Submersed Aquatic Vegetation Targets for the Turbidity-Impaired Reach of the Upper Mississippi River Pool 2 to Upper Lake Pepin

**Prepared for the Minnesota Pollution Control Agency
Pool 2 - Lake Pepin Turbidity TMDL Project**

by

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Introduction

The Minnesota Pollution Control Agency (MPCA) has identified the Mississippi River reach extending from the mouth of the Minnesota River to Lake Pepin as exceeding the state turbidity criterion for fish and aquatic life (MPCA 2008). Similarly, the Wisconsin Department of Natural Resources (WDNR) has identified the river reach from the mouth of the St. Croix to upper Lake Pepin as having excessive suspended sediment that is negatively influencing submersed aquatic vegetation (SAV) growth as well as contributing to high rates of sedimentation in Lake Pepin (WDNR 2006). The MPCA is working with numerous organizations and the WDNR to develop and implement watershed total maximum daily loads (TMDLs) to address excess turbidity as well as nutrient inputs to achieve state water quality standards in the impaired reach of the Upper Mississippi River (UMR). Information on this TMDL study can be found at the following MPCA web site: http://www.pca.state.mn.us/water/tmdl/tmdl-lakepepin.html.

Although Minnesota has a numeric criterion of 25 nephelometric turbidity units (NTU) in state water quality standards, there are no specific criteria for suspended sediment or total suspended solids (TSS). Correlation analysis between TSS and turbidity provides a means of establishing a surrogate TSS concentration that is consistent with Minnesota's turbidity criterion and provides a basis for developing watershed goals for sources of sediment input. Initial evaluations by MPCA for monitoring sites along the Minnesota River, the major source of sediment input to the Mississippi River above Lake Pepin, suggests a TSS surrogate concentration of about 100 mg/L would be roughly equivalent to the state turbidity criterion (Campbell et al. 2008). An evaluation of long term data collected by the Metropolitan Council of Environmental Services (MCES) for the Mississippi River during the summer months at Lock and Dam 3 suggests a TSS–turbidity surrogate concentration of 64 mg/L (Figure 1). These surrogate TSS concentrations may not offer adequate protection for the growth and development of SAV based on a comparison to recently proposed light penetration-related water quality criteria for SAV in the Upper Mississippi River by the Upper Mississippi River Conservation Committee (UMRCC 2003, Table 1).

Aquatic vegetation is an important component of the UMR pools and strongly influences fish and aquatic life habitat as well as providing food for waterfowl (Janecek 1988, Korschgen 1988, Johnson and Jennings 1998, Rybicki and Landwehr 2007, Knights et al. 2008). SAV is a particularly useful biological indicator to gage the impacts of turbidity or TSS since it is sensitive to changes in light availability and is negatively impacted by conditions of high turbidity or low transparency (Jackson and Starret 1959, Chambers and Kalff 1985). Further, SAV has been used to assess water quality conditions and define restoration goals (Dennison et al. 1993, Chesapeake Bay Program 2000) because it is an important ecological indicator of ecosystem health in freshwater aquatic systems.

Since the WDNR's impaired waters listing has indicated excessive sediment or turbidity is negatively influencing SAV growth in border waters of the Mississippi River in Pool 3 and upper Pool 4 and there is uncertainty whether Minnesota's turbidity criterion will adequately protect SAV in the turbidity-impaired reach of the UMR (Pool 2 to Upper Lake Pepin), site-specific water quality criteria as well as river management and restoration activities need to be considered to protect and promote SAV growth in this reach of river. In order to advance and support new water quality criteria development, a review of existing SAV information from the UMR system was conducted as a means of identifying an appropriate SAV target for this turbidity-impaired reach of the UMR. This report provides a summary of SAV information on the UMR, identifies a SAV target, an initial criterion for TSS, and suggested methods for evaluating attainment of these water quality goals.

Methods

SAV frequency of occurrence data from the UMR system was compiled from two sources. The first was the Long Term Resource Monitoring Program (LTRMP) surveys in selected pools of the UMR system available from USGS Upper Midwest Environmental Sciences Center at La Crosse, Wisconsin (http://www.umesc.usgs.gov/data_library/vegetation/graphical/veg_front.html). Their data represented randomly collected samples from major aquatic areas or "strata" including main channel border (MCB), side channel (SC), contiguous backwater, isolated backwater and impounded (open areas above dams) during mid-summer periods of 1998 to 2007. Most of LTRMP's SAV data was collected from specific study pools on the UMR (Pool 4, 8,13 and 26) and the La Grange Pool on the Illinois River (Yin and Langrehr 2005). Additional data were available from LTRMP-sponsored surveys in a few other UMR pools (5, 7, & 11 in 2002 and 12 in 2001).

The second source of SAV information was obtained from WDNR's and MNDNR's aquatic vegetation surveys of Pools 1 to 11 funded by USEPA as part of a pilot monitoring project following Environmental Mapping and Assessment Program (EMAP) guidance (US EPA 2008). The EMAP sampling also collected random samples but the surveys were conducted over longer assessment reaches that encompassed multiple pools and concentrated on sampling the main channel and side channel borders or off-channel impounded or backwater areas that were adjacent to these channels. The actual sampling by both methods were identical and utilized multiple rake samples and visual observations around the perimeter of an anchored boat (Yin and Langrehr 2005). A summary of the LTRMP and EMAP vegetation sampling designs is presented in Table 2. The SAV information described here focused on frequency of occurrence data of all recorded species.

Water quality data (TSS) from main channel of the Mississippi River were obtained from a multi-agency database compiled for the UMR (UMRCC, 2002) or

directly from private, state and federal agencies that maintain monitoring stations on the UMR.

Results

Spatial Distribution of SAV

LTRMP SAV frequency collected during the initial stratified random sampling (SRS) in key (primary) study pools of the UMR system between 1998 to 2003 revealed notable differences between pools as well as between aquatic areas (Figure 2). The frequency of occurrence of SAV in LTRMP key study pools was highest in lower Pool 4, Pool 8 and Pool 13. SAV was rarely recorded in backwater and impounded strata of Pool 26 and was not recorded at all in the aquatic strata sampled in the La Grange Pool in the lower Illinois River. In general, a gradient in the frequency of SAV exists in each study pool with highest occurrence in isolated backwaters followed by contiguous backwaters, side channels and main channel border with decreasing occurrence in each of these strata (Yin and Langrehr 2005). These authors indicated primary factors influencing this distribution included water clarity, current velocity, water depth and wind fetch. In addition, tailwater areas generally had little SAV due to deep fluctuating water levels with high current velocity. Yin and Langrehr also reported that more than 80% of the variance in SAV frequency of occurrence in study pools could be explained by turbidity and water level fluctuation but these factors explained little of year-to-year variation (Figure 3). Of these two variables, turbidity was believed to be a stronger factor influencing SAV frequency between study pools.

Spatial differences in turbidity and water level fluctuation were likely important factors influencing SAV frequency in upper and lower Pool 4 (Figure 2). Water transparency is substantially greater below Lake Pepin due to settling of suspended solids within the lake and water level fluctuations are less in the lower portion of Pool 4, which is closer to the pool's regulatory dam. This longitudinal change in SAV within a navigational pool has also been found in Pool 8 and 13 (Langrehr and Moore 2008). These longitudinal changes in SAV occurrence within a pool need to be considered when setting goals for turbidity abatement or in-river restoration activities and would be particularly important when evaluating the potential for SAV growth in tailwater areas where seasonal water level changes can be quite high.

Temporal Changes in SAV

The frequency of occurrence of LTRMP stratified random sampling SAV data was compiled for a 10-year period (1998 to 2007) for LTRMP study Pools 4 (upper and lower), 8 and 13 (Figure 4). The data were grouped by the commonly sampled strata (MCB, SC and contiguous backwater or "backwater") for each of these study areas. Isolated backwaters and impounded strata were not included since these aquatic areas were not sampled in each study pool. Data for Pool 26

and the La Grange Pool on the Illinois River were also not considered due to the absence or low occurrence of SAV in these pools.

In general, temporal differences between years within a given sampling strata were moderate with no clear pattern of increasing or decreasing trends over the 10-year period within the MCB or SC sampling strata. The occurrence of SAV in upper Pool 4 was quite variable in the two channel strata and was absent in some years. In contrast, SAV was found in all backwater strata from each of the study areas during the 10-year period. There did appear to be a general increase in SAV frequency in the backwater strata of Pool 13 over the 10-year period (Figure 4).

