, Ankcorn 2003, Anderson 2005). While the manufactured meters comply with standard method requirements of the EPA, different results may occur when using different types of turbidity meters and sensors. The variation occurs across different manufacturing company sensors and even within different generations of the same model sensor within a company. To address this issue, the United States Geological Survey (USGS) developed a reporting unit/category system to distinguish between the different sensor groups (Miller 2004, Anderson 2005).

Differences in turbidity values between meters have been observed in Minnesota through various monitoring efforts.

With the development of turbidity (and other variables) TMDLs well under way in Minnesota, the Minnesota Pollution Control Agency (MPCA) developed a Turbidity TMDL Protocol (MPCA 2007) as guidance to assist projects in completing the work needed for a turbidity TMDL. The issue of differences in measurements of turbidity between different meters was addressed in two ways. First, the protocol identified the need to use the turbidity reporting units/categories adopted by the USGS to differentiate data sets by type of turbidity meter. The MPCA began using the reporting categories for data being entered into STORET in 2005.

Secondly, the protocol identified a list of options/recommendations to use/follow when a project has one or more types of turbidity data. At the time of the protocol development, it was envisioned that use of this list would be sufficient in the short term as paired measurements of the data types were made and compared. The list of options assumed that the type of data present in a project would largely determine which reporting unit would be used in evaluating the data against the turbidity standards of 10 or 25 NTU. This, in essence, is what has been done for the turbidity TMDLs that have been approved by EPA prior to 2008.

The difficulty of selecting a "method" from this list of options became apparent fairly quickly for various reasons in three projects. In the Minnesota River Turbidity TMDL project, a difference in turbidity values between the MPCA and Metropolitan Council Environmental Services (MCES) monitoring programs had been recognized and discussed prior to and following the completion of the protocol. The primary differences are likely due to the use of different turbidimeters in the two labs. The MCES lab used a Hach 2100A meter to measure turbidity (J. Klang, personal communication, 2006). This meter measures turbidity via a single white light source and a single light detector located at 90 degrees to the light source. The USGS unit reporting category for this meter is NTU. The MDH lab used a Hach 2100AN meter to measure turbidity. This meter is set to measure turbidity utilizing a single white light source and two (multiple) light detectors. One detector is located at 90 degrees to the light source and the second light detector is located at a wider angle with a "ratio" compensation being made between the two (J. Klang, personal communication, 2006). The USGS unit reporting category for this meter is NTRU.

The protocol includes a description of the differences. The impact of the difference was thought to be important, but a decision on which to use in evaluating the standard was not made until the project timeline required a decision be made to identify a target for the HSPF modeling of the basin. The MPCA technical team for the project decided to use the NTU reporting category and, hence, the MCES turbidity data in the targeting work. The difference between the data sets was shown in a small set of paired (same water samples) turbidity measurements made by the MCES and Minnesota Department of Health (MDH) Laboratories where a "difference factor" of 0.55 was estimated in some way, but not formally documented.

The next turbidity project to face a decision on what and/or how to deal with turbidity data with different reporting units was the West Fork Des Moines River Turbidity TMDL project. In this case, the initial analysis and evaluation of the turbidity data combined together resulted in an apparent difference in the sediment reduction needed between two watersheds in the project. In working to document this unexpected difference, it was determined that the water samples from two watershed projects were analyzed by different laboratories – one being the MDH Lab measuring turbidity as NTRU and the other being the Minnesota Valley Testing Laboratory (MVTL) measuring turbidity as NTU. In discussing a means in which to "correct" the data, the project team decided to make the assumption that the difference between the two measurement types was the same as for the paired-data set of MCES and MDH turbidity measurements completed as part of a river remote sensing and monitoring project conducted in 2004. Subsequent estimates of load reductions needed in the two watersheds were very similar, as expected given the similarity of the watersheds. However, the relationship between the paired data had not been fully completed and documented, so MPCA staff began completing the data analysis with this document describing the results of the work.

A third turbidity TMDL project to encounter a problem related to a difference between reporting unit values was the Pipestone Creek Turbidity TMDL. In this project, the TMDL was originally developed with a lower TSS target. During the TMDL review, MPCA reviewed the calculation of the TMDL target for TSS. By going back to the water quality data documentation for the monitoring done in the project, it was determined that all of the turbidity data was measured as NTRU by the MDH Lab rather than as NTU, resulting in an overly stringent TSS target. Subsequent use of the initial ratio between NTRU and NTU in the paired data set provided a "better" / "more representative" evaluation of the current conditions to the turbidity standard.

Methods

With these issues and situations at the forefront of needs in completing turbidity TMDLs, this document presents a statistical evaluation of the paired data set for application in the Minnesota River, West Fork Des Moines River, and Pipestone Creek Turbidity TMDLs. The paired data are from water quality monitoring conducted as part of a river remote sensing study in 2004 by MPCA staff.

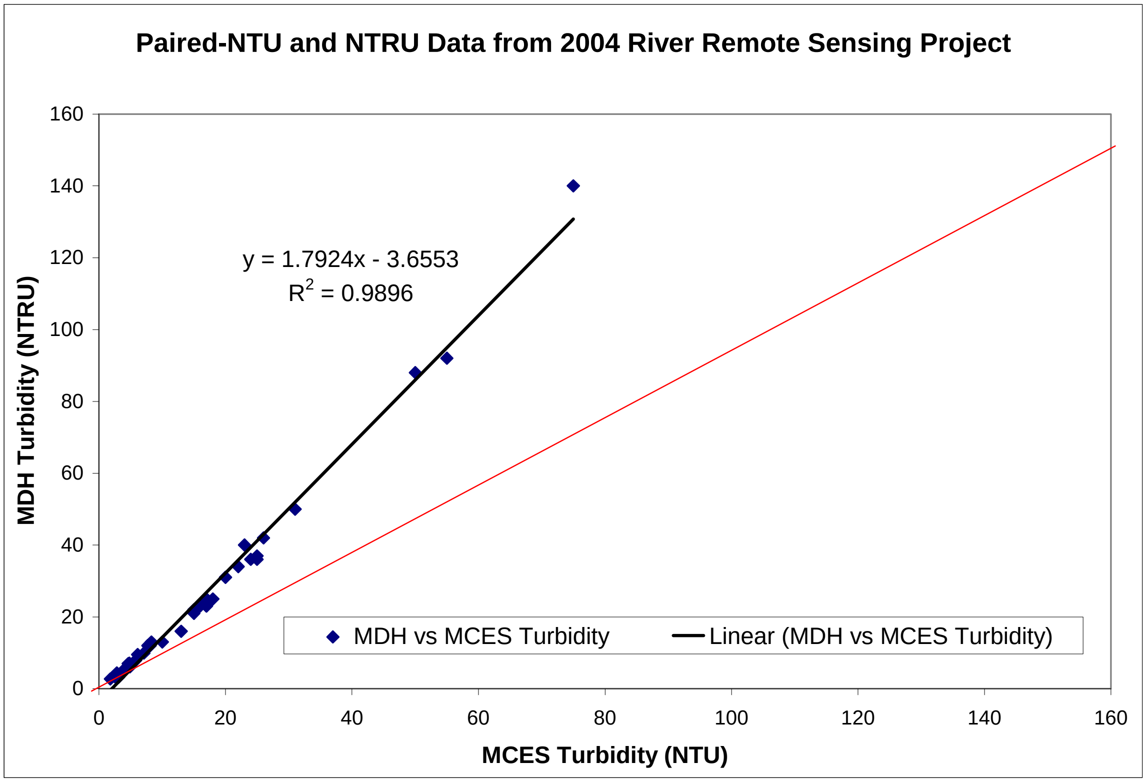
Excel and Minitab were used to analyze the paired laboratory turbidity data. The goal of the analysis was to use appropriate statistical methods to provide a "conversion" factor for estimating NTU values from measured NTRU values for use in the West Fork Des Moines River and Pipestone Creek Turbidity TMDLs given the absence of paired measurements from those project areas.

Summary statistics, tests for normality, linear regression, and paired-t tests and a nonparametric test parallel to a t-test were used for the analyses. The data and selected analyses are included at the end of this appendix.

Results

Linear regression of the raw data was initially completed to check if the initial difference factor of 0.55 was determined in this way (Figure 1). The results appear to indicate that this is the means in which the initial number was determined. However, summary statistics and histograms in Excel and tests for normality in Minitab indicate that the data is not normally distributed; such that parametric statistics (i.e., linear regression) should not be used on the raw data.

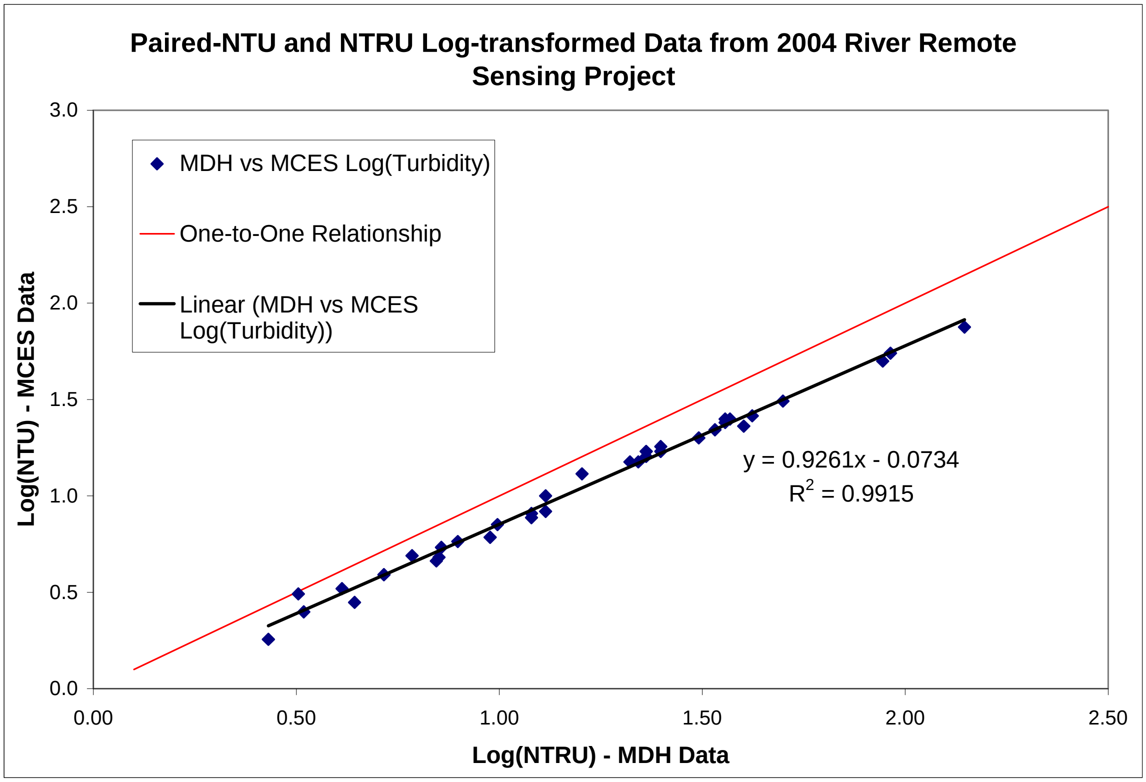
Figure 1.



The data were then log-transformed and evaluated to see if the log-transformed data were normally distributed. Summary statistics and histograms in Excel and tests for normality in Minitab indicate that the transformed data are nearly and acceptably normally distributed, respectively.

Linear regression analyses were then completed on the log-transformed data. The Excel regressions were done assigning the NTU data as the independent variable and the NTRU data as the dependent variable. The resulting regression equation resulted in the predicted y-variable being NTRU rather than NTU; therefore, the equation had to mathematically be solved for NTU. To reduce the chance of making a mistake in solving the equation for NTU, the Minitab regressions were run with the independent variable as NTRU and dependent variables as NTU. The resulting equation provided the predicted y-variable directly as NTU values. The switch to this approach occurred when a mistake in the math was found in the intermediate analysis work.

Figure 2.



Converting the predicted log-transformed value back to standard units (NTU) is done by taking the anti-log of the predicted number. Statistical analyses are often stopped at this point, especially in the natural sciences. However, statistical research has demonstrated that doing so results in a biased retransformation estimate. To correct this bias, there are various bias-correction factor procedures available for use. For this data, the Duan's Smearing Estimator (USGS, undated) was used. The effect of the bias-correction in this data was minimal; however, it is still the method of choice in this evaluation to complete the analyses following formal statistical procedures.

The final regression analysis and retransformation of the predicted variable in units of NTU resulted in the equation:

NTU = 10^(-0.0734+0.926*LOG(NTRU))/1.003635.

It is important to note when using this approach to "convert" NTRU to NTU values that the variability in measurements and characteristics of the water is probably much greater than the "accuracy" inferred by the significant digits used in this analysis. The estimated NTU turbidity values are best reported as integers, except for values less than ten where a single decimal place is adequate.

Table 1 provides a comparison of NTRU values to the predicted NTU values along with the ratio between the predicted NTU and observed NTRU values. Given the log-transformation and retransformation, the ratio between the values varies from low to high values with the difference between predicted NTU and measured NTRU being the least (highest ratio) at lower turbidity levels and greatest (lowest ratio) at higher turbidity levels. The ratio ranges from 0.6 to 0.65 for estimated turbidities (NTU) between 100 and 20, respectively. The ratio between the predicted and measured values at 25 NTU is 0.64.

Table 1. NTRU and "Estimated NTU" values based on regression of paired turbidity data from the 2004 River Remote Sensing Project.

NTRU	"Estimated NTU"	Ratio
1	0.84	0.84
5	3.74	0.75
10	7.1	0.71
15	10.33	0.70
20	13.48	0.67
25	16.58	0.66
30	19.63	0.65
35	22.64	0.65
39	**25.02**	**0.64**
40	25.62	0.64
45	28.57	0.64
100	59.84	0.60

Given the differences in the standard procedures for the two meters and the relatively wide geographic range of the remote sensing study rivers, a visual check of regressions using two subsets of the paired data was performed. A subset of data less than 40 NTU was selected to check for a possible affect on the relationship due to dilution of samples for turbidities greater than 40 when using Standard Methods with a Hach 2100A turbidimeter. The second subset to be checked was data from the Blue Earth River Basin assuming that its location was "most similar" to that of the Des Moines River and Pipestone Creek. Figure 3 plots these with the "all data" regression. They show little difference between them, so the "all data" regression equation was used in calculating NTU values from the measured NTRU values in the turbidity TMDLs for the West Fork Des Moines River and Pipestone Creek.

Figure 4 plots the estimated NTU values versus a range of NTRU values based on the final regression analysis of the paired data set.

Figure 3.

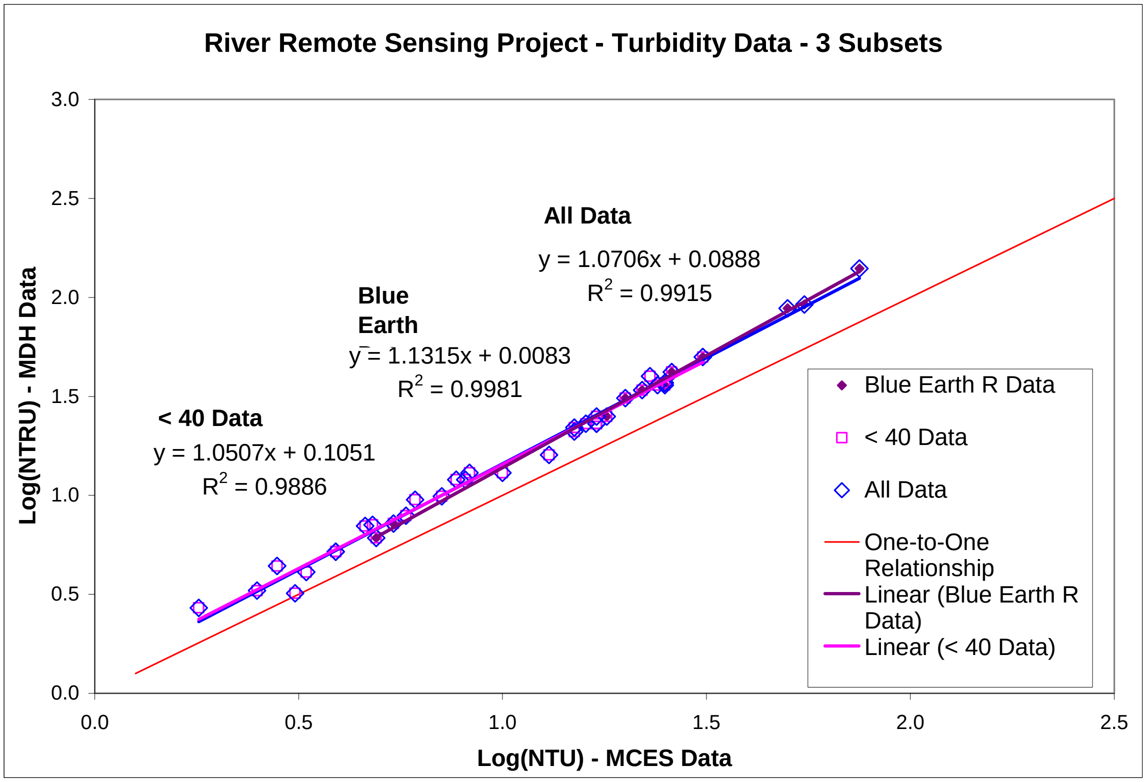
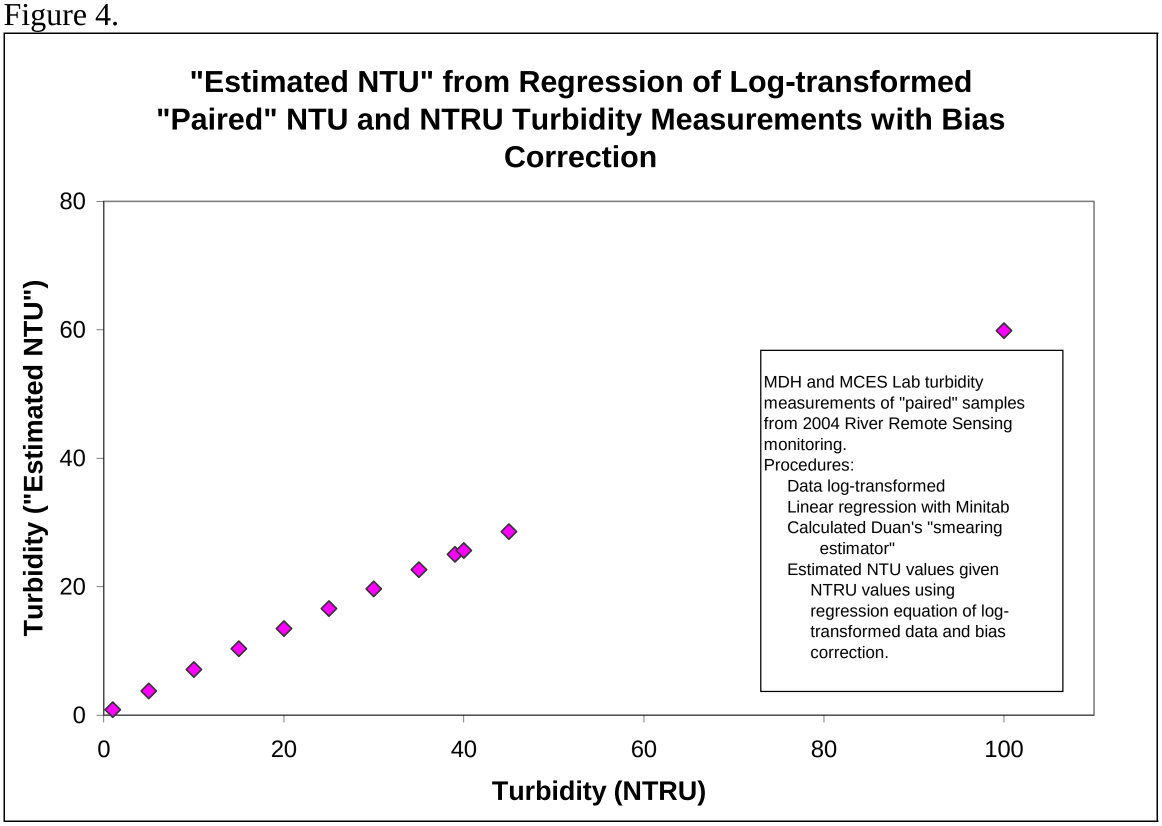


Figure 4.



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River Remote Sensing Project

MCES and MDH Laboratory Analytical Data for Turbidity

All samples were collected on August 19, 2004

Site Description	Basin ID	Time	NTU	NTRU
LeSueur River at Hwy 66 Bridge in South Bend Twp.	LESUEUR	9:15	75	140
Minnesota River at Co Rd 42 Bridge in Judson	MINNESOTA	8:45	50	88
Blue Earth River at Hwy 169 Bridge in Mankato	BLUEEARTH	14:30	55	92
Blue Earth River Upstream of the Confluence with the LeSueur	BLUEEARTH	10:00	26	42
LeSueur River (Gravel Pit) Upstream of the Confluence with the Blue Earth	LESUEUR	9:30	4.9	6.1
Blue Earth River at Rapidan Dam	BLUEEARTH	8:25	22	34
Blue Earth River Upstream of the Confluence with Watonwan	BLUEEARTH	11:30	31	50
Watonwan River Upstream of Confluence with Blue Earth	WANTONWAN	11:40	5.4	7.2
Blue Earth River Upstream of the Pool Created by the Rapidan Dam	BLUEEARTH	12:00	18	25
Center of the Pool on the Blue Earth River Upstream of the Rapidan Dam	BLUEEARTH	12:50	20	31
Crow River at Hwy 55 Bridge in Rockford	CROW_R	8:30	15	22
North Fork of Crow River at Farmington Ave Bridge	CROW_R	9:00	17	23
South Fork of Crow River at Farmington Ave Bridge	CROW_R	9:25	7.1	9.9
Rum River at Main Street Bridge in Anoka	RUM	7:15	5.8	7.9
Mississippi River at Hwy 169 Bridge near Anoka	MISSISSIPPI	10:20	3.1	3.2
Mississippi River 250m Upstream of Confluence with the Crow River	MISSISSIPPI	13:20	2.5	3.3
Crow River at River Road Bridge near the Confluence with the Mississippi River	CROW_R	13:45	6.1	9.5
Mississippi River Downstream of Goodin Island - Right Descending Bank	MISSISSIPPI	14:45	3.9	5.2
Mississippi River Downstream of Goodin Island - Left Descending Bank	MISSISSIPPI	15:00	2.8	4.4
Mississippi River Downstream of Cloquet Island - Center Channel	MISSISSIPPI	10:50	3.3	4.1
Mississippi River at Hwy 5 Bridge	MISSISSIPPI	12:43	4.6	7
Mississippi River side of Pike Island	MISSISSIPPI	13:10	4.8	7.1
Minnesota River side of Pike Island	MINNESOTA	13:50	25	37
Minnesota River at Fort Snelling between I494 and Hwy 55	MINNESOTA	13:35	24	36
Mississippi River at I35E Bridge - Right Descending Bank	MISSISSIPPI	14:54	7.7	12
Mississippi River at I35E Bridge - Left Descending Bank	MISSISSIPPI	14:42	23	40
Mississippi River at Smith Ave High Bridge in St. Paul - Right Descending Bank	MISSISSIPPI	14:15	15	21
Mississippi River at Smith Ave High Bridge in St. Paul - Left Descending Bank	MISSISSIPPI	14:25	17	23
Mississippi River at Lock and Dam No. 2	MISSISSIPPI	9:00	16	23
Mississippi River downstream of Hwy 61 Bridge near Hastings	MISSISSIPPI	8:47	17	25
St. Croix River at Hwy 10 Bridge near Prescott	ST_CROIX	9:15	1.8	2.7
Mississippi River One-Half Mile Downstream of Prescott Island - Right Descending Bank	MISSISSIPPI	9:41	10	13
Mississippi River One-Half Mile Downstream of Prescott Island - Left Descending Bank	MISSISSIPPI	9:55	13	16
Mississippi River Three Miles Downstream from Prescott Island - Right Descending Bank	MISSISSIPPI	10:11	8.1	12
Mississippi River Three Miles Downstream from Prescott Island - Left Descending Bank	MISSISSIPPI	10:21	8.3	13
Minnesota River at Sibley Park	MINNESOTA	14:45	25	36
Mississippi River at Hayden Creek Confluence	MISSISSIPPI	9:50	3.9	5.2

Appendix D. Methodology for Load Duration Curves

Appendix D Contents:

D.1 Data Sources

The data used in this TMDL report were collected in the field by numerous government agencies, their contractors, and helpful citizens. Without the effort of the individuals in these organizations it would not be possible to conduct a rigorous water quality study to determine appropriate loadings for the Zumbro River watershed.

The load duration curve method described below was used to calculate the total maximum daily load (TMDL) for turbidity. This method depends on three basic parameters: stream flow (i.e. discharge in cubic feet per second), turbidity (or surrogate) measurements, and time. The date and time of flow measurements and turbidity measurements were used to correlate these two types of data.

Nine flow gauges provided flow data for the impaired reaches considered in this TMDL. Most of these gauges have been operated for several years and daily flow data is available from the Minnesota DNR's HYDSTRA database. For the purposes of this TMDL, FTS DTS-12 turbidimeters were installed at these gauge locations and set to measure average turbidity at intervals of 15 minutes (some intervals were 10 minutes or 30 minutes) to provide a finer view of the variation of turbidity over time. To relate with turbidity in the duration curves, 15 minute flow measurements were also recorded. The "continuous" DTS-12 turbidimeters record data in FNU turbidity units, and were reported in the HYDSTRA database as well. Continuous flow and continuous turbidity were typically available for the study period of 2007 and 2008, but datasets were reduced due to the winter conditions, equipment malfunctions, and discarding data that did not reliably agree with laboratory turbidity sample results.

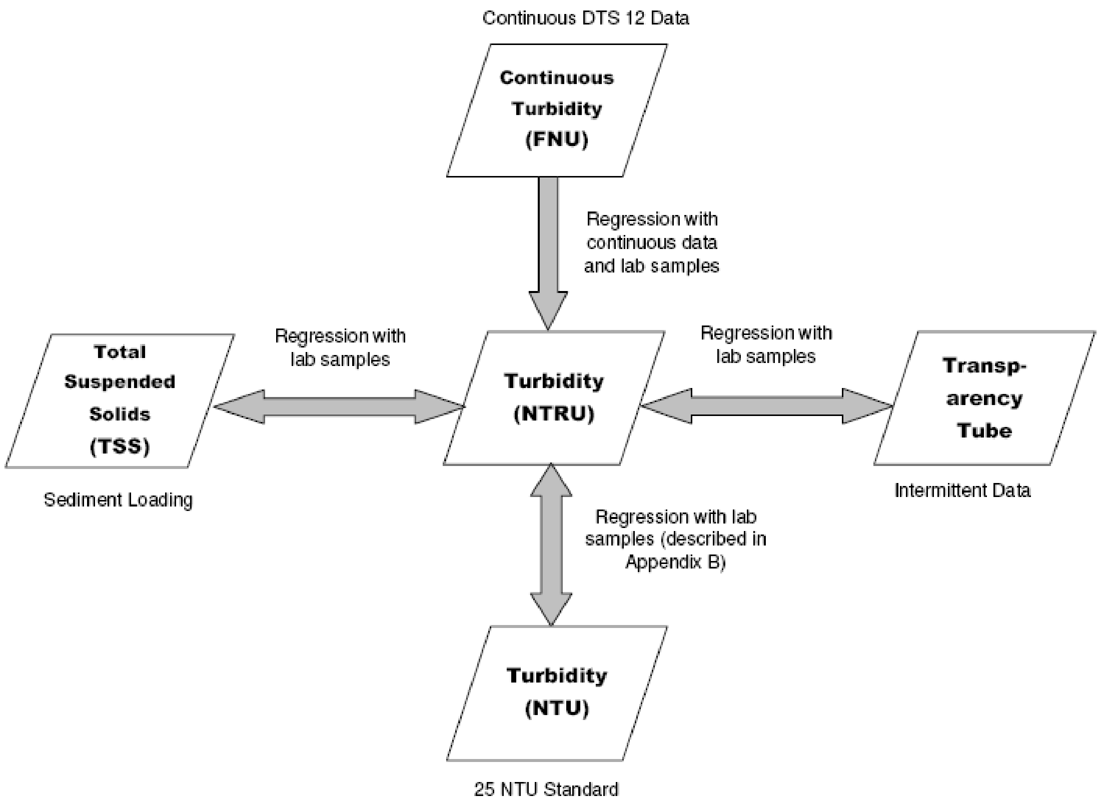
Periodic grab samples at all flow levels taken at the gauge sites were sent to the Minnesota Department of Health Laboratory in St Paul to be analyzed. The two laboratory parameters used in this TMDL were TSS (mg/L) and turbidity (NTRU). This data was accessed through MPCA's STORET database.

At each sampling event a transparency tube reading was also taken and reported to STORET. The transparency tube is a simple gauge of water clarity similar to a Secchi disc and therefore is a good indicator for turbidity. On some stream reaches transparency tube measurements were the only turbidity readings taken, generally by citizen volunteers, and reported to STORET.

D.2 Turbidity & TSS Data Conversion

The threshold for turbidity impairments, 10% of measurements exceeding a turbidity reading of 25 NTU, is straightforward. The process used to compare data in other units of turbidity, transparency tube readings, and TSS data to the 25 NTU standard requires additional explanation. Figure D.1 is a graphical representation of the relationships developed between the data sets used for this project. The central link is formed by the laboratory sample analysis, which was deemed most reliable link to the other measurements of turbidity.

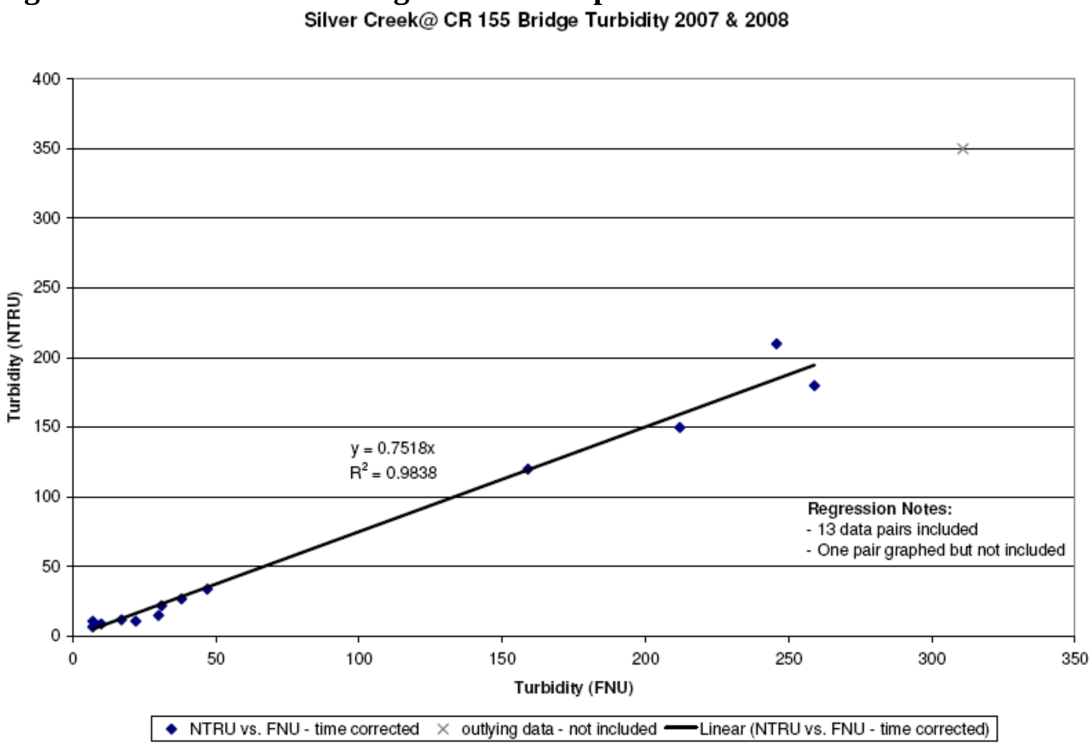
Figure D.1: Data Relationships Diagram



<u>Continuous turbidity (FNU) and MDH Laboratory turbidity (NTRU):</u> For each gauge/monitoring site, sample data taken to the lab (STORET database) in 2007 and 2008 was correlated by date and time to specific turbidity measurements (HYDSTRA database) using the VLOOKUP function in Microsoft's Excel software. One hour was subtracted from the Central Daylight times reported to STORET to match directly with the Central Standard times used in HYDSTRA. It was found that a linear regression best described the relationship between FNU and NTRU turbidity units. Figure D.2 is an example of a regression graph for Silver Creek.

There were large variations in the relationship between FNU and NTRU data at very high turbidities that had a skewing effect on the linear regressions in the lower turbidity range. As a result, the NTRU – FNU regressions for each site excluded correlated data pairs with NTRU values that were greater than 400 (along with other obvious outliers). This is likely due to the differences in the analytical equipment. The approach for the regressions has greater potential to improve the reliability of the sediment loadings as turbidity rarely exceeded 400 NTRU and would not skew the turbidity relationships in the range of the 25 NTU standard, where more of the observed flows occurred. A summary of the linear regression and goodness of fit (R^2) parameter for each gauge is shown in Table D.1 on the following page.

Figure D.2: NTRU – FNU Regression Example



<u>Laboratory turbidity (NTRU) and Standard (NTU)</u>: Continuous turbidities, converted to NTRU and then to NTU was used as the basis for the duration curves. This TMDL used the methodology developed by the MPCA for paired NTRU – NTU turbidity data, which is described in detail in Appendix C.

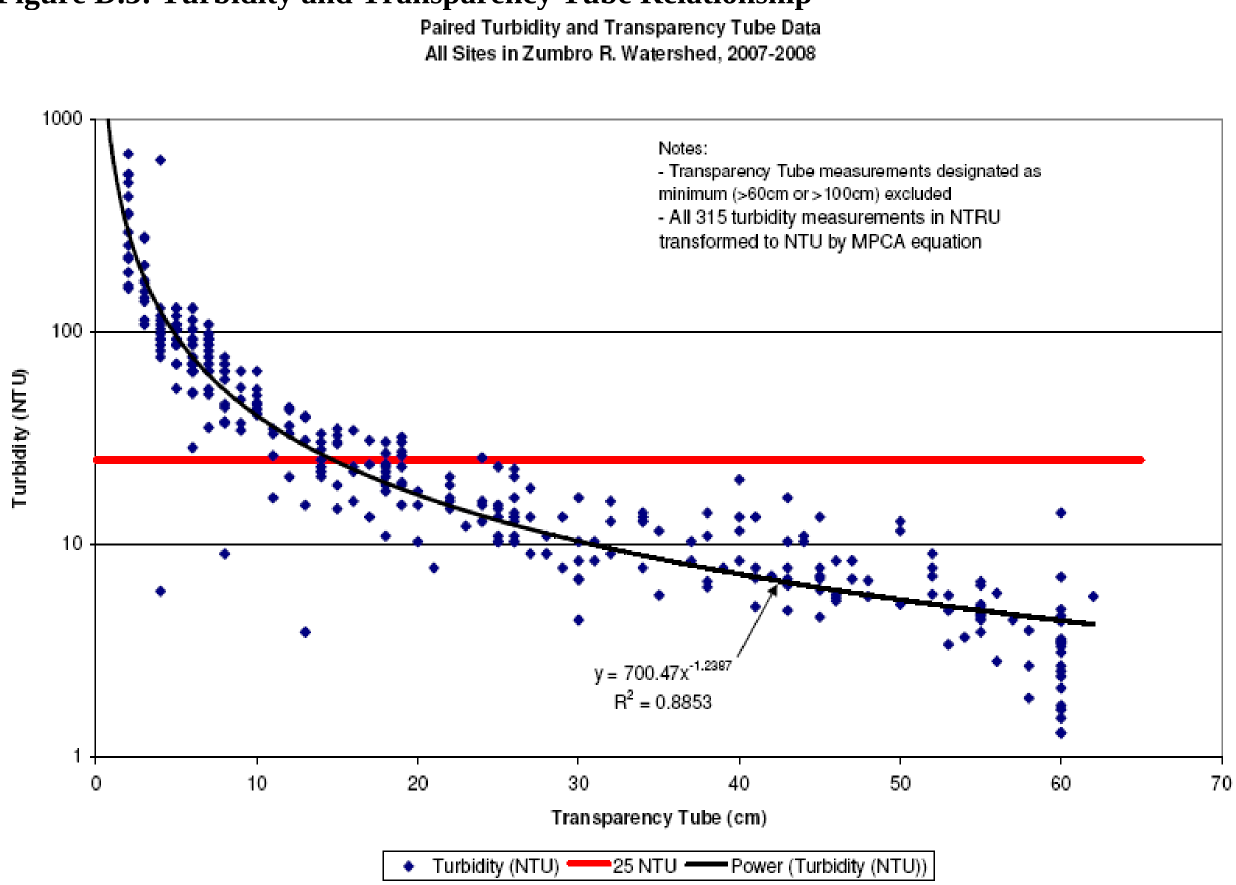
<u>Laboratory turbidity (NTRU) and Total Suspended Solids (TSS, mg/L)</u>: A conversion from turbidity to TSS is necessary to describe the amount of solids (sediments) that corresponds to a specific turbidity and to calculate allowable loading (see section B.3 of this Appendix). This could be done reliably because the STORET database contained TSS and NTRU data pairs for almost all samples in 2007 and 2008. The TSS – NTRU relationship was best described by a power regression or a second order polynomial regression, depending on the site. Coefficients and R^2 values are shown in Table D.1; an example graph is Figure D.3. The far right column of Table D.1 contains the TSS equivalent to 25 NTU used in the loading calculations. These values are derived by converting 25 NTU to NTRU using the equation in Appendix C, then applying the NTRU to TSS conversion.

Table D.1: Turbidity and TSS Regressions

Gauge & Continuous Turbidity Monitoring Site	Hydstra ID	Storet ID	Used for Reaches: (AUID 07040004 - SUFFIX). 'Native' reach suffix is *italic*	(NTRU)= C x (FNU), this column is C	R^2	included # of data pairs	TSS - Turbidity Correlation Type	included # of data pairs (power or poly)	(TSS)=A x (NTRU)^B, this column is A	(TSS)=A x (NTRU)^B, this column is B	Power R^2	(TSS)=D(NTRU)^2 + E(NTRU), this column is D	(TSS)=D(NTRU)^2 + E(NTRU), this column is E	Polynomial R^2	TSS (mg/L) equivalent to 25 NTU standard
Silver Creek @ CR 155 bridge	H41050001	S001-572	-*552* , -553	0.7518	0.9838	13	Power	27	1.9008	0.9725	0.9466	--	--	--	67
Bear Creek @ US 14	H41051001	S000-800	-556, -539, -540, -*538*	0.5506	0.9987	7	Power	25	1.8324	1.0008	0.9608	--	--	--	72
SF Zumbro @ Hwy 14	H41061001	S004-385	-*536*	0.6788	0.9959	5	Power	26	2.524	0.9073	0.9622	--	--	--	70
Cascade Creek @ 7th St NW	H41064001	S001-354	-639, -*581*	0.5903	0.8996	8	Power	27	1.6407	0.9937	0.946	--	--	--	62
SF Zumbro @ 90th St	W41049001	S003-802	-601, -*507*	0.8386	0.9896	35	Power	39	2.7448	0.8818	0.9673	--	--	--	69
SBMF Zumbro @ 272nd St, Mantorville	H41067001	S001-729	-592, -526, -*525*	0.5285	--	1	Power	31	2.4685	0.9125	0.9196	--	--	--	70
Milliken Creek @ CSAH 9	H41016001	S004-486	-*554*	0.8239	0.9839	18	Poly	26	--	--	--	-0.0007	1.2562	0.9231	48
MF Zumbro @ CSAH 3, Pine Island	H41015001	S004-382	-*522*	0.6787	0.5764	9	Poly	27	--	--	--	-0.0011	1.8737	0.892	71
Zumbro R. @ Kellogg	H41043001	S004-384	-*501*	0.7582	0.9352	55	Power	76	4.8215	0.804	0.8892	--	--	--	92
			Summary	average	average	total		total	average	average	average	average	average	average	average
			Statistics	0.6888222	0.920388	151		304	2.1852	0.9447667	0.950417	-0.0009	1.56495	0.90755	69

<u>Laboratory turbidity (NTRU) and Transparency Tube Reading (cm)</u>: The transparency tube is useful for quickly determining the magnitude of turbidity in a stream, but it has its limitations. It is important to note that for transparency tube data there is an inverse relationship to turbidity, meaning that lower readings in centimeters correspond to lower water clarity and thus higher turbidity. In very turbid waters visibility is greatly reduced and readings of less than 10 cm are not uncommon. In the single-digit centimeter range the effects of sources of error such as different ambient light and the eyesight of the observer may be relatively larger than errors of similar magnitude would be at the tube's mid-range. The upper limit for most transparency tubes is 60cm, and if the disc at the bottom can be seen clearly when the tube is full, the measurement must be marked as ">60cm". Given a longer (but impractical) tube, it is possible that a measurement >60cm may be 61 cm or 161 cm. Thus data marked as ">60" was excluded from the regression between the transparency tube and turbidity. To form a dataset large enough, NTU (transformed from NTRU by the aforementioned equation) – transparency tube pairs from the entire Zumbro River watershed for 2007 and 2008 were plotted on one graph and a generalized regression was determined, as shown on Figure D.3. The horizontal red line on Figure D.3 represents the 25 NTU standard. Back-calculating yields 15 cm on the transparency tube as equivalent to 25 NTU. There is one data point that is greater than 60 on the graph, because a few transparency tubes are 100 cm long.

Figure D.3: Turbidity and Transparency Tube Relationship

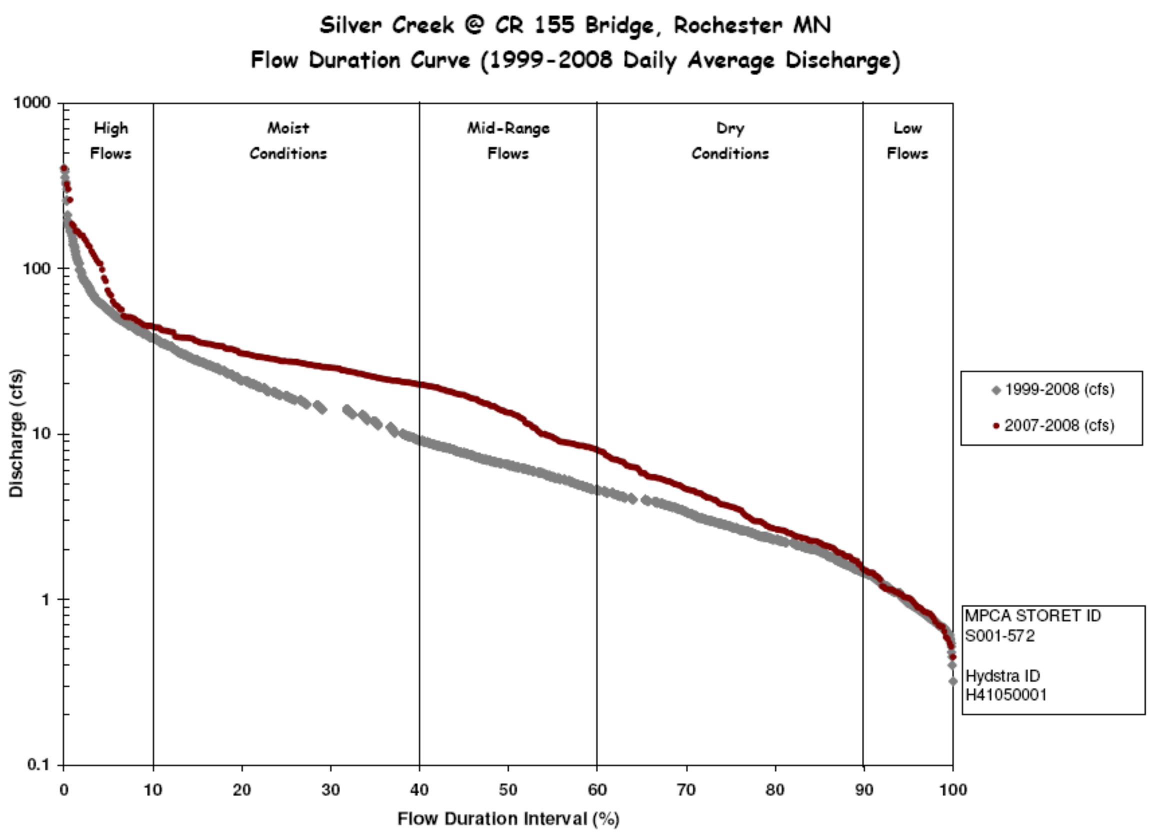


D.3 Duration Curve Methodology

The loading capacity determination used for this report is based on the "Duration Curve" process developed for the "Revised Regional Total Maximum Daily Load Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota" (MPCA, 2006) and "West Fork Des Moines River Watershed Total Maximum Daily Load Report: Excess Nutrients (North and South Heron Lake), Turbidity, and Fecal Coliform Bacteria Impairments" (MPCA, 2008).

