Determination of the Effects of Fine-Grained Sediment and Other Limiting Variables on Trout Habitat for Selected Streams in Wisconsin

By Barbara C. Scudder, Jeffery W. Selbig, and Robert J. Waschbusch

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.61	kilometer
pound (lb)	453,600	milligram
tons/mi^2	0.3503	tonnes/km^2 (tonnes per square kilometer)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8\ (°C) + 32.$$

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million. Other units of measurement used in this report are microsiemens per centimeter at 25°Celsius (µS/cm), micrometers (µm).

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Abstract

Two Habitat Suitability Index (HSI) models, developed by the U.S. Fish and Wildlife Service, were used to evaluate the effects of fine-grained (less than 2 millimeters) sediment on brook trout (*Salvelinus fontinalis*, Mitchill) and brown trout (*Salmo trutta*, Linnaeus) in 11 streams in west-central and southwestern Wisconsin. Our results indicated that fine-grained sediment limited brook trout habitat in 8 of 11 streams and brown trout habitat in only one stream. Lack of winter and escape cover for fry was the primary limiting variable for brown trout at 61 percent of the sites, and this factor also limited brook trout at several stations. Pool area or quality, in stream cover, streambank vegetation for erosion control, minimum flow, thalweg depth maximum, water temperature, spawning substrate, riffle dominant substrate, and dissolved oxygen also were limiting to trout in the study streams. Brook trout appeared to be more sensitive to the effects of fine-grained sediment than brown trout. The models for brook trout and brown trout appeared to be useful and objective screening tools for identifying variables limiting trout habitat in these streams. The models predicted that reduction in the amount of fine-grained sediment would improve brook trout habitat. These models may be valuable for establishing instream sediment-reduction goals; however, the decrease in sediment delivery needed to meet these goals cannot be estimated without quantitative data on land use practices and their effects on sediment delivery and retention by streams.

INTRODUCTION

Brook trout and brown trout are prized sport fish inhabiting cold-water streams in the United States. The brook trout, *Salvelinus fontinalis* (Mitchill), is the only stream-dwelling trout native to Wisconsin (Becker, 1983). Brown trout (*Salmo trutta*, Linnaeus), introduced into Wisconsin waters in 1887, now are present throughout Wisconsin but are most common in cold-water streams in southern and central Wisconsin. Brown trout may be tolerant of streams that have become unsuitable for brook trout because of increased summer temperatures and turbidity from land-management activities (Becker, 1983).

Reproductive success of brook trout and brown trout decreases with increasing amounts of fine-grained sediment in spawning areas (Peters, 1965; Harshbarger, 1975; Waters, 1995). In this report, fine-grained sediment is less than 2 mm in diameter. This includes sand, silt, and clay. Spawning of brook and brown trout occurs from October to December or early January in redds made in gravel bottoms of Wisconsin streams. Redds often are located in riffle areas or at the tail of pools where upwelling or downwelling water currents in gravel ensure optimal stream velocities and dissolved-oxygen concentrations for embryos (Avery and Niermeyer, 1999; Brynildson and others, 1963; Becker, 1983). Location of redds in these areas also minimizes harmful effects of sedimentation because fine-grained sediments are generally rapidly removed to other stream areas by the relatively fast water velocities. Higher percentages of fine sediment in redds is generally detrimental to the survival of fish embryos to emergence (Chapman, 1988). Fine sediment may entomb embryos and reduce intergravel water flows, removal of embryo wastes, and intergravel dissolved-oxygen supply to embryos (Bjornn and Reiser, 1991; Cordone and Kelly, 1961; McFadden, 1961; Peters, 1965; Koski, 1966; Harshbarger, 1975; Ringler and Hall, 1975, Waters, 1995). Sand concentrations greater than approximately 15 percent in spawning gravel were found to reduce the number of emerging brook trout fry (Hausle, 1973). In addition, sedimentation (>10 percent fine-grained sediment) may result in decreased production of invertebrates associated with riffle areas, thus decreasing food availability for fry (Chutter, 1969; Crouse and others, 1981). Berkman and Rabeni (1987) found that greater amounts of fine sediment decreased the abundance of benthic insectivorous and herbivorous fishes as well as fishes requiring a clean gravel substrate for spawning.

