

**STREAM QUALITY IN THE
ROCK RIVER BASIN OF
WISCONSIN**

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INTRODUCTION

The Rock River Partnership and the Wisconsin Department of Natural Resources are currently evaluating the feasibility and potential benefits of phosphorus trading in the Rock River Basin. A critical issue is the relationship between overall stream quality and ambient phosphorus concentrations. The goal of this research is to explore this issue, primarily through field studies.

Stream quality can be related to a number of factors, depending on how the stream is used and on society's priorities for these uses. The emphasis in this study was on factors that affect the ability of a stream to support a desirable fishery. These factors include base flow, temperature, dissolved oxygen, turbidity, substrate characteristics, and channel form.

In our investigation of stream quality in the Rock River Basin, we conducted field studies to address the following questions: (1) What is the status of stream quality at representative rural sites throughout the Rock River Basin, where stream quality is defined with respect to the ability of a stream to support a desirable fishery? (2) How is stream quality at the sampling sites related to river and watershed characteristics? (3) Does stream quality change in response to increases or decreases in available phosphorus?

METHODS AND DATA PRESENTATION

SITE SELECTION

The Rock River Basin is a large watershed with a wide variety of conditions. A detailed study of the entire watershed was clearly beyond the scope of this project. Therefore, we chose to focus our investigation on a number of smaller watersheds within the Rock River Basin.

We selected study watersheds based on the following criteria: (1) the study watersheds must be well distributed throughout the Rock River Basin; (2) watershed areas must be large enough to support a substantial fishery, yet small enough to allow detailed investigation (roughly 10-75 square miles); (3) primary land use must be agricultural and urban land use must be minimal; (4) there must be no major point-sources of pollution; (5) there must be easy access to the stream at the sampling site defining each watershed.

Using topographic maps, we obtained a general idea of the land-use, location, size and access points, such as road crossings and parks, of potential study watersheds. We also referred to the WDNR's "Water Quality Management Plan for the Lower Rock River Basin" (1998) and

“Water Quality Management Plan for the Upper Rock River Basin” (1995), which provide brief descriptions of some of the streams. Based on this information, we created a list of prospective sites. After visiting each prospective watershed, we selected 14 sites. These are listed in Table 1. The combined area of these watersheds is 440.4 mi², representing 12% of the Rock River Basin (3,780 mi²). The watersheds are displayed on the Rock River Basin map (Figure 1).

Stream Name	Downstream Sampling Site	Watershed Size (sq. mi.)
Allen Creek	Peoppel Rd., near Ft. Atkinson	8.7
Bass Creek	Kessler Rd., near Afton	57.5
Calamus Creek	County S, near Lowell	16.5
Crawfish River	Johnson Rd, near Columbus	55.2
Deer Creek	County N, near Ft. Atkinson	23.9
Duck Creek	Betschler Rd., Jefferson County	27.2
Johnson Creek	County Y, near Johnson Creek	40.0
Little Oconomowoc River	Kilbourne Rd., near North Lake	12.6
Little Turtle Creek	North Rd, near Allen Grove	43.7
Maunsha River	County TT, downstream of Deansville State Wildlife Area	36.2
Marsh Creek	Burdick Rd., near Janesville	27.5
Oconomowoc River	Funk Rd., near North Lake	37.0
Saunders Creek	Central Park, downtown Edgerton	40.9
Scuppernong River	County N, near Eagle	13.5

Table 1: Study Sites – Stream Name, Location, and Watershed Size

The WDNR selected and monitored additional sites on the main stem of the Rock River and a few of its largest tributaries, such as the Yahara River and Bark River. Due to their size we did not incorporate these sites into our investigation.

DATA COLLECTION

In order to conduct a thorough investigation of stream quality, many kinds of data were collected, including data on water chemistry, stream biota, and the physical characteristics of the streams and their watersheds. All data were collected between May 1998 and November 1999. Some of the data were collected wholly or partly by personnel of the WDNR.

GRAB SAMPLES

Background

Water chemistry plays a vital role in the stream ecosystem, and its determination is an essential part of any stream quality study. Chemical constituents, such as dissolved oxygen, nitrogen, phosphorus and chlorophyll a, are important indicators of stream health. Physical attributes, such as turbidity and suspended solids, are also important and often included in water chemistry analyses.

Inputs of nutrients, particularly nitrogen and phosphorus, contribute to freshwater eutrophication. Eutrophication has many adverse effects on aquatic systems; the most obvious are increased growth of algae and aquatic vegetation (Carpenter *et al.* 1998, Sawyer *et al.* 1994), resulting in low dissolved oxygen concentrations, harm to aquatic organisms, and poor aesthetics. In general, phosphorus is the limiting nutrient in freshwaters.

Constituents

The WDNR collected monthly grab samples for each of our study sites from May 1998 to November 1998. The State Hygiene Lab analyzed the grab samples for the following nutrients: total phosphorus (TP), dissolved reactive phosphorus (DRP), ammonia-nitrogen (NH₃-N), nitrate-nitrogen (NO₃-N), and total Kjeldahl nitrogen (TKN). Analysis for turbidity, trichromatic chlorophyll, monochromatic chlorophyll, and suspended solids was conducted by WDNR personnel at the DNR Research Center in Madison, WI. Chlorophyll analyses were not conducted on the November samples; suspended solids were only measured on the September, October, and November samples. The data are given in Appendices A and B.

Phosphorus

Phosphorus is a natural component of soils, sediments, and stream and lake waters; however, levels are commonly elevated by anthropogenic sources. The phosphorus compounds that are most significant to water quality are inorganic phosphates; organic forms of phosphorus play a lesser role (Sawyer *et al.* 1994). Organic phosphorus originates from biological sources, such as animal waste and decaying plant material. The main anthropogenic sources of inorganic phosphates are point discharges from water treatment plants, wastewater treatment plants, and industrial plants; and non-point discharges from agricultural and other lands on which chemical fertilizers have been applied. Transformations also convert some of the organic phosphorus to inorganic phosphorus after reaching the stream. As implied by the name, a point source

discharges to a stream at a single place, usually through a pipe. Nonpoint sources introduce phosphates to streams through overland flow. Phosphates applied as fertilizer and organic phosphorus in land-spread manure are only partially used for plant growth; most of the remaining phosphorus attaches to soil particles. Consequently, overland flow carries the phosphorus along with the soil, into receiving streams.

In our project, two forms of phosphorus were measured: total phosphorus (TP) and dissolved reactive phosphorus (DRP). Total phosphorus includes both inorganic phosphates and organic phosphorus. DRP is a component of total phosphorus, representing only some of the phosphates. DRP is the most available form of phosphorus for biological use; however, it is not the only available form. For that reason, total phosphorus is often a better indicator of the effective phosphorus load in a stream.