The load duration curve approach relies on having a flow record that reasonably represents the range of conditions that would be expected. This is typically accomplished by using a long-term flow record, but continuous flow data was generally only available for the 2007-2008 period. Some of the gauges had daily flows recorded in the HYDSTRA database going back many years, so the appropriateness of using 2007-2008 flow data was assessed by comparing daily data from 2007 and 2008 to daily data from the available range. For the example of Silver Creek below, daily flow data was available from 1999 and later. The darker line represents the set of 2007-2008 data while the wider gray line represents all available daily flow data. In general it appears that mid-range flows were slightly higher than average in 2007-2008 at most sites, but that overall these two years can be considered representative, and no attempt was made to further 'fit' the data to the long-term flow record.

Figure D.4: Comparison of 2007-2008 Flows to Recorded Flows



Loading capacities for specific pollutants are related directly to flow rate. As flows increase, the loading capacity of the stream will also increase. Thus, it is necessary to determine loading capacities across the range of flow. To illustrate portions of the flow record it is useful to divide up the record into "flow zones."

For this approach, daily flow values for each site are sorted by flow volume, from highest to lowest and a percentile scale is then created (where a flow at the X^{th} percentile means X% of all measured flows equal or exceed that flow). Five flow zones are illustrated in this approach: "high" (0-10^{th} percentile), "moist" (10^{th}- 40^{th} percentile), "mid-range" (40^{th}-60^{th} percentile), "dry" (60^{th}-90^{th} percentile) and "low" (90^{th}-100^{th} percentile). The flows at the mid-points of each of these zones (i.e., 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles) can then be multiplied by the water quality standard concentration and a conversion factor to yield the allowable loading capacity or TMDL at those points.

For turbidity, the total suspended solids (TSS) equivalent to the turbidity standard is used. (A regression is used to determine the TSS equivalent, see preceding Appendix.)
For example, if the equivalent to 25 NTU was determined to be 50 mg/L TSS and "mid-range" (50^{th} percentile) flow is 100 cubic feet/sec, the TMDL for TSS would be:

$$100 \text{ cubic feet/sec} \times 50 \text{ mg/L TSS} \times 28.31 \text{ L/cubic ft} \times 86{,}400 \text{ s/day} \div 907{,}184{,}740 \text{ mg/ton} = 13.4 \text{ tons TSS/day}$$

TMDLs were calculated for all the flow zones for each listed reach of the project. The TMDLs were then divided into a Margin of Safety (MOS), Wasteload Allocations (WLAs) and a Load Allocation (LA).

For this TMDL an explicit ten percent MOS was used.

D.4 Determination of Land Areas Subject to NPDES MS4 Waste Load Allocations in the Zumbro River Watershed

The shapefile lu_20.shp obtained from the City of Rochester was used to define the areas which would fall under the MS4 WLA in the Year 2020. The Model_1 field was used to estimate landuse/landcover. Guidance provided in an email from Mike Trojan, MPCA, on May 1, 2009 (which included a description of the agricultural exemption [CWA Section 502(14)], a table with Twin City Metro land uses and recommendations of what to include in the MS4 WLA) were used.

Interpretation of aerial photos (2008) and professional judgement were used to determine the MS4 WLA area for Open Space and Very Low Density Residential Landuse. There were no attributes indicating that an Open Space was a Park or if it was just undeveloped. Typically, open spaces within or immediately adjacent to the core city area were included in the MS4 WLA area. Very Low Density (and sometimes Low Density) landuse was interpreted as being included in the MS4 WLA area based on the isolation and size of the polygon representing the land use. Residential land uses consisting of one or two houses and/or were obviously farmsteads were excluded from the MS4 WLA area.

Nearly all polygons with agriculture as its class were excluded from the MS4 WLA area, including larger areas within the Core City. Photo interpretation was used to examine smaller areas as agriculture within the core city area. Some of these small areas were not agricultural and were included in the MS4 WLA area.

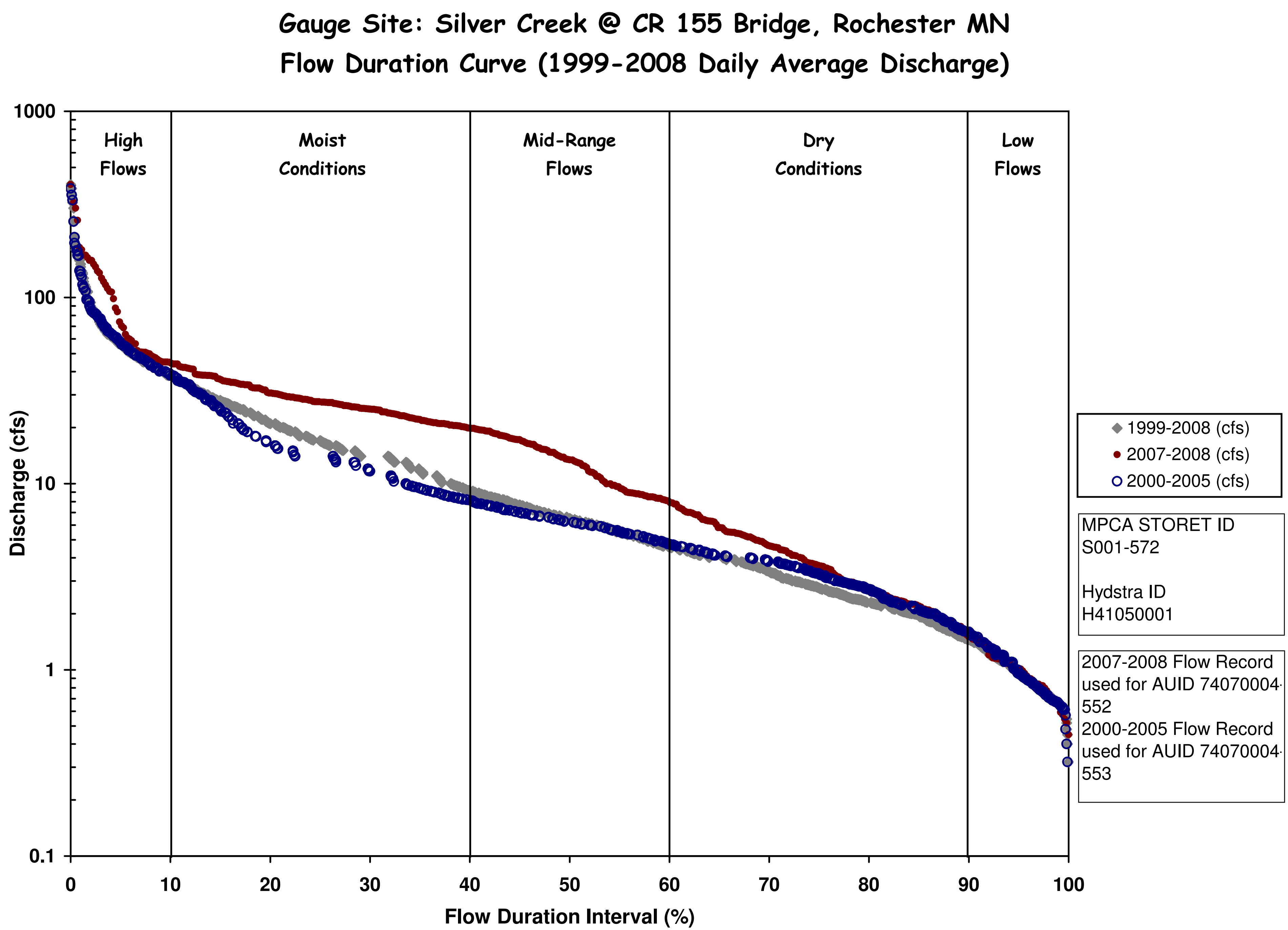
All polygons classed as Right-of-way (including MnDOT and County) were included in the MS4 WLA area.

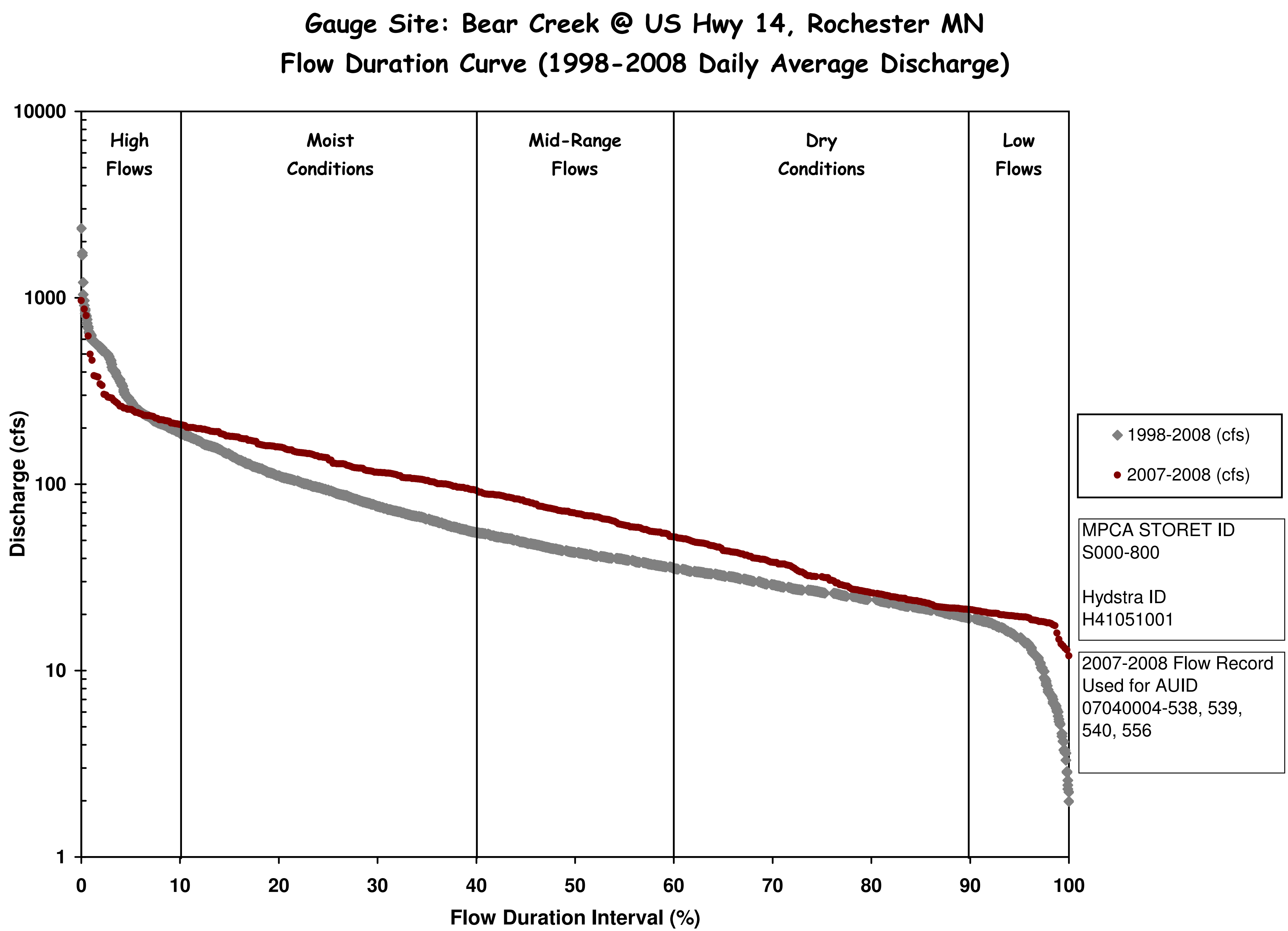
The table below shows the breakdown of areas and basic assumptions used to determine its MS4 WLA area status.

Table D.2: MS4 Wasteload Allocation Area Determinations

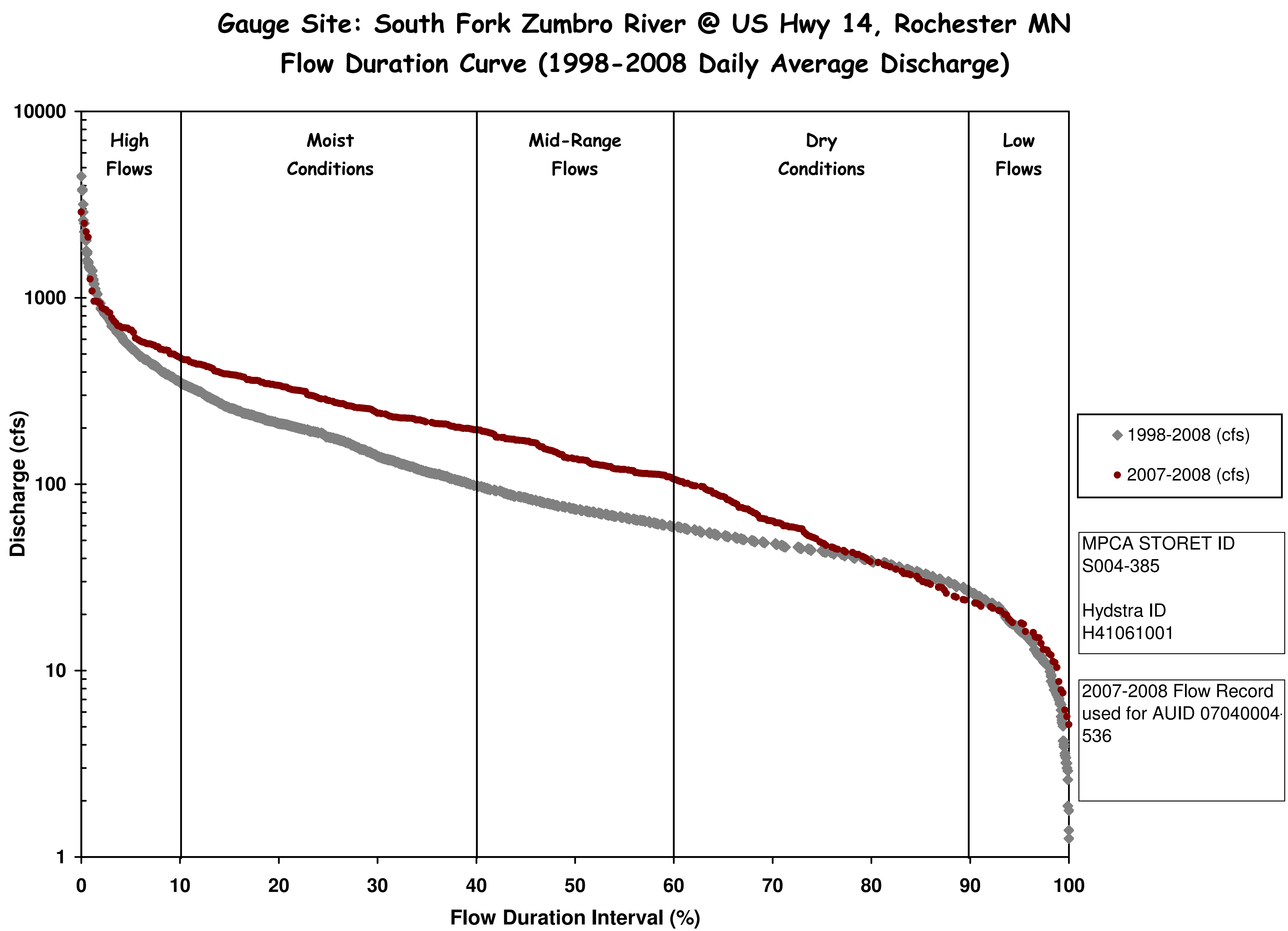
MODEL_1 Value	Comment	Area (acres)	
		Area in WLA	Area out of WLA
<No Value>	Value based on aerial photo interpretation	9	29
Commercial/Industrial	100 Percent WLA	4,781	0
Golf Course	100 Percent WLA	861	0
High Density Residential	100 Percent WLA	1,537	0
Institutional	100 Percent WLA	1,550	0
Low Density Residential	Remote areas not included	11,671	121
Medium Density Residential	100 Percent WLA	922	0
Open Space	If open space was within City or adjacent to existing development it was included in WLA	2,949	5,948
Open Space-C		3,413	2,460
Pits and Quarries	100 Percent WLA	564	0
Right-of-Way	100 Percent WLA	2,828	0
Row Crop Agriculture	Most agriculuture excluded. Some "slivers" were identified within developed areas which appeared in error. These smallareas were included in WLA	167	17,805
Row Crop Agriculture-C		92	721
Very Low Density Residential	Isolated residential, adjacent to farmland, or seperated from the main developed areas were excluded from the WLA	1,910	1,498
Water	Water bodies within the main developed areas were included in WLA	860	308
Total		34,114	28,889

D.5 Flow Duration Curves

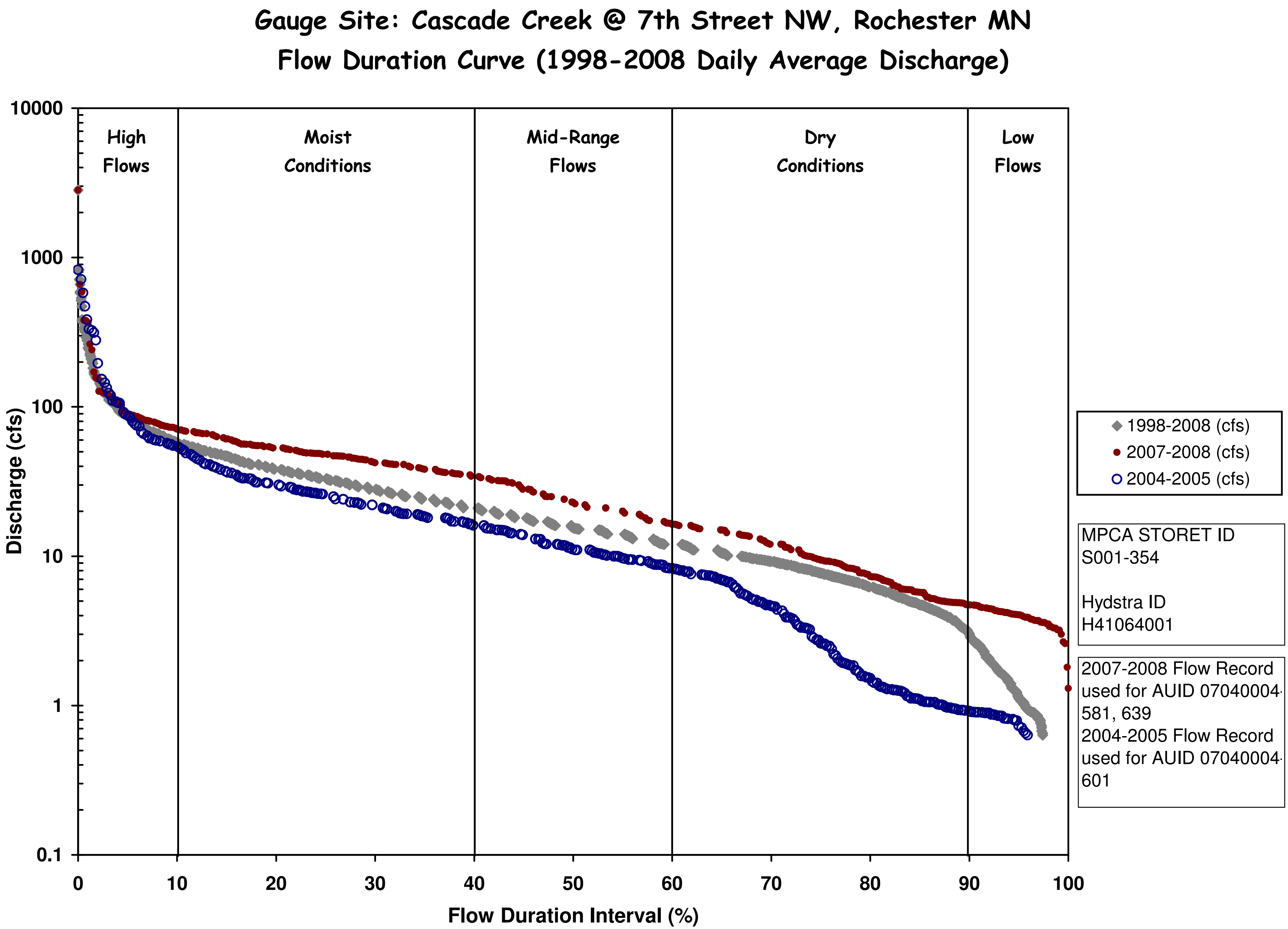

Gauge Site: Silver Creek @ CR 155 Bridge, Rochester MN
Flow Duration Curve (1999-2008 Daily Average Discharge)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
Discharge (cfs)
1000
100
10
1
0.1
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
1999-2008 (cfs)
2007-2008 (cfs)
2000-2005 (cfs)
MPCA STORET ID
S001-572
Hydstra ID
H41050001
2007-2008 Flow Record used for AUID 74070004-552
2000-2005 Flow Record used for AUID 74070004-553

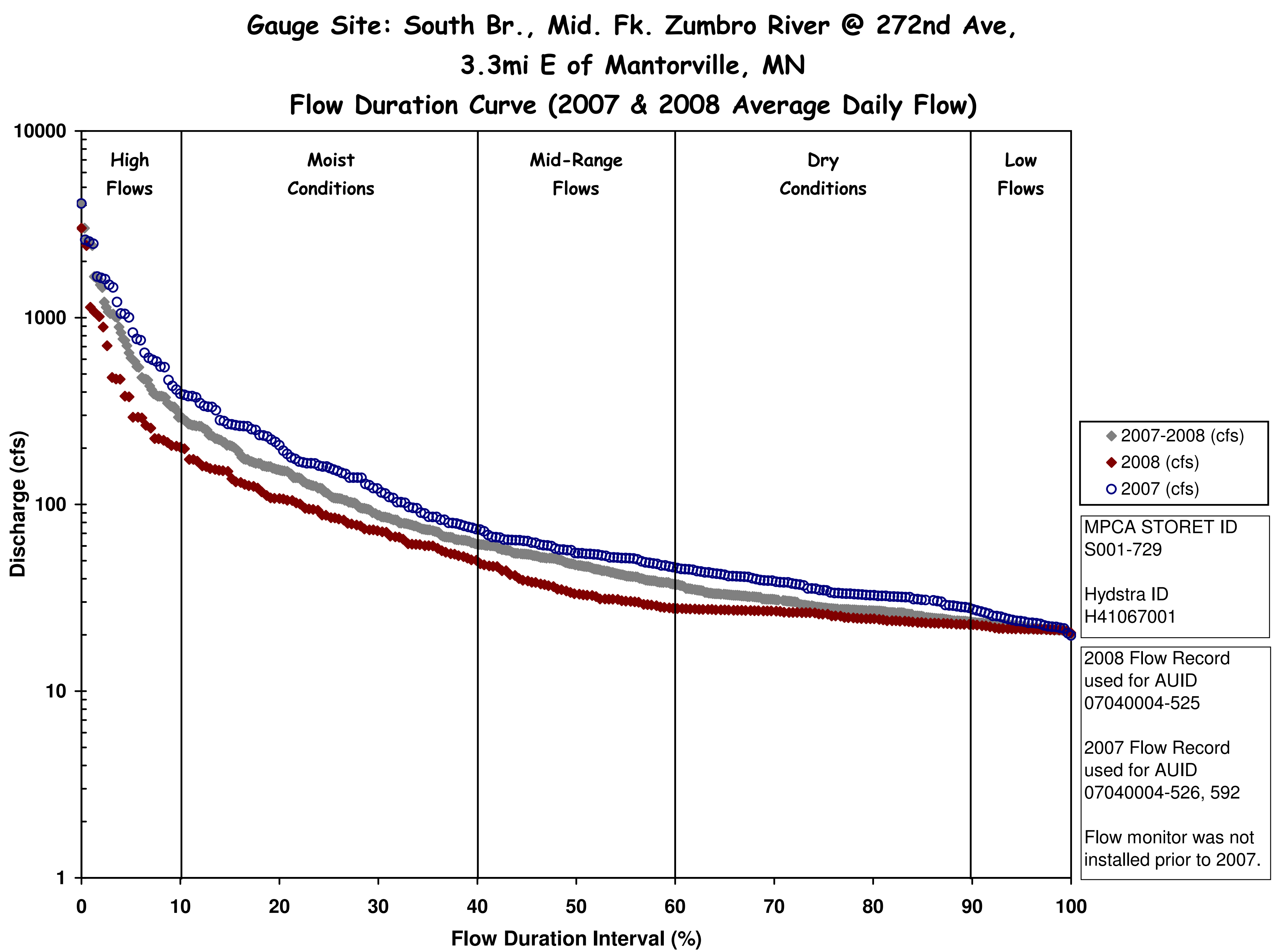


Gauge Site: Bear Creek @ US Hwy 14, Rochester MN
Flow Duration Curve (1998-2008 Daily Average Discharge)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
Discharge (cfs)
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
1998-2008 (cfs)
2007-2008 (cfs)
MPCA STORET ID
S000-800
Hydstra ID
H41051001
2007-2008 Flow Record
Used for AUID
07040004-538, 539,
540, 556

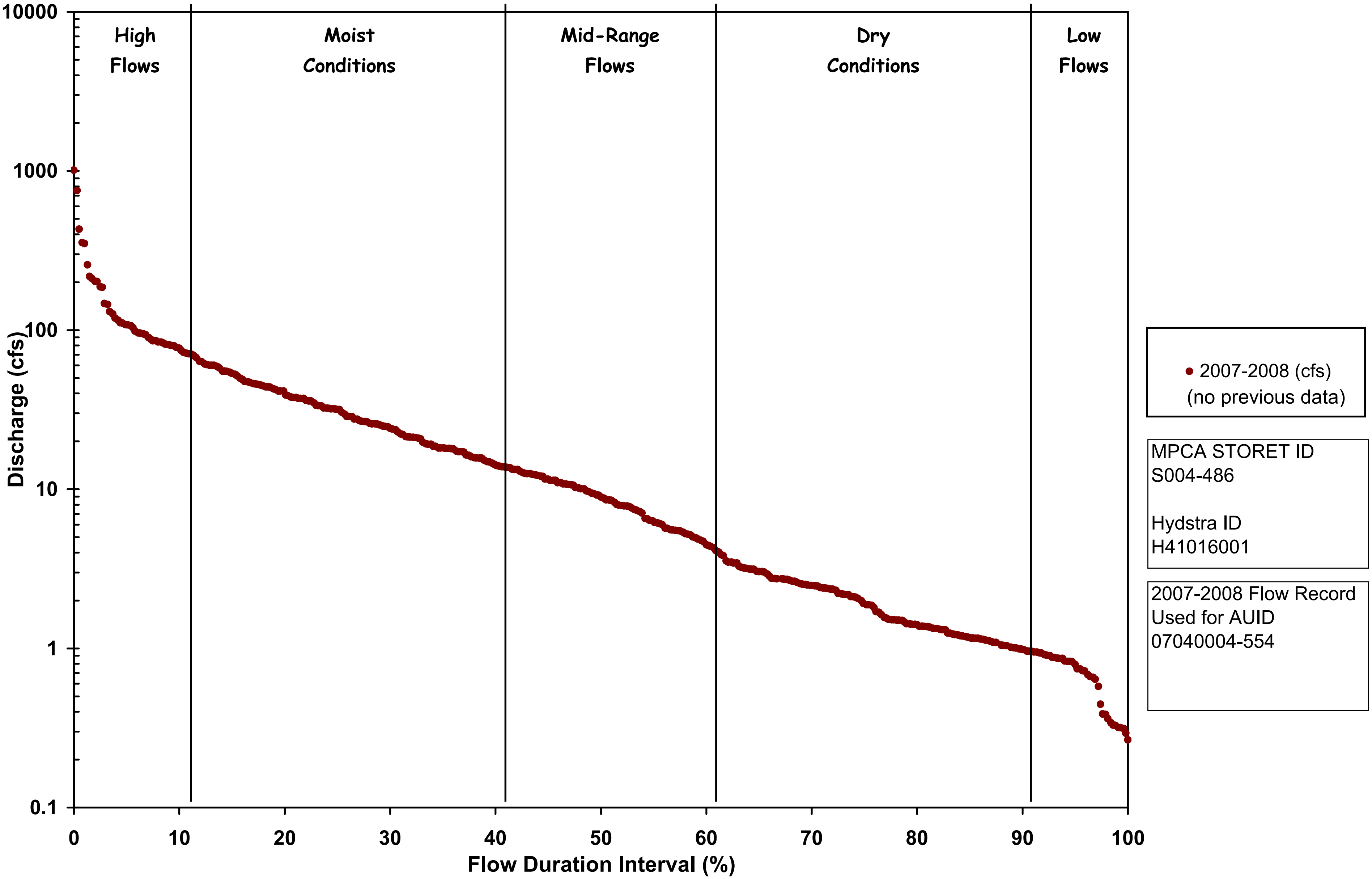


Gauge Site: South Fork Zumbro River @ US Hwy 14, Rochester MN
Flow Duration Curve (1998-2008 Daily Average Discharge)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
Discharge (cfs)
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
1998-2008 (cfs)
2007-2008 (cfs)
MPCA STORET ID
S004-385
Hydstra ID
H41061001
2007-2008 Flow Record used for AUID 07040004-536


Gauge Site: Cascade Creek @ 7th Street NW, Rochester MN
Flow Duration Curve (1998-2008 Daily Average Discharge)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
10000
1000
100
10
1
0.1
Discharge (cfs)
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
1998-2008 (cfs)
2007-2008 (cfs)
2004-2005 (cfs)
MPCA STORET ID
S001-354
Hydstra ID
H41064001
2007-2008 Flow Record used for AUID 07040004-581, 639
2004-2005 Flow Record used for AUID 07040004-601


Gauge Site: South Br., Mid. Fk. Zumbro River @ 272nd Ave,
3.3mi E of Mantorville, MN
Flow Duration Curve (2007 & 2008 Average Daily Flow)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
Discharge (cfs)
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
2007-2008 (cfs)
2008 (cfs)
2007 (cfs)
MPCA STORET ID
S001-729
Hydstra ID
H41067001
2008 Flow Record used for AUID 07040004-525
2007 Flow Record used for AUID 07040004-526, 592
Flow monitor was not installed prior to 2007.

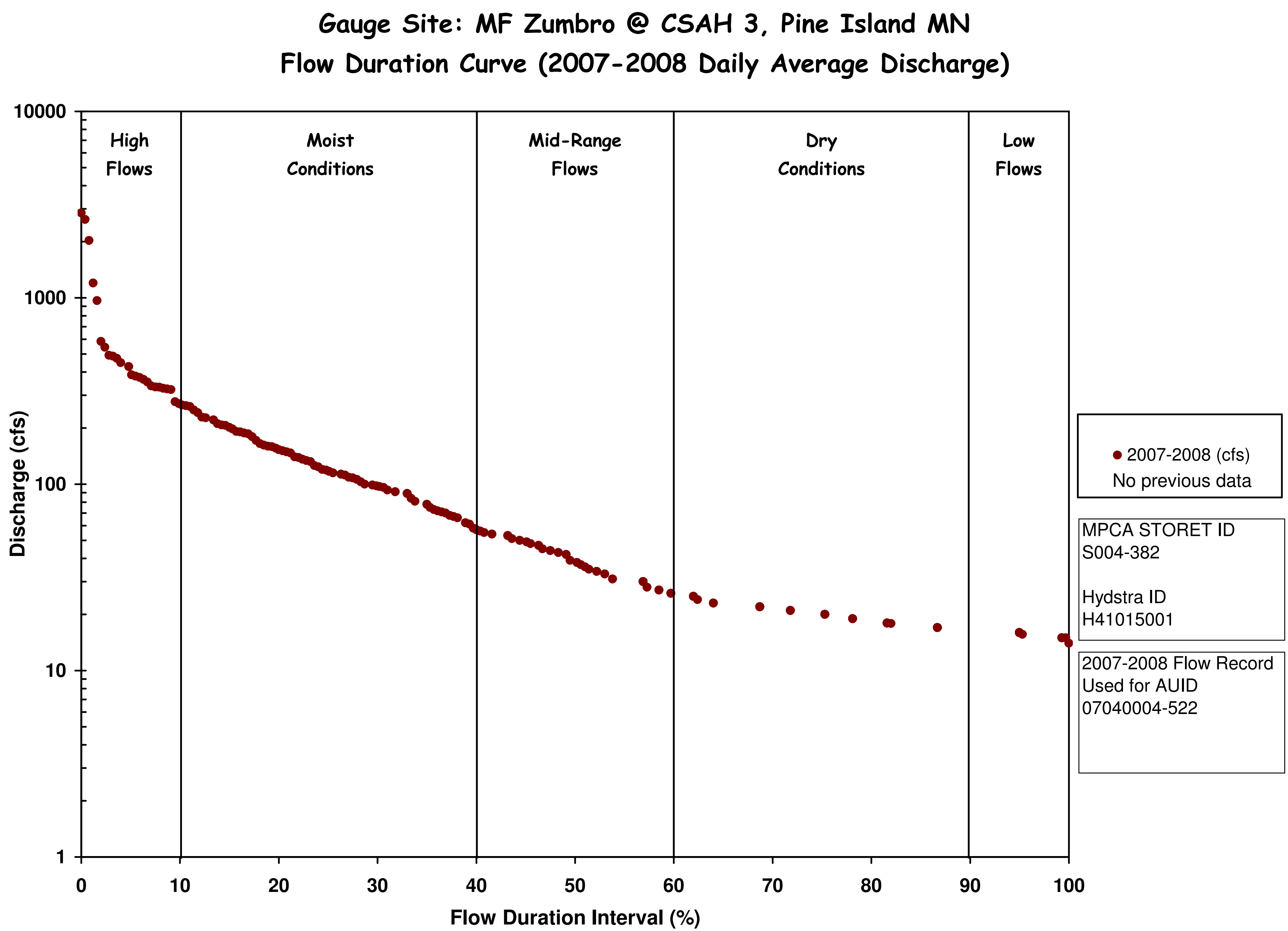
Gauge Site: Milliken Creek @ CSAH 9, near Concord, MN
Flow Duration Curve (2007-2008 Daily Average Discharge)

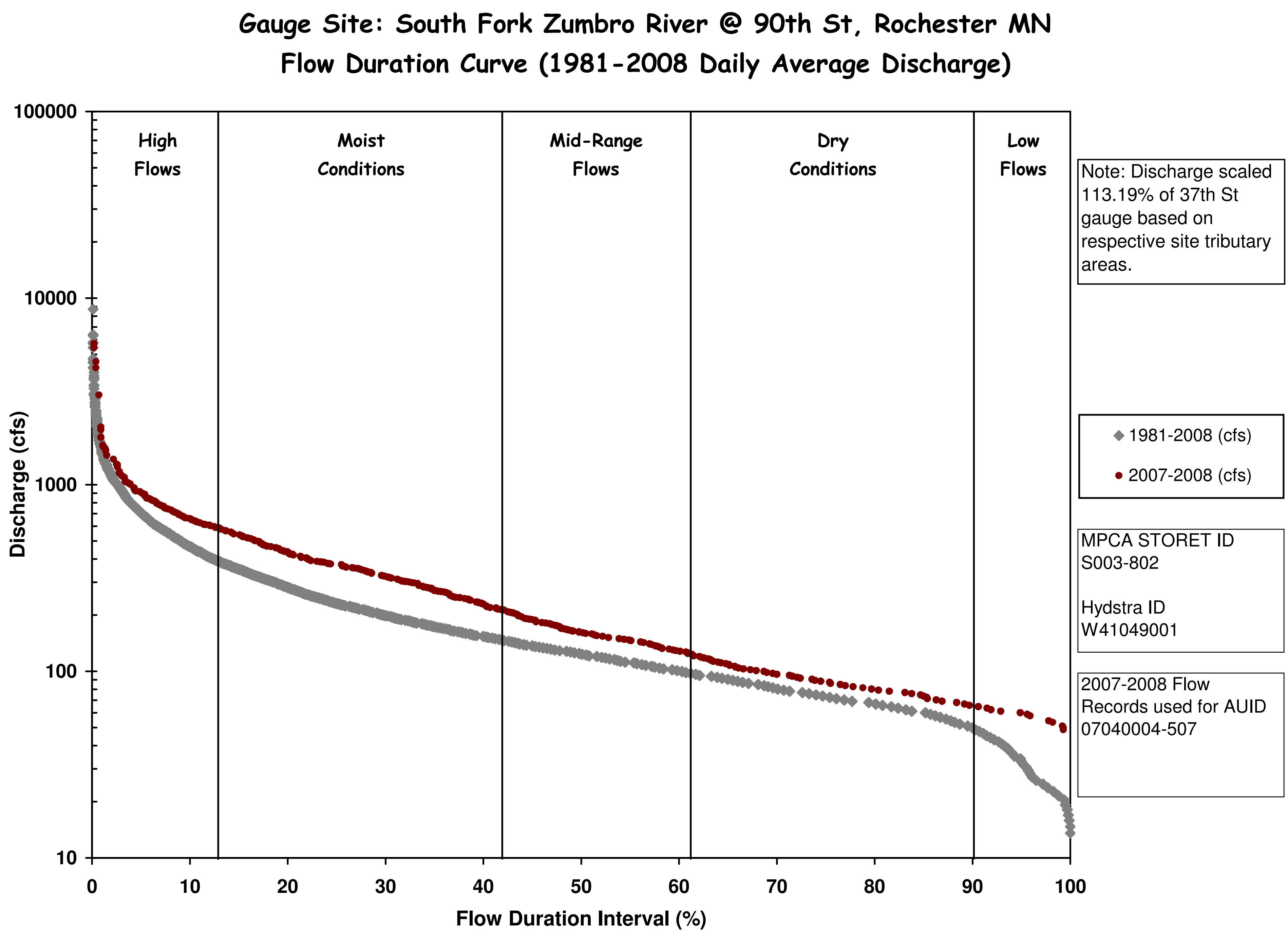


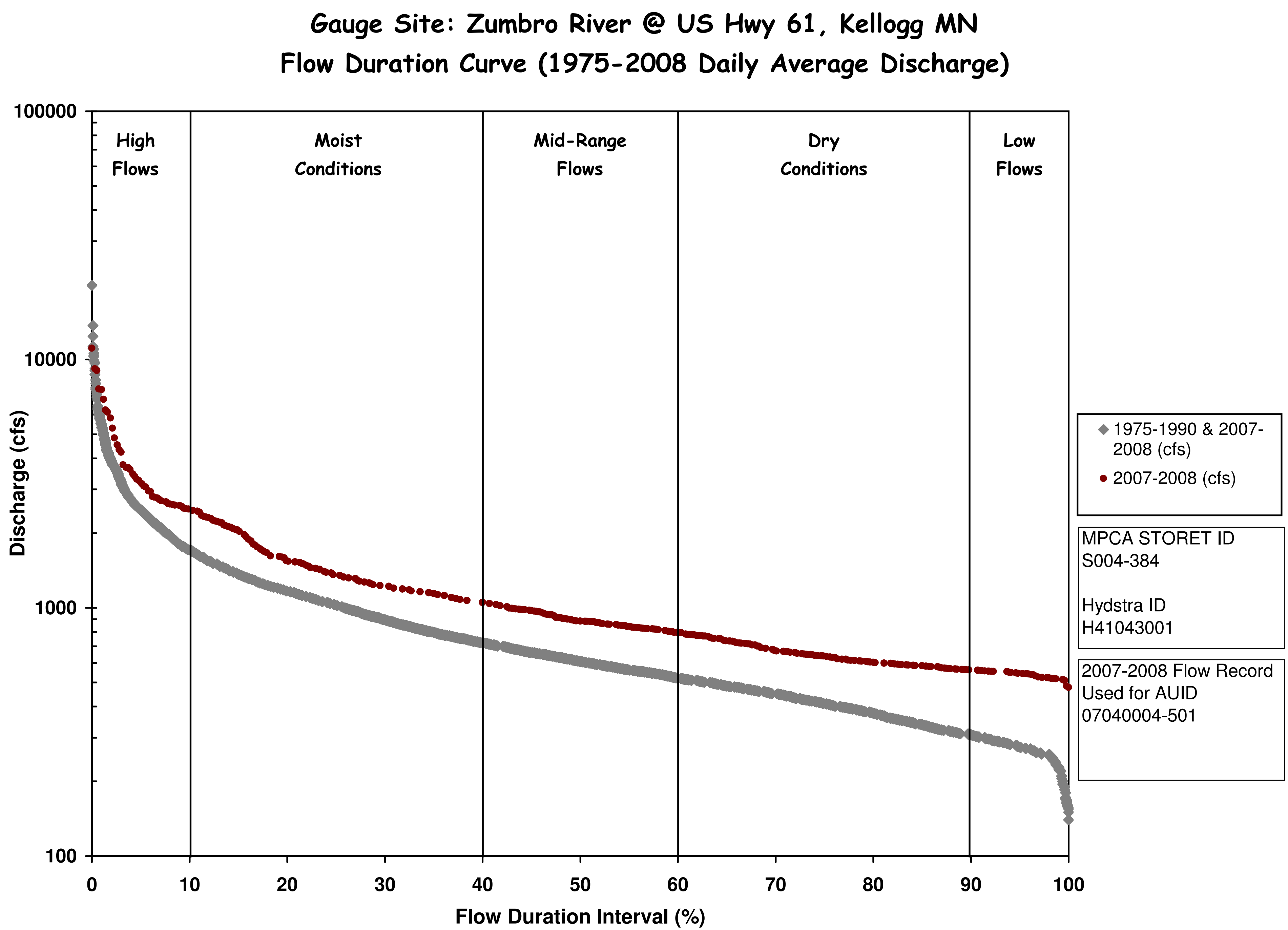
MPCA STORET ID
S004-486

Hydstra ID
H41016001

2007-2008 Flow Record
Used for AUID
07040004-554


Gauge Site: MF Zumbro @ CSAH 3, Pine Island MN
Flow Duration Curve (2007-2008 Daily Average Discharge)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
Discharge (cfs)
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
2007-2008 (cfs)
No previous data
MPCA STORET ID
S004-382
Hydstra ID
H41015001
2007-2008 Flow Record
Used for AUID
07040004-522


Gauge Site: South Fork Zumbro River @ 90th St, Rochester MN
Flow Duration Curve (1981-2008 Daily Average Discharge)
Discharge (cfs)
100000
10000
1000
100
10
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
Note: Discharge scaled 113.19% of 37th St gauge based on respective site tributary areas.
1981-2008 (cfs)
2007-2008 (cfs)
MPCA STORET ID S003-802
Hydstra ID W41049001
2007-2008 Flow Records used for AUID 07040004-507



Gauge Site: Zumbro River @ US Hwy 61, Kellogg MN
Flow Duration Curve (1975-2008 Daily Average Discharge)
High Flows
Moist Conditions
Mid-Range Flows
Dry Conditions
Low Flows
100000
10000
1000
100
Discharge (cfs)
0
10
20
30
40
50
60
70
80
90
100
Flow Duration Interval (%)
1975-1990 & 2007-2008 (cfs)
2007-2008 (cfs)
MPCA STORET ID
S004-384
Hydstra ID
H41043001
2007-2008 Flow Record Used for AUID 07040004-501

Appendix E: Stream Channel Summary

BARR

To: Greg Wilson

From: Jeff Weiss

Subject: Zumbro River TMDL survey analysis

Date: May 8, 2009

Project: 23550100

Background

As part of the Zumbro River Total Maximum Daily Load (TMDL) project, twelve sites throughout the Zumbro River watershed were surveyed to gauge the condition of several streams at different locations within the watershed. The surveys were completed in October and November of 2007. Where possible, the surveys from 2007 were compared to previous surveys done for FEMA floodplain mapping in order to determine if the channels have changed in the intervening time. This memorandum provides a summary of the work done, analysis of the streams, and how they have changed.