The frequency of SAV occurrence in Pools 4 (excluding upper Pool 4 above Lake Pepin), 8 and 13 averaged 70.8, 28.5 and 18.0 % in the backwater, SC and MCB strata, respectively, over the 10-year period (Figure 4). These differences in SAV frequency within these strata were generally consistent with the previous assessment for the initial LTRMP record for years 1998 to 2003 (Figure 2). The average frequency of occurrence for these three sampling strata provide an initial benchmark for establishing SAV targets for the turbidity impaired reach of Pool 2 to Lake Pepin assuming equivalent turbidity, depth, water level fluctuation, wind fetch and other factors can be attained or provided through reductions of suspended solids input and using in-river habitat restoration projects where feasible.

SAV Correlations Between Aquatic Areas

Regression analysis of SAV frequency of occurrence of all LTRMP SAV data, grouped by study pool, revealed significant correlations between MCB, SC and backwater sampling strata (Figures 5A-C). Linear regression models using the frequency of SAV occurrence in MCB as the independent variable explained roughly 60% of the variation of SAV frequency in SC or backwater strata. The regression of backwater versus SC SAV frequency revealed a substantially greater correlation (r^2=90%) using a polynomial model. A closer inspection of the latter model indicated that very little gain in backwater SAV frequency occurs once SC SAV frequency reaches 20%. These correlations suggests that if a SAV frequency target was selected for a particular aquatic area (i.e. main channel border) then estimates of the corresponding SAV frequency of occurrence can be made on the other two aquatic areas (SC or backwater).

SAV Frequency of Occurrence in Pools 1 to 11

In the summer of 2006 to 2008, the MDNR and WDNR conducted systemic SAV sampling over a 270 mile reach of the Mississippi extending from Minneapolis, MN (Pool 1) to Dubuque, IA (Pool 11). The sampling design followed a probabilistic approach consistent with USEPA EMAP procedures (Diaz-Ramos et al. 1996). The assessment units were divided into 7 hydrologic assessment

reaches that were segmented by major tributary inflows including the Minnesota, St. Croix, Chippewa, Black, Root and Wisconsin Rivers. The sampling design did not utilize the same aquatic strata utilized by the LTRMP vegetation component. Instead, this reach-based sampling concentrated on main channel and side channel borders and off-channel impounded or backwater areas that were adjacent to these channels. In addition, the EMAP design sampled shallower water and a smaller depth range than the LTRMP method, 0.2 to 2.0 m versus 0 to 2.5 m, respectively (Table 2).

The results of the EMAP surveys revealed a substantial difference in the frequency of occurrence of SAV above and below the Chippewa River (Figure 6). SAV frequency of occurrence was less than 16% in the three assessment reaches above the Chippewa River during each of the three monitoring years. In contrast, SAV occurrence averaged about 44% in the four assessment reaches below the Chippewa River during a similar period. The lowest occurrence of SAV occurred in the Twin Cities reach, which encompasses all of Pool 1 and a short 3.5-mile tailwater reach of Pool 2 above the Minnesota River. This river reach is believed to offer habitat conditions that are less conducive to SAV growth due to a narrow deep flowing channel with generally coarse substrate. Targets for SAV growth should exclude the Twin Cities reach due to natural or anthropogenic factors (impoundment) that limit its development in this reach of river. In addition, the river reach within the St. Paul Area of Pool 2 is heavily influenced by shoreline riprap, barge fleeting and marine terminals and SAV development within the channel border of this corridor would likely be unattainable due to these irreversible cultural changes. As a result, SAV targets applicable for the Twin Cities-a reach (Minnesota River to St. Croix River) should apply below these major urban influences.

Comparison of LTRMP vs EMAP SAV Surveys

The SAV sampling design for LTRMP and EMAP are based on different approaches and present some challenges when trying to compare these surveys. As discussed previously, the LTRMP design is aquatic area (strata) based within a given navigation pool. EMAP is a reach-based design that focused on collecting samples within or near the MCB and SC borders or areas adjacent to these channels. In addition as noted above, the sampling depth between the two surveys were slightly different (Table 2). These factors need to be considered when making comparisons between the sampling designs.

It was possible to provide a general comparison of the LTRMP and EMAP designs by evaluating the SAV sampling results for lower Pool 4 and Pool 8 where both methods were used during years 2006 to 2008 (Figure 7). The results of this evaluation indicate that the EMAP data were generally similar to the combined MCB and SC strata of the LTRMP design. The only major deviation occurred in Pool 8 in 2008 where the difference in SAV frequency of occurrence between designs exceeded 20%. Main channel border SAV data

collected using LTRMP methods were always less than EMAP results, but the general temporal changes by both methods were similar within each pool. The ratio of SAV percent frequency of occurrence of EMAP to LTRMP MCB averaged 1.75 when all data were combined. A similar ratio of EMAP to LTRMP MCB+SC SAV frequency averaged 0.82. These ratios provide an approximate method for comparing the two different SAV monitoring designs. However, the use of the ratios needed to be treated with some caution due to limited amount of data available to make these comparisons.

SAV Frequency of Occurrence versus Total Suspended Solids

The average frequency of occurrence of SAV measured by LTRMP in the MCB in pools of UMR system were compared to the average summer (June-September) TSS concentrations in the respective pools during years when the SAV surveys were completed (Figure 8). Although there is appreciable scatter in the relationship, some obvious patterns are apparent. Highest SAV frequency occurred in the UMR pools where the average summer TSS concentration was less than 30 mg/L. These results are generally consistent with the revised UMRCC light-related water quality criteria (Table 1), which suggests a summer (May 15 – Sept 15) average TSS criterion $\leq$ 30 mg/L. A threshold is apparent at summer average TSS concentrations exceeding 60 mg/L where SAV was absent at levels exceeding this value. SAV was not found in the MCBs of Pool 26 and the La Grange Pool of the Illinois River, which exhibited average summer TSS concentrations ranging from 75 to 135 mg/L. It is suspected that these high TSS concentrations would severely limit light penetration or provide substantial particulate material that could settle on SAV plant tissues resulting in severe light limitation. Long term summer average (June-Sept, 1978-08) TSS concentration at Locks and Dams 2 and 3 (combined data) was 47 mg/L (Table 3), which was above the revised UMRCC criterion but below the acute threshold.

Regression analysis indicated the SAV x TSS relationship fit a polynomial model the best (highest r^2) and yielded a significant correlation (r^2=0.63, Figure 8). This model provides an estimate of the expected SAV response in the MCB at varying average summer TSS concentrations. Using the revised UMRCC light penetration-related TSS criterion of 30 mg/L yields an estimated SAV frequency of occurrence of about 13% for the MCB. The model can also be used in a reverse direction to establish an average TSS target concentration for the main channel as a function of the desired levels of SAV in the MCB.

SAV Target for the Turbidity Impaired Reach of Pool 2 to Lake Pepin

It is difficult to define a clear biological basis for the minimum SAV target for the turbidity impaired reach of river above Lake Pepin. We believe the vegetation target should be better than existing conditions and achieve a state that is ecologically desirable and socially acceptable. Recent EMAP vegetation surveys conducted in the turbidity impaired reach of the river above Lake Pepin during

the summers of 2006-08 indicated an average SAV frequency of occurrence of 13%. However, these surveys were conducted during a period of reduced river flows, which contributed to lower summer average TSS concentrations (35 mg/L at Locks and Dams 2 and 3) and didn't provide an accurate assessment of the status of SAV during periods of more typical flows and TSS concentrations. The predicted SAV frequency of occurrence for a longer period of record (1976-08) was only 9% for an EMAP-based sampling design due to substantially greater average summer TSS concentrations (47 mg/L, Table 3).

We evaluated four different approaches for establishing a SAV target. These included SAV targets derived from EMAP-based sampling of a reference reach, LTRMP-based MCB sampling of a reference reach, historic conditions and extrapolation from light penetration-related criteria proposed by the UMRCC. Where applicable, the frequency of occurrence of SAV for EMAP and LTRMP MCB sampling designs was derived and the corresponding TSS concentration estimated based on the SAV versus TSS relationship described previously and illustrated in Figure 8.

