COLOR IN THE UPPER WISCONSIN RIVER: SOURCES AND EFFECTS ON PRIMARY PRODUCTION

by

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ABSTRACT

The Wisconsin River, which drains 21% of the state of Wisconsin, has been extensively used for power production and industrial and municipal wastewater disposal. Man's past uses of the river caused serious water quality problems. However, water quality in the Wisconsin River has substantially improved since the implementation of the wastewater treatment requirements of the 1972 amendments to the Federal Water Pollution Control Act (PL 92-500). The sixteen pulp and paper mills on the Upper Wisconsin River may in the future be required to further treat their wastes to remove true color and increased amounts of suspended solids.

At present, the color of the Wisconsin River is significantly influenced by wastewater discharges from the pulp and paper industry, especially during periods of low flow. During seven water quality surveys, their cumulative contribution to true color ranged from 2.2% at Hat Rapids Dam in May, 1979, to 62.9% at Mosinee Flowage in August, 1979. Similar results were observed for apparent color.

The effect of color and associated effects of light penetration on the growth of the indigenous algal populations of a large Wisconsin River reservoir, Lake Du Bay, were investigated. A special experimental apparatus was constructed for field studies. Plastic bags six feet long were attached to a wooden raft and filled with river water diluted with well water to simulate color changes which might be caused by reduction of industrial discharges. Light and dark bottles filled with water from a common source were then inoculated with a radioactive sodium bicarbonate solution and incubated in the bags. Light penetration in the bags was measured for the total visible spectrum and the blue, green, and red spectral ranges. Carbon assimilation rates were found to increase as water color decreased, except for occasional instances of surface inhibition. The overall average increase in carbon assimilation rates in bags, with a true color decrease of 27.6% and an apparent color decrease of 22.2%, was 28.2%. Increases in carbon assimilation rates varied with depth, from 8.9% at .2 meters, to 54.5% at 1.2 meters. Multiple regression analysis indicated that red light penetration was the most significant predictor of carbon assimilation rate changes.

The contribution of industry to the true and apparent color of the Wisconsin River therefore appears to lower algal productivity in reservoirs. However, one such reservoir, Lake Du Bay, is presently considered eutrophic as a result of nutrient inputs from industries, municipalities, and tributaries. Reduction of nutrient pollution, especially from nonpoint sources, will be necessary to prevent increases in nuisance algal blooms if industrial color discharges are reduced in the future. Such relationships must be seriously considered in water quality planning and implementation of the provisions of PL 92-500.

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Finally, I would like to thank my husband Dave, who helped with field work, lab work, and housework with limitless patience and generosity through the two year duration of this project.

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INTRODUCTION

The Wisconsin River is a multiple-use river that drains nearly 21% of the state of Wisconsin (Figure 1). The river has been called "the nation's hardest working river" because of its extensive development for power production and flood control. The 25 hydroelectric dams on the main stem produce nearly a billion kilowatt-hours of electricity each year (Derleth 1969). Major industries, especially the pulp and

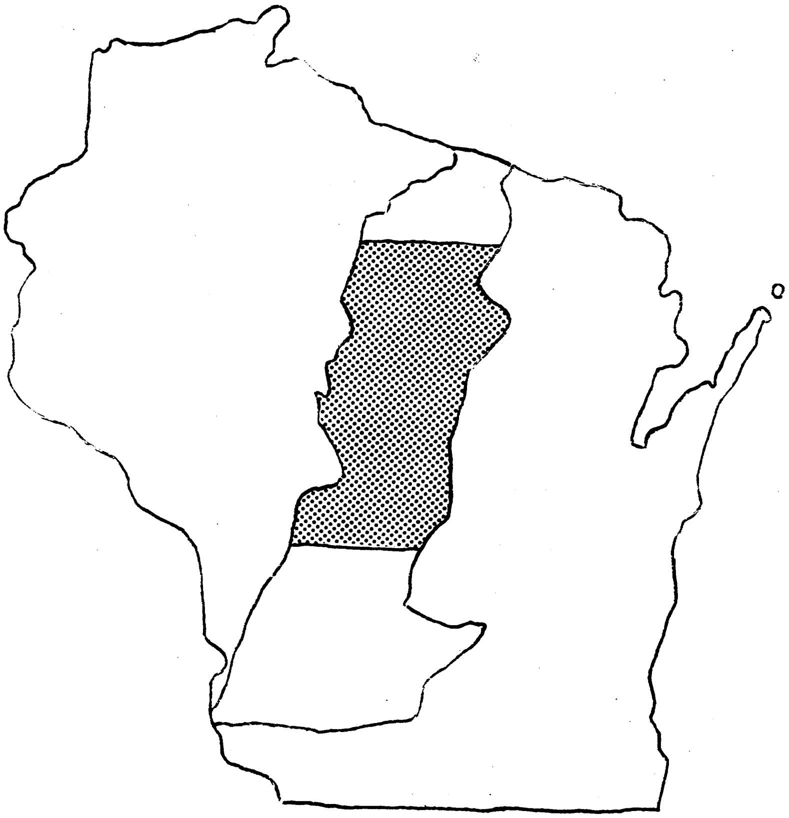


Figure 1. Map showing location of the Wisconsin River basin in the state of Wisconsin. The shaded portion indicates the study area.

paper industry, use the river as a source of process water, and both industries and municipalities discharge wastewater to it. With steadily improving water quality and the energy shortages of recent years, the river has become increasingly important for recreational uses such as fishing, boating, and swimming.

The segment of the river covered by this study extends from Rhinelander to Petenwell Flowage (Figure 2). Most of this area is in the geographical province known as the Northern Highlands (Martin 1965). North of Merrill, the drainage is characterized by many lakes and crooked systemless streams, while south of Merrill, stream drainage is dendritic and there are few natural lakes.

Soils in the Upper Wisconsin basin range from well-drained sandy upland soils in the north, to heavier loamy upland soils in the central part of the basin, to level sandy soils in the south. In 1975, land use in the entire Wisconsin River basin was 47.1% forest land, 31.8% cropland, 10.7% grassland, 4.1% urban land, and 6.3% other uses (Wisconsin Department of Natural Resources 1975a).

Water quality problems on the Upper Wisconsin River began almost as soon as the first white settlers arrived. By the early 1840's, the basin was being extensively logged, and rapids in the river were being dynamited to facilitate floating the logs downstream. This removal of the forest resulted in severe erosion and flooding problems (Derleth 1969).

With logging came the construction of dams for sawmills.

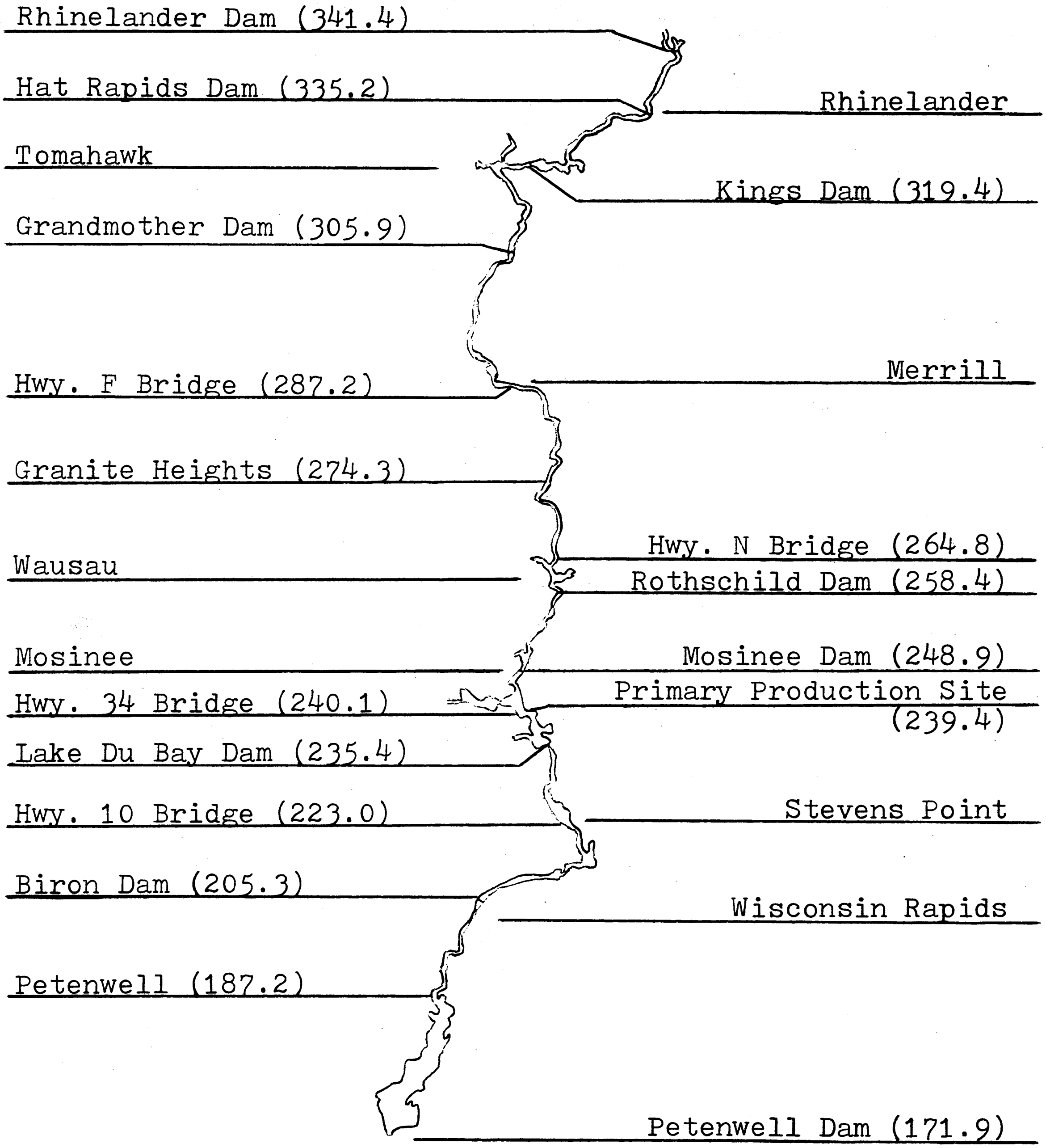


Figure 2. Map of the study area, showing sampling locations and Wisconsin Department of Natural Resources river mile designations (). General locations of valley cities are also indicated.

Late in the nineteenth century, there were almost 200 dams on the Wisconsin River. Most of these dams had slides for the passage of logs. Eventually, most were removed. A few dams were converted to hydro power, but highly variable flows made their operation difficult. In 1907, power and paper companies along the Wisconsin River organized the Wisconsin Valley Improvement Company, and were authorized by law to build and operate a reservoir system on the Wisconsin River and its tributaries for power production, navigation, flood control, and other public purposes. The reservoirs and hydroelectric power dams managed by this company are still significant features on the river today.

The pulp and paper industry entered the valley in the early 1870's and used the trees not considered worth cutting by the earlier lumber men. By the early 1900's, Senator Robert M. LaFollette began working for legislation to control pollution from this industry which was "pouring hundreds of thousands of tons of waste into the streams of Wisconsin, fouling the water, (and) destroying all life" (Derleth 1942). After 1925, the water quality in the river began to improve as pollution abatement laws were passed and as industry found it increasingly profitable to recycle waste materials.

As late as the mid 1970's, floating fibrous sludge mats, noxious odors, and anaerobic conditions were still problems on some segments of the Upper Wisconsin River (Wisconsin Department of Natural Resources 1975b). However, today all major industries and many municipalities on the Upper

Wisconsin have complied with the treatment requirements of the 1972 amendments to the Federal Water Pollution Control Act (Public Law 92-500). Suspended solids and BOD discharges have been greatly reduced, and the dissolved oxygen levels have substantially improved.

The water quality in the Wisconsin River today is perhaps better than it had been in the past hundred years, but all pollution has not yet been eliminated. Further improvements in water quality may come through implementation of the Wisconsin Department of Natural Resources wasteload allocation plan for the basin, and through the enforcement of the provision of Public Law 92-500 which requires elimination of discharges of pollutants into navigable waters by 1985, where technically and economically achievable. Color and suspended solids are two major components of pulp mill discharges that might be eliminated under this law.

The current Environmental Protection Agency water quality criteria for color and suspended solids discharges, alone or in combination, state that the compensation depth, or the depth at which plants balance oxygen production with respiration, must not be reduced by more than 10%. However, the Wisconsin Department of Natural Resources is not presently monitoring industrial color discharges.

The pulp and paper industry has investigated the effects of suspended solids on the aquatic environment and concluded that, in general, installation of tertiary treatment facilities to further reduce suspended solids discharges would be expensive but would produce little environmental benefit (Costa and McKeown 1979). However, considerable evidence has been collected which suggests that color and suspended solids may have damaging effects on both primary producers and invertebrates (Stockner and Cliff 1976, Soniassy et al. 1975, and Cairns 1968).

Nonpoint pollution is also a significant factor in the Wisconsin River watershed. Large inputs of nitrogen and phosphorus from tributaries in agricultural watersheds compound the river's problems. Blooms of blue-green algae are common in the reservoirs in summer. Collection of data showing both industrial impacts, and the interactions between point and nonpoint sources of pollution, is essential to evaluating the necessity for, and potential effects of, further pollution abatement.

Objectives

This research, then, has three main purposes:

1. to determine the impact of industry, especially the pulp and paper industry, on true and apparent color levels in the Wisconsin River.
2. to investigate the effects of true and apparent color on the river system, especially on its primary production, and predict the effects of decreased color levels.
3. to determine the trophic status of Lake Du Bay, the major sources and effects of nutrient pollution, and their relationships to the effects of color on primary production.

Sources of Color in Natural Waters

True color in water is generally composed of high molecular weight organic acids. Shapiro (1957) found the yellow coloring in Lower Linsley Pond, Connecticut, to be composed entirely of colored and colorless dicarboxylic acids with molecular weights around 456. These acids originated in soils, lake sediments, and decomposing vegetation, but were different from soil humic acids which generally have molecular weights around 1400. Shapiro proposed the name "humolimnic acids" for these compounds.

Since wetlands tend to contain large amounts of decomposing and soluble organic materials (Wetzel 1975), the main natural source of true color in the Wisconsin River is probably drainage from bogs and swamps in the northern part of the basin. As the river enters the southern part of the Northern Highland, below Merrill, there are fewer wetlands and true color in the tributaries decreases.

Particulate materials combine with the true color to produce the apparent color. Small organisms such as algae and bacteria, detritus, and soil and other inorganic particles all contribute to apparent color.

Sources of Color in Pulp and Paper Mill Effluents

The 14 pulp mills on the Wisconsin River produce 7 different types of pulp, related to the raw materials used and the type of paper products manufactured (Table 1). Each

Table 1. Pulp types produced in Wisconsin River pulp mills (Dyer 1979).

Pulp type	Mill	Location	Products
Deinked pulp	Georgia-Pacific	Tomahawk	Tissue paper
	Ward Paper	Merrill	Bond, mimeo, writing papers
Groundwood	Tomahawk Power and Pulp	Tomahawk	--
	Consolidated Papers	Whiting	Enamel book papers
	Consolidated Papers	Biron	Enamel book papers
Kraft	Mosinee Papers	Mosinee	Toweling and specialty papers
	Consolidated Papers	Wisconsin Rapids	--
	Nekoosa Papers	Nekoosa	Bond, manifold, offset papers
Rags	Plover Papers	Plover	Rag bond and writing papers
Semichemical	Owens-Illinois	Tomahawk	Corrugated medium
Sulfite			
Calcium	Rhinelander Papers	Rhinelander	Glassine and grease-proof papers
	Weyerhaeuser	Rothschild	Packaging and writing papers
Magnesium	Wausau Papers	Brokaw	Bond, ledger, mimeo papers
	Nekoosa Papers	Port Edwards	Bond, duplicating, offset papers

process has economic as well as environmental advantages and disadvantages.

All raw wood pulping processes separate wood fibers by removing the lignin that cements them together. Groundwood pulping is a mechanical process in which logs are scraped and ground between large stones. The heat of friction helps to dissolve the lignin and separate the fibers. Groundwood pulping is an inexpensive, high-yield process, but is not suitable for papers requiring strength or permanence unless special coatings are applied. Semichemical pulping combines the groundwood process with a chemical cooking process to soften the wood. Generally, 65-85% of the wood is yielded as pulp (Council on Economic Priorities 1972).

Chemical pulping separates wood into individual fibers by chemical dissolution of the lignin. Although chemical pulps can be used in a wider variety of products, up to 55% of the wood may be dissolved and wasted (Jones 1973). The two main chemical pulping types are the alkaline kraft and the acid or neutral sulfite processes.

Kraft pulping is widespread in the southern United States and accounts for 60% of the pulp produced in the entire United States (Council on Economic Priorities 1972). It produces a strong, dark pulp suitable for cardboard, grocery bags, and other packaging products. The digesting chemicals are NaOH and Na_2S. Because the economic feasibility of this process depends on recovering heat and chemicals, the extracted portions of the wood are burned off and the pulping liquor is reused. However, in this process methyl mercaptan (CH_2SH) and hydrogen sulfide (H_2S) may be released, producing the characteristic "rotten cabbage" odor of older kraft mills.

Sulfite pulping produces an easily bleached soft pulp suitable for high-quality papers. A sulfite or bisulfite of Ca, Mg, Na or NH_3 is combined with H_2SO_3 to digest wood chips. Intricate liquor recovery systems have been developed in recent years for spent sulfite liquors. Calcium is the only base for which there is presently no practical chemical recovery system. Calcium based mills therefore tend to concentrate on recovering usable byproducts from their spent pulping liquors. Rhinelander Papers, for example, grows yeast on these liquors.

Bleaching of the pulp combines chlorine with residual lignin and removes it from the fibers. These chlorinated lignins are the largest source of true color in mill effluents. Since sulfite pulp is generally more highly bleached than kraft pulp, sulfite mills are the larger contributors of true color to receiving waters (Kluesener 1968).

Suspended solids which contribute to apparent color in pulp and paper mill effluents generally consist of bacterial flocs and biosolids from the wastewater treatment process, fine fibers lost from the paper machines, and coatings and fillers used in the papermaking process (Costa and McKeown 1979, and Zanella et al. 1978).

Industrial Wastewater Treatment

Treatment of mill wastes concentrates on removal of BOD and suspended solids, two parameters for which discharge is currently regulated. Conventional secondary biological treatment is very efficient for BOD and suspended solids removal, but poor at removing true color (Wong and Prahacs 1977).

Physical-chemical tertiary treatments are necessary for true color removal. One such process, the PPRIC carbon treatment process, involves 4 steps: addition of powdered activated carbon, aeration, addition of alum and polyelectrolytes, and clarification. In a pilot study at a bleached kraft mill, this process removed toxicity, 75-80% of the color, and 20-40% of the remaining BOD. Color can also be removed by filtering the effluent through packed columns of activated carbon or resins. Ozone decolorization has also proved effective, but because it breaks down the otherwise resistant color molecules, it produces large increases in BOD. Most color removal processes for kraft mills could provide 80-95% true color removal at a capital cost of $1-3 million and an operating cost of $1-3 per air-dry ton of pulp produced. Costs are more difficult to estimate for sulfite mills because of the necessary association of color removal processes with existing liquor recovery systems (Wong and Prahacs 1977).

Suspended solids removal beyond present levels could be accomplished by addition of flocculating chemicals, dissolved-air flotation-foam separation processes, and ultrafiltration techniques (Jones 1973, and Wong and Prahacs 1977).

MATERIALS AND METHODS

Water Chemistry

River and tributary samples were generally collected from bridges with a 3-liter PVC Van Dorn sampler. Temperature was immediately determined in the field. Mill effluents were generally 24 hour composite samples collected by mill personnel.

Laboratory analyses generally followed the procedures listed in Standard Methods (APHA 1976). pH and conductivity were measured with a Corning Digital 110 pH meter and a Lab-Line Instruments Lectro-Mho meter, respectively. Alkalinity was determined by titration.

Total reactive phosphorus was measured by the stannous chloride method using a Bausch and Lomb Spectronic 88. Ammonia and nitrate-nitrite nitrogen, total Kjeldahl nitrogen, and total phosphorus were determined by Technicon Autoanalyzer (Technicon 1977).

Color was determined by the 1973 method of the National Council of the Paper Industry for Air and Stream Improvement (Carpenter and Berger 1973). Samples were adjusted to pH 7.6 and analyzed in a Bausch and Lomb Spectronic 88 at 465 nm. Apparent color was run on unfiltered samples. Samples for true color were filtered through Whatman GF/C filters.

Whatman GF/C filters were also used to filter total and volatile suspended solids and chlorophyll samples. Chlorophyll was analyzed by the trichromatic method. Calculations of chlorophyll a, b, and c were made from the EPA formulas (Weber 1973). A spectrophotometric pheophytin determination was also made, using the method described in Standard Methods (APHA 1976). The ratio of absorbance at 663 nm before and after acidification for pheophytin determination was also calculated (663B/663A).

Color Calculations

Flow data for the Wisconsin River and for storage reservoirs on tributary streams were obtained from the Wisconsin Valley Improvement Company. Flows for other gauged tributaries in the basin were obtained from the U.S. Geological Survey. Industries provided discharge data for the dates sampled. Ungauged tributary flows were estimated from flows of gauged tributaries using the sizes of the watersheds (USDA 1966) and the dominant basin soil types (Finley 1970).

Calculations of the relative contributions of sources to river color were made using the following relationship:

$\Sigma(\text{concentration} \times \text{flow}) / \Sigma\,\text{flow} = \text{final concentration}$

The formula was used first with all the tributaries and industries sampled in each segment, giving a predicted value for the present color of the river. The predicted value was then compared to the value actually observed to determine the accuracy of the prediction. The calculation was then repeated, omitting the concentrations and flows of industry, so that the contributions of the major tributaries could be found. The calculations were cumulative, so the predicted river values for a segment became the new river values for the subsequent segment.

Such calculations are necessarily based on the assumption that the river is well mixed, and relative contributions of the various sources are constant over the retention time of the areas sampled. This approach is rather simplistic but necessary for the great amount of area covered in the study.

Primary Production

In order to study the effects of water color on carbon assimilation rates in Lake Du Bay, a special apparatus was constructed. A 12-foot wooden raft was constructed with protruding 18-inch square frames which supported 6-foot long transparent plastic bags.

Bags were filled with river water or river water diluted to desired color levels with well water. Analysis of this well water gave true color values of less than 10 and apparent color values of less than 25 platinum-cobalt color units. The bags were set up the day before primary production experiments were run to allow temperature equilibration.

Samples for primary production measurements were collected from the upper meter in a 5-gallon plastic pail and transferred to 300-ml glass BOD bottles. The bottles were then inoculated with .20 mls of $NaH^{14}CO_3$, with an activity range of 1.28-2.41 uci/.20 mls. Light bottles were attached to holders on calibrated chains and suspended in the bags. Other light bottles were suspended at desired depths from a metal bar supported by two floats in approximately 10 feet of water. Dark bottles were incubated in a plastic bin filled with river water and set in approximately 1 foot of water to provide temperature control. The incubation period was 4 hours.

Samples were packed in ice and returned to the lab within 3 hours after incubation. Carbon assimilation was determined by the membrane filtration technique described by Lind (1974). A 25-ml subsample was filtered through a 47-mm diameter Millipore membrane filter and washed with 25 mls of distilled water. The filter was then dissolved in 20 mls of a napthalene-dioxane fluor (Schindler 1966) and assayed in a Packard Instruments 3320 liquid scintillation spectrometer. Total carbon assimilated was calculated from the equations of Lind (1974). Counting efficiency was determined by the internal standardization method.

Light penetration was determined <u>in situ</u> and in the bags with a Montedoro-Whitney submarine photometer (model LMT-8A) and Schott color filters VG9 (green), RG610 (red), and BG12 (blue). The instrument was recalibrated for response of 100% at the surface for each filter used. Light factors used in statistical analysis were calculated by the method of Talling (1957), assuming that 46% of the incident solar radiation was available for photosynthesis, with a 10% surface loss. Distribution of the remaining energy in the spectral regions was assumed to be 35% green, 35% red, and 30% blue. Samples for color and suspended solids analysis were also collected from the bags at the end of the incubation period.

Effluent Bioassays

Samples for sulfite mill effluent bioassays were collected from Rothschild Dam (river mile 258.4) and Mosinee Flowage (river mile 248.9) with a Van Dorn bottle. Final effluent from the Weyerhaeuser treatment plant was collected by plant employees. River water samples were filtered through .45 u Millipore membrane filters to remove indigenous organisms after prefiltration with a .8 u Reeve Angel glass fiber filter.

Bioassays were run in an environmental chamber at 450 foot-candles at 23.0 ± .5° C. Twenty mls of sample were placed in 20 ml glass scintillation vials, which were sealed with parafilm to prevent gas exchange or leakage under the screw caps. Light intensity was measured at shelf level with a Weston model 756 Sunlight Illumination Meter.

A sterile, unialgal culture of *Anabaena* sp. was obtained from Carolina Biological Supply and cultured in a modified PAAP media (Bartsch 1969). Inoculum for the tests was prepared by suspending cells from a week-old culture in a sodium bicarbonate solution. The final concentration of the inoculum was 3.75×10^3 filaments/ml in the vial, containing .1 mg chlorophyll *a* / liter.

Dilutions of .5%, 1%, 5%, and 10% effluent were prepared with filtered Rothschild river water and unfiltered final effluent. Two light bottles and one dark bottle were prepared for each sample assayed.

Samples were inoculated with .73 uci of $NaH^{14}CO_3$. Positions of samples in the incubator were changed each hour to compensate for possible light or temperature gradients. After a four hour incubation period, samples were prepared for liquid scintillation counting by the same methods used for primary production experiments. Counting efficiency was determined by the channels-ratio method first described by Baillie (1960).

Nutrient Bioassays

Algal nutritional bioassays were run according to the EPA algal assay procedure (U.S. Environmental Protection Agency 1971). Samples were collected at the Lake Du Bay Dam (river mile 235.4) in January and March, 1979. On the date of collection, half the sample was filtered through .45 u Millipore membrane filters, and 100-ml aliquots were set up in 500-ml Erlenmeyer flasks. The remainder of the sample was autoclaved in 100-ml aliquots in 500-ml flasks.