Methods

Where site conditions allowed, the entire survey was completed by utilizing survey grade GPS. If tree cover prevented the use of GPS, then at least two points on each cross sections were surveyed with the use of the survey grade GPS.

The exact sites for the locations of the twelve assessment locations were chosen to be within the bounds of previous FEMA studies, if possible, in order to compare survey results to previous surveys and determine if the channels have changed over time. At each site, at least two representative cross sections were surveyed at riffles within the reach. Bankfull indicators were also surveyed in order to estimate vital channel characteristics. Pebble counts were completed to assess the state of the stream bed and how it may contribute to sediment load in flood flows. Other assessment tools, such as the Pfankuch's assessment and BEHI assessment, were completed in order to compile a baseline of a range of stream characteristics and measurements. These baseline characteristics and measurements can be used in the TMDL process to help determine sources of sediment contributions to stream, and they can be used to continue to assess stream health during implementation of the TMDL. Table 1 provides a summary of the sites, and the watersheds for each site can be seen in Figures 1 – 12.

Table 1. Survey locations.

Site number	*Stream name*
1	Bear Creek
1B	Badger Run
2	Silver Creek
3	South Fork Zumbro River
4	Cascade Creek
5	South Fork Zumbro River
6	Middle Fork Zumbro River
7	South Branch Middle Fork Zumbro River
8	North Branch Middle Fork Zumbro River
9	North Fork Zumbro River
10	Zumbro River
11	West Indian Creek
12	Zumbro River

As can be seen in Table 1, a thirteenth site was added at Badger Run. This was done for two reasons. First, it was located adjacent to Bear Creek and the survey could be completed with minimal additional effort. Second, Badger Run had been surveyed in 2006 as part of a new round of FEMA studies in Olmsted County. Given the extremely large rainfall event that occurred in the summer of 2006 and after the FEMA survey was completed, it was decided to duplicate some of the cross sections from the FEMA survey to determine what impact the 2006 floods had on this stream.

The surveys from 2007 were compared to the surveyed channels from the previous FEMA studies, which were obtained from the Minnesota DNR. Given the fact that the previous FEMA studies were conducted approximately 10 to 25 years ago, it was impossible to know exactly where cross sections were surveyed. Therefore, the comparison was done by using several cross sections in the FEMA HEC-2 and HEC-RAS models in the vicinity of the 2007 survey locations. Cross section dimensions were averaged together to characterize the channel at the time of the previous FEMA study. For Site 11, a FEMA study had not been completed anywhere on that stream or on any similar nearby stream, so no comparison could be made. For another location, Site 8, the previous FEMA modeling was unavailable from the DNR which made a comparison impossible to complete.

For each site in the Site Summaries section, there are four tables that compare channel dimensions between the 2007 survey and the previous survey in the FEMA models. Table A compares the bankfull dimensions. While completing the 2007 surveys, it was possible to locate bankfull indicators to complete the analysis. However, the cross sections in the FEMA models did not contain this information and it was necessary to estimate the bankfull elevation in the FEMA models. Because of the need to estimate the bankfull elevation for the FEMA studies, this comparison does not yield the most optimal comparison. However, it still provides some interesting results so it was included in the Site Summaries.

The comparisons in Table A appeared to be misleading since the results indicated that the channel had gotten significantly smaller at almost every site. While the comparisons in Table A provide some interesting and useful information, they cannot accurately tell the entire story about any changes to the channels in the intervening years. To get a more complete story, three additional comparisons were made. The first two utilized relationships developed by the Minnesota DNR, which used survey data from several sites to develop relationships between watershed area and bankfull channel dimensions. These relationships are presented in Appendix A. By setting one dimension, such as bankfull cross section area, of both the 2007 and FEMA surveys equal to the expected value from the DNR relationships, it was possible to use a common staring point for both surveys from which other channel dimensions could be compared. This method was completed for two different channel dimensions: bankfull depth (Table B) and bankfull cross section area (Table C). The last comparison made (Table D) simply used the top of the bank for each cross section as the reference point for the channel dimensions. However bank height is not consistent along any stream reach. Therefore, similar to the comparison in Table A, this was an interesting comparison but difficult to use to draw meaningful conclusions.

The Site Summaries also contain a summary of the pebble counts in the channel bed and the distribution of sediment sizes in the bankfull flats (Table E). Pfankuch and BEHI ratings are also included for each site.

Results

Survey comparison for individual sites is presented in the Site Summaries Section. Figures 13 to 39 provide comparisons between the 2007 and FEMA surveys for all sites for the following channel parameters: cross section area, bankfull width, mean depth, maximum depth, flow capacity, width-depth ratio, and entrenchment ratio. The graphs are set up with equal scales on the x- and y- axes, so any deviation away from the 1:1 slope through the center of the graph indicates a change in the channel dimensions. For example, in Figure 13, the data point for Site 10 is far away from an imaginary 1:1 diagonal line through the graph. This indicates that the channel was significantly larger for the FEMA survey than it was for the 2007 survey. The following table provides a summary of Figures 13 through 38:

Table 2. Key to Figures 13 through 38.

Figures	*Basis of comparison*	*Table in Site Summaries*
13 – 19	Estimated bankfull elevation	A
20 – 25	Match expected bankfull cross section area from DNR relationships (Appendix A)	B
26 – 31	Match expected bankfull depth from DNR relationships (Appendix A)	C
32 – 38	Top of bank	D

The results in the figures will be examined in two ways. First, the trends within each method of comparison will be discussed, followed by trends across the comparisons for the same channel parameter.

Comparison at Estimated Bankfull Elevation (Figures 13 – 19)

The comparisons of the channel dimensions using estimated bankfull elevation (Figures 13 – 19) show that the majority of channel dimensions have gotten smaller over time. This is particularly true for the mean depth, maximum depth, width-depth ratio and entrenchment ratio comparisons, and it is true to a lesser extent for the width-depth ratios. If one of these parameters is getting smaller, then it makes sense that the rest of them are also getting smaller since they are all related. There are two potential causes for such a trend: the channel could be filling in with sediment, or the channel could be getting wider. The channel could fill in with sediment if the upper watershed is supplying too much sediment for the flow in the stream to efficiently carry through the system. If this were the case, then it would be reasonable to expect that bed substrate would be dominated by sand and silt. This was the case for a few sites, but in general, the sites did not show any signs of the channels being filled with fine sediment. Therefore, this is not likely to be a cause.

The second potential cause for this trend is that the channels are getting wider. This is something that commonly occurs as the watershed hydrology changes, particularly if the altered hydrology results in higher peak flows and higher total flow volumes. The Zumbro River watershed has seen additional development in the Rochester area, and it is reasonable to assume that additional drain tile has been placed in agricultural lands between the 2007 survey and the FEMA surveys. Furthermore, widening streams would exhibit eroding banks, which were observed in many places throughout the watershed. Therefore it is possible that the hydrology has been altered and the streams are getting wider as this trend suggests.

Comparison at the Expected DNR Bankfull Cross Section Area (Figures 20 – 25)

Cross section parameters (Figures 20 – 25) were examined at cross section areas approximately equal to the expected bankfull cross section area from the DNR (Appendix A). Most of the figures in this comparison do not show any particular trends. There is typically and equal mix of sites with larger or smaller values compared to the previous survey and they are all relatively close to the 1:1 line, indicating that the parameters have not changed much. However, the width-depth ratio (Figure 24) and the entrenchment ration (Figure 25) show some interesting results. The width-depth ratios are also roughly equally split on either side of the 1:1 line; however a few sites show dramatic changes the previous surveys. Sites 3, 9, and 10 show fairly large increases in the width-depth ratio, while Sites 1B, 2, and 7 show relatively large decreases. Given that the rest of the parameters, notably the bankfull width and depth, did not show a changing trend, this result is surprising. An increase in width-depth ratio would indicate that the channel is becoming wider and/or shallower, which would be consistent with the trend observed in the previous comparison. A decreasing width-depth ratio indicates a deeper and/or narrower channel.

The entrenchment ratio comparisons in Figure 25 indicate that all of the sites have a smaller entrenchment ratio now than they did when the previous FEMA survey was completed. This would indicate that each of the channels is more entrenched than during the FEMA surveys. For this to be true, each of the channels would have had to have experienced noticeable downcutting into the channel bed. Field observations do not support this conclusion, so it is unclear as to why this trend is presenting itself. This is discussed in more detail in the comparison of all entrenchment ratio figures.

Comparison at the Expected DNR Bankfull Width (Figures 26 – 31)

Cross section parameters (Figures 26 – 31) were examined at bankfull widths approximately equal to the expected bankfull widths from the DNR (Appendix A). The results are similar to that from the previous comparison. The graphs do not show any particular trends and the points are split roughly equally on either side of the 1:1 line on most graphs. However, there are a couple of significant outliers. Site 9 shows a significantly larger cross section area in the 2007 survey while Site 1B shows a much smaller area. Similar results for Site 1B were observed in previous comparisons, so this is consistent with the possibility that sediment as washed downstream and partially filled this channel. However, the result for Site 9 appears to be an anomaly as it is inconsistent with other results. Also, Site 10 shows a much larger width-depth ratio in the 2007 survey. As mentioned earlier, erosion was observed at Site 10, and it is likely the cause of the increase in the width-depth ratio.

This comparison also resulted in virtually all the sites having a smaller entrenchment ratio than in the previous FEMA surveys. The cause remains unclear but is discussed in the entrenchment ratio comparison section.

Comparison at the Top of the Bank (Figures 32 – 38)

Cross section parameters (Figures 32 – 38) were examined at the top of the bank for all cross sections in the 2007 survey and the FEMA surveys. Once again, Site 10 shows a significant increase in bankfull width (Figure 33). Sites 1A, 1B, and 5 all had large decreases in bankfull width. The mean depths (Figure 34) and maximum depths (Figure 35) for this comparison were also consistently smaller for this comparison. And once again, the width-depth ratios (Figure 37) and the entrenchment ratios (Figure 38) were almost all smaller, with the exception of the width-depth ratio for Site 10. Like the first comparison, these trends indicate that either the channel is filling with sediment or it is becoming wider. Field observations support the possibility of the channels becoming wider to a much greater degree than the possibility that they are filling with sediment.

Cross section area comparisons (Figures 13, 26, and 32)

Figures 13, 26, and 32 (with a basis of comparison at the estimated bankfull elevation, at the expected DNR bankfull depth, and from the top of the bank, respectively) compare the bankfull cross section areas between the 2007 survey and the previous FEMA surveys. The fourth comparison (set equal to the expected DNR area) was not included because the areas were set equal to each other. The three figures show varying results. All three figures indicate that the channel at Site 1B has actually gotten smaller since the previous survey. This is interesting because the previous survey for this site was in 2006, so it would be unexpected that the channel would become smaller in only one year’s time. However, a significant flood occurred in the autumn of 2006 that may have cause significant channel alterations at this site. Given that the reach for this site is in a flat area near the confluence with Bear Creek, it is possible to conclude that the reason for the channel to become smaller is that portions of the channel filled in with sediment washing in from the upper watershed.

Figure 13 also shows that Site 5 has become much smaller in size in the time since the previous survey, while Site 6 has become much larger. Figure 26 shows a significant channel enlargement for Site 9. The comparison in Figure 31 does not show extreme enlargement or shrinkage, but it does show some moderate enlargement at Site 6 and 7 and some moderate shrinking at Site 3.

Bankfull width comparisons (Figures 14, 20, 27, and 33)

Figures 14, 20, 27, and 33 (with a basis of comparison at the estimated bankfull elevation, the expected DNR bankfull area, the expected DNR bankfull depth, and from the top of the bank, respectively) compare the bankfull widths for all sites between the 2007 survey and the previous FEMA surveys. The only semi-consistent result across these figures is that the bankfull width at Site 10 appears to have gotten significantly larger (Figures 20, 27, and 32). Recent erosion (likely from the 2006 flood) was evident at this site and could have contributed to the increase in bankfull width.

Another interesting result is for Site 5. Figures 14 and 32 show that the bankfull width at Site 5 has gotten smaller, while Figure 27 shows that it has gotten larger. It is not clear what is causing this result, especially considering that Site 5 appeared to be stable.

Mean depth comparisons (Figures 15, 21, 28, and 34)

Figures 15, 21, 28, and 34 (with a basis of comparison at the estimated bankfull elevation, the expected DNR bankfull area, the expected DNR bankfull depth, and from the top of the bank, respectively) compare the mean depths for all sites between the 2007 survey and the previous FEMA surveys. Figure 15 shows that Site 10 has had a significant decrease in mean depth, which would be consistent with the increase in bankfull width discussed in the previous section. Otherwise, the results on the figures show mean depths have stayed relatively consistent. There is some deviation from the 1:1 lines, but these deviations provide conflicting results. For example, Figure 21 shows that the mean depth has increased at the majority of the sites, while Figure 34 shows that they have decreased. The results in Figure 21 would indicate that the channel is getting narrower and deeper for the same cross sectional area, while the results in Figure 34 indicate that the opposite is happening. The differences can be attributed to the different methods used to examine this parameter.

Bankfull depth comparisons (Figures 16, 22, and 35)

Figures 16, 22, and 35 (with a basis of comparison at the estimated bankfull elevation, the expected DNR bankfull area, and from the top of the bank, respectively) compare the bankfull depths for all sites between the 2007 survey and the previous FEMA surveys. Figures 22 and 35 do not show any particular trend, however Figure 16 shows most sites with smaller bankfull depths in 2007 than they had in the previous survey. Given the difficulty in estimating the bankfull depths for the previous survey, it is likely that this trend is a result of insufficient data from the HEC-2 models.

Flow capacity comparisons (Figures 17, 23, 29, and 36)

Figures 17, 23, 29, and 36 (with a basis of comparison at the estimated bankfull elevation, the expected DNR bankfull area, the expected DNR bankfull depth, and from the top of the bank, respectively) compare the channel flow capacity for all sites between the 2007 survey and the previous FEMA surveys. All figures except Figure 17 indicate that the flow capacity in the channels has remained remarkably consistent between the 2007 survey and the FEMA survey, even though Figure 29 shows a slight increase in flow capacity. Figure 17 shows significant decreases in flow capacity for Sites 3, 5, and 10, and an increase in capacity at Site 6. Once again, these differences can be attributed to poor data quality in the HEC-2 models, and this is less likely to be the trend than the other three figures. The fact that the flow capacities have remained essentially the same in the other three figures is a strong indication that significant channel alterations have not occurred since the previous FEMA studies.

Width-depth ratio comparisons (Figures 18, 24, 30, and 37)

Figures 18, 24, 30, and 37 (with a basis of comparison at the estimated bankfull elevation, the expected DNR bankfull area, the expected DNR bankfull depth, and from the top of the bank, respectively) compare the width-depth ratios for all sites between the 2007 survey and the previous FEMA surveys. In general, these figures show a no trend for the width-depth ratios. Most of the figures show a relatively even distribution of the points across the 1-1 lines. The exception to this is Figure 37 which shows most of the site as having smaller width-depth ratios compared to the FEMA surveys. This contradicts the trends observed in previous comparisons and could be a result of the surveyed points at the tops of the banks. All of the figures show a significant increase for the width-depth ratio at Site 10, which is consistent with previous observations. They also show a relatively consistent increase in the width-depth ratio at Site 3.

Entrenchment ratio comparisons (Figures 19, 25, 31, and 38)

Figures 19, 25, 31, and 38 (with a basis of comparison at the estimated bankfull elevation, the expected DNR bankfull area, the expected DNR bankfull depth, and from the top of the bank, respectively) compare the entrenchment ratios for all sites between the 2007 survey and the previous FEMA surveys. All of the figures show that there is a decrease in the entrenchment ratio between the previous surveys and the 2007 survey. It is counterintuitive since the ratio is decreasing, but this indicates that the channels have become more entrenched over time. When channels become entrenched, a larger portion of their flood flows are retained in the channel, which increases velocities and increases erosion. Typically, a stream that is becoming more entrenched is also cutting down into the stream bed or is getting wider. As noted earlier, downcutting was not observed at any of the sites. Other comparisons indicate that the channels may be becoming wider, and field observations noted many eroding banks.

WARSSS Analysis

The characteristics of the Zumbro River watershed are fairly uniform; therefore, most of the subwatersheds associated with each of the study reaches are very similar. Therefore, the WARSSS analysis considers the entire watershed. There are three major changes to the landscape within the Zumbro River watershed that can have significant impacts on the streams: the conversion of land to farmland, urban development, and flood control structures. These changes have direct or indirect impacts on many important variables that impact the stability of the stream systems, including: changes to stream flow magnitude, timing and duration; changes to riparian vegetation; surface disturbance; surface and subsurface hydrology; and sediment movement through the system.

The pre-settlement land use within the Zumbro River watershed was predominantly forest with some areas of oak savanna and prairie. As settlement occurred, the forests were cleared and the land and been converted almost entirely to farmland. The only areas not currently used as farmland are municipalities and the steepest slopes between the high plain and the lower valley, along with some areas immediately adjacent to the streams. The only forested areas remaining are on the steep valley slopes, some riparian areas, parks, conservation areas, and some isolated stands on individual parcels. These landscape changes can have significant impacts on streams because the hydrology is fundamentally altered with such a dramatic land use and vegetation change. The agricultural landscape is also prone to releasing excess sediment to the stream from farm field runoff, especially prior to modern farming practices that work to prevent such erosion. However, since the most dramatic portion of these landscape changes occurred approximately 75 to 150 years ago, it can be assumed that the watershed has adjusted at least in part to its new hydrology.

It should also be noted that the man-made changes to the watershed's hydrology did not once the forests were converted to farmland. The use of drain tile in farm fields adds another layer to the altered hydrology. In a virgin watershed, there are typically many land locked sub-basins that do not have a natural surface outlet under normal conditions. Runoff reaches the low point in the basin and remains in a wetland or infiltrates into the groundwater. The groundwater from both the land locked basins and from rain that infiltrated in basins directed connected to the streams eventually reaches the streams in the watershed, but it is long past the time when the rain first fell on the landscape. The use of drain tiles eliminates the land locked basins and increases the rate at which all infiltrated rain reaches the nearest stream. This works to increase the peak flow rates in all flood events.

Urban development, primarily in Rochester, is another significant land use change that is currently impacting streams within the city and those downstream as well. Typical complications from urban development include increases in both the rate and volume of runoff and a decrease in infiltration. Sites 1-5 are the most directly affected by impacts of urban development. Sites 10 and 12 likely see some impacts as well, however the presence and impacts of Lake Zumbro both mitigate those impacts and create additional impacts that would have a greater influence on the Zumbro River.

At least two significant flood control structures have been completed, creating Lake Shady and Lake Zumbro. Reservoirs such as these can have significant downstream impacts. Obviously, they alter the flow moving through the structure, so the channel shape downstream of the structure often changes in response to the altered flow patterns. The structures also disrupt the natural sediment transport within the stream channel. Sediment in the flow drops out of the flow in the calm waters behind the dams. Clear water released from the dams naturally picks up new sediment from the downstream channel, and because new sediment is not being washed down from upstream, erosion occurs in the downstream channel.

Surface erosion and streambank erosion are two directly observed impacts of the land use within the watershed. Analysis of the survey data and comparison to previous survey data showed signs of channel enlargement, aggradation and degradation.

WARSSS analysis applies a risk rating of different variables and their impacts on the stream. The risk ratings are Very Low, Low, Moderate, High, and Very High. Tables 3 and 4 provide a summary of the risks in the Zumbro River watershed. The sites affected column in Table 3 refers to the sites or watersheds studied in this analysis. Sites listed in this table are sites that are either currently affected or sites with a high likelihood of being affected in the future.

Table 3. WARSSS risk ratings for impacts of several variables.

Variable	*Impact*	*Risk Rating*	*Sites Affected*
Increased impervious area from urban development	Flow-related sediment increase	Very High	1, 1B, 2, 3, 4, 5
Percent of watershed in vegetative altered state	Increase in flow	Low to Very High[1]	All
Percent of riparian vegetation in altered state	Bank erosion	Low to Very High[1]	All
Surface disturbances and roads	Increase in flow and sediment supply	Very High[2]	All
Slope gradient	Mass wasting of stream banks	High to Very High	1B, 2, 6, 7, 8, 9, 12

1 – The entire watershed is in an altered vegetative state from an historical pre-development perspective. If farmland that has been in production for several decades is not considered an altered state, then the risk is reduced to Low for those areas still in farmland, however the risk remains High to Very High for those watersheds experiencing development pressure since it also changes the vegetation.
2 – Road density is only increasing as Rochester continues to grow. However, most of the watershed experiences an annual surface disturbance with spring planting.

Table 4 (below) provides a summary of a variety of parameters that can impact the stream. Each parameter is briefly defined below:

Mass Wasting – Mass wasting is erosion from the failure of large hillsides that create a large amount of exposed, unvegetated soil that can easily wash into any nearby streams. The hillsides can be immediately adjacent to the stream or it can be some distance away.

Roads – Roads can cause direct contribution of sediment into the stream due to cut banks, road fill, and road surface runoff. Roads also increase the impervious area of the watershed and alter natural overland flow patterns.

Surface Erosion – Surface erosion is erosion that occurs on the normal landscape and is exacerbated by surface disturbance, such as agriculture, mining, and land clearing.

Stream flow change – Stream flow change is the potential for changes to the fundamental flow regime in the stream due to man made activities, such as vegetation modification, installation of reservoirs, installation of drain tiles, and urban development.

Streambank erosion – Streambank erosion is the risk of streambank erosion due to such variables as the riparian vegetation, the ratio of the bank height to the bankfull height, and the ratio of the radius of curvature to the bankfull width.

In-channel mining – In-channel mining is the process of mining stream bed material for industrial use. This type of mining can create headcuts, cause instability, and accelerate streambank erosion.

Direct channel disturbance – Direct channel disturbance includes parameters and activities that directly influence the stability of the channel and streambanks, such as: altering riparian vegetation, straightening the channel, dredging, building levees, and livestock grazing.

Channel enlargement – Channel enlargement is the risk of the channel to incise and/or widen at an accelerated rate to due changes in flow, clear water discharge, direct disturbance, and streambank erosion.

Aggradation – Aggradation is the risk of excess sediment accumulating in the stream and raising the channel bed. The causes can include excess erosion upstream, altering the ability of the channel to carry sediment through its reaches, and imbalance between sediment supply and flow.

Channel evolution – Channel evolution considers the amount of erosion that typically takes places as channels transform from one type of stream to another. Each type of stream has a typical geometry for which it is stable. If watershed changes force the stream to change its type, then some erosion typically occurs during the transformation, however, some transformations cause more disturbance than others.

Degradation – Degradation is the opposite of aggradation. It is the lowering of the channel bed, and it causes major channel disturbances that are felt throughout the watershed, both upstream and downstream. Degradation is often caused by an increase in channel flow and/or an increase in channel velocities, clear water discharge from reservoirs, channel straightening, or other imbalances between sediment supply and flow.

Table 4. Erosion risks for the RRISSC analysis

Site	*Name*	*Mass Erosion*	*Roads*	*Surface Erosion*	*Stream flow Change*	*Streambank Erosion*	*In-channel mining*
1	Bear Creek	Low	Moderate	Moderate	High	Moderate	Very Low
1B	Badger Run	Low	Moderate	Moderate	High	Very High	Very Low
2	Silver Creek	Low	Moderate	Moderate	High	Very High	Very Low
3	S. Fork Zumbro R.	Very Low	Moderate	High	High	Low	Very Low
4	Cascade Creek	Very Low	Moderate	High	High	Moderate	Very Low
5	S. Fork Zumbro R.	Very Low	Moderate	High	High	Moderate	Very Low
6	Mid Fork Zumbro R	Very Low	Low	High	Moderate	High	Very Low
7	S Br Mid Fork Zumbro R	Very Low	Very Low	Very High	Moderate	Very High	Very Low
8	N. Br. Mid Fork Zumbro R.	Very Low	Very Low	Very High	Moderate	Very High	Very Low
9	N. Fork Zumbro R.	Very Low	Very Low	Very High	Moderate	Moderate	Very Low
10	Zumbro R.	Very Low	Very Low	High	Moderate	Low	Very Low
11	West Indian Cr.	Moderate	Very Low	Moderate	Moderate	Low	Very Low
12	Zumbro R.	Low	Low	Very High	Moderate	Moderate	Very Low

Table 4 (continued)

Site	*Name*	*Direct Channel Disturbance*	*Channel Enlarge-ment*	*Aggrad-ation*	*Channel Evolution*	*Degrad-ation*	*Overall Risk*
1	Bear Creek	Very Low	Moderate	Low	Low	Low	Low
1B	Badger Run	Very Low	Moderate	Low	Very High	Low	Moderate
2	Silver Creek	Very Low	Moderate	Low	Low	Moderate	Moderate
3	S. Fork Zumbro R.	Very Low	Low	Low	Very Low	Low	Low
4	Cascade Creek	Very Low	Low	Low	Moderate	Low	Low
5	S. Fork Zumbro R.	Very Low	Low	Moderate	Very Low	Low	Low
6	Zumbro R	Very Low	Moderate	Low	Very Low	Moderate	Low
7	S. Br. Mid. Fork Zumbro R.	Very Low	Low	Low	Low	Low	Moderate
8	N. Br. Mid Fork Zumbro R.	Very Low	Moderate	Low	Low	Low	Moderate
9	N. Fork Zumbro R.	Very Low	Moderate	Low	Low	Low	Low
10	Zumbro R.	Very Low	Low	Low	Low	Low	Low
11	West Indian Cr.	Very Low	Low	Low	Moderate	Low	Low
12	Zumbro R.	Very Low	Moderate	Moderate	Low	Low	Moderate

As can be seen in Table 4, five of the sites have a moderate overall risk excess sediment delivery to the stream. The remaining sites all have low overall risks. Additional analysis of sediment contribution from each site is provided in the individual site summaries.

Pfankuch and BEHI Assessments

The Pfankuch assessment is a means to quantify reach stability. It applies scores to several parameters within the three categories of upper banks, lower banks, and stream bed. The Pfankuch assessment sheet is in Appendix B. While the assessments can be used as a snapshot of stream stability at one time, they are especially useful for monitoring changes in the streams over time. Assessments were completed at each site. The results are summarized in Table 5 and Figure 39. Lower scores indicate streams with greater stability and higher scores indicate instability. The score thresholds for Pfankuch ratings are as follows: Excellent: Less than 38; Good: 38 – 76; Fair: 77 – 114; Poor: greater than 114.

Bank erosion hazard index (BEHI) is method for assessing the potential for future erosion. It uses the following variables: Bank height to bankfull height ratio, root depth to bank height ratio, percent of root density, bank angle, and percent of surface protection. The score sheets are provided in Appendix B. The results are summarized in Table 5 and Figure 40. The score thresholds for BEHI ratings are as follows: very low: 5 – 9.5; low: 10 – 19.5; moderate: 20 – 29.5; high: 30 – 39.5; very high: 40 – 45; and extreme: 46 – 50.

Table 5. Pfankuch and BEHI scores for each survey site

Site	Pfankuch score	Pfankuch rating	BEHI score	BEHI rating
1a	76	Good	38.5	High
1b	87	Fair	40.5	Very High
2	79	Fair	34.5	High
3	81	Fair	25.8	Moderate
4	68	Good	27.5	Moderate
5	64	Good	27.6	Moderate
6	79	Fair	35.2	High
7	84	Fair	30.4	High
8	76	Good/Fair	36.4	High
9	69	Good	32.5	High
10	75	Good	18.5	Low
11	79	Fair	27.8	Moderate
12	91	Fair	44.5	Very High

As can be seen in Table 5, nearly all the sites are very near the threshold between a Good and Fair Pfankuch rating. As this rating suggests, most of the streams have distinct potential for instability but they are not necessarily in an active state of instability or rapid morphology.

The scores for the BEHI ratings are much more variable, with erosion potential ratings of low to very high. All of the sites with high and very high BEHI ratings had tall, bare, eroding banks. The low and moderate sites also had tall banks, but they were more vegetated.

The reason for the differences in ranges of ratings for the Pfankuch and BEHI ratings is that the Pfankuch rating considers the entire reach, while the BEHI rating examines one particular bank. Therefore, the Pfankuch ratings represent average conditions the BEHI ratings represent acute conditions are a particular site.

Conclusions

This study examined 13 sites within the Zumbro River watershed. The sites were surveyed and the channel dimensions were compared to previous surveys at 11 of the sites. Assessments for stability, erosion potential, and sediment delivery were completed for each of the sites.

There are few conclusions able to be drawn about general trends throughout the watershed. Most of the sites had only fair Pfankuch ratings, indicating that they are currently experiencing some instability and may continue to experience instability in the future. Further more, 8 of the 13 sites had high or very high bank erosion potential. Both of these issues can easily lead to excess sediment loads in the stream during high flows.

Sediment concentrations in high flows likely come from the stream bed and banks. Many of the sites have fine bed materials that are easily mobilized in high flows and most of the sites have erosion problems that are larger than what could be considered typical or natural bank erosion. Furthermore, the WARSSS analysis indicates that only five sites (1b, 2, 7, 8, and 12) have even a moderate risk of excess sediment loading from the contributing watershed. Therefore, it is more likely that sediment concentrations in high flow originate from the streams themselves.

SITE SUMMARIES

Site 1: Bear Creek

Table 1a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	113	156
Width (ft)	45	49
Mean depth (ft)	2.5	3.1
Max depth (ft)	4.3	5.3
Flow capacity (cfs)	333	584
Width-depth ratio	17.9	26.2
Entrenchment ratio	2.3	14.3
Rosgen classification	C	C

Table 1b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	35	66
Width (ft)	31	45
Mean depth (ft)	1.1	1.5
Max depth (ft)	2.0	2.0
Flow capacity (cfs)	66	147
Width-depth ratio	28.6	32.0
Entrenchment ratio	1.2	1.7
Rosgen classification	C	C

Table 1c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	66	66
Width (ft)	32	44
Mean depth (ft)	2.1	1.6
Max depth (ft)	3.0	3.3
Flow capacity (cfs)	173	153
Width-depth ratio	15.2	30.9
Entrenchment ratio	2.4	2.8
Rosgen classification	C	C

Table 1d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	148	300
Width (ft)	54	106
Mean depth (ft)	2.7	2.9
Max depth (ft)	5.1	5.6
Flow capacity (cfs)	469	1042
Width-depth ratio	20.5	38.8
Entrenchment ratio	5.1	15.3
Rosgen classification	C	C

Table 1e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	0.15	0.29
D_{35} (mm)	0.24	1.9
D_{50} (mm)	0.32	N/A
D_{65} (mm)	0.44	N/A
D_{84} (mm)	0.8	N/A
D_{95} (mm)	1.5	N/A

Pfankuch rating: 76 – Good   BEHI rating: 40.8 – Very High
This reach of Bear Creek appeared to be stable. The banks were in good shape and were without atypical erosion. The riparian vegetation was largely in tact. Large woody debris was present in the stream. The one area of erosion on this site appeared to be caused entirely by large woody debris deflecting flow into the bank.

The upper watershed consists of farmland and it is assumed that the land use has not changed significantly for several decades. Some portions of the lower watershed are starting to see development pressure. Increased development in the watershed will likely lead to higher flows. Given the very mobile stream bed, this could cause some significant effects on this stream.

Tables 1a, 1b, 1c and 1d show that the channel has undergone some changes since the previous survey was done for FEMA modeling in 1994. The channel appears to have gotten smaller in nearly every sense. It is possible that the stream is currently aggrading, as evidenced by the large concentration of relatively small grain sizes in the stream bed. On the other hand, similar sized particles were found in the floodplain and larger particles were not present on sandbars and bankfull flats.

One of the most distinctive features of this site is that the stream bed sediment was almost entirely sand. The particle size distribution in Table 1e illustrates this. It is possible that this is a result of material being washed downstream from steeper upper reaches in the watershed and deposited in reaches with a lower gradient. The bed material would become mobile in flows less than bankfull flow. The sediment material in the bankfull flat was quite a bit larger than that present within the stream. A complete distribution of the bankfull flat sediment was not available because the particle sizes were larger than the sieves used to complete the analysis.

The WARSSS analysis indicates that this stream has a low to moderate risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed and development pressure in the lower watershed pose the most immediate threats to the stream and because of these activities, it has a high risk of impacts due to stream flow changes. The watershed has moderate risks for roads, surface erosion, streambank erosion, and channel enlargement.

The Pfankuch rating of good supports the conclusion that this site is relatively stable, even though the BEHI rating indicates that individual banks have very high erosion potential. Part of the reason for the very high erosion potential in the BEHI rating is the sand bed. Sand beds can scour very easily, which can quickly undermine stream banks. If the bed were gravel instead of sand, the BEHI rating would likely be “moderate.”

For all the analysis methods, this stream typed out as a Rosgen Type C stream. Type C streams with sandy stream bed are very sensitive to disturbance, sediment supply and have a very high erosion potential. They have only a fair recovery potential.

Site 1B: Badger Run

Table 1Ba. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	124	106
Width (ft)	34	32
Mean depth (ft)	3.7	3.3
Max depth (ft)	5.9	5.3
Flow capacity (cfs)	380	315
Width-depth ratio	9.4	9.7
Entrenchment ratio	35.3	40.7
Rosgen classification	E	E

Table 1Bb. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	21	21
Width (ft)	20	23
Mean depth (ft)	1.1	0.9
Max depth (ft)	1.6	1.6
Flow capacity (cfs)	30	28
Width-depth ratio	18.9	28.8
Entrenchment ratio	1.1	1.3
Rosgen classification	G	F

Table 1Bc. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	42	42
Width (ft)	21	23
Mean depth (ft)	2.0	1.9
Max depth (ft)	2.6	2.8
Flow capacity (cfs)	87	86
Width-depth ratio	10.9	12.3
Entrenchment ratio	1.4	1.5
Rosgen classification	G	B

Table 1Bd. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	124	135
Width (ft)	34	46
Mean depth (ft)	3.7	2.9
Max depth (ft)	5.9	5.0
Flow capacity (cfs)	384	385
Width-depth ratio	9.4	16.6
Entrenchment ratio	9.4	8.3
Rosgen classification	E	C

Table 1Be. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	0.062	Not sampled
D_{35} (mm)	0.2	Not sampled
D_{50} (mm)	0.3	Not sampled
D_{65} (mm)	0.36	Not sampled
D_{84} (mm)	0.47	Not sampled
D_{95} (mm)	0.81	Not sampled

Pfankuch rating: 87 – Fair BEHI rating: 38.4 – High

This reach of Badger Run did not appear to be stable. The channel was severely entrenched and many banks on both sides of the stream were actively eroding. The banks likely contribute sediment during high flows. Since the channel is so entrenched, this reach will likely see additional significant bank failures as the channel tries to reach a new equilibrium with the contributing watershed.

The upper watershed consists of farmland and it is assumed that the land use has not changed significantly for several decades. Some portions of the lower watershed are starting to see development pressure. Increased development in the watershed will likely lead to higher flows. Given the mobile stream bed, this could cause some significant effects on this stream.

The cross sections surveyed in 2007 matched the exact locations of where cross sections were surveyed in 2006 for a new FEMA study. Therefore, the comparisons in Table 1Ba, 1Bb, 1Bc, and 1Bd show that the channel has undergone some changes in only 1 year. The channel's cross sectional area, width and depth have all increased. It is possible that the severe flooding in late 2006 contributed to much of the change from 2006 to 2007. However, the channel was already severely entrenched prior to this flooding, so the additional erosion is just another step as the channel continues to erode as it works to find a new equilibrium.

The channel bed (Table 1Be) was composed of silt and sand, so it is likely to be mobilized during high flows. Bankfull indicators were difficult to find within this reach. In fact, no distinctive bankfull flats were found, and no bankfull flat sediment samples were taken.

The WARSSS analysis indicates that this stream has a moderate overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed and development pressure in the lower watershed pose the most immediate threats to the stream, and because of these activities, it has a high risk of adverse impacts due to increases in flow. The streambanks are also currently eroding and the channel is entrenched, so the stream has a very high risk of additional streambank erosion and channel evolution. The watershed also has a moderate risk due to roads, channel enlargement, and surface erosion.

The Pfankuch rating of Fair supports the conclusion that this reach is moderately unstable. The BEHI rating (High) is only for one surveyed bank, but several banks along this reach are very similar.

The different analysis methods result in different Rosgen ratings; however, based on field observations, this stream is likely a Type E stream. Type E streams are also very sensitive to disturbance, but have a low sensitivity to sediment supply and only moderate streambank erosion potential. They have a good recovery potential. Evidence in the field indicates that this Type E stream has already experienced some disturbances and streambank erosion. However, it should continue to cover naturally on its own.

Site 2: Silver Creek

Table 2a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	45	138
Width (ft)	22	53
Mean depth (ft)	2.1	2.6
Max depth (ft)	3.4	4.0
Flow capacity (cfs)	227	724
Width-depth ratio	11.2	20.9
Entrenchment ratio	2.4	4.8
Rosgen classification	E/C	C

Table 2b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	12	26
Width (ft)	15	24
Mean depth (ft)	0.8	1.1
Max depth (ft)	1.6	1.6
Flow capacity (cfs)	35	80
Width-depth ratio	18.6	24.9
Entrenchment ratio	1.5	2.2
Rosgen classification	B	C

Table 2c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	40	43
Width (ft)	21	43
Mean depth (ft)	1.9	1.3
Max depth (ft)	3.2	2.2
Flow capacity (cfs)	193	132
Width-depth ratio	11.5	24.4
Entrenchment ratio	2.3	2.5
Rosgen classification	E/C	C

Table 2d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	277	409
Width (ft)	61	96
Mean depth (ft)	4.6	4.2
Max depth (ft)	8.6	8.2
Flow capacity (cfs)	2428	3554
Width-depth ratio	13.5	23.3
Entrenchment ratio	6.6	9.1
Rosgen classification	C	C

Table 2e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	5.3	0.28
D_{35} (mm)	10	0.33
D_{50} (mm)	18	0.38
D_{65} (mm)	28	0.44
D_{84} (mm)	56	0.58
D_{95} (mm)	97	0.85

Pfankuch: 79 – Fair BEHI: 34.5 – High

This reach of Silver Creek did not appear to be stable. The instability is most apparent in the frequent, tall actively eroding banks. The large banks likely contribute a significant amount of sediment to the stream during high flows. The bed was rocky, as indicated by the D_{50} of 18 mm. Headcuts were observed in some places along the stream, which undoubtedly is contributing to the erosion problems. The channel sediment was clean and lacked any noticeable plant or algae growth. Not all stream beds have aquatic plants and algae growing on them, however rocky bed sediments typically develop a dirty, aged appearance as they are exposed to years of turbid flood flows. Many of the bed particles in Silver Creek were dirty and appeared aged, but a higher number than expected were relatively clean. This is an indication that the bed is mobile in high flows. In many streams, this is not an indicator of poor stream health and, in fact, most stream beds are expected to be mobile to a certain extent. Given the size of the typical bed particles in Silver Creek and the size of the stream it would not be expected that the bed particles are as mobile as they appear to be.

The floodplains were well vegetated. Bankfull flats with fresh sediment deposits were only discovered in a few places. It is unknown if the bank erosion has been ongoing or if the erosion is a result of the large flows in 2006. The riparian vegetation consisted of mature trees and forest undergrowth and was largely in tact. A lot of large woody debris was present in the stream, some of it obviously from freshly eroded banks.

The upper watershed consists of farmland and it is assumed that the land use has not changed significantly for several decades. There is a large pond in the upper watershed that appears to be man-made. The date of its construction is unknown.

Tables 2a, 2b, 2c, and 2d show that the channel has undergone some changes since the previous survey was done for FEMA modeling in 1994. Some discrepancy is expected because the reach surveyed in 2007 was approximately one mile upstream of the cross sections used from the 1994 survey. The contributing watershed area for the 1994 survey is approximately 20% larger than that for the 2007 survey, but this does not come close to fully accounting for the differences in channel dimensions. Table 2c appears to offer the best basis for comparison since the values between the two surveys are not nearly as far apart. According to Table 2c, it appears that Silver Creek has grown narrower and deeper. The sediment in the channel bed is fairly large, and it would take flows at least as large as a bankfull event to mobilize the current bed. There is evidence that the current bed material has been mobilized since similar sized particles are present in bankfull flats. Furthermore the fact that so many large banks are actively eroding indicates some sort of systemic disturbance.

Table 2e shows that the sediment size in the stream bed is relatively large. The bankfull flat sampled near the surveyed cross section had much smaller particles than that found in the stream bed. However, as noted above, other areas were observed where rocks of similar size as that in the stream bed were on the floodplain.

The WARSSS analysis indicates that this stream has a moderate overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed and development pressure in the lower watershed pose the most immediate threats to the stream, and because of these activities, it has a high risk of adverse impacts due to increases in flow. The streambanks are also currently eroding, so the stream has a very high risk of additional streambank erosion. Despite the abundant streambank erosion, significant erosion from channel evolution is not expected, in part because the channel is not expected to evolve into a different stream type. The watershed also has a moderate risk due to roads, channel enlargement, surface erosion, and degradation.

This reach appears to be near the border between a Rosgen Type C and Type E stream, however, given its setting in riparian characteristics, it is likely to be a Type C stream. Type C streams with larger bed sediment are only moderately sensitive to disturbance and sediment supply. They have moderate streambank erosion potential and have good recovery potential. Much like Site 1B, this site is experiencing some obvious disturbances, but it should eventually recover on its own.

Site 3: South Fork Zumbro River

Table 3a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	299	485
Width (ft)	117	107
Mean depth (ft)	2.5	4.5
Max depth (ft)	4.2	6.5
Flow capacity (cfs)	845	2096
Width-depth ratio	38.9	26.1
Entrenchment ratio	2.5	6.6
Rosgen classification	C	C

Table 3b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	166	192
Width (ft)	82	84
Mean depth (ft)	2.1	2.3
Max depth (ft)	3.2	3.1
Flow capacity (cfs)	400	508
Width-depth ratio	40.3	38.1
Entrenchment ratio	2.2	2.2
Rosgen classification	C	C

Table 3c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	201	206
Width (ft)	108	93
Mean depth (ft)	1.9	2.3
Max depth (ft)	3.8	3.8
Flow capacity (cfs)	455	545
Width-depth ratio	58.5	43.5
Entrenchment ratio	2.3	2.7
Rosgen classification	C	C

Table 3d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	423	730
Width (ft)	141	157
Mean depth (ft)	3.1	4.9
Max depth (ft)	5.6	8.3
Flow capacity (cfs)	1331	3187
Width-depth ratio	47.6	36.4
Entrenchment ratio	2.0	7.7
Rosgen classification	C	C

Table 3e Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	2.1	0.66
D_{35} (mm)	5.9	1.8
D_{50} (mm)	10	N/A
D_{65} (mm)	16	N/A
D_{84} (mm)	27	N/A
D_{95} (mm)	39	N/A

Pfankuch rating: 81 – Fair BEHI: 25.8 – Moderate

This reach of the Zumbro River appears to be stable. No significant erosion was observed in the stream banks. The stream bed consisted of particles ranging from sand to cobbles, and many of the larger particles were well embedded, which indicates stable bed material. The entrenchment ratio is not particularly large, but the flood prone area is wide enough to convey large flows.

The riparian vegetation consisted of grasses, shrubs and mature trees. A small amount of large woody debris was present in the stream and some was present on the bankfull flats.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. There are no major reservoirs in the upper watershed.

Tables 3a, 3b, 3c, and 3d show that the channel has remained fairly unchanged since the previous survey was done for FEMA modeling in 1994. The comparison in Table 3a makes it appear that the channel has gotten significantly smaller. However, the result for the previous survey is likely to be caused by relatively poor survey data. The comparisons in Tables 3b and 3c show parameters that are relatively close to each other and within acceptable ranges for this sort of comparison. It is easy to conclude that this reach is essentially unchanged over the last 14 years.

Table 3e shows that the bed sediment is mostly gravel and ranged from sand to cobbles. Bankfull flats were also mostly gravel. The gravel bed for a stream of this size would easily be mobilized in large floods.

The WARSSS analysis indicates that this stream has a low overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed and development pressure in the lower watershed pose the most immediate threats to the stream, and because of these activities, it has a high risk of adverse impacts due to increases in flow. This watershed was also given a high risk of surface erosion due to a higher percentage of the watershed being in farmland. The watershed also has a moderate risk due to additional roads being built as urban development increases.
The Pfankuch rating was only fair, which is a little surprising considering that the reach does not exhibit any instability issues. However, it is a large stream with only a gravel stream bed, which can be susceptible to erosion problems, as seen in the Rosgen discussion below. The BEHI assessment showed only moderate erosion potential for the stream banks.