EMAP-Based Reference Reach

EMAP SAV sampling of the river reach extending from the Chippewa River to Lock and Dam 11 was considered to represent a desirable reference since this area is not considered to be impaired by turbidity or TSS and was judged to provide healthy and desirable SAV plant communities. EMAP-based SAV sampling of this reach of river during the summers of 2006-08 yielded an average SAV frequency of occurrence of approximately 44% (Figure 6). It was believed that achieving a SAV frequency of occurrence of at least half this value (22%) would be a reasonable target for the turbidity-impaired reach above Lake Pepin. This EMAP-based SAV criterion would yield an estimated LTRMP SAV frequency of occurrence of ~13% for the MCB and corresponded to an average summer TSS target concentration of 28 mg/L (Table 3).

LTRMP-Based Reference Reach

Pool 13 is the southern-most Mississippi River navigation pool currently sampled for aquatic vegetation by LTRMP. Although SAV is found below Pool 13 in the Mississippi River, its distribution and abundance is generally lower below this pool (Johnson and Hagerty 2008). It is believed that Pool 13 provides SAV conditions that are desirable and provide a reasonable target for the turbidity-impaired reach of the River above Lake Pepin. SAV is common in Pool 13 and neither the bordering states of Illinois nor Iowa consider the waters of this pool to be impaired by turbidity or TSS. The average SAV frequency of occurrence for the MCB of Pool 13 was 13% based on LTRMP sampling during 1998 to 2007. An equivalent EMAP-based SAV target would be ~23% (Table 3). The average summer TSS concentration in the main channel of Pool 13 was 31 mg/L during this 11 year period based on LTRMP data.

Historic Conditions

Black and white photographs of upper Lake Pepin to Red Wing, Minnesota on July 25 of 1951 indicated substantial beds of aquatic vegetation in littoral areas of Lake Pepin, side channels and backwater areas. In addition, notable beds of SAV were visible in these photos. An example photograph of upper Lake Pepin is provided in Figure 9. These photographs provide a relevant reference to establish SAV and TSS targets since they reflect a desirable historic condition within the turbidity impaired study reach. Although we were unable to establish the actual SAV frequency of occurrence in these photos, we were able to derive historic TSS concentrations from Lake Pepin sedimentation rate measurements (Engstrom et al. 2009) and historical turbidity measurements at Red Wing, Minnesota by early Sanitary District Surveys available from the Metropolitan Council Environmental Services.

Core-derived estimates of TSS concentrations were based on the ratio of whole-lake sedimentation rate measurements for Lake Pepin versus annual average TSS concentrations at Lock and Dam 3 for a similar time intervals (1980-1990 and 1990-1996). Dividing sedimentation rates by this ratio yielded annual average TSS estimates for earlier coring intervals (1900-1975, Figure 10). This analysis indicated decadal annual average TSS concentrations of approximately 22 mg/L at Lock and Dam 3 for the 1950s. A corresponding decadal estimate of summer average TSS for this period was 34 mg/L based on a contemporary ratio of summer (June-September) versus annual average TSS at Lock and Dam 3.

Earliest TSS concentration estimates of the Mississippi River near Red Wing were derived from transparency measurements made in September 1921 by Galtsoff (1924). Galtsoff reported a transparency of about 80 cm in the river above Lake Pepin. This transparency corresponds with an estimated TSS concentration of approximately 16 mg/L based on a regression of TSS versus Secchi depth (r^2 = 0.575) of data collected by LTRMP in Pool 8 and 13 (Giblin et al. in prep). A similar analysis of Secchi depth and TSS data collected in the river above Lake Pepin revealed a similar TSS value of 13 mg/L (Rob Burdis, MDNR, personal communications). These TSS values compare favorably with sedimentation-based summer average TSS estimate for the 1910-1930 sediment dating interval (plotting point 1920, Figure 10).

Early Whipple-Jackson turbidity measurements of the Mississippi River at Red Wing by Sanitary District Surveys (Minneapolis-St. Paul) provided a more direct estimate of TSS concentrations that may be related to historical SAV conditions. Turbidity measurements were routinely collected during longitudinal sampling of the Mississippi River from Minneapolis to Wabasha, Minnesota (below Lake Pepin). Two to three surveys per month were typically collected during ice-free periods with fewer surveys during winter conditions (Cathy Larson, personal communications). TSS measurements were occasionally made during these surveys and provided a means for deriving turbidity-based estimates of TSS

concentrations through regression analysis. The turbidity units are based on silica scale in parts per million. Larson derived the following regression equation based on the available TSS and turbidity measurements during the 1935-36 period:

$$\text{TSS mg/L} = 0.794 \text{ (Turbidity) } -0.112, \quad r^2 = 0.905.$$

This equation was used to derive estimates of annual and summer average TSS concentrations for 1949-1951 as another means to verify the sedimentation-based TSS measurements described above (Figure 10). The turbidity-based estimates of TSS were found to be comparable to those derived from sedimentation rates and yielded summer and annual average TSS concentrations of 21 and 30 mg/L, respectively for this 3 year period. For 1951, the year of the reference photo (Figure 9), the summer average TSS was 38 mg/L. This value was used as a potential target (Table 3) since it provided an estimate of summer TSS concentrations present during 1951. However, it should be recognized that the summer averaging period in 1951 (June-September) would have represented TSS conditions occurring before and after this photo was taken. The estimated summer average TSS in 1950 was 21 mg/L, which likely benefited SAV growth observed in the 1951 through the production of SAV propagules during the previous year's growth period. Therefore the actual TSS levels associated with the SAV depicted in the July 1951 photo may have reflected average summer concentrations ranging from between 21 and 38 mg/L.

The selection of the early 1950s as a desirable reference for TSS also provides a target for sedimentation reductions in Lake Pepin. Excessive sedimentation rates along with reduced SAV growth provided the primary basis for identifying sediment impairment in this river reach by Wisconsin (WDNR 2006). Average decadal estimates of whole-lake sedimentation in Lake Pepin during the 1940s and 1950s was approximately 540,000 MT/year and are about 40% lower than rates measured during the early to mid-1990s (Engstrom et al. 2009).

UMRCC TSS Criterion

The UMRCC proposed light-related water quality criteria to protect and enhance SAV in the Upper Mississippi River (UMRCC 2003). Although this group provided criteria for summer average light extinction, transparency, TSS and turbidity, a specific frequency of occurrence target for SAV was not provided. The primary light criteria was based on achieving a summer average light extinction coefficient of 3.42 m^{-1}. The corresponding TSS criteria associated with this light extinction coefficient was initially estimated to be 25 mg/L. However, subsequent analysis by a study carried out by LTRMP in pools 8 and 13 indicated the TSS criterion was closer to 30 mg/L (Giblin et al., in prep). This modified TSS value, in conjunction with the SAV versus TSS relationships described previously (Figure 8), was used to estimate a SAV frequency targets for the turbidity impairment following EMAP or LTRMP MCB sampling. The

corresponding SAV frequency estimates yielded values of 21% and 12%, respectively, for these sampling methods (Table 3).

Recommended SAV Target and Associated TSS Criterion

We suggest the SAV target for the turbidity impaired reach of Pool 2 to Lake Pepin be based on the average of the four targeting approaches described above and summarized in Table 3. This yields an average SAV frequency of occurrence of approximately 21% following an EMAP-based sampling design for main channel and side channel borders or about 12% using a LTRMP sampling design for the MCB. These SAV targets are roughly two times existing conditions based on long term historical estimates (1976-2008) from TSS-dervied SAV frequencies. To evaluate attainment of these SAV targets, it is recommended that the initial monitoring frequency be based on a minimum of at least 3 annual EMAP-based surveys over a 5 year period. To simplify the SAV monitoring design and to make it consistent with the recommended TSS monitoring described below, we suggest the attainment of the SAV target be evaluated by focusing on the river reach extending from Lock and Dam 2 to the Rush River in upper Lake Pepin. Once the target has been consistently achieved, then a re-evaluation of the monitoring frequency can be made.

Achieving the EMAP and MCB LTRMP SAV frequencies can be expected to yield improved SAV frequency of occurrence in other aquatic areas (side channels and backwaters, Table 4), but these would be considered secondary targets since they were not directly linked with main channel TSS concentrations.