The U.S. Fish and Wildlife Service (USFWS) developed Habitat Suitability Index (HSI) models based on available life-history information and the assumption that habitat quality and quantity can be described numerically (Raleigh, 1982; Raleigh and others, 1986). Armour and others (1984) discuss these models in the larger context of habitat evaluation procedures. Wesche and Goertler (1987) provide feedback on a test of the brown trout model in Wyoming streams. The underlying assumption of the models is that a direct linear relation exists between the HSI value and the carrying capacity of the stream for the fish species. The HSI value may be used to compare different streams, one site in a stream over time, or several sites in a stream with each other. It is a useful screening tool for identifying streams that may have habitat problems or sites within a stream that have less-suitable habitat than others. These models can be applied to find ways to improve the habitat quality for a given species through management actions in an affected area. Additionally, the models could be applied before and after implementation of watershed-management practices to evaluate the effectiveness of the practices or to evaluate the impacts of developments. This information may improve the successful implementation of best-management practices by allowing relatively rapid progress checks during implementation.

Purpose and Scope

The Wisconsin Department of Natural Resources (WDNR) Priority Watershed Program wanted to assess various quantitative techniques for estimating pollutant reduction goals. The HSI models showed promise for estimating sediment-reduction goals for streams and predicting effects of implementing such goals. Our study used selected HSI models to identify limiting variables for brook and brown trout in three watersheds in Wisconsin, to determine the relative importance of sediment-related variables, and to evaluate the utility of the models for establishing sediment-reduction goals. After interpretation of results from the first two watersheds, methods for collecting habitat data were revised and habitat data was collected and analyzed for a third watershed. The scope of this report is limited to analysis of fish habitat data collected in 1990–91 for 11 streams in 3 watersheds of west-central and southwestern Wisconsin.

Study Area

Most of the study streams were in the "Driftless Area" of Wisconsin, which is characterized by steep terrain, loamy soils, and a lack of glacial deposits. Most streams in the area have accentuated peak flows, with many sites showing evidence of major erosion. According to Hindall (1975), streams in the Driftless Area had the largest average annual yields of suspended sediment in Wisconsin. The loamy, very silty soils, steep slopes, and predominantly agricultural land use of the area contribute to average annual suspended sediment yields of about 238 tonnes per square kilometer (Hindall, 1976). Yields considerably larger were observed for one stream in this area after two major floods (Kammerer and Batten, 1982). Dominant agriculture is corn, hay, and alfalfa, often as contour crops and for dairy pasture. Riparian buffer zones of natural vegetation are usually relatively narrow (less than 10 m wide).

Eleven streams from three watersheds were selected for HSI analysis (fig. 1 and appendix 1). Habitat information was collected for two or more sampling stations per stream in most cases. This allowed for an examination of between-station habitat variability and improved characterization of the streams. Two watersheds, the middle Kickapoo and the middle Trempealeau, were used to assess habitat collection procedures. The Kickapoo and Trempealeau River watersheds are located entirely in the Driftless Area. The streams selected were chosen for HSI analysis primarily because of high embeddedness ratings or large silt concentrations at one or more of the stations sampled. Embeddedness is the degree to which larger sediment particles are surrounded or covered by fine-grained sediment (sand or finer). The Kickapoo watershed has greater topographic relief and generally is more wooded and less farmed than the Trempealeau (table 1). The middle Trempealeau River watershed has a larger percentage of agricultural land than the middle Kickapoo, 73 percent compared to 61 percent (Wisconsin Department of Natural Resources, 1992a and 1992b). In addition, more of this agricultural land is cropland/grassland in the Trempealeau watershed, (54 percent in Trempealeau compared to 38 percent in Kickapoo). Wisconsin Non-point (WIN) analysis by the Wisconsin Department of Natural Resources (WDNR) estimated that