This reach is a Rosgen Type C stream. Type C streams with gravel beds are highly sensitive to disturbance and sediment supply, and have very high streambank erosion potential. Fortunately, they also have good recovery potential, so this reach can recover well on its own if it experiences any future disturbances.

Site 4: Cascade Creek

Table 4a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	34	81
Width (ft)	19	47
Mean depth (ft)	1.8	2.6
Max depth (ft)	2.6	5.1
Flow capacity (cfs)	89	247
Width-depth ratio	10.4	35.8
Entrenchment ratio	4.1	8.7
Rosgen classification	E/C	C

Table 4b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	17	14
Width (ft)	15	14
Mean depth (ft)	1.2	1.0
Max depth (ft)	1.6	1.6
Flow capacity (cfs)	34	27
Width-depth ratio	12.7	13.4
Entrenchment ratio	1.9	10.7
Rosgen classification	E/C	C

Table 4c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	41	41
Width (ft)	28	20
Mean depth (ft)	1.6	2.4
Max depth (ft)	2.9	3.6
Flow capacity (cfs)	100	119
Width-depth ratio	10.3	11.3
Entrenchment ratio	2.8	8.2
Rosgen classification	E/C	C

Table 4d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	43	91
Width (ft)	26	29
Mean depth (ft)	1.7	3.5
Max depth (ft)	3.0	5.6
Flow capacity (cfs)	52	358
Width-depth ratio	15.8	36.1
Entrenchment ratio	3.6	13.9
Rosgen classification	C	C

Table 4e Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	0.27	0.17
D_{35} (mm)	2.1	0.28
D_{50} (mm)	6.9	0.37
D_{65} (mm)	12	0.49
D_{84} (mm)	30	1.4
D_{95} (mm)	74	N/A

Pfankuch rating: 68 – Good BEHI: 27.5 – Moderate

This reach of Cascade Creek appeared to be stable. The bed sediment was well embedded. Some bank erosion was present higher on the stream banks. The eroded areas were partially vegetated and the bank toe was vegetated above the water line. The steepest, least vegetated banks were above the bankfull elevation, so they are not likely to be contributing significant amounts of sediment to the stream in typical annual flood events. The bed is assumed to contribute some sediment to flood flows.

The riparian vegetation mostly consisted of grasses with some trees present on the upper banks. The vegetation was vigorous and it completely covered bankfull flats.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. There are no major reservoirs in the upper watershed.

Tables 4a, 4b, 4c and 4d show that the channel has remained fairly unchanged since the previous survey was done for FEMA modeling in 1993. The comparison is Table 4a makes it appear that the channel has shrunk significantly in the past 15 years; however this is not likely to be the case. The comparisons in Tables 4b and 4c indicate that the channel has maintained its basic dimensions since 1993. It is easy to conclude that this reach is essentially unchanged over the last 15 years.

Table 4e indicates that the stream bed consists mostly of gravel and cobble. The bankfull flats observed on this reach consisted mostly of material much finer than that found in the stream bed. This is an indication that the large particles in the bed are well-embedded and are not readily mobilized for the flows in this stream.   Algae growth was relatively abundant, which indicates that the bed particles in the riffles are not very mobile.

The WARSSS analysis indicates that this stream has a low overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed and development pressure in the lower watershed pose the most immediate threats to the stream, and because of these activities, it has a high risk of adverse impacts due to increases in flow. This watershed was also given a high risk of surface erosion due to a high percentage of the watershed being in farmland. The watershed also has a moderate risk due to roads, streambank erosion, and channel evolution.

This stream had a good Pfankuch rating and moderate BEHI bank erosion potential. This supports the conclusion that this site is stable.

This stream is also a borderline Type C/E stream, and the channel parameters indicate that it is on the Type E side of the border. Type E streams with gravel beds can have a very high sensitivity to channel disturbances, moderate sensitivity to sediment supply, and high streambank erosion potential. Fortunately, they also have a good recovery potential. Even though this stream has the potential to be highly sensitive to these features, it is currently in good shape with its well-embedded sediment and well-vegetated streambanks.

Site 5: Zumbro River

Table 5a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	413	890
Width (ft)	113	175
Mean depth (ft)	3.6	5.2
Max depth (ft)	5.4	9.7
Flow capacity (cfs)	1459	4230
Width-depth ratio	31.4	38.4
Entrenchment ratio	3.0	8.6
Rosgen classification	C	C

Table 5b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	287	202
Width (ft)	110	90
Mean depth (ft)	2.7	2.3
Max depth (ft)	4.2	4.2
Flow capacity (cfs)	815	525
Width-depth ratio	42.0	41.1
Entrenchment ratio	1.2	2.5
Rosgen classification	F	C

Table 5c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	354	355
Width (ft)	111	113
Mean depth (ft)	3.2	3.2
Max depth (ft)	4.8	5.7
Flow capacity (cfs)	1137	1151
Width-depth ratio	35.0	36.9
Entrenchment ratio	2.7	4.6
Rosgen classification	C	C

Table 5d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	888	1106
Width (ft)	138	228
Mean depth (ft)	6.5	5.2
Max depth (ft)	9.0	10.6
Flow capacity (cfs)	4541	4943
Width-depth ratio	21.5	51.5
Entrenchment ratio	4.0	7.0
Rosgen classification	C	C

Table 5e Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	0.54	0.51
D_{35} (mm)	1.5	0.60
D_{50} (mm)	3.4	0.68
D_{65} (mm)	5.7	0.78
D_{84} (mm)	10	0.91
D_{95} (mm)	19	1.0

Pfankuch rating: 64 – Good BEHI: 27.6 – Moderate

This reach of the Zumbro River appears to be relatively stable. Some erosion was observed on the outside bends of stream banks; however, this is a typical location to observe erosion. The eroded areas are on both the bank toe and higher on the bank, so the eroded banks are likely to contribute to sediment load during high flows.

The riparian vegetation primarily consisted of grasses and mature trees. Some shrubs were present as well. Some large woody debris was present in the stream.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. There are no major reservoirs in the upper watershed. This site is just downstream of the city of Rochester, so the city makes up most of what could be considered the lower watershed for this site. Rochester has been growing at a rapid rate in recent years. This will causes significant changes to the hydrology. Despite the size of the river at this location, the impacts are likely to become more evident as Rochester increases in size.

Tables 5a, 5b, 5c, and 5d show that the channel has remained fairly unchanged since the previous survey was done for FEMA modeling in 1994. Similar to other sites, the first table (Table 5a) does not provide a very good comparison since it appears that the channel has gotten considerably smaller. Tables 5b and 5c provide a decent comparison and show indications that the channel has gotten wider and shallower. For the same cross sectional area in Table 5c, the 2007 channel is not as deep as the 1994 channel. Similarly, in Table 5b, the 2007 channel is wider than the 1994 channel at the same depth. Therefore it appears that it is easy to conclude that this reach is aggrading and widening over the past 14 years.

The stream bed consisted mostly of sand and gravel particles with some cobbles (Table 5e). The particles were not particularly well embedded in this reach, which is a possible indication that the sediment has been recently moved and deposited. The sediment size in this channel would be easily mobilized in flood flows, so this reach undoubtedly contributes to stream turbidity. The sediment in the bankfull flats was mostly sand.

The WARSSS analysis indicates that this stream has a low overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed and development pressure in the lower watershed pose the most immediate threats to the stream, and because of these activities, it has a high risk of adverse impacts due to increases in flow. This watershed was also given a high risk of surface erosion due to a high percentage of the watershed being in farmland. The watershed also has a moderate risk due to roads and streambank erosion.

This reach had the best Pfankuch rating of all the reaches surveyed. It was in good shape and appeared to be stable. The BEHI rating indicates that the banks have only moderate erosion potential.

This reach is a Rosgen Type C stream. Type C streams with gravel beds are highly sensitive to disturbance and sediment supply, and have very high streambank erosion potential. Fortunately, they also have good recovery potential, so this reach can recover well on its own if it experiences any future disturbances.

Site 6: Middle Fork Zumbro River

Table 6a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	892	649
Width (ft)	151	131
Mean depth (ft)	6.0	4.9
Max depth (ft)	8.1	7.4
Flow capacity (cfs)	3464	2304
Width-depth ratio	25.6	25.2
Entrenchment ratio	3.3	3.2
Rosgen classification	C	C

Table 6b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	395	316
Width (ft)	135	100
Mean depth (ft)	2.9	3.1
Max depth (ft)	4.6	4.6
Flow capacity (cfs)	971	820
Width-depth ratio	47.3	32.5
Entrenchment ratio	1.3	1.9
Rosgen classification	F	B

Table 6c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	409	406
Width (ft)	135	122
Mean depth (ft)	3.1	3.4
Max depth (ft)	4.7	5.5
Flow capacity (cfs)	1023	1091
Width-depth ratio	44.8	36.8
Entrenchment ratio	1.8	2.3
Rosgen classification	B	C

Table 6d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	867	678
Width (ft)	144	129
Mean depth (ft)	6.0	5.2
Max depth (ft)	8.1	7.6
Flow capacity (cfs)	3413	2466
Width-depth ratio	24.0	27.5
Entrenchment ratio	3.1	3.5
Rosgen classification	C	C

Table 6e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	4.1	0.54
D_{35} (mm)	12	0.71
D_{50} (mm)	23	0.88
D_{65} (mm)	37	1.3
D_{84} (mm)	57	N/A
D_{95} (mm)	82	N/A

Pfankuch rating: 79 – Fair BEHI: 35.2 – High

This reach of the Zumbro River did not appear to be particularly stable. Tall eroding banks were observed on both sides of the river and large areas of freshly deposited materials were present on bankfull flats. The eroding banks were partially vegetated, but showed signs of recent slumps or are in imminent danger of slumping. These eroding banks are very likely to contribute significant amounts of sediment during high flows.

The stream bed (Table 6e) consisted of relatively large particles consisting mostly of coarse gravel. There is a flood control dam a short distance upstream from this site. The area behind the dam has silted in considerably, which means that this downstream reach has been sediment starved since the dam's construction. When stream are starved of sediment, it leads to two of the distinctive characteristics observed in this reach, eroding banks and bed sediment without fine particles. Streams have a natural ability to carry sediment in their flow and they work to carry as much as they are able. Flood control structures force the flows to slow down and drop their sediment load behind the dams. Flows leaving the dam are then relatively clean and the river tries to gather new sediment to carry in the flow. In doing so, the stream banks and stream bed both get eroded. In the case of this reach on the Zumbro River, the fine particles have been washed away from the stream bed, leaving particles consisting of mostly gravel. Therefore, it appears that the flow has gathered more of its desired sediment load from the tall eroding stream banks.

The material deposited on bankfull flats was mostly sand, which was not found much in the channel bed while conducting the pebble count. The sand on the bankfull flats likely washed down from other areas upstream or was recently eroded from nearby eroding banks.

The riparian vegetation was a mix of mature trees and grasses, depending on the location and land management by the landowners. Some large woody debris was present in the stream.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries.

Tables 6a, 6b, 6c, and 6d show comparisons of the channel dimensions from the 2007 survey and the FEMA modeling survey in 1994. All three comparisons show parameters that are relatively close to each other despite the obvious signs of erosion. From this analysis it is possible to conclude that this reach is essentially unchanged over the last 14 years. Given the erosion present on the site, a large change in channel dimensions would have been expected.

The WARSSS analysis indicates that this stream has a low overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed poses the most immediate threats to the stream. However, because the landscape was changed to farming several decades ago, it has only a moderate risk of adverse impacts due to increases in flow. This watershed was also given a high risk of surface erosion due to a high percentage of the watershed being in farmland, and it also has a high risk of streambank erosion. The watershed also has a moderate risk due to stream flow changes, channel enlargement, and degradation.

The Pfankuch rating for this site was “fair” and supports the observation that this site is not completely stable. The BEHI assessment showed high erosion potential as well.

This reach is a Rosgen Type C stream. Type C streams with gravel beds are highly sensitive to disturbance and sediment supply, and have very high streambank erosion potential. Fortunately, they also have good recovery potential, so this reach can recover well on its own if it experiences any future disturbances.

Site 7: South Branch Middle Fork Zumbro River

Table 7a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	366	649
Width (ft)	93	131
Mean depth (ft)	4.0	4.9
Max depth (ft)	4.8	7.4
Flow capacity (cfs)	1541	2304
Width-depth ratio	23.7	25.2
Entrenchment ratio	2.3	3.2
Rosgen classification	C	C

Table 7b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	211	181
Width (ft)	90	96
Mean depth (ft)	2.4	2.0
Max depth (ft)	3.2	3.4
Flow capacity (cfs)	634	484
Width-depth ratio	38.7	52.1
Entrenchment ratio	1.2	4.4
Rosgen classification	B	C

Table 7c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	224	223
Width (ft)	90	117
Mean depth (ft)	2.5	2.2
Max depth (ft)	3.6	4.0
Flow capacity (cfs)	701	641
Width-depth ratio	35.9	69.6
Entrenchment ratio	1.2	4.0
Rosgen classification	B	C

Table 7d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	685	472
Width (ft)	139	126
Mean depth (ft)	5.0	4.0
Max depth (ft)	8.1	6.0
Flow capacity (cfs)	3347	1994
Width-depth ratio	28.2	35.0
Entrenchment ratio	3.6	4.6
Rosgen classification	C	C

Table 7e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	3.8	0.49
D_{35} (mm)	14	0.59
D_{50} (mm)	20	0.67
D_{65} (mm)	27	0.76
D_{84} (mm)	43	0.9
D_{95} (mm)	72	0.99

Pfankuch rating: 84 – Fair BEHI: 30.4 – High

This reach of the Zumbro River is very much like Site 6 except the eroding banks are not as tall and there is not a flood control structure upstream. Eroding banks were present on both sides of the stream and many of the banks show significant recent erosion. These banks are very likely to contribute to sediment load during high flows.

The sediment in the bed (Table 7e) is relatively large, but the bed is likely mobilized during high flows. Approximately half of the sediment particles have the dirty aged look that indicates that they have been a part of the bed for a long time. The other half looks clean, indicating that they have recently moved either within the bed or into the stream. Bankfull flats contained a lot of sand and some particles about the size found in the bed.

The riparian vegetation consisted of grasses and mature trees. Some large woody debris was present in the stream.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. There are no major reservoirs in the upper watershed.

The comparisons in Tables 7a, 7b, 7c and 7d show very similar things that the comparisons for Site 6 did. Despite some obvious erosion problems, the channel dimensions do not appear to have changed significantly since the last survey for FEMA modeling in 1986. It is possible to conclude that this reach is essentially unchanged over the last 22 years.

The WARSSS analysis indicates that this stream has a moderate overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed poses the most immediate threats to the stream. However, because the landscape was changed to farming several decades ago, it has only a moderate risk of adverse impacts due to increases in flow. This watershed was given a very high risk of surface erosion due to a high percentage of the watershed being in farmland, and because the farmland often lacks significant buffers between it and the stream. The stream also has a very high risk of additional streambank erosion. The watershed has a moderate risk due to stream flow changes.

The Pfankuch rating for this site was “fair” and supports the observation that this site is not completely stable. The BEHI assessment showed high erosion potential as well.

This reach is a Rosgen Type C stream. Type C streams with gravel beds are highly sensitive to disturbance and sediment supply, and have very high streambank erosion potential. Fortunately, they also have good recovery potential, so this reach can recover well on its own if it experiences any future disturbances.

Site 8: North Branch Middle Fork Zumbro River

Table 8a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	109	n/a
Width (ft)	52	n/a
Mean depth (ft)	2.1	n/a
Max depth (ft)	3.2	n/a
Flow capacity (cfs)	350	n/a
Width-depth ratio	24.5	n/a
Entrenchment ratio	1.6	n/a
Rosgen classification	B	n/a

Table 8b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	115	n/a
Width (ft)	55	n/a
Mean depth (ft)	2.1	n/a
Max depth (ft)	2.7	n/a
Flow capacity (cfs)	371	n/a
Width-depth ratio	26.3	n/a
Entrenchment ratio	1.5	n/a
Rosgen classification	B	n/a

Table 8c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	127	n/a
Width (ft)	55	n/a
Mean depth (ft)	2.4	n/a
Max depth (ft)	3.8	n/a
Flow capacity (cfs)	579	n/a
Width-depth ratio	24.3	n/a
Entrenchment ratio	1.8	n/a
Rosgen classification	B	n/a

Table 8d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	334	n/a
Width (ft)	84	n/a
Mean depth (ft)	3.9	n/a
Max depth (ft)	6.4	n/a
Flow capacity (cfs)	1679	n/a
Width-depth ratio	22.7	n/a
Entrenchment ratio	4.3	n/a
Rosgen classification	C	n/a

Table 8e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	12	0.88
D_{35} (mm)	21	N/A
D_{50} (mm)	29	N/A
D_{65} (mm)	39	N/A
D_{84} (mm)	55	N/A
D_{95} (mm)	78	N/A

Pfankuch rating: 76 – Good/Fair

BEHI: 36.4 – High

This reach of the Zumbro River is very similar to Site 7. Significantly eroding banks were present on both sides of the stream and many of the banks show significant recent erosion. Many banks are actively slumping with trees half fallen into the river. These banks undoubtedly contribute to sediment load during high flows.

The sediment in the bed (Table 8e) is relatively large, but the bed is likely mobilized during high flows. Approximately half of the sediment particles have the dirty aged look that indicates that they have been a part of the bed for a long time. The other half looks clean, indicating that they have recently moved either within the bed or into the stream. Bankfull flats mostly consisted of particles of about the same size found in the bed.

The riparian vegetation consisted of grasses and mature trees. Large woody debris was present in the stream and the slumping banks will continue to contribute more woody debris in the near future.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. There are no major reservoirs in the upper watershed.

Previous FEMA models for this reach were not available in order to compare channel dimensions. The dimension measured during the 2007 survey match expected dimensions fairly well. The Minnesota DNR has developed relationships between measured channel bankfull dimensions and contributing watershed areas. The dimensions for this reach match the expected values very well. Given the amount of erosion on this stream, this result was not expected.

The WARSSS analysis indicates that this stream has a moderate overall risk of adverse impacts due to watershed characteristics and changes. Farming in the upper watershed poses the most immediate threats to the stream. However, because the landscape was changed to farming several decades ago, it has only a moderate risk of adverse impacts due to increases in flow. This watershed was given a very high risk of surface erosion due to a high percentage of the watershed being in farmland, and because the farmland often lacks significant buffers between it and the stream. The watershed also has a very high risk due to streambank erosion, and it has a moderate risk due to stream flow changes and channel enlargement.

This reach is on the border between being a good and fair Pfankuch rating. Field observations would indicate that the reach should lean towards the fair rating, considering the extent of eroding banks present. The bed material will continue to help this reach remain relatively stable, but the banks will likely continue to erode. The BEHI bank erosion potential is high, which is very consistent with the level of erosion observed in the reach.

This reach types out as a Rosgen Type B stream. These streams have a moderate sensitivity to disturbance and sediment supply. They also typically have low streambank erosion potential, which is not at all consistent with field observations. It is possible that this stream is undergoing significant morphological changes and is it will be a Type B stream for a short period of time. Based on site conditions, it would be expected that this stream would be either a Type C or Type E stream.

Site 9: North Fork Zumbro River

Table 9a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	413	307
Width (ft)	68	60
Mean depth (ft)	6.1	5.0
Max depth (ft)	6.9	7.2
Flow capacity (cfs)	1594	1155
Width-depth ratio	11.4	13.6
Entrenchment ratio	5.5	9.6
Rosgen classification	E/C	C

Table 9b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	156	80
Width (ft)	63	41
Mean depth (ft)	2.5	1.9
Max depth (ft)	2.9	2.9
Flow capacity (cfs)	347	297
Width-depth ratio	25.4	21.2
Entrenchment ratio	1.1	1.4
Rosgen classification	F	B/F

Table 9c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	152	152
Width (ft)	63	50
Mean depth (ft)	2.4	3.1
Max depth (ft)	2.9	4.6
Flow capacity (cfs)	332	391
Width-depth ratio	26.9	16.6
Entrenchment ratio	1.1	3.6
Rosgen classification	F	C

Table 9d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	413	479
Width (ft)	68	73
Mean depth (ft)	6.1	6.5
Max depth (ft)	7.2	9.8
Flow capacity (cfs)	1594	1996
Width-depth ratio	11.4	13.6
Entrenchment ratio	7.3	12.2
Rosgen classification	E/C	C

Table 9e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	11	0.32
D_{35} (mm)	20	0.5
D_{50} (mm)	28	0.66
D_{65} (mm)	41	0.86
D_{84} (mm)	98	1.3
D_{95} (mm)	180	1.8

Pfankuch rating: 69 – Good BEHI: 32.5 – High

This reach of the Zumbro River appears to be mildly unstable and in the process of widening. The banks are fairly vertical, and not well vegetated. Fresh bank erosion was not as obvious on this reach as it was on other reaches, but there were many places where the potential was high for future erosion. Therefore the banks likely contribute to the sediment load during high flows.

The sediment in the bed (Table 9e) is relatively large and embedded. This reach had a higher percentage of cobbles and some boulders in the bed that other reaches. The larger sized particles help to prevent the bed from downcutting during high flows. Therefore, the sediment is large enough that it is likely to remain primarily as bedload during the most frequent flood events. It would likely take significant flooding to suspend the bed material into the flow. Bankfull flats were difficult to find in this reach. Those that were found mostly consisted of sand particles, which were not found in abundance in the stream bed.

The riparian vegetation consisted of mature trees. Large woody debris was present in the stream and the slumping banks will continue to contribute more woody debris in the near future. Farmland was very close to the stream. The buffer between farm fields and the stream was not

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. There are no major reservoirs in the upper watershed.

The comparisons in Tables 9a, 9b, 9c, and 9d show that this reach has gotten shallower and wider since the last survey for FEMA modeling in 1988. This could be a contributing factor the frequent bank erosion. Another interesting comparison is the bankfull cross-sectional areas in Tables 9a and 9c. The value in Table 9a is the area as measured during the survey and the value in Table 9c is the expected value based on the contributing watershed area. The fact that they are as far apart as they are could be an indication that the channel has experienced a significant disturbance and has become too large. However, as noted above, bankfull indicators were difficult to find, and it is possible that the estimated bankfull cross-sectional area in Table 9a is an overestimation. It is also important to note that the cross sectional area in Table 9b is roughly the same as that in Table 9c. This means that the expected bankfull depth corresponds well to the expected bankfull cross sectional area. This relationship is not expected to hold for depth and areas that are larger or smaller than bankfull. Therefore, this is an indication that the estimated bankfull cross sectional area in Table 9a is too large. However, when comparing the 2007 survey to the 1988 survey in all three tables, it appears as though the channel has been enlarging.

The WARSSS analysis indicates that this stream has a low overall risk of adverse impacts due to watershed characteristics and changes. Farming in the watershed poses the most immediate threats to the stream. However, because the landscape was changed to farming several decades ago, it has only a moderate risk of adverse impacts due to increases in flow. This watershed was given a very high risk of surface erosion due to a high percentage of the watershed being in farmland, and because the farmland often lacks significant buffers between it and the stream. The watershed also has a moderate risk due to streambank erosion, stream flow changes, and channel enlargement.

The Pfankuch rating was good for this stream, largely because the sediment is well-embedded and stable. The BEHI rating was high for erosion potential, and this is consistent with field observation of eroding banks.

This reach is very much on the border between Rosgen Type C and Type E streams. It can be expected that this reach will continue to have a moderate to high sensitivity to disturbances and moderate streambank erosion potential.

Site 10: Zumbro River

Table 10a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	451	1262
Width (ft)	189	197
Mean depth (ft)	2.4	6.5
Max depth (ft)	3.9	10.0
Flow capacity (cfs)	1366	6849
Width-depth ratio	77.7	34.0
Entrenchment ratio	1.4	4.7
Rosgen classification	B/F	C

Table 10b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	961	530
Width (ft)	293	145
Mean depth (ft)	3.4	3.7
Max depth (ft)	5.7	5.7
Flow capacity (cfs)	3184	1893
Width-depth ratio	90.7	37.8
Entrenchment ratio	1.3	2.1
Rosgen classification	F	B

Table 10c. Comparison of channel dimensions when cross section area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	650	653
Width (ft)	213	162
Mean depth (ft)	3.1	4.1
Max depth (ft)	4.9	6.7
Flow capacity (cfs)	2072	2515
Width-depth ratio	71.3	41.8
Entrenchment ratio	1.3	2.3
Rosgen classification	F	C

Table 10d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	1272	1107
Width (ft)	318	147
Mean depth (ft)	4.5	7.2
Max depth (ft)	7.0	10.0
Flow capacity (cfs)	4935	6717
Width-depth ratio	83.4	21.7
Entrenchment ratio	1.8	5.7
Rosgen classification	B	C

Table 10e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	3.6	0.75
D_{35} (mm)	16	N/A
D_{50} (mm)	32	N/A
D_{65} (mm)	62	N/A
D_{84} (mm)	120	N/A
D_{95} (mm)	170	N/A

Pfankuch rating: 75 – Good BEHI: 18.5 – Low

At first glance, this reach of the Zumbro River appears to be relatively stable despite the fact that it is immediately downstream of Lake Zumbro. Some fresh bank erosion was present, but it was an amount that could be considered normal for this size of a river. There is an extremely tall, rather steep bank on the west bank of the river near the junction of County Road 21 and Highway 7. This bank is located on an outside bend, which is typically susceptible to erosion; however the bank is showing very few signs of erosion. Therefore the banks probably contribute some sediment in high flows, but they are not likely to be major contributors to the sediment load.

The sediment in the bed (Table 10e) is relatively large and embedded. This reach had a higher percentage of cobbles and some boulders in the bed that other reaches. The larger sized particles help to prevent the bed from downcutting during high flows. Therefore, the sediment is large enough that it is likely to remain primarily as bedload during the most frequent flood events. It would likely take significant flooding to suspend the bed material into the flow. Bankfull flats were present and contained sediment particles of similar size to that found in the stream. The majority of the bed of this stream is more likely to be part of the bedload of the stream than it is to be part of the suspended load.

The riparian vegetation consisted of mature trees. Large woody debris was present in the stream and the few slumping banks will continue to contribute more woody debris in the near future.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. Lake Zumbro is immediately upstream of this study reach and Shady Lake in Oronoco is a short distance upstream of Lake Zumbro. The City of Rochester sits in the middle of the watershed. As discussed earlier, the rapid development in Rochester will contribute to erosive stresses in all streams below the city, including this one.

The comparisons in Tables 10a, 10b, 10c, and 10d show that this reach has gotten shallower and wider since the last survey for FEMA modeling in 1986. If the channel is getting wider, then more bank erosion would have been expected. Given the age of Lake Zumbro, it would not be expected that this channel would be continuing to alter its shape unless the flow management in Lake Zumbro has changed significantly. However, given the fact that this channel is either a Type B or F in the Rosgen classification, it is expected that this channel will continue to undergo some changes.

The WARSSS analysis indicates that this stream has a low overall risk of adverse impacts due to watershed characteristics and changes. Farming in the watershed poses the most immediate threats to the stream. However, because the landscape was changed to farming several decades ago, it has only a moderate risk of adverse impacts due to increases in flow. This watershed was given a high risk of surface erosion due to a high percentage of the watershed being in farmland.

Despite the fact that some erosion was observed on this reach, the Pfankuch rating was good and the BEHI rating showed low potential for future erosion.

This reach types out as a Rosgen Type B stream. These streams have a moderate sensitivity to disturbance and sediment supply. They also typically have low streambank erosion potential, which is not at all consistent with field observations. It is possible that this stream is undergoing significant morphological changes and is it will be a Type B stream for a short period of time. Based on site conditions, it would be expected that this stream would be either a Type C or Type E stream.

Site 11: West Indian Creek

Table 11a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	60	n/a
Width (ft)	23	n/a
Mean depth (ft)	2.5	n/a
Max depth (ft)	3.3	n/a
Flow capacity (cfs)	282	n/a
Width-depth ratio	9.4	n/a
Entrenchment ratio	9.5	n/a
Rosgen classification	E	n/a

Table 11b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	27	n/a
Width (ft)	19	n/a
Mean depth (ft)	1.5	n/a
Max depth (ft)	1.8	n/a
Flow capacity (cfs)	89	n/a
Width-depth ratio	12.7	n/a
Entrenchment ratio	1.6	n/a
Rosgen classification	B	n/a

Table 11c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	45	n/a
Width (ft)	22	n/a
Mean depth (ft)	2.1	n/a
Max depth (ft)	2.7	n/a
Flow capacity (cfs)	184	n/a
Width-depth ratio	10.6	n/a
Entrenchment ratio	4.2	n/a
Rosgen classification	E	n/a

Table 11d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	60	n/a
Width (ft)	23	n/a
Mean depth (ft)	2.5	n/a
Max depth (ft)	3.3	n/a
Flow capacity (cfs)	282	n/a
Width-depth ratio	9.4	n/a
Entrenchment ratio	7.8	n/a
Rosgen classification	E	n/a

Table 11e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	11	0.27
D_{35} (mm)	26	0.35
D_{50} (mm)	35	0.45
D_{65} (mm)	43	0.57
D_{84} (mm)	75	0.82
D_{95} (mm)	110	1.1

Pfankuch rating: 79 – Fair BEHI: 27.8 – Moderate

This reach of the West Indian Creek appears to be moderately unstable due to bank erosion. Many banks along the reach were showing signs of erosion. Some banks are actively slumping with trees half fallen into the creek. These banks undoubtedly contribute to sediment load during high flows.

The sediment in the bed is relatively large (Table 11e), and it is large enough that the bed is not likely to be mobilized except during the highest flows. The sediment was well embedded. Bankfull flats mostly consisted of particles smaller than the average size found in the bed.

The riparian vegetation consisted of grasses and mature trees. Large woody debris was present in the stream and the slumping banks will continue to contribute more woody debris in the near future.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. There are no major reservoirs in the upper watershed. There is a considerable elevation difference between the upper watershed and the study reach despite the relatively small watershed. This causes steep stream gradients which can contribute to erosion.

Previous FEMA models for this reach were not available in order to compare channel dimensions. The dimension measured during the 2007 survey match expected dimensions adequately. The Minnesota DNR has developed relationships between measured channel bankfull dimensions and contributing watershed areas. This watershed is assumed to be steeper than the average watershed used in developing the DNR relationships. This likely leads to higher peak flows than would normally be expected for the given contributing area and would result in a larger than expected channel.

The WARSSS analysis indicates that this stream has a low overall risk of adverse impacts due to watershed characteristics and changes. Farming in the watershed poses the most immediate threats to the stream. However, because the landscape was changed to farming several decades ago, it has only a moderate risk of adverse impacts due to increases in flow. The watershed also has a moderate risk due to mass erosion, surface erosion, stream flow changes, and channel evolution.

The Pfankuch rating was fair, primarily due to the bank erosion observed. The stream bed appears to be stable, so significant instability is not expected on this reach. The BEHI rating was moderate. It likely would have been high but the banks heights are not tall relative to the bankfull height. Furthermore, the large sediment in the stream bed helps to maintain bank stability.

This is a Rosgen Type E stream. Type E streams with cobble beds can have a high sensitivity to channel disturbances, low sensitivity to sediment supply, and moderate streambank erosion potential. Fortunately, they also have a good recovery potential. Even though this stream has the potential to be sensitive to these features, it is currently in fairly good shape with its well-embedded sediment. If vegetation can become re-established on the stream banks, then this stream will be in very good shape.

Site 12: Zumbro River

Table 12a. Comparison of bankfull dimensions from 2007 survey and previous survey

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	1610	1701
Width (ft)	184	362
Mean depth (ft)	8.8	9.7
Max depth (ft)	11.3	12.9
Flow capacity (cfs)	8566	9651
Width-depth ratio	21.0	19.4
Entrenchment ratio	2.7	4.5
Rosgen classification	C	C

Table 12b. Comparison of channel dimensions when bankfull depth is equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	761	695
Width (ft)	171	149
Mean depth (ft)	4.5	4.6
Max depth (ft)	6.5	6.5
Flow capacity (cfs)	2612	2487
Width-depth ratio	38.3	32.3
Entrenchment ratio	1.3	1.2
Rosgen classification	F	F

Table 12c. Comparison of channel dimensions when cross sectional area equal to expected value.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	1003	1008
Width (ft)	175	158
Mean depth (ft)	5.7	6.6
Max depth (ft)	7.9	8.8
Flow capacity (cfs)	4057	4443
Width-depth ratio	30.5	25.6
Entrenchment ratio	2.3	2.9
Rosgen classification	C	C

Table 12d. Comparison of channel dimensions from the top of channel bank in each survey.

Parameter	*2007*	*Previous*
Cross-section area (ft^2)	1610	2000
Width (ft)	184	185
Mean depth (ft)	8.8	10.8
Max depth (ft)	11.3	14.5
Flow capacity (cfs)	8566	12229
Width-depth ratio	21.0	17.3
Entrenchment ratio	2.7	4.5
Rosgen classification	C	C

Table 12e. Sediment characteristics

Percentile	*Stream Bed*	*Bankfull Flat*
D_{16} (mm)	0.5	0.23
D_{35} (mm)	1.2	0.30
D_{50} (mm)	2.5	0.36
D_{65} (mm)	4.7	0.43
D_{84} (mm)	7.5	0.59
D_{95} (mm)	13	0.86

Pfankuch rating: 91 – Fair BEHI: 44.5 – High

This reach of the Zumbro River appears to be relatively unstable from the standpoint of bank erosion. Most of the banks are showing some moderate to severe erosion. Since they are composed of a mixture of sand and silt, they are not as cohesive as clay banks and are more susceptible to erosion. These banks undoubtedly contribute sediment to the river during high flows.

The sediment in the bed is consists of a mix of sand and gravel (Table 12e). This is a marked difference from other reaches studied. Sites 1 and 1B are the only other sites with sediment that small. It should be noted that the average slope for this reach is lower than most of the other reaches. Therefore, flood flows are likely to be slower here than in the upper watershed, thereby allowing smaller particles such as sand and gravel to fall out of the suspended sediment in the flow. Nonetheless, the sediment in this reach would be easily mobilized during high flows and would surely contribute to the sediment load. Bankfull flats were present and contained sediment particles of similar size to that found in the stream.

The riparian vegetation consisted of a mix of mature trees and grasses. Large woody debris was present in the stream and the many slumping banks will continue to contribute more woody debris in the near future.

The upper watershed consists almost entirely of farmland, and it is assumed that the land use has not changed significantly for several decades. From aerial photos, it appears that there is very little riparian vegetation adjacent to tributaries. Lake Zumbro is immediately upstream of this study reach and Shady Lake in Oronoco is a short distance upstream of Lake Zumbro. The City of Rochester sits in the middle of the watershed. As discussed earlier, the rapid development in Rochester will contribute to erosive stresses in all streams below the city, including this one.

The comparisons in Tables 12a, 12b, 12c, and 12d show that this reach has gotten a little shallower and a little wider since the last survey for FEMA modeling in 1986, however the differences between the two surveys could be attributed to natural variability. On the other hand, the bank erosion observed is consistent with a widening stream.

The WARSSS analysis indicates that this stream has a moderate overall risk of adverse impacts due to watershed characteristics and changes. Farming in the watershed poses the most immediate threats to the stream. However, because the landscape was changed to farming several decades ago, it has only a moderate risk of adverse impacts due to increases in flow. This watershed was given a very high risk of surface erosion due to a high percentage of the watershed being in farmland, and because the farmland often lacks significant buffers between it and the stream. The watershed also has a moderate risk due to stream flow changes, streambank erosion, channel enlargement, and aggradation.

As noted earlier, this reach has many eroding banks, which contributes to the poorest Pfankuch score of all the sites studied. It has a poor rating because the banks are actively eroding and the bed substrate is primarily sand and gravel. The BEHI rating was also the highest for all the sites, and very nearly earned the “extreme” rating for bank erosion potential.

This reach is a Rosgen Type C stream. Type C streams with gravel beds are highly sensitive to disturbance and sediment supply, and have very high streambank erosion potential. This reach is already experiencing these types of disturbances. Fortunately, these types of streams have good recovery potential, so this reach can recover well on its own if the sources of disturbance can be mitigated.

FIGURES

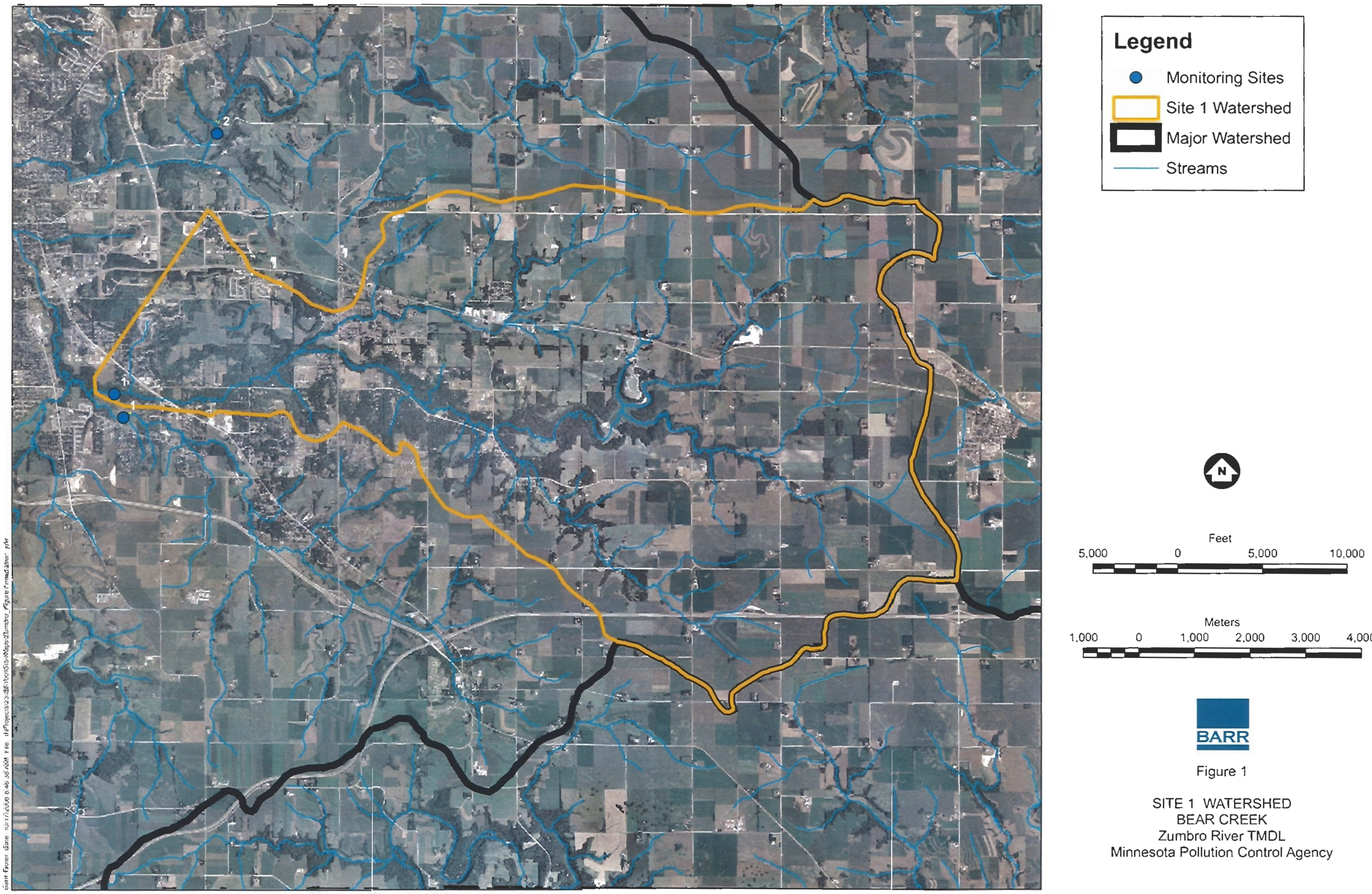


Figure 1

SITE 1 WATERSHED
BEAR CREEK
Zumbro River TMDL
Minnesota Pollution Control Agency

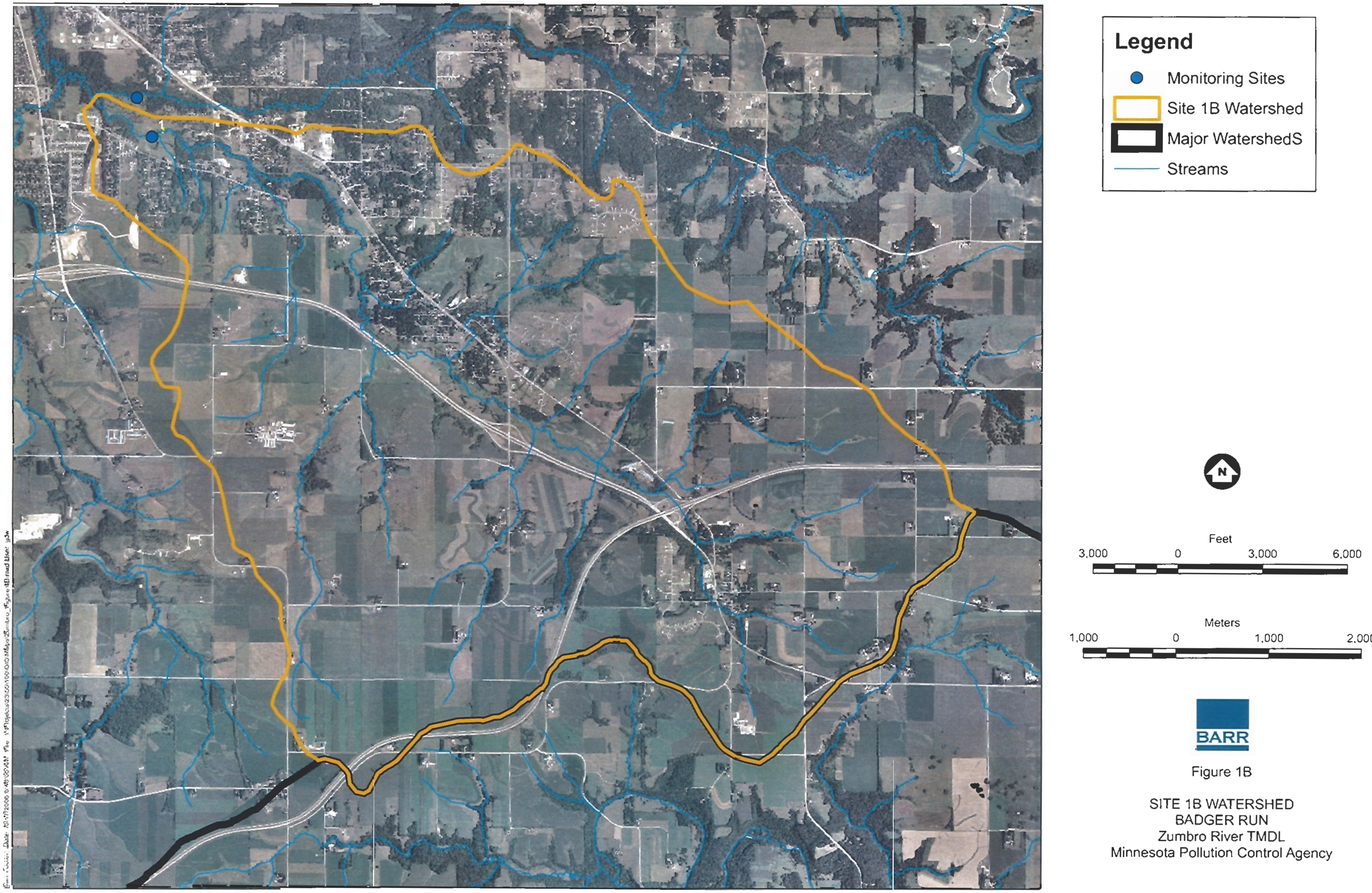


Figure 1B

SITE 1B WATERSHED
BADGER RUN
Zumbro River TMDL
Minnesota Pollution Control Agency