To achieve the above SAV targets, summer average TSS concentrations will need to be reduced about 32% (47 to 32 mg/L) from existing conditions based on the combined monitoring data for Locks and Dams 2 and 3 (Table 3). It is suggested that attainment be based on achieving a median and 90th percentile summer average TSS concentrations of 32 and 44 mg/L, respectively, based on combined bi-weekly monitoring at Locks and Dams 2 and 3. The 90th percentile was derived for main channel summer average data (1998-07) for Pool 13, a desirable reference pool that was used to derive the SAV targets (Table 3). Achieving these TSS criteria will improve the conditions for SAV growth throughout the turbidity impaired reach and result in reduced sediment infilling of Lake Pepin.

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Table 1. Recommended light penetration-related water quality criteria proposed by the Upper Mississippi River Conservation Committee. Derived from Table 1 in UMRCC, 2003.

Variable	Value*	Basis
Light Extinction Coefficient (Primary Criterion)	3.42 m^{-1}	Average growing season light extinction necessary to promote *Vallisneria* growth and reproduction at 0.8 m depth
Secchi Disk Depth	0.5 m	Light extinction vs Secchi depth regression, WDNR data for Pools 4-11
Total Suspended Solids	25 mg/L**	Light extinction vs TSS regression - WDNR data for Lock & Dam 8 & 9
Turbidity	20 NTU	Light extinction vs turbidity regression - LTRMP data for Pools 8 & 13.

* Values should be applied as a growing season average (May 15 to September 15) based on bi-weekly measurements.

** New information collected by the federal Long Term Resource Monitoring Program in Pools 8 and 13 suggest this number should be changed to 30 mg/L (Giblin et al. *in prep.*)

Table 2. Summary of vegetation sampling designs used by the federal Long Term Resource Monitoring Program (LTRMP) and Minnesota's and Wisconsin's Environmental Monitoring and Assessment Program (EMAP) on the Upper Mississippi River.

Sampling Information	LTRMP	EMAP
Period of Record	1998 - 2008	2006-2008
Sampling Reach	Pool-based. For the Minnesota-Wisconsin border includes: upper and lower Pool 4, Lake Pepin and Pool 8.	USGS hydrologic unit reaches along the Mississippi River (segmented by major tributary inflows). Includes the reach from St. Anthony Falls Lock and Dam (Pool 1) in Minneapolis, MN to LD 11 near Dubuque, IA.
Aquatic Strata	Main channel border, side channel, impounded, contiguous backwater, isolated backwater and Lake Pepin	Main channel border, side channel and areas adjacent to these channels
Randomization Scheme	Random points within a defined grid of each sampling strata within each reach. Grid size: 50x50 m	Longitudinally stratified random points along defined centerline of channels. Random selection of right or left bank. Random percent distance from 2 m depth to shore.
Depth Range	0 to 2.5 m	0.2 to 2.0 m
Bathymetry	Needed to establish sampling grid.	Not required.
Collection Method	LTRMP vegetation sampling methods. Includes visual observation and rake sampling around an anchored boat.*	LTRMP vegetation sampling methods. Includes visual observation and rake sampling around an anchored boat.*

* Yin and Langrehr 2005.

Table 3. Submersed aquatic vegetation and total suspended solids (TSS) targets. Underlined values are based on measured EMAP, LTRMP or mulit-agency monitoring surveys. Summer average TSS based on the June-September period.

Condition/Target	Avg. SAV Frequency		Summer Avg. TSS	Basis/Comments
	EMAP[1]	LTRMP[2]		
Existing Conditions				
Minnesota R. to Chippewa R.	13%	~7%	35	EMAP surveys & MCES TSS data for LD 2 & LD 3 (2006-08)
Long term historical conditions	~9%	~5%[P]	47	MCES data for LD 2 & LD 3 (1976-2008) SAV estimated from TSS vs SAV regression and EMAP vs LTRMP relationship[1]
Proposed Targets				
50% of SAV Frequency Chippewa R - LD 11	22%	~13%	~28[P]	TSS predicted from TSS vs SAV regression SAV derived from EMAP 2006-08 surveys
Avg. SAV Frequency of Pool 13 Main Chan. Border	~23%	13%	31	Avg. SAV & TSS for 1997-2007 SAV derived from LTRMP surveys
Historic SAV Conditions upper Lake Pepin & upper Pool 4	~15%	~8%[P]	~38	1951 aerial photographs of upper Lake Pepin and upper Pool 4. TSS levels were estimated from turbidity x TSS regression from Mlps/St. Paul Sanitary District at Above Red Wing site
UMRCC TSS Criteria	~21%	~12%[P]	30*	Upper Mississippi River Conservation Committee light-related water quality criteria for SAV
Recommended Targets	**~21%**	**~12%**	**~32**	**Average based on four preceeding targets TSS measured at LD 2 & 3 (combined data) SAV measured from LD 2 to Rush River**

[1]Environmental Monitoring and Assessment Program sampling methods are ~1.75 times LTRMP SAV frequency results for the main channel border.
[2]Long Term Resource Monitoring Program sampling strata for the main channel border.
*Modified TSS criteria based on Giblin et al. (in prep).
[P]Predicted from LTRMP MCB SAV vs TSS regression.

Table 4. Submersed aquatic vegetation (SAV) targets for Pool 2 to Lake Pepin using Environmental Monitoring and Assessment Program (EMAP) and Long Term Resource Monitoring (LTRMP) surveys.

Sampling Design	Aquatic Areas Represented	SAV Target Percent Frequency	Basis
EMAP	Main Channel Side Channel & adjacent aquatic areas	21 Primary Targets	Considers an average of 4 targets: Half of reference (Chip. R. to LD 11) 1951 SAV & TSS conditions in upper Lake Pepin LTRMP MCB SAV data for Pool 13 EMAP vs LTRMP MCB comparion[1]
LTRMP	Main Channel Border (MCB)	12	
LTRMP	Side Channel (SC)	~18 Secondary Targets[3]	Regression of SC and MCB[2] $SC = (1.27 \times MCB) + 2.6$
LTRMP	Contiguous Backwater (BW)	~49	Regression of BW and MCB[2] $BW = (2.42 \times MCB) + 19.6$

[1]Based on EMAP and LTRMP data collected in lower Pool 4 and Pool 8.

[2]Based on LTRMP stratified random sampling of multiple pools in the Upper Mississippi River.

[3]Expected SAV frequency if primary target is achieved. It does not include within-pool management actions to improve conditions for SAV growth or persistence.
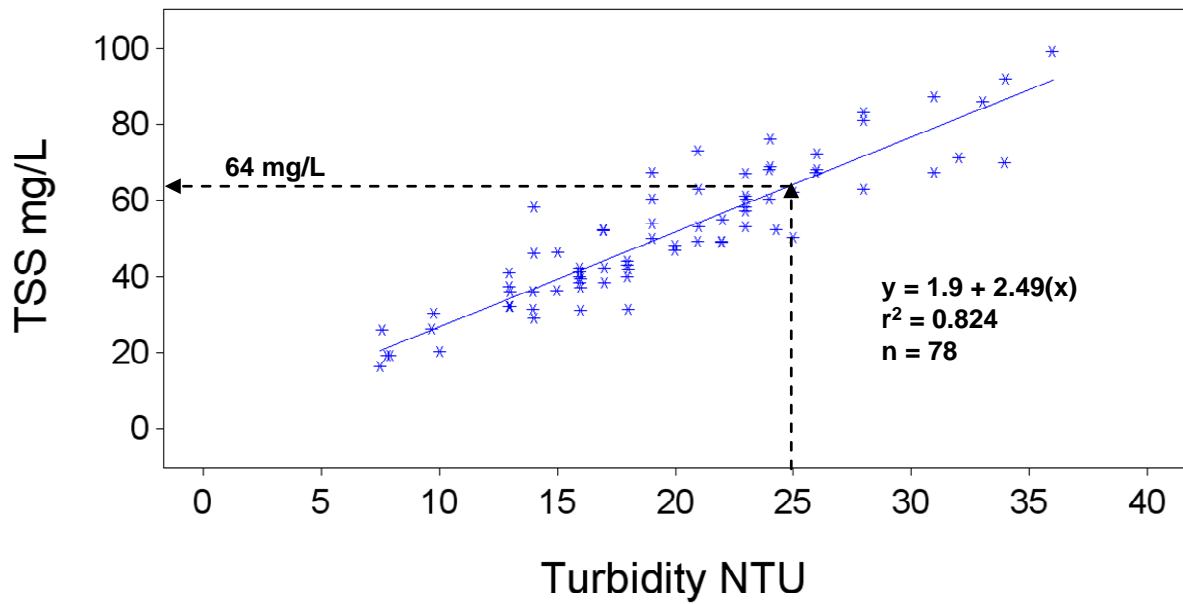
Figure 1. Linear regression of total suspended solids (TSS) versus turbidity based on summer data (June-September) collected by the Metropolitan Council Environmental Services (MCES) at Lock and Dam 3 for years 1990 to 1999.

