Proposed Light-Related Water Quality Criteria Necessary to Sustain Submersed Aquatic Vegetation in the Upper Mississippi River

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Submersed aquatic vegetation (SAV) is an important component of the aquatic habitat in the Upper Mississippi River (UMR) navigation pools. Leaves, seeds and vegetative propagules are a source of food for waterfowl. The submerged plants provide a substrate for invertebrate and periphyton colonization, habitat for larval and adult fish, and help stabilize fine sediments from boat waves and wind-induced sediment resuspension (Korschgen 1988 and Janecek 1988). Submersed aquatic plants have been used to assess water quality and to provide a measure of ecosystem health (Dennison et. al. 1993).

We believe greater river and watershed management efforts need to be directed to protecting and enhancing SAV on the UMR. In particular, efforts to reduce the negative effects of high turbidity or suspended particulate matter during the growing season are warranted to ensure the continued survival of SAV beds within historic ranges and densities in the UMR navigation pools. To achieve this goal, we are recommending specific and consistent light-related water quality criteria be adopted by water quality management agencies having jurisdiction over the UMR that will be protective of SAV growth and reproduction. These criteria are needed for monitoring, assessing impairments, formulating river and watershed management strategies, and evaluating management efforts that seek to enhance and protect SAV beds in the UMR. We believe consistent and scientifically based criteria are necessary to help target river or watershed sources contributing to excessive turbidity or suspended particulate matter concentrations in the river. These efforts may not only help sustain and enhance SAV communities but will also help achieve goals to reduce other sediment-related impairments on the river (UMRCC 2000).

Background

A substantial decline in SAV in the UMR was reported following the 1987-89 drought (Kimber et al. 1995a and McFarland and Rogers 1998). Although this decline was widespread, specific field surveys documenting the decline are limited. Primary information illustrating the decline was available from federal SAV monitoring activities in Weaver Bottoms, Pool 5, and Lake Onalaska, Pool 7, (Figure 1a). In addition, a comparison of SAV in 1975 versus 1991 revealed a substantial reduction in SAV frequency and biomass in Pool 8 (Fischer 1997). Although the specific reasons for the decline have not been established, possible causative factors include decreased light availability, nitrogen limitation, increased water temperature and hydraulic factors (Kimber et al. 1995a, Rogers et al. 1995, Sullivan 1995).

Total suspended solids (TSS) monitoring in portions of the river where the SAV decline indicated summer average concentrations ranging from about 20-40 mg/L preceding and during the drought (1980-89, Figure 1b). It is difficult to accurately establish the temporal and spatial SAV response during this period due to the limited and disrupted monitoring activities. However, the available data suggests SAV was declining in Lake Onalaska in the early 1980s (1980-83) followed by a recovery just prior to the 1987-89 drought. Vast beds of SAV were still present in many UMR pools in 1987 based on a review of color aerial photographs from September 1987 and general observations by river biologists. Submersed aquatic vegetation declined precipitously in Weaver Bottoms in 1988 to 1989 and likely reflected a similar unmeasured decline that was apparent in Lake Onalaska and other areas of the UMR during this period.

Following the 1987-89 drought, tributary flows increased and yielded very high TSS concentrations in the river, especially in 1990 (Figure 1b). These conditions resulted in a substantial reduction in light penetration in the Mississippi River as measured by the Wisconsin Department of Natural Resources (WDNR) at Lock Dam 8 and 9 and Weaver Bottoms (Figure 2). It is recognized that the loss of the SAV also contributed to decreased light penetration as a result of increased sediment resuspension due decreased sediment stability. SAV provides resistance to sediment resuspension by dampening the impacts of waves or current velocity. However, we believe the recovery of SAV following the drought was primarily driven by the availability of adequate light energy for SAV growth and reproduction during the growing season (May-September).

Since the mid- to late 1990s, SAV has increased in many areas as illustrated by *Vallisneria* monitoring at Lake Onalaska (Figure 1a), observations in Pool 9, and monitoring studies performed by the federal Long Term Resource Monitoring Program (LTRMP) in Pools 8 and 13 (Yao Yin, USGS, and Heidi Langrehr, WDNR, Personal Communications). In contrast, SAV has remained low in Weaver Bottoms where sediment resuspension, turbid inflows and phytoplankton contributed to reduced light penetration throughout the 1990s (Nelson 1998 and Sullivan 1996).