A unicellular green alga, Selenastrum capricornutum, and a filamentous blue-green alga, Anabaena flos-aquae, were used as test species. Cells were washed in a sodium bicarbonate solution before inoculation. Anabaena inoculum was prepared by running the culture through a Waring blendor to separate the filaments. Initial cell concentrations in the test flasks were 1000 cells/ml for Selenastrum and 10,000 cells/ml for Anabaena.

Nutrient spikes for the January Selenastrum assays consisted of the following:

P: 10 mls of 3.48 mg/l K_2HPO_4 (.006 mg P/ 110 mls).

N: 5 mls of 85 mg/l $NaNO_3$ (.07 mg N/ 105 mls).

N+P: 5 mls $NaNO_3$ solution and 10 mls K_2HPO_4 solution.

January assays were run in duplicate and March assays were run in triplicate. Assays were conducted in an environmental chamber under constant light and temperature conditions. Flasks were covered with aluminum foil and swirled daily to permit air exchange and prevent sedimentation. Growth was monitored over a 14-day period by using a Bausch and Lomb Spectronic 88 at 680 nm to measure optical density, and by filtering the assays through tared Whatman GF/C filters to determine the final dry weight of the algal cells.

Statistical Methods

Multiple regression analysis was performed using the Statistical Package for the Social Sciences program (Nie et al. 1975) on a Burroughs 6700 digital computer. Other statistical analyses used the "Minitab" program (Ryan et al. 1976).

RESULTS AND DISCUSSION

Color Trends on the Prairie River

Whipple (1914) found that natural rivers have two yearly periods of maximum true color, from May to June and from November to December, which are mainly influenced by precipitation. In winter and early spring, snow and snowmelt cause color dilution. Color increases in spring as wetland areas drain and meltwaters provide progressively less dilution. In summer, color decreases since wetland drainage is low except during high rainfall periods. Fall rains again increase color.

Daily apparent color values for the Prairie River were obtained for the period January, 1974 to February, 1980 from Ward Paper Company, Merrill, Wisconsin. Color was run by the visual comparison method (APHA 1976). The values were averaged, and average monthly apparent color was statistically compared to mean monthly temperature, mean monthly flow, and monthly precipitation (Table 2).

Highest color values occurred in summer, and were best correlated with high flows and high precipitation values. Wetland drainage and washing in of particulate materials are probable causes.

Color dropped slightly in the fall and more dramatically in the winter months, and was significantly related to flow. In spring, color again increased, correlated to temperature and flow. Temperature is probably a better predictor of flow conditions than precipitation during the spring runoff period.

Table 2. Seasonal changes in Prairie River apparent color (platinum-cobalt color units) in relation to mean monthly flow (cms), mean monthly temperature (°C) and monthly precipitation (mm).

	N	Mean	S.D.	Correlation to color
March-May				
Apparent color	16	56.0	25.7	
Flow	16	8.6	5.8	.596*
Temperature	16	4.6	7.2	.706**
Precipitation	16	66.8	37.3	.401
June-August				
Apparent color	16	60.9	44.0	
Flow	16	4.3	3.0	.800**
Temperature	16	18.0	1.7	-.142
Precipitation	16	100.7	51.0	.654**
September-November				
Apparent color	15	59.9	32.9	
Flow	15	4.2	1.3	.800**
Temperature	15	6.0	6.3	.463
Precipitation	15	61.7	38.5	.571*
December-February				
Apparent color	15	17.1	16.0	
Flow	15	2.6	.4	.641**
Temperature	15	-11.9	3.8	.500
Precipitation	15	27.1	12.1	.513
Overall				
Apparent color	62	48.8	35.7	
Flow	62	5.0	4.0	.545**
Temperature	62	4.4	11.8	.552**
Precipitation	62	66.0	45.4	.662**

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Overall, precipitation was the best predictor of color in the Prairie River, with flow and temperature also highly significant.

Color Trends on the Wisconsin River at Rhinelander and Mosinee

The reservoir system of the Wisconsin River prevents natural seasonal color changes from being fully expressed in the Wisconsin River basin (Figure 3). Water stored in spring and fall is released during summer and winter, making color values more uniform throughout the year. In addition, enhanced biological activity in the quiet water of reservoirs may affect color values downstream when this stored water is released.

True and apparent color were high at Rhinelander in the spring and early summer of 1978. High precipitation and snowmelt may have caused greater flushing of the large areas of wetlands in the Upper Wisconsin basin. In 1979, spring precipitation was lower, and true color declined with flow. Apparent color was significantly correlated with precipitation ($r = .931$) through the sampling period.

True color at Mosinee did not show a clear relationship with any of the climatic variables. Apparent color showed a significant negative correlation with flow ($r = .744$) through the sampling period. The occurrence of high apparent color at low flows may indicate enhanced biological activity at low flows or the impact of the concentration of industrial and municipal suspended solids dischargers in the Wausau area.

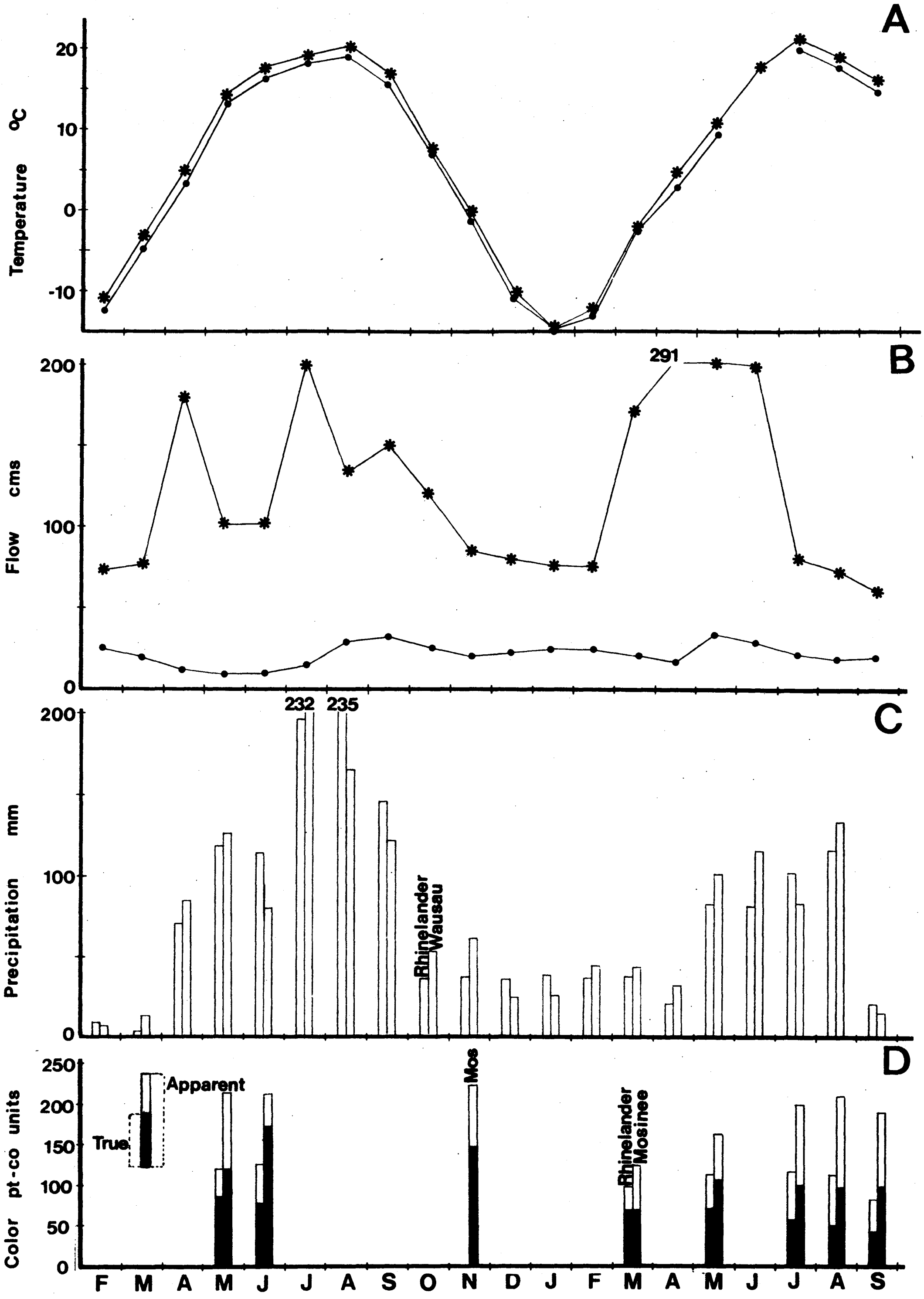


Figure 3. A. Mean monthly temperature at Rhinelander (●) and Wausau (✱). B. Mean monthly flow of the Wisconsin River at Rainbow Lake (●) and Rothschild (✱). C. Monthly precipitation at Rhinelander and Wausau. D. True and apparent color at Rhinelander (river mile 341.4) and Mosinee Flowage (river mile 248.9) for the period February, 1978 to September, 1979.

Accuracy of Predictions of Present River Color

The original objective of this research was to study the impact of all the Wisconsin River pulp and paper mills from Rhinelander to Nekoosa on the color of the Wisconsin River. However, because of the problems inherent in timely collection and analysis of samples from such a large area, only the segment of the river from Rhinelander to Lake Du Bay was sampled in 1979.

Although in general the same sampling sites were used on each date sampled, the accuracy of the predictions of present river color varied. True color predictions were most accurate at low flows, while apparent color predictions were most accurate at high flows. The 1979 predictions in general were closer to the observed values than the two 1978 sets, after initial problems with sampling sites and laboratory procedures were resolved (Figures 4 and 5).

Since all samples for one set of predictions (except the June, 1978 set) were collected within a 36-hour period, variations in quality of inputs were minimized. However, sampling times were not adjusted to the time of travel of specific inputs to the river. Therefore, previous inputs to and natural changes in reservoirs may have affected samples collected at reservoir sites.

Evaluation of sources of color in the Wisconsin River would ideally include consideration of the many unmeasured natural processes which operate. Even in the free-flowing segments, such factors as evaporation, groundwater dilution,

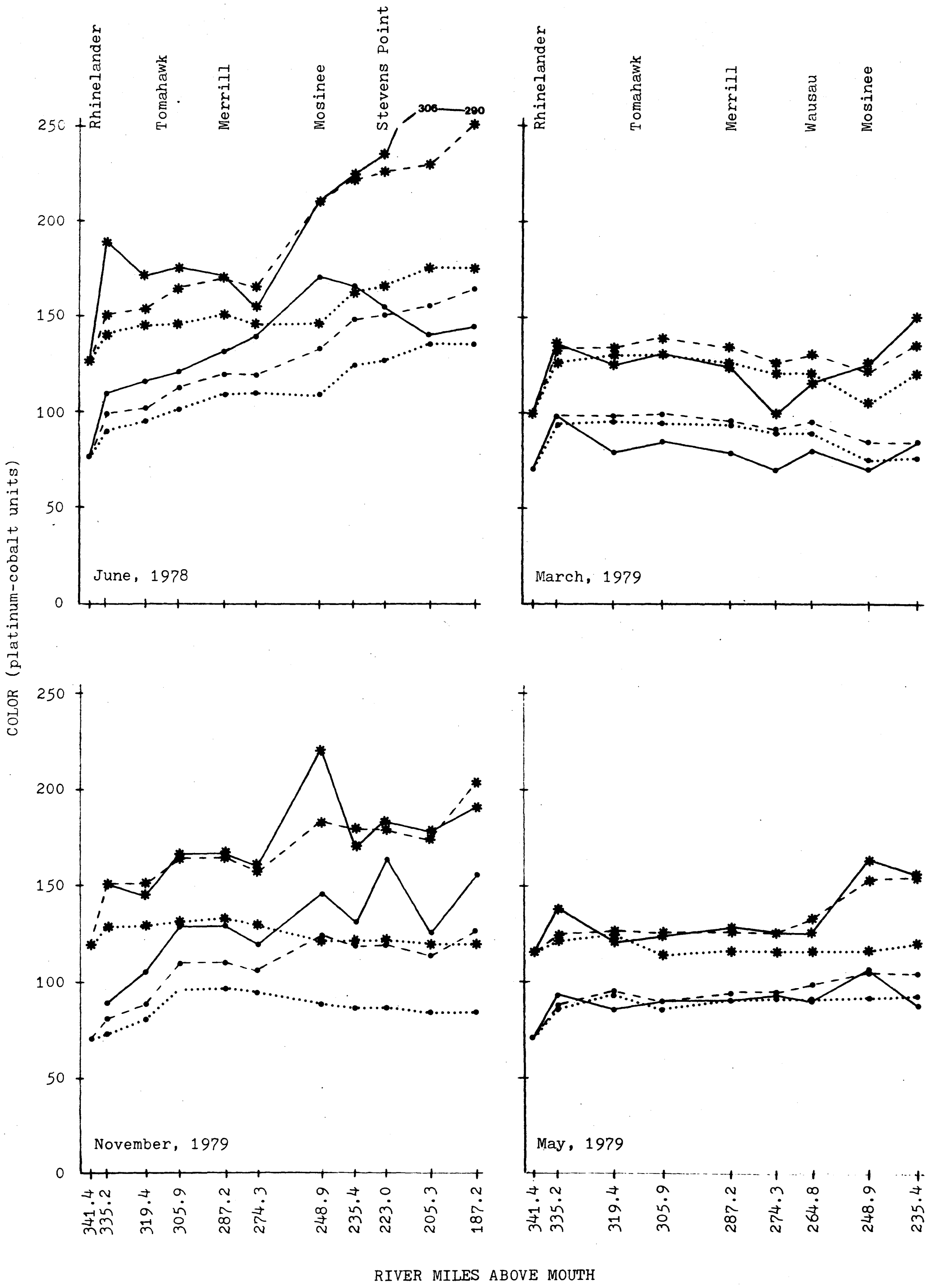


Figure 4. True (●) and apparent (✱) color values which were observed (——), predicted from all inputs (---), and predicted from the contributions of only the major tributaries (·····) for Wisconsin River sites from June, 1978, to May, 1979.

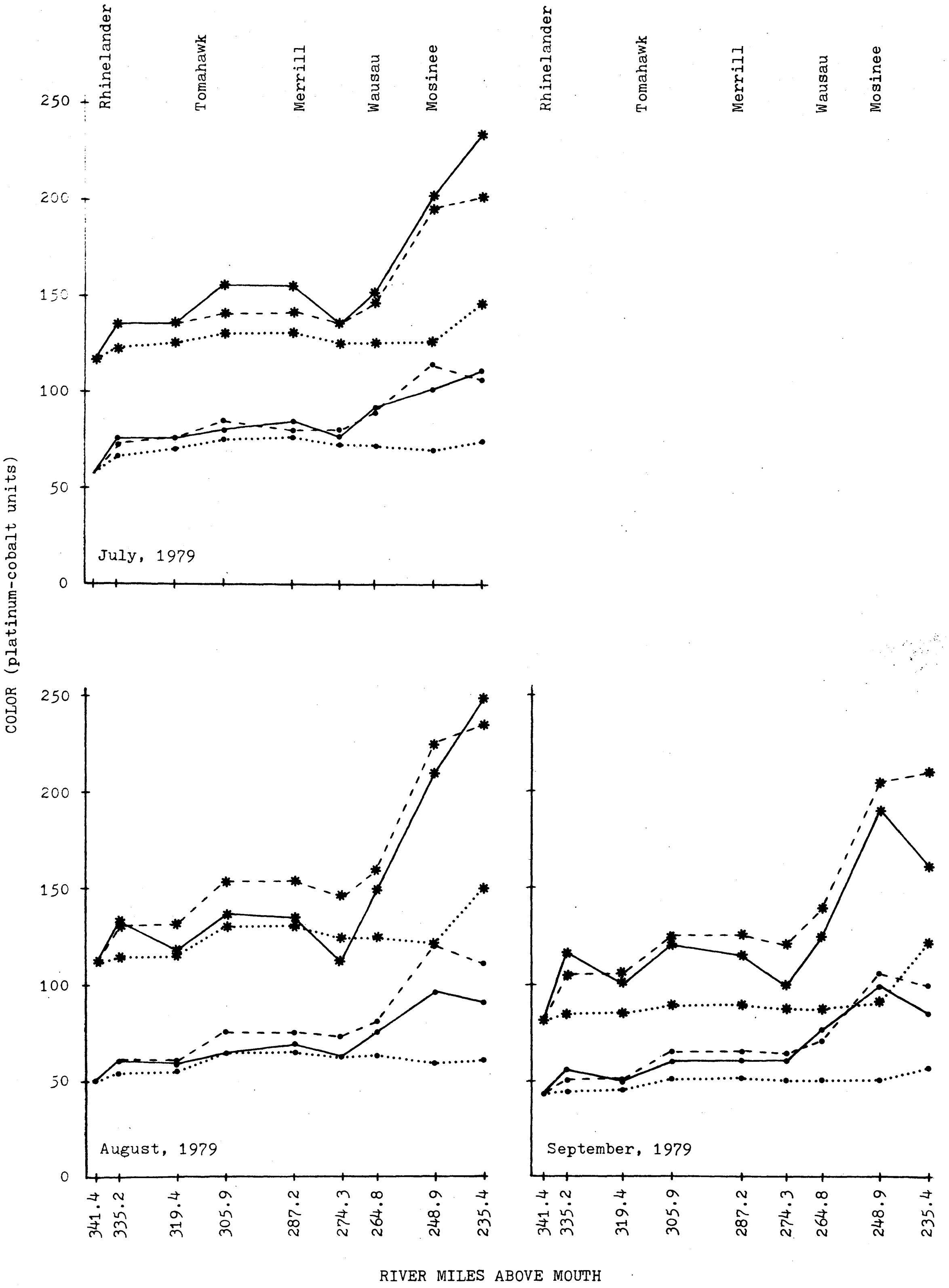


Figure 5. True (●) and apparent (✱) color values which were observed (——), predicted from all inputs (---), and predicted from the contributions of only the major tributaries (·····) for Wisconsin River sites from July to September, 1979.

overland drainage, unsampled small tributaries, settling and breakdown of particulates, and biological activities may have important effects.

Bleaching of true color by sunlight may be an important natural removal process. Whipple (1914) found that up to 50% of the true color could be bleached out at the surface of a reservoir in one month. Kluesener (1968) demonstrated this effect in lab studies for samples from Petenwell Flowage, Wisconsin River, and also found that in the dark, anaerobic decomposition caused color to increase. However, Juday and Birge (1933) found that color in northern Wisconsin lakes did not change appreciably over a period of months, and therefore did not support Whipple's findings.

Blue-green algae have also been shown to have color removing abilities. Jewson (1977) found that in Lough Neagh, Northern Ireland, true color varied inversely with the blue-green algae population during the summer months. He estimated that these color changes produced a change of .5 in the extinction coefficient for blue light and .1 for red and green light. However, the average extinction coefficients in Lake Du Bay in the summer of 1979 were 9.51 for blue light, 2.27 for red light, and 4.04 for green light. Color removed by blue-green algae would therefore cause minimal changes in the extinction coefficients for Lake Du Bay.

Lee et al. (1978a) found removal of true color by algae in 3-liter flasks to be 29%, 49%, and 61% after 10, 20, and 45 days of incubation, respectively. The depth of water in these incubation flasks was not mentioned, but was probably not more than 20-30 cm. It is therefore not known to what depth and so to what extent this algal activity might have been effective in natural waters.

Photooxidation and biological activity may have been the reason that some true color values in the Wisconsin River were lower than predicted (Figure 5), but turbidity and the mixing action of wind and waves would probably cause reductions in nature to be smaller than those in lab studies.

The general agreement of observed and predicted values, as shown by the averages of unexplained color units (Table 3) confirms both the suitability of our sampling sites and the smaller impact of natural color changes in the river itself compared to the measurable impacts of tributaries and industries. The overall average error for all sites from Rhinelander to Lake Du Bay was less than 1% for both true and apparent color.

Predictions for the Rhinelander to Hat Rapids segment were often lower than observed values. However, color values for samples taken two miles upstream in the Hat Rapids flowage, below all the monitored discharges for that segment, were very similar to those taken below the dam. The average discrepancies of 4.0% for true color and 6.8% for apparent color then probably result from decomposition of the mucky bottom or surface drainage from the wetlands in that segment.

Both true and apparent color generally decreased between Hat Rapids and Kings Dam, although predictions usually showed

Table 3. Means and standard deviations of true and apparent color values, color units not accounted for by calculations including all measured inputs, differences between predictions which include and exclude industry, and average percentages of present river color contributed by industry for the seven Wisconsin River water quality surveys.

	Site	River mile	N	Average river value	S.D.	Unexplained average value*	S.D.	Industrial average value	S.D.	% from industry
True color	Rhinelander	341.4	6	61.5	12.9	--	--	--	--	--
	Hat Rapids	335.2	7	83.1	19.6	3.3	4.0	6.0	2.2	7.9
	Kings Dam	319.4	7	81.9	23.9	-3.0	11.8	5.4	2.4	7.2
	Grandmother Dam	305.9	7	90.1	26.4	-0.9	7.7	9.6	3.4	11.5
	Merrill	287.2	7	92.0	28.2	-0.7	4.5	9.0	4.0	10.6
	Granite Heights	274.3	7	88.6	30.2	-0.7	5.8	8.1	3.8	10.1
	Wausau	264.8	5	83.0	7.6	3.4	6.1	14.4	7.3	17.7
	Mosinee Flowage	248.9	7	113.3	34.4	-1.1	15.2	35.4	19.9	33.0
	Lake Du Bay	235.4	7	108.1	31.1	-4.0	12.7	28.7	15.0	28.1
	Stevens Point	223.0	2	159.5	6.4	9.0	33.9	27.0	7.1	16.9
	Biron	205.3	2	133.0	11.3	-25.0	8.5	25.0	7.1	19.1
	Petenwell	187.2	2	151.0	7.1	6.5	14.8	36.5	10.6	24.1
Apparent color	Rhinelander	341.4	6	108.2	15.7	--	--	--	--	--
	Hat Rapids	335.2	7	143.1	22.9	9.7	13.9	13.6	7.6	9.8
	Kings Dam	319.4	7	130.9	23.2	-12.1	6.5	12.6	8.3	10.1
	Grandmother Dam	305.9	7	144.7	21.9	0.9	7.9	21.1	10.7	14.9
	Merrill	287.2	7	142.1	22.6	-2.7	3.4	19.8	11.1	14.3
	Granite Heights	274.3	7	126.1	25.1	-10.8	7.6	18.1	10.7	14.8
	Wausau	264.8	7	133.6	15.9	8.4	11.1	27.4	16.9	20.4
	Mosinee Flowage	248.9	7	189.0	33.9	9.8	14.1	66.8	34.4	34.1
	Lake Du Bay	235.4	7	192.1	41.4	-2.8	29.0	56.1	26.1	29.1
	Stevens Point	223.0	2	210.0	36.8	11.5	3.5	58.5	0.7	28.2
	Biron	205.3	2	242.0	90.5	34.0	48.1	53.5	0.7	23.8
	Petenwell	187.2	2	241.0	69.3	-26.5	13.4	80.5	6.4	35.3

* Negative values indicate predicted value > observed value.

no change. Underestimation of the influence of tributaries in this segment, or a treatment effect of the large reservoir, are the probable reasons for the average 3.7% error in true color and 9.2% error in apparent color predictions.

Predictions for true color in the free-flowing segment from Grandmother Dam to Granite Heights were generally good. Apparent color predictions were often too high, perhaps indicating a treatment effect as solids are broken down in these faster-flowing waters.

The Wausau to Mosinee segment was difficult to predict both because of the magnitudes of the changes and the many possible influences in an urban area. The Wausau sewage treatment plant is the largest on the Upper Wisconsin River, and the effect of its discharge, which was not monitored for this study, may be a significant part of the average error of 6.3% in apparent color calculations for this segment.

Below Mosinee, large flowages such as Lake Du Bay, Biron, and Petenwell become major components of the river system. Longer retention times in these reservoirs increase the potential for natural color changes and lessen the ability to trace specific discharges. Therefore, the accuracy of predictions of present color for these reservoirs was somewhat lower.

Impacts of Industry on River Color

Effects of industry on river color were determined by their inclusion in and exclusion from the color calculation formula. Since industrial discharge volumes are fairly constant over time, their greatest impact occurs at low flows (Table 4).

Percentages of color contributed by industry were calculated by dividing the difference between predicted river color with and without industry by the observed river color, even when the predicted color with industry exceeded the observed value. Since the industrial effluents were generally 24-hour composite samples collected by mill presonnel, and since flows from mills are accurately gauged, the value for (color x flow) from each industry was assumed to be correct. Predicted values were then assumed to be higher than observed values because of groundwater and unmeasured tributary dilutions and treatment processes in-river and not because of behavior of the mill effluent.

Except at times when the discharges from the Tomahawk and Spirit reservoirs are large and highly colored, the major tributaries of the Wisconsin River do not cause a significant increase in river color between Rhinelander and Mosinee (Figures 4 and 5). Color often increases in Lake Du Bay from the Little Eau Pleine River, which drains the marshy Mead Wildlife Area.

The impact of the Rhinelander sulfite mill discharge is increased by the smaller flow of the river in the northern section. The Tomahawk semi-chemical mill has a large and highly colored discharge, but its impact is lessened by the entrance of the Tomahawk and Spirit Rivers, which generally double the Wisconsin River's flow. A tissue mill in Tomahawk

Table 4. Minimum, maximum, and average percentages of true and apparent color contributed by industry at Wisconsin River sites, average and range of color units, and the dates of occurrence.