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Figure 2. Average percent frequency of occurrence of submersed aquatic vegetation (SAV) measured in Long Term Resource Monitoring Program study pools in the Upper Mississippi River system during mid-summer from 1998 to 2003.
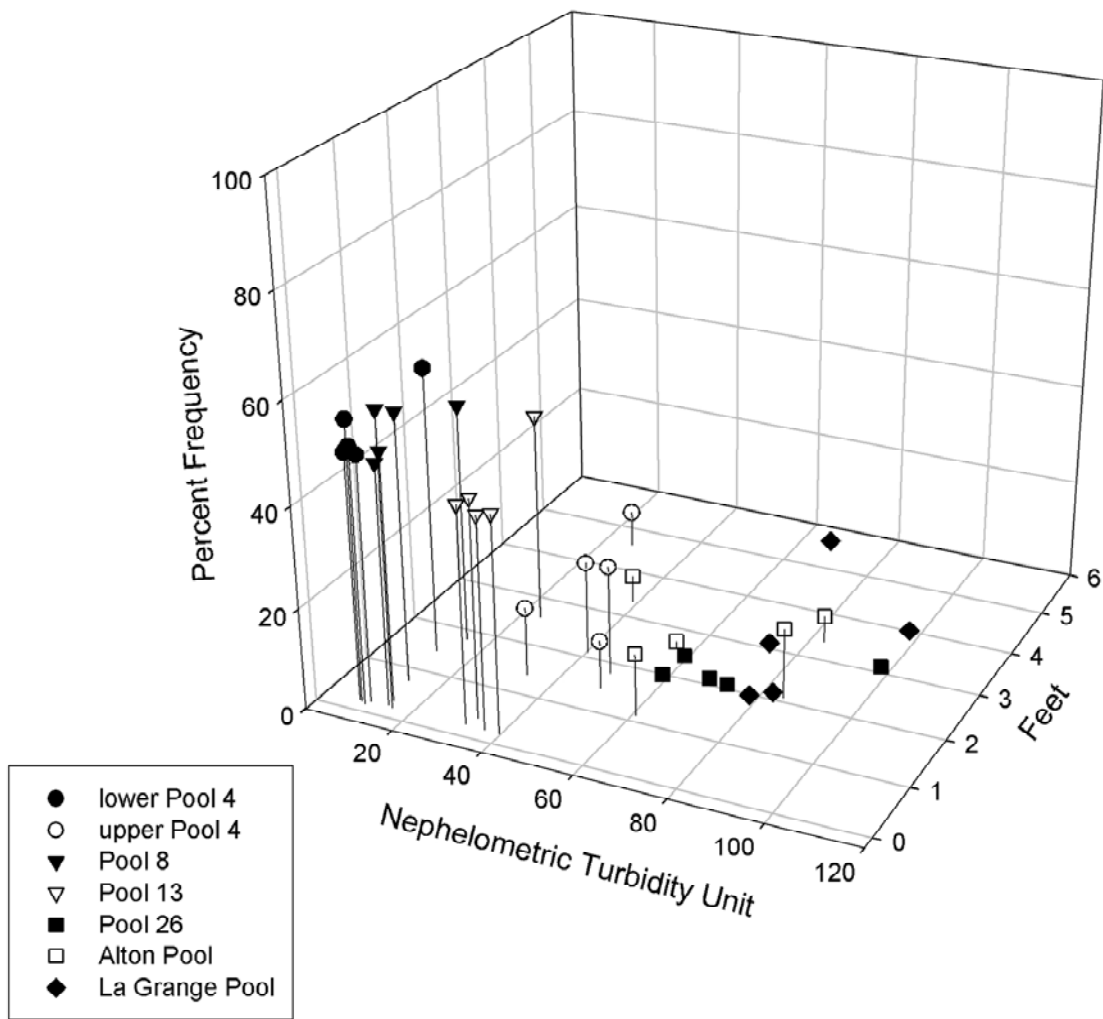
Figure 3. Percent frequency of submersed aquatic vegetation measured mid-summer versus average turbidity and water level fluctuation (standard deviation) measured May 1 to August 31 during years 1998 to 2002 by the Long Term Resource Monitoring Program (Figure 3.2 from Yin and Langrehr, 2005).
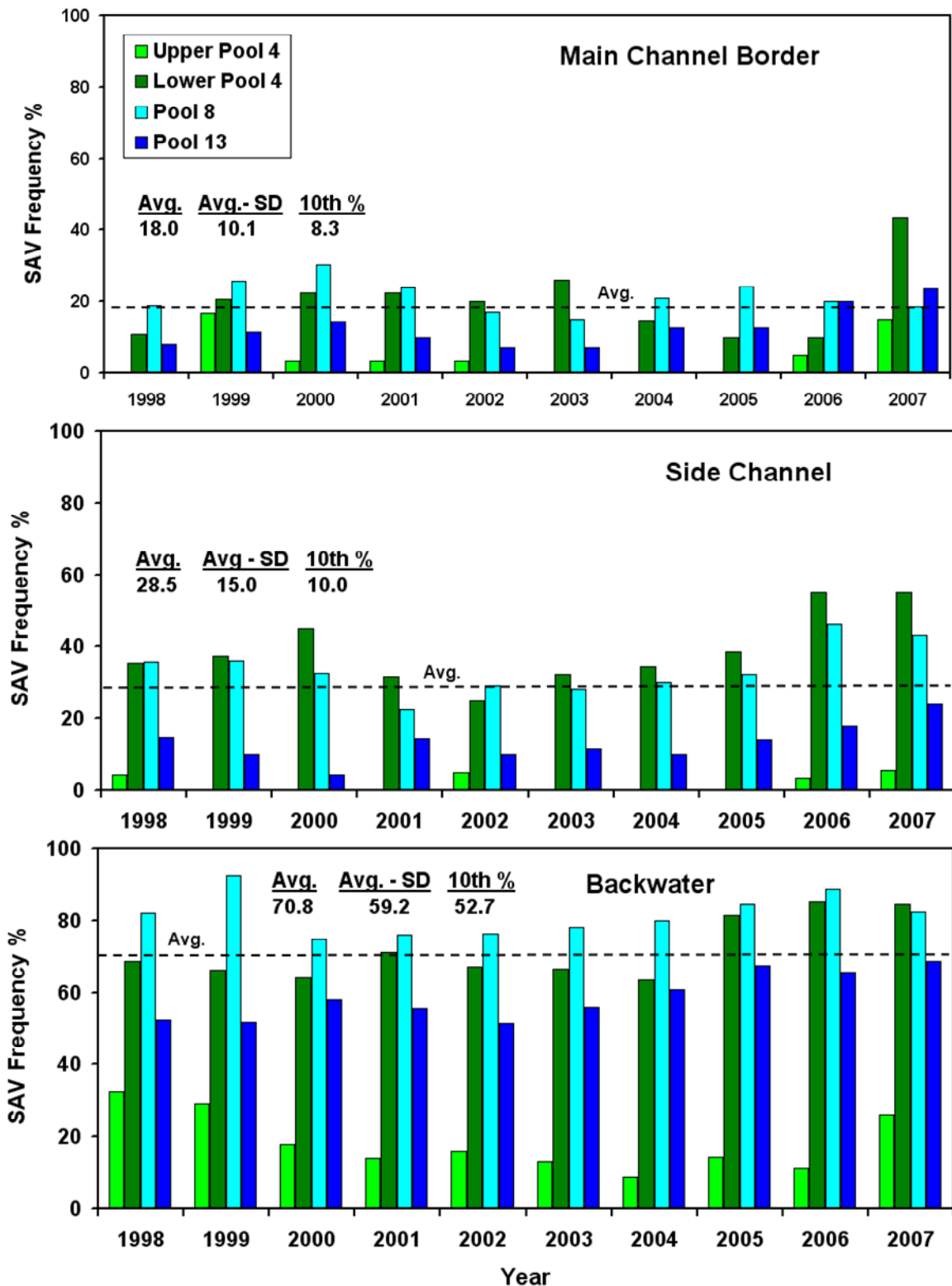
Figure 4. Percent frequency of occurrence of submersed aquatic vegetation (SAV) measured in three aquatic areas (strata) in Pools 4 (upper & lower), 8 and 13 of the Upper Mississippi River by the Long Term Resource Monitoring Program. Average, average-standard deviation and the 10th percentile of SAV frequency excluded data for upper Pool 4.
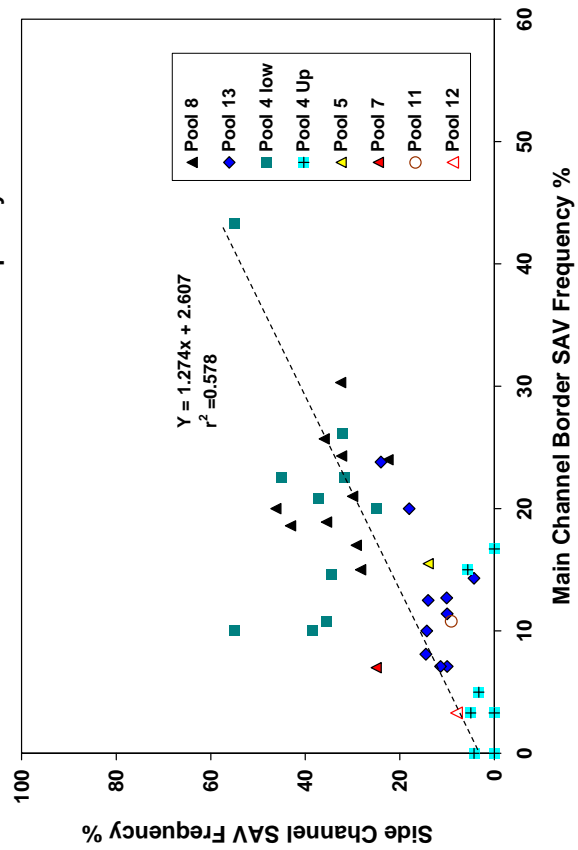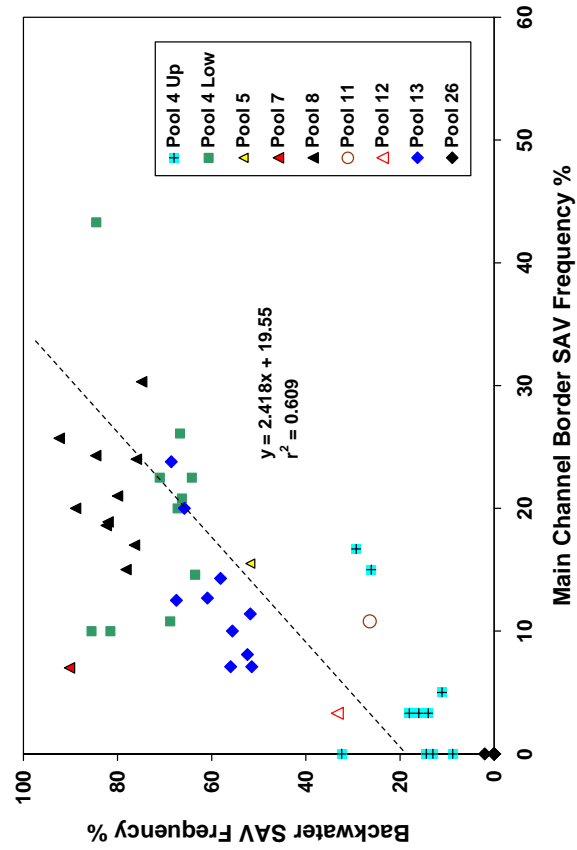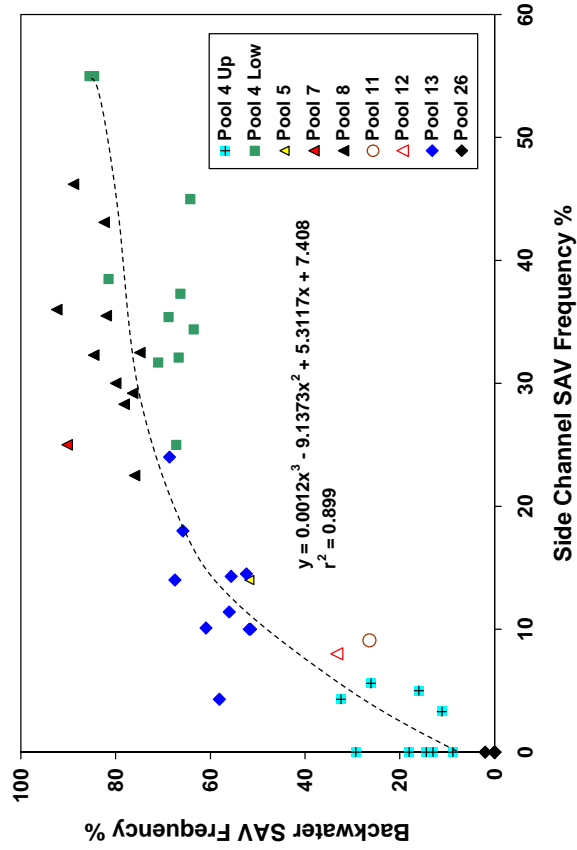
Figure 5. The relationship between backwater and main channel border (**A**) side channel and main channel border (**B**) and backwater and side channel (**C**) submersed aquatic vegetation (SAV) percent frequency of occurrence based on mid-summer sampling conducted by the Long Term Resource Monitoring Program on the Upper Mississippi River 1998 to 2007.