Nitrogen

Nitrogen is present naturally in aquatic systems; however, anthropogenic inputs have significantly increased nitrogen levels. Nitrogen compounds important to water quality are $\text{NO}_3\text{-N}$, $\text{NH}_3\text{-N}$, and organic nitrogen. Nitrogen-fixation, which occurs in soils and in aquatic systems, is a natural source of $\text{NH}_3\text{-N}$. The main anthropogenic sources are fertilizers containing $\text{NH}_3\text{-N}$, animal waste from barnyards, and treated effluent from wastewater plants. When fertilizers are applied to crops, nitrogen is generally in the $\text{NH}_3\text{-N}$ form. Plants use some of the $\text{NH}_3\text{-N}$, and some is converted to $\text{NO}_3\text{-N}$ in the upper layers of soil. $\text{NH}_3\text{-N}$ adsorbs to soil particles and remains near the surface, while $\text{NO}_3\text{-N}$ can percolate into the groundwater. Therefore, $\text{NO}_3\text{-N}$ is the predominant form in groundwater, while $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$ and organic N are all important in surface water. Under low-oxygen conditions $\text{NO}_3\text{-N}$ is converted to gaseous N through denitrification.

$\text{NO}_3\text{-N}$ concentrations typically found in streams are not toxic to aquatic life. However, at certain levels in drinking water $\text{NO}_3\text{-N}$ can cause a potentially fatal disease in infants called “blue baby” syndrome. The USEPA has set the Drinking Water Standard for $\text{NO}_3\text{-N}$ at 10 mg/l. $\text{NH}_3\text{-N}$ ranges from about 10 $\mu\text{g/l}$ in some natural waters to more than 30 mg/l in wastewater. $\text{NH}_3\text{-N}$ can be toxic to some fish species at high levels. In the studied streams no measurements approached this level. Organic nitrogen can vary from a few hundred $\mu\text{g/l}$ to more than 20 mg/l in raw sewage (APHA et al. 1998). It is generally measured as total Kjeldahl nitrogen, which is organic N plus $\text{NH}_3\text{-N}$.

Chlorophyll a

Chlorophyll a is a pigment found in all photosynthetic plants, including algae; its measurement is used as an indicator of algal biomass. Algae can be divided into two categories, benthic and suspended algae. Benthic algae grow on rocks, woody debris, aquatic plants and other submerged surfaces, while suspended algae are free-floating within the water column. The grab samples collected in this investigation represent only suspended algae. Two different methods were used to analyze chlorophyll a for the grab samples, the trichromatic and monochromatic methods. We primarily used the trichromatic chlorophyll a data, because the trichromatic method is considered to be more accurate.

Turbidity

Turbidity is a measure of visual water clarity. It is a function of suspended matter, such as clay, silt, soluble colored organic compounds, plankton (i.e. algae) and other microscopic organisms (APHA et al. 1998). High turbidity is a common trait of poor water quality, because it is indicative of high levels of pollutants, most notably excessive sediment and biomass. Additionally, turbidity is an important aesthetic characteristic of water by humans. The USEPA drinking water standard is 0.5-1.0 NTU.

Suspended Solids

Suspended solids are defined as all undissolved solids in water (Sawyer et al. 1994). Their measurement is often used as a measure of strength of pollution and as an indicator of the aesthetic quality of water. Measurement units are usually mass per unit volume. For this study, suspended solids were only measured for the last two months of grab samples. Given the limited number of measurements, the data did not prove useful.

Data Averaging

All analyses and plots based on the grab sample data use the geometric mean of the monthly values of each constituent. The geometric mean (Landweher 1978) was used in place of the arithmetic mean because of the positive skew exhibited by the constituent data.

FIELD INVESTIGATIONS

Methods

In June 1998 we began conducting field investigations of the study sites and their respective watersheds. The goal of these investigations was to assess the existing conditions of each stream. Visual observations were recorded and a few physical measurements were made.

We explored all accessible stream reaches upstream of the study sites. Access points were located at road crossings and in public recreation areas. At each access point, we waded approximately 100 yards in both the upstream and downstream directions. We recorded information on stream width and depth, water clarity, temperature, flow rate, streambed material, riparian conditions, channel morphology, and aquatic vegetation. These data were mostly qualitative. For example, water clarity was described by choosing one of the following classifications: very clear, clear, fairly clear, slightly turbid, turbid, very turbid. Flow rate was described as either: fast, medium-fast, medium, medium-slow, or slow. In addition, interesting or unusual stream characteristics were recorded, and the surrounding landscape features were noted while driving between access points. Descriptions of each stream/watershed and photographs are in Appendix C.

Stream Quality Rank

Upon completion of the field investigations, we subjectively ranked the streams from best (#1) to worst (#14). The stream ranking (Table 2) was based heavily on water clarity, streambed composition and channel morphology. For example, the Little Oconomowoc River is characterized by clear water, a streambed composed of gravel, cobble, sand and natural fibrous muck (in wetlands), and riffle-run-pool sequences throughout its length. This stream was ranked near the top of our list (#2). The Maunsha River is very turbid, a large portion of the streambed is covered with a thick silt layer, many channel reaches have been straightened and possess long runs of unchanging depth. This stream was ranked near the bottom of our list (#13) . These two examples are typical of streams ranked at the high or low ends of our scale. Streams that fell in the middle of the scale generally possessed a combination of the characteristics of the Little Oconomowoc and Maunsha Rivers. In some cases, other observations were weighed heavily as well. For example, although Duck Creek has fairly clear water, it received a low ranking because it contained many dead fish. Note that the stream ranking did not incorporate the information obtained from the analyses of the grab samples.

Our stream quality ranking was intended as a subjective measure of stream quality based on observations collected at all accessible stream reaches upstream of the primary sampling site. It is not reproducible by others and hence its utility is somewhat limited. But it does provide information about stream quality throughout the watershed. Given the resources of this project, it would not have been possible to collect quantitative information at such a large spatial scale.

Stream Name	Rank
Scuppernong River	1
Little Oconomowoc River	2
Oconomowoc River	3
Marsh Creek	4
Allen Creek	5
Deer Creek	6
Crawfish River	7
Bass Creek	8
Saunders Creek	9
Little Turtle Creek	10
Calamus Creek	11
Duck Creek	12
Maunsha River	13
Johnson Creek	14

Table 2: Stream Quality Rank

BASE FLOW MEASUREMENT

Background

Base flow can be defined as “water that enters from persistent, slowly varying sources and maintains stream flow between water-input events” (Dingman, p. 316, 1994). Base flow is important for sustaining a quality fishery in a stream and for dilution of pollutants. Base flow per unit drainage area gives insight into the hydrology of a watershed. For example, streams that have relatively small base flow per unit drainage area are probably dominated by surface inputs, while streams with large base flow per unit area are most likely fed primarily by ground water. Ground water domination of stream flow typically indicates better infiltration in the watershed.