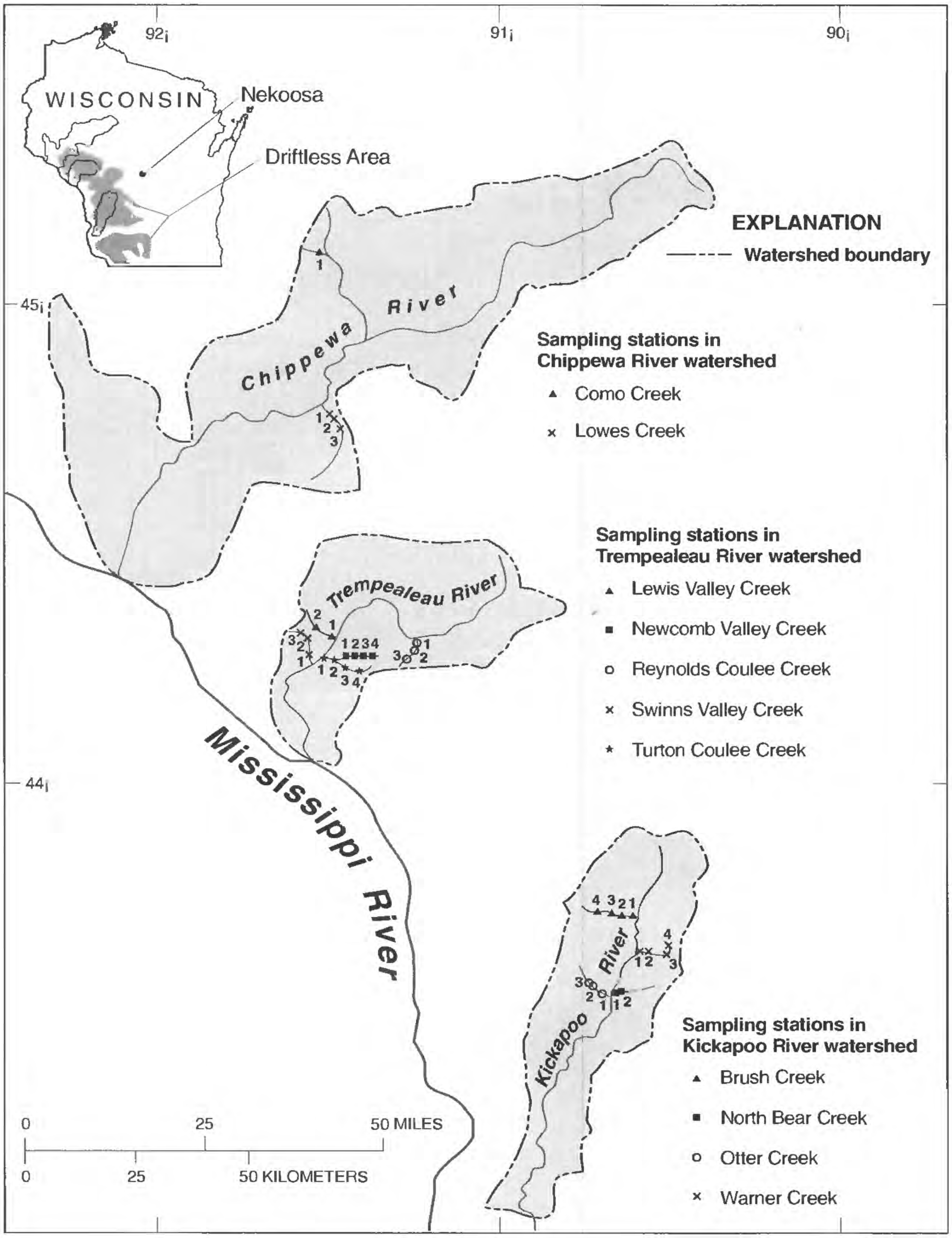

Figure 1. Location of the Kickapoo, Trempealeau, and Chippewa watersheds in Wisconsin together with 11 study streams and location of sampling stations where brook and brown trout habitat were examined by Habitat Suitability Index analysis.

93–96 percent of the sediment loading for these subwatersheds was due to agricultural land use (Wisconsin Department of Natural Resources, 1992a).

Table 1. Percent agriculture in subwatersheds of the 11 study streams

[Values for Kickapoo and Trempealeau watersheds estimated by the Wisconsin Department of Natural Resources Wisconsin Nonpoint (WIN) analysis (WDNR, 1992a); ND, no data available]

Stream name	Percent Agriculture
Middle Kickapoo River watershed	
Brush Creek	80
North Bear Creek	59
Otter Creek	48
Warner Creek	54
Middle Trempealeau River watershed	
Lewis Valley Creek	75
Newcomb Valley Creek	ND
Reynolds Coulee	74
Swinns Valley Creek	89
Turton Coulee Creek	ND
Chippewa River watershed	
Como Creek	[1]92
Lowes Creek	[2]54

[1] The Como Creek estimate is from 1992 WIN analysis by Chippewa County, Soil Conservation Service, Jane Tetzlaff-Jensen, oral commun., June 29, 1993.

[2] Estimate provided by Sharon Thibodeau, Eau Claire County, Department of Planning and Development, written commun., July 30, 1993.

Revised habitat collection procedures were used in the Lowes Creek and Como Creek watersheds. The upper part of the Lowes Creek watershed lies inside the Driftless Area and is characterized by relatively steep relief and loamy soils. Approximately 54 percent of the watershed is agricultural land (S. Thibodeau, Eau Claire County Department of Planning and Development, written commun., July 30, 1993). The drainage for Como Creek is completely outside the Driftless Area. The Como Creek watershed was estimated by the Soil Conservation Service WIN model to contain 73 percent cropland and 19 percent pasture in 1992 (Jane Tetzlaff-Jensen, Chippewa County, oral commun., June 29, 1993; Soil Conservation Service, 1992). Flows for Como and Lowes Creeks generally are more stable than flows for streams in the Driftless Area (K. Schreiber, Wisconsin Department of Resources, oral commun., 1990); however, increased fine-grained sediment input to both streams is a concern for trout fisheries in these streams.