Site	River Mile	N	Average %	Minimum %	Date	Maximum %	Date	Color Units	
								Average	Range
True color									
Hat Rapids	335.2	7	7.9	2.2	5-79	14.3	9-79	6	2- 8
Kings Dam	319.4	7	7.2	2.3	5-79	14.0	9-79	5	2- 8
Grandmother Dam	305.9	7	11.5	5.5	5-79	21.7	9-79	10	5- 13
Merrill	287.2	7	10.6	3.8	3-79	21.7	9-79	9	3- 13
Granite Heights	274.3	7	10.1	3.2	5-79	20.0	9-79	8	3- 12
Wausau	264.8	5	17.7	7.4	3-79	27.6	9-79	14	6- 21
Mosinee Flowage	248.9	7	33.0	12.8	3-79	62.9	8-79	35	9- 61
Lake Du Bay	235.4	7	28.1	8.2	3-79	53.8	8-79	29	7- 49
Stevens Point	223.0	2	16.9	14.2	6-78	19.5	11-78	27	22- 32
Biron	205.3	2	19.1	14.2	6-78	24.0	11-78	25	20- 30
Petenwell	187.2	2	24.1	20.0	6-78	28.2	11-78	37	29- 44
Apparent color									
Hat Rapids	335.2	7	9.8	2.2	5-79	18.8	9-79	14	3- 23
Kings Dam	319.4	7	10.1	1.6	5-79	21.2	9-79	13	2- 23
Grandmother Dam	305.9	7	14.9	8.3	7-79	31.4	9-79	21	11- 38
Merrill	287.2	7	14.3	5.7	3-79	32.2	9-79	20	7- 37
Granite Heights	274.3	7	16.2	5.1	3-79	34.7	9-79	18	5- 34
Wausau	264.8	5	22.2	7.7	3-79	41.6	9-79	27	9- 52
Mosinee Flowage	248.9	7	36.6	13.6	3-79	60.5	9-79	69	17-115
Lake Du Bay	235.4	7	30.7	9.3	3-79	54.7	9-79	56	14- 88
Stevens Point	223.0	2	29.3	25.0	6-78	31.5	11-78	59	58- 59
Biron	205.3	2	24.0	17.3	6-78	30.3	11-78	54	53- 54
Petenwell	187.2	2	35.3	26.2	6-78	44.3	11-78	81	76- 85

and a wastepaper pulping firm in Merrill are too small to significantly change river color.

Between Granite Heights and Mosinee, two large sulfite mills, and to a lesser extent, a chemical processing plant, contribute to the most dramatic color increase in the river. Analysis of tributaries in this segment shows that the natural color actually decreases slightly, emphasizing the effect of industry.

From Mosinee Flowage to Biron, the mill discharges are small in relation to river flow, and their color values are lower. Analysis of two data sets for the Stevens Point to Biron segment indicates that these industries actually lower river color slightly. At Wisconsin Rapids and Nekoosa, two large mills discharge highly colored effluents, but large river flows and already high color values cause the color increases in this segment to be lower than those in the Wausau area.

It might be argued that the observed increases in apparent color downstream from mills result from increased biological activity rather than suspended solids produced by mills. Recent industry studies have concluded that the 30-200 mg/l of suspended solids discharged to receiving waters by the pulp and paper industry biological treatment systems (NCASI 1978) consist largely of bacterial flocs and other biosolids. They reported that these materials are quickly oxidized and removed from the system without settling or causing harmful turbidity levels (Costa and McKeown 1979). Nutrients released in this decomposition process, however, may increase production of other biological materials in the receiving waters (Lee et al. 1978b).

If increased production of biomass does occur in the Wisconsin River as a result of decomposition of industrial biosolids, chlorophyll levels might be a suitable index to that increase. In the upper part of the river, chlorophyll levels generally do not change much between sites, especially where retention times are short. Summer chlorophyll levels do increase substantially between Granite Heights and Mosinee, so apparent color increases due directly to industry may be overestimated in that segment. However, the Mosinee to Lake Du Bay segment often shows a larger chlorophyll increase with a smaller increase in apparent color. In addition, the Rib and Eau Claire Rivers form flowages just before they enter the Wisconsin River in the Granite Heights to Mosinee segment, and their summer chlorophyll content is also often high. Some of the increase in chlorophyll in the Wisconsin River is then accounted for when the apparent color contributions of these tributaries are calculated.

Another study by the Institute of Paper Chemistry found biological materials to be only 40-66% of the total nonsettleable solids discharged by the pulp and paper industry. Clay coatings and fillers comprised up to an additional 20% (Zanella et al. 1978). These nondegradable, nonsettleable inorganic solids may then be an important component of the apparent color contribution of the pulp and paper industry to the

Wisconsin River.

Contrary to the common belief that the color of the Wisconsin River is natural, industry is here shown to have a significant impact, measurable even during the high flows of spring runoff. The most significant increases in color occur in the Granite Heights to Mosinee Flowage segment, followed by the Biron to Petenwell and Rhinelander to Grandmother Dam segments.

Effects of Industry on River Conductivity

The contributions of major tributaries and industries to the conductivity of the Wisconsin River were calculated by the same method used for color calculations. The average results for the five 1979 river surveys are presented in Figure 6. The accuracy of conductivity predictions from all major inputs was similar to the accuracy of color predictions (Figures 4 and 5). Since the conductivities of industrial effluents are significantly higher than river and tributary conductivities, the calculations excluding industry predict lower river conductivity, similar to the results obtained for color.

Conductivity, like true color, is often considered a conservative component. Many of the major ions contributing to conductivity, such as chloride and sulfate, are relatively unaffected by biological activity. The results of this conductivity analysis reconfirm that the calculation procedure used is an adequate representation of the behavior of conservative components entering the Wisconsin River system from

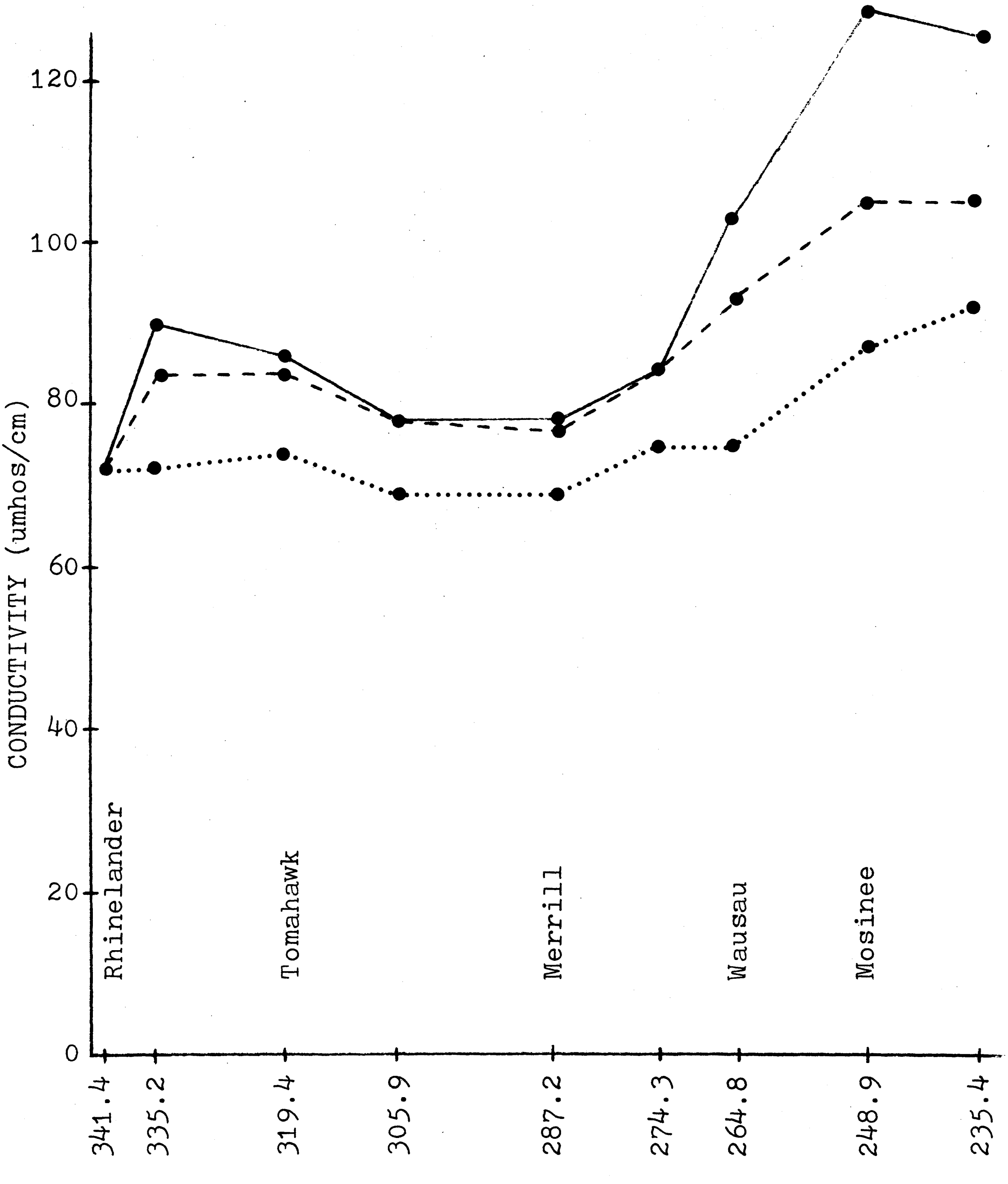


Figure 6. Average conductivity values which were observed (——), predicted from all inputs (---), and predicted from the contributions of only the major tributaries (······) for Wisconsin River sites during five water quality surveys from March to September, 1979.

major tributaries and industries.

Effects of Light Penetration on Algal Growth

Sunlight is the primary energy source for the entire aquatic ecosystem in which the algae are the primary producers. The nutrient and dissolved oxygen content of water, its color and turbidity, its production of fish, and therefore its suitability for recreational and industrial uses may be affected by primary production. Wastewater discharges which affect the penetration of light may therefore have important effects on both aquatic ecosystems and potential human uses of water.

Early researchers in primary production, such as Ryther (1956), emphasized light as a limiting factor and defined the relationships between visible light penetration and maximum photosynthesis. More recently, attempts have been made to define the effects of the spectral penetration of light on algal productivity.

Strong attenuation of light in the 400-500 nannometer wavelengths, the blue to green range, is evident in eutrophic waters (Ganf 1974, Jewson 1977), in highly colored dystrophic waters (Juday and Birge 1933), and in waters receiving pulpmill effluent (Stockner and Cliff 1976). This attenuation is caused primarily by dissolved organic material, since suspended materials decrease overall light penetration but are comparatively unselective of wavelength (Wetzel 1975).

Similar spectral effects occur in Wisconsin River water

(Figure 7). Filtered water from two Wisconsin River sites, a sulfite mill discharge, and a natural peat bog was analyzed in a spectrophotometer at 50 nm intervals from 400-700 nm, using a 2-cm light path. Absorbance was greater in the Mosinee sample than in the Rhinelander sample at all wavelengths, but especially in the 400-500 nm range. Mill effluent and bog water, which both contain higher amounts of dissolved organics, showed similar absorbance patterns and the same maxima in the blue to green range. Brezonik (1978) found that highly colored neutral sulfite pulping wastes, commercial humic acid, and colored lake water have essentially the same sources of humates and therefore the same absorbance spectra.

Color can also be shown to have a significant effect on the light extinction coefficients determined in field studies (Figure 8). White light extinction coefficients were plotted against true color values for 11 Wisconsin River sites in June and July, 1979. An excellent correlation coefficient (r=.905) was found for the two sets of data. The results indicate that light penetration decreased with increases in true color. No significant relationship was found between apparent color and the extinction coefficient on this date.

When the relationship between true color and the light extinction coefficient is known, the relationship of true color discharges to changes in compensation depth can also be obtained. Such information can lead to the establishment of acceptable color discharge levels to insure that the compensation depth will not be changed more than 10% by any one

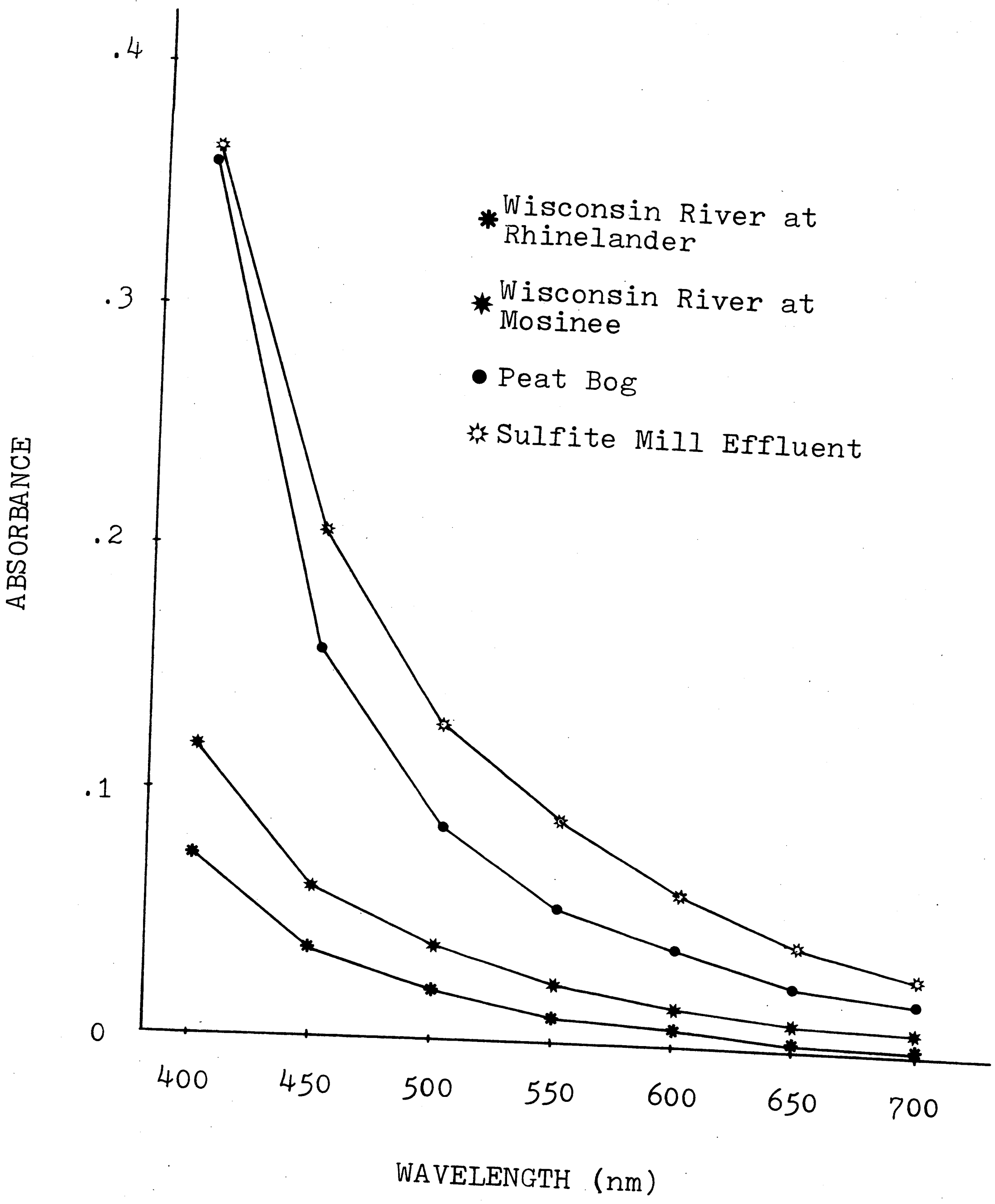


Figure 7. Absorbance of light in a spectrophotometer at 50 nannometer intervals by Wisconsin River water, water from a natural peat bog, and sulfite mill effluent.

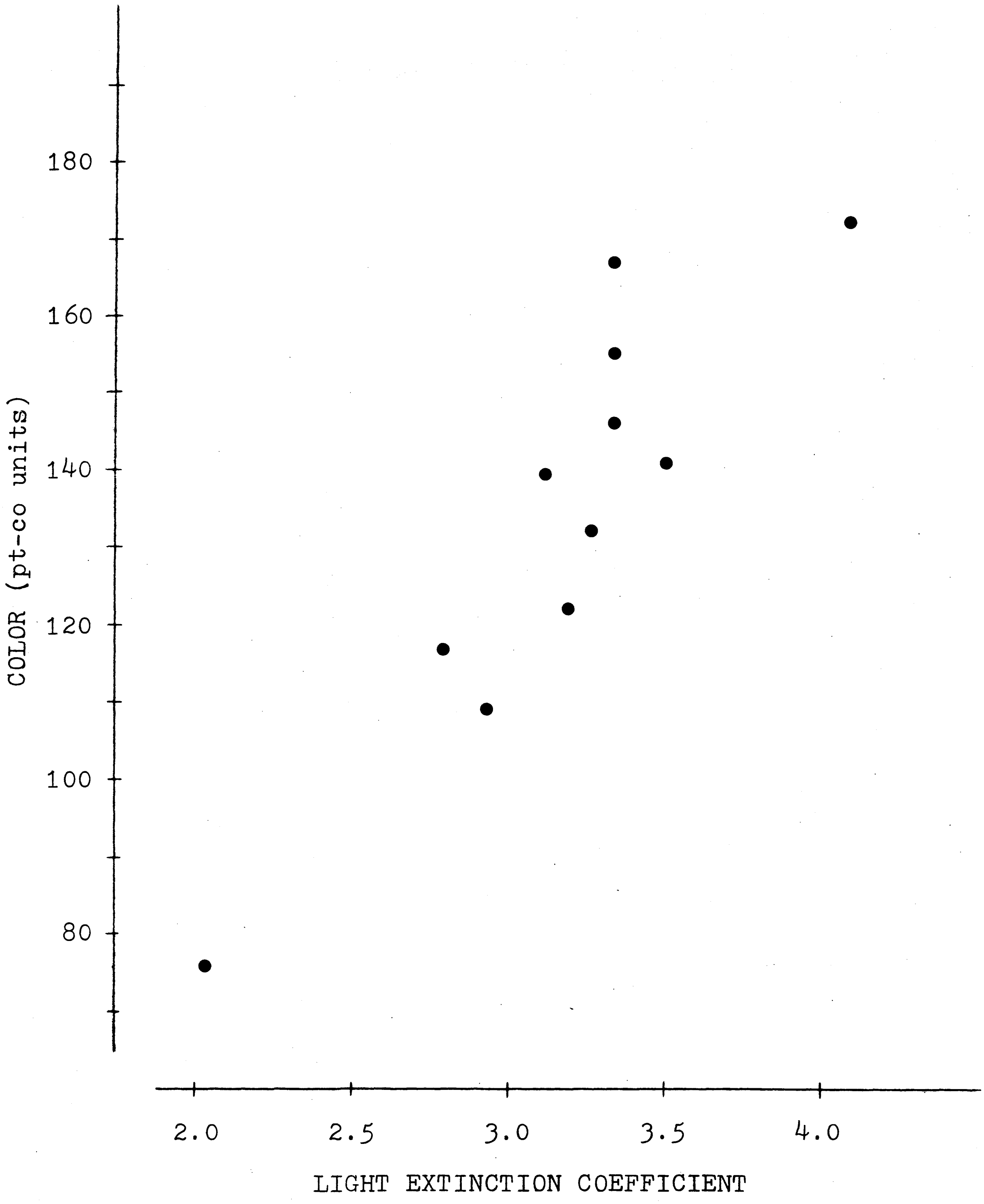


Figure 8. Observed relationship between light extinction coefficient and true color value for 11 Wisconsin River sites in June and July, 1978.

discharger. A sample table giving acceptable color discharges in each segment is presented as Table 5.

Table 5. Allowable effluent true color levels (pt-co units) for June 27-July 8, 1978, for each discharger in the segment with indicated discharge volumes.

	5	10 million gallons/day	15	20
Rhinelander to Hat Rapids	1390	749	534	427
Hat Rapids to Kings Dam		-- no dischargers --		
Kings Dam to Grandmother Dam	5717	2924	1991	1525
Grandmother Dam to Merrill		-- no dischargers --		
Merrill to Granite Heights	4093	2111	1449	1119
Granite Heights to Mosinee Flowage	4820	2475	1692	1301
Mosinee Flowage to Lake Du Bay Dam	3762	1952	1348	1046
Lake Du Bay Dam to Stevens Point		-- no dischargers --		
Stevens Point to Biron Dam	8059	4110	2792	2172
Biron Dam to Petenwell	7530	3845	2615	2001

The basis for the calculations was the predicted natural color of the river in each segment, as obtained from previous calculations. The extinction coefficients were calculated from the following regression equation:

$$\text{extinction coefficient} = 0.017\,(\text{true color (pt-co units)}) + 0.95$$

$R^2 = .819^{**}$ $N = 11$

**Significant at the 0.01 level.

The compensation depth was then calculated as:

compensation depth = (4.605 / light extinction coefficient). This formula was derived from the light extinction equations of Lind (1974). The compensation depth was then decreased by 10%, and the calculation procedure was then reversed to give a new true color value for the river. Discharge levels which would not cause the river color to exceed the new color value were then calculated by resolving the formulas used in predicting river color.

The allowable color discharge levels are therefore related both to the flow and natural color of the river and the flow and color of the tributaries. Such a calculation procedure considers the effect of a discharge on an entire river segment. However, working tables for enforcement purposes would probably use only actual color immediately above the discharge, and the flow conditions. Color discharge regulation would then be based on the theoretical effect of the discharge if it were well-mixed across the river immediately at the discharge point.

Although no individual discharger exceeded the 10% limit based on analysis of true color discharges during this sampling run, the cumulative effect of the dischargers was to reduce the compensation depth by as much as 14% below predicted natural levels (Table 6). At low flows, greater compensation

Table 6. Estimated percent decreases in compensation depth caused by the cumulative effect of pulp and paper industry true color discharges from June 27-July 8, 1978, at 10 Wisconsin River sites.

Site	% decrease in compensation depth
Hat Rapids Dam	4.3
Kings Dam	4.4
Grandmother Dam	7.0
Merrill	5.5
Granite Heights	4.9
Mosinee Flowage	13.3
Lake Du Bay Dam	11.3
Stevens Point	10.9
Biron Dam	9.3
Petenwell	13.5

depth reductions might be expected. In addition, further collection of data might indicate that apparent color discharges also have a significant effect on compensation depth.

Reduction of light penetration by true color can have a significant effect on algal production. Soniassy et al. (1975) passed light through varying depths of bleached kraft mill effluent in plastic compartments suspended above Selenastrum capricornutum cultures. Resulting reductions in light penetration of 10%, 21%, and 40% lowered algal production by 18%, 56%, and 79%, respectively.

Turbidity is another important factor influencing light penetration in natural waters. Lee et al. (1978b) predicted that turbidity produced by suspended solids would have less impact than true color on algal production, because true color molecules absorb light, while suspended solids scatter a portion of the light. Turbid conditions might then favor blue-green algae, because their pseudovacuoles keep them in the upper layers of water where scattering effects would be greatest. In addition, suspended solids cause warming of near-surface waters, which might also contribute to the success of blue-green algae, since they prefer warmer temperatures (Hammer 1964).

General decreases in light penetration also favor dominance of blue-green algae. Brown and Richardson (1968) have identified blue-green algae as the group best able to compete at low light intensities. Mur et al. (1978) found that the outcome of competition between <u>Oscillatoria</u>, a blue-green alga, and <u>Scenedesmus</u>, a green alga, in mixed culture, was solely determined by the intensity of light to which the culture was subjected. At low light intensities, <u>Oscillatoria</u> was favored. At high light intensities, <u>Scenedesmus</u> outcompeted <u>Oscillatoria</u> when both were inoculated simultaneously. If <u>Oscillatoria</u> was reinoculated after the numbers of <u>Scenedesmus</u> became sufficient to produce self-shading, <u>Oscillatoria</u> was able to outcompete and eliminate <u>Scenedesmus</u>. Such light relationships, along with differences in respiration rates influenced by temperature (Jones 1977) may help to account for observed seasonal succession in natural waters.

The success of blue-green algae at low light intensities may be attributable to their increased production of phycobilins, which allows them to use a broader range of wavelengths in photosynthesis (Brown and Richardson 1968).

Transfer of energy to chlorophyll a by these accessory pigments is very efficient (Govindjee and Braun 1972). In addition, the concentration of carotenoids, pigments which act as blue light filters, decreases at low light intensities, so their photosynthetic capacity in blue light increases (Hallidal 1970).

Although their capacity to use blue light can be increased, blue-green algae are still less efficient at using blue light than are other algal phyla (Govindjee and Braun 1972). When Stockner and Cliff (1976) compared the absorption spectra of chlorophyll a and accessory pigments to the spectral absorbance of pulpmill effluent, they stated that selective absorption of light in the 400-500 nm wavelengths by mill effluent was the most important factor limiting diatom growth in Howe Sound, British Columbia. Such selective absorption would be of less importance to blue-green algae. Blue-green algae are generally dominant in eutrophic waters, where blue light is most often the least penetrating spectral component (Ganf 1974).

Trophic Status of Lake Du Bay

Light penetration is extremely important to algal growth, but without sufficient nutrients, or in the presence of toxic substances, adequate light penetration might have little effect. For this reason, this section examines the trophic status of Lake Du Bay, its sources of nutrients, and the relative contributions of industrial, municipal, and nonpoint sources. The following sections will deal with problems of toxicity of mill effluents to algae.

By subjective aesthetic analysis, Lake Du Bay would be considered an eutrophic reservoir. Although intuitive description of a body of water as eutrophic is fairly simple, establishment of procedures to assign a numerical value to the degree of eutrophication is very difficult because of the complex interactions between chemical, biological, and physical parameters. Many trophic state indices have been proposed as researchers have attempted to find simple methods of classifying bodies of water.

Reckhow (1978) has reported on a comparison of four chlorophyll a level classifications done by the EPA National Eutrophication Survey. All define the separation between mesotrophic and eutrophic lakes as 8.8-15 ug/l chlorophyll a. Lake Du Bay, with summertime chlorophyll a levels of 30-70 ug/l, would be considered quite eutrophic by this criterion.