Methods

We measured base flow during dry periods in the Fall of 1998 and the Fall of 1999. A current meter was used to measure the velocity and depth at many points across the width of the stream channel, and the midsection method was used to calculate the base flow.

The watersheds for our study sites have different drainage areas; therefore, we normalized the data by dividing the base flow by the drainage area. Drainage areas were determined from USGS 7.5" quadrangle maps.

The resulting base flow data for the study sites are listed in Table 3. At the Duck Creek site excessive aquatic vegetation made use of the current meter difficult. Thus, base flow was estimated based on a partial measurement in September of 1998, and not measured in November of 1999. At the Johnson Creek site the flow is nearly stagnant at low stages, making current meter measurements highly uncertain. Current meter measurements were made on Johnson Creek in September 1998; the flow was not measured in November 1999. The Maunsha River site at County Hwy. TT posed the same problem as Johnson Creek; therefore, base flow was measured at an upstream site at Janisch Rd.

Precipitation can cause base flow to vary widely in time. To account for this variability we standardized the stream flow data using flows measured at nearby USGS gaging stations. The stations used are located at Piscasaw Creek near Walworth, the Yahara River at Windsor, and the South Branch Rock River at Waupun. For each study site, the standardized, or indexed, base flow was determined as the ratio of the base flow to the stream flow at the nearest gage (Table 3).

Stream	Base Flow - Sep. 1998			Base Flow - Nov. 1999		
	cfs	cfs/mi ²	Indexed	cfs	cfs/mi ²	Indexed
Allen Cr.	5.7	0.66	3.69	2.8	0.32	1.34
Bass Cr.	33.5	0.58	3.49	24.6	0.43	1.78
Calamus Cr.	0.4	0.02	0.09	1	0.06	0.30
Crawfish R.	19.9	0.36	1.40	13.8	0.25	1.23
Deer Cr.	1.6	0.07	0.43	3	0.13	0.52
Duck Cr.*	1.6	0.06	0.41	NM	NM	NM
Johnson Cr.	1.65	0.04	0.26	NM	NM	NM
Little Oconomowoc R.	0.9	0.07	1.01	1.7	0.13	1.03
Little Turtle Cr.	11.5	0.26	1.58	9.6	0.22	0.92
Marsh Cr.	18.4	0.67	3.77	10.9	0.40	1.65
Maunsha R. (Janisch Rd.)	7.1	0.20	0.76	5.4	0.15	0.73
Oconomowoc R.	14.4	0.39	5.50	20.8	0.56	4.31
Saunders Cr.	11.3	0.28	1.56	8.2	0.20	0.84
Scuppernong R.	3.4	0.25	1.61	4	0.30	1.23

* Estimated based on partial measurement. NM = Not measured.

Table 3: Base Flow Measurements

BIOTIC INDICES

Background

Aquatic organisms are sensitive to changes in their environment and therefore reflect stream and watershed conditions. Several groups of organisms have been used as indicators of stream ecosystem quality. In an effort to quantify these bioassessments, biotic indices have been

developed for three groups of organisms - fish, macroinvertebrates, and diatoms.

Macroinvertebrate and fish indices have proven to be effective in many environments and geographic locations (Lyons 1992, Berkman and Rabeni 1987, Karr 1991, Hilsenhoff 1982). Methods of determining these indices have been standardized to a large degree. However, methods vary somewhat depending on region, environment, and personal preference. Since biotic indices have relatively recently emerged as a monitoring tool, methods continue to be refined.

Methods for determining an index based on macroinvertebrates, such as mayflies, caddisflies, aquatic beetles, were developed in Wisconsin in the late 1970's and early 1980's (Hilsenhoff 1977, 1982). The HBI (Hilsenhoff Biotic Index) has been used extensively by the WDNR to monitor streams in this state. A fish index, known as the IBI (Index of Biotic Integrity), was introduced in the early 1980's (Karr 1981). It was modified for use in warmwater Wisconsin streams by John Lyons (1992).

The HBI targets the organic and nutrient pollution load in streams. Pollutants affect the ability of each macroinvertebrate species to survive in a particular stream. For the purpose of calculating the index, each species is assigned a tolerance value from 0–10, according to its ability to survive in polluted waters. Higher values are given to species that are tolerant of pollution and vice versa; thus, high index scores indicate poor water quality (Hilsenhoff 1987). Macroinvertebrate samples are collected by disturbing the streambed just upstream of an aquatic dip net.

The IBI is a measure of the biotic integrity of a stream. Biotic integrity can be defined as a stream's ability to support a balanced community of aquatic organisms (Karr 1981). The IBI is based on a series of fish community attributes, referred to as metrics, that reflect species richness and composition, trophic and reproductive function, and fish abundance and condition; the Wisconsin IBI consists of 12 metrics (Table 4) (Lyons 1992).

Species Richness and Composition
1. Total number of native species
2. Number of darter species
3. Number of sucker species
4. Number of sunfish species
5. Number of intolerant species
6. % (by number of individuals) tolerant species
Trophic and Reproductive Function
7. % omnivores
8. % insectivores
9. % top carnivores
10. % lithophilous spawners (lay eggs on clean gravel or cobble; do not build or protect nests)
Fish abundance and Condition
11. Number of individuals per 300 m sampled
12. % with deformities, eroded fins, lesions or tumors

Table 4: Wisconsin Fish IBI Metrics

The IBI is calculated for a stream site by comparing the values for each metric to expectations for high quality streams of a similar size, located in the same ecoregion, and possessing the same temperature regime (warmwater or coldwater). Each metric is scored from 0-10, and the values of the first ten metrics are summed to compute the IBI score, which ranges from 0-100. The last two metrics are used only if they exceed extreme values and can only lower the IBI. The overall IBI score is then used to determine a biotic integrity rating as shown in Table 5. It is important to note that the IBI evaluates a complex natural system and the raw score tends to oversimplify the situation (Lyons 1992). Thus, more attention should be paid to the rating rather than the raw score (Karr et al. 1986). Fish samples are collected for this analysis by electroshocking methods.

Overall IBI Score	Biotic Integrity Rating
100-65	Excellent
64-50	Good
49-30	Fair
29-20	Poor
19-0	Very poor
No score (few or no fish)	Very poor

Table 5: Wisconsin IBI Ratings

Methods

For our investigation of the Rock River Basin, the WDNR collected macroinvertebrate samples for each study site and determined the HBI. Fish samples were collected from 5 sites and the IBI's were calculated. The HBI and IBI values obtained for our study sites are displayed in Table 6. The IBI for the Maunasha River was collected at an upstream site near Janisch Rd. Recall that high HBI values indicate poor stream quality, while high IBI values indicate good stream quality.