Acknowledgments

The authors acknowledge the assistance of John D. Lyons, Michael T. Kaminski, Kenneth W. Schreiber, and Timothy D. Simonson of the WDNR for providing ideas on habitat sampling and HSI analysis. In addition, Kenneth W. Schreiber provided the fish collection and fish-habitat data for the Kickapoo and Trempealeau watersheds, fish collection and some water-quality data, and gave logistical support during site visits in all three watersheds. Paul Pajak of the USFWS provided expertise in use of the HSI models for priority watershed sediment-reduction goals. Bryce Richardson, Paul Hoffmann, and Pat Valencia of the WDNR collected the fish and fish-habitat data in the Kickapoo and Trempealeau watersheds. The authors also thank Bill Rose of the USGS for contributing his ideas on sediment transport in streams, Timothy D. Simonson, John Lyons, and Herbert S. Garn (USGS) provided helpful comments on an earlier version of the manuscript. Funding for this study was provided by the U.S. Geological Survey (USGS) in cooperation with the WDNR.

METHODS

Data Collection

In late June through early September 1990, the WDNR sampled for fish and habitat at a large number of streams in the middle Kickapoo and middle Trempealeau watersheds. Nine of these streams were chosen for HSI analysis (fig. 1). The number of stations sampled on a creek varied from two to four. Habitat data were collected for 305-m reaches upstream or downstream of each station using transects every 3.05 m and according to Lyons (1990; also see Simonson, 1993; and later version in Simonson and others (1994). An evaluation of the precision and accuracy of these habitat measures is provided in Wang and others, 1996. According to Wang and others (1996), the precision of habitat variable estimates ranged from 0–32 units (95 percent confidence intervals), depending on the variable type and habitat homogeneity. About 70 percent of the confidence intervals were less than 10 units. Accuracy for substrate variable measurement was high but was influenced by substrate homogeneity. Mean estimated substrate values were closely correlated ($r^2 \geq 0.85$, $p < 0.01$) with digitized values obtained from photographs. Habitat sampling required approximately 2 hours per station. This protocol was not designed for use with the HSI models, and application of the models to this data set was an after-the-fact decision. Fish were collected in May 1990 in the middle Kickapoo watershed and from late June to early August 1990 in the middle Trempealeau watershed. Numbers of brook and brown trout were determined by towed or backpack electroshocking devices using a single pass of the 305-m reach without blocknets. Water-clarity, air and water temperature, and flow volume were recorded at the time of habitat data collections. Additional information, including water quality data, on WDNR monitoring of these two watersheds can be found in Schreiber (1991a and 1991b).

In 1991, habitat sampling was conducted by the USGS during August in the lower Chippewa watershed. Habitat data were collected at one station on Como Creek and at three stations on Lowes Creek (fig. 1) specifically for input into the HSI models for brook trout and brown trout. Data for other habitat characteristics were collected along 305-m reaches using 12 transects on Como Creek and 20 transects at each station on Lowes Creek. On Como Creek, a single-pass sampling for trout was conducted in August 1991 by the WDNR using a towed electroshocking device. Lowes Creek data on numbers of brook and brown trout were from WDNR collections made in 1987.

Transects were begun at a distance from culverts or bridges where no channel widening or flow effects were detectable (Como Creek, 16 m; Lowes Creek, 67 to 125 m). A single discharge measurement was made at the downstream end of each station using a pygmy meter. At each transect, stream width was measured using an open-reel tape, habitat type was noted (that is, pool, riffle, or run and whether the transect was at a potential trout-spawning area), and the percentages of instream fish cover, streambank stability, and percentages and types of streambank vegetative cover were visually estimated. Water depth, velocity, percentage of shade, embeddedness, and stream-bottom substrate data were collected at four equally spaced positions across each transect. The latter three characteristics were visually estimated. Stream-bottom surface coverage by each substrate type (that is, cobble, gravel, and so forth) and embeddedness were estimated using a 30-cm wide x 50-cm height viewing tube constructed of plastic polyvinyl chloride (PVC) and plexiglass with a marked nine-square grid on the clear base. Each 9 x 9-cm square was assumed to equal approximately 10 percent coverage.