Carlson (1977) produced a trophic index which he felt could be applied equally well to all surface waters, including free-flowing rivers. Secchi disk depth, total phosphorus concentration, or chlorophyll a levels are used to calculate a trophic number on a scale of 0-100. Carlson intended to avoid use of the terms oligotrophic, mesotrophic, and eutrophic, but inevitably such labels were applied to his system. Numbers less than 40 were considered oligotrophic, and those greater than 50, eutrophic (Reckhow 1978). Index numbers for Lake Du Bay averaged 70 (Table 7), again emphasizing its eutrophic nature.

A further development in lake classification has been

Table 7. Carlson's (1977) trophic state index numbers for Lake Du Bay from May, 1978, to September, 1979.

	Secchi Disk	Chlorophyll *a*	Total P	All
Mean	63	68	72	70
S.D.	--	4.5	5.9	5.9
N	1	3	11	15

the creation of loading formulas designed to describe the amounts of nutrients that could enter a lake without changing its trophic state. The first such formula was described by Vollenweider (1968), based on the relationship between mean depth and productivity.

To apply this formula to Lake Du Bay, yearly phosphorus and nitrogen loading for industries and tributaries from Granite Heights to Lake Du Bay was calculated, based on the observed loading for five sampling dates in 1979. Loading for municipalities was calculated based on data from the Wisconsin Department of Natural Resources water quality model "Qual-III" (Sullivan 1980). Data were available for the following locations:

Industries: Wausau Papers, Weyerhaeuser, American Can, Mosinee Papers.

Tributaries: Rib, Eau Claire, Big Eau Pleine, Little Eau Pleine, Little Eau Claire Rivers.

Municipalities: Brokaw, Wausau, Rothschild, Mosinee.

Although the data are crude, the magnitude of the difference between "dangerous" loading levels and those presently entering the river (Table 8) suggests that all three sources listed may have serious effects on water quality, but that tributaries have the greatest impact on total nutrient loading. Municipalities generally have the greatest percentage of available nutrients, while nutrients discharged from industry are mainly not in immediately available forms.

However, Vollenweider and others quickly realized that one of the most important factors was missing from the loading calculations: the flushing time of the body of water. A lake with a shorter retention time would suffer less damage from high nutrient loading on an annual basis than a similar lake whose flushing time was much longer. For Lake Du Bay, which is not a natural inland lake, but a hydropower reservoir on a large river system, the consideration of retention time becomes essential.

To calculate retention time, an historical average flow for Lake Du Bay was obtained by regression analysis. Monthly average flows for the Lake Du Bay dam and the Centralia dam at Wisconsin Rapids were calculated from daily values. An excellent correlation (r = .995) was found between the two stations, allowing estimation of the historical average flow at Lake Du Bay dam at 3872 cfs from the Centralia historical average of 4933 cfs.

The maximum storage capacity of Lake Du Bay is 2,065 million cubic feet (Andrae 1980). With a surface area of 6830 acres, the mean depth at full capacity would be 7 feet. Dividing the storage capacity by the average annual flow

Table 8. Yearly phosphorus and nitrogen loading ($g/m^2/yr$) to Lake Du Bay from industries, municipalities, and tributaries from Granite Heights to Lake Du Bay, as compared to Vollenweider's (1968) "dangerous" levels.

	Total P	Reactive P	% of total	Total N	Soluble Inorganic N	% of total
Vollenweider's "dangerous" levels at mean depth 5 m.	0.13			2.0		
Industries	2.94	0.97	32.9	23.32	4.14	17.7
Municipalities	1.26	--	--	6.81	--	--
Tributaries	10.44	5.56	53.3	148.18	62.29	44.7
Wisconsin River at Granite Heights	6.63	2.26	34.0	90.15	32.42	36.0
Wisconsin River at Lake Du Bay dam	33.34	16.20	48.6	609.02	231.94	38.1

results in a retention time of 6.2 days. Vollenweider's 1976 formula for critical phosphorus loading can then be applied:

$$Lc = Pc\ z\ \left(\frac{1+\sqrt{T}}{T}\right)$$

where Lc = critical phosphorus loading ($g/m^2/yr$)
Pc = critical phosphorus concentration (mg/l)
z = lake mean depth (m)
T = hydraulic retention time (yr)

Eutrophic loading for Lake Du Bay can then be calculated as 2.80 $g/m^2/yr$. By this criterion, reactive phosphorus loading from industries alone would not be significant. However, since the industry contends that most particulate materials discharged are broken down in the receiving waters (Lee et al. 1978b), the industrial total phosphorus loading of 2.94 $g/m^2/yr$ may be quite significant.

The timing of nutrient loading may also be a significant factor in eutrophication in impoundments. Although tributary loading is highest on an annual basis, much tributary loading occurs in spring and may be rapidly flushed through the system. However, loading from industries and municipalities is fairly constant year round. Under low flow conditions, point sources could be expected to have a greater effect on eutrophication.

Algal Nutritional Bioassays

An alternative method of assessing the trophic status of a body of water is the Algal Assay procedure (U.S. Environmental Protection Agency 1971). Test algae are grown in the water of interest under laboratory conditions. Controls indicate the amounts of nutrients presently available or ultimately available for algal growth, and the resulting trophic state. Nutrient spikes are used to indicate which nutrients are immediately or ultimately limiting.

Algal assays were run on Lake Du Bay dam water in January and March, 1979. January assays were run with two test algae, *Selenastrum capricornutum* and *Anabaena flos-aquae*, while only *Selenastrum* assays were run in March.

Filtered *Selenastrum* assays conducted in January indicated phosphorus as the primary immediate limiting nutrient. Addition of phosphorus stimulated growth over the control (Figure 9). The secondary limiting nutrient was nitrogen, because the nitrogen + phosphorus spike produced additional growth over the phosphorus spike alone.

Filtration as a sample pretreatment is necessary to remove indigenous organisms that might otherwise interfere with the growth of the test algae. However, some authors have stated that this procedure might produce erroneous results. Phosphorus forms not measured in the reactive phosphorus test run before the bioassays may later become biologically available as a result of chelating substances produced by the algae, or by disturbance of chemical equilibria (Clasen and Bernhardt 1974). In addition, filtering the January samples through a membrane filter removed about 35% of the phosphorus present in reactive forms (Table 9). The low chlorophyll *a* value (.9 ug/l), and the time of year, indicate that most of this phosphorus was not contained in organisms, but rather was sorbed onto particles and so might have been biologically

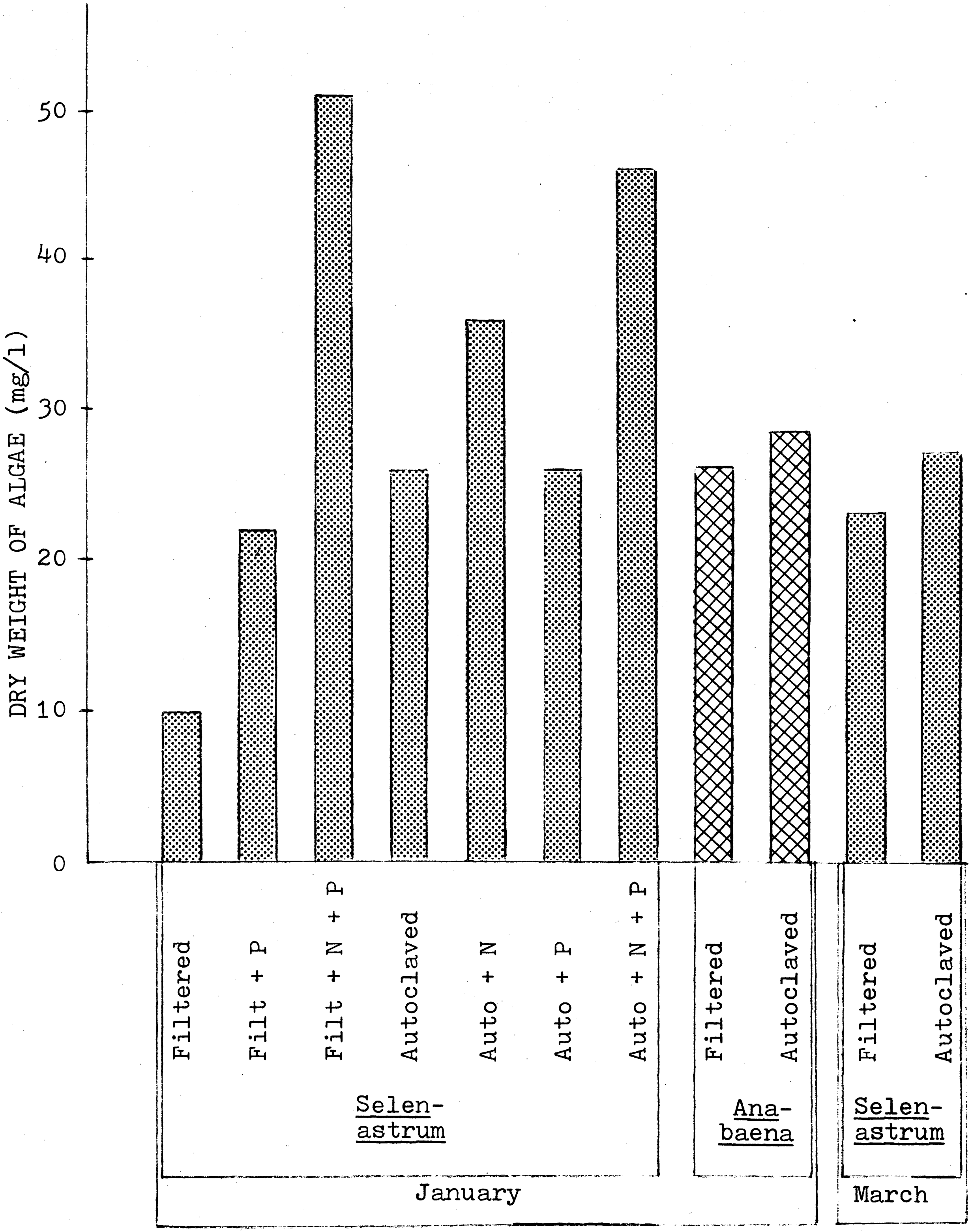


Figure 9. Results of Selenastrum and Anabaena nutritional bioassays on Lake Du Bay water (river mile 235.4) in January and March, 1979, expressed as dry weight of algae produced.

Table 9. Nutrient data associated with algal nutritional bioassays on Lake Du Bay water in January and March, 1979.

		Raw	Filtered	Autoclaved
January 1979	Reactive-P	.040	.026	.047
	Total-P	.073	.048	.068
	NH_4-N	.07	.07	.07
	NO_2-NO_3-N	.28	.28	.28
	TSIN	.35	.35	.35
	Kjeldahl-N	1.21	--	1.17
	TSIN:SRP	--	13.5	7.4
	Limiting	--	P	N
March 1979	Reactive-P	.042	.026	.050
	Total-P	.066	.040	.070
	NH_4-N	.18	.18	.18
	NO_2-NO_3-N	.25	.28	.32
	TSIN	.43	.46	.50
	Kjeldahl-N	.77	.40	.67
	TSIN:SRP	--	17.7	10.0
	Limiting	--	P	N

available in the natural system.

The autoclaved Selenastrum assays conducted in January showed nitrogen as the primary limiting nutrient, indicating that the ultimate nutrient demand in the reservoir is for nitrogen (Figure 9). This nitrogen limitation may be one of the causes of the dominance of nitrogen-fixing blue-green algae over green algae in the river.

The ratio of total soluble inorganic nitrogen (TSIN) to soluble reactive phosphorus (SRP) provides supplemental information about nutrient limitation. A TSIN:SRP ratio less than 11.3 indicates that nitrogen is limiting, while one greater than 11.3 indicates phosphorus limitation (Miller et al. 1976). By this criterion, the filtered samples were phosphorus limited, with a ratio of 13.5, while the autoclaved samples were nitrogen limited, with a ratio of 7.4, in agreement with the bioassay results (Table 9).

Dillon and Rigler (1974) have reported that waters with a total nitrogen:total phosphorus ratio greater than 12 are phosphorus limited, while those with a ratio less than 12 are nitrogen limited. By this criterion, raw water samples from Lake Du Bay are generally borderline phosphorus limited, with the overall average ratio for 8 dates being 12.9. The dominance of blue-green algae indicates that phosphorus levels are extremely important in controlling the present algae population. Such results emphasize the need for phosphorus control, especially from nonpoint sources.

Yield factors have been calculated to predict the dry weight of Selenastrum or Anabaena that will be produced in a bioassay experiment. Expected yields for Selenastrum are 0-.1 mg/l in oligotrophic, .11-.8 mg/l in mesotrophic, and .81-20 mg/l in eutrophic waters (Miller et al. 1974). The soluble reactive phosphorus concentration (if $\geq$ .01 mg/l) multiplied by 430 indicates the biomass of Selenastrum that can be expected (in mg/l dry weight) if phosphorus is the limiting factor. Similarly, multiplying the total soluble inorganic nitrogen concentration by 38 indicates the expected biomass if nitrogen is the limiting factor (Shiroyama et al. 1973). A similar factor of 450 multiplied by the soluble reactive phosphorus concentration indicates the expected yield of Anabaena. The yield factors for these two algae are not statistically significantly different (Shiroyama et al. 1976).

The yields indicated in Figure 9 are sufficient to consider Lake Du Bay eutrophic. However, although the yield factors for the two algae are not significantly different, the yield of Anabaena in filtered samples is more than twice the yield of Selenastrum in January. Such a discrepancy does not occur in the autoclaved samples. The possibility then exists that an unknown factor favored the growth of blue-green algae over green algae in unautoclaved samples.

Such a factor might have been an organic substance that was destroyed by autoclaving. Color could also have affected the results by limiting light penetration, although the small volume of sample used should have limited such problems. However, color was observed to be lighter after samples were autoclaved.

To explore the possibility of experimental error, Selenastrum bioassays were again run in March, 1979. Lake Du Bay itself was still mostly ice-covered, although greater areas were open upstream. No evidence of inhibition was found in the filtered samples. The March results again indicated phosphorus limitation in filtered samples and nitrogen limitation in autoclaved samples. Since the autoclaved samples in January and March were both nitrogen limited, but more nitrogen was available in the March samples, the March autoclaved growth was higher than the January autoclaved growth. Although the filtered samples, which were both phosphorus limited, contained the same levels of soluble reactive phosphorus, the difference between the January and March samples is large. This fact also supports the possibility of growth inhibition in the filtered Selenastrum assays run in January. Further experimentation under winter conditions would be necessary to establish the reason for the inhibition.

Toxicity of Mill Effluents to Algae

Possible direct toxicity of mill effluents to algae must be considered when examining factors affecting primary production in the Wisconsin River. Both the kraft and sulfite pulping processes extract many toxic compounds from wood (Easty et al. 1978). In 1977, Moore and Love reported that effluent from a kraft mill on Lake Superior inhibited photosynthesis in the natural phytoplankton population at concentrations as low as .01%. They concluded that high pH and presence of unidentified toxic substances were the main inhibiting factors. Eloranta (1978) found similar toxicity to phytoplankton in kraft and sulfite wastewaters, although sulfite wastes were slightly less toxic at concentrations of less than 1%.

The above-mentioned studies were done on untreated or clarified effluents. However, modern wastewater treatment systems remove a large portion of the toxicity through biological and physical-chemical processes (Easty et al. 1978). Effluent pH is also adjusted in the treatment process, so pH changes in the receiving waters are avoided. The main effects of treated mill effluent may then be either an inhibition of photosynthesis through reduction of light penetration or a stimulation of photosynthesis by increasing nutrients.

In November, 1979, effluent from the Weyerhaeuser sulfite mill in Rothschild (river mile 258.2) was assayed for possible toxicity to a blue-green alga, Anabaena. The Weyerhaeuser mill was chosen because it is large, producing 400 tons of packaging, wrapping, and printing papers a day from its calcium-base sulfite pulp (Dyer 1979). The mill's average wastewater discharge is 10 million gallons/day. Because of its location, its discharge might have influenced the results of the primary production experiments performed in Lake Du Bay.

Carbon assimilation bioassays were run on samples from Rothschild dam, directly above the mill, and Mosinee Flowage, nine miles below the mill. Weyerhaeuser effluent was added to filtered Rothschild river water samples at concentrations of .5%, 1%, 5%, and 10% effluent. Mill effluent increased the growth of the algae over the control up to a concentration of 5% (Table 10). Increasing the concentration to 10% caused growth to be less than in the control.

The Mosinee sample was included to compare river water below the mill to the dilutions made with effluent and river water above the mill. A site like Mosinee, nine miles below Rothschild, has the advantage of allowing a long distance for effluent to mix with the receiving water. Its disadvantage is that in that distance, several small tributaries, a small municipal sewage treatment plant, and another industry also discharge to the river and influence the water quality. However, the chemical composition of the tributaries would not be

Table 10. Results of carbon assimilation bioassays on Weyerhaeuser sulfite mill effluent samples. Dilution water was collected at Wisconsin River sites at Rothschild and Mosinee. Associated chemical parameters are also included.

	Rothschild river water +					Mosinee river water +
% effluent	0	.5	1	5	10	0
Carbon assimilation mg/m^3/hr	43.6	46.4	62.9	67.5	38.2	49.4
pH	7.6	7.6	7.6	7.6	7.7	7.4
conductivity umhos/cm	122	139	155	290	450	136
alkalinity mg/l as $CaCO_3$	28	32	33	49	68	28
ortho-P* mg/l	.035	.037	.038	.052	.068	.031
total-P* mg/l	.052	.063	.074	.164	.276	.042
NH_4-N* mg/l	.08	.12	.16	.48	.89	.13
NO_2-NO_3-N* mg/l	.35	.35	.35	.35	.35	.35
TKN* mg/l	.83	1.00	1.17	2.54	4.25	.90
color* pt-co units	98	154	209	655	1212	115
TSS* mg/l	0	1.4	2.9	14.3	28.5	0

*values for dilutions calculated from values for Rothschild and Weyerhaeuser effluent.

expected to be as different from the river water as the effluent is.

The average flow of the Wisconsin River at Merrill for the week of November 12, 1979, as reported by the Wisconsin Valley Improvement Company, was 2104 cfs. If the mill's average discharge for that week was 15 cfs (10 mgd), the concentration of effluent in the river at Mosinee would fall between the .5% and 1% dilutions. The carbon assimilation measured for the Mosinee samples did fall within that expected range, as did the ammonia values (Table 10).

Increased growth in the dilutions and Mosinee sample may have been caused by increased alkalinity or nutrient content. Stockner and Cliff (1976) found that nutrient enrichment adjacent to mills was primarily caused by an increase in carbon from wood sugars. Carbon may be especially important in the Wisconsin River, where the natural alkalinity is low. However, although alkalinity increased in the dilutions, the alkalinity at Mosinee and Rothschild were the same.

Nitrogen and phosphorus compounds may also have increased growth. Phosphorus concentrations were less in the Mosinee sample than in the Rothschild sample. Ammonia, however, did increase significantly in both the dilutions and at Mosinee. Although blue-green algae do have nitrogen-fixing abilities, they are stimulated to grow and store nutrients when exogenous concentrations of nitrogen are high (Stewart et al. 1978). In addition, ammonium-N is the preferred form (Syrett 1962).

The decrease in growth at the 10% effluent level may have been caused by increased levels of an unknown chemically inhibiting substance, or by increased color and suspended solids levels in the vials.

The chemical composition of mill effluent varies over time, and depends both on the specific pulping process in use in the mill at any point in time, and the retention time of effluent in the treatment system (Rainville et al. 1975). Since the chemistry of river water also changes with time, sampling must be done under a variety of conditions, especially critical low flow conditions, to get a complete assessment of changes in the river that may be caused by effluent discharges. However, from the recent literature, and the results of the Weyerhaeuser bioassays, it appears that mill effluent is not toxic to phytoplankton at concentrations normally found in the river, after receiving secondary treatment. Instead, mill effluent can stimulate the growth of algae by adding nutrients to the receiving water.

Results of Primary Production Experiments in Lake Du Bay

Complete results of primary production experiments on Lake Du Bay are presented as Appendix C. Important results of these experiments are described in the following section.

The previous sections have established that nutrient pollution is the greatest stimulus to algal productivity in Lake Du Bay. However, it has also been established that color and suspended solids in the river may limit production. The raft experiments described in this section were designed to determine the potential effects of changes in color and resultant changes in light penetration on algal production in Lake Du Bay. To improve the sensitivity of the measurements, samples for light and dark bottle experiments were collected from the upper meter of water in calm areas where large amounts of algae had been observed. Since representative samples were not collected with depth, and since only one site was used, these measurements should not be used as representative values for present primary production in all of Lake Du Bay.

Changes in light penetration caused by the experimental setup caused slight differences between *in situ* carbon assimilation rates and carbon assimilation rates in control bags. The following regression equation was derived for converting raft control values to *in situ* values at corresponding depths:

$$\underset{\underline{\text{in}}\ \underline{\text{situ}}\ (\text{mg/m}^3\text{/hr})}{\text{carbon assimilation}} = 4.31 + 1.06\ (\underset{\text{in control bag }(\text{mg/m}^3\text{/hr})}{\text{carbon assimilation}})$$

93.3% of the variation in the *in situ* values was related to the variation in raft values, showing that the experimental apparatus represented the natural system fairly accurately.

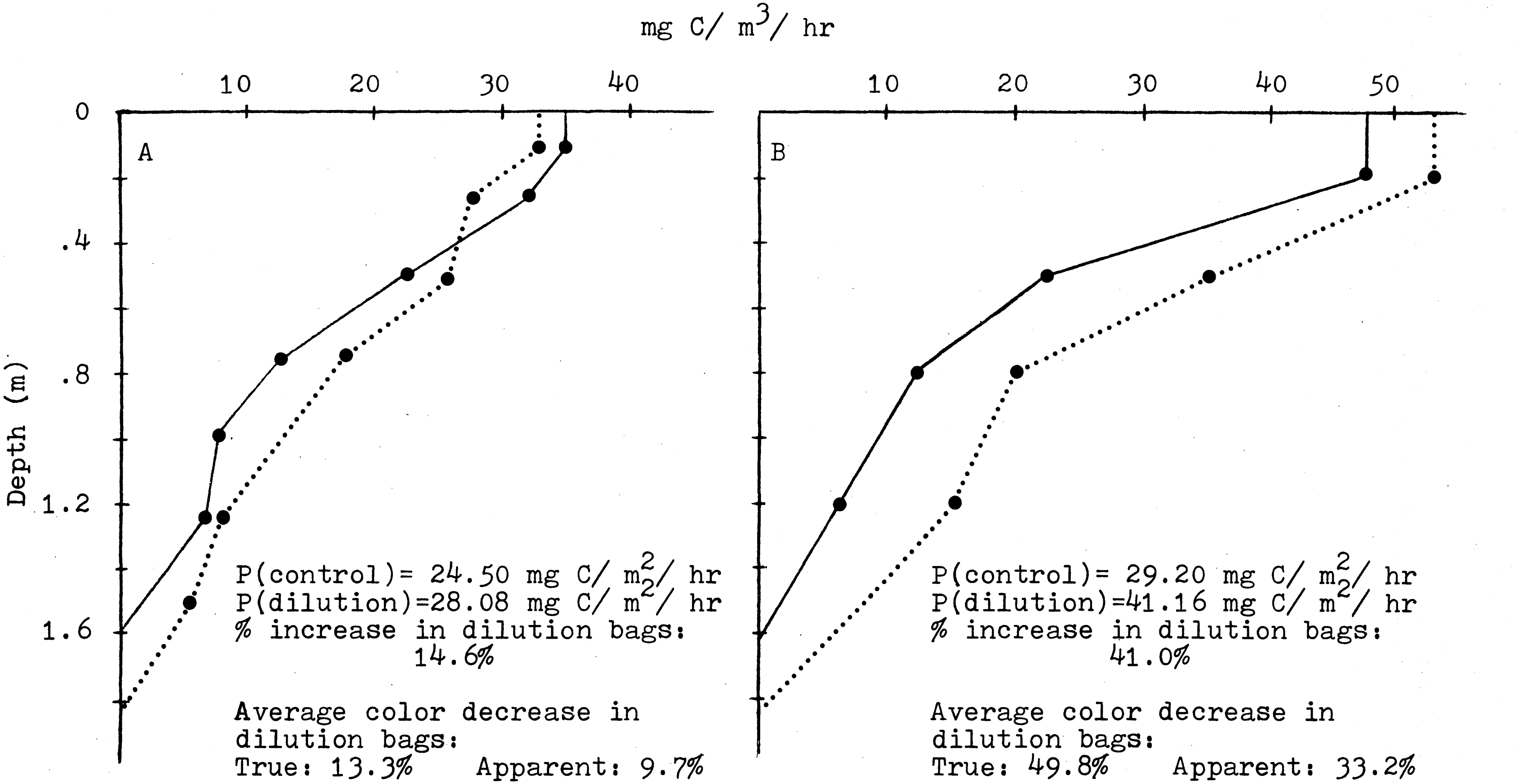
In turbid waters such as Lake Du Bay, scattered light is an important component of the light available to algae (Wetzel 1975). In the raft experiments, scattered light reaching algae in the diluted river water bags might first have been filtered through the more colored river water surrounding the bags. The procedure then probably underestimated the effects of decreased river color. In addition, light penetration in general was slightly less in the control bags than in the open water.

Dilutions were made by pumping well water into the bags through a garden hose with a gas-powered pump for a specific time interval. Bags filled with dilution water for the same time interval were considered to be one set. Differences in pumping rates and in the placement of bags on the frames generally caused dilutions in one set to have slightly different true and apparent color values. Since the samples were then not always well matched, analyses of the data became more difficult.

Differences between the control bags and dilution bags were least on an overcast day (June 21). Absolute carbon assimilation rates were greater as the season progressed, reaching their maximum after the algal bloom conditions became apparent in early July.

In general, dilution bags produced greater carbon assimilation rates than the corresponding control bags. Changes in areal photosynthetic rates were difficult to estimate because of variations in color values in the dilution bags. Comparison of photosynthesis-depth profiles for the best-matched set, collected on June 28, shows that an average 49.8% decrease in true color and 33.2% decrease in apparent color produced a 41.0% increase in areal photosynthesis (Figure 10).