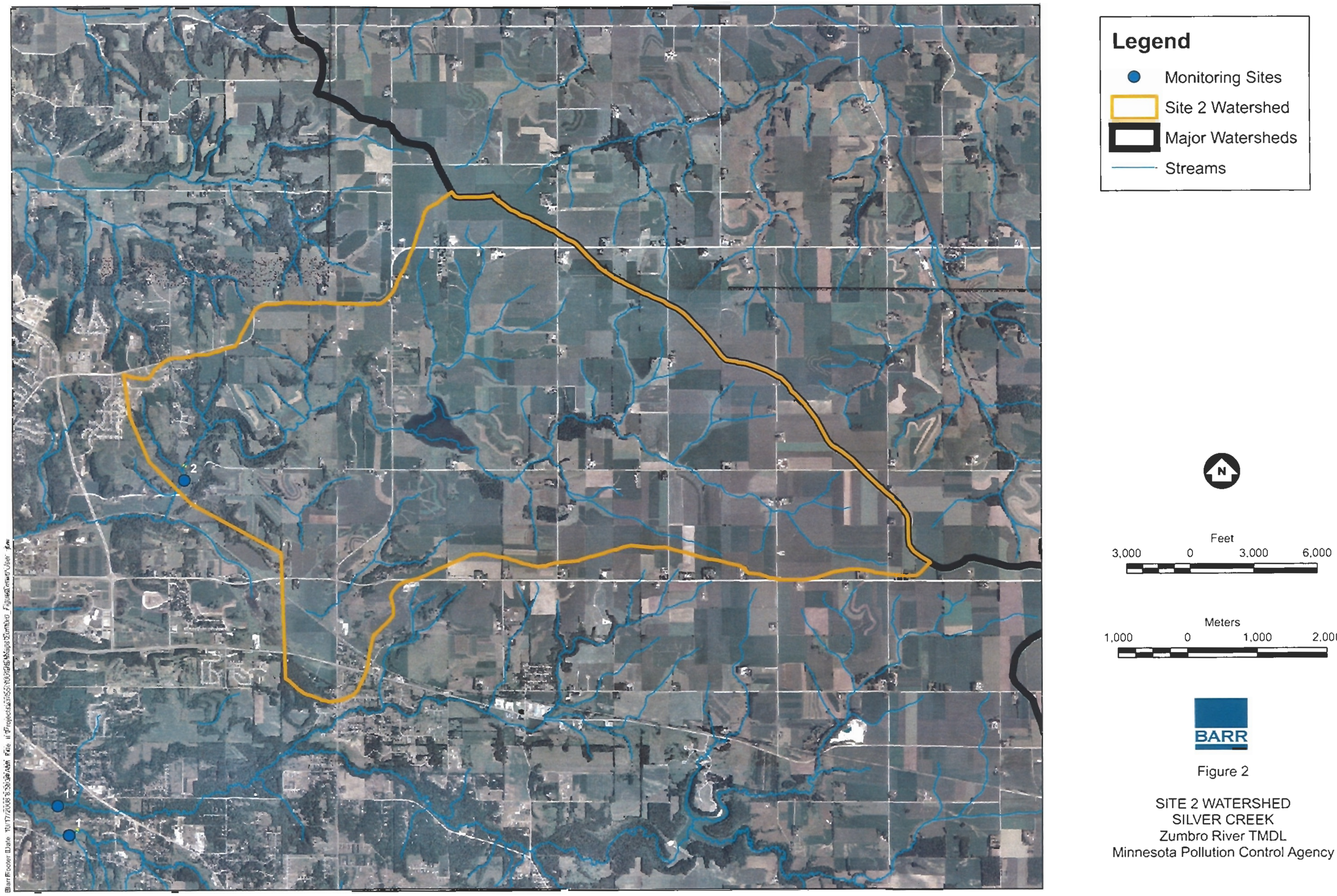


Figure 2

SITE 2 WATERSHED
SILVER CREEK
Zumbro River TMDL
Minnesota Pollution Control Agency

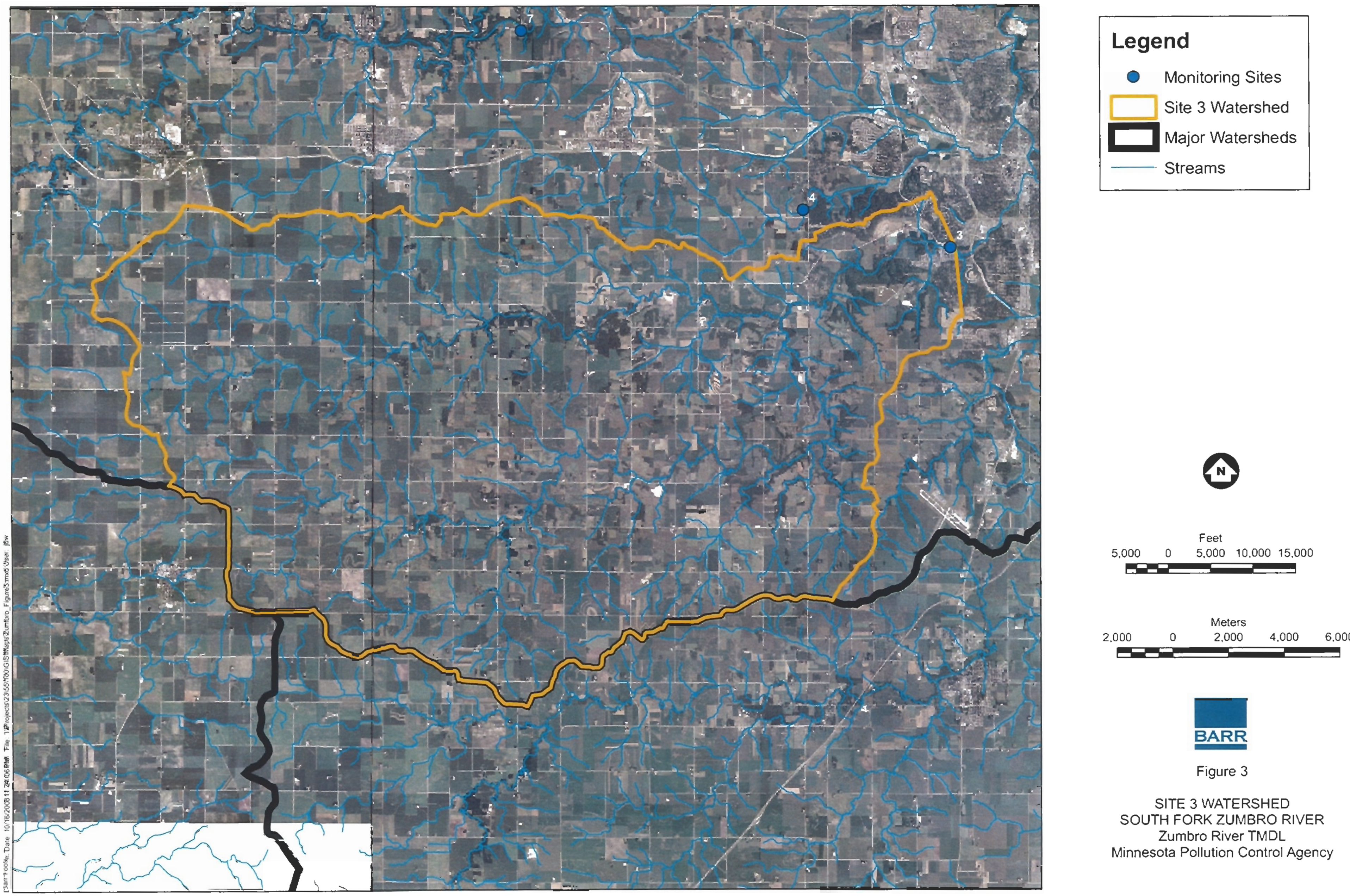


Figure 3

SITE 3 WATERSHED
SOUTH FORK ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency

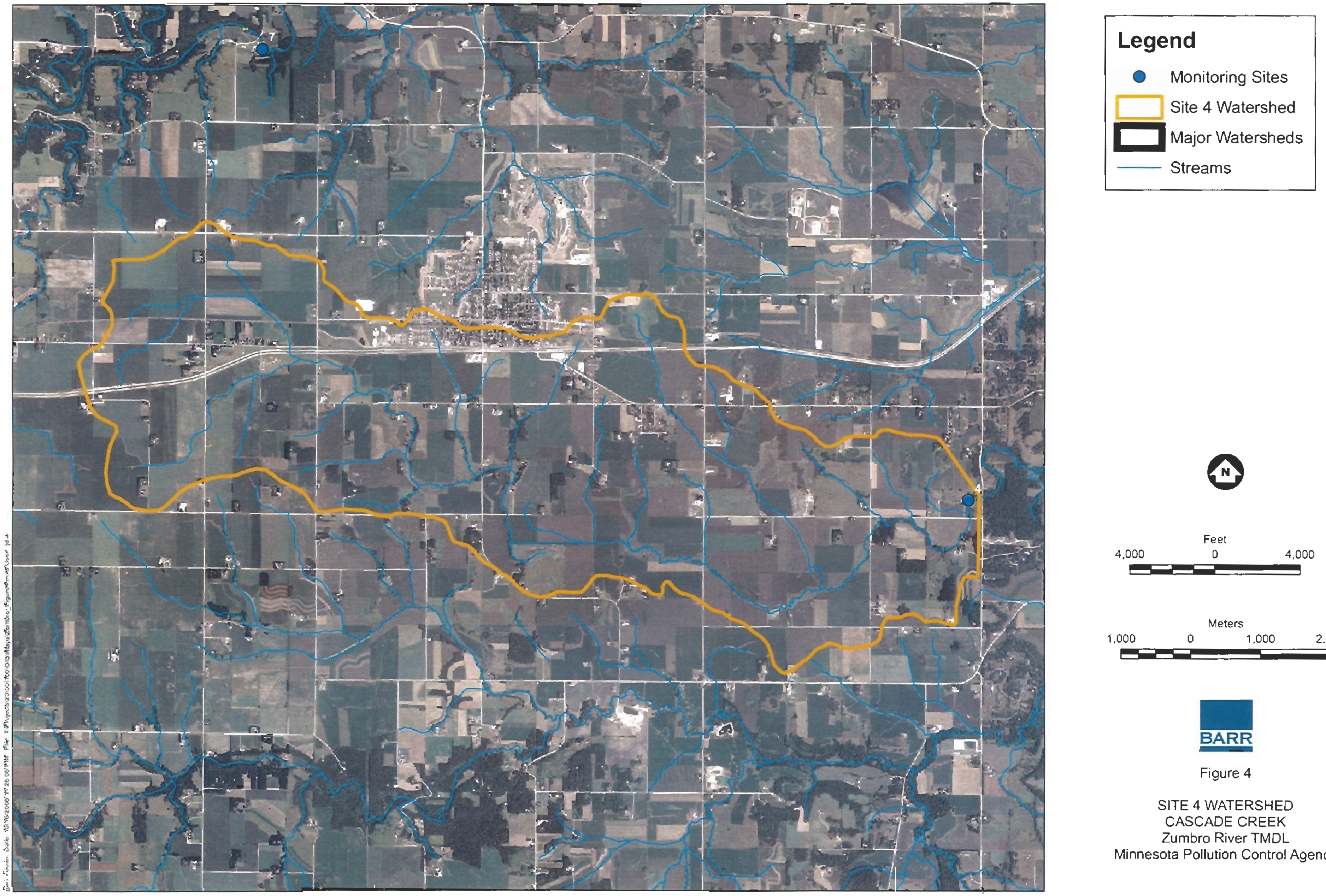


Figure 4

SITE 4 WATERSHED
CASCADE CREEK
Zumbro River TMDL
Minnesota Pollution Control Agency

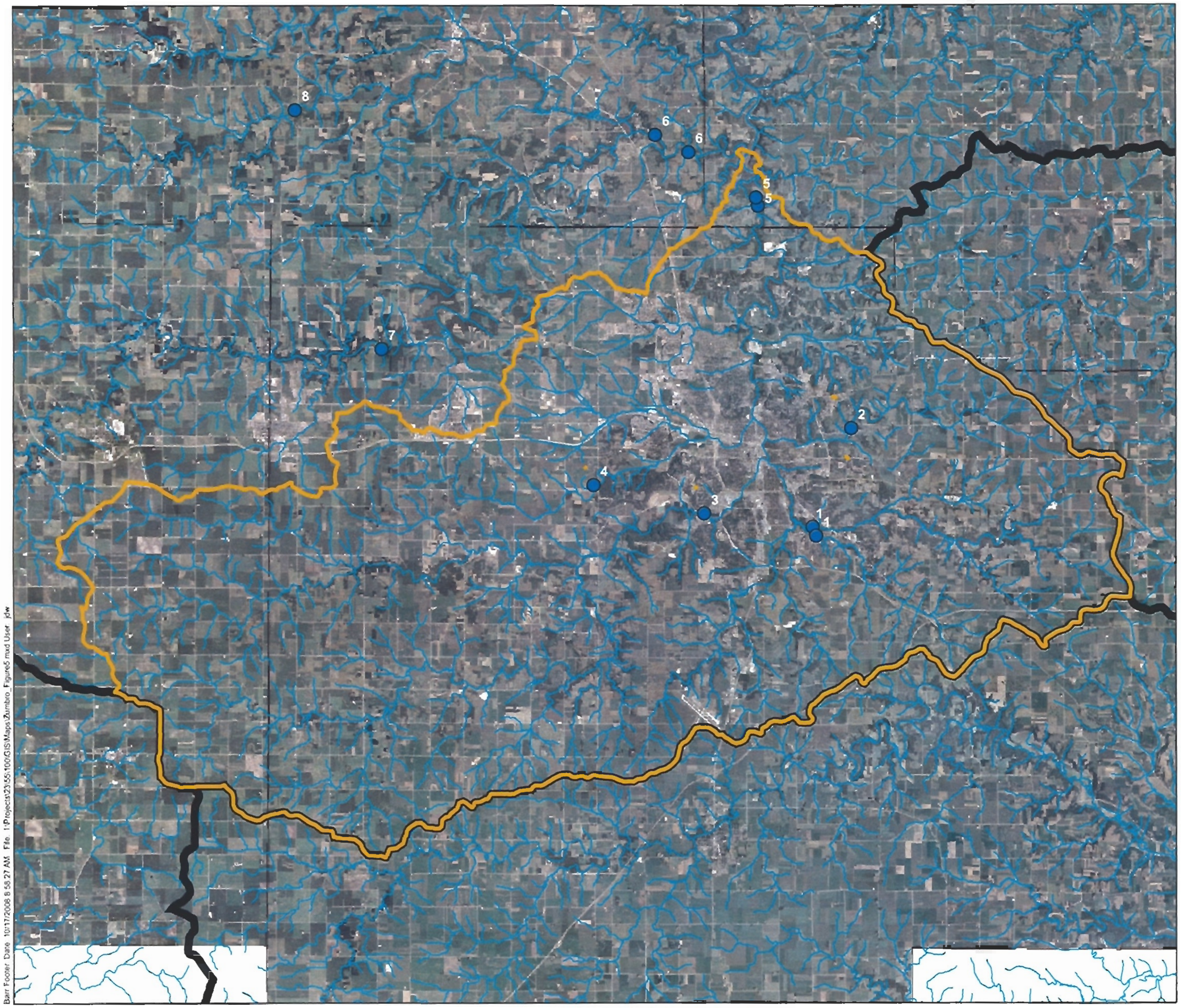


Figure 5

SITE 5 WATERSHED
SOUTH FORK ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency

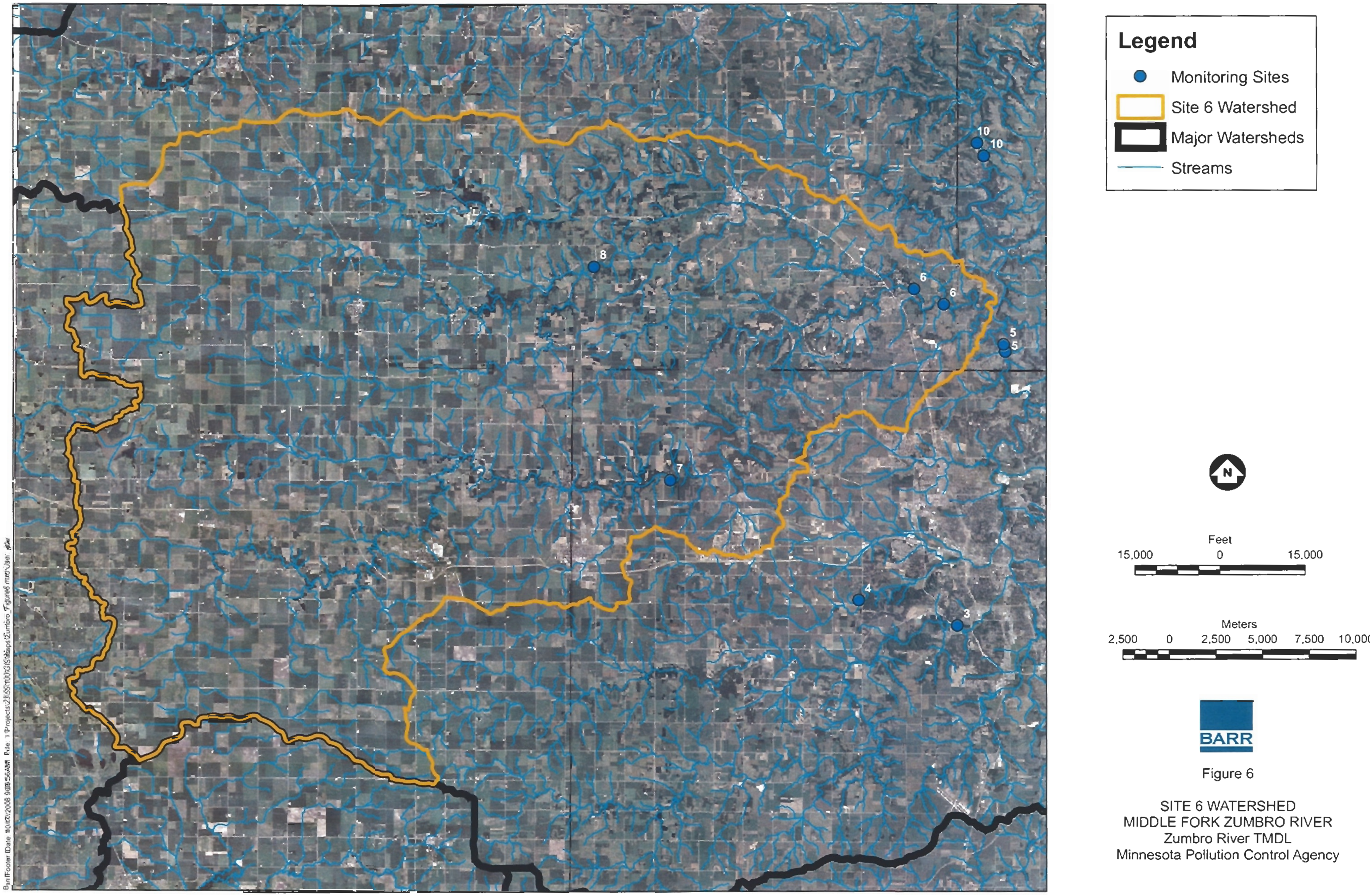


Figure 6

SITE 6 WATERSHED
MIDDLE FORK ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency

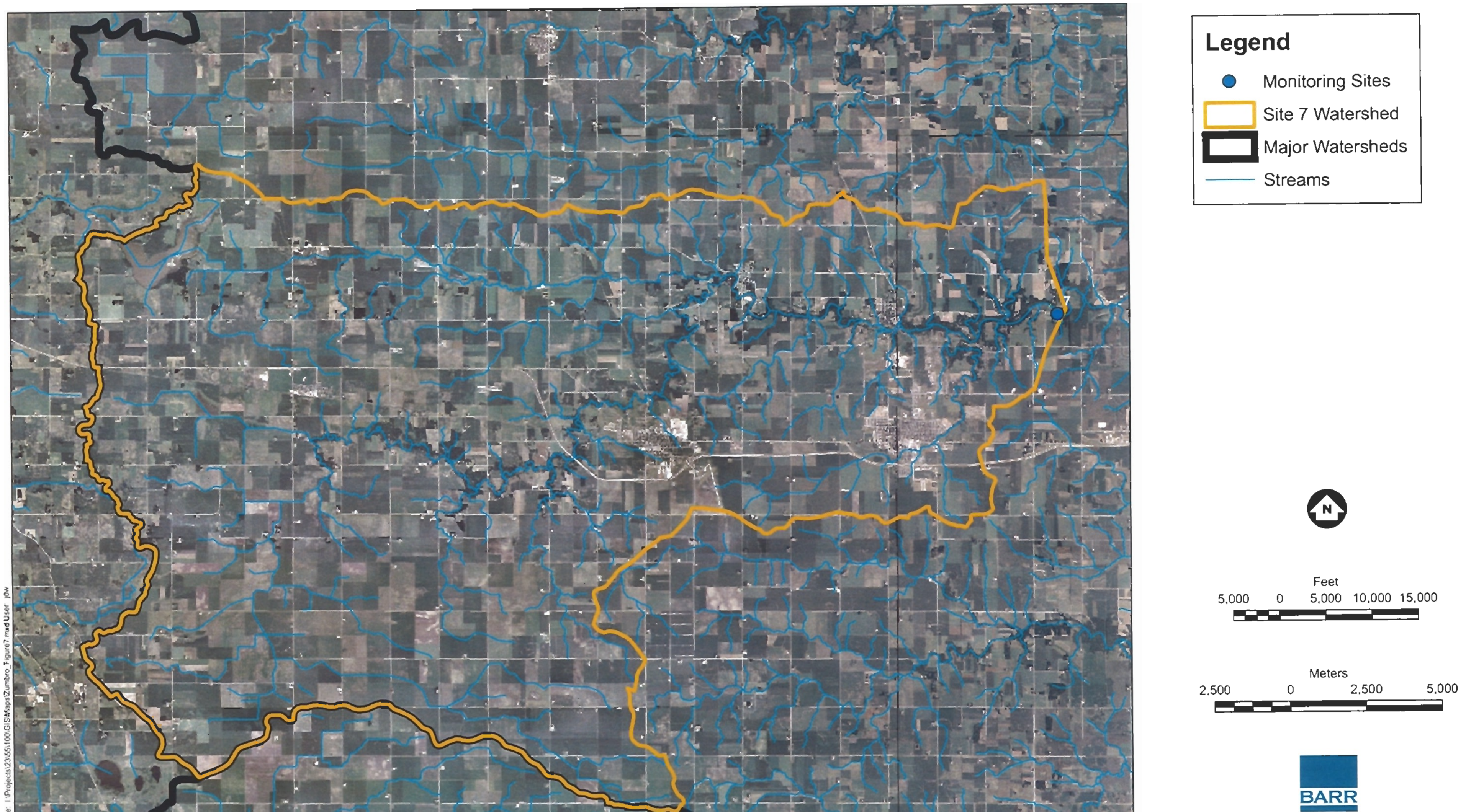
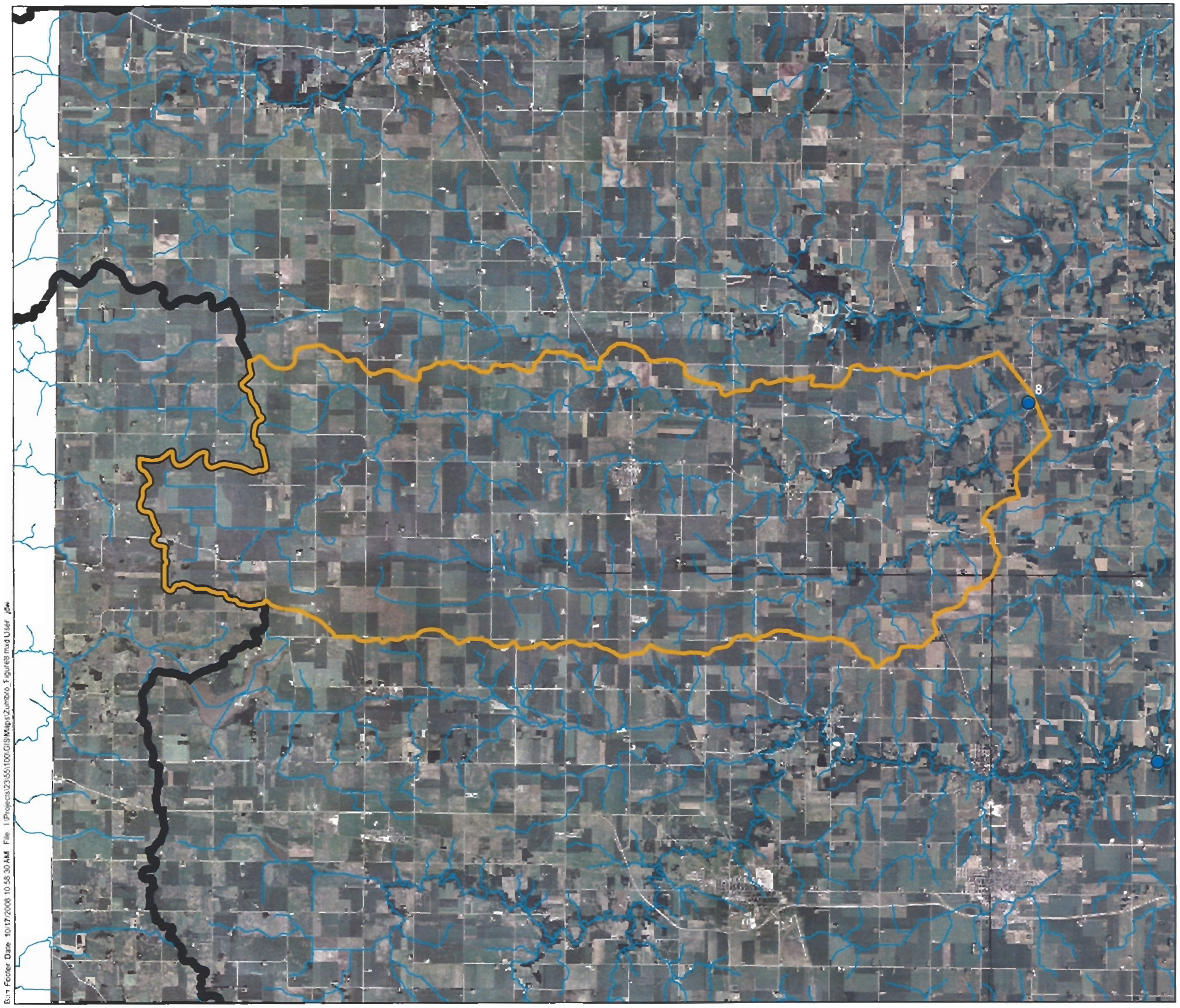


Figure 7

SITE 7 WATERSHED
SOUTH BRANCH MIDDLE FORK ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency



Legend

- Monitoring Sites
- Site 8 Watershed
- Major Watersheds
- Streams

N

Feet
5,000 0 5,000 10,000 15,000

Meters
2,500 0 2,500 5,000

BARR

Figure 8

SITE 8 WATERSHED
NORTH BRANCH MIDDLE FORK ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency

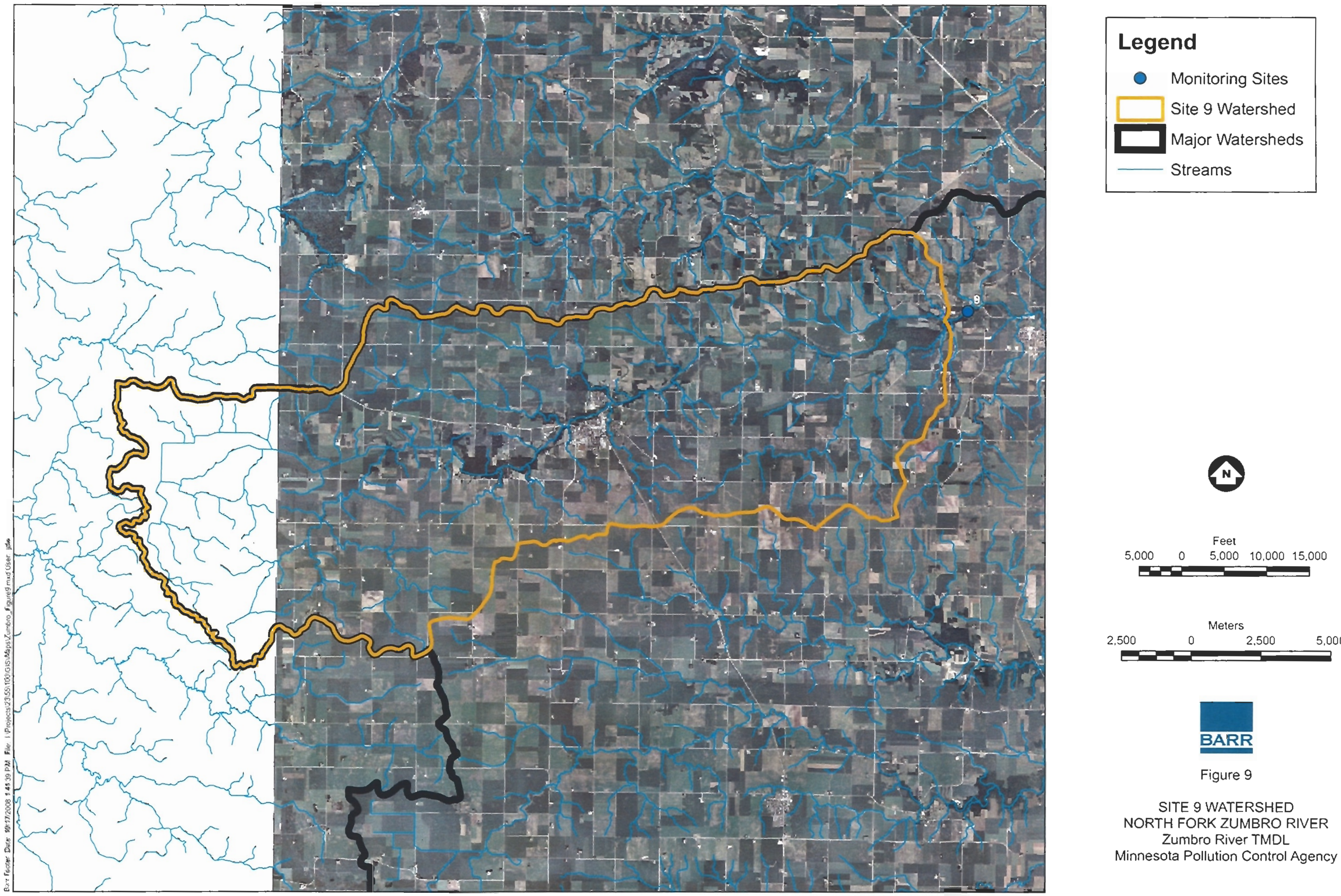


Figure 9

SITE 9 WATERSHED
NORTH FORK ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency

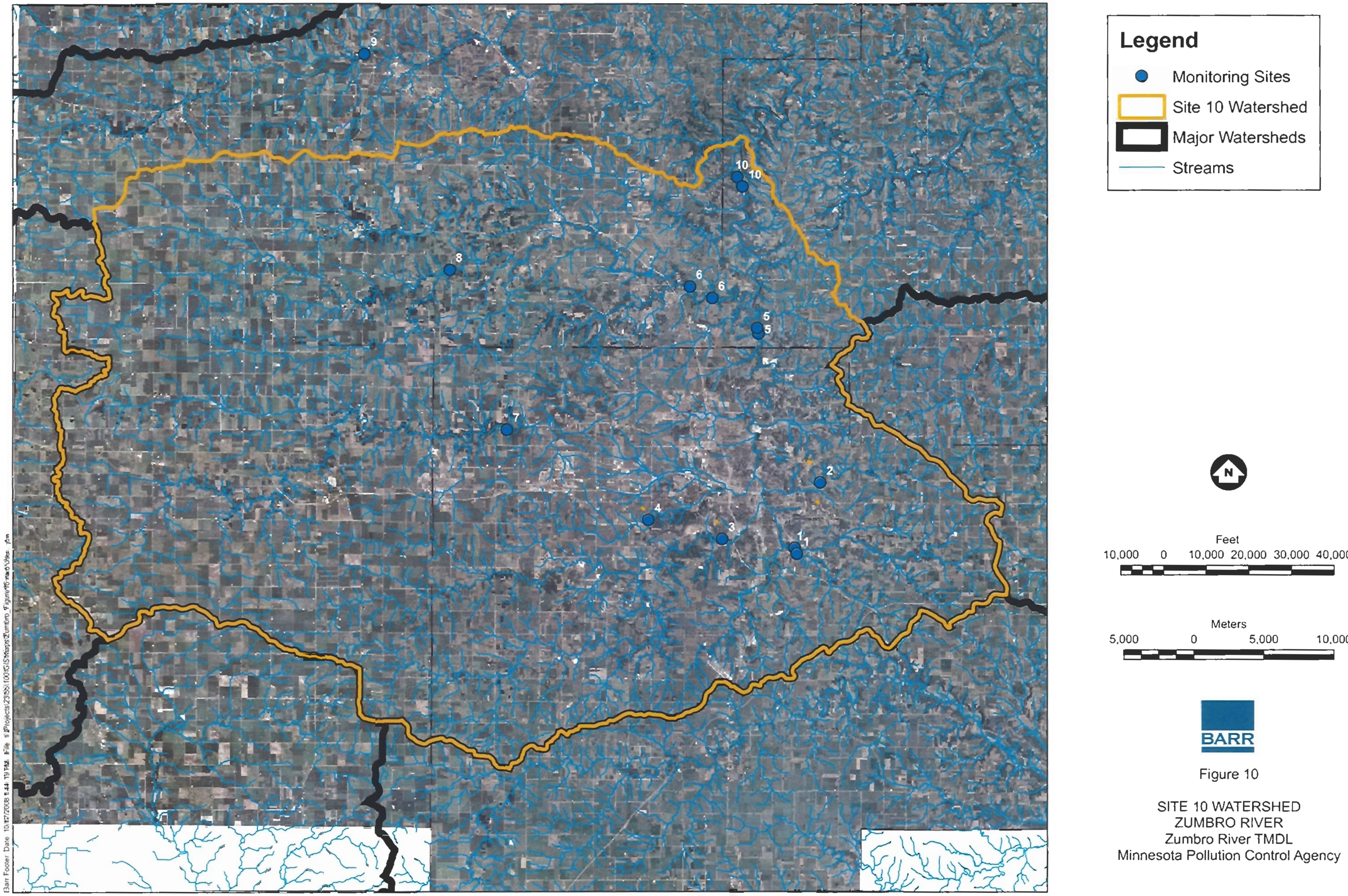


Figure 10

SITE 10 WATERSHED
ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency

Barr Footer Date: 10/17/2008 1:44:19 PM File: I:\Projects\23\55\1003\GIS\Maps\Zumbro_Figure10.mxd User: jfm

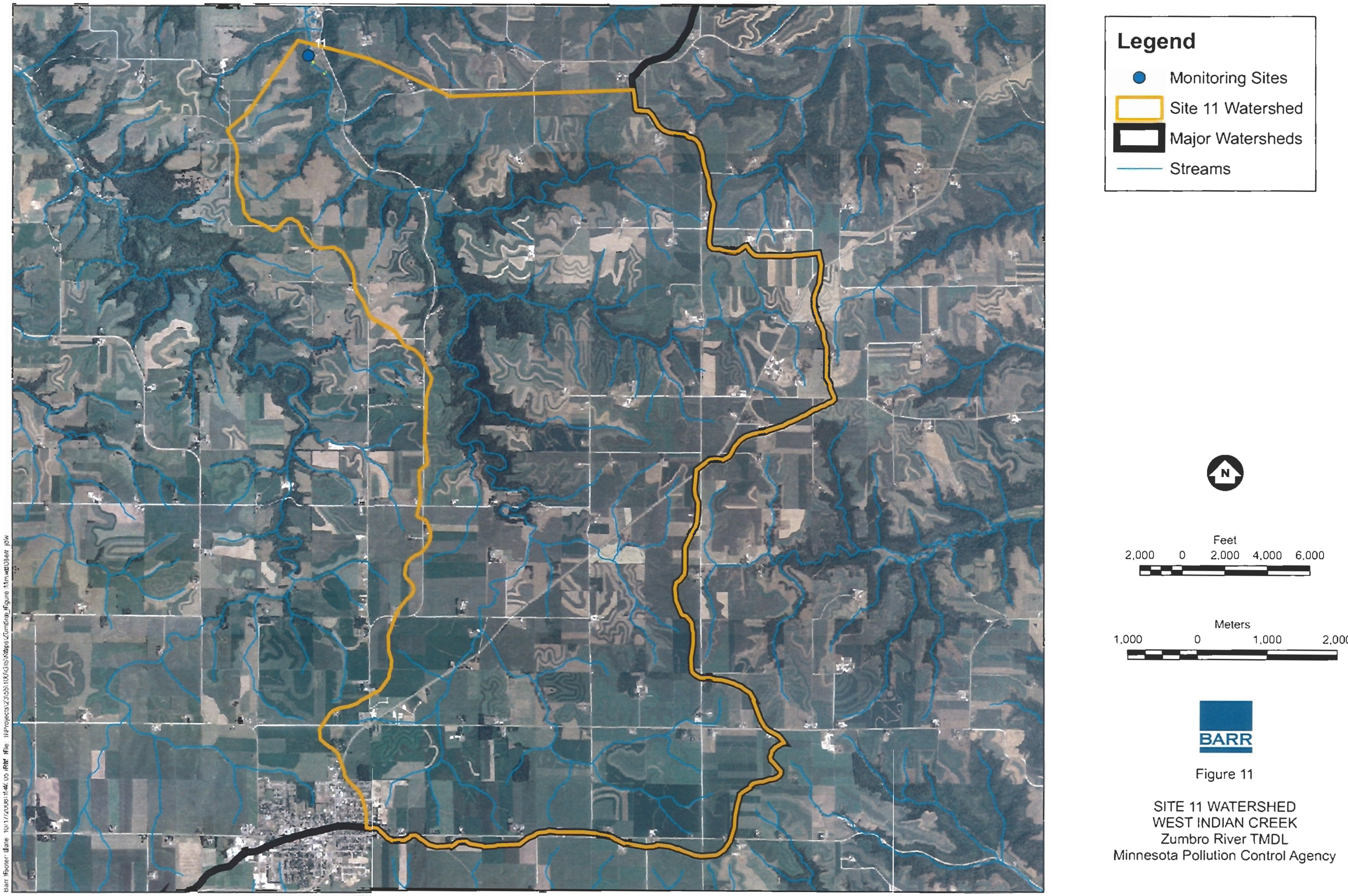
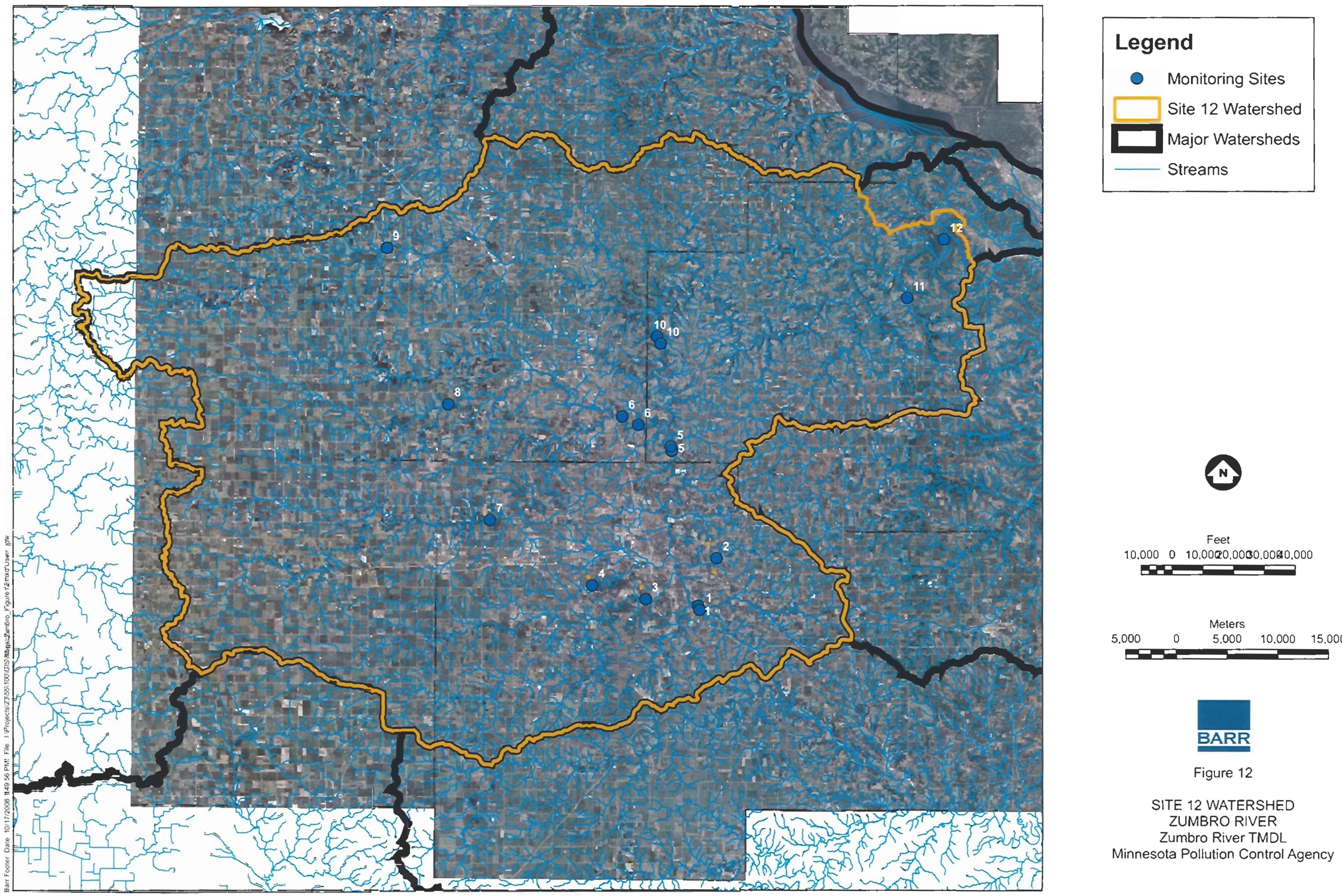


Figure 11

SITE 11 WATERSHED
WEST INDIAN CREEK
Zumbro River TMDL
Minnesota Pollution Control Agency



Legend
Monitoring Sites
Site 12 Watershed
Major Watersheds
Streams
1
2
3
4
5
6
7
8
9
10
11
12
Feet
10,000 0 10,000 20,000 30,000 40,000
Meters
5,000 0 5,000 10,000 15,000
BARR
Figure 12
SITE 12 WATERSHED
ZUMBRO RIVER
Zumbro River TMDL
Minnesota Pollution Control Agency

Figure 13. Bankfull cross section area comparison between 2007 survey and previous survey.