Light-Related Water Quality Criteria for Submersed Aquatic Vegetation

The negative impact of high turbidity or suspended particulate matter on SAV is well known and has been documented in many systems including Lake Chautauqua, Illinois (Jackson and Starret 1959), Rice Lake Wisconsin (Engel and Nichols 1994), and Chesapeake Bay (Dennison et al. 1993). These impacts are expressed through a reduction in light energy on leaf surfaces, which contribute to reduced growth and reproduction (Korschgen et al. 1997 and Kimber et al. 1995b). The maximum depth of colonization of SAV has been directly linked to the transparency of water (Chambers and Kalff, 1985 and Canfield et al. 1985). Their regression plots of the maximum colonization depth versus Secchi disk depth are similar (Figure 3a) and suggests the relationship may have broad application to many freshwater systems. For example, this simple relationship could be used to establish the target depth for SAV establishment in the UMR navigation pools. Water quality management efforts would then be directed at controlling turbidity or suspended particulate matter to provide the necessary underwater light conditions to support SAV growth and reproduction. A similar approach has been suggested for Chesapeake Bay (Dennison et al. 1993).

In order to establish light penetration-related water quality criteria to protect SAV on the river, we need to determine a reasonable colonization depth for these plants. Rather than basing this depth on some arbitrary number, this value should be based on the observed depth distributions of SAV from the navigation pools during time periods when these plants were common and flourishing. For example, *Vallisneria americana (wildcelery)*, is an important species in the upper navigational pools and has been reported at depths ranging from 0.1 to 2.8 m based on LTRMP vegetation monitoring of Pools 4, 8 and 13 during 1998 to 2001 (USGS, 2003). The median depth of occurrence was 0.8 m. Studies of *Vallisneria* in Pool 8 during 1983-85 indicated this plant was present at sites with a mean depth of 0.88 m (Korschgen et al. 1997). Using a target SAV colonization depth of 0.8 m and the regression equations presented in Figure 3a, a target Secchi depth transparency of approximately 0.4 m is derived.

An alternative approach for criteria development would be to determine the specific light requirements of a "key" submergent species and then base the light criteria on these studies. This research has been conducted in the UMR for wildcelery and provides the most direct support for establishing criteria that will be protective of this species in the river. The results of this work are highlited below:

- "*Limit suspended sediment concentrations to <20 mg/L so that the annual 1% penetration depth will be between 1 to 1.5 m. This depth should provide adequate light energy for successful growth and reproduction and enough potential habitat area for good aquatic plant distribution and diversity*"

(Korschgen et al 1997). Using an average 1% depth of 1.25 m yields a light extinction coefficient of 3.68 m^{-1}.

- "*Survival, growth, and reproduction of seedlings were significantly greater in treatments with a least 9% of surface light availability over the growing season… These light requirements are the same as those for plants grown from"* winter *"buds*" (Kimber et al. 1995b). This corresponds to a light extinction coefficient of 3.01 m^{-1} based on the existing median depth distribution of this species in the river (0.8 m).

- "*plants required at least 8.7% of surface light for tubers to be produced in 94 days…For a longer growing season (*109 days), *plants produced replacement-weight tubers in treatments with at least 5% of surface light …plants in lower light environments maybe able to produce overwintering tubers at lower light levels if the" growing" season is sufficiently long*" (Kimber et al. 1995a). Using the 5% surface light requirement corresponds to a light extinction coefficient of 3.74 m^{-1} at a targeted water depth of 0.8 m.

Recommended Vertical Light Extinction Coefficient Criterion: Use the logarithmic average of the above extinction coefficients ($\ln[(e^{-3.68} + e^{-3.01} + e^{-3.74})/3]$) to obtain an average value of **<u>3.42 m^{-1}</u>**. **This corresponds to an average compensation depth (1% of surface light) of 1.35 m. This equates to 6.5% of surface light at a depth of 0.8 m** using the light penetration definition provided below. These criteria should be applied as a growing season average (May 15 -September 15) which represents the typical period of growth in the UMR (Donnermeyer and Smart 1985). These criteria reflect the minimum light criteria necessary to sustain and enhance SAV on the river. If light penetration were greater, we would anticipate greater depths of colonization. Although these criteria were derived for a single species, wildcelery, these light conditions will favor the growth and development of other SAV species as well since wildcelery establishment will contribute to reduced turbidity and improved light conditions in the riverine pools (Korschgen et al. 1997).