Percent increases in carbon assimilation increased with depth (Table 11), partly because the absolute values decreased, but possibly also because of the "surface depression effect" recognized by most experimenters. One cause for surface depression may be ultraviolet light, which is rapidly attenuated



P(control)= 24.50 mg C/ m^2/ hr
P(dilution)=28.08 mg C/ m^2/ hr
% increase in dilution bags:
14.6%

Average color decrease in dilution bags:
True: 13.3% Apparent: 9.7%

P(control)= 29.20 mg C/ m^2/ hr
P(dilution)=41.16 mg C/ m^2/ hr
% increase in dilution bags:
41.0%

Average color decrease in dilution bags:
True: 49.8% Apparent: 33.2%

Figure 10. Photosynthesis-depth curves for Lake Du Bay raft experiments on June 6 (A) and June 28, 1979 (B), showing results for control (——) and dilution (····) bags.

Table 11. Percent changes in carbon assimilation with changes in true and apparent color in dilution bags for 1979 raft experiments in Lake Du Bay.

Depth (m)		True color decrease	Apparent color decrease	Carbon assimilation increase
.2-.25	Mean	29.0%	25.5%	8.9%
	S.D.	15.9	10.7	14.6
	N	6	6	6
.5	Mean	25.2%	19.5%	14.2%
	S.D.	16.2	13.3	39.3
	N	7	7	7
.75-.8	Mean	31.7%	25.3%	33.3%
	S.D.	11.8	10.9	23.8
	N	6	6	6
1.2-1.25	Mean	25.2%	19.5%	54.5%
	S.D.	16.2	13.3	59.6
	N	7	7	7
All	Mean	27.6%	22.2%	28.2%
	S.D.	14.6	11.9	41.5
	N	26	26	26

but is especially damaging to near-surface algae (Lund 1965 and Jewson 1977). Wisconsin River water, because of its high true color, may filter out much of this ultraviolet light (Sullivan 1978), but the dilution bags may allow more to pass through.

Photorespiration has more recently been identified as a likely cause for surface depression of photosynthesis (Harris and Lott 1973). Intense production of oxygen at the high light intensities in near-surface bottles may inhibit uptake of carbon dioxide by causing competition for enzymes. Photosynthetic products become oxidized, causing consumption of oxygen and production of carbon dioxide. As its name indicates, this process occurs only in the light. It has been observed that larger values are obtained for daily production with a series of short incubation periods rather than one long incubation period (Vollenweider 1974). Photorespiration may account for some of the differences.

Although surface depression may occur with increased light penetration, increased primary production at greater depths may still allow the areal rate to be greater in the less colored water. On June 6, an average 13.3% decrease in true color and 9.7% decrease in apparent color produced a 14.6% increase in the areal photosynthetic rate, even though the rate at .1 meter was 6.8% lower (Figure 10). In areas shallower than .5 meters, the surface depression effect might dominate, but such areas would be likely to contain macrophytes which could outcompete the algae for nutrients. Therefore, the general effect of increased water clarity would still be an increased production of plant biomass.

In mixed flowing systems such as the Wisconsin River where algae continually circulate through a large part of the water column, the surface depression may not occur naturally and may be only an artifact of enclosing the community in bottles.

Because light penetration was less in control bags than in the open water, and because of the possibility of an artificial decrease in near-surface production rates because of experimental conditions, the results obtained in the raft experiments should be considered conservative estimates of the effects of light penetration on primary production in Lake Du Bay.

Factors Influencing Carbon Assimilation Rates

True and apparent color changes both had significant influences on carbon assimilation rates in dilution bags (Figure 11). However, the scattering of points indicates that more than one factor must be considered in attempting to explain the observed changes in carbon assimilation rates.

Changes in algal species composition may have influenced changes in both absolute carbon assimilation rates and relative increases in dilution bags. Blue-green algae, especially *Aphanizomenon flos-aquae*, are the dominant summer bloom-formers in Lake Du Bay (Sullivan 1978). Chlorophyll *c* values indicated that diatoms, most likely *Melosira*, were also present during the sampling periods (Table 12). The first sampling date

Table 12. Chlorophyll data for samples collected for incubation in 1979 raft experiments in Lake Du Bay.

Date	Chlorophyll *a*	Chlorophyll *b*	Chlorophyll *c*
	ug/1		
June 6	21.57	1.64	8.72
June 21	6.58	.93	3.10
June 28	18.95	1.46	7.26
July 18	29.80	2.73	10.09

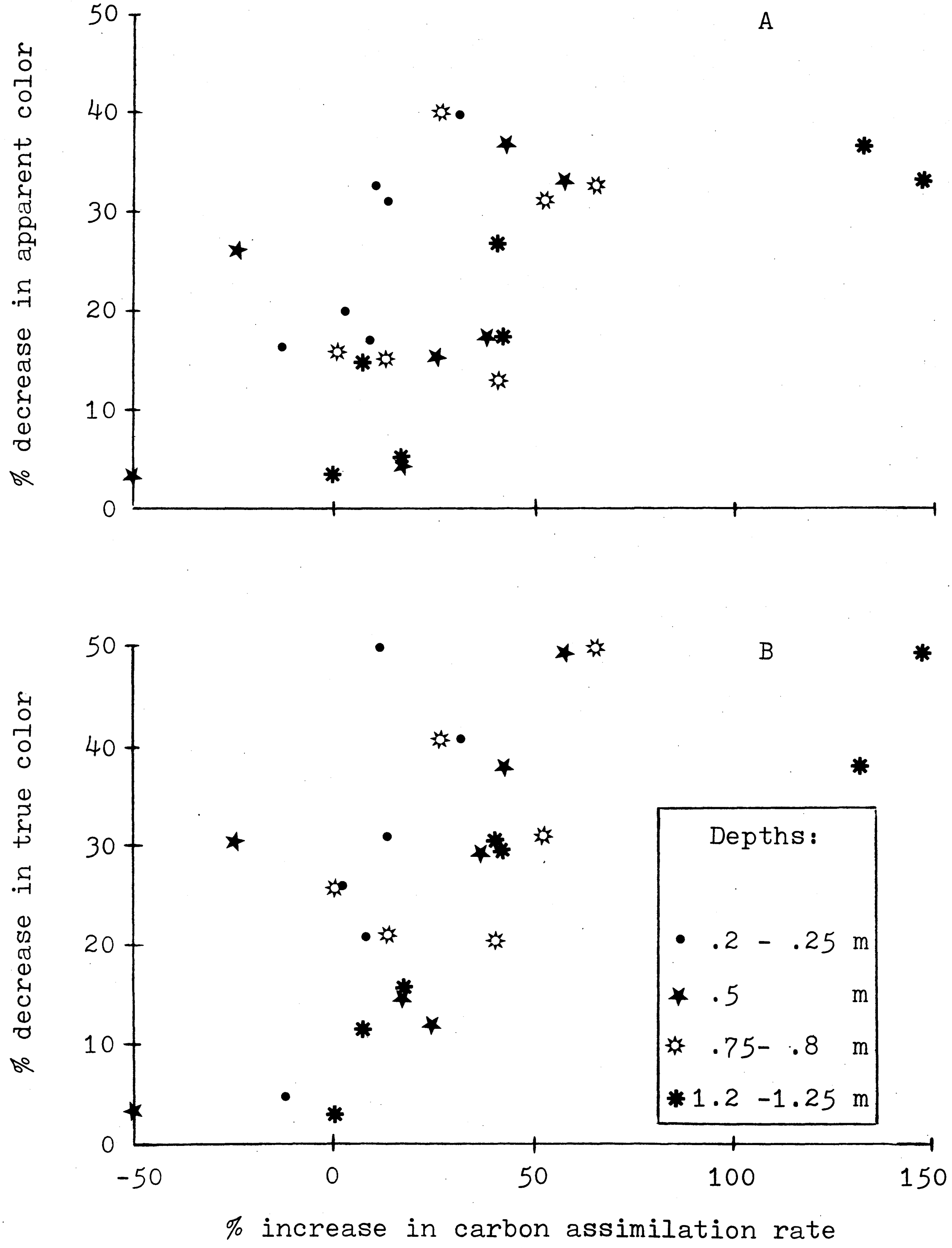


Figure 11. Changes in carbon assimilation rate with changes in apparent color (A) and true color (B) between dilution bags and control bags for raft experiments performed in the summer of 1979. Negative values indicate inhibitory effects.

(June 6) preceded the normal start of the blue-green algae bloom. The severe surface depression on this date indicates that the algae present in late spring may have been more sensitive to increases in light penetration than the blue-green algae which occurred later in the season.

Water chemistry data for the four sampling dates (Table 13) indicate that nutrient levels and temperature were generally suitable for good algal growth, with blue-greens being favored by decreasing inorganic nitrogen levels as the season progressed. Nutrient levels were not believed to have influenced changes in carbon assimilation rates between control bags and dilution bags on any sampling date, since the normal profiles with depth were maintained. However, different nutrient levels may have greatly influenced the changes in absolute carbon assimilation rates between sampling dates.

Table 13. Water chemistry data for samples collected for incubation in 1979 raft experiments in Lake Du Bay.

Date	Temp $^{\circ}$C	pH	Ortho P	NH_4 N	NO_2-NO_3 N	Alkalinity as $CaCO_3$
			←	mg/l		→
June 6	21.0	7.30	.020	.32	.09	31
June 21	20.0	7.00	.068	.04	.15	20
June 28	22.0	7.08	.032	<.03	.15	16
July 18	25.0	7.24	.040	<.03	.14	35

When absolute carbon assimilation rates were statistically related to light penetration values, both white light and each of the major spectral blocks were significantly correlated to the carbon assimilation rates (Table 14). Red light, the most penetrating spectral component, was the most important of the spectral blocks. Other researchers have also found that the most penetrating spectral component was an important determinant of primary production values (Talling 1971, Jones 1977, and Jewson 1977). However, light penetration over the total visible spectrum was just as significantly correlated to carbon assimilation values as red light was. Blue light was slightly less significant, both because of its lesser importance to blue-green algae and its higher extinction coefficients. Absolute carbon assimilation rates were not statistically compared with physical parameters such as color and suspended solids because these parameters did not vary with depth in the bags. Insufficient data were obtained to

Table 14. Correlation coefficients with carbon assimilation ($mg/m^3/hr$) as the dependent variable and light factors (langleys/day) as the independent variables (N = 20).

Independent variable	r
White light	.665**
Red light	.658**
Green light	.622**
Blue light	.522*

* Significant at the 0.05 level.
** Significant at the 0.01 level.

statistically compare samples matched for depth.

Although the light penetration was not determined for each bag separately, dilution bags from one set were assumed to be more closely related to each other than to any other set of bags. Therefore, relative changes in light penetration were applied to all bags of one set.

Results of multiple regression analysis of percent changes in carbon assimilation rates with changes in these and other environmental factors are presented as Table 15. These factors included light penetration, color and suspended solids data,

Table 15. Results of forward stepwise multiple regression on data collected in 1979 raft experiments in Lake Du Bay, using percent increase in carbon assimilation in dilution bags over control bags as the dependent variable. Various environmental parameters were used as independent variables.

Percent increase in carbon assimilation in dilution bags =

1. 0.323 (% increase in green light penetration**)
   -0.374 (% increase in red light penetration**) + 7.65

   R^2= 0.805** N= 19

2. 0.584 (% increase in white light penetration**)- 1.317

   R^2= 0.575** N= 19

3. -1.744 (% decrease in true color**) + 53.206 (depth**(m))
   +0.080 (incident solar radiation* (langleys/day)) - 85.057

   R^2= 0.695** N= 27

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* Significant at the 0.05 level.
** Significant at the 0.01 level.

nutrient and chlorophyll levels, and incident solar radiation. Light penetration again appeared as the most important variable. When light penetration data was omitted, the following three factors became most significant: the change in true color, the depth at which the samples were incubated, and the incident solar radiation. These factors would combine to give a good approximation of light penetration data.

Although the preceding discussion has considered mainly changes in light penetration as important predictors of carbon assimilation rates, it must be remembered that these light penetration changes were caused by changing the true and apparent color of the water. The combined effects of the optical properties of the dissolved and suspended materials in the water produced the observed increases in algal production in dilution bags.

The data show that increasing light penetration by reducing color can be expected to cause an increase in total algal production in Lake Du Bay and possibly in other reservoirs on the Wisconsin River. Since high nutrient levels have already made summer algal blooms a nuisance on the river, especially south of Wausau, the value of decreasing color and suspended solids discharges from industries may appear questionable. However, the literature does indicate that the present light conditions may be best suited for blue-green algae, and that improved light penetration might favor growth of more desirable planktonic species, or periphyton or macrophytes in shallower areas. Control of both point and nonpoint sources of nutrients, especially phosphorus, is an important simultaneous goal, but nonpoint nutrient pollution should not be used as an excuse to reject the 1985 goals of zero discharge from industries.

Effect of Mill Shutdowns on River Water Quality

An obvious approach to studying the impacts of industry on water quality in the Wisconsin River would be to sample extensively during periods of mill shutdown. However, several complications make this approach less effective than would be expected. The first is that the mills do not all shut down for the same period of time. In addition, their secondary treatment plants must continue to operate and discharge small volumes of waste throughout the mill shutdown period. Mill effluents from upstream may reach a downstream site several days after mill closing. Since the flow of the river is controlled, traditional hydrologic analyses become more difficult to perform. Finally, rainfall during the period might provide dilution.

Daily sampling was done from July 2-6, 1979, to examine the effect of the July 4 holiday shutdowns on water quality from Granite Heights (river mile 274.3) to Lake Du Bay dam (river mile 235.4). Mills in this segment were closed 2-3 days from July 3-5. Complete results of this survey are presented in Appendices D and E, and flow data is presented in Appendix G. Pertinent results are summarized in this section.

Effluent strength, as estimated by conductivity values, was variable but did not decrease significantly through the week. Effluent true and apparent color, however, did decrease through the week. Total volume of effluent discharged by Wausau Papers, Weyerhaeuser, American Can and Mosinee Papers ranged from 7.79 million gallons on July 4 to 27.63 million gallons on July 6. An average discharge for these industries during a normal workweek is 31.2 million gallons, as estimated from five sampling surveys.

A rainfall event occurred over the basin during the study week, with the heaviest rains occurring on July 3. An isohyetal map of that event is presented as Figure 12. The heaviest rains occurred north and east of the study area, so the first sampling site at Granite Heights should still have provided an adequate control. However, rainfall events, and the resulting increases in flow, have been observed to cause increases in both water clarity and dissolved oxygen levels.

True and apparent color levels remained relatively consistent or increased slightly through the week at Granite Heights, but dropped through the week at the next four sites (Figure 13). Travel time from Wausau Dam to Mosinee Dam was approximately .8 days (Sullivan 1980), so changes in that area appeared rapidly. However, from Mosinee Dam to Lake Du Bay Dam, the time of travel was approximately 4.3 days, so the Lake Du Bay samples did not show much change during the sampling period.

Conductivity followed color trends as previously observed, remaining relatively constant at Granite Heights and Lake Du

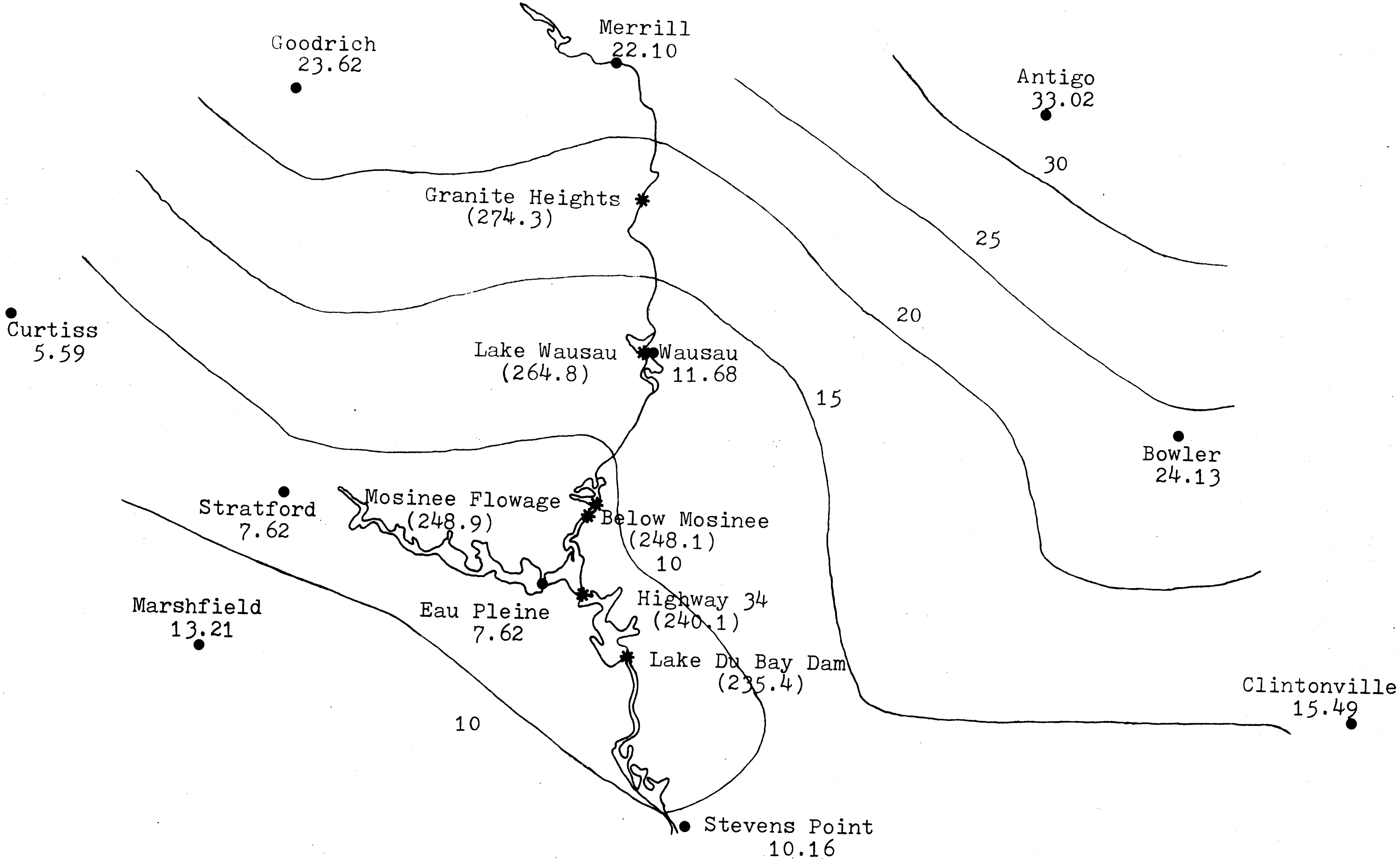

Figure 12. Isohyetal map showing rainfall in millimeters in the central Wisconsin River basin on July 3 and 4, 1979. Sampling sites for water quality are indicated with an asterisk. River miles are given in parentheses. Contour interval = 5 millimeters.

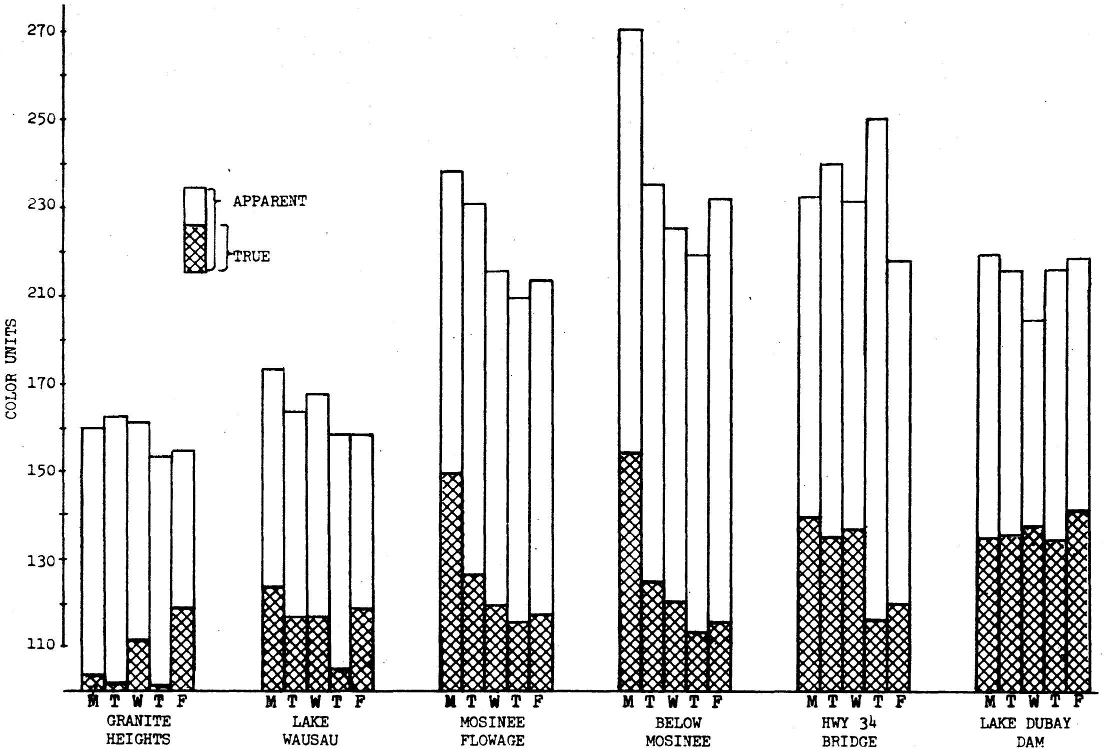

Figure 13. Daily true and apparent color measurements at six Wisconsin River sites from Monday, July 2, to Friday, July 6, 1979.

Bay dam, and decreasing through the week at the middle sites (Figure 14). The pH rose slightly from Mosinee Flowage to the Highway 34 bridge, perhaps indicating increased biological activity in this segment caused by decreases in color.

Chlorophyll levels did not significantly increase at any site during the sampling period. However, the algae may have been much more active during this period of increased light penetration. Stockner and Cliff (1976) reported a 10-fold decrease in the mean annual carbon assimilation rates of algae between an area of clear water and one affected by a pulpmill effluent stain. The difference in mean annual chlorophyll

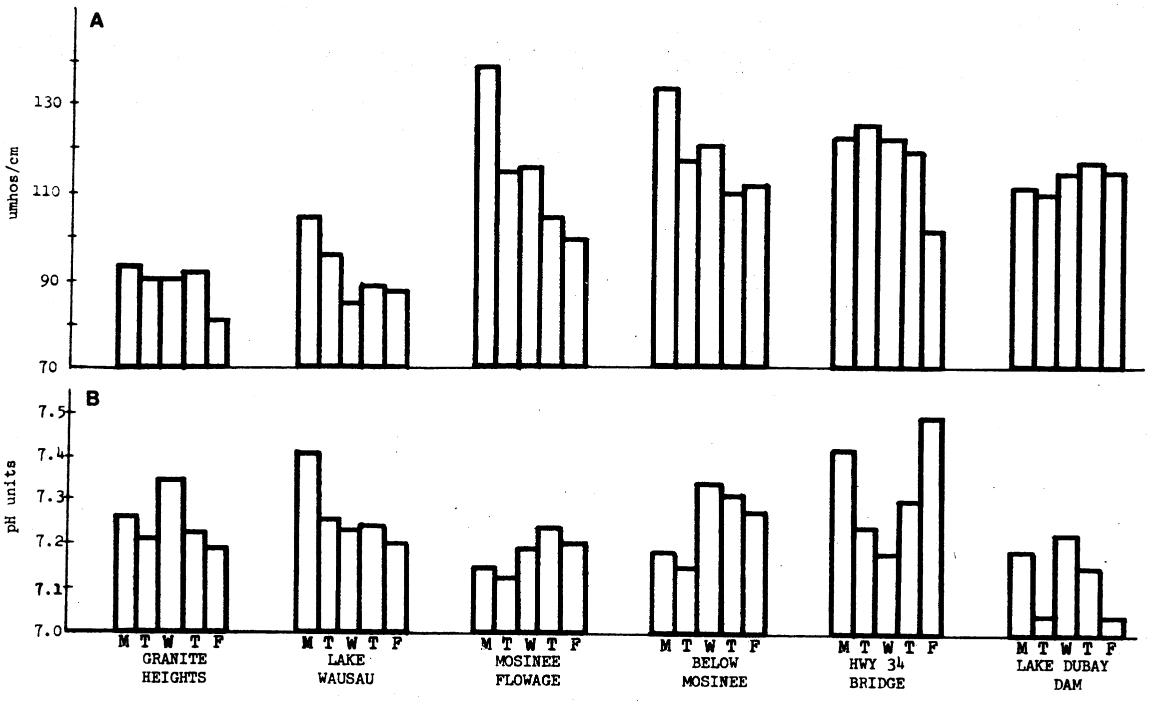

Figure 14. Daily conductivity (A) and pH (B) measurements at six Wisconsin River sites from Monday, July 2, to Friday, July 6, 1979.

levels between the two sites was very small, from 1.28 to 1.04 mg/m^3, but the Secchi disk readings decreased from 5.8 m to 1.0 m. No species changes were noted between the two sites, which were both located in the same estuary. Samples collected at depths under the floating effluent stain, and incubated in the zone of clearer water, showed significantly higher production rates. Stockner and Cliff concluded that the major factor reducing growth in the area affected by effluent was decreased light penetration.

Evidence that an increase in algal production may have occurred is found in Wisconsin Department of Natural Resources data collected during this period (Table 16). Oxygen levels

Table 16. Values for various parameters at the Highway 34 bridge site (river mile 240.1) for July 2-6, 1979. Dissolved oxygen data and extinction coefficients were provided by the Wisconsin Department of Natural Resources.