Stream	HBI	IBI	
		Score	Rating
Allen Cr.	4.56	47	Fair
Bass Cr.	5.4	---	---
Calamus Cr.	7.67	---	---
Crawfish R.	4.99	45	Fair
Deer Cr.	5.65	---	---
Duck Cr.	7.75	50	Good
Johnson Cr.	6.06	---	---
Little Oconomowoc R.	2.91	---	---
Little Turtle Cr.	5.01	---	---
Marsh Cr.	4.56	---	---
Mauneshia R. (Cty. TT)	6.83	---	---
Mauneshia R. (Janisch Rd.)	4.69	5	Very Poor
Oconomowoc R.	5.05	43	Fair
Saunders Cr.	5.7	---	---
Scuppernong R.	6.15	---	---

Table 6: HBI and IBI for Rock River Sites

DISSOLVED OXYGEN MEASUREMENT

Background

Dissolved oxygen (DO) concentration is one of the most important characteristics of water quality. An adequate supply of DO is essential for growth and reproduction of fish and other aquatic organisms. When DO concentrations fall below certain levels, many species cannot carry out these basic life functions. Therefore, low DO is associated with degraded stream ecosystems.

The saturation concentration of oxygen in water is temperature dependent and ranges from 14.6 mg/l at 0°C to 7 mg/l at 35°C in freshwaters. Therefore, the saturation concentration is lowest during the warmest months of the year. In Wisconsin, streams are warmest in July, August, and September, when daily mean water temperatures are about 20°C and the saturation concentration is 9 mg/l (Greb and Graczyk 1993). DO concentrations below the saturation concentration are caused by biochemical oxygen demand (BOD) and plant respiration.

BOD is defined as the amount of oxygen required for bacteria to decompose organic matter in streams. Sources of organic wastes include municipal sewage treatment plants, industrial plants (e.g. food processing, pulp mills), excessive amounts of decaying plant material, and animal waste. Bacteria use up the oxygen and DO decreases until the organic matter is completely decomposed, which can take several days. If oxygen depletion is complete, the water becomes anoxic or anaerobic and anabolic decomposition of the organic matter continues. DO levels can stay low for extended periods of time if the source of organic matter is continuous or frequent.

Low DO concentrations can also be attributed to diurnal DO fluctuations caused by plant respiration and photosynthesis. An example of diurnal DO fluctuation is shown in Figure 2a; these data were collected this past summer in the Maunsha River. DO concentrations increase due to daytime photosynthesis and decrease during nighttime respiration. A study of nine Wisconsin streams found that diurnal DO fluctuations could be as much as 14 mg/l (Greb and Graczyk 1993). Lower daily minimum DO concentrations and larger ranges of diurnal DO fluctuation were linked with greater productivity in these streams.

Methods

In the summer and fall of 1999, we measured DO concentrations in our streams in order to determine the minimum DO concentration and the magnitude of DO fluctuation. DO concentrations normally vary from day to night (diurnal fluctuation), and therefore must be measured frequently throughout a day to obtain maximum and minimum levels. We used water quality multiprobes to measure DO every 15 minutes for roughly one-week periods at each of our study sites.

We used two water quality multiprobes (Hydrolabs) to measure and record DO and temperature. These units contain built-in data loggers that record water quality parameters at specified intervals (e.g. every 30 minutes) during a specified duration of time (e.g. 14 days). We set up the Hydrolabs to record data every 15 minutes for 6 to 9 day periods. The multiprobes were calibrated before each use to improve measurement accuracy.

The Hydrolab units were camouflaged with colored duck tape to prevent tampering. The units were positioned on the streambed in either of two ways. For soft-bottom streams, the units were fastened to a plastic fixture with legs that were pushed into the streambed. For hard-bottom streams, rocks were used to hold the units in place. The Hydrolabs were then secured with steel

cable to a fixed object, usually a tree, to prevent them from being swept away in case of a flood. Upon retrieval of the multiprobe units, data were downloaded onto a laptop computer. Calculations were performed in Excel spreadsheets.

The Hydrolab deployments began at the end of June and were completed the first week of October. Initially, we had only one unit, as the other was being retrofitted with data-logging capabilities. Therefore, the first three streams were monitored one at a time. When the second Hydrolab was ready, we began pairing streams to allow for more direct comparisons. Whenever possible, we setup good/bad pairs (based on rank); for example, the Little Oconomowoc River (#2) and Duck Creek (#12). As expected, the streams showed diurnal fluctuations for both temperature and DO with only a few exceptions. Plots of DO and temperature versus time were constructed for each stream and paired streams were placed on the same graph (i.e. Little Oconomowoc and Duck appear on one graph). The plots are shown in Figures 3a to 3i.

In an ideal situation we would have had a multiprobe deployed at each measurement site for the entire summer; however, this was not economically feasible. Because probes were moved from site to site over a 3.5 month period, the water temperatures varied from site to site. The minimum and maximum water temperatures were 10.1°C to 28.7°C, which correspond to DO saturation levels of about 11 mg/l and 8 mg/l respectively. For the purpose of comparing DO levels across streams and for statistical analysis, we used DO percent saturation, which is independent of temperature variations.

SEDIMENT ANALYSIS

Background

Sediment from soil erosion is a serious threat to stream ecosystems. In agricultural areas the main source of sediment is farm fields; in urban areas the main source is mismanaged construction sites. Other sources include mines, cut-over forests, and unpaved roads. During storm or irrigation events, sediment is carried by surface runoff into streams and lakes. Excessive amounts of sediment can severely degrade habitats for aquatic biota, transport large concentrations of adsorbed nutrients, and diminish aesthetic value of waters.

There is substantial evidence that increased sedimentation reduces macroinvertebrate populations and diversity (Berkman and Rabeni 1987) by filling the spaces between rocks and gravel (where these organisms live), hindering filter-feeding mechanisms, and clogging gills.

Increased turbidity attenuates light needed for photosynthesis, which limits growth of aquatic plants and algae. Benthic algal production is further reduced because stable surfaces used for attachment, such as stones and woody debris, are buried. In turn, these effects decrease populations of fish that feed specifically on these organisms. Fish that require a clean gravel and cobble streambed for spawning are impacted to an even greater extent (Berkman and Rabeni 1987).

Methods

It is difficult to quantify the amount of sediment in a stream channel network, because of the high degree of spatial and temporal variability. We explored the development of a simple method to quantify the overall availability of sediment in a stream channel network; however, the method was not sufficiently developed to apply in this study. Instead, sediment availability was assessed on a qualitative basis.