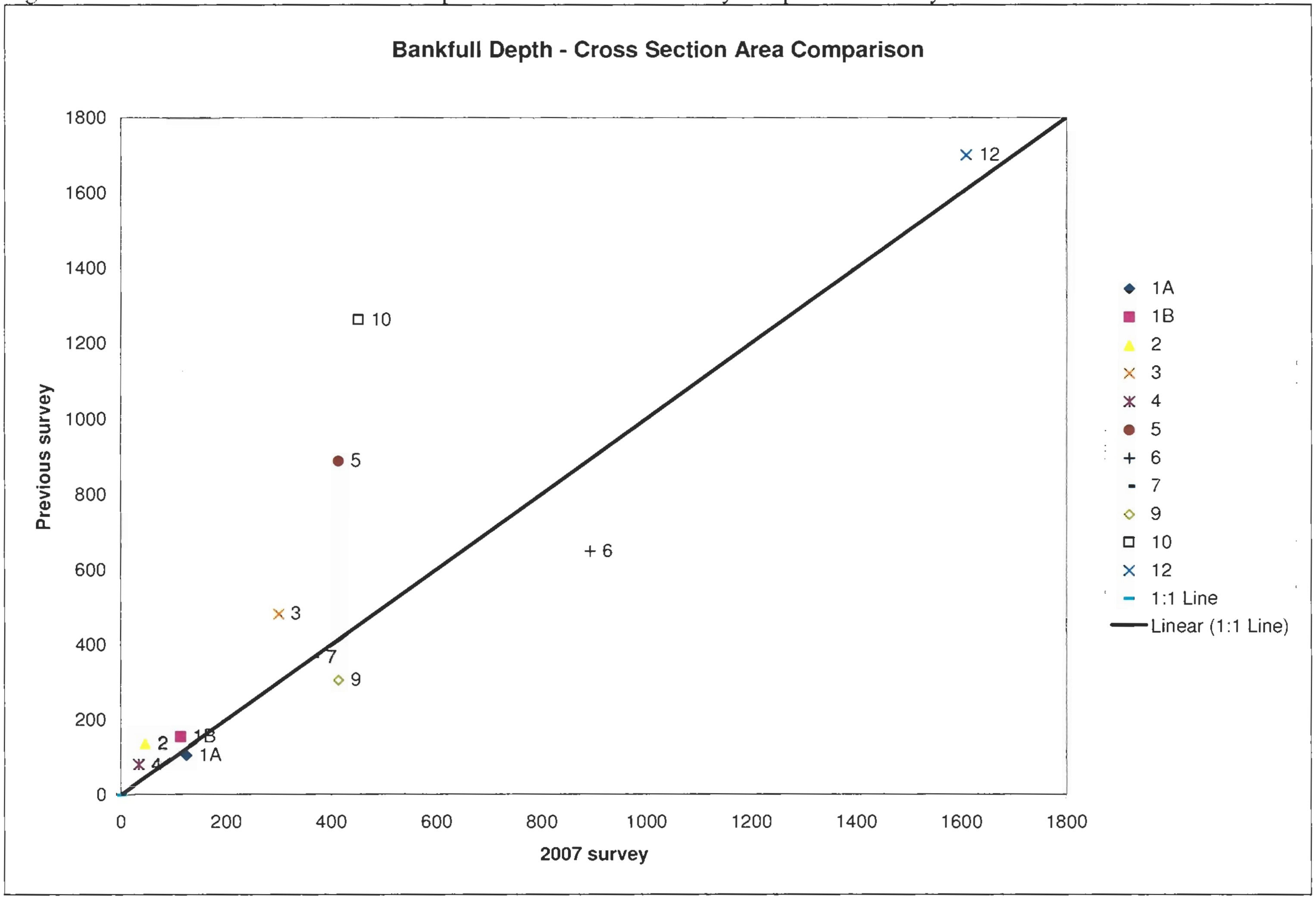


Figure 14. Bankfull width comparison between 2007 survey and previous survey.

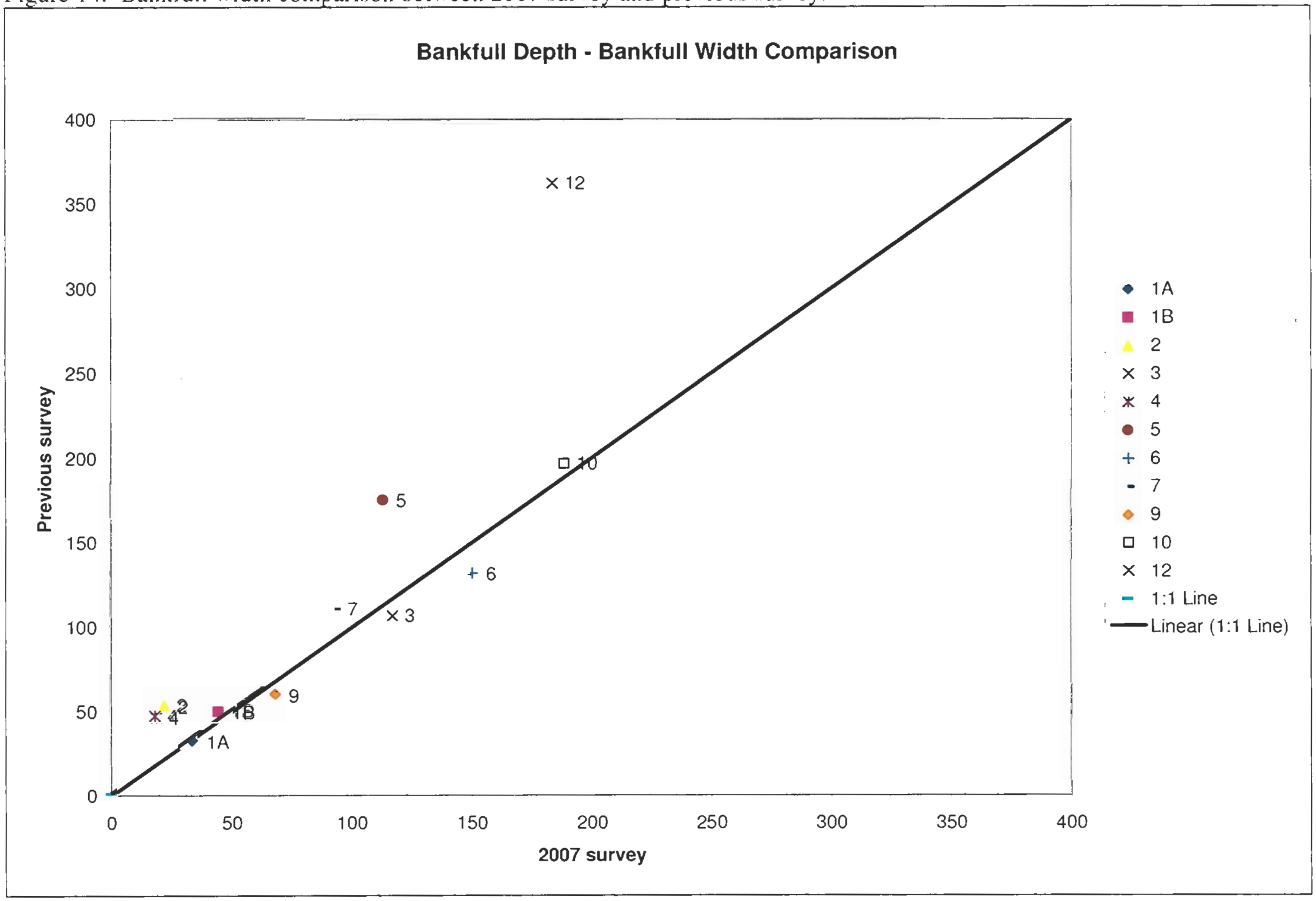


Figure 15. Mean depth comparison between 2007 survey and previous survey.

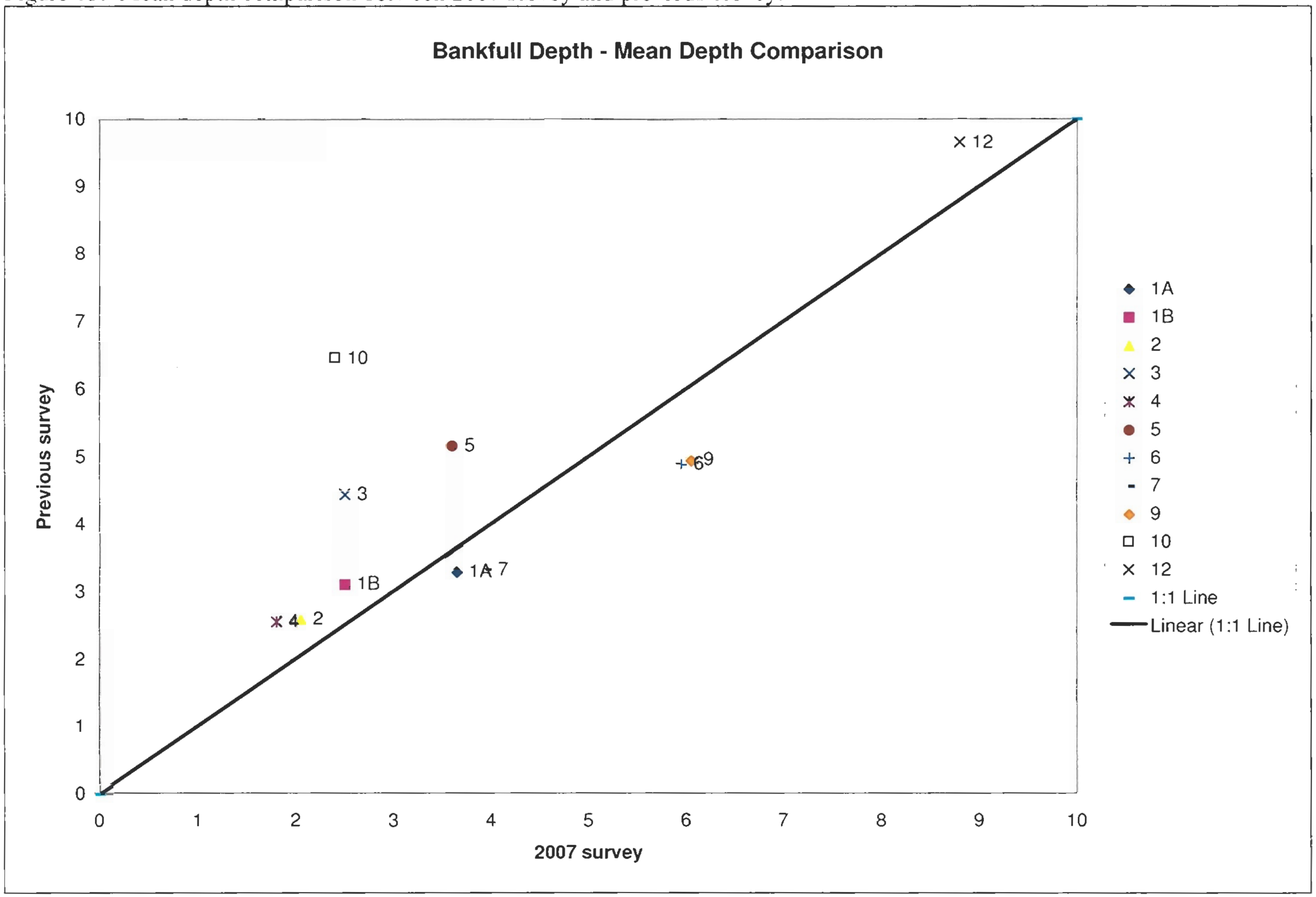


Figure 16. Bankfull depth comparison between 2007 survey and previous survey.

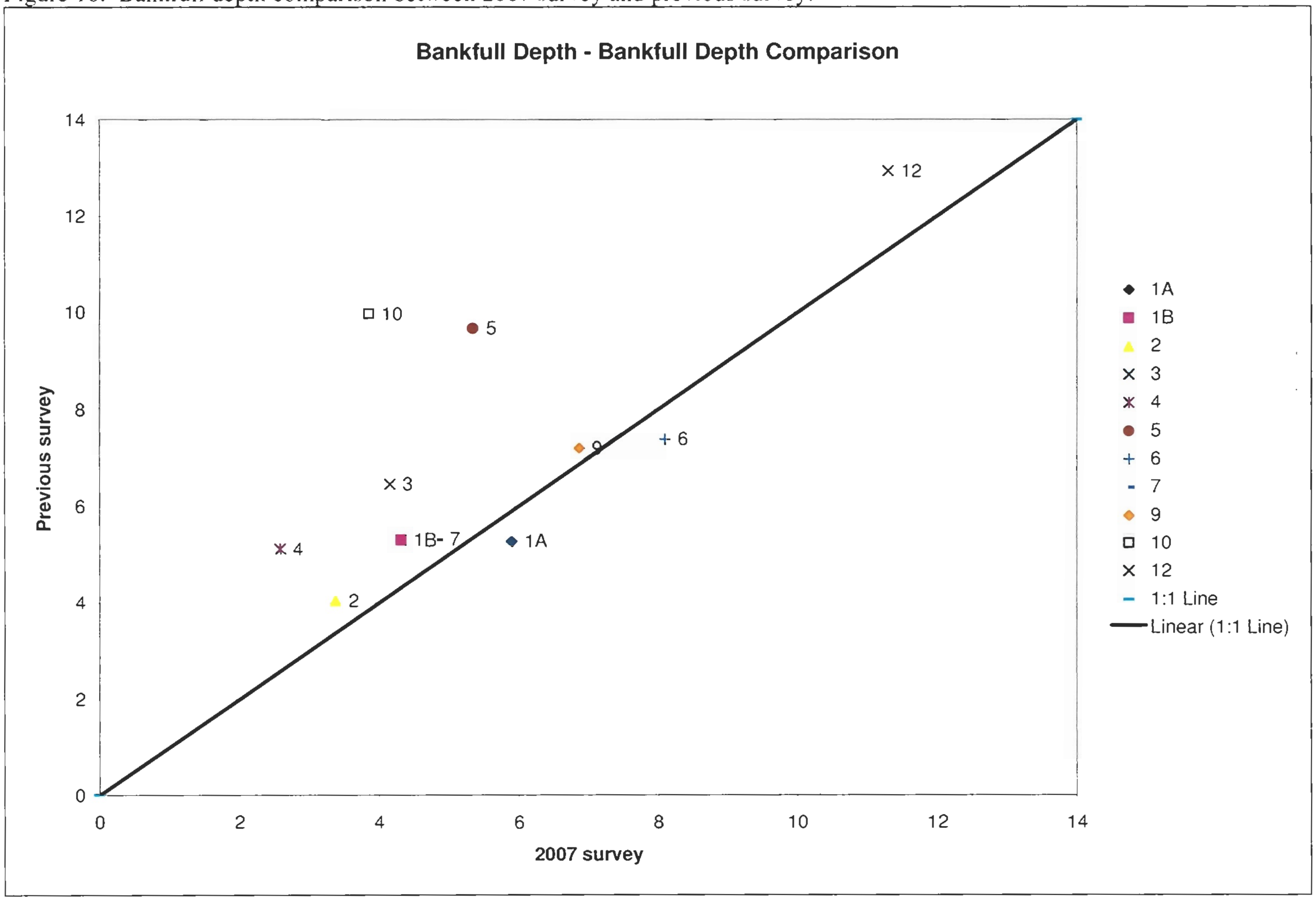


Figure 17. Bankfull flow comparison between 2007 survey and previous survey.

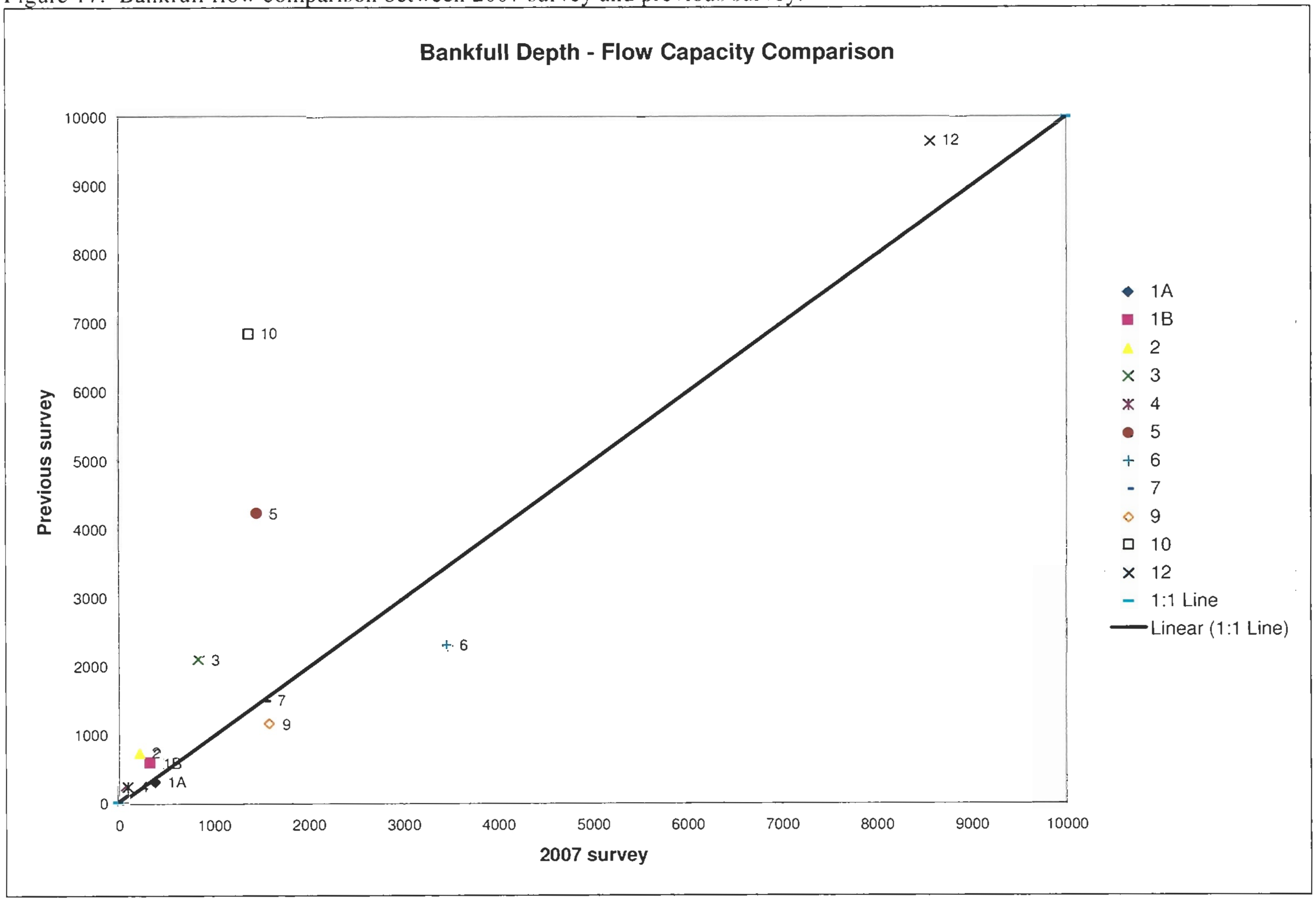


Figure 18. Width-Depth ratio comparison between 2007 survey and previous survey.

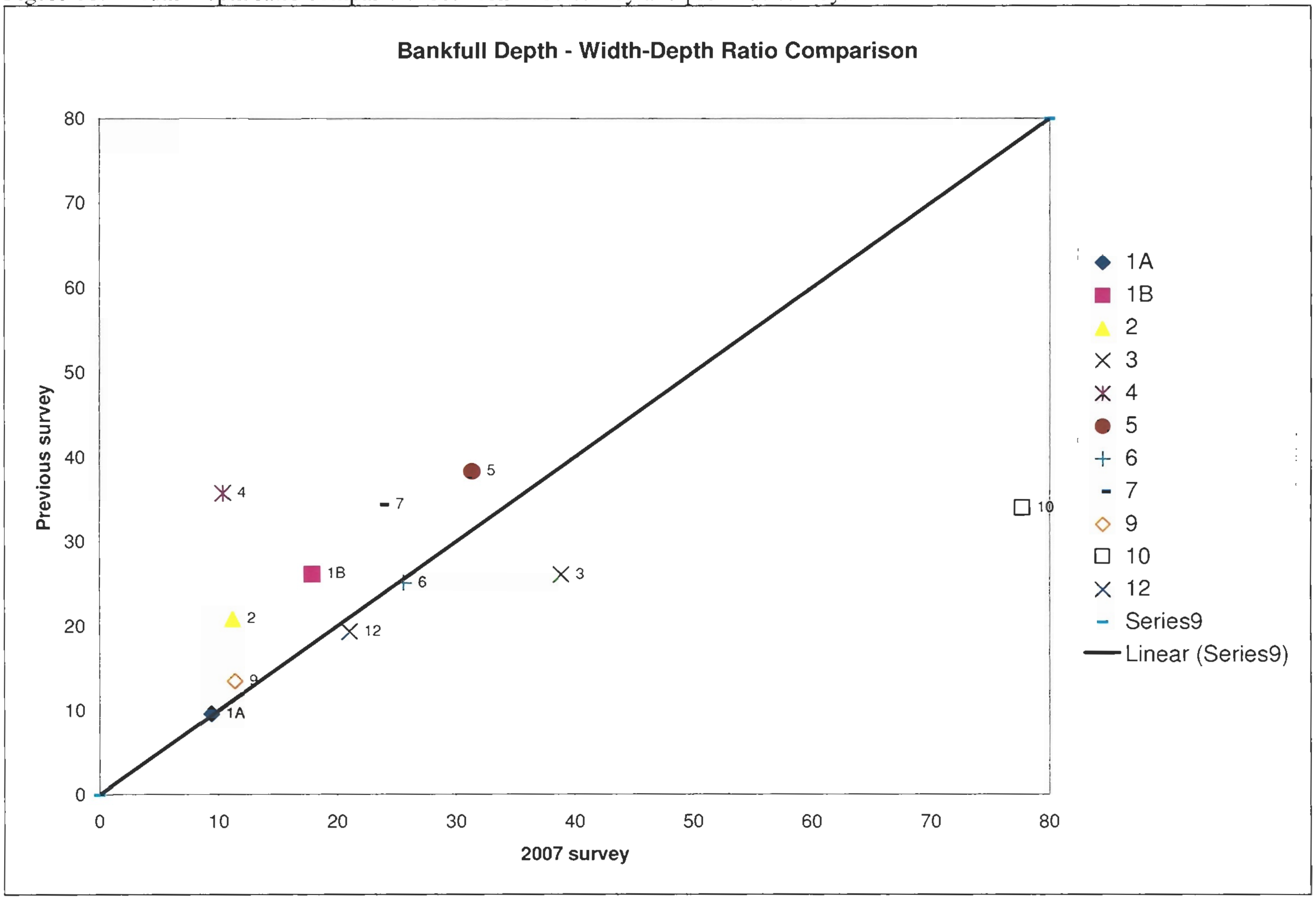


Figure 19. Entrenchment ratio comparison between 2007 survey and previous survey.

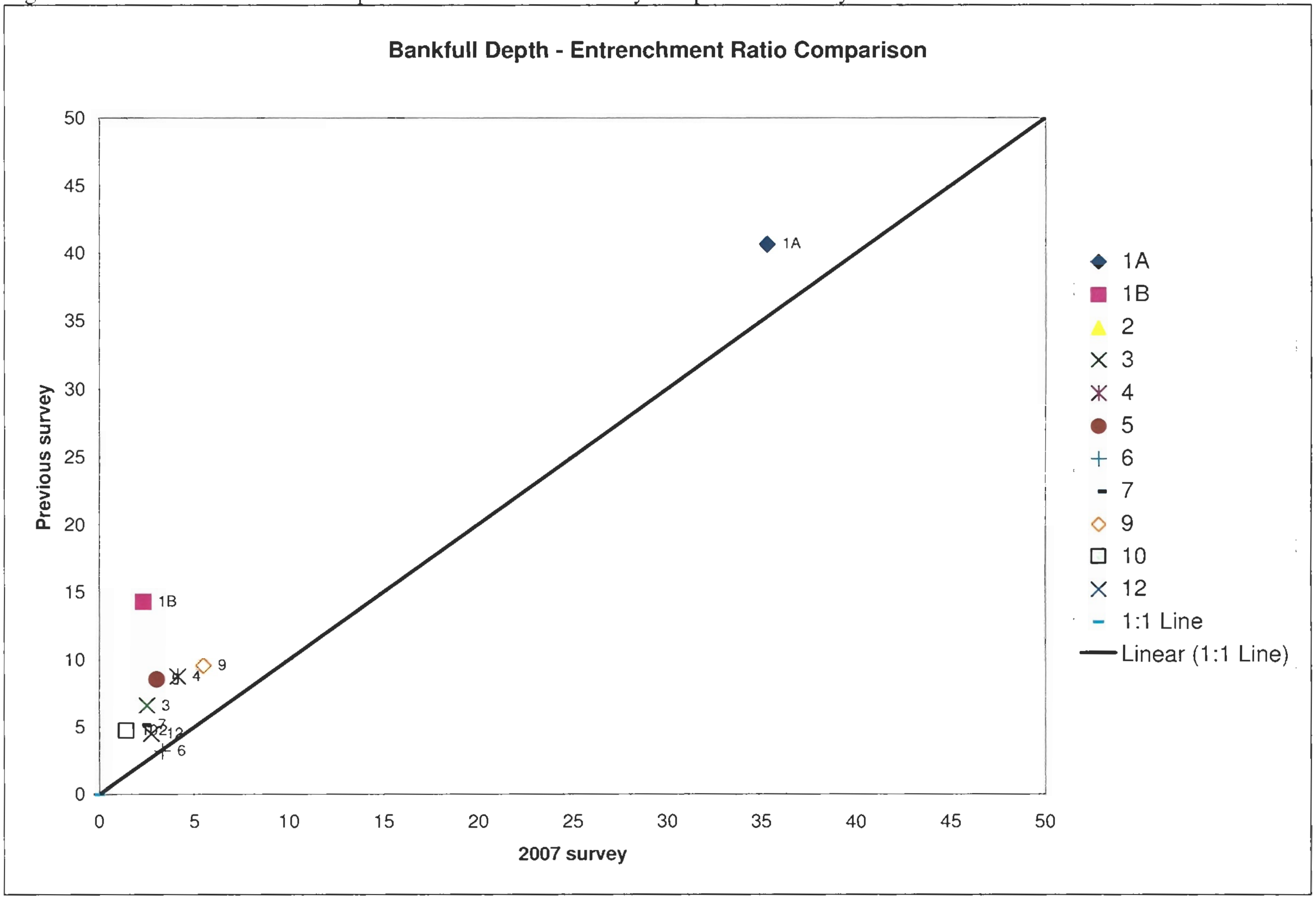


Figure 20. Bankfull width comparison between 2007 and previous surveys when matching the expected bankfull cross section area.

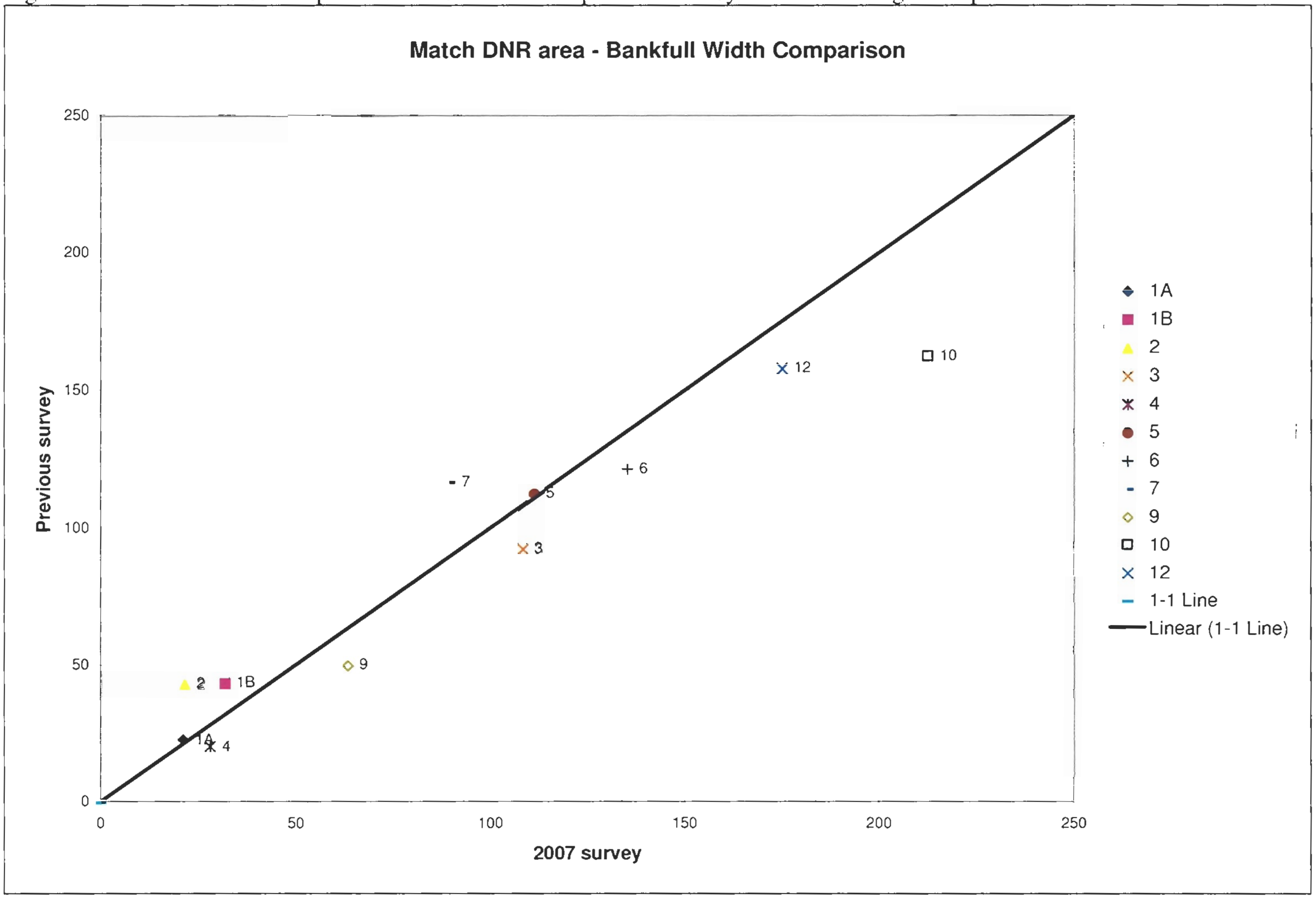


Figure 21. Mean depth comparison between 2007 and previous surveys when matching the expected bankfull cross section area.

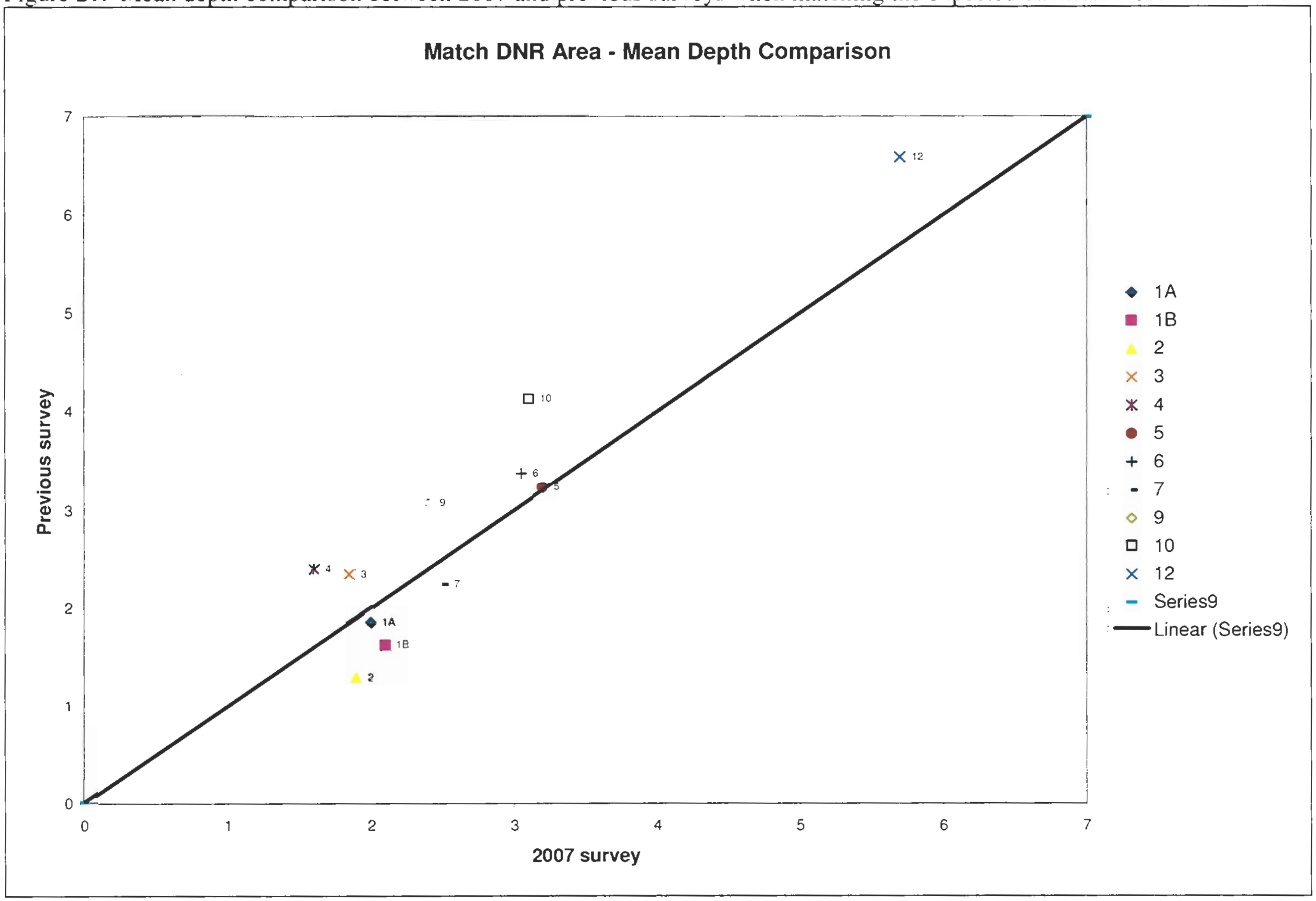


Figure 22. Maximum depth comparison between 2007 and previous surveys when matching the expected bankfull cross section area.

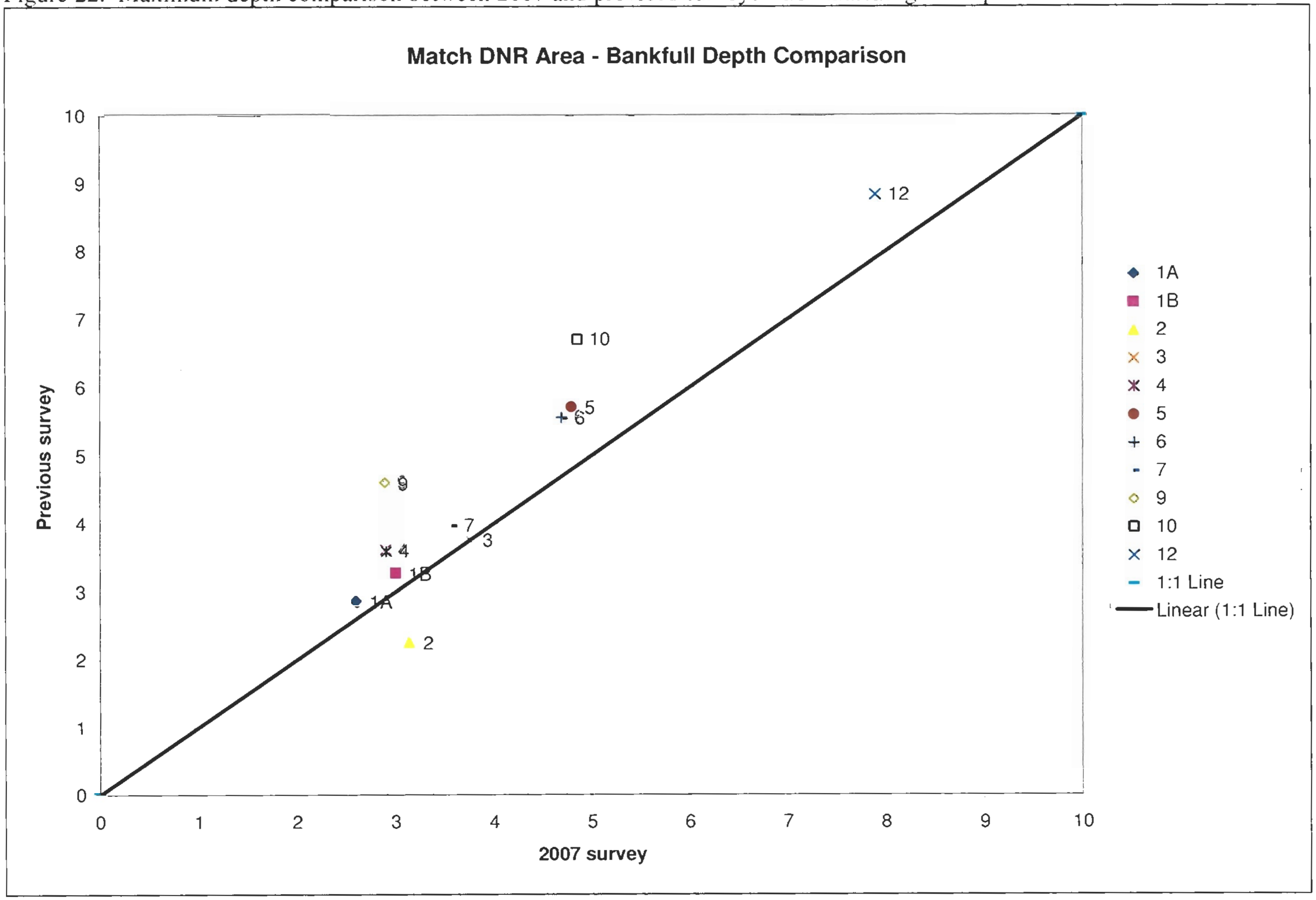


Figure 23. Bankfull flow comparison between 2007 and previous surveys when matching the expected bankfull cross section area.

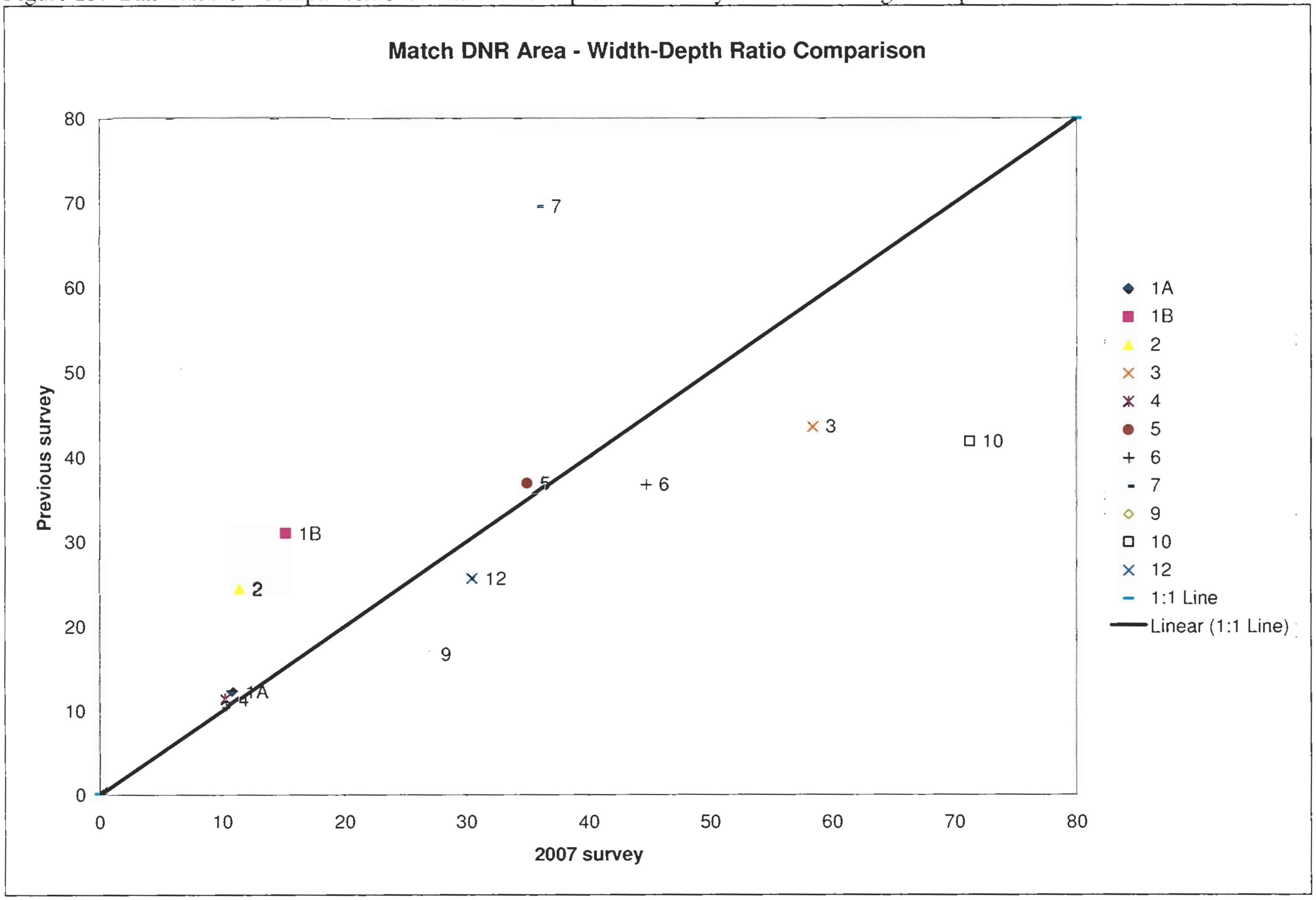


Figure 24. Width-depth ratio comparison between 2007 and previous surveys when matching the expected bankfull cross section area.

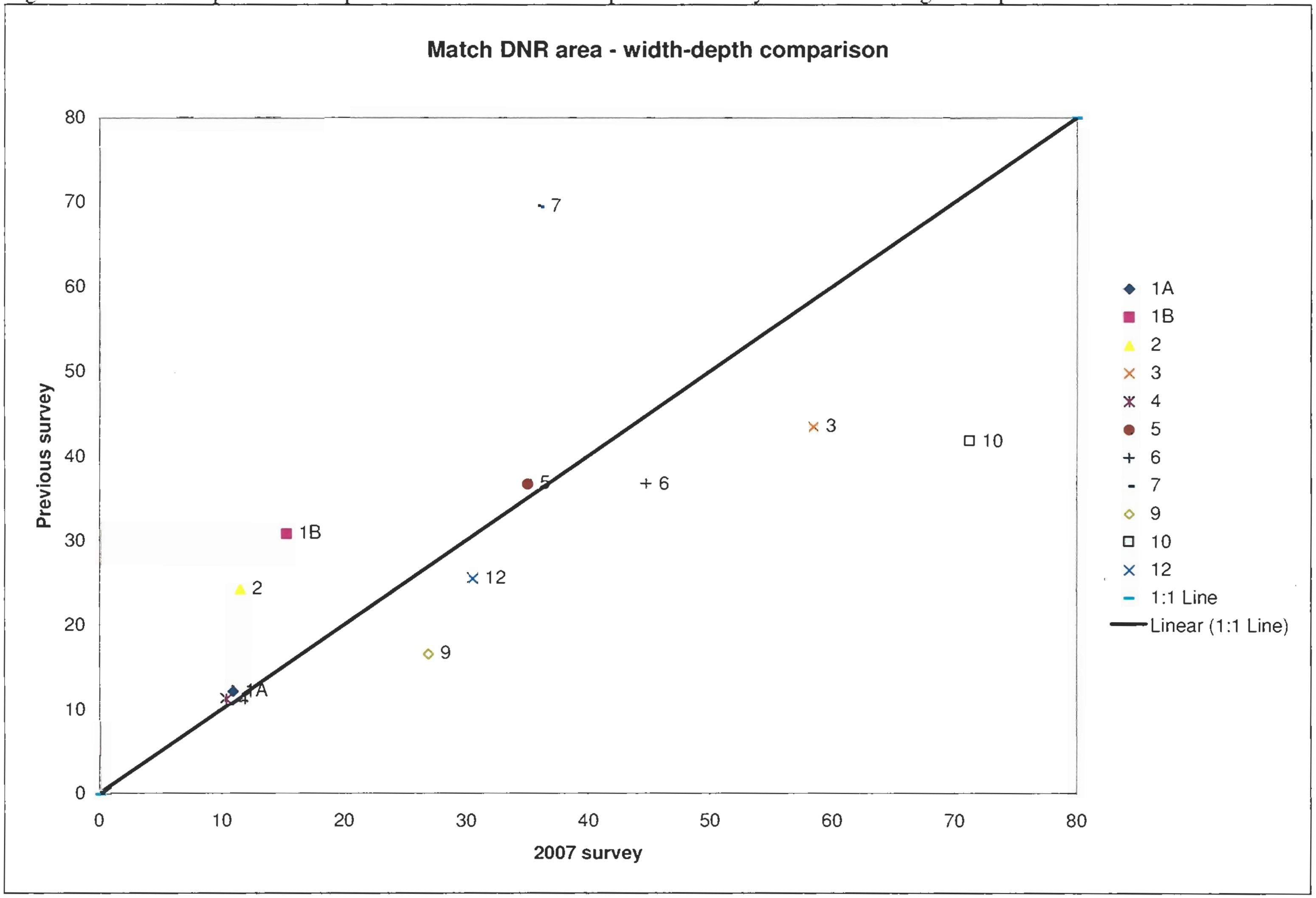


Figure 25. Width-depth ratio comparison between 2007 and previous surveys when matching the expected bankfull cross section area.