	July 2	July 3	July 4	July 5	July 6
Chlorophyll total, ug/l	48.37	40.67	31.50	29.75	34.15
Temperature °C	24.8	24.2	22.9	22.4	25.1
D.O. Surface mg/l	8.0	8.0	8.3	10.2	--
D.O. Average mg/l	6.8	6.8	7.2	8.2	--
True color pt-co units	139	134	136	117	119
Apparent color pt-co units	219	220	211	230	197
Extinction coefficient	--	--	2.76	2.54	--

increased through the week, although chlorophyll levels declined. Color also decreased toward the end of the week, and light penetration increased. Some of the increases in oxygen can also be attributed to the decreased BOD loading and increased flow, but at the prevailing water temperatures it is likely that algal activity was necessary to explain the increase in oxygen content over the saturation levels of 8.1-8.5 ppm. Flow from the Big Eau Pleine River was reported as zero through the week and so should not have affected the results.

Nutrient levels did not show any consistent decreases during the study week, in agreement with the evidence that the pulp and paper industry is not the largest source of nutrients in this segment (Figure 15). Some of the trends, such as the increases in phosphorus at Lake Wausau and the decreases in phosphorus below Mosinee, could not be explained by simple loading calculations or loading calculations weighted for increases in flow. Such trends may be attributable to natural variation, or the effects of increased flushing and/or river water dilution. However, the steady increase in inorganic nitrogen below Mosinee may have been related to industrial discharges, as nitrogen loading from Mosinee Papers increased through the week. Since the mills are capable of discharging substances at levels far above baseline, to a much greater degree than the tributaries, they can have significant impacts on nutrient levels at specific times and places, especially during low flows.

Loading calculations by segments were not used for this week because all inputs were not monitored, and industrial discharges could not be assumed to be constant. Rainfall and increased flow may also have affected the results. However, observation of the data indicates that parameters generally affected by industry, as observed during previous river surveys, did decrease during mill shutdown, while those less affected by mill discharges changed less.

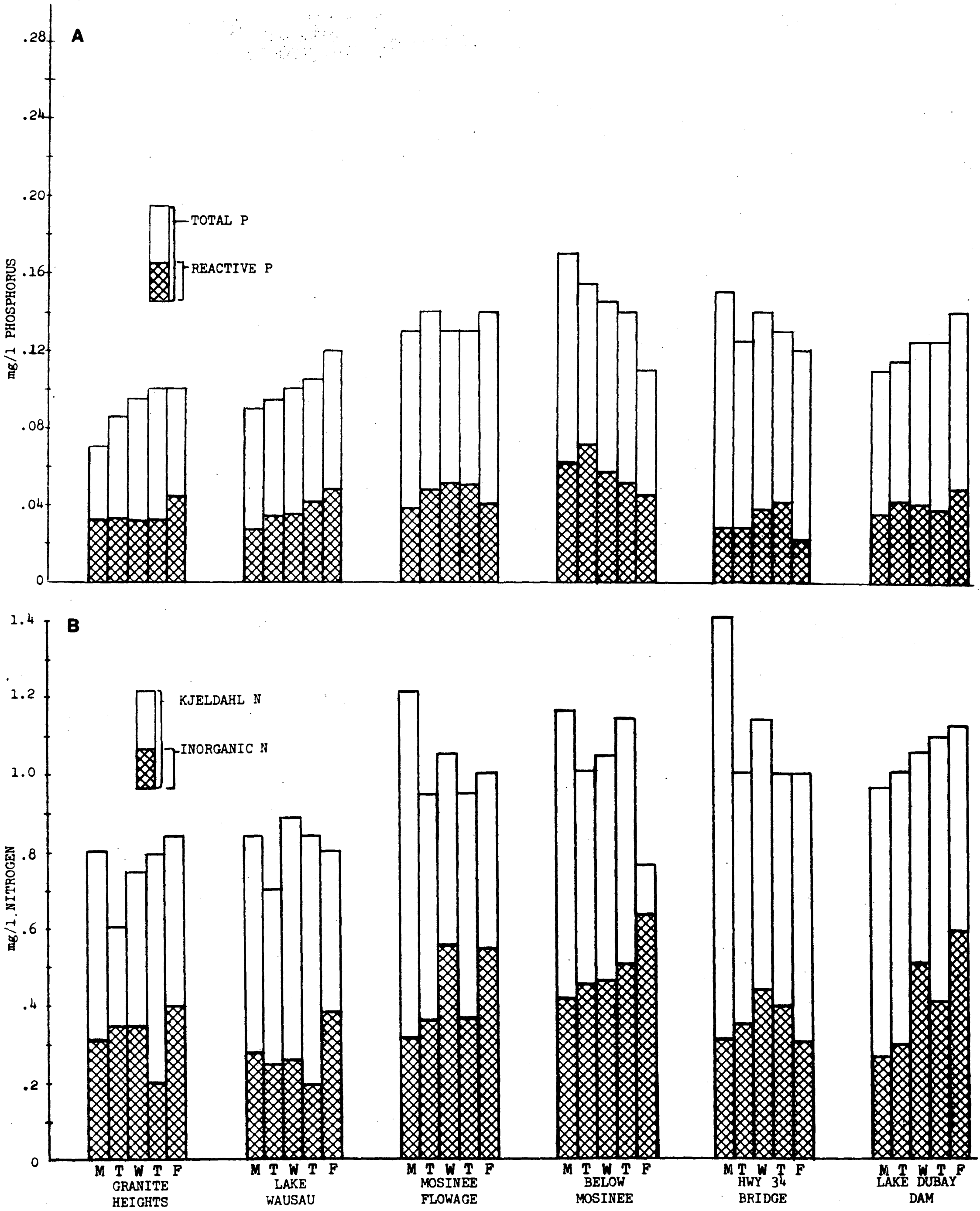

Figure 15. Daily inorganic and total phosphorus (A) and inorganic and Kjeldahl nitrogen (B) measurements at six Wisconsin River sites from Monday, July 2, to Friday, July 6, 1979.

CONCLUSIONS

1. True color in natural waters is caused by high molecular weight organic acids which are produced in wetlands and other areas of decaying organic matter. Seasonal trends are regulated by precipitation, with maxima in late spring and late fall. Apparent color includes true color and suspended particulate materials, which consist of both living and dead organic materials and inorganic particles.
2. Seasonal color trends in the Wisconsin River are reduced by the buffering effect of the reservoir storage system and the effects of wastewater discharges.
3. Industries, especially sulfite pulp mills, cause a significant percentage of both the true and apparent color in the Wisconsin River, especially during periods of low flow. The greatest increase in river color occurs between Granite Heights and Mosinee and is caused by dischargers in the Wausau area.
4. True color from all sources causes a decrease in overall light penetration and a dramatic reduction of blue light penetration in the river. Apparent color also decreases overall light penetration.
5. A number of trophic state indices can be used to define Lake Du Bay as an eutrophic reservoir. Industries, municipalities, and nonpoint sources are all major sources of nutrient pollution, but the largest loading of both nitrogen and phosphorus occurs from tributaries.
6. Algal nutritional bioassays indicated that the primary

immediate limiting nutrient in Lake Du Bay is phosphorus, while the ultimate limiting nutrient is nitrogen. Nitrogen to phosphorus ratios indicate borderline phosphorus limitation. The presence of summer blooms of nitrogen-fixing blue-green algae emphasizes the importance of phosphorus levels in controlling the algae population.

7. Bioassays using sulfite mill effluent diluted with river water indicated that mill effluent is not toxic to *Anabaena* at concentrations normally found in the river, but causes stimulation of growth by addition of nutrients. However, an effluent concentration of 10% caused inhibition of carbon assimilation.

8. Experiments in Lake Du Bay showed that increased light penetration caused by decreased color could produce a significant increase in carbon assimilation by the indigenous algae population, since nutrients are generally sufficient. Future reductions in point source discharges of color and suspended solids might result in increased nuisance algal blooms, or, with control of nutrient pollution, a change in species composition to more desirable algal forms.

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APPENDIX A

River survey water chemistry data for June 27-July 8, 1978.

	River Mile	Date	Temp $^{\circ}$C	pH	Conductivity umhos/cm	Alkalinity as CaCO$_3$	Ortho P	Total P	NH$_4$-N	NO$_2$-NO$_3$ N	TKN	TSS	VSS	True Color	Apparent Color
						mg/l								pt-co units	
Wisconsin River sites															
Rhinelander Dam	341.4	6-27-78	21.2	7.43	68	22	.030	.048	.12	<.03	1.47	7.5	5.0	76	126
Hat Rapids Dam	335.2	6-27-78	24.0	7.15	85	20	.021	.083	<.03	<.03	1.59	10.0	8.0	109	190
Kings Dam	319.4	6-27-78	21.7	7.13	82	18	.019	.054	<.03	.12	.74	4.0	1.0	117	172
Grandmother Dam	305.9	6-28-78	23.4	7.25	80	34	.020	.081	.07	.25	.98	3.5	2.0	122	176
Merrill	287.2	6-28-78	23.4	7.21	79	22	.033	.096	<.03	.05	.91	4.5	2.5	132	172
Granite Heights	274.3	6-28-78	23.7	7.43	73	46	.047	.086	.11	.05	.95	3.0	2.0	139	154
Mosinee Flowage	248.9	6-29-78	24.5	7.02	146	34	.048	.160	.07	.16	1.26	6.5	3.0	172	211
Lake Du Bay	235.4	6-29-78	25.2	7.59	116	30	.020	.117	<.03	.19	1.26	4.0	3.0	167	224
Stevens Point	223.0	7- 8-78	24.1	7.16	85	22	.044	.089	.11	.18	1.30	8.5	4.5	155	236
Biron	205.3	6-29-78	29.0	9.17	126	36	.047	.159	<.03	.04	1.16	10.0	5.5	141	306
Petenwell	187.2	7- 8-78	23.0	7.32	104	28	.070	.132	.14	.26	.86	13.0	5.5	146	290
Tributaries															
Pelican River	340.6	6-27-78	--	6.94	72	16	.113	.143	.04	.09	1.12	6.0	3.5	191	241
Noisy Creek	333.6	6-27-78	23.1	7.03	91	32	.067	.098	<.03	.03	1.23	8.5	6.0	186	224
Big Pine River	323.4	6-27-78	23.0	7.85	124	50	.102	.110	<.03	<.03	.91	3.5	<.5	60	124
Tomahawk River	315.9	6-27-78	23.8	7.37	64	22	.011	.039	<.03	<.03	.60	5.5	2.5	88	125
Somo River	315.1	6-27-78	25.3	6.78	47	14	.007	.047	<.03	<.03	1.65	5.5	4.5	193	241
Spirit River	312.3	6-27-78	20.3	7.01	60	14	.024	.073	<.03	<.03	1.30	4.0	3.0	197	214
New Wood River	295.2	6-28-78	23.0	7.84	85	32	.032	.089	<.03	<.03	.88	4.5	2.5	169	183
Copper River	291.3	6-28-78	22.0	7.55	86	40	.056	.180	<.03	.03	.91	4.0	3.0	245	272
Prairie River	286.3	6-28-78	23.3	7.91	152	68	.038	.063	<.03	.26	.49	2.5	1.5	97	102
Pine River	280.6	6-28-78	23.3	8.27	94	36	.020	.064	<.03	<.03	.56	2.5	1.0	101	111
Trappe River	276.0	6-28-78	22.2	7.47	88	34	.046	.105	.14	.03	.98	5.0	1.5	145	165
Rib River	262.6	6-28-78	24.7	7.56	138	26	.063	.150	<.03	<.03	.60	5.0	1.5	105	151
Eau Claire River	261.1	6-28-78	24.5	7.83	192	72	.102	.152	<.03	.12	.66	6.5	2.0	73	132
Bull Jr. Creek	249.7	6-28-78	22.7	7.31	97	34	.056	.105	<.03	.09	1.14	4.0	2.0	285	323
Hog Creek	246.0	6-29-78	19.5	7.06	87	28	.040	.111	<.03	.19	.91	13.5	3.5	164	284
Big Eau Pleine	241.8	6-29-78	23.0	9.81	127	36	.011	.141	<.03	<.03	2.73	15.0	14.5	102	239
Little Eau Pleine	235.6	6-29-78	22.2	7.07	142	46	.074	.271	.14	.12	1.75	6.0	2.0	297	320
Hay Meadow Creek	225.4	6-29-78	23.0	7.65	107	46	.020	.063	<.03	.37	.96	6.5	3.0	324	376
Plover River	219.1	7- 8-78	23.8	7.45	177	80	.017	.049	.07	.16	1.12	5.5	2.5	208	236
Little Plover R.	217.1	7- 8-78	20.0	8.03	333	134	.005	.020	.28	3.06	.56	2.0	1.0	45	57
Mill Creek	212.6	6-29-78	22.0	7.73	192	60	.817	.823	<.03	.18	1.47	4.0	<.5	221	288
Mosquito Creek	204.2	6-29-78	21.8	7.11	146	38	.104	.186	.14	.37	.58	5.5	2.0	73	145
Moccasin Creek	195.2	6-29-78	22.3	7.20	142	28	.051	.112	.37	.37	.42	4.5	2.5	81	132

APPENDIX A continued

River survey water chemistry data for June 27-July 8, 1978 (continued).

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Alkalinity as $CaCO_3$	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
									mg/l					pt-co units	
Industries															
Rhinelander Papers	341.3	6-26-78	--	7.55	485	50	.026	.144	4.94	2.01	12.08	31.5	21.5	288	438
Georgia-Pacific	315.8	6-26-78	--	7.35	235	28	.051	.223	1.05	.23	4.64	28.0	23.0	27	376
Owens-Illinois	313.1	6-26-78	--	7.88	480	200	.901	1.153	.25	<.03	3.61	63.0	57.0	1347	2500
Ward Paper	285.9	6-27-78	--	7.78	1140	382	.200	2.471	<.03	<.03	3.97	257.0	85.0	1020	4892
Wausau Papers	271.1	7- 7-78	--	7.49	1420	290	.233	.633	54.70	.25	68.23	196.0	156.0	1178	5495
Weyerhaeuser	258.2	7- 7-78	--	6.90	900	160	.327	.730	3.10	.07	10.82	104.0	66.0	1439	2690
Mosinee Papers	248.9	6-28-78	--	7.02	480	123	.609	.828	4.78	<.03	9.45	31.0	23.0	243	773
Cons.- Stevens Pt.	222.4	6-28-78	--	7.15	560	58	.071	.071	1.66	1.17	3.01	31.0	15.0	13	185
Cons.- Wis. River	219.9	6-28-78	--	7.48	600	142	.983	1.028	<.03	<.03	1.37	8.6	6.7	103	189
Plover Papers	218.7	6-28-78	--	7.05	425	96	.020	.373	1.17	<.03	5.83	32.0	28.0	65	656
Cons.- Wis. Rapids	202.4	6-28-78	--	7.05	1580	96	.109	.298	3.17	.07	6.30	60.0	43.0	657	1478
Nekoosa Papers	195.5	6-28-78	--	6.83	2100	378	.569	1.323	9.57	<.03	13.23	29.3	25.3	384	862

APPENDIX A continued

River survey water chemistry data for November 3-5, 1978.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Alkalinity as $CaCO_3$	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						mg/l								pt-co units	
Wisconsin River sites															
Hat Rapids Dam	335.2	11- 3-78	7.9	6.97	87	--	.026	.066	.09	.12	.80	5.0	3.5	89	151
Kings Dam	319.4	11- 3-78	7.7	7.15	79	--	.029	.056	.08	.16	.70	4.0	3.0	106	145
Grandmother Dam	305.9	11- 3-78	8.0	7.11	77	--	.035	.050	.06	.16	.66	2.5	1.0	129	168
Merrill	287.2	11- 4-78	7.1	7.20	79	--	.030	.070	.09	.18	.64	1.5	<.5	129	168
Granite Heights	274.3	11- 4-78	7.7	7.29	85	--	.034	.052	.04	.22	.64	2.5	2.0	119	160
Mosinee Flowage	248.9	11- 4-78	9.5	7.15	129	--	.027	.086	.16	.30	1.08	5.3	4.3	147	222
Lake Du Bay	235.4	11- 4-78	10.0	7.26	130	--	.037	.074	.17	.34	.92	2.5	2.5	131	170
Stevens Point	223.0	11- 5-78	9.1	7.40	130	--	.061	.068	.25	.38	.82	4.0	3.0	164	184
Biron	205.3	11- 4-78	9.1	7.45	141	--	.051	.094	.15	.42	.92	5.0	4.0	125	178
Petenwell	187.2	11- 4-78	10.0	7.18	192	--	.039	.102	.15	.56	.94	3.5	3.0	156	192
Tributaries															
Pelican River	340.6	11- 3-78	--	7.01	78	--	.118	.154	.38	.26	1.12	4.5	2.0	170	210
Tomahawk River	315.9	11- 3-78	--	7.30	71	--	.012	.034	.02	.12	.64	3.5	2.0	104	131
Spirit River	312.3	11- 3-78	--	7.22	62	--	.033	.052	.02	.10	.80	.5	<.5	169	191
New Wood River	295.2	11- 3-78	--	7.57	77	--	.021	.058	.01	<.01	.60	1.0	1.0	129	147
Copper River	291.3	11- 3-78	--	7.45	88	--	.051	.074	.06	.02	.52	.5	.5	131	166
Prairie River	286.3	11- 4-78	--	7.88	164	--	.023	.036	.05	.04	.18	.5	.5	55	70
Pine River	280.6	11- 4-78	--	7.60	99	--	.003	.024	.02	.22	.28	1.5	1.0	66	75
Rib River	262.6	11- 4-78	--	7.31	148	--	.034	.060	.03	.36	.52	4.0	3.0	57	85
Eau Claire River	261.1	11- 4-78	--	8.12	216	--	.026	.036	.01	.56	.34	1.0	1.0	37	55
Big Eau Pleine	235.6	11- 4-78	--	8.26	124	--	.049	.124	.04	.08	1.16	7.0	4.5	66	123
Plover River	219.1	11- 5-78	--	8.29	343	--	.015	.034	.06	1.00	.24	.5	<.5	30	46
Mill.Creek	212.6	11- 4-78	--	8.08	310	--	.347	.408	.16	.42	1.14	12.0	6.0	68	149
Moccasin Creek	195.2	11- 4-78	--	6.95	128	--	<.002	.040	.03	.58	.22	.5	.5	39	51
Industries															
Rhinelander Papers	341.3	(G)11- 3-78	--	--	--	--	--	--	--	--	--	48.7	29.3	430	1145
Georgia-Pacific	315.8	11- 2-78	--	--	--	--	--	--	--	--	--	41.0	29.5	50	510
Owens-Illinois	313.1	11- 3-78	--	--	--	--	--	--	--	--	--	90.0	82.0	2040	4230
Ward Paper	285.9	11- 2-78	--	--	--	--	--	--	--	--	--	51.0	27.0	255	1670
Wausau Papers	271.1	11- 5-78	--	--	--	--	--	--	--	--	--	87.0	64.0	1130	3200
Weyerhaeuser	258.2	(G)11- 6-78	--	--	--	--	--	--	--	--	--	23.5	17.0	4070	4900
Mosinee Papers	248.9	(G)11- 6-78	--	--	--	--	--	--	--	--	--	36.0	26.0	65	530
Cons.-Stevens Pt.	222.4	11- 3-78	--	--	--	--	--	--	--	--	--	14.0	7.5	10	140
Cons.-Wis. River	219.9	11- 3-78	--	--	--	--	--	--	--	--	--	4.3	2.0	75	130
Plover Papers	218.7	11- 3-78	--	--	--	--	--	--	--	--	--	41.0	24.5	35	525
Cons.-Wis. Rapids	202.4	11- 3-78	--	--	--	--	--	--	--	--	--	19.5	15.0	605	980
Nekoosa Papers	195.5	11- 3-78	--	--	--	--	--	--	--	--	--	79.0	54.0	940	2190

(G) denotes grab sample; all other industrial samples are 24-hour composites.

APPENDIX A continued

River survey water chemistry data for March 27-28, 1979.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Alkalinity as $CaCO_3$	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						←			mg/l				→	pt-co units	
Wisconsin River sites															
Rhinelander Dam	341.4	3-27-79	1.0	6.76	80	--	.018	.040	.09	.20	1.60	1.5	.5	70	98
North Hat Rapids	338.0	3-27-79	1.0	6.69	99	--	.018	.040	.15	.25	1.60	4.5	2.5	85	131
Hat Rapids Dam	335.2	3-27-79	1.0	6.61	98	--	.016	.060	.14	.30	1.60	3.5	2.0	98	137
Kings Dam	319.4	3-27-79	0.0	6.87	101	--	.025	.030	.10	.35	1.04	3.0	2.0	79	125
Grandmother Dam	305.9	3-27-79	1.0	6.66	87	--	.061	.080	.14	.40	1.04	6.5	1.5	85	131
Merrill	287.2	3-28-79	1.0	6.65	83	--	.049	.060	.14	.40	1.04	3.5	2.0	79	123
Granite Heights	274.3	3-28-79	0.0	6.64	75	--	.030	.040	.12	.55	.76	3.0	2.0	70	98
Lake Wausau	264.8	3-28-79	1.0	6.71	90	--	.039	.060	.06	.40	1.12	4.0	2.0	81	116
Mosinee Flowage	248.9	3-28-79	1.0	6.62	93	--	.040	.060	.10	.75	1.04	5.5	2.0	70	125
Lake Du Bay	235.4	3-28-79	0.4	6.41	102	--	.108	.160	.48	1.00	2.36	5.0	2.0	85	151
Tributaries															
Pelican River	340.6	3-27-79	0.0	6.25	77	--	.013	.060	.12	.45	1.16	3.5	2.0	117	155
Noisy Creek	333.6	3-27-79	0.0	6.31	72	--	.017	.030	.04	.30	.80	2.5	2.0	112	149
Big Pine River	323.4	3-27-79	1.0	6.91	90	--	.052	.060	.08	.40	.80	3.5	2.5	72	108
Tomahawk River	315.9	3-27-79	0.0	6.85	77	--	.017	.030	.08	.25	.56	2.0	0.5	59	108
Somo River	315.1	3-27-79	1.0	6.43	70	--	.023	.040	.04	.50	.96	2.5	1.0	102	131
Spirit River	312.3	3-27-79	1.0	6.20	67	--	.035	.050	.06	.45	1.00	5.5	2.5	91	139
New Wood River	295.2	3-27-79	1.0	6.15	55	--	.019	.060	.02	.45	.92	6.0	3.5	91	123
Copper River	291.3	3-27-79	1.0	6.08	70	--	.031	.040	.04	.40	.76	5.0	1.0	91	127
Prairie River	286.3	3-28-79	1.0	7.02	91	--	.035	.050	.02	.45	.88	4.5	1.5	81	110
Pine River	280.6	3-28-79	1.0	6.31	64	--	.020	.030	.04	.45	.72	3.0	1.5	75	91
Trappe River	276.0	3-28-79	1.0	6.41	64	--	.025	.080	.10	.50	1.00	2.5	2.0	66	83
Rib River	262.6	3-28-79	0.0	6.66	110	--	.044	.080	.14	.60	.89	3.5	0.5	52	78
Eau Claire River	261.1	3-28-79	1.0	6.72	98	--	.049	.090	.10	1.65	.76	3.5	1.0	61	84
Bull Jr. Creek	249.7	3-28-79	1.0	5.89	56	--	.007	.040	<.02	1.10	.56	2.0	1.5	69	84
Big Eau Pleine	241.8	3-28-79	1.0	6.80	123	--	.144	.260	.72	.30	2.16	12.5	3.0	81	185
Little Eau Claire	237.1	3-28-79	1.0	6.01	47	--	.016	.040	.04	1.05	.64	2.0	1.0	71	83
Little Eau Pleine	235.6	3-28-79	1.0	6.29	100	--	.115	.200	.52	1.30	1.84	5.5	1.5	84	134
Industries															
Rhinelander Papers	341.3	3-26-79	--	7.66	565	--	.012	.200	3.27	.11	8.32	33.0	21.0	360	608
Georgia-Pacific	315.8	3-26-79	--	7.02	242	--	.012	.270	<.02	.15	3.60	46.0	32.0	37	430
Owens-Illinois	313.1	(G)3-27-79	--	7.33	940	--	10.18	12.36	5.83	<.03	16.80	152.0	134.0	1900	3900
Ward Paper	285.9	3-27-79	--	7.72	1060	--	.188	1.32	.06	.10	3.44	96.0	40.0	230	1375
Wausau Papers	271.1	3-27-79	--	7.18	1640	--	.081	.740	.44	<.03	7.52	60.0	47.0	1155	1680
American Can	258.2	3-27-79	--	7.19	245	--	.034	.480	<.03	<.03	3.20	20.0	19.0	260	480
Weyerhaeuser	258.2	3-27-79	--	7.00	2340	--	.272	2.36	1.24	<.03	19.20	270.0	194.0	3320	6860
Mosinee Papers	248.9	3-27-79	--	6.91	640	--	.329	.660	1.58	.32	8.96	80.0	65.0	500	1150

(G) denotes grab sample; all other industrial samples are 24-hour composites.