Note: Light penetration is defined as:

$$Io = Iz\, e^{-kz} \quad \text{or} \quad k = [\ln(Io) - \ln(Iz)] / z$$

where

Io = Surface or upper light measurement
Iz = Light measurement at depth z
e = Base of natural logarithms (2.71828…)
k = Light extinction coefficient
z = Depth interval between Io & Iz

also by definition, the compensation depth (1% of surface light) =

$$(z_{I1\%}) = [\ln(100) - \ln(1)] / k \quad \text{or} \quad 4.605 / k$$

Comparing the recommended compensation depth (1.35 m) to an average of measurements made in the Mississippi River at Lock and 8 and 9 by the WDNR over the last 15 years indicates this value was not achieved between 1989 and 1996 (Figure 3b) and generally corresponds with a period of reduced SAV on the river. Since 1996, the recommended compensation depth has been achieved and is consistent with the observed recovery of SAV in Pools 7, 8 and 9 in the last several years. In contrast, average July and August light penetration measurements made by the WDNR in Weaver Bottoms indicate a substantially longer period of reduced light penetration. The average of July and August compensation depth measurements at Weaver Bottoms started to exceed the recommended value in 2001 and 2002. To date, SAV has not recovered on Weaver Bottoms and has generally lagged behind other areas of the river, including the eastern portion of Pool 5, which exhibits greater transparency (Nelson 1998). Increased SAV on Weaver

Bottoms would be expected in the future if favorable light penetration persists during future growing seasons.

Conversion of the Recommended Light Extinction Coefficient Criterion to Other Water Quality Measurements

Few water quality monitoring programs measure light penetration directly using underwater light sensing equipment. In order to convert the recommended light extinction coefficient criterion (3.42 m^{-1}) to commonly measured field or laboratory variables, the relationship between light extinction and relevant water quality variables (Secchi depth, total suspended solids and turbidity) need to be described for the Mississippi River. These relationships have been established based on long term water quality monitoring conducted on the Mississippi River by the WDNR or through monitoring conducted by the federal Long Term Resource Monitoring Program (LTRMP), (Figure 4a,b, & c). Based on regression equations provided in these figures, a listing of the recommended surrogate light penetration-related water quality criteria are provided in Table 1.

Table 1. Recommended light-related water quality criteria necessary to support and sustain submersed aquatic vegetation in the Upper Mississippi River.

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.

A comparison of the 0.5 m Secchi depth criterion to transparency measurements made throughout the UMR System by the federal LTRMP indicate this value is not achieved in the lower portion of the UMR and in the Illinois River (La Grange Pool), (Figure 5). The results are consistent with the observed distribution of LTRMP wildcelery data that indicate an absence of this species at sites failing to meet this criterion. In addition, average summer turbidity measurements generally meet or approach the 20 ntu criterion where wildcelery is found but are absent from study reaches where this value is exceeded (Pool 26, Open River and the LaGrange Pool on the Illinois River), (USGS 2003).

Recommendations for Submersed Aquatic Vegetation Protection and Management

The primary application of the above light criteria are intended for those portions of the UMR system where SAV has been historically found. It is recognized that SAV establishment will not be possible throughout the entire river due to natural factors (velocity, depth, naturally high turbidity or TSS levels and other factors) that prevent SAV growth and development. These considerations will be necessary when applying these criteria to the UMR System. The use of the above criteria should be considered for habitat projects where SAV development and protection are important habitat objectives. Further, we believe State water quality management agencies should consider the above light-related water quality criteria for Mississippi River as well as tributary streams discharging to reaches where SAV development and protection have been identified as important management objectives or goals. These criteria should be considered when assessing surface waters as part of biennial assessments (Section 305b reporting) or when defining water quality impairments (Section 303d). Attainment of the light penetration criteria in the UMR will not only improve habitat conditions for SAV but will also help meet identified goals for reducing sediment related problems on the UMR and its backwaters (UMRCC 2002).