For water-quality data at Como and Lowes Creeks, hydrolabs (Datasonde Model 2H) were installed for 3 days (8/30/91 to 9/2/91) at station 1 on Como Creek and at station 3 on Lowes Creek to record water temperature (for maximum during warmest period), pH, and dissolved oxygen every half hour.

WDNR data collected at the same or nearby (less than one-half mile away) Lowes Creek sites were used for nitrate-nitrogen (average for April through June 1991). These data also were used for average maximum water temperature (RYAN TempMentor continuous readings for April 1991) and average minimum dissolved oxygen concentration during embryo development (YSI dissolved oxygen meter connected to a LICOR datalogger; continuous readings for June 1991). Data for April 8, 1991 was input for maximum water temperature during embryo development at all stations on Lowes and Como Creeks as the time of fry emergence for brown trout was assumed to be March to Mid-April. WDNR data for June 11–19, 1991 at Lowes Creek were used for minimum dissolved oxygen and associated temperatures because these values were the lowest recorded by the WDNR and also were lower than those recorded by the USGS hydrolab in August 1991. Additional information on WDNR monitoring of Como Creek can be found in Schreiber (1992).

Where measured values at the study streams were not available, because the streams were not gaged and measurement otherwise would have been difficult, habitat characteristics (mean annual flows, average annual base and peak flows, maximum and average maximum water temperature during April through May) were estimated from mean values for nearby USGS gaged streams (Holmstrom and Erickson, 1990). For example, some variables for Como and Lowes Creeks were those from USGS 1990 data for Tenmile Creek near Nekoosa, Wisconsin (USGS station number 05401050; Holmstrom and others, 1991), which was considered to have flow characteristics similar to these streams. For a few habitat variables where data was unavailable for nearby gaged streams of similar flow characteristics, we assumed optimum values based on the HSI model response curves in Raleigh (1982) and Raleigh and others (1986). A description of data sources for all HSI variables is found in appendix 2.