Percent frequency of occurrence of submersed macrophytes
EMAP vegetation grant data

Hydrologic Assessment Reach
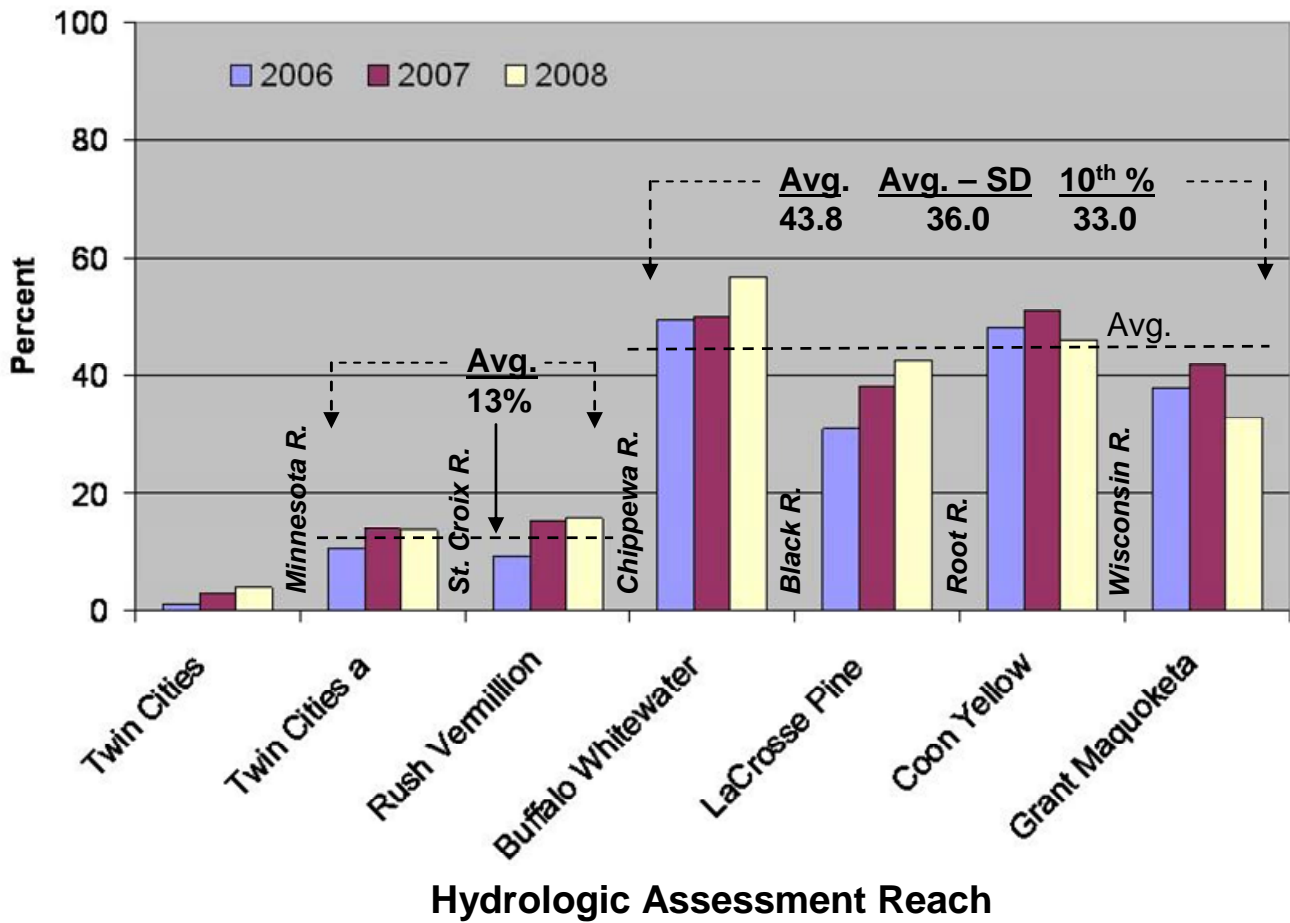
Reach	Reach Description
Twin Cities	St. Anthony Falls to Minnesota River
Twin Cities a	Minnesota River to St. Croix River
Rush Vermillion	St. Croix River to Chippewa River
Buffalo Whitewater	Chippewa River to Lock & Dam 6
La Crosse Pine	Lock & Dam 6 to Root River
Coon Yellow	Root River to Wisconsin River
Grant Maquoketa	Wisconsin River to Lock & Dam 11