Although we believe improving and maintaining an adequate underwater light penetration is critical for SAV growth and survival, we understand that other factors (water level changes, waves, nutrients, floods, substrate composition and herbivore activity and other factors) also play a role in governing the development and persistence of SAV communities on the river. Continued monitoring and research are warranted to further our understanding of factors controlling SAV distribution and abundance on the river. In particular, the response of SAV to ongoing water level management activities, changes in river flow, nutrient enrichment, habitat rehabilitation projects or other human-induced disturbances on the river need to be explored. The negative impacts of excessive nutrient enrichment in enhancing filamentous algae or epiphytic plant growth on SAV may be especially important since these attached plants have been implicated as a critical factor contributing to submersed aquatic macrophyte declines in freshwater systems (Phillips et al. 1978). Their work suggests excessive canopies of filamentous algae and other attached algae may lead to increased competition for light and nutrients and may promote the "switch" from a SAV dominated system to one dominated by algae. Current efforts by states and EPA to address nutrient criteria in lakes and rivers should consider nutrient-related impairments on SAV communities.

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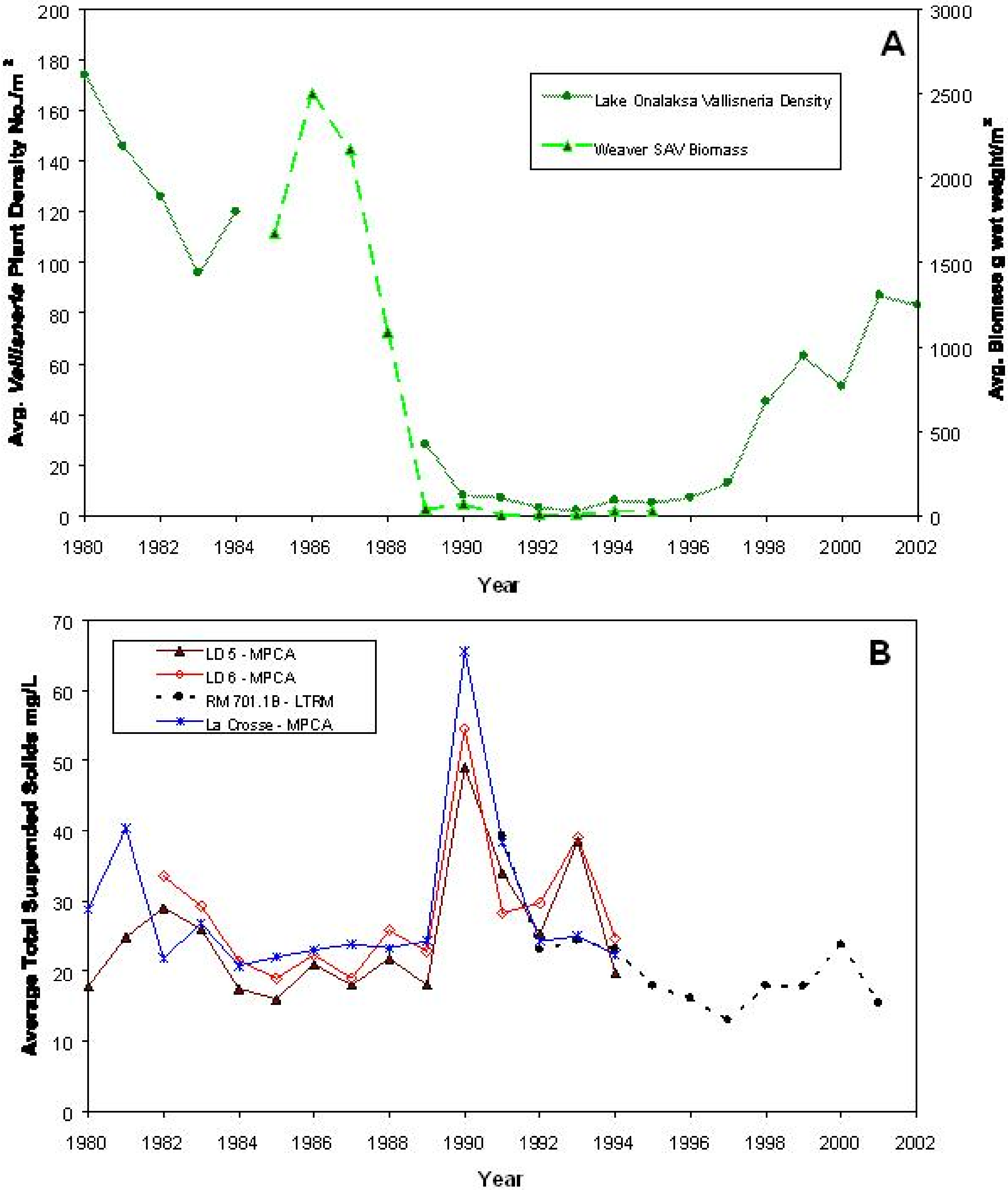