As presented in the field investigations discussion, sediment played a large role in our stream health rank. However, because other factors were considered as well, we felt it was beneficial to perform a qualitative rating for sediment alone. Based on field observations, each stream was rated on a scale from 1-5 (Table 7). When estimating the percentage of bed covered and sediment layer thickness, we combined all stream reaches that were investigated. For example, the Oconomowoc River has 0-25 % sediment coverage of the combined areas of the five reaches we investigated on that stream; for these covered areas the estimated depth of sediment was 1”-6”. The results of the sediment rating for our streams are shown in Table 8.

Rating	% of Bed Covered	Average Sediment Layer Thickness
1	□ 0	None
2	0-25	thin (1”-6”)
3	25-50	thin-thick
4	50-75	thin-thick
5	75-100	thick (6”-3’)

Table 7: Sediment Rating Method

Stream	Sediment Rating
Allen Cr.	1
Bass Cr.	2
Calamus Cr.	3
Crawfish R.	3
Deer Cr.	3
Duck Cr.	4
Johnson Cr.	5
Little Oconomowoc R.	1
Little Turtle Cr.	3
Marsh Cr.	2
Mauneshia R.	5
Oconomowoc R.	2
Saunders Cr.	3
Scuppernong R.	1

Table 8: Sediment Rating for Rock River Basin Streams

SOIL ANALYSIS

Background

Soil type influences the drainage characteristics in a watershed (Skaggs et al. 1994). Well-drained soils allow rainwater and irrigation water to infiltrate, while poorly drained soils cause water to pool and flow overland into surface waters. This can affect the types of pollutants found in streams, because some pollutants, such as phosphorus, are associated with surface waters and others, such as nitrate-nitrogen, with subsurface water.

Methods

We used two GIS soil databases to determine soil texture and drainage for all of our watersheds. A statewide database (STATSGO) was used to evaluate every watershed and a more detailed county database (SSURGO) was used to evaluate watersheds in Dane, Rock and Jefferson Counties. ArcINFO and ArcVIEW were used to determine soil distributions based on an approach similar to that described below for land use. Numeric scores from 1-10 were assigned to each soil type, based on grain size and drainage properties (see Appendix E for results). The state and county data were analyzed separately. Both analyses showed that there is

little difference in the dominant soil types in the studied watersheds.

LAND USE

Background

Non-point pollution from agricultural and urban land uses has caused severe degradation of stream ecosystems (Wang et al. 1997). The situation in Wisconsin is no exception (Wang et al. 1997). In the Rock River Basin, agriculture is the dominant land use. Heavy application of fertilizers and dense concentrations of livestock have increased nitrogen and phosphorus inputs to streams, contributing to eutrophication (Carpenter et al. 1998). Pesticide and herbicide application have introduced toxicants into surface water. Farming practices, such as poor tilling and planting methods, have increased erosion and thus sediment loads to streams. Stream channelization and wetland drainage, done to expand cropland, has destroyed habitat and changed natural hydrologic conditions.

Methods

In view of the effects of land use on stream ecosystems, we explored the relationship between stream quality and land use for our study sites. Our goal was to determine if there were significant correlations between land use and the water quality data, HBI, and stream rank. Using GIS (geographical information systems) we determined land use composition for each watershed, as described below.

Watersheds were delineated from topographic contour lines displayed on USGS 7.5" quadrangle maps. Clear film was laid on top of the maps and the drainage divides were drawn by hand. The USGS maps contain latitude and longitude coordinates and these were labeled for several points on each watershed drawing. The next step was to digitize the maps into an AutoCAD format. Latitude and longitude coordinates were converted to the Wisconsin Transverse Mercator system; this is the coordinate system used by the land use database. Using a digitizing table, the watershed boundaries were entered into AutoCAD. The AutoCAD files were then converted to ArcINFO files. In ArcINFO, the watershed coverages were overlaid onto a GIS land use database called Wiscland. Land use composition was calculated by ArcINFO for each watershed. The results are summarized in Figure 3 and details of the results are displayed in Appendix D.

DATA INTERPRETATION

INTRODUCTION

In the course of this study we collected a large amount of information on a number of variables, involving both stream-quality and watershed characteristics. Given the potentially complex interrelationships between these variables, the primary method for data interpretation was graphical. Numerous bivariate plots were constructed and scrutinized in order to uncover patterns that suggest, support, or contradict hypothesized relationships. The statistical significance of observed relationships between variables was evaluated using linear regression. Below we report on our most interesting findings, organized around the following themes: variations in stream-quality indicators across streams, relationships between stream-quality indicators and watershed characteristics, and relationships between stream-quality indicators and eutrophication. These themes correspond to the questions that this research intended to address.

VARIATIONS IN STREAM-QUALITY INDICATORS

To explore variations in stream-quality indicators across streams we plotted indicator values against the ranked streams, where the latter was based on our subjective ranking (Figures 4-12). This also enabled us to see how our ranking compared to other indicators of stream quality. We were particularly interested in the following indicators: nutrient concentrations (total phosphorus, dissolved reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, and total Kjeldahl nitrogen); trichromatic chlorophyll a concentrations; average minimum daily dissolved oxygen levels; turbidity; unit-area base flow; biotic indices (HBI and IBI); and our sediment score. Regression analysis indicated that all of these stream-quality indicators, except nitrate-nitrogen, total Kjeldahl nitrogen, and unit-area base flow, are correlated with our ranking at the 0.01 significance level.

Sediment and Turbidity

As seen in Figure 4, our sediment score correlates very well with our subjective stream rankings. This is not surprising, as observations of streambed sediment contributed heavily to our subjective stream ranking. Turbidity (measured at low flow) also correlates with our subjective ranking (Figure 5). However, with the exception of the Maunsha River and Johnson Creek, the streams with the lowest subjective rankings and the highest sediment scores, the turbidity values are fairly low. Higher turbidities are expected during higher flows. It is also

notable that Calamus and Duck Creeks, which are the third and fourth lowest ranked streams, have turbidity levels below most of the other streams.

Nutrients

Of the nutrients, total phosphorus has the strongest relationship with our subjective ranking (Figure 6). The Maunsha River and Calamus Creek have total phosphorus concentrations well above those of the remaining streams. The contributing watersheds of both streams are predominantly agricultural and have no point discharges; hence the high total phosphorus concentrations are likely to be due mainly to agricultural runoff. Ammonia-nitrogen (Figure 7) correlates with our subjective ranking at the 0.01 significance level; total Kjeldahl nitrogen (Figure 8) correlates with our subjective ranking at the 0.05 significance level.