Figure 6. Percent frequency of occurrence of submersed aquatic vegetation measured mid-summer in the Upper Mississippi River from the Twin Cities to Lock & Dam 11 by the Minnesota and Wisconsin Department's of Natural Resources. This work was supported by U.S. EPA's Environmental Monitoring & Assessment Program (EMAP) effort for the Upper Mississippi River. Average, average-standard deviation and the 10th percentile of SAV percent frequency excluded hydrologic assessment reaches above the Chippewa River.
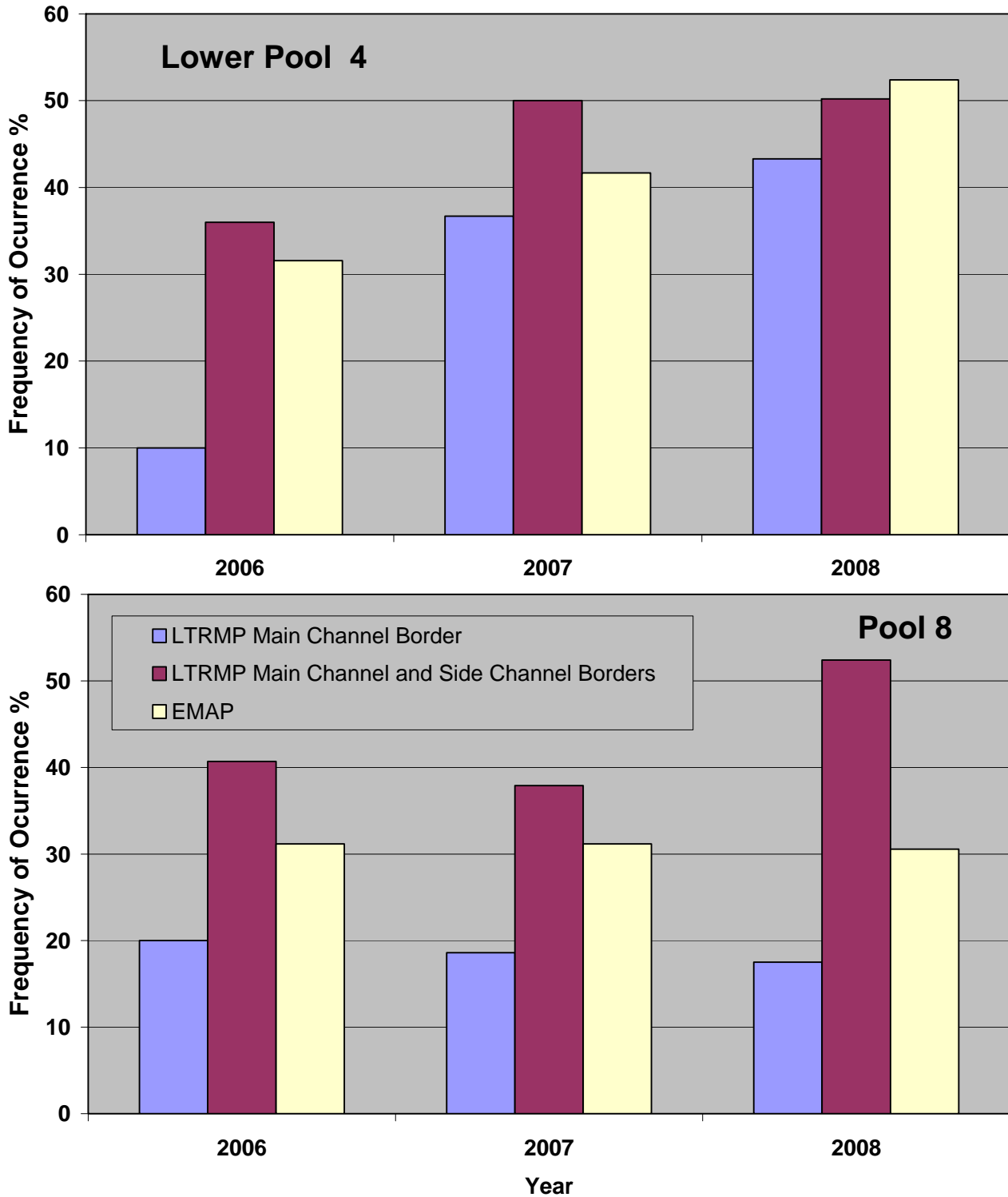
Figure 7. Comparison of percent frequency of occurrence of submersed aquatic vegetation measured mid-summer in lower Pool 4 and Pool 8 of the Upper Mississippi River by the Minnesota and Wisconsin Department's of Natural Resources Environmental Monitoring & Assessment Program (EMAP) and by the Long Term Resource Monitoring Program (LTRMP) for the main channel border and side channel aquatic areas in 2006 to 2008.