Figure 1. **A**. Submersed aquatic vegetation monitoring conducted in the Mississippi River at Lake Onalaska (Pool 7) and in Weaver Bottoms (Pool 5) by the US Fish & Wildlife Service. **B**. Average summer (June-Sept) total suspended solid concentrations in the Mississippi River from Lock and Dam 5 to La Crosse, Wisconsin (Pool 8). Data obtained from the Minnesota Pollution Control Agency (MPCA) and the federal Long Term Resource Monitoring Program.

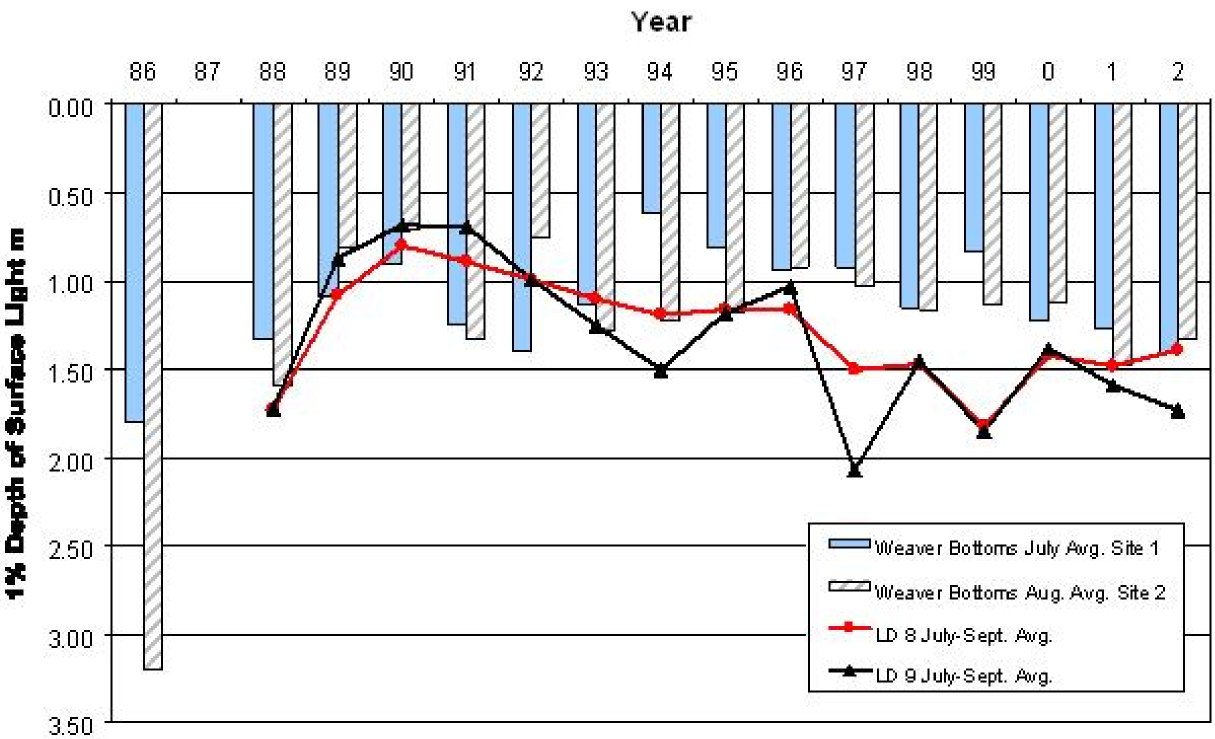
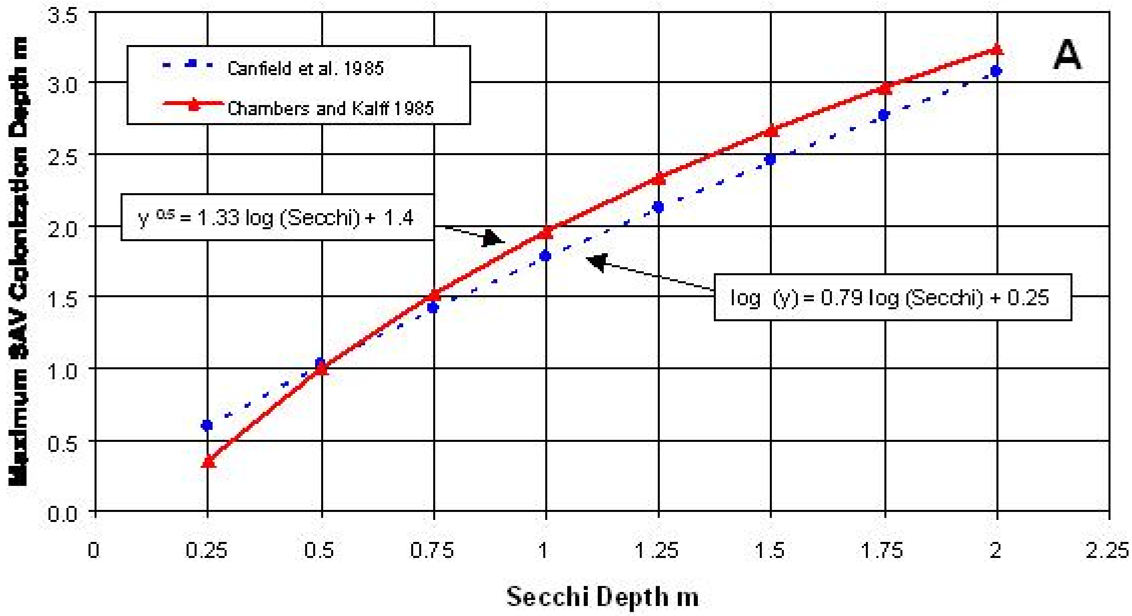