APPENDIX A continued

River survey water chemistry data for May 22-23, 1979.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Alkalinity as $CaCO_3$	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						mg/l								pt-co units	
Wisconsin River sites															
Rhinelander Dam	341.4	5-22-79	13.4	7.06	55	--	.024	.100	--	--	.60	4.5	3.5	71	114
North Hat Rapids	338.0	5-22-79	13.5	6.92	62	--	.015	.075	--	--	.76	4.0	3.0	91	137
Hat Rapids Dam	335.2	5-22-79	13.5	6.91	62	--	.017	.080	--	--	.80	4.0	4.0	93	138
Kings Dam	319.4	5-22-79	14.2	6.96	60	--	.017	.090	--	--	.60	3.0	1.5	86	121
Grandmother Dam	305.9	5-22-79	13.8	6.95	57	--	.020	.070	--	--	.56	3.5	3.0	90	124
Merrill	287.2	5-22-79	14.1	6.99	55	--	.017	.070	--	--	.52	4.0	3.0	91	128
Granite Heights	274.3	5-23-79	12.1	7.05	61	--	.026	.100	--	--	.76	5.0	2.5	93	126
Lake Wausau	264.8	5-23-79	12.8	7.02	67	--	.038	.100	--	--	.68	5.5	2.5	90	126
Mosinee Flowage	248.9	5-23-79	13.3	6.95	84	--	.034	.115	--	--	.84	7.5	2.5	107	164
Lake Du Bay	235.4	5-23-79	14.8	7.11	91	--	.040	.130	--	--	.92	7.5	3.0	88	157
Tributaries															
Pelican River	340.6	5-22-79	12.7	6.65	52	--	.009	.070	--	--	.72	2.0	1.5	113	136
Noisy Creek	333.6	5-22-79	10.8	6.58	52	--	.005	.055	--	--	.64	2.5	2.5	131	149
Big Pine River	323.4	5-22-79	9.8	7.14	78	--	.037	.100	--	--	.60	2.5	2.5	89	102
Tomahawk River	315.9	5-22-79	13.8	7.03	49	--	.011	.055	--	--	.52	4.0	2.5	61	84
Somo River	315.1	5-22-79	13.0	6.81	44	--	.035	.065	--	--	.76	3.0	1.5	119	146
Spirit River	312.3	5-22-79	13.8	6.96	45	--	.018	.060	--	--	.68	2.5	2.5	89	114
New Wood River	295.2	5-22-79	11.6	7.07	45	--	.034	.085	--	--	.84	1.0	1.0	133	141
Copper River	291.3	5-22-79	12.4	6.85	45	--	.040	.095	--	--	.84	2.5	1.0	151	163
Prairie River	286.3	5-22-79	13.2	7.39	90	--	.032	.085	--	--	.64	3.5	2.5	96	112
Pine River	280.6	5-23-79	9.8	7.11	58	--	.006	.070	--	--	.80	3.0	2.0	96	114
Trappe River	276.0	5-23-79	10.3	6.94	60	--	.017	.070	--	--	.84	3.5	1.5	96	107
Rib River	262.6	5-23-79	12.1	7.07	104	--	.025	.085	--	--	.80	6.0	1.0	78	129
Eau Claire River	261.1	5-23-79	11.3	7.34	118	--	.032	.095	--	--	.80	2.5	2.5	83	102
Bull Jr. Creek	249.7	5-23-79	11.2	6.39	46	--	.023	.055	--	--	.92	4.5	1.0	135	151
Big Eau Pleine	241.8	5-23-79	13.8	7.36	96	--	.015	.080	--	--	.88	11.0	2.5	31	99
Little Eau Claire	237.1	5-23-79	12.9	6.36	41	--	.015	.085	--	--	1.00	3.0	1.0	101	132
Little Eau Pleine	235.6	5-23-79	13.3	6.81	75	--	.050	.180	--	--	1.40	8.0	3.5	97	168
Industries															
Rhinelander Papers	341.3	5-21-79	--	7.21	505	--	.072	.330	--	--	8.08	18.0	14.0	268	390
Georgia-Pacific	315.8	5-21-79	--	6.84	232	--	.041	.540	--	--	3.36	53.0	35.5	78	415
Owens-Illinois	313.1	5-21-79	--	7.53	790	--	1.00	4.48	--	--	10.15	114.0	108.0	1590	4210
Ward Paper	285.9	5-22-79	--	7.69	1180	--	.423	3.69	--	--	3.00	212.0	108.0	226	1525
Wausau Papers	271.1	5-22-79	--	6.86	1750	--	.046	1.40	--	--	11.52	125.0	91.0	1260	2700
American Can	258.2	5-22-79	--	7.23	190	--	.014	.148	--	--	3.44	13.5	10.5	166	233
Weyerhaeuser	258.2	5-22-79	--	7.19	2300	--	.991	2.72	--	--	17.57	233.0	183.0	3150	6990
Mosinee Papers	248.9	5-22-79	--	6.76	350	--	.825	--	--	--	11.73	44.5	32.0	101	339

APPENDIX A continued

River survey water chemistry data for July 31-August 1, 1979.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Alkalinity as $CaCO_3$	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						mg/l								pt-co units	
Wisconsin River sites															
Rhinelander Dam	341.4	7-31-79	22.8	7.41	74	--	.011	.060	.02	<.02	.74	3.5	3.0	58	117
North Hat Rapids	338.0	7-31-79	23.2	7.04	84	--	.015	.065	.10	.04	.90	7.5	5.5	76	140
Hat Rapids Dam	335.2	7-31-79	23.2	6.98	95	--	.016	.070	.10	.06	1.10	5.5	3.0	76	136
Kings Dam	319.4	7-31-79	23.7	7.44	90	--	.017	.075	.10	.20	1.02	3.5	3.0	76	136
Grandmother Dam	305.9	7-31-79	23.6	7.21	82	--	.019	.070	.08	.08	.98	4.5	2.0	80	156
Merrill	287.2	7-31-79	24.5	7.48	81	--	.018	.075	.02	.06	.94	4.5	2.0	84	154
Granite Heights	274.3	8- 1-79	22.1	7.50	91	--	.012	.070	<.02	.12	.70	6.0	3.0	76	135
Lake Wausau	264.8	8- 1-79	23.1	7.45	115	--	.008	.115	.04	.06	1.04	5.5	1.5	92	152
Mosinee Flowage	248.9	8- 1-79	24.6	7.30	152	--	.016	.115	.04	.12	1.10	7.0	3.5	101	201
Lake Du Bay	235.4	8- 1-79	26.0	8.51	137	--	.027	.200	<.02	<.02	1.84	15.5	12.0	111	234
Tributaries															
Pelican River	340.6	7-31-79	21.7	7.09	93	--	.111	.145	.32	.16	1.06	3.0	2.0	161	189
Noisy Creek	333.6	7-31-79	18.8	7.17	115	--	.071	.100	.06	.06	.58	4.0	2.0	141	180
Big Pine River	323.4	7-31-79	16.7	7.72	127	--	.086	.100	.08	.24	.40	.5	.5	79	99
Tomahawk River	315.9	7-31-79	22.7	7.32	69	--	.010	.045	.08	.02	.60	3.5	3.0	70	124
Somo River	315.1	7-31-79	22.2	7.22	75	--	.012	.055	.04	<.02	.84	1.5	1.5	124	172
Spirit River	312.3	7-31-79	23.0	7.00	61	--	.032	.095	.16	.02	1.24	4.5	4.0	180	233
New Wood River	295.2	7-31-79	22.8	8.14	121	--	.033	.140	.06	<.02	.92	1.0	.5	99	103
Copper River	291.3	7-31-79	22.0	7.92	120	--	.070	.115	.02	.02	.76	2.0	1.5	145	164
Prairie River	286.3	7-31-79	22.6	8.31	196	--	.013	.055	.02	.02	.40	5.0	2.5	34	83
Pine River	280.6	8- 1-79	18.3	7.89	118	--	.003	.035	<.02	.14	.50	3.5	.5	52	76
Trappe River	276.0	8- 1-79	18.7	7.53	136	--	.015	.040	.04	.20	.54	3.0	1.5	44	77
Rib River	262.6	8- 1-79	22.8	7.62	148	--	.025	.120	.08	.08	.80	8.5	2.0	40	139
Eau Claire River	261.1	8- 1-79	21.8	7.97	240	--	.117	.170	.06	.38	.60	7.0	2.5	42	139
Bull Jr. Creek	249.7	8- 1-79	20.0	7.21	105	--	.015	.085	.02	.20	1.22	5.0	1.0	143	212
Big Eau Pleine	241.8	8- 1-79	22.7	7.78	115	--	.064	.180	.18	.02	1.42	12.0	7.5	52	141
Little Eau Claire	237.1	8- 1-79	21.8	7.20	106	--	.002	.115	.10	.04	1.74	12.5	9.0	87	235
Little Eau Pleine	235.6	8- 1-79	25.8	8.30	142	--	.091	.295	.02	<.02	1.98	19.5	11.5	151	343
Industries															
Rhinelander Papers	341.3	7-30-79	--	7.42	500	--	.001	.100	1.40	.20	8.80	21.0	7.0	255	485
Georgia-Pacific	315.8	7-30-79	--	7.40	225	--	.005	<.100	.02	<.02	1.60	20.0	7.0	40	280
Owens-Illinois	313.1	7-30-79	--	7.78	700	--	.930	1.60	.60	<.20	3.20	38.5	32.0	1200	1705
Ward Paper	285.9	7-31-79	--	7.96	1220	--	.390	2.10	.04	<.02	4.40	157.0	63.0	140	1775
Wausau Papers	271.1	7-31-79	--	7.10	2500	--	.022	.600	2.00	<.20	12.8	57.0	41.0	1735	2295
American Can	258.2	7-31-79	--	7.08	560	--	.007	.300	1.06	.02	4.80	28.5	26.0	355	545
Weyerhaeuser	258.2	7-30-79	--	7.41	2500	--	.122	1.80	1.60	<.20	20.0	168.0	122.0	3490	6065
Mosinee Papers	248.9	7-31-79	--	6.96	440	--	.193	.700	3.80	.40	9.60	41.5	34.5	80	385

APPENDIX A continued

River survey water chemistry data for August 14-15, 1979.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Alkalinity as $CaCO_3$	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						mg/l								pt-co units	
Wisconsin River sites															
Rhinelander Dam	341.4	8-14-79	18.7	7.47	74	--	.016	.070	.02	<.02	.78	4.0	3.0	51	112
North Hat Rapids	338.0	8-14-79	19.2	7.14	96	--	.010	.110	.12	.04	1.42	4.0	2.5	61	131
Hat Rapids Dam	335.2	8-14-79	20.0	7.19	98	--	.012	.085	.16	.05	1.46	4.5	2.0	61	133
Kings Dam	319.4	8-14-79	20.3	7.40	89	--	.013	.070	.06	.08	.86	4.0	2.5	59	118
Grandmother Dam	305.9	8-14-79	20.0	7.47	79	--	.010	.090	.02	.02	.96	5.5	3.0	65	137
Merrill	287.2	8-14-79	20.8	7.70	83	--	.008	.085	.02	.05	.82	3.5	1.5	69	135
Granite Heights	274.3	8-15-79	17.2	7.60	97	--	.010	.080	.10	.08	.74	4.5	3.0	63	112
Lake Wausau	264.8	8-15-79	19.3	7.64	110	--	.019	.100	.06	.06	.76	6.5	1.5	76	149
Mosinee Flowage	248.9	8-15-79	19.7	7.52	148	--	.025	.155	.14	.08	1.08	9.5	4.5	97	210
Lake Du Bay	235.4	8-15-79	21.2	7.91	137	--	.030	.205	.05	.04	1.46	16.0	6.5	91	248
Tributaries															
Pelican River	340.6	8-14-79	17.6	7.22	93	--	.165	.250	.56	.18	1.50	1.5	1.0	122	156
Noisy Creek	333.6	8-14-79	15.9	7.38	119	--	.038	.085	.02	.02	.52	2.5	<.5	91	140
Big Pine River	323.4	8-14-79	13.9	7.70	125	--	.086	.120	.06	.16	.40	2.0	2.0	58	79
Tomahawk River	315.9	8-14-79	18.7	7.56	66	--	.010	.070	.02	<.02	.86	6.0	2.5	66	140
Somo River	315.1	8-14-79	17.9	7.60	86	--	.008	.045	.02	<.02	.70	1.0	.5	97	116
Spirit River	312.3	8-14-79	19.8	7.45	62	--	.030	.110	.03	.03	1.36	5.5	4.0	160	203
New Wood River	295.2	8-14-79	17.7	8.48	142	--	.024	.045	<.02	<.02	.32	1.0	.5	38	40
Copper River	291.3	8-14-79	18.1	7.96	111	--	.066	.125	<.02	<.02	.88	4.5	1.5	118	146
Prairie River	286.3	8-14-79	18.8	8.27	186	--	.018	.070	<.02	.02	.38	6.5	2.5	29	87
Pine River	280.6	8-15-79	18.8	7.73	108	--	.006	.040	.03	.08	.42	2.0	<.5	56	75
Trappe River	276.0	8-15-79	14.1	7.41	108	--	.014	.050	.06	.10	.50	2.5	1.5	58	81
Rib River	262.6	8-15-79	17.4	7.67	151	--	.031	.110	.02	.18	.72	7.5	2.0	44	118
Eau Claire River	261.1	8-15-79	17.1	8.25	220	--	.100	.140	.04	.30	.44	4.5	2.0	31	71
Bull Jr. Creek	249.7	8-15-79	15.5	7.31	93	--	.022	.060	.05	.38	.50	3.0	2.0	101	138
Big Eau Pleine	241.8	8-15-79	20.7	8.29	103	--	.032	.190	.06	.02	1.68	30.0	12.0	42	189
Little Eau Claire	237.1	8-15-79	16.0	7.29	98	--	.015	.155	.04	.04	1.78	17.0	14.5	77	215
Little Eau Pleine	235.6	8-15-79	21.0	7.60	141	--	.109	.360	.24	.02	2.33	33.0	13.5	136	432
Industries															
Rhinelander Papers	341.3	8-13-79	--	7.78	580	--	.023	.400	4.0	.20	19.6	28.0	24.0	260	640
Georgia-Pacific	315.8	8-13-79	--	6.99	215	--	<.002	.500	.06	<.02	2.40	10.0	6.5	24	144
Owens-Illinois	313.1	8-13-79	--	7.80	800	--	1.31	2.80	1.8	<.20	5.60	79.0	72.0	1975	3415
Ward Paper	285.9	8-14-79	--	7.99	950	--	.271	1.30	.20	<.20	2.80	58.5	30.0	168	810
Wausau Papers	271.1	8-14-79	--	7.32	1600	--	1.72	4.00	4.4	<.20	14.8	74.0	49.5	1760	2640
American Can	258.2	8-14-79	--	7.44	850	--	.007	.300	.02	<.02	.80	68.0	59.5	390	580
Weyerhaeuser	258.2	8-14-79	--	7.49	1550	--	.915	5.40	2.0	<.20	34.0	358.0	273.0	5970	10150
Mosinee Papers	248.9	8-14-79	--	6.76	480	--	1.88	2.30	11.6	.60	16.4	41.5	32.5	86	370

APPENDIX A continued

River survey water chemistry data for September 27-28, 1979.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Alkalinity as $CaCO_3$	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						←			mg/l				→	pt-co units	
Wisconsin River sites															
Rhinelander Dam	341.4	9-27-79	15.3	7.19	77	--	.020	.045	<.01	<.02	.72	4.0	2.5	43	82
Hat Rapids Dam	335.2	9-27-79	16.2	7.15	99	--	.024	.065	.01	.06	1.24	6.0	2.5	56	117
Kings Dam	319.4	9-27-79	16.6	7.43	89	--	.018	.070	.10	.18	.86	5.5	4.0	50	99
Grandmother Dam	305.9	9-27-79	16.4	7.21	84	--	.040	.075	.04	.10	.62	4.5	3.5	60	121
Merrill	287.2	9-27-79	17.9	7.62	88	--	.024	.055	.02	.04	.70	4.5	3.0	60	115
Granite Heights	274.3	9-27-79	18.2	8.53	95	--	.025	.050	.01	.04	.66	4.5	3.0	60	98
Lake Wausau	264.8	9-28-79	18.0	7.62	132	--	.016	.075	<.01	.04	.70	6.5	3.0	76	125
Mosinee Flowage	248.9	9-28-79	19.2	7.47	166	--	.040	.110	.02	.10	.82	7.0	3.0	99	190
Lake Du Bay	235.4	9-28-79	19.5	8.11	165	--	.021	.100	.01	.10	.98	7.0	5.0	84	161
Tributaries															
Pelican River	340.6	9-27-79	14.7	7.14	98	--	.095	.165	.03	.08	1.10	4.5	3.5	103	179
Noisy Creek	333.6	9-27-79	13.7	7.12	111	--	.075	.080	.14	.04	.54	3.5	2.0	98	140
Big Pine River	323.4	9-27-79	12.1	7.55	130	--	.073	.090	.03	.22	.32	5.0	2.5	45	78
Tomahawk River	315.9	9-27-79	16.5	7.21	71	--	.023	.055	.13	.02	.60	2.5	1.0	56	86
Somo River	315.1	9-27-79	15.6	7.30	92	--	.015	.050	.01	<.02	.68	3.5	2.5	84	117
Spirit River	312.3	9-27-79	17.0	7.37	75	--	.050	.175	.02	<.02	1.34	12.0	8.0	103	173
New Wood River	295.2	9-27-79	15.8	8.31	166	--	.040	.040	.01	<.02	.26	1.0	<.5	25	35
Copper River	291.3	9-27-79	17.3	7.88	160	--	.070	.070	<.01	.02	.50	1.0	1.0	78	96
Prairie River	286.3	9-27-79	16.3	8.29	200	--	.029	.050	.01	.02	.44	6.5	3.0	31	82
Pine River	280.6	9-27-79	18.8	8.89	121	--	.012	.025	.02	.08	.46	1.5	.5	41	56
Trappe River	276.0	9-27-79	18.0	8.04	154	--	.018	.065	.03	.10	.38	2.5	1.5	41	58
Rib River	262.6	9-28-79	18.0	7.68	140	--	.040	.125	.05	.06	.92	11.5	4.5	64	179
Eau Claire River	261.1	9-28-79	16.9	8.99	260	--	.070	.080	.02	.18	.44	2.5	1.0	31	76
Bull Jr. Creek	249.7	9-28-79	17.0	7.28	134	--	.028	.045	.01	.30	.44	2.0	.5	80	138
Big Eau Pleine	241.8	9-28-79	17.8	7.76	108	--	.030	.120	.05	.02	1.52	13.0	8.5	41	152
Little Eau Claire	237.1	9-28-79	18.0	7.46	126	--	.013	.180	.01	.02	2.12	16.0	12.0	82	232
Little Eau Pleine	235.6	9-28-79	19.2	7.84	138	--	.113	.240	.02	<.02	1.64	17.5	9.5	163	352
Industries															
Rhinelander Papers	341.3	9-26-79	--	7.82	580	--	.045	.100	.10	.40	16.8	30.5	19.5	273	760
Georgia-Pacific	315.8	9-26-79	--	7.15	245	--	.016	.200	.02	<.02	1.60	33.0	24.0	24	310
Owens-Illinois	313.1	9-26-79	--	7.63	830	--	1.35	3.00	3.20	<.20	7.20	96.0	84.0	1455	4410
Ward Paper	285.9	9-26-79	--	8.18	1310	--	.150	.500	.10	<.20	3.60	50.0	23.0	215	820
Wausau Papers	271.1	9-27-79	--	7.34	2150	--	.110	1.00	2.00	<.20	12.8	82.0	49.0	1455	2800
American Can	258.2	9-27-79	--	7.39	920	--	.110	.700	<.01	<.02	3.60	36.0	33.0	370	535
Weyerhaeuser	258.2	9-27-79	--	7.67	2400	--	1.36	3.30	.10	<.20	15.6	234.0	148.0	4380	7810
Mosinee Papers	248.9	9-27-79	--	6.62	470	--	.590	.700	.60	.80	6.40	55.0	39.5	100	670

APPENDIX B

Chlorophyll data for Wisconsin River water quality survey, June 27-July 8, 1978.

	River Mile	Date	Chl a	Chl b	Chl c	Pheophytin	Chl a - Pheophytin	663B/ 663A
			←		ug/l		→	
Wisconsin River sites								
Rhinelander Dam	341.4	6-27-78	11.85	.76	5.00	1.30	11.05	1.63
Hat Rapids Dam	335.2	6-27-78	17.47	1.61	7.44	3.21	15.59	1.58
Kings Dam	319.4	6-27-78	11.56	1.17	3.94	3.42	9.56	1.52
Grandmother Dam	305.9	6-28-78	16.67	1.62	3.64	0	16.93	1.70
Merrill	287.2	6-28-78	7.18	.65	.59	1.03	6.55	1.60
Granite Heights	274.3	6-28-78	4.87	.39	.33	0	5.16	1.70
Mosinee Flowage	248.9	6-29-78	7.11	1.27	3.87	4.40	4.60	1.36
Lake Du Bay	235.4	6-29-78	26.51	1.79	6.64	0	26.68	1.70
Stevens Point	223.0	7- 8-78	12.49	1.10	1.93	1.25	11.72	1.63
Biron	205.3	6-29-78	47.69	6.14	16.89	0	48.31	1.70
Petenwell	187.2	7- 8-78	12.86	.59	1.99	0	16.04	1.70
Tributaries								
Pelican River	340.6	6-27-78	3.18	.47	2.08	1.67	2.23	1.40
Noisy Creek	333.6	6-27-78	1.27	.51	1.56	0	1.32	1.70
Big Pine River	323.4	6-27-78	2.26	.48	1.16	1.30	1.53	1.38
Tomahawk River	315.9	6-27-78	6.42	.34	1.19	.77	5.93	1.62
Somo River	315.1	6-27-78	5.40	1.32	2.00	1.12	4.83	1.57
Spirit River	312.3	6-27-78	7.27	1.12	2.97	3.13	5.48	1.45
New Wood River	295.2	6-28-78	3.02	.77	1.78	1.60	2.14	1.40
Copper River	291.3	6-28-78	5.56	.67	1.66	0	6.83	1.70
Prairie River	286.3	6-28-78	4.92	.82	.90	1.75	3.91	1.48
Pine River	280.6	6-28-78	2.10	.47	1.74	2.24	.82	1.19
Trappe River	276.0	6-28-78	4.08	.33	1.08	2.61	2.54	1.35
Rib River	262.6	6-28-78	18.21	2.96	6.25	2.37	16.95	1.61
Eau Claire River	261.1	6-28-78	6.82	1.00	1.23	2.37	5.45	1.49
Bull Jr. Creek	249.7	6-29-78	2.74	1.02	4.77	.36	2.64	1.62
Hog Creek	246.0	6-29-78	2.55	.47	0	2.55	1.07	1.21
Big Eau Pleine	241.8	6-29-78	113.63	0	28.32	0	127.77	1.70
Little Eau Pleine	235.6	6-29-78	20.16	3.17	10.64	6.68	16.39	1.50
Hay Meadow Creek	225.4	6-29-78	5.80	0	1.85	0	9.03	1.70
Plover River	219.1	7- 8-78	2.93	.05	.71	1.41	2.08	1.42
Little Plover R.	217.1	7- 8-78	1.69	.58	.91	.41	1.50	1.55
Mill Creek	212.6	6-29-78	4.75	2.63	7.56	2.87	3.35	1.38
Mosquito Creek	204.2	6-29-78	5.48	1.43	2.81	3.79	3.36	1.33
Moccasin Creek	195.2	6-29-78	10.71	2.05	5.80	2.73	9.23	1.54

APPENDIX B continued

Chlorophyll data for Wisconsin River water quality surveys, November 3-5, 1978 (A) and March 27-28, 1979 (B).

	River Mile	Date	Chl *a*	Chl *b*	Chl *c*	Pheophytin	Chl *a* - Pheophytin	663B/ 663A
			←		ug/l		→	
Wisconsin River sites				A				
Hat Rapids Dam	335.2	11- 3-78	4.92	.68	1.97	.51	4.64	1.63
Kings Dam	319.4	11- 3-78	5.58	.88	3.08	.07	5.59	1.69
Grandmother Dam	305.9	11- 3-78	3.63	.53	1.01	.37	3.43	1.63
Merrill	287.2	11- 4-78	2.75	0	0	0	3.01	1.70
Granite Heights	274.3	11- 4-78	3.65	.26	1.05	0	4.86	1.70
Mosinee Flowage	248.9	11- 4-78	2.87	.41	.77	0	3.20	1.70
Lake Du Bay	235.4	11- 4-78	6.58	1.06	3.13	0	7.33	1.70
Stevens Point	223.0	11- 5-78	7.60	1.04	3.12	.04	7.61	1.70
Biron	205.3	11- 4-78	8.40	1.57	3.03	.74	8.05	1.64
Petenwell	187.2	11- 4-78	6.57	.82	2.93	.13	6.52	1.69
Wisconsin River sites				B				
Rhinelander Dam	341.4	3-27-79	.74	.62	1.66	0	1.40	1.70
North Hat Rapids	338.0	3-27-79	.72	.49	1.35	0	.95	1.70
Hat Rapids Dam	335.2	3-27-79	.21	0	.40	0	.25	1.70
Kings Dam	319.4	3-27-79	.59	.17	.57	0	1.04	1.70
Grandmother Dam	305.9	3-27-79	1.04	.40	1.24	0	1.21	1.70
Merrill	287.2	3-28-79	1.08	.52	1.99	0	1.30	1.70
Granite Heights	274.3	3-28-79	1.14	.28	1.67	0	1.28	1.70
Lake Wausau	264.8	3-28-79	1.05	.47	1.41	.73	.67	1.33
Mosinee Flowage	248.9	3-28-79	.77	0	0	.58	.40	1.29
Lake Du Bay	235.4	3-28-79	1.66	.39	1.42	2.87	0	1.00

APPENDIX B continued

Chlorophyll data for Wisconsin River water quality surveys, May 22-23, 1979 (A) and July 31-August 1, 1979 (B).

	River Mile	Date	Chl *a*	Chl *b*	Chl *c*	Pheophytin	Chl *a* - Pheophytin	663B/ 663A
			←		ug/l		→	
Wisconsin River sites				A				
Rhinelander Dam	341.4	5-22-79	6.75	.88	2.72	1.00	6.19	1.60
North Hat Rapids	338.0	5-22-79	6.35	1.08	2.86	.45	6.17	1.65
Hat Rapids Dam	335.2	5-22-79	6.40	.87	2.68	.65	6.05	1.63
Kings Dam	319.4	5-22-79	7.41	1.35	2.56	0	7.59	1.70
Grandmother Dam	305.9	5-22-79	6.02	1.37	1.14	.60	5.75	1.63
Merrill	287.2	5-22-79	5.23	.75	2.10	.68	4.85	1.61
Granite Heights	274.3	5-23-79	4.72	.88	1.44	1.13	4.10	1.55
Lake Wausau	264.8	5-23-79	5.42	1.22	2.95	1.78	4.46	1.50
Mosinee Flowage	248.9	5-23-79	7.41	1.24	3.86	1.69	6.49	1.56
Lake Du Bay	235.4	5-23-79	13.95	3.24	7.44	2.24	12.86	1.60
Wisconsin River sites				B				
Rhinelander Dam	341.4	7-31-79	15.75	1.59	4.34	0	15.91	1.70
North Hat Rapids	338.0	7-31-79	12.72	1.38	2.89	0	12.74	1.70
Hat Rapids Dam	335.2	7-31-79	11.62	1.79	3.31	1.64	10.72	1.61
Kings Dam	319.4	7-31-79	27.71	1.55	6.73	0	28.96	1.70
Grandmother Dam	305.9	7-31-79	18.90	1.88	4.72	1.32	18.12	1.65
Merrill	287.2	7-31-79	17.96	1.45	4.41	0	18.09	1.70
Granite Heights	274.3	8- 1-79	16.83	2.96	9.00	1.57	16.09	1.64
Lake Wausau	264.8	8- 1-79	18.67	1.98	4.33	0	19.25	1.70
Mosinee Flowage	248.9	8- 1-79	31.60	3.73	9.44	1.46	30.80	1.67
Lake Du Bay	235.4	8- 1-79	70.90	3.09	18.64	0	72.88	1.70

APPENDIX B continued

Chlorophyll data for Wisconsin River water quality survey, August 14-15, 1979.