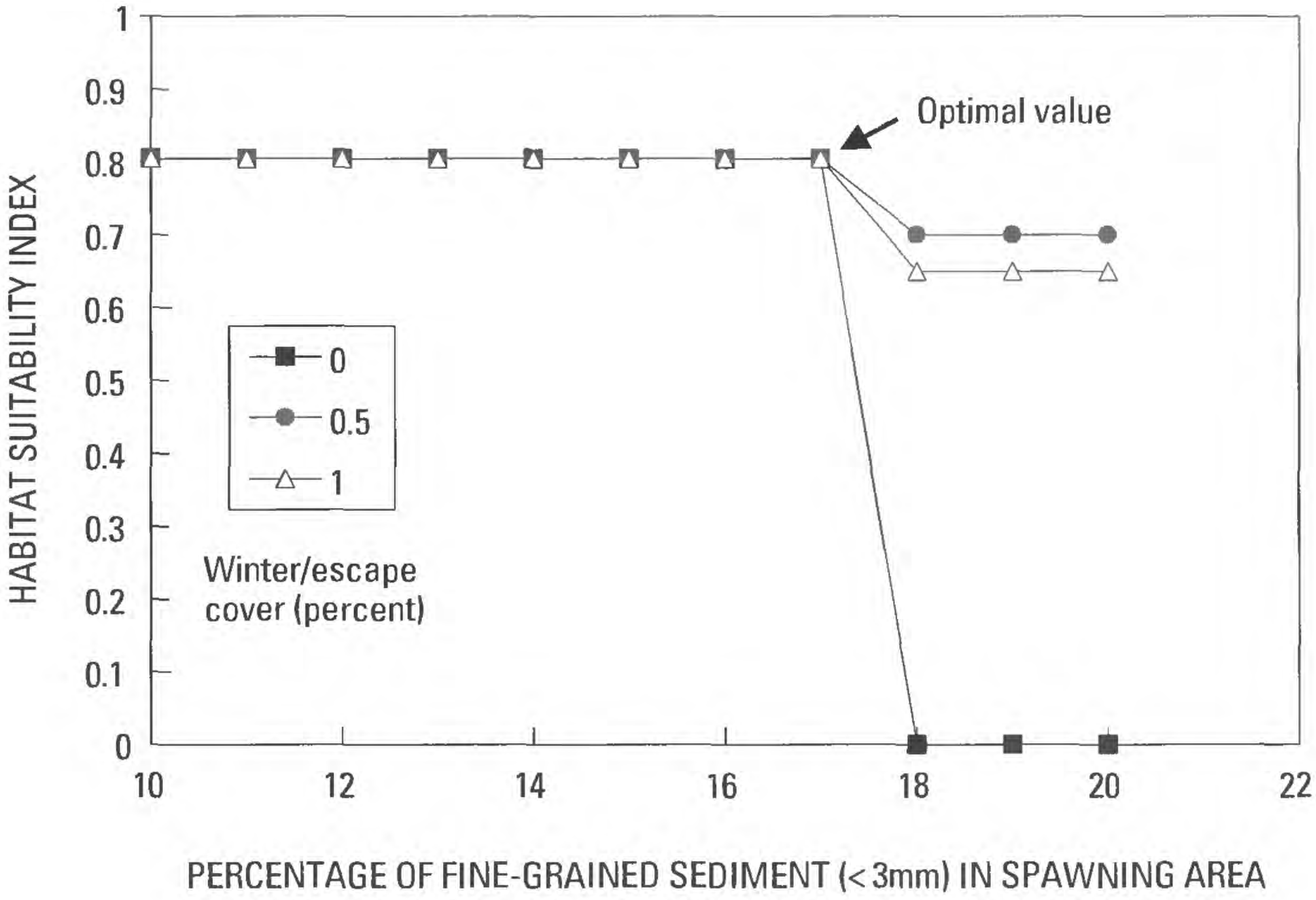

Figure 2. Response curves showing how the HSI for brook trout is affected when the percentage of fine-grained sediment (<3 mm) in spawning areas varies with the percentage of substrate for winter and escape cover (station 1, Lowes Creek—August 1991). (Arrow points to the optimum value for percentage of fines at all three cover values and the threshold value for percentage of fines at all three cover values and the threshold value for percentage of fines when cover is equal to 0).

Application of Habitat Suitability Index Models

The most up-to-date HSI models available for brook trout (Brook trout model, riverine, cold; February 1988 modification; Raleigh, 1982) and brown trout (Brown trout model, riverine; September 1988 modification; Raleigh and others, 1986) were applied to the fish-habitat data collected for the 11 streams using version 2.1 of Micro-HSI, Habitat Evaluation Procedure (HEP) Software (U.S. Fish and Wildlife Service, 1989). The model software allowed calculation of HSI values for different cover/vegetation types within a study area. In this study, this option was instead used to separate the different stations sampled at a stream so that a separate HSI value for each station as well as an overall HSI value for the stream could be calculated at the same time. The model output indicates the overall suitability of the stream for the species of interest on a scale of 0.00–0.24 ("totally unsuitable"), 0.25–0.49 ("below average"), 0.50–0.74 ("average"), 0.75–0.99 ("good"), and 1.00 ("excellent") (U.S. Fish and Wildlife Service, 1981). Additional information from USFWS (1980, 1981) was used for model application and interpretation.

Using the model, the amount of change in a variable(s) needed to optimize fish-habitat suitability was estimated. Model-sensitivity analyses helped determine which habitat variables were most important in improving the suitability of a stream for a given fish species. Limiting habitat variables were changed by ±10 percent to observe their effect on the HSI value. Habitat variables also were changed by more than 10 percent; however, a different habitat variable sometimes became limiting at that point. The response curves generated by the HSI model were useful for viewing how the HSI value might change along a range of values for one or two variables. The curves also were useful for determining optimum and threshold values for variables. Threshold values were considered as values of a variable beyond which dramatic changes would occur in the HSI value. Because not all variables were given equal weight in calculation of HSI values, the intermediate-function values option allowed the model user to determine the effect each variable had on the calculation. This option also aided in determining the optimum values of a variable. Figure 2 shows an example of an HSI response curve with two variables and the approximate optimal value for one variable. The intermediate-function value was particularly useful in cases where the sensitivity analysis was uninformative due to an HSI value of 0.00, and it allowed the user to determine which variables were primarily responsible for the value.

The HSI values for brook trout and brown trout were calculated differently. The brook trout model calculated one HSI value. The HSI values for brown trout were composed of separate Life Requisite Suitability Index (LRSI) values for each life stage, including adult, juvenile, fry, embryo, and other. The other category refers to variables that affect all life stages. The overall HSI value for brown trout calculated at a station was equal to the minimum LRSI value at that station.

The HSI models for brook trout and brown trout assumed that optimal spawning substrate was predominantly gravel with ≤ 5 percent fine-grained sediment. Fine-grained sediment ≥ 30 percent was assumed to result in small survival rates of embryos and emerging fry (Raleigh, 1982; Raleigh and others, 1986). The brook trout HSI model allowed for percentages of fine-grained sediment up to a maximum of 60 percent and the brown trout HSI model allowed for input of a maximum value of 40 percent fine-grained sediment. The time of fry emergence for both fishes was assumed to be March through mid-April for the study streams, although Avery and Niermeyer recently reported emergence of brown trout fry from mid-March through early May in one central Wisconsin stream (Avery and Niermeyer, 1999).