Figure 2. Average light penetration measurements in the Mississippi River during July and August at Weaver Bottoms (Pool 5) and June-September at Lock and Dam 8 & 9. Data collected by the Wisconsin Department of Natural Resources. Light penetration measurements represent the 1% depth of surface photosynthetically active radiation (PAR).



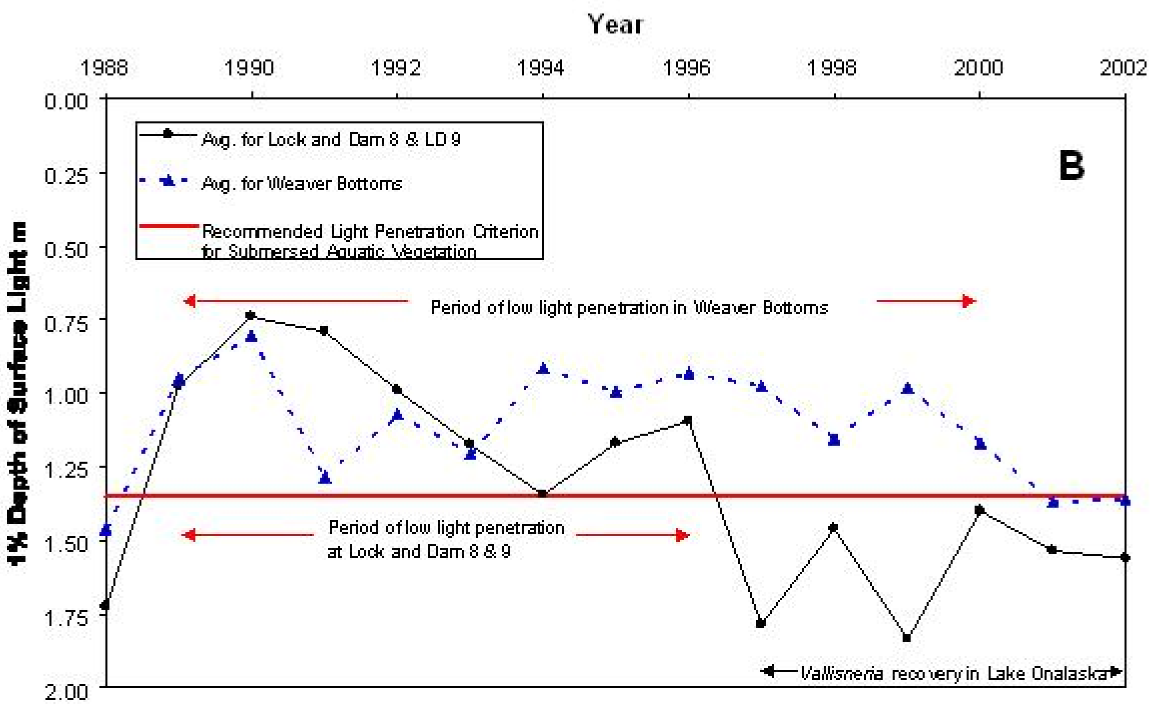


Figure 3. **A**. Reported relationships between the maximum submersed aquatic vegetation (SAV) depth and Secchi depth transparency. **B**. Average light penetration measurements made by the Wisconsin Department of Natural Resources at Lock and Dam 8 & 9 and Weaver Bottoms (Pool 5) in comparison to the recommended light penetration criterion (average summer 1% depth $\geq$ 1.35 m) to support submersed aquatic vegetation in the Mississippi River.