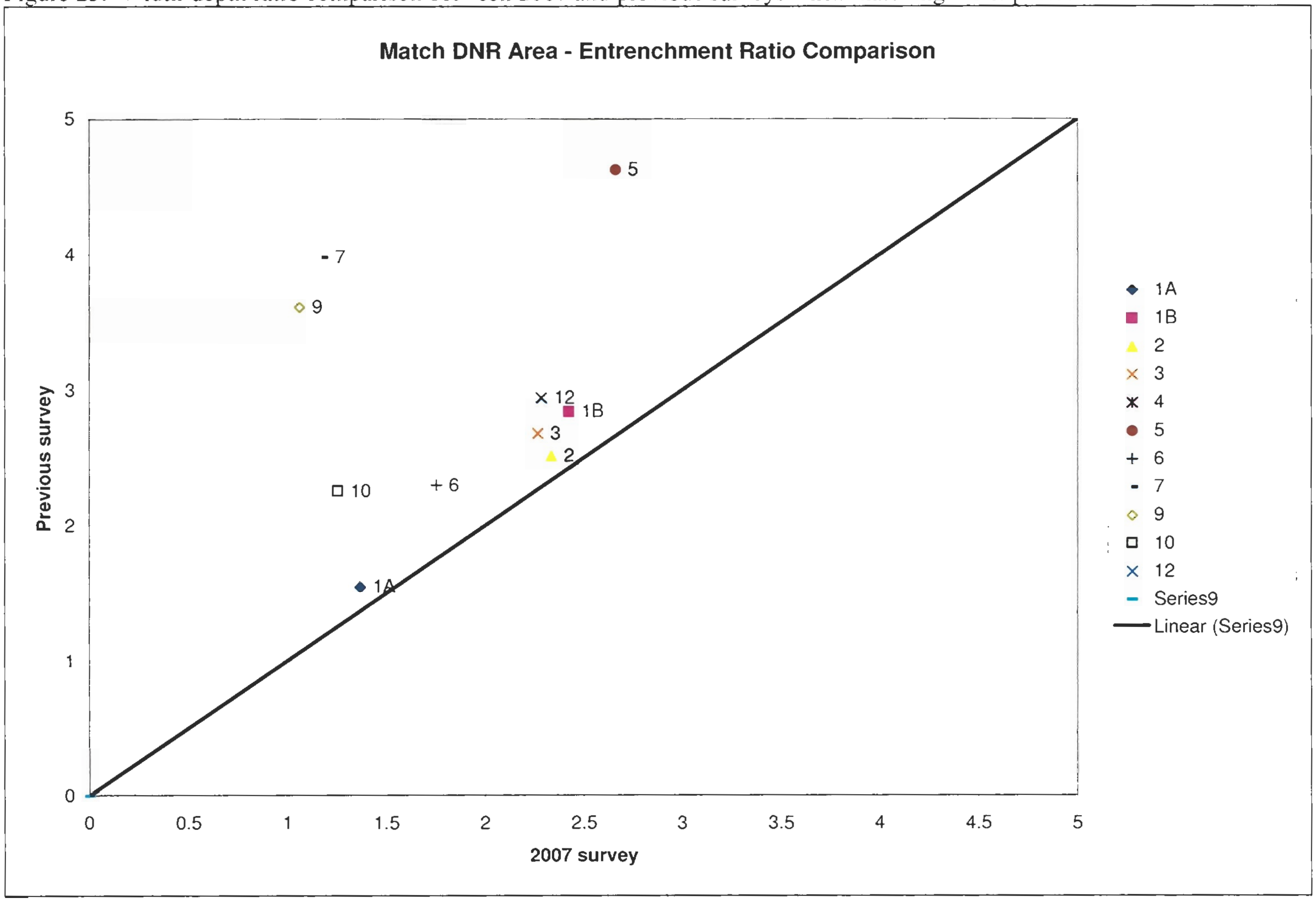


Figure 26. Bankfull area comparison between 2007 and previous surveys when matching the expected bankfull depth.

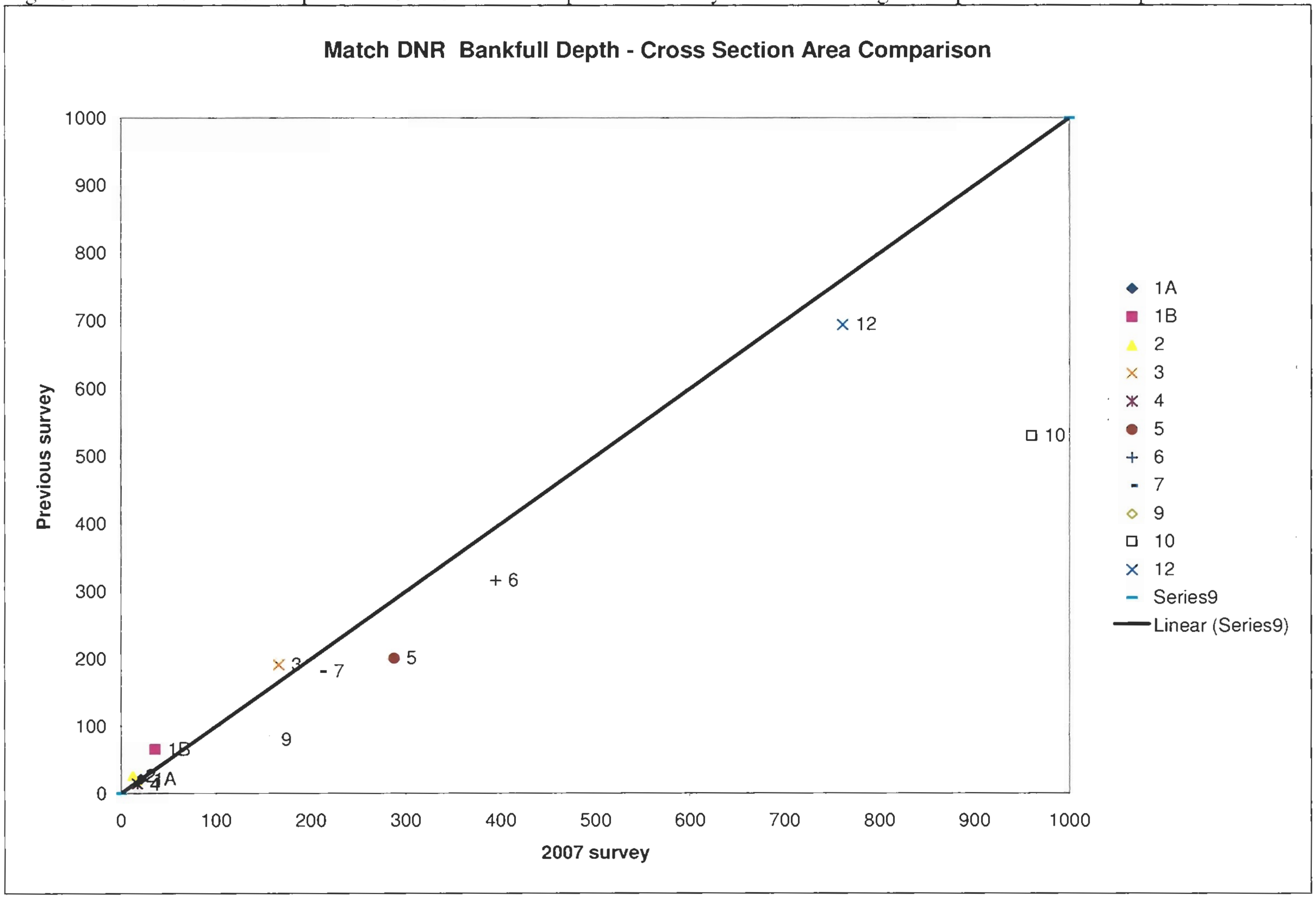


Figure 27. Bankfull width comparison between 2007 and previous surveys when matching the expected bankfull depth.

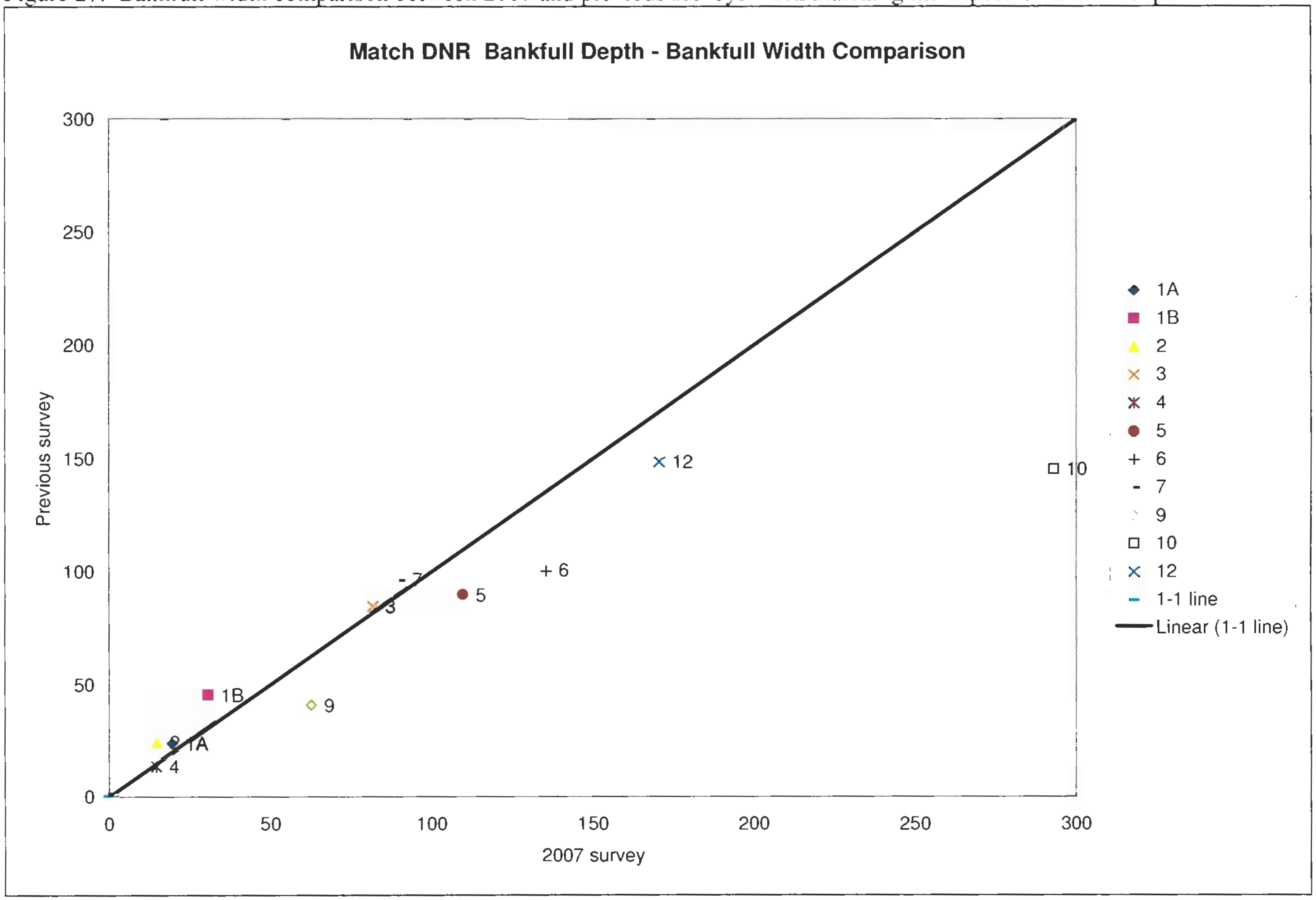


Figure 28. Mean depth comparison between 2007 and previous surveys when matching the expected bankfull depth.

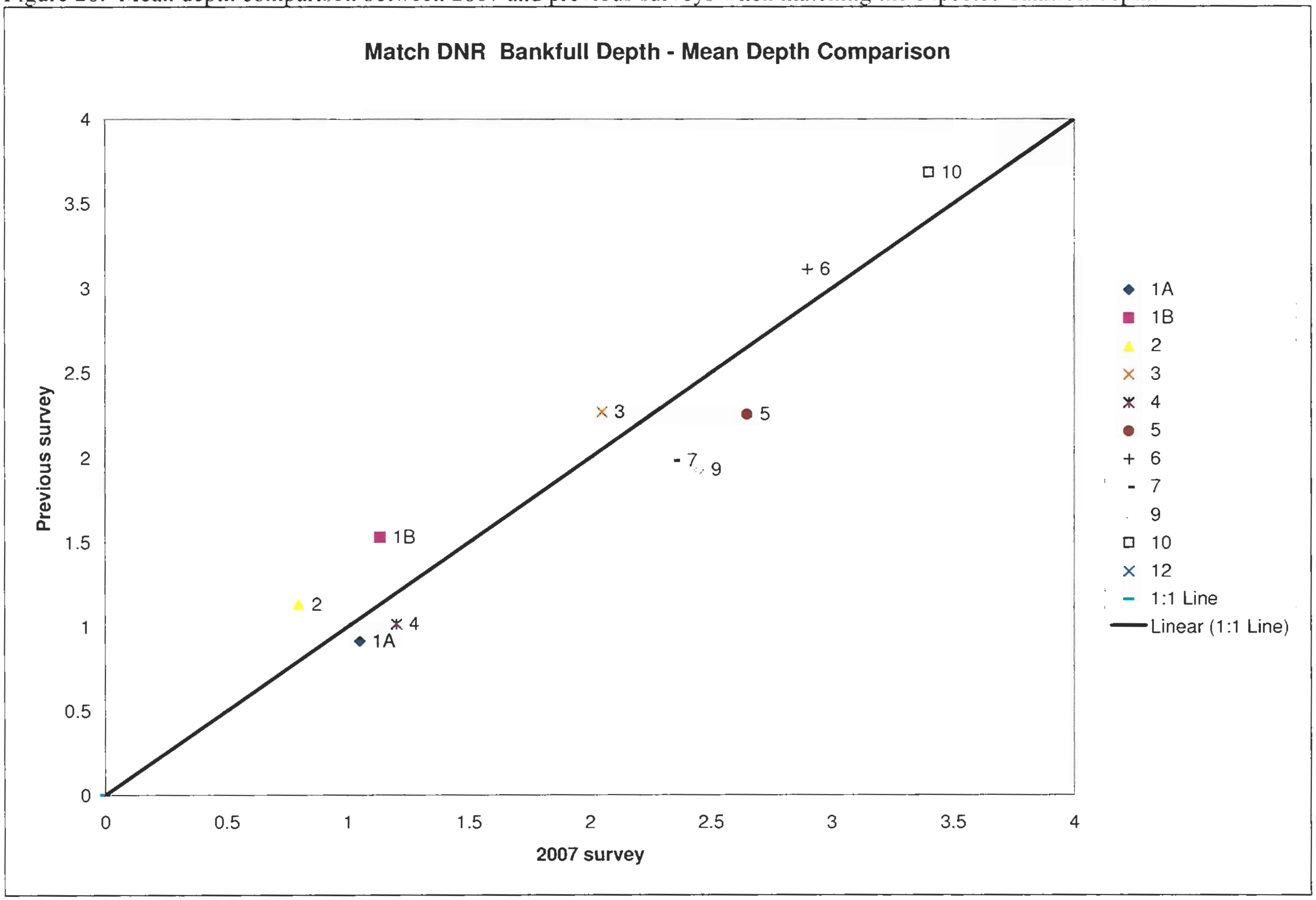


Figure 29. Bankfull flow comparison between 2007 and previous surveys when matching the expected bankfull depth.

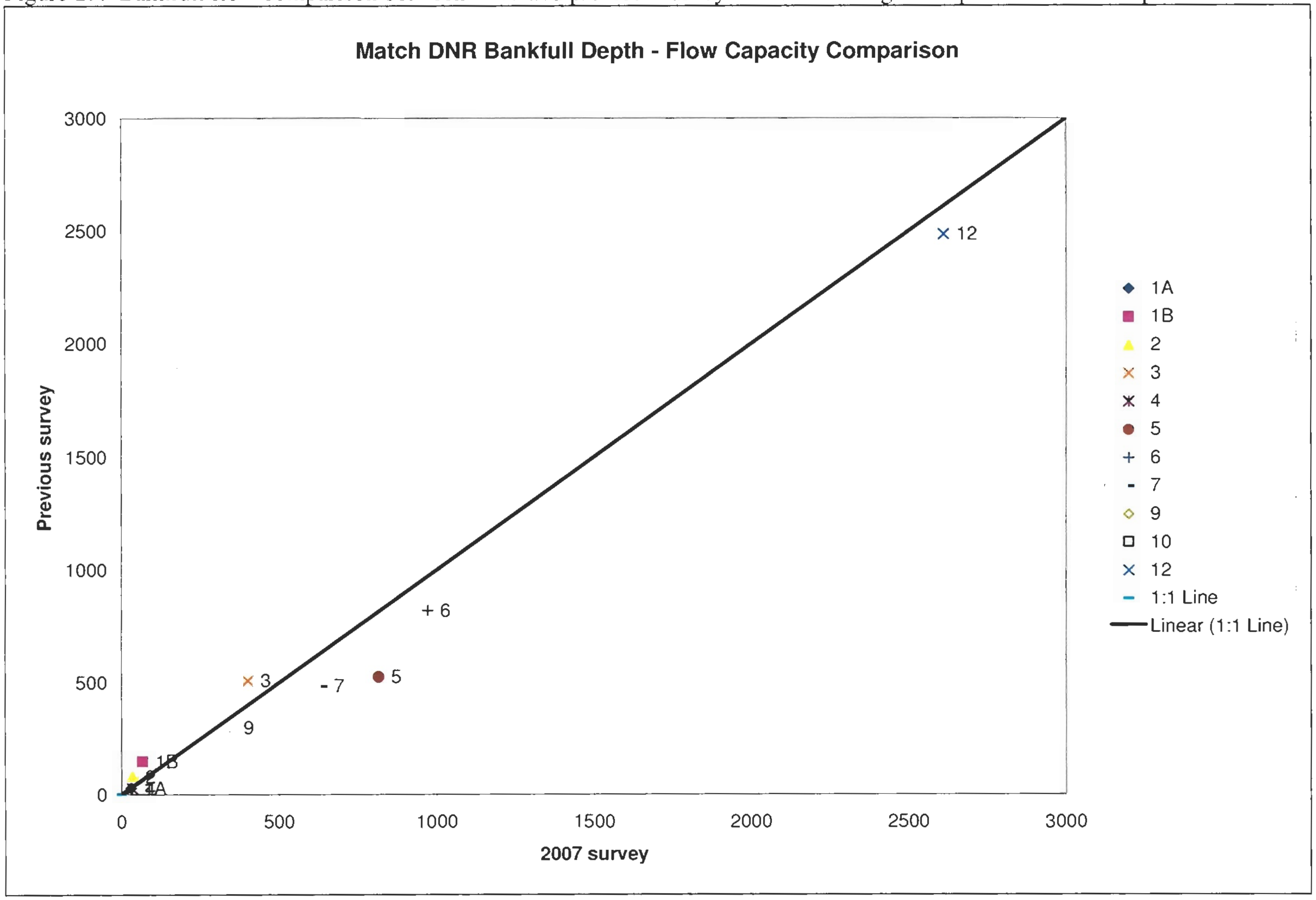


Figure 30. Width-depth comparison between 2007 and previous surveys when matching the expected bankfull depth.

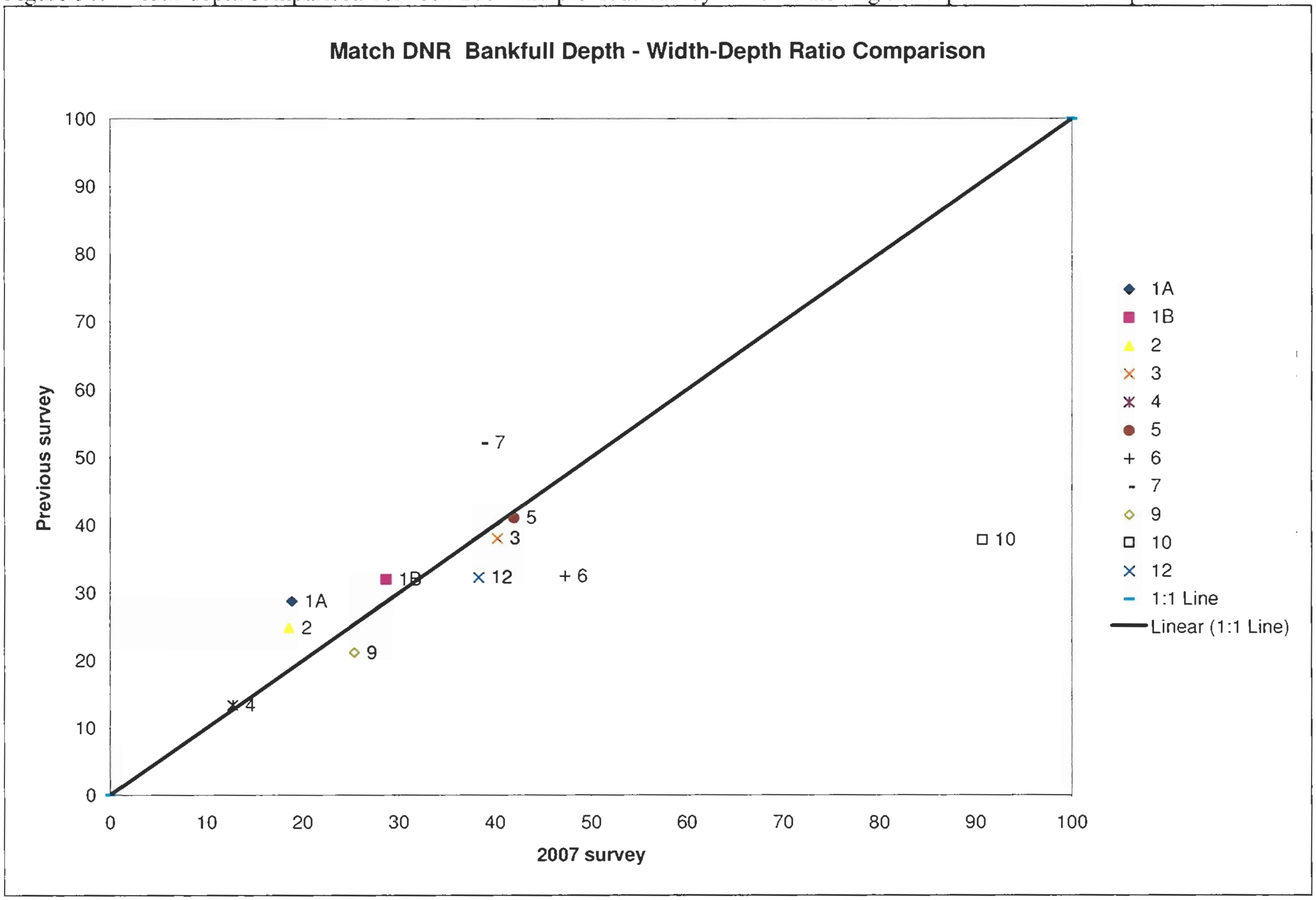


Figure 31. Entrenchment ratio comparison between 2007 and previous surveys when matching the expected bankfull depth.

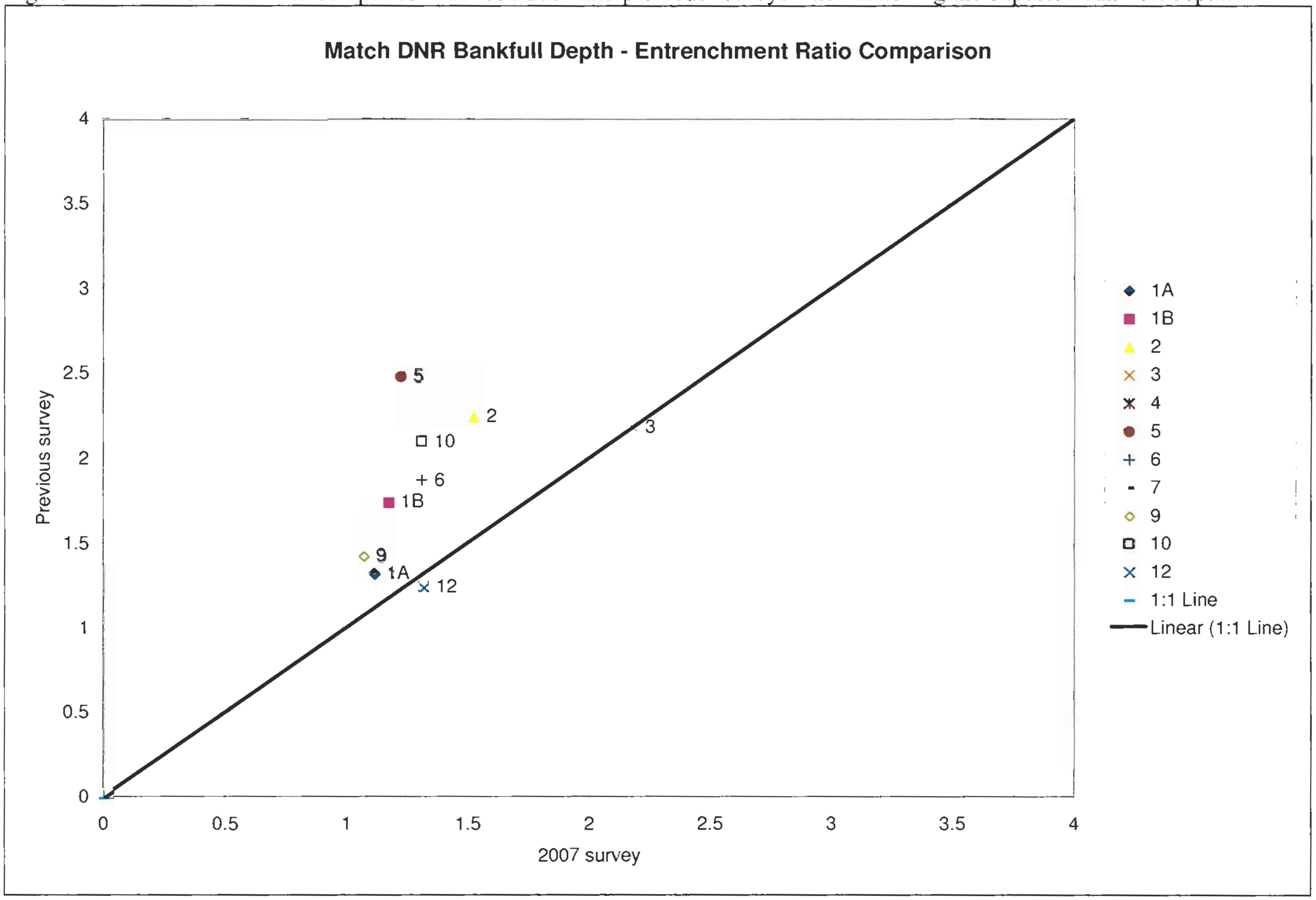


Figure 32. Bankfull cross section area comparison from the top of the bank between 2007 survey and previous survey

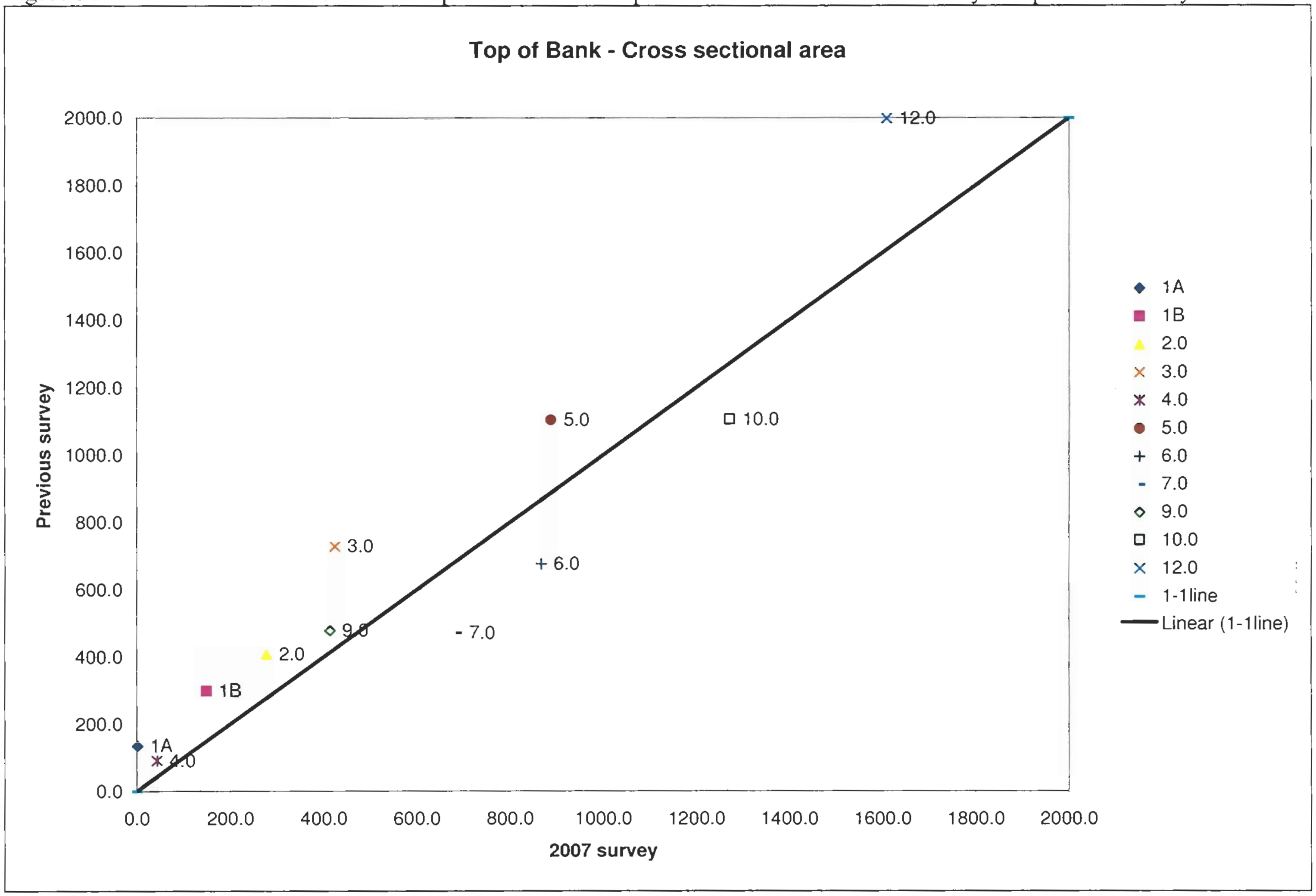


Figure 33. Bankfull width comparison between 2007 survey and previous survey, comparison made at the top of the bank.

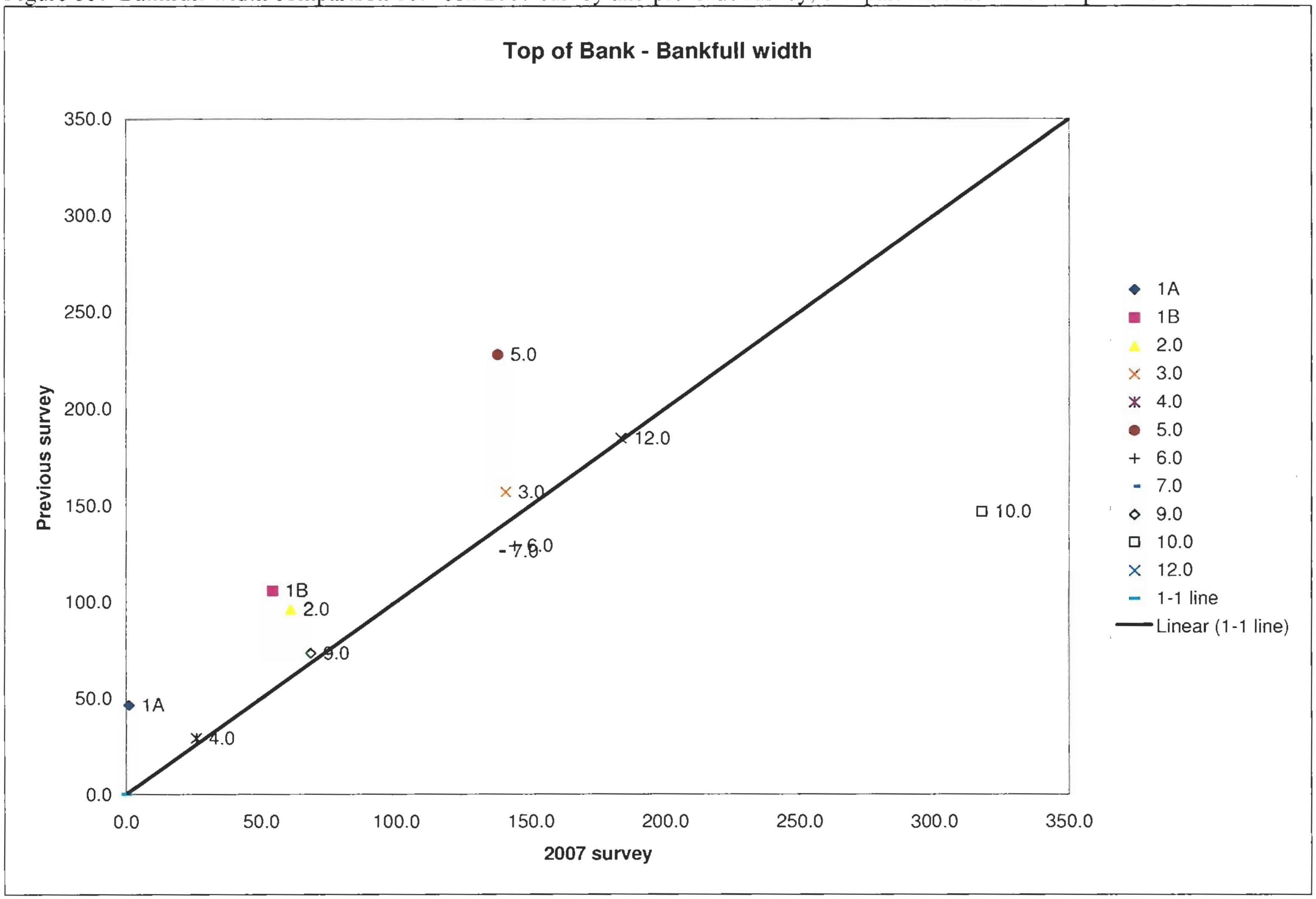


Figure 34. Mean depth comparison between 2007 survey and previous survey, comparison made at the top of the bank.

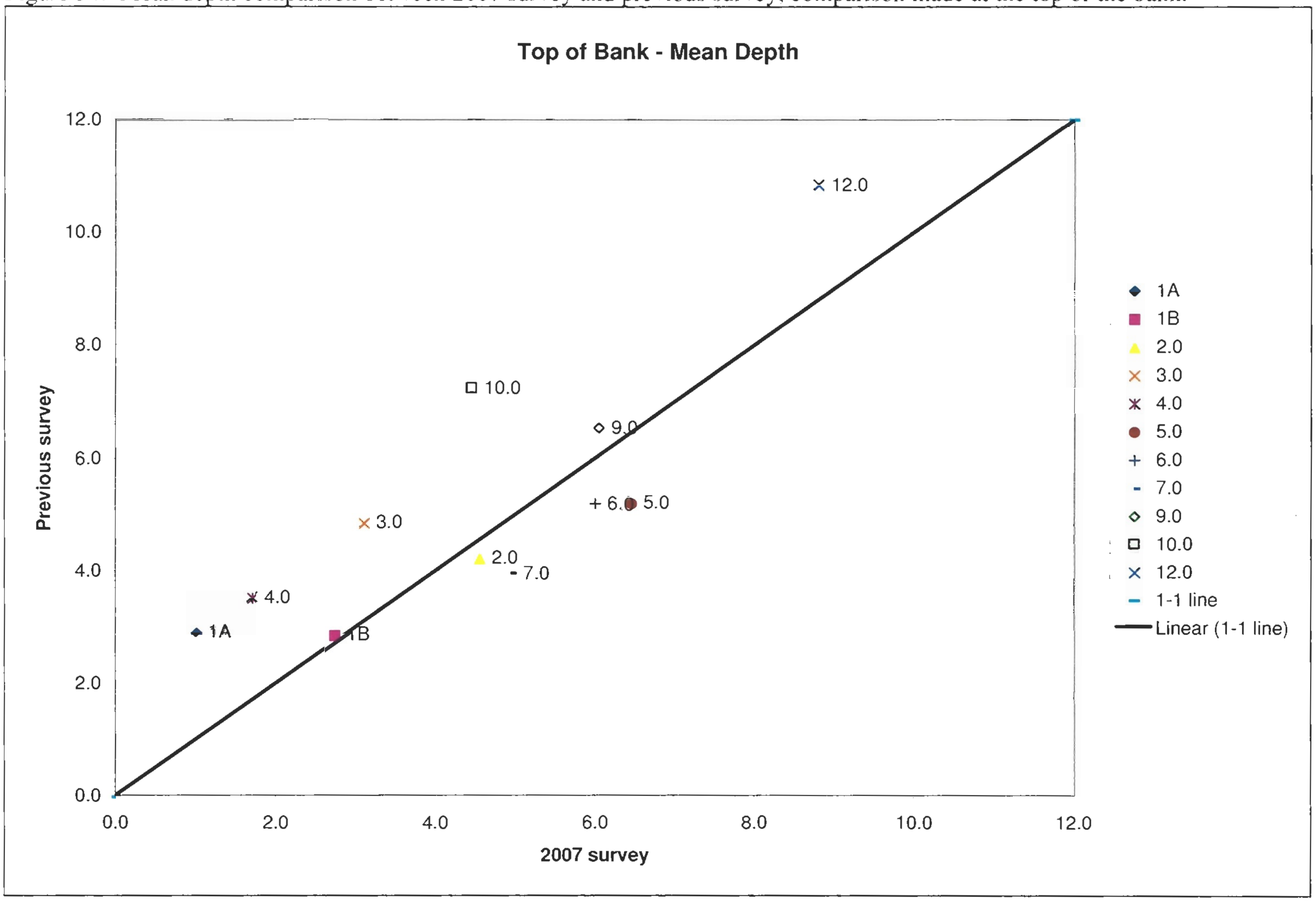


Figure 35. Maximum depth comparison between 2007 survey and previous survey, comparison made at the top of the bank.

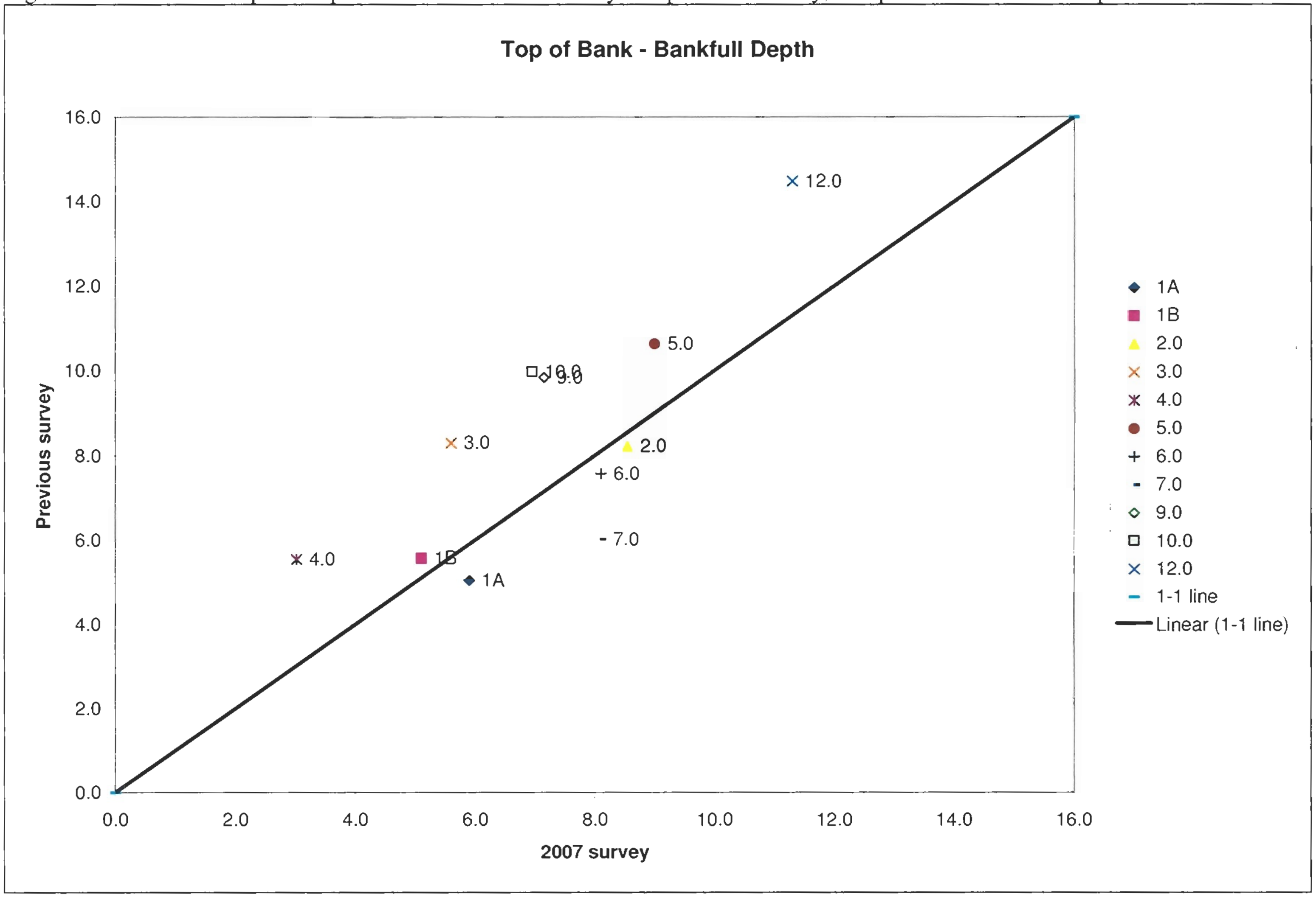


Figure 36. Comparison of channel flow capacity at the top of the bank between 2007 survey and previous survey.