RESULTS

Habitat characteristics for the 11 study streams are summarized in table 2. The percentage of fine-grained sediment was quite variable among the streams. Sand ranged from 0 to 90 percent in the streams, and silt ranged from 0 to 70 percent. The percentage of silt was less than 30 at nine of eleven streams. Clay was absent from most stream sites. The only stream sites where the percentage of clay exceeded 5 percent were in the Trempealeau watershed on Reynolds Coulee Creek, where concentrations ranged from 20 percent of the substrate at sampling station 1 to 80 percent at station 3.

The distribution of brook trout differed from brown trout in the streams and brook trout were less common. Brook trout were collected from three streams in the Trempealeau watershed and one stream in the Chippewa watershed. Total lengths of captured brook trout ranged from 51–214 mm at station 1 on Newcomb Creek to 76–328 mm at station 3 on Turton Creek; both are in the Trempealeau watershed. Brown trout were found at eight stations, representing four different streams from those where brook trout were collected. Brown trout collected were generally small, suggesting that many or all may have been stocked. Artificial stocking of trout could likely confound validation of model predictions. Stocking of some of the study streams (Schreiber, 1991a) may have contributed to the number of brown trout collected at some stations where the HSI model predicted "below average" or "unsuitable" habitat.

Kickapoo River Watershed

Brush Creek—Habitat for brook trout in Brush Creek ranged from "totally unsuitable" to "good" at the four stations sampled, and the overall HSI for this creek was "below average" (table 3). Winter cover in the form of deep pools, log jams, and undercut banks with tree roots and debris in streams provides shelter and reduces velocities (Tschaplinski and Hartman, 1983). An HSI value of 0.00 at station 1 was due to a lack of winter and escape cover for fry (10–40 cm cobbles and boulders). However, fine-grained sediment in spawning areas and fine-grained sediment as the dominant substrate in riffle-run areas also were limiting variables. For example, a decrease in the fine-grained sediment to optimal values in spawning and riffle-run areas increased the HSI value for station 1 from "totally unsuitable" to "good" habitat (table 3); however, a similar decrease at station 2 did not substantially increase the HSI value. If the average size of fine gravel (not measured) at station 3 was assumed to be 1.6 cm (upper limit of fine-gravel size = optimum) and the percentages of fine-grained sediment in spawning and riffle-run areas were set to optimal values, the HSI value for this station increased from "totally unsuitable" to "good." The percentages of fine-grained sediment at station 4 were small and decreases did not change HSI values. When fine-grained sediment was decreased to optimal values at stations 1 and 3, assuming the average size of fine gravel was 1.6 cm at station 3, the overall habitat for the creek achieved a "good" rating. No brook trout were found in Brush Creek.

The overall HSI value for brown trout in Brush Creek was "totally unsuitable" (table 4). The percentage of fine-grained sediment in spawning and riffle-run areas was moderate to large at stations 1, 2, and 3. A decrease in fine-grained sediment to an optimal value of

Table 2. Summary of habitat data collected for Kickapoo and Trempealeau watersheds during 1990 and Chippewa watershed during 1991

[dominant bank cover within 5 meters of the stream is categorized as cultivated (CU), grass or lawn (GR), forested (FO), meadow (MD), open pasture (OP), shrubs (SH), or wood pasture (WP), and is listed alphabetically. For the Kickapoo and Trempealeau watersheds only, bank erosion is rated on a scale of 1 (heavy) to 4 (none); canopy cover is rated on a scale of 1 (closed) to 3 (open); clarity is rated on a scale of 1 (clear) to 3 (turbid); embeddedness of cobble or gravel is rated on a scale of 1 (<5%) to 5 (>75%) or NA if no cobble or gravel present on streambottom; instream cover is rated on a scale of 1 (none) to 4 (abundant). Pool quality for all streams is rated as 1 (good: 50% or more of pools are = 0.90 meter deep), 2 (moderate: 50% or more of pools between 0.15–0.90 meter deep), or 3 (poor: 50% or more of pools are = 0.15 meter deep); mm, millimeter]