Nitrate-nitrogen concentrations (Figure 9) have a less clear relationship with our subjective ranking. Marsh Creek, the Crawfish River, Bass Creek, Little Turtle Creek, and the Maunsha River all have nitrate-nitrogen concentrations much higher than the remaining streams, even though the first three of these streams have high to middle subjective rankings. As discussed in the landuse section, we believe that these high nitrate-nitrogen concentrations are due to agricultural drainage practices.

Dissolved Oxygen

Minimum dissolved oxygen levels (expressed as percentage saturated) correlate well with our subjective rankings, decreasing with poorer rankings (Figure 10). Calamus and Duck Creeks have by far the lowest minimum dissolved oxygen concentrations. This is consistent with the observations of excessive growths of aquatic weeds.

Chlorophyll a

Chlorophyll a concentrations also correlate well with our subjective rankings (Figure 11). One apparent outlier is the Oconomowoc River, which has a very high chlorophyll a concentration in spite of its excellent ranking. The likely reason is the presence of several upstream lakes and impoundments.

HBI

HBI values correlate well with our subjective ranking (Figure 12), with one notable exception. The Scuppernong River, our highest ranked stream, has a relatively poor HBI value. This may be explained in large part by the fact that the sampling site is in a long reach of low-gradient straightened channel that cuts through a wetland and has a soft-bottomed bed of fibrous

organic muck. It is recommended that HBI sample be taken from rock or gravel riffles or runs (Hilsenhoff, 1987), because this is the preferred habitat of the macroinvertebrates being collected. In the future it would be interesting to collect samples at an upstream or downstream site with a more suitable streambed.

Also note that the HBI correlates very well with average minimum dissolved oxygen (Figure 13). A simple two-parameter polynomial fit to the data explains 87% of the variance in average minimum dissolved oxygen. (The polynomial fit is only intended for quantifying the strength of the relationship, and should not be used for predictive purposes.) This finding is consistent with the assertion of Hilsenhoff (1998, p. 2) that the HBI “primarily measures effects of oxygen depletion resulting from organic or nutrient pollution.”

IBI

A potentially good integrating measure of stream quality is the index of biotic integrity (IBI), which is based on fish community attributes, including species richness and composition, trophic and reproductive function, and fish abundance and condition. Due to time and budget constraints, the WDNR was only able to estimate the IBI for five of our fourteen streams.

Unfortunately, the IBI results are highly equivocal. The Maunsha River, our second lowest ranked stream, had an IBI score of 5. But Duck Creek, our third lowest ranked stream, had the highest IBI score (50). The three remaining IBI scores were 43, 45, and 47. The differences between these latter four IBI scores are not large enough to be meaningful.

The relatively high Duck Creek IBI is particularly interesting, given that the stream had very low minimum dissolved oxygen levels and an HBI indicative of high organic loading. However, Duck Creek also had very low turbidity, no fine-grained sediment at the sampling site (although there was extensive sediment at upstream locations), and abundant aquatic weeds that provide good habitat for fish. Also, just over a mile downstream of our sampling site Duck Creek flows into the Bark River, a stream with a warm-water sport fishery (WDNR 1998). So although Duck Creek is highly eutrophic and has low dissolved oxygen, it has other attributes that enable a good fish population to establish.

Unit-Area Discharge

Unit-area discharge is not correlated with our subject ranking at the 0.5 significance level. Part of the reason may have to do with drain tiles, as discussed below.

STREAM-QUALITY INDICATORS AND WATERSHED CHARACTERISTICS

As discussed above, a number of indicators of stream quality vary in a consistent manner across our streams. In this section we explore the relationships between some of these indicators and watershed characteristics.

Agriculture

In our study streams, the fraction of watershed in agriculture varies from about 20% to over 90%. Surprisingly, if the three highest-ranked streams are ignored (left most data points on Figure 14), there is no relationship between subjective rank and fraction of watershed in agriculture.

Consideration of nutrients suggests a possible explanation of this apparent anomaly. Figure 15 illustrates the relationship between total phosphorus and fraction of watershed area in agriculture. Note that there is a strong increasing relationship, except for the four streams with the highest fractional areas in agriculture. Contrast this with the case of nitrate-nitrogen (Figure 16), in which the same four streams have by far the highest nitrate values. We suspect that drain-tiling is the reason for this contrasting behavior.

Drain-tiles lower the water table, creating additional pore space in the soil, increasing infiltration rates, and decreasing surface runoff. Hence drain-tiling reduces the export of sediment, phosphorus, and other substances that are transported by surface runoff, and increases the export of other substances that are primarily transported by subsurface drainage. This effect has been documented in numerous studies, a large number of which are summarized by Skaggs et al. (1994). (Drain-tiled lands also tend to be flat, and less subject to soil erosion. However, we found no correlation between total phosphorus and basin relief.)

We have observed drain tiles in the channels of the four streams with the highest fractional areas in agriculture. However, it would have been very difficult to quantify the extent of drain-tiling in our 14 watersheds. Nonetheless, given the strong evidence in the scientific literature supporting the relationship between high nitrate levels and extent of drain-tiling, we believe that drain-tiling is a compelling explanation for why the four streams with the highest fractional areas in agriculture have lower phosphorus concentrations, less sediment, and generally higher unit-area base flow and quality than other streams with significantly less agricultural activity.

Forests

Only three stream-quality measures are significantly correlated with fraction of watershed in forests-- subjective rank, sediment score and nitrate. In all cases the significance of the correlation depends on the three streams with low watershed area in agriculture. Hence the absence of agriculture is probably more important than the presence of forests.

Wetlands

Only two stream-quality measures are significantly correlated with fraction of watershed in wetlands-- nitrate-nitrogen and unit-area base flow. In each case the significance of the correlation is due to the streams that have high nitrate levels (apparently as a result of drain-tiling). These streams have virtually no wetlands, high nitrate-nitrogen values, and high unit-area flows. Hence the significant correlation of nitrate-nitrogen and unit-area base flow to fraction of watershed in wetlands is most likely due to drain-tiling, rather than wetlands.

It may seem surprising that there are not strong relationships between various stream-quality indicators and wetland area, given the well-known beneficial functions of wetlands. From Figure 17 it can be seen that many of the low-ranked streams have relatively high fractional areas in wetland. For example, Duck and Johnson Creeks, which we ranked third to last and last, have the third and fourth highest fractional areas in wetland. We believe that this is due to the fact that many of the wetlands in our watersheds have been strongly degraded by agricultural practices, particularly channelization. This is certainly true of the wetlands in Duck and Johnson Creeks.