	River Mile	Date	Chl a	Chl b	Chl c	Pheophytin	Chl a - Pheophytin	663B/ 663A
			←		ug/l		→	
Wisconsin River sites								
Rhinelander Dam	341.4	8-14-79	17.23	.99	3.42	0	18.26	1.70
North Hat Rapids	338.0	8-14-79	17.24	1.13	4.82	.11	17.11	1.70
Hat Rapids Dam	335.2	8-14-79	15.83	1.62	3.98	.24	15.69	1.69
Kings Dam	319.4	8-14-79	17.74	1.45	4.94	.48	17.42	1.68
Grandmother Dam	305.9	8-14-79	21.07	1.36	5.75	0	21.68	1.70
Merrill	287.2	8-14-79	16.36	1.44	5.01	0	16.74	1.70
Granite Heights	274.3	8-15-79	14.71	0	2.72	0	14.79	1.70
Lake Wausau	264.8	8-15-79	17.59	1.69	3.60	0	18.28	1.70
Mosinee Flowage	248.9	8-15-79	32.99	4.43	9.80	0	34.52	1.70
Lake Du Bay	235.4	8-15-79	43.64	3.87	13.42	1.46	42.73	1.68
Tributaries								
Pelican River	340.6	8-14-79	1.91	.23	.42	.19	1.80	1.63
Noisy Creek	333.6	8-14-79	3.91	.15	.49	.65	3.50	1.59
Big Pine River	323.4	8-14-79	2.73	.30	.0	--	--	--
Tomahawk River	315.9	8-14-79	17.83	.28	1.50	--	--	--
Somo River	315.1	8-14-79	4.08	.23	.75	--	--	--
Spirit River	312.3	8-14-79	24.16	.69	3.97	--	--	--
New Wood River	295.2	8-14-79	.92	.17	.34	--	--	--
Copper River	291.3	8-14-79	1.68	0	0	--	--	--
Prairie River	286.3	8-14-79	6.88	0	.86	--	--	--
Pine River	280.6	8-15-79	2.71	.46	1.23	1.21	2.02	1.44
Trappe River	276.0	8-15-79	2.50	.98	.38	1.00	1.99	1.47
Rib River	262.6	8-15-79	15.78	2.27	3.49	.93	15.30	1.66
Eau Claire River	261.1	8-15-79	5.47	1.21	2.12	2.27	4.21	1.45
Bull Jr. Creek	249.7	8-15-79	1.78	.25	.79	.50	1.50	1.53
Big Eau Pleine	241.8	8-15-79	61.27	4.20	20.57	0	64.29	1.70
Little Eau Claire	237.1	8-15-79	55.40	2.75	13.13	0	57.72	1.70
Little Eau Pleine	235.6	8-15-79	83.23	7.53	22.19	0	85.51	1.70

APPENDIX B continued

Chlorophyll data for Wisconsin River water quality survey, September 27-28, 1979.

	River Mile	Date	Chl a	Chl b	Chl c	Pheophytin	Chl a - Pheophytin	663B/ 663A
			←		ug/l		→	
Wisconsin River sites								
Rhinelander Dam	341.4	9-27-79	9.37	1.13	3.66	.72	8.97	1.65
Hat Rapids Dam	335.2	9-27-79	11.34	1.24	3.41	.17	11.25	1.69
Kings Dam	319.4	9-27-79	22.90	1.96	7.72	.61	22.51	1.68
Grandmother Dam	305.9	9-27-79	12.34	1.49	5.86	1.37	11.58	1.63
Merrill	287.2	9-27-79	13.00	.13	.25	0	13.86	1.70
Granite Heights	274.3	9-27-79	10.93	.90	3.92	0	11.27	1.70
Lake Wausau	264.8	9-28-79	12.82	.43	3.49	0	13.88	1.70
Mosinee Flowage	248.9	9-28-79	22.13	1.75	6.46	3.22	20.19	1.60
Lake Du Bay	235.4	9-28-79	35.46	1.44	10.85	0	36.15	1.70

APPENDIX C

Primary production and associated data collected during raft experiments on Lake Du Bay (river mile 239.4), on June 6, 1979. Weather: Sunny, calm, temperatures in 70's ($^{\circ}$F).

	Depth m	Carbon assimilation mg/m^3/hr	% increase	True color pt-co units	% decrease	Apparent color pt-co units	% decrease	TSS mg/l	% decrease
Control bags:									
e white[1] : 3.74	.1*	34.9		91		140		8.0	
e red : 1.87	.25	32.0		86		142		7.5	
e blue : 7.24	.5	22.3		91		140		6.5	
e green : 3.44	.75*	12.3		91		140		8.0	
	1.0	7.3		86		142		7.5	
	1.25	6.9		91		140		6.5	
Dilution set 1:									
e white : 3.37	.1	32.6	-6.8	82	9.9	122	12.9	6.0	25.0
e red : 2.32	.25	27.6	-13.8	82	4.7	122	14.1	6.0	20.0
e blue : 6.57	.5	25.8	15.7	77	15.4	134	4.3	7.0	-7.7
e green : 3.37	.75*	17.2	39.8	72	20.9	122	12.9	7.0	12.5
	1.25	8.0	15.9	77	15.4	134	4.3	7.0	-7.7
	1.5*	5.2		72		122		7.0	
<u>In situ</u>									
e white : 2.95	.1	36.6		86		157		8.5	
e red : 1.61	.25	34.2							
e blue : 8.39	.5	23.4							
e green : 3.09	1.0	8.0							
	1.5	5.6							
	2.0	3.6							

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[1] light extinction coefficient.

* indicates samples incubated in the bag for which extinction coefficients are presented.

APPENDIX C continued

Primary production and associated data collected during raft experiments on Lake Du Bay (river mile 239.4), on June 21, 1979. Weather: Overcast and windy, temperatures in 70's (°F).

	Depth m	Carbon assimilation mg/m^3/hr	% increase	True color pt-co units	% decrease	Apparent color pt-co units	% decrease	TSS mg/l	% decrease
Control bags:									
	.2	16.6		146		215		4.0	
	.5	13.7		146		211		5.0	
	.8	5.8		146		215		4.0	
	1.2	2.5		146		211		5.0	
Dilution set 1:									
	.2	17.0	2.4	108	26.0	172	20.0	4.5	-12.5
	.5	6.4	-53.3	142	2.7	204	3.3	5.5	-10.0
	.8	5.9	1.7	108	26.0	172	20.0	4.5	-12.5
	1.2	2.5	0	142	2.7	204	3.3	5.5	-10.0
Dilution set 2:									
	.2	21.7	30.7	86	41.1	129	40.0	3.0	25.0
	.5	10.4	-24.1	102	30.1	155	26.5	4.0	20.0
	.8	7.3	25.9	86	41.1	129	40.0	3.0	25.0
	1.2	3.5	40.0	102	30.1	155	26.5	4.0	20.0
<u>In situ</u>:									
e white[1] : 4.57	.2	18.5		144		222		6.0	
e red : 3.46	.5	11.1							
e blue :12.15	.8	5.9							
e green : 5.79	1.2	4.4							
	1.5	3.1							
	2.0	2.3							

[1] light extinction coefficient.

APPENDIX C continued

Primary production and associated data collected during raft experiments on Lake Du Bay (river mile 239.4), on June 28, 1979. Weather: Sunny, hazy, temperatures in 80's (°F).

	Depth m	Carbon assimilation mg/m^3/hr	% increase	True color pt-co units	% decrease	Apparent color pt-co units	% decrease	TSS mg/l	% decrease
Control bags:									
e white[1] : 3.31	.2	47.7		136		208		9.0	
e red : 2.09	.5	22.4		135		208		6.5	
e blue : 9.23	.8	12.1		136		208		9.0	
e green : 3.86	1.2	6.2		135		208		6.5	
Dilution set 1:									
e white : 2.55									
e red : 1.82	.5	30.5	36.2	96	28.9	172	17.3	6.5	0
e blue : 7.11									
e green : 2.90	1.2	8.7	40.3	96	28.9	172	17.3	6.5	0
Dilution set 2:									
e white : 2.31	.2	52.6	10.3	68	50.0	140	32.7	5.5	38.9
e red : 1.51	.5	35.2	57.1	68	49.6	138	33.7	6.0	7.7
e blue : 4.99	.8	20.0	65.3	68	50.0	140	32.7	5.5	38.9
e green : 2.28	1.2	15.3	146.8	68	49.6	138	33.7	6.0	7.7
In situ:									
e white : 3.57	.2	48.5		133		208		9.0	
e red : 2.30	.5	30.4							
e blue : 9.79	.8	19.4							
e green : 4.19	1.2	9.8							
	1.5	7.5							
	2.0	9.3							

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[1] light extinction coefficient.

APPENDIX C continued

Primary production and associated data collected during raft experiments on Lake Du Bay (river mile 239.4), on July 18, 1979. Weather: Sunny, temperatures in 70's (^{o}F).

	Depth m	Carbon assimilation mg/m^3/hr	% increase	True color pt-co units	% decrease	Apparent color pt-co units	% decrease	TSS mg/l	% decrease
Control bags:									
e white[1] : 3.25	.2*	168.3		106		194		11.5	
e red : 2.33	.5	90.5		102		194		10.0	
e blue : 8.55	.8*	76.8		106		194		11.5	
e green : 3.95	1.2	21.1		102		194		10.0	
Dilution set 1:									
e white : 2.44	.2	184.7	9.7	84	20.8	165	14.9	11.5	0
e red : 1.59	.5*	113.5	25.4	90	11.8	165	14.9	10.0	0
e blue : 7.09	.8	88.3	15.0	84	20.8	165	14.9	11.5	0
e green : 2.92	1.2*	22.7	7.6	90	11.8	165	14.9	10.0	0
Dilution set 2:									
e white : 2.43	.2*	192.1	14.1	73	31.1	133	31.4	8.0	30.4
e red : 2.02	.5	128.9	42.4	63	38.2	123	36.6	10.0	0
e blue : 5.17	.8*	116.9	52.2	73	31.1	133	31.4	8.0	30.4
e green : 2.61	1.2	48.6	130.3	63	38.2	123	36.6	10.0	0
In situ:									
e white : 2.90	.2	161.8		100		203		10.5	
e red : 1.69	.5	137.0							
e blue : 7.72	.8	93.2							
e green : 3.10	1.2	39.4							
	1.5	29.7							
	2.0	24.2							

[1] light extinction coefficient.

* indicates samples incubated in the bag for which extinction coefficients are presented.

APPENDIX D

Wisconsin River water chemistry data for July 4 mill shutdown survey, 1979.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						mg/l							pt-co units	
Wisconsin River sites														
Granite Heights	274.3	7-2-79	20.2	7.25	92	.031	.070	.05	.25	.80	2.5	2.0	103	160
Lake Wausau	264.8	7-2-79	23.0	7.40	104	.027	.090	.06	.20	.84	5.0	2.5	124	173
Mosinee Flowage	248.9	7-2-79	23.1	7.14	138	.038	.130	.05	.25	1.20	8.5	4.5	148	217
Below Mosinee	248.1	7-2-79	22.8	7.17	133	.061	.170	.15	.25	1.16	11.5	5.0	154	250
Highway 34	240.1	7-2-79	24.8	7.40	122	.027	.150	.10	.20	1.40	8.5	4.5	139	212
Lake Du Bay	235.4	7-2-79	22.7	7.18	111	.035	.110	.06	.20	.96	7.0	1.5	133	199
Industries														
Wausau Papers	271.1	7-2-79	--	6.79	1500	.596	2.80	8.5	1.0	16.0	96.0	69.0	1160	2195
Mosinee Papers	248.9	7-2-79	--	6.93	580	1.89	2.00	4.7	<.50	12.8	123.0	99.0	470	1735
Wisconsin River sites														
Granite Heights	274.3	7-3-79	20.3	7.20	89	.032	.085	.04	.30	.60	7.0	5.0	101	163
Lake Wausau	264.8	7-3-79	23.4	7.25	95	.035	.095	.04	.20	.70	5.5	4.0	117	163
Mosinee Flowage	248.9	7-3-79	23.2	7.12	113	.048	.140	.09	.25	.94	9.0	5.0	126	211
Below Mosinee	248.1	7-3-79	23.7	7.04	116	.072	.155	.12	.30	1.00	9.5	5.5	124	215
Highway 34	240.1	7-3-79	24.2	7.24	125	.028	.125	.08	.25	1.00	7.5	5.0	134	220
Lake Du Bay	235.4	7-3-79	22.3	7.03	109	.042	.115	.09	.20	1.00	6.0	3.5	134	195
Industries														
Wausau Papers	271.1	7-3-79	--	7.01	1600	2.28	3.80	8.5	.05	17.6	124.0	86.0	945	2320
Mosinee Papers	248.9	7-3-79	--	6.96	950	2.11	2.75	12.0	.25	19.8	52.0	41.0	760	1490
Wisconsin River sites														
Granite Heights	274.3	7-4-79	19.7	7.34	89	.031	.095	.14	.20	.74	7.0	2.0	111	161
Lake Wausau	264.8	7-4-79	20.2	7.22	84	.036	.100	.05	.20	.88	6.0	3.0	117	167
Mosinee Flowage	248.9	7-4-79	21.9	7.23	115	.051	.130	.29	.25	1.04	7.0	2.0	119	195
Below Mosinee	248.1	7-4-79	21.6	7.33	120	.058	.145	.20	.25	1.04	9.5	4.0	120	205
Highway 34	240.1	7-4-79	22.9	7.16	122	.038	.140	.17	.25	1.14	11.5	5.0	136	211
Lake Du Bay	235.4	7-4-79	22.8	7.22	113	.040	.125	.25	.25	1.04	5.0	3.0	136	184

APPENDIX D continued

Wisconsin River water chemistry data for July 4 mill shutdown survey, 1979.

	River Mile	Date	Temp °C	pH	Conductivity umhos/cm	Ortho P	Total P	NH_4-N	NO_2-NO_3 N	TKN	TSS	VSS	True Color	Apparent Color
						mg/l							pt-co units	
Industries														
Wausau Papers	271.1	7-4-79	--	7.22	1290	2.49	3.40	7.7	.50	14.4	64.0	45.0	890	2120
Mosinee Papers	248.9	7-4-79	--	7.22	950	.353	3.25	9.8	10.0	15.0	49.0	44.0	715	1350
Wisconsin River sites														
Granite Heights	274.3	7-5-79	19.4	7.21	91	.032	.100	.03	.15	.78	5.0	1.5	99	153
Lake Wausau	264.8	7-5-79	21.4	7.24	88	.042	.105	.03	.15	.84	8.5	4.0	105	159
Mosinee Flowage	248.9	7-5-79	21.3	7.27	104	.050	.130	.10	.25	.94	13.5	5.0	115	189
Below Mosinee	248.1	7-5-79	21.2	7.30	109	.051	.140	.19	.30	1.14	11.5	4.0	113	199
Highway 34	240.1	7-5-79	22.4	7.29	119	.041	.130	.13	.25	1.00	12.5	4.5	117	230
Lake Du Bay	235.4	7-5-79	22.4	7.14	116	.038	.125	.19	.20	1.08	9.0	3.5	133	195
Industries														
Wausau Papers	271.1	7-5-79	--	7.23	1540	4.32	5.75	--	<.05	22.0	94.0	56.0	995	2115
American Can	258.2	7-5-79	--	7.45	360	.027	.650	.24	.25	3.20	112.0	36.0	1170	1615
Mosinee Papers	248.9	7-5-79	--	7.27	875	2.87	3.65	2.65	11.5	11.4	65.0	45.0	475	1205
Wisconsin River sites														
Granite Heights	274.3	7-6-79	20.5	7.18	80	.045	.100	.19	.20	.84	6.0	1.5	119	155
Lake Wausau	264.8	7-6-79	22.8	7.20	86	.048	.120	.17	.20	.80	3.5	3.0	119	159
Mosinee Flowage	248.9	7-6-79	22.7	7.19	99	.040	.140	.28	.25	1.00	9.0	4.5	117	192
Below Mosinee	248.1	7-6-79	22.5	7.26	101	.045	.110	.32	.30	.76	12.5	5.0	119	211
Highway 34	240.1	7-6-79	25.1	7.47	102	.023	.120	.04	.25	1.00	8.5	5.0	119	197
Lake Du Bay	235.4	7-6-79	23.0	7.03	114	.049	.140	.32	.25	1.12	6.0	2.5	140	197
Industries														
Wausau Papers	271.1	7-6-79	--	7.07	1120	1.94	3.80	6.5	.50	13.2	89.0	49.0	565	1425
American Can	258.2	7-6-79	--	7.27	260	.180	1.40	2.1	.50	4.0	14.5	12.0	1205	1370
Mosinee Papers	248.9	7-6-79	--	7.08	750	2.16	2.80	3.8	10.0	7.6	40.0	26.0	355	820

APPENDIX E

Wisconsin River chlorophyll data for July 4 mill shutdown survey, 1979.

	River Mile	Date	Chl a	Chl b	Chl c	Pheophytin	Chl a - Pheophytin	663B/ 663A
			ug/l					
Granite Heights	274.3	7- 2-79	5.08	.84	1.31	1.74	4.08	1.49
Lake Wausau	264.8	7- 2-79	7.44	1.04	2.21	2.42	6.05	1.50
Mosinee Flowage	248.9	7- 2-79	16.93	2.47	4.78	2.13	15.76	1.62
Below Mosinee	248.1	7- 2-79	16.36	2.55	4.05	3.66	14.30	1.56
Highway 34	240.1	7- 2-79	32.67	6.51	9.19	3.65	30.87	1.63
Lake Du Bay	235.4	7- 2-79	13.05	.67	2.92	3.34	11.01	1.54
Granite Heights	274.3	7- 3-79	4.73	.22	.98	2.17	3.42	1.43
Lake Wausau	264.8	7- 3-79	5.72	.33	1.29	.64	5.31	1.63
Mosinee Flowage	248.9	7- 3-79	13.54	2.05	4.37	1.42	12.79	1.63
Below Mosinee	248.1	7- 3-79	18.39	2.32	5.15	2.40	17.03	1.61
Highway 34	240.1	7- 3-79	27.50	4.55	8.62	1.25	26.97	1.67
Lake Du Bay	235.4	7- 3-79	11.92	1.61	4.37	3.58	9.87	1.51
Granite Heights	274.3	7- 4-79	7.36	1.05	2.20	2.48	5.93	1.49
Lake Wausau	264.8	7- 4-79	5.81	.57	.94	1.35	5.00	1.55
Mosinee Flowage	248.9	7- 4-79	15.54	2.55	4.73	4.15	13.20	1.53
Below Mosinee	248.1	7- 4-79	15.45	2.18	4.81	4.12	13.10	1.53
Highway 34	240.1	7- 4-79	25.77	3.88	8.23	9.27	20.46	1.51
Lake Du Bay	235.4	7- 4-79	11.74	2.00	3.73	3.71	9.65	1.51
Granite Heights	274.3	7- 5-79	7.18	1.51	1.88	3.07	5.45	1.45
Lake Wausau	264.8	7- 5-79	7.16	.64	0	2.72	5.53	1.47
Mosinee Flowage	248.9	7- 5-79	12.97	1.66	3.05	4.73	10.22	1.48
Below Mosinee	248.1	7- 5-79	12.99	1.26	1.58	2.62	11.43	1.57
Highway 34	240.1	7- 5-79	20.06	3.03	6.66	5.82	16.76	1.52
Lake Du Bay	235.4	7- 5-79	11.99	1.61	4.06	5.12	9.02	1.45
Granite Heights	274.3	7- 6-79	7.00	.92	1.58	1.62	6.07	1.55
Lake Wausau	264.8	7- 6-79	8.41	.95	3.35	.97	7.86	1.62
Mosinee Flowage	248.9	7- 6-79	13.11	1.67	3.49	1.79	12.09	1.61
Below Mosinee	248.1	7- 6-79	12.81	1.26	3.30	2.54	11.31	1.57
Highway 34	240.1	7- 6-79	24.51	3.93	5.71	3.21	22.77	1.61
Lake Du Bay	235.4	7- 6-79	11.61	.13	2.38	1.54	10.59	1.61

APPENDIX F

Flow data for Wisconsin River water quality surveys, 1978-1979.

	River Mile	June 1978	November 1978	March 1979	May 1979	July 1979	August 1979	September 1979
Wisconsin River dam sites								
Rhinelander Dam	341.4	575	930	740	1130	660	660	720
Hat Rapids Dam	335.2	850	980	1100	1700	850	750	750
Kings Dam	319.4	924	1039	1208	2145	944	835	771
Grandmother Dam	305.9	1800	2443	2549	3151	1593	1699	1451
Merrill Dam	286.1	1639	2498	4839	4183	2277	1865	1737
Wausau Dam	265.6	1726	2551	5828	4149	2005	1959	1769
Rothschild Dam	258.4	1720	2459	8872	5056	2351	2338	1631
Lake Du Bay Dam	235.4	2400	2886	18708	6074	2563	2633	2275
Stevens Point Dam	222.5	2894	3200					
Biron Dam	205.3	2850	3307					
Industries								
Rhinelander Paper	341.3	23.70	24.44	22.73	21.92	24.45	23.87	25.19
Georgia-Pacific	315.8	.474	.524	.510	.411	.321	.384	.168
Owens-Illinois	313.1	10.48	10.00	8.40	9.10	9.00	8.58	10.16
Ward Paper	285.9	.891	1.044	1.054	1.016	1.307	.883	1.137
Wausau Papers	271.1	9.48	10.49	12.30	13.65	13.20	11.03	11.88
Weyerhaeuser	258.2	15.93	15.30	17.20	16.823	18.477	16.331	17.281
American Can	258.2			2.242	2.356	2.635	2.245	2.437
Mosinee Papers	248.9	6.19	18.47	17.30	16.20	15.39	15.613	16.823
Cons.- Stevens Pt.	222.4	2.24	2.50					
Cons.- Wis. River	219.9	4.70	4.21					
Plover Papers	218.7	.924	.840					
Cons.-Wis. Rapids	202.4	31.95	35.98					
Nekoosa Papers	195.5	47.96	39.14					

APPENDIX F continued

Flow data for Wisconsin River water quality surveys, 1978-1979.

	River Mile	June 1978	November 1978	March 1979	May 1979	July 1979	August 1979	September 1979
Tributaries Estimated flows at entrance to Wisconsin River								
Pelican River	340.6	86	113	755	615	62	30	15
Noisy Creek	333.6	49		433	352	35	17	8
Big Pine River	323.4	25		218	178	18	8	4
Tomahawk River	315.9	650	921	343	1046	748	913	710
Somo River	315.1	97		1336	197	27	17	9
Spirit River	312.3	75	100	350	260	70	65	55
New Wood River	295.2	65	31	896	132	18	11	6
Copper River	291.3	77	37	1056	156	21	13	8
Prairie River	286.3	124	138	662	308	138	128	100
Pine River	280.6	62	70	334	155	70	64	50
Trappe River	276.0	51		274	128	57	53	41
Rib River	262.6	117	186	2613	461	98	126	70
Eau Claire River	261.1	109	161	1380	436	143	133	105
Bull Jr. Creek	249.7	9		108	34	11	10	8
Big Eau Pleine	241.8	0	280	2275	0	380	338	350
Little Eau Claire	237.1			138	148	98	87	86
Little Eau Pleine	235.6	172		921	429	192	178	139
Hay Meadow Creek	225.4	44						
Plover River	219.1	166	122					
Little Plover R.	217.1	11	8					
Mill Creek	212.6	147	108					
Mosquito Creek	204.2	19	14					
Moccasin Creek	195.2	19	14					
Measured flows								
Pelican at Rhinelander		35	46	307	250	25	12	6
Spirit at Spirit Falls		58	28	800	118	16	10	6
Spirit at dam		75	100	350	260	70	65	55
Tomahawk at Rice Dam		650	921	343	1046	748	913	710
Prairie at Merrill		93	104	498	232	104	96	100
Eau Claire at Kelly		95	140	1200	379	124	116	91
Rib		117	186	2613	461	98	126	70
Big Eau Pleine at dam		0	280	2275	0	380	338	350
Little Plover at Plover		11	8	14	15	10	9	9

APPENDIX G

Flow data in cfs for July 4 mill shutdown period, 1979.

Site	River Mile	July 2	July 3	July 4	July 5	July 6
		←		flow (cfs)		→
Wisconsin River sites						
Merrill Dam	286.1	2062	3002	3511	3122	2368
Wausau Dam	265.6	1960	2779	3356	3312	2517
Rothschild Dam	258.4	1990	3355	3942	3574	2767
Lake Du Bay Dam	235.4	1954	2508	3496	3909	3291
Industries						
Wausau Papers	271.1	9.25	1.50	5.07	8.37	11.99
Weyerhaeuser	258.2	7.127	2.441	1.694	4.703	15.070
American Can	258.2	.312	.227	.282	2.064	2.294
Mosinee Papers	248.9	14.2	8.3	5.0	10.0	13.4
Tributaries						
Rib		173	317	288	218	176
Eau Claire		131	152	228	219	180
Eau Pleine		0	0	0	0	0