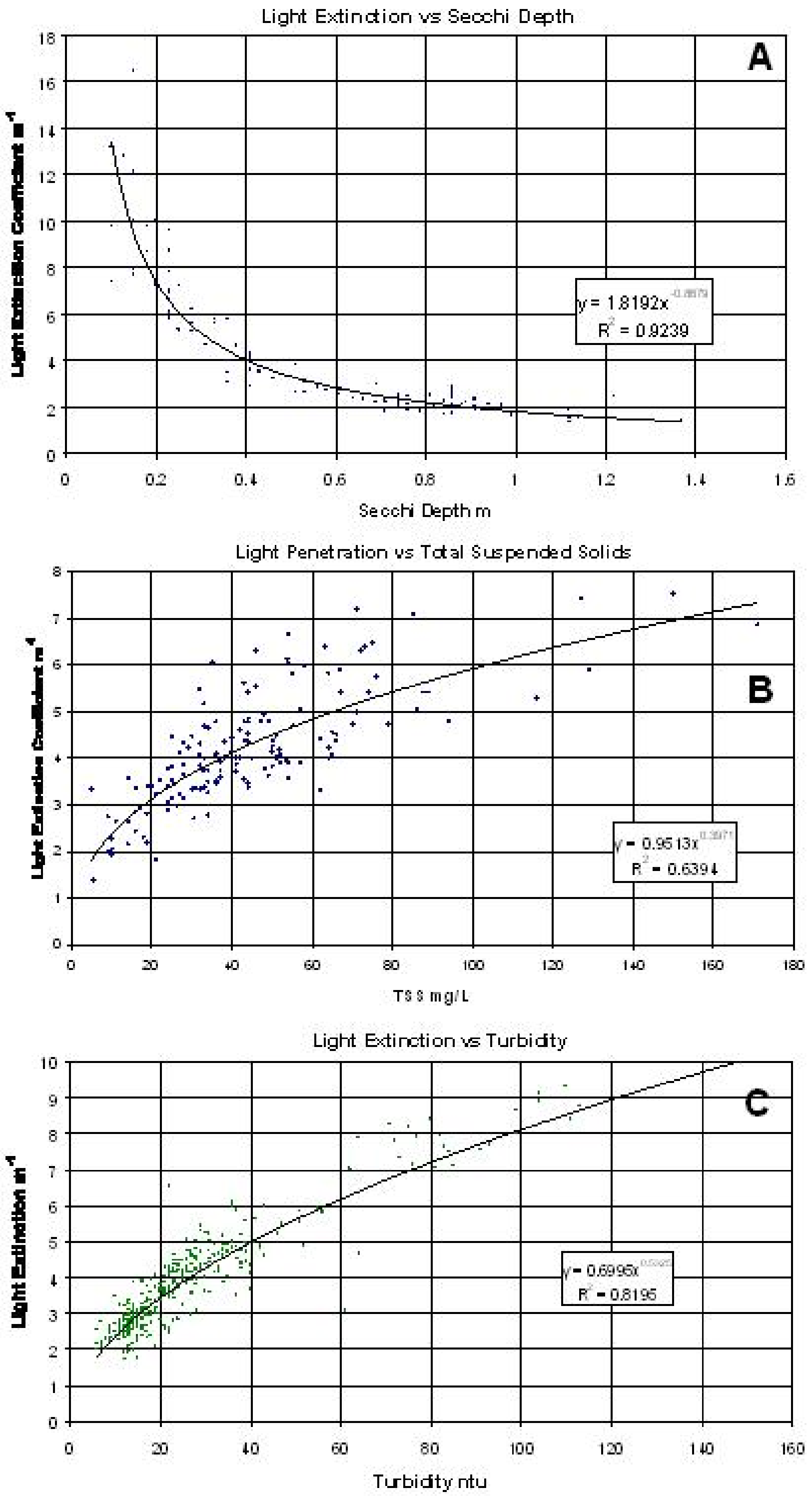


Figure 4. **A**. Relationship between light extinction and Secchi disk transparency based on measurements by the Wisconsin Department of Natural Resources (WDNR) in Pools 4 to 11. **B**. Relationship between light extinction and total suspended solids based on measurements by the WDNR at Lock and Dam 8 & 9. **C**. Relationship between light extinction and turbidity based on summer season measurements made by the federal Long Term Resource Monitoring Program in Pools 8 & 13 in 2003 (unpublished LTRM data).

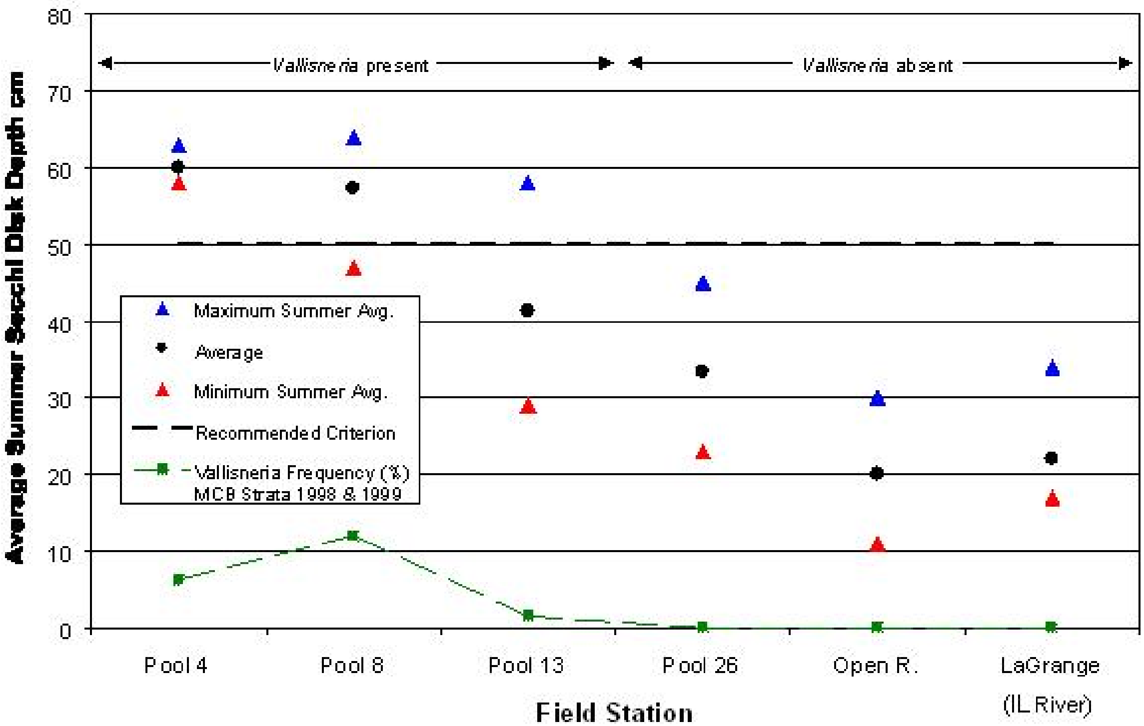


Figure 5. Average Secchi depth transparency measured by the federal Long Term Resource Monitoring Program (LTRMP) on the Mississippi and Illinois Rivers. The data represent an average of main channel and side channel samples collected during July-August between 1993 and 1999. Data for the 1993 for Pool 26 were not included because this reach was highly influenced by a major flood. The presence or absence of *Vallisneria americana* was derived from a review of LTRM summer vegetation survey data (all strata) collected from1998 to 2001. The average % frequency of occurrence of *Vallisneria* was determined from main channel border strata (MCB) collected in 1998 &99 (Yao Yin, Upper Mississippi Environmental Sciences Center, USGS, personal communications).