Basin Relief

Figure 18 is a plot of our subjective ranking vs. relief. Note that the four highest ranked streams all have high relief. There are two obvious explanations for this. Most importantly, in the Rock River Basin the areas of highest relief tend to have less land in agriculture and more in woods and wetlands. For example, our three highest ranked streams, Scuppernong River, the Little Oconomowoc River, and the Oconomowoc River, all have less than 50% of their watershed area in agriculture. A second factor is that higher basin relief generally results in streams with higher gradients, higher velocity flows, and less fine-grained sediment on the bed. This illustrates an important point-- stream quality is affected by natural factors as well as human impacts. (Note, however, that high relief in a dominantly agricultural landscape generally results in greater stream degradation, due to increased soil and channel erosion.)

Stream Gradient

As expected, stream gradient at our sampling sites has a significant negative correlation with sediment score and the HBI, both at the 0.01 significance level. (Remember that low HBI means higher quality.) Stream gradient also has a significant negative correlation with chlorophyll a and a significant positive correlation with average minimum dissolved oxygen levels, both at the .05 significance level.

EUTROPHICATION

Eutrophication is a major water quality problem in the agricultural Midwest, and especially in the Rock River Basin. Eutrophication of low-flowing water bodies, such as lakes, is well understood. This is not the case for streams (USGS, 1999), due to their wide variations in water velocity, turbidity, and bed conditions. Eutrophication results from excessive nutrients, which can contribute to high primary productivity, usually in the form of floating and attached algae and aquatic weeds. The main problem caused by this excessive productivity is low dissolved oxygen, which in extreme cases is fatal to fish and other organisms. Lowering of dissolved oxygen results from both plant respiration and decay.

We found many signs of eutrophication in the Rock River Basin. On a reconnaissance tour of the Beaver Dam River in Mud Lake State Wildlife Area we observed large amounts of suspended blue-green algae, presumably originating from upstream Beaver Dam lake. Impoundments on the Bark and Oconomowoc Rivers exhibited excessive growth of aquatic weeds and algae. On many reaches of our sample streams we observed excessive amounts of aquatic weeds. In particular, large portions of Calamus and Duck Creeks were covered by duckweed mats and choked by rooted aquatic weeds.

Nutrient levels in our study streams are also high. Based on data from U.S. streams in natural areas with minimal human impact, the U.S. Geological Survey has specified “enrichment levels” as a means of evaluating nutrient levels (Table 9). Of our 14 study streams, eight exceeded the USGS enrichment levels for total phosphorus, nine exceeded the level for nitrate, and one exceeded the level for ammonia. Another measure of comparison is provided by Dodds et al. (1998), based on data from over 1300 temperate streams. Two thirds of these streams had total phosphorus concentrations below 0.075 mg/l. Nine of our streams exceeded this level.

Nutrient	Enrichment Levels (mg/l as N or P)
NH ₃ -N	0.1
NO ₃ -N	0.6
Total Phosphorus	0.1

Table 9: Estimates of National Background Concentrations (USGS 1999)

It is generally considered that phosphorus is the limiting nutrient for primary productivity in freshwater. (As discussed below, other factors, such as turbidity may also limit primary productivity). For our study streams (Figure 19), the correlation between chlorophyll a and total phosphorus is highly significant (0.01 significance level). There is one obvious outlier, the Oconomowoc River, which has unusually high chlorophyll a levels because of the upstream lakes. If the Oconomowoc River is excluded, total phosphorus explains about two thirds of the variance in chlorophyll a.

High productivity in a stream is not necessarily a serious problem. One problem that can be linked to high productivity is oxygen. The dissolved oxygen standard set by the USEPA and most state agencies is 5 mg/l for warm-water species. Daily minimum dissolved concentrations less than 4 mg/l, and particularly less than 2 mg/l, indicate strong potential for harm to aquatic fauna (Smale and Rabeni, 1995). Among our streams, Duck and Calamus Creeks had average minimum dissolved oxygen concentrations below 2 mg/l, while Johnson and Maunsha Creeks had average minimum oxygen concentrations below 5 mg/l. Note that we observed dead fish on a tributary of Duck Creek during our initial watershed exploration.

Average minimum dissolved oxygen concentrations decreased with total phosphorus (Figure 20). The relationship explains only about 30% of the variance in dissolved oxygen concentrations, although the explained variance increases to 50% if Duck Creek is removed. In any case, factors other than phosphorus are also involved in oxygen depletion.

One likely factor is turbidity. High turbidity limits light penetration, and hence is a limiting factor for the growth algae and aquatic weeds. Although plant photosynthesis produces oxygen, the plant organic matter produced is also a source of oxygen demand when microbes

oxidize organic matter and consume oxygen during respiration. In general, attached algae are the main contributors to diurnal fluctuations in dissolved oxygen in streams (Pogue and Anderson, 1994; Thyssen, 1982; Welch, 1992). Because attached algae are generally low in the water column, they will be strongly affected by light attenuation due to high turbidity.

Data from the Maunsha River, Calamus Creek, Johnson Creek, and Duck Creek indicate a relationship between minimum dissolved oxygen levels and turbidity. Base flow phosphorus concentrations for these four streams were all high (Figure 6). However, minimum dissolved oxygen levels for Calamus and Duck Creeks were considerable lower than those of the Maunsha River and Johnson Creek. Also note that the latter have much lower diurnal DO ranges. Both of these effects appear to be due to the much higher turbidity of the Maunsha River and Johnson Creek.

Stream	Total P (mg/l)	Turbidity (NTU)	Daily Minimum DO (mg/l)	Daily DO Range (mg/l)
Maunsha R.	0.25	16.1	4.9	2.2
Calamus Cr.	0.24	5.6	1.7	5.6
Johnson Cr.	0.17	24.0	4.1	1.4
Duck Cr.	0.12	4.1	1.1	3.7

Table 10: Relationship Between DO, Turbidity and Phosphorus

Although turbidity in the Maunsha River and Johnson Creek may somewhat mitigate the impact of high nutrient levels on dissolved oxygen, the negative impacts of excessive amounts of fine-grained sediment may be worse than the benefits associated with higher dissolved oxygen. Even with very low minimum oxygen levels, based on the WDNR fish survey Duck Creek does support fish. On the other hand, very few fish were found in the Maunsha at an upstream site that has significantly higher quality than our sampling site.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

RESEARCH OBJECTIVES

As stated in the introduction to this report, this research was intended to explore the following questions:

- What is the status of stream quality at representative sites throughout the Rock River Basin, where stream quality is defined with respect to the ability of a stream to support a desirable fishery?
- How is stream quality at the sampling sites related to river and watershed characteristics?
- Does stream quality change in response to increases or decreases in available phosphorus?