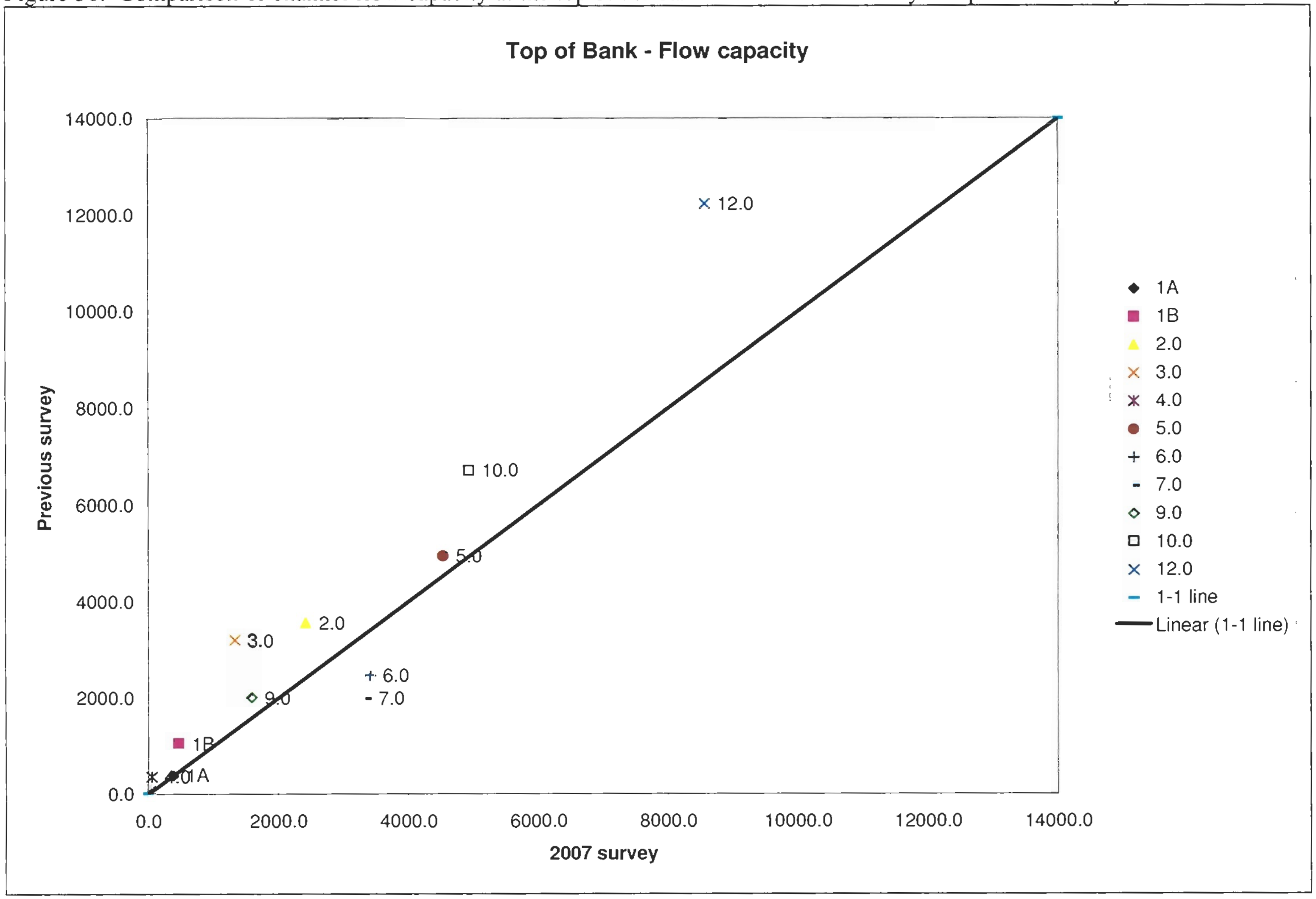


Figure 37. Comparison of the width-depth ratio between the 2007 survey and the previous surveys, comparison made at the top of the bank

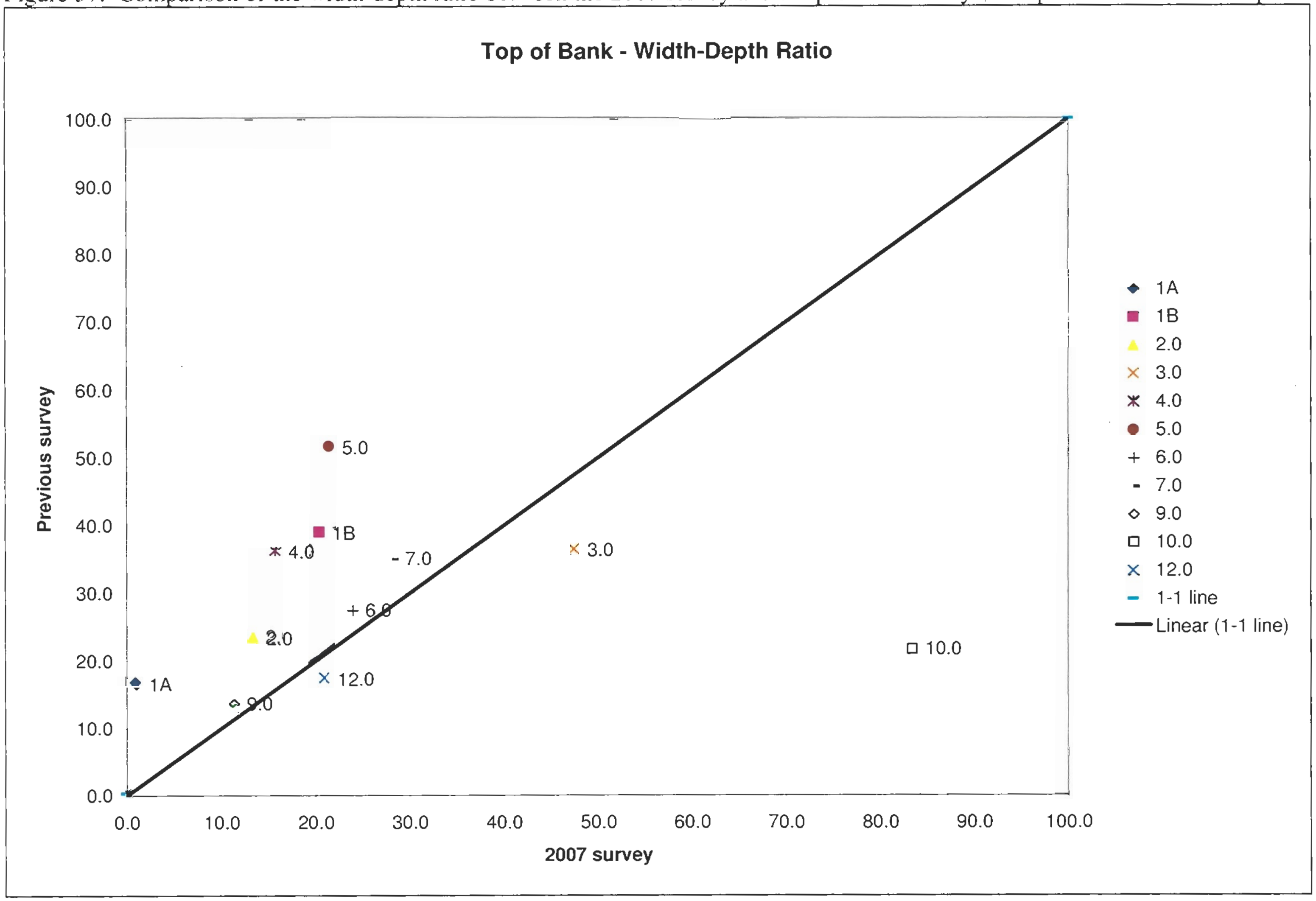


Figure 38. Comparison of the entrenchment ratio between 2007 survey and the previous survey, comparison made at the top of the bank.

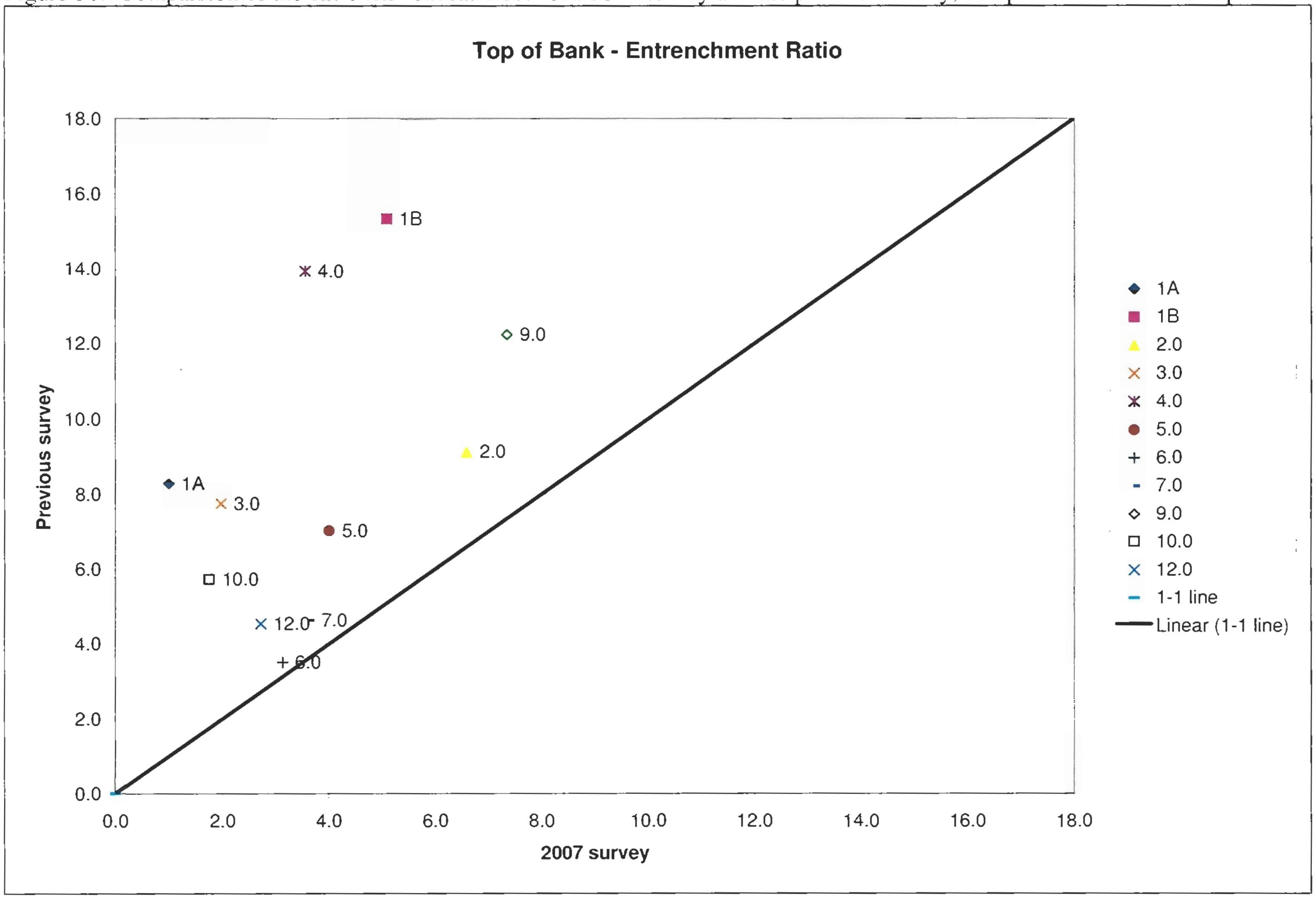


Figure 39. Pfankuch scores

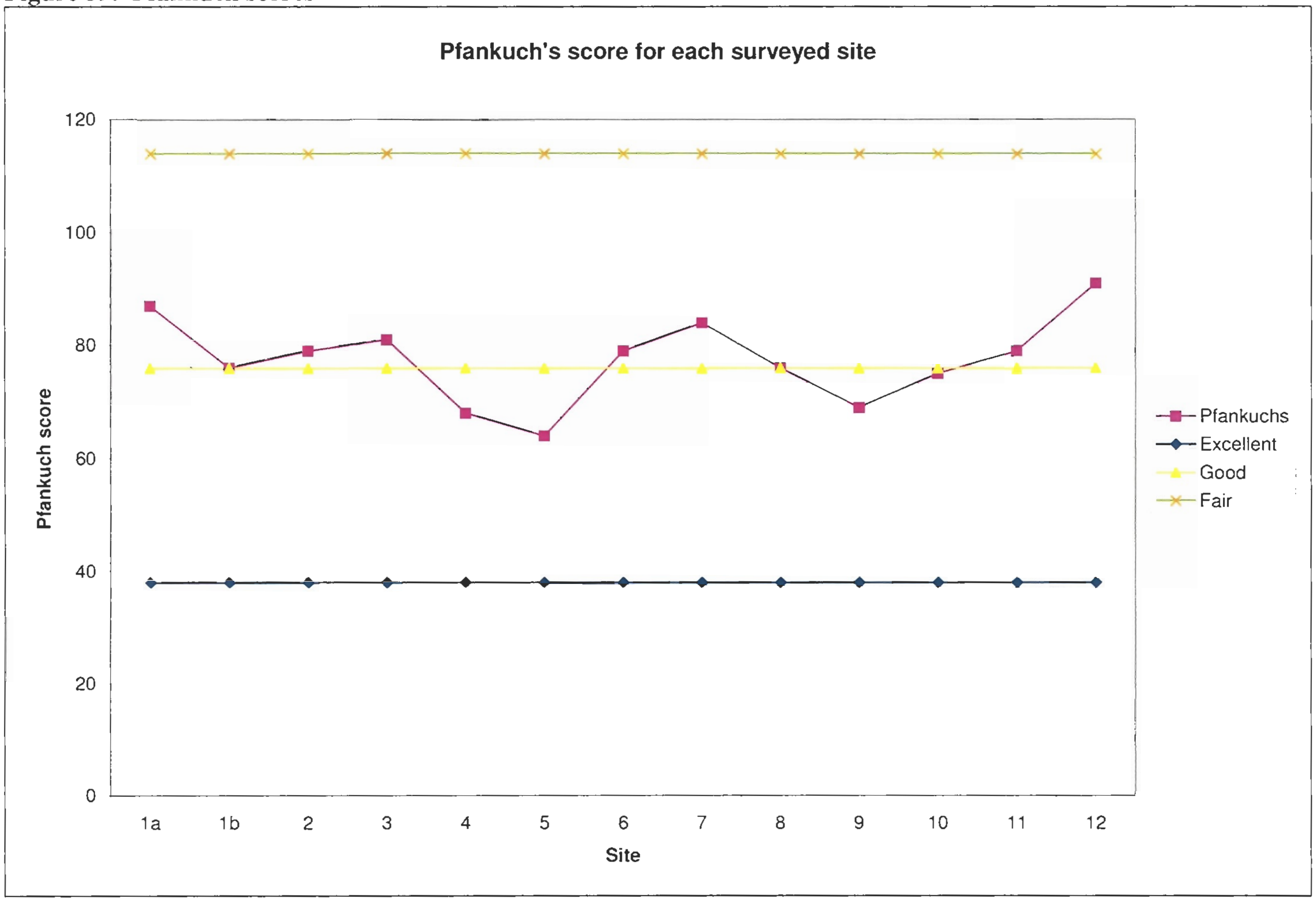
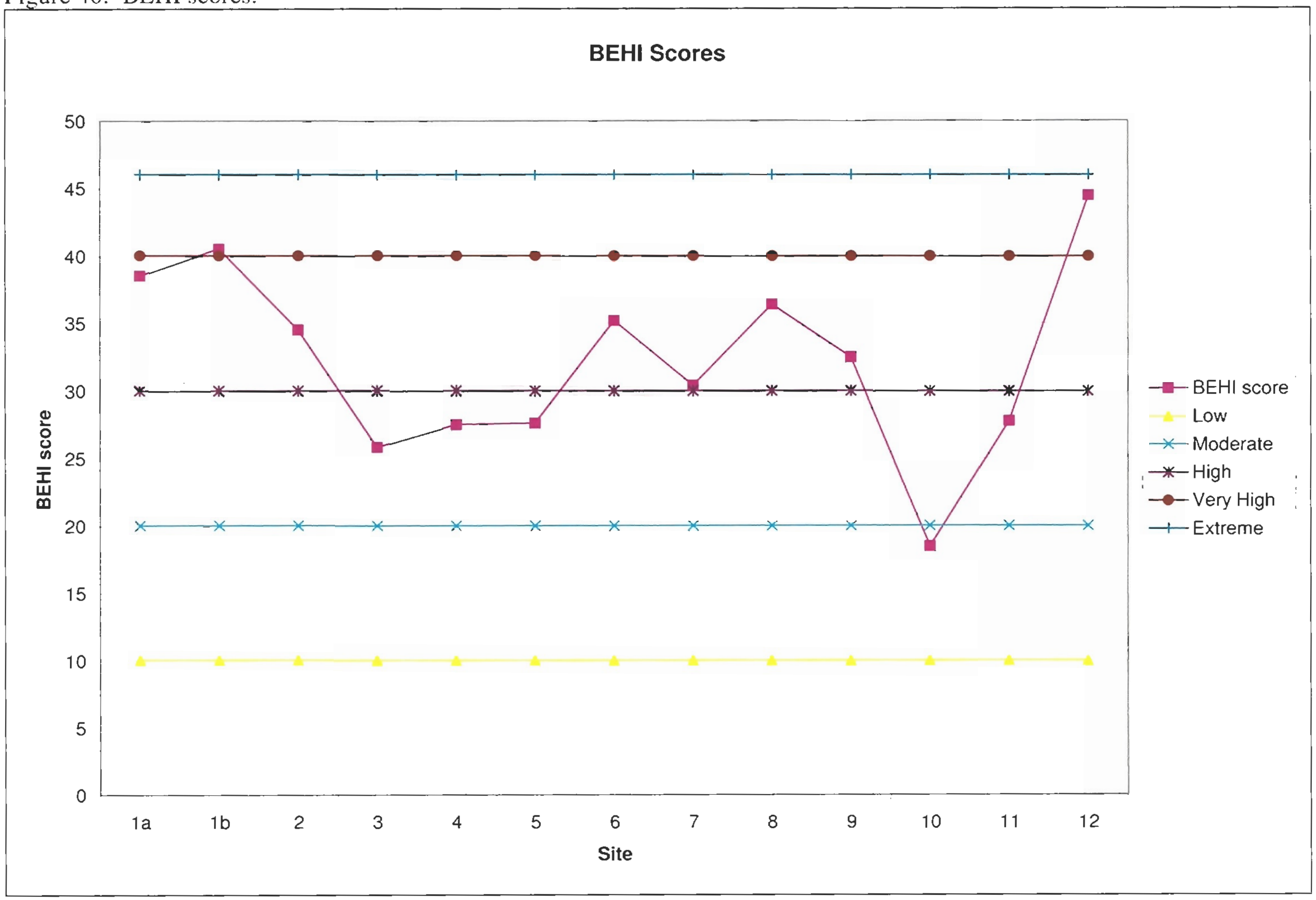


Figure 40. BEHI scores.



PHOTOS

Photo 1-1. Looking upstream at Site 1.

Photo 1-2. Looking downstream toward recent erosion at Site 1.

Photo 1B-1. Looking upstream at Site 1B.

Photo 1B-2. Looking downstream at Site 1B.

Photo 1B-3. Bank erosion, Site 1B.

Photo 1B-4. Bank erosion, Site 1B.

Photo 2-1. Looking downstream at Site 2.

Photo 2-2. Looking upstream at Site 2.

Photo 2-3. Bank erosion at Site 2.

Photo 2-4. Bank erosion at Site 2.

Photo 3-1. Looking upstream at Site 3.

Photo 3-2. Looking downstream at Site 3.

Photo 4-1. Looking upstream at Site 4.

Photo 4-2. Looking downstream at Site 4.

Photo 4-3. Bank erosion at Site 4.

Photo 4-4. Algae growth on sediment at Site 4.

Photo 5-1. Looking upstream at Site 5.

Photo 5-2. Looking downstream at Site 5.

Photo 6-1. Looking upstream at Site 6.

Photo6-2. Looking downstream at Site 6.

Photo 6-3. Bank erosion at Site 6.

Photo 6-4. Fresh deposits at Site 6.

Photo 7-1. Looking upstream at Site 7.

Photo 7-2. Looking downstream at Site 7.

Photo 7-3. Bank erosion at Site 7

Photo 7-4 Bank erosion at Site 7.

Photo 8-1. Looking upstream at Site 8

Photo 8-2. Looking downstream at Site 8

Photo 8-3. Bank erosion, Site 8

Photo 8-4. Poor grazing practices near Site 8.

Photo 9-1. Looking upstream at Site 9.

Photo 9-2. Looking downstream at Site 9.

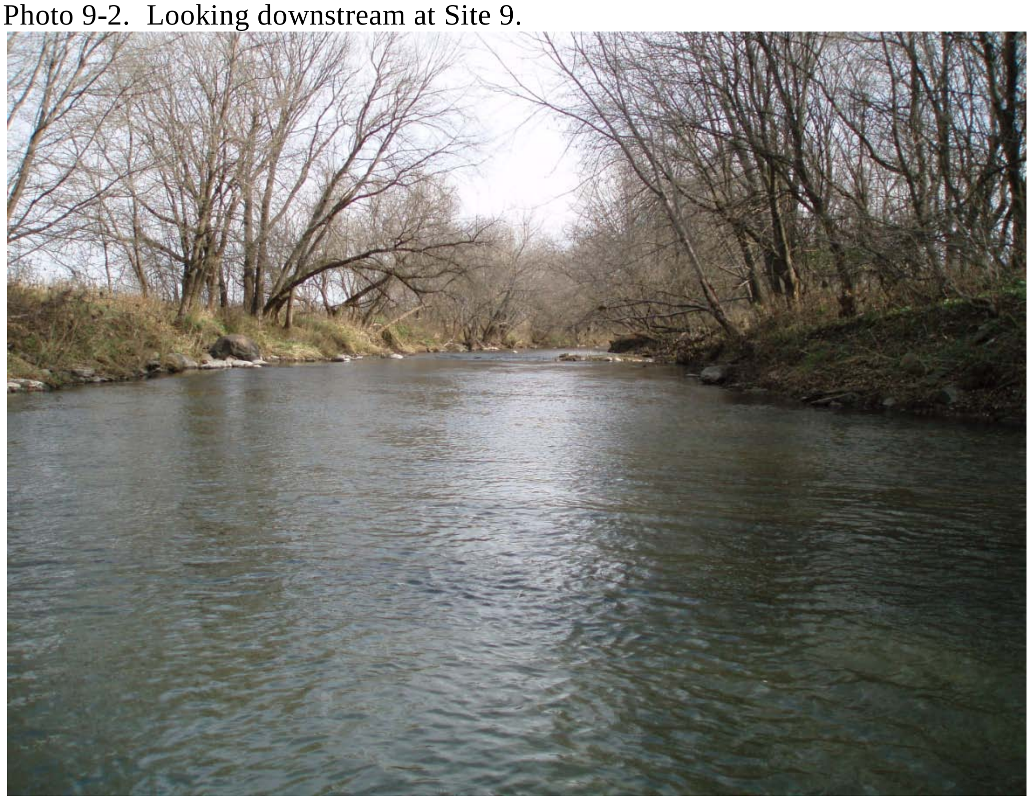


Photo 9-3. Hill erosion adjacent to Site 9.

Site 9-4. Bank erosion at Site 9.

Photo 10-1. Looking upstream at Site 10

Photo 10-2. Looking downstream at Site 10

Photo 11-1. Looking upstream at Site 11.

Photo 11-2. Looking downstream at Site 11.

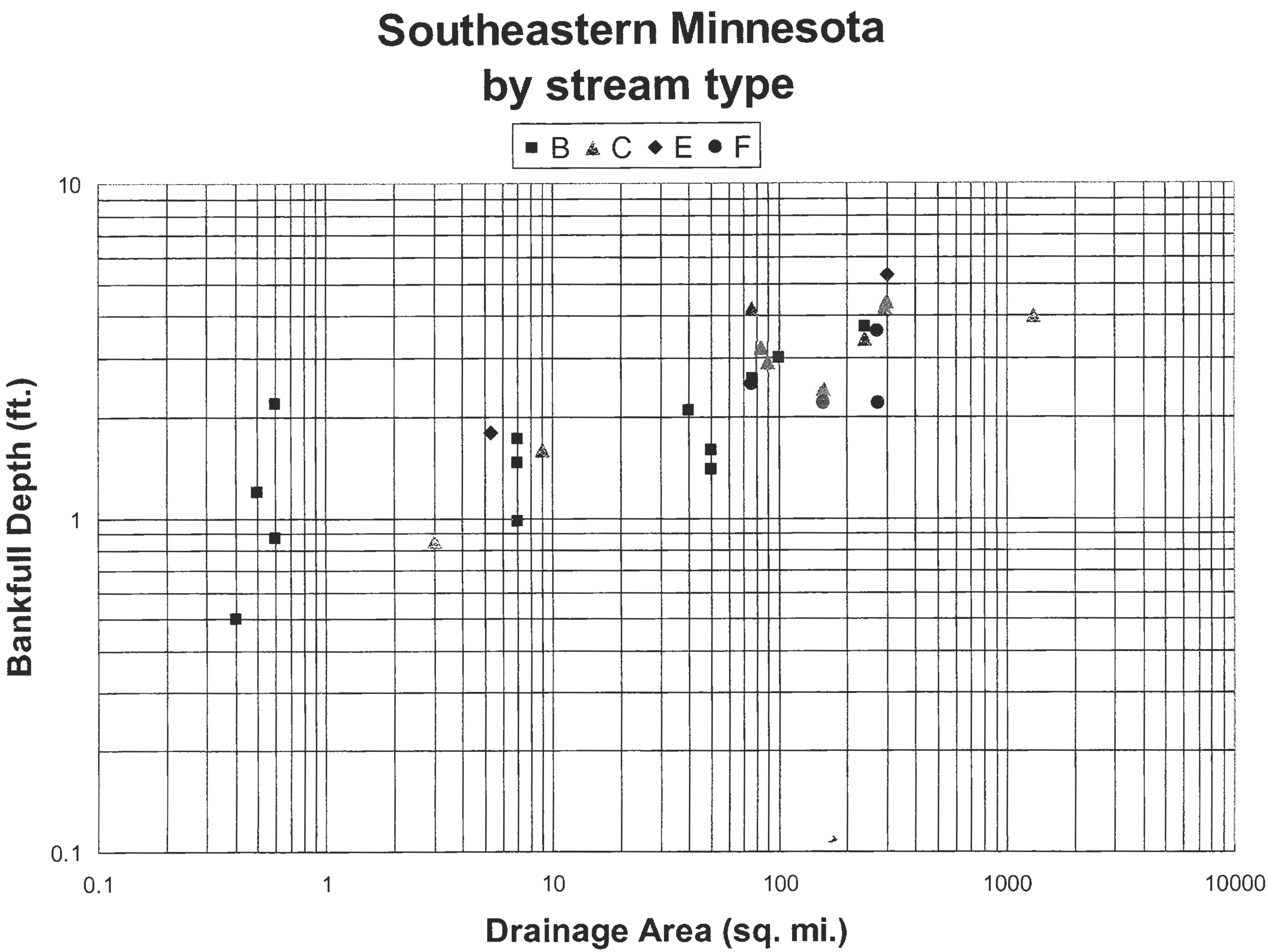
Photo 12-1. Looking upstream at Site 12.

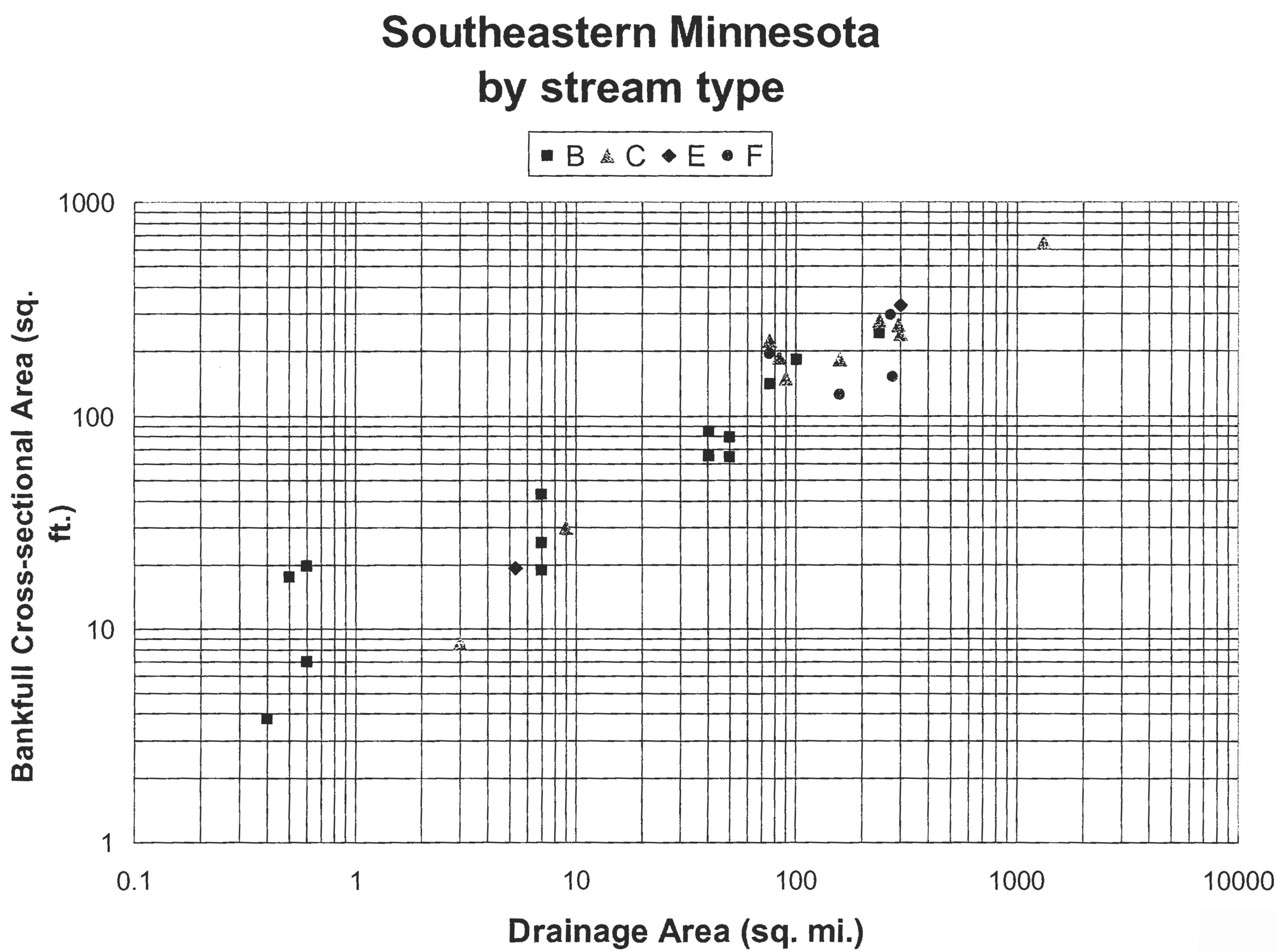
Photo 12-2. Looking downstream at Site 12.

Photo 12-3. Bank erosion at Site 12.

Photo 12-4. Bank erosion at Site 12.

APPENDIX A:
DNR RELATIONSHIPS BETWEEN BANKFULL DIMENSIONS AND WATERSHED AREA


Southeastern Minnesota
by stream type
B C E F
10
1
0.1
0.1
1
10
100
1000
10000
Bankfull Depth (ft.)
Drainage Area (sq. mi.)



Southeastern Minnesota
by stream type
B
C
E
F
Bankfull Cross-sectional Area (sq. ft.)
1000
100
10
1
0.1
1
10
100
1000
10000
Drainage Area (sq. mi.)

APPENDIX B:
PFANKUCH AND BEHI SCORING SHEETS

Worksheet 19. Modified Pfankuch Channel Stability Rating Procedure Summary

Stream: ____________ Reach: ____________ Date: ______ Observers: ____________ Comments: ____________

Location	Key	Category	Excellent Description	Rating	Good Description	Rating	Fair Description	Rating	Poor Description	Rating
Upper Banks	1	Landform Slope	Bank slope gradient <30%.	2	Bank slope gradient 30-40%.	4	Bank slope gradient 40-60%.	6	Bank slope gradient 60%+.	8
	2	Mass Wasting	No evidence of past or future mass wasting.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly year long.	9	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	6	Moderate to heavy amounts, predominantly larger sizes.	8
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep, dense soil binding root mass.	3	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species & less vigor indicating poor, discontinuous, and shallow root mass.	12
Lower Banks	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	1	Adequate. Bank overflows are rare. W/D ratio = 8-15.	2	Barely contains present peaks. Occasional overbank floods. W/D ratio = 15-25.	3	Inadequate. Overbank flows common. W/D ratio > 25.	4
	6	Bank Rock Content	65%+ w/ large angular boulders. 12"+ common.	2	40-65%. Mostly boulders and small cobbles 6-12".	4	20-40%. With most in the 3-6" diameter class.	6	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges, surfaces smooth, flat.	2	Corners and edges well rounded in 2 dimensions.	3	Well rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, ie 35-65% mixture range.	3	Predominantly bright, 65%+, exposed or scoured surfaces.	4
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	4	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom Size Distribution	No size change evident. Stable material 80-100%.	4	Distribution shift light. Stable material 50-80%.	8	Moderate change in sizes. Stable materials 20-50%.	12	Marked distribution change. Stable materials 0-20%.	16
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	6	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30-50% affected. Deposits and scour at obstructions, constrictions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic Vegetation	Abundant growth moss-like, dark green perennial. In swift water, too.	1	Common. Algae forms in low velocity and pool areas. Moss here, too.	2	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perrenial types scarce or absent. Yellow-green, short term bloom may be present.	4
			Excellent Total =		Good Total =		Fair Total =		Poor Total =	

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstable	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+

Stream Type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4	G5	G6
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
Fair (Mod. unstable	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

Grand Total =

Stream Type =

Modified Channel Stability Rating =

Worksheet 21. Summary of bank erosion hazard index (BEHI)

Bank Erosion Hazard Rating Guide

Stream | Reach | Date | Crew

Bank Erosion Potential	Bank Height (ft): / Bankfull Height (ft):		Bank Height/ Bankfull Ht	Root Depth/ Bank Height	Root Density %	Bank Angle (Degrees)	Surface Protection%
	VERY LOW	Value	1.0-1.1	1.0-0.9	100-80	0-20	100-80
		Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	LOW	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55
		Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	MODERATE	Value	1.2-1.5	0.49-0.3	54-30	61-80	54-30
		Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	HIGH	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15
		Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	VERY HIGH	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10
		Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	EXTREME	Value	>2.8	<0.05	<5	>119	<10
		Index	10	10	10	10	10
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	V = value, I = index					**SUB-TOTAL** (Sum one index from each column)	

Bank Material Description:

Bank Materials

- **Bedrock** (Bedrock banks have very low bank erosion potential)
- **Boulders** (Banks composed of boulders have low bank erosion potential)
- **Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)
- **Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt Clay** (+ 0: no adjustment)

BANK MATERIAL ADJUSTMENT

Stratification Comments:

Stratification

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

STRATIFICATION ADJUSTMENT

VERY LOW	LOW	MODERATE	HIGH	VERY HIGH	EXTREME
5-9.5	10-19.5	20-29.5	30-39.5	40-45	46-50

Bank location description (circle one)

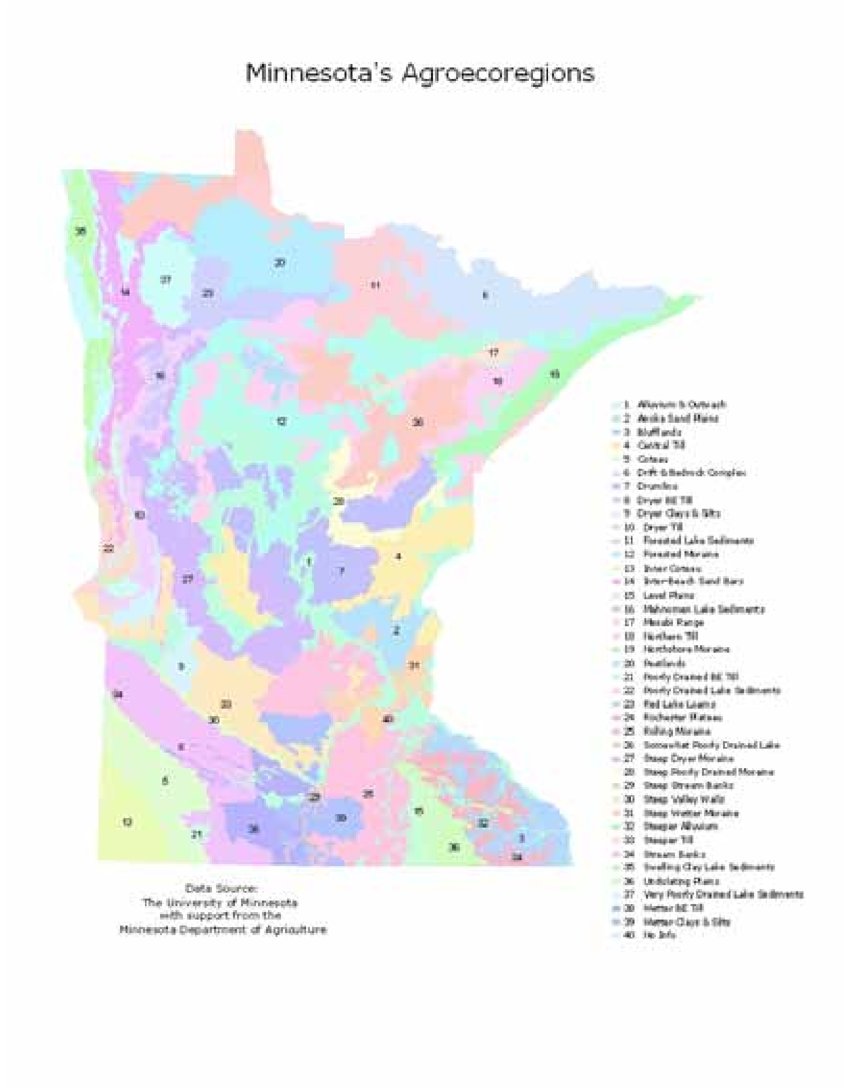
Straight Reach Outside of Bend

GRAND TOTAL
BEHI RATING

Appendix F. Agroecoregion BMP Matrix

The matrix below was developed by David Mulla of the Department of Soil, Water, and Climate of the University of Minnesota and provides Best Management Practice (BMP) options based on agroecoregion. These agroecoregions for Minnesota are shown in the figure to the right. The agroecoregions for the Zumbro River watershed are shown in Figure 1.1.

Ratings in the table that follows are High (H), Medium (M) and Low (L). High means a practice that will be very effective over a large area. Low means a practice that will be very effective, but is suitable only for small portions of the agroecoregion.



NRCS #	Conservation Practices	Alluvium & Outwash	Anoka Sand Plains	Blufflands	Central Till	Coteau	Drumlins	Dryer Blue Earth Till	Dryer Clays & Silts	Dryer Till	Inner Coteau	Inter-Beach Sand Bars	Level Plains	Mahnomen Lake Sediments	Poorly Drained Blue Earth Till	Poorly Drained Lake Sediments	Rochester Plateau	Rolling Moraine	Somewhat Poorly Drained Lake	Steep Dryer Moraine	Steep Stream Banks	Steep Valley Walls	Steep Wetter Moraine	Steeper Alluvium	Steeper Till	Stream Banks	Swelling Clay Lake Sediments	Undulating Plains	Very Poorly Drained Lake Sediments	Wetter Blue Earth Till	Wetter Clays & Silts
	Riparian																														
393	**Grass Filter Strip**[1]	M	L	M-H		M	L	M-H		H	L	M	H	L	L	L	M	H	L	H	H	M	H	H	M	H	M	M	L	H	L
391	**Riparian Forest Buffer**	M	L	M-H		L	L			L		M	M			L	M	L	H	M	M	H	H		L	L		M	L	L	
580	**Streambank & Shoreline Protection**	L		H		H		L-M					L			M	M	M	L	H	H	H	H	M	M	H	M	L	L	M	M
657	**Wetland Restoration**[2] *	L	L				M	H				L	L	L	M	H		L	H	M		M	M		L		M		M	H	M
659	**Wetland Enhancement**						M	H								M			H												M
	Upland																														
328	**Conservation Crop Rotation**[3]	M	L	H		H	M	M	M	H	M	L	M	L	M	M	H	H	L	M	H	M	H	M	L	L		L	M	L	L
329	**Conservation Tillage**[4]	M	L	H		H	M	H	M	M	M	M	M	L	M		H	H	L	H	H	L	H	M	H	H		M		H	M
	Primary Crop																										L		L		
	Secondary Crop																										M		M		
332	**Contour Buffer Strip**					H				M	L		M				M	M		H			L					M		L	
330	**Contour Farming**		L	H		H	M	L		H	M		M				H	**H**	**L**	**H**			**H**	**M**	**L**			**M**		**M**	
340	**Cover Crop**	M	M	L		L		L-M			M											L	L		L			L		L	L
342	**Critical Area Planting**	M	M	L		L		L				M			L		L	M		M	H	H	M	H	L	H		L		M	
643	**Declining Habitat Restoration & Mgt**[5] *							M-H			M			L	M	L			H	M		M					M		M		L
362	**Diversion**					H											M	L			M									M	

NRCS #	Conservation Practices	Alluvium & Outwash	Anoka Sand Plains	Blufflands	Central Till	Coteau	Drumlins	Dryer Blue Earth Till	Dryer Clays & Silts	Dryer Till	Inner Coteau	Inter-Beach Sand Bars	Level Plains	Mahnomen Lake Sediments	Poorly Drained Blue Earth Till	Poorly Drained Lake Sediments	Rochester Plateau	Rolling Moraine	Somewhat Poorly Drained Lake	Steep Dryer Moraine	Steep Stream Banks	Steep Valley Walls	Steep Wetter Moraine	Steeper Alluvium	Steeper Till	Stream Banks	Swelling Clay Lake Sediments	Undulating Plains	Very Poorly Drained Lake Sediments	Wetter Blue Earth Till	Wetter Clays & Silts
554	Drainage Water Mgnt[6]							M-H					M	M	M-H	H		M	M						M		H	L	M	M	H
	Field Border																														L
655	Forest Harvest Trails & Landings						M												H	M									M		
666	Forest Stand Improvement						M												H	M									M		
	Gully Erosion	L		H		H		L									H	H		M	H	H	M		M	M		L		M	L
410	Grade Stabilization			H		H											H					M	M		L			L		M	L
412	Grass Waterway			M		H		L		M	M						H	M		M	H		M		L			L		M	L
600	Terrace			M		H				L	M						H	M					L		L			M		L	
638	Water and Sediment Control Basin			H		H		L		L							H	H		M	H		H		M			L		M	L
	Grass Cover (CRP only) [7]*	M	L	H		H	L	L		H	L	M					H	H		H	M	H	H	L	M	M	M	L	L	H	L
512	Pasture & Hayland Planting	M	M	H		H	H	L-M		M	M						H	H	M	H			M		L	M		L		L	L
528A	Prescribed Grazing	M	L	M-H		H	H	L-M			L						M	M	M	M			M		L	M		L		L	L
350	Sediment Basin	M	L	M		M	L	L									M	H		M	H		H		M			L		M	
725	Sinkhole Treatment[8]			M													H											L			
585	Stripcropping[9]			H		M					M		M				H			M								L		L	
612	Tree/Shrub Planting *						M									L			M	M		M	M	L		M			M		
472/382	Use Exclusion / Fencing	M	L	L		H	H	L			H		L				M	L	M	M		L	M		L	H		M	M	L	
645	Upland Wildlife Habitat Management[10]*			M		M		M-H		H	M				M	L	M		M	M		M	L				L		M		L
658	Wetland Creation							H								L			H												
657	Wetland Restoration[11]	L	L				M	H				L	M	M	M	H		L	H	M		L	M		L		M	L	H	M	H
	Wind Erosion																														

NRCS #	Conservation Practices	Alluvium & Outwash	Anoka Sand Plains	Blufflands	Central Till	Coteau	Drumlins	Dryer Blue Earth Till	Dryer Clays & Silts	Dryer Till	Inner Coteau	Inter-Beach Sand Bars	Level Plains	Mahnomen Lake Sediments	Poorly Drained Blue Earth Till	Poorly Drained Lake Sediments	Rochester Plateau	Rolling Moraine	Somewhat Poorly Drained Lake	Steep Dryer Moraine	Steep Stream Banks	Steep Valley Walls	Steep Wetter Moraine	Steeper Alluvium	Steeper Till	Stream Banks	Swelling Clay Lake Sediments	Undulating Plains	Very Poorly Drained Lake Sediments	Wetter Blue Earth Till	Wetter Clays & Silts
589	**Cross-Wind Ridges / X-Wind Stripcropping / X-Wind Trap Strips**	L	M					M	H	L		H		M	L-M	M			M	L							H		M		
422	**Hedgerow/ Herbaceous Wind Barrier**	L	M						H	L		H		M	L-M	M			M	L							H		M		
380/ 650	**Windbreak / Shelterbelt / Living Snow Fence** *	L	M						H	L		H		M	L-M	M			M	L							H		M		

* A common CRP cover type in Minnesota

[1] Effectiveness depends on complementary upland practices (which may be true for several other practices in this table as well)

[2] In riparian zones, this means floodplain wetlands

[3] Refers to the addition of at least a third crop—one that is resource-conserving and regionally appropriate—to an existing 2-crop rotation.

[4] Refers to NRCS Standards 329A-329C (Residue Management) which encompass No-Till, Strip-Till, Mulch-Till and Ridge-Till

[5] When the habitat being restored is native prairie, this is effectively an enhanced version of a typical CRP grass stand.

[6] Refers to a range of "conservation drainage" practices, some currently in Mn-NRCS Standard 554 Drainage Water Management and many not; examples include blind inlets, rock inlets, and tile spacing and depth.

[7] Some CRP grass stands are planted with special attention to use of native species, while others are not (need to specify if there is a significant difference in terms of water quality).

[8] Treatment is typically with filter strips and/or diversions

[9] Includes contour stripcropping as well as stripcropping on flatter land

[10] In the Northern Tallgrass Prairie region, this often consists of grassland restoration

11 In uplands (esp. in the Northern Tallgrass Prairie region), depressional "prairie potholes" are often the type of wetlands being restored

Zumbro River watershed 303(d) impairments and agroecoregions.