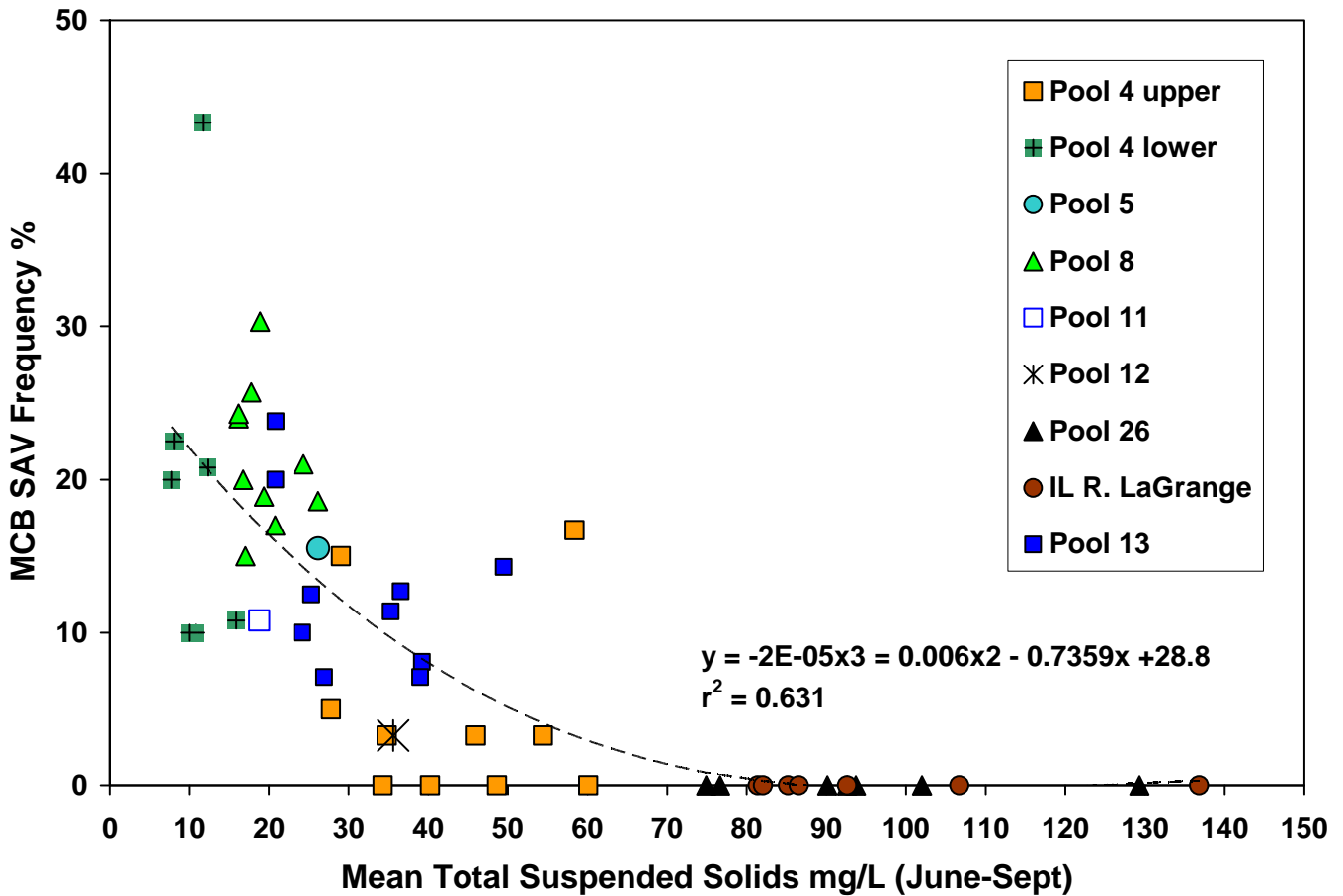
Figure 8. Percent frequency of occurrence of submersed aquatic vegetation (SAV) measured mid-summer in the man channel border (MCB) by the Long Term Resource Monitoring Program (1998-2007) versus average main channel total suspended solids concentration during June 1 to September 30th. Total suspended solids data were derived from multiple sources (UMRCC, 2002).
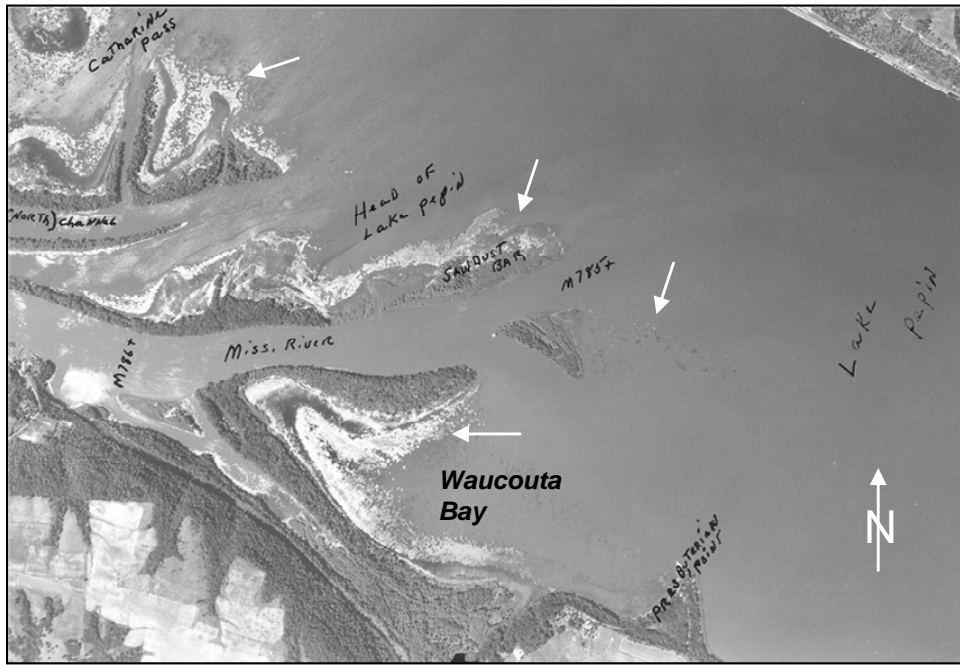
Figure 9. Black and white aerial photograph of upper Lake Pepin showing beds of aquatic vegetation (white arrows). The photo was taken July 25, 1951.
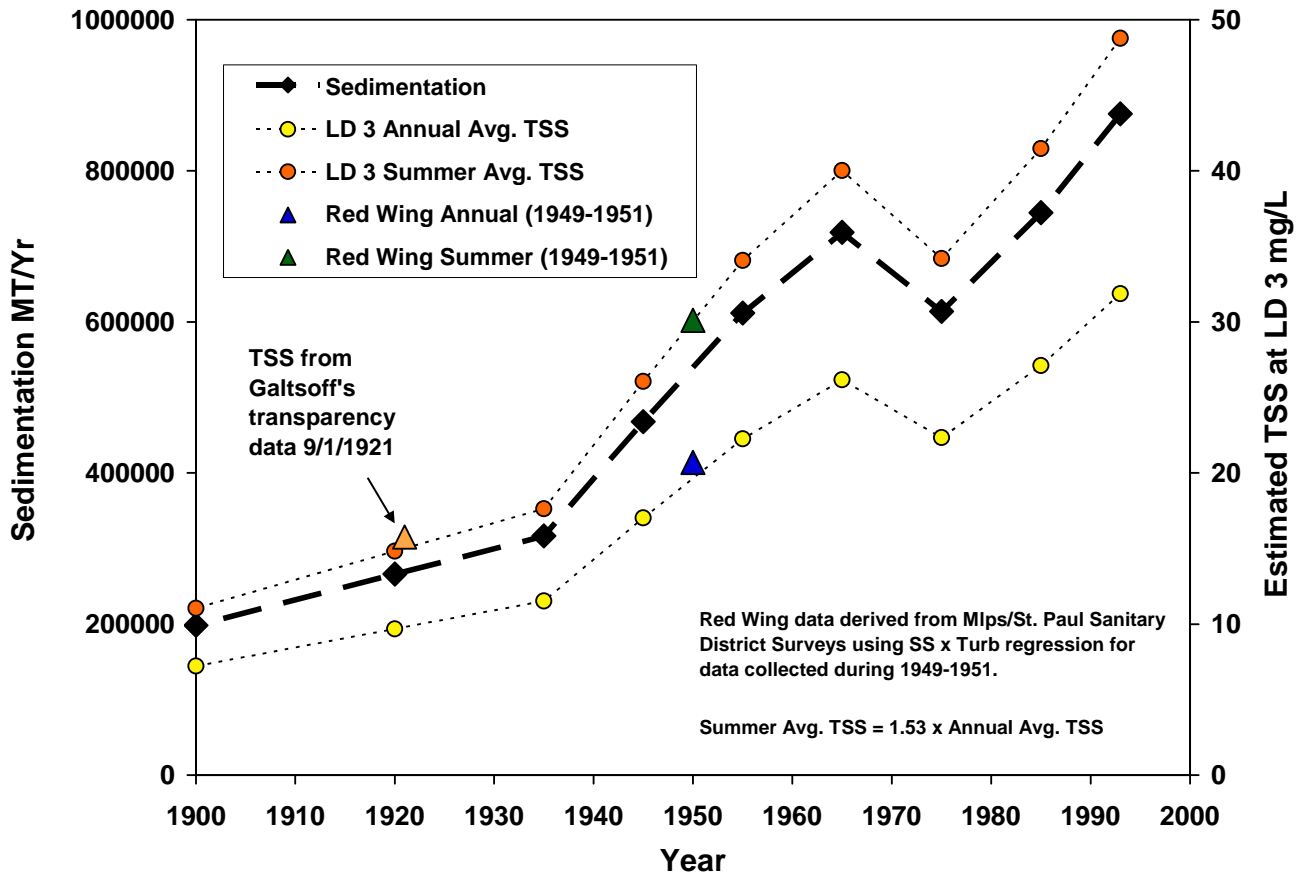

Figure 10. Whole-lake sedimentation rate measurements from sediment coring measurements (Engstrom et al. 2009) and estimated sedimentation-derived total suspended solids (TSS) concentrations at Lock and Dam 3 near Red Wing, MN.