METHODS

In cooperation with the Wisconsin Department of Natural Resources, we investigated 14 small watersheds in the Rock River Basin, the aggregate area of which was about 12% of the total basin area. These watersheds ranged in size from about 9 to 58 square miles, and were spread throughout the Rock River Basin. The primary land use was agriculture, although some of the watersheds had large areas in forest and wetland.

Data on stream quality were obtained from six monthly low-flow water samples, continuous monitoring of dissolved oxygen and temperature for one-week periods in the summer and early fall, two base flow measurements, estimates of biotic indices, and observations of the extent of fine-grained sediment deposits. The water samples (which were collected by the WDNR) were analyzed primarily for nutrient concentrations (total phosphorus, dissolved reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, and total Kjeldahl nitrogen), chlorophyll a concentrations, and turbidity. Two biotic indices were determined by the WDNR. The Hilsenhoff Biotic Index (HBI) is based on macroinvertebrates and is intended to measure organic and nutrient loading. The Index of Biotic Integrity (IBI) is a fish index that is intended to measure the ability of a stream to support a balanced community of organisms. We also subjectively ranked each of the sites based on extensive observations of stream quality through the watersheds.

PRINCIPAL FINDINGS

To a great extent, the various indicators of stream quality vary in a consistent fashion across the 14 streams. All indicators but nitrate-nitrogen and unit-area base flow are correlated with our subjective ranking at least the 0.05 significance level. The lack of correlation of nitrate-nitrogen and unit-area base flow is likely due to drain-tiling.

In our judgement, fine-grained sediment, derived primarily from agricultural activity, is the most serious problem in our study streams. The low-quality streams have many low-gradient reaches in which the streambed is covered with fine-grained sediment. Such reaches provide very poor habitat for aquatic organisms. In the worst two streams the water is turbid even at low flows.

There is clear evidence of eutrophication in our streams, due to phosphorus enrichment. Of our 14 study streams, eight exceeded the USGS enrichment level for total phosphorus. Where light is not limiting, there is excessive growth of aquatic weeds. Chlorophyll a concentrations correlate significantly with phosphorus levels. More importantly, minimum dissolved oxygen levels correlate significantly with phosphorus concentrations. For two of our streams the measured weekly average dissolved oxygen levels were below 2 mg/l, a level which can be lethal to aquatic organisms. Two other streams had levels below 5 mg/l, the most common standard for warm-water streams. For the latter two streams, high turbidity appears to mitigate the impact of phosphorus on minimum oxygen levels. Finally, the HBI correlates very strongly with minimum dissolved oxygen, indicating its usefulness as a stream indicator.

The dominant land use in our study watersheds is agriculture; hence stream quality there is largely determined by agricultural activities. Most of the sediment and phosphorus in our streams is ultimately derived from runoff from agricultural lands. However, the relationships between these and other indicators of stream quality appear to be complicated by the role of drain-tiling. The four watersheds with the highest fractional area in agriculture have relatively low amounts of sediment and phosphorus at the sampling sites, while they have the highest levels of nitrate. It appears that this is due to drain-tiling in these watersheds. Drain-tiling decreases soil moisture and hence increases infiltration rates and decreases surface runoff and the associated transport of sediment and phosphorus.

Although several of our watersheds have significant fractional areas in wetland, there is little evidence that these wetlands have a beneficial effect on stream quality. This is probably due to the fact that many of these wetlands have been significantly degraded by agricultural activities, such as channelization. (Channelization effectively disconnects the stream from the wetland.)

MANAGEMENT RECOMMENDATIONS

Efforts to improve the quality of rural streams in the Rock River Basin should focus on control of sediment. Fine-grained sediment is clearly the most serious problem in our study streams. Furthermore, most of the phosphorus in these streams is associated with sediment.

In general, significant reduction of sediment loads to Rock River Basin streams will greatly improve stream quality, by reducing the amount of fine-grain sediment in the stream and the concentrations of phosphorus. (It may take years, however, for stream quality to improve, because of the large amount of sediment stored on the streambed.) The resulting increases in water clarity could worsen eutrophication and lower minimum dissolved oxygen levels wherever phosphorus concentrations remain high because of point discharges. In those streams, eutrophication may be a water quality problem unless instream phosphorus concentrations are sufficiently reduced. In flowing waters, reduction in phosphorus concentrations to levels that limit the growth of attached algae may be difficult to achieve.

Before European settlement, most of the Rock River Basin consisted of wetlands. Today most of these wetlands have been drained, and a large portion of the remaining wetlands have been degraded by agricultural activities. Restoration of degraded wetlands may be an effective strategy for improving stream quality.

Serious efforts to improve stream quality in the Rock River Basin should target degraded streams with high potential for significant improvement. This would include streams that have high-gradient reaches, flow into larger streams with good fish populations, and have opportunities for wetland restoration.

These management recommendations pertain to stream quality problems in the small to medium rural tributaries of the Rock River. They were not intended to address problems on the main stem of the Rock River, although they certainly have some relevance to these problems.

RESEARCH RECOMMENDATIONS

Phosphorus Trading Ratios

Phosphorus discharge trading between point and non-point dischargers requires the specification of a “trading ratio,” defined as the number of units of phosphorus that must be targeted for removal by a non-point-source management practice to be equivalent to a unit of phosphorus targeted for removal by a point-source treatment practice. The present stance of phosphorus regulators, most notably the USEPA, is that the ratio should be 2 or more. The apparent rationale is that, compared to point-source treatment practices, non-point-source management practices are much less reliable at delivering the removal target. However, this ignores the fact that most non-point-source management practices control phosphorus by limiting sediment delivery to streams. Given the fact that fine-grain sediment is perhaps the most important problem for small to medium rural streams in the Rock River Basin, a strong argument can be made for a lower trading ratio. Additional research is needed to assess the optimal trading ratio.

Sediment Assessment

The standard method of quantifying sediment load, through measurements of streamflow and sediment concentration, is very expensive. Furthermore, because of hydrologic variability and the significant storage of sediment on the streambed, many years of data on sediment load are required to estimate sediment loads and assess the benefits of sediment control practices in a watershed. Research is needed to develop more cost-effective methods.

HBI

Our results support the assertion of Hilsenhoff (1998, p. 2) that the HBI “primarily measures effects of oxygen depletion....” Additional data should be collected to further test this result.

Potential Benefits of Drain-tiling

It appears that drain-tiling has benefited stream quality in some of our study watersheds. This suggests the possibility of using drain-tiling as a water-quality management practice, in conjunction with small constructed wetlands to control nitrate contamination. Note that such an approach might also reduce nitrate contamination of groundwater. Of course, nutrient management should be encouraged on all agricultural lands. Also, as discussed above, reversion of low-lying agricultural lands to wetlands would also improve stream quality.

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