Variable	Kickapoo watershed			
	Brush Creek	**North Bear Creek**	**Otter Creek**	**Warner Creek**
Bank cover - dominant	FO/OP	MD/OP	FO/MD/OP	FO/GR/MD/OP
Bank erosion (1–4)	1–2	1–3	1–2	1–4
Canopy cover (1–3)	2–3	3	2–3	2–3
Clarity (1–3)	1–3	1	1	1
Depth - mean (m)	0.21–0.40	0.22–0.58	0.19-0.46	0.16-0.35
Depth - mean maximum (m)	0.31–0.64	0.30–0.75	0.27–0.57	0.21–0.49
Discharge (m^3/s)	0.12–0.50	0.11–0.22	0.05–0.12	0.01–0.34
Embeddedness - cobble (1–5)	NA–2	NA	NA–1	NA–2
Embeddedness - gravel (1–5)	NA–4	3	NA–2	2–4
Gradient (m/km)	2.8	9.1	8.1	6.1
Instream cover (1–4)	2–3	3–4	2–3	2–4
Pool length - total (m)	17.4–115	151–152	19.8–108	61.9–167
Pool quality (1–3)	2	2	2	2-3
Riffle length - total (m)	41.8–98.8	25.3–52.7	60.0–75.3	23.8–141
Silt depth - pools (m)	0–0.15	0–0.24	0.12–0.21	0–0.06
Silt depth - runs (m)	0–0.06	0–0.12	0.03–0.09	0–0.03
Silt depth - riffles (m)	0	0	0	0
Substrate type (%)				
Clay (< .004 mm)	0	0	0	0
Silt (.004 mm)	0–35	10–20	20–70	0–10
Sand (.062 mm)	20–60	30–70	10–20	10–80
Fine gravel (2 mm)	5–30	5–10	0	5–10
Coarse gravel (16 mm)	0–40	5–50	20–30	5–50
Cobble/rubble (65 mm)	0–10	0	0–30	0–25
Small boulder (250 mm)	0	0	0	0
Large boulder (>500 mm)	0	0	0	0
Bedrock	0	0	0	0
Temperature (°C)	11–13	14	9–11	9–16
Width - mean (m)	3.8–6.8	2.6–5.9	3.4–4.8	0.85–6.6
Number of sites	4	2	3	4

Variable	Trempealeau watershed			
	Lewis Valley Creek	**Newcomb Valley Creek**	**Reynolds Coulee Creek**	**Swinns Valley Creek**
Bank cover - dominant	MD/OP	FO/MD/OP/WP	FO/MD	CU/MD/OP
Bank erosion (1–4)	1–4	2–3	2–4	3–4
Canopy cover (1–3)	2–3	2–3	1–3	2–3
Clarity (1–3)	1	1–3	1–3	1
Depth - mean (m)	0.10–0.15	0.09–0.15	0.11-0.17	0.13-0.21
Depth - mean maximum (m)	0.13–0.20	0.13–0.20	0.16–0.26	0.20–0.29
Discharge (m^3/s)	0.02–0.08	0–0.04	0.01–0.07	0.02–0.20
Embeddedness - cobble (1–5)	1–2	2–4	NA–2	NA–1
Embeddedness - gravel (1–5)	2–3	2–4	NA–5	1–5
Gradient (m/km)	3.8	5.7	3.9	8.9
Instream cover (1–4)	2–4	2–4	3–4	2–4
Pool length - total (m)	30.2–125	29.5–43.6	78.0–109	11.6–140
Pool quality (1–3)	2	2–3	2	2

Table 2. Summary of habitat data collected for Kickapoo and Trempealeau watersheds during 1990 and Chippewa watershed during 1991—Continued

Variable		Trempealeau watershed				
		Lewis Valley Creek	Newcomb Valley Creek	Reynolds Coulee Creek	Swinns Valley Creek	Turton Coulee Creek
Riffle length - total (m)		61.9–66.8	80.2–151	43.6–136	2.74–72.5	79.6–190
Silt depth - pools (m)		0–0.15	0	0	0–0.02	0–0.02
Silt depth - runs (m)		0–0.21	0	0	0–0.02	0
Silt depth - riffles (m)		0	0	0	0	0
Substrate type (%)						
Clay	(< .004 mm)	0	0	20–80	0	0–5
Silt	(.004 mm)	0–30	0	0–20	0–5	0–30
Sand	(.062 mm)	40–90	40–95	0–20	10–90	60–90
Fine gravel	(2 mm)	0–10	0–20	0–70	5–45	0–10
Coarse gravel	(16 mm)	5–10	0–30	0–5	0–40	0–20
Cobble/rubble	(65 mm)	0–10	0–20	0	0–5	0
Small boulder	(250 mm)	0–5	0–30	0–5	0–5	0
Large boulder	(>500 mm)	0	0–10	0	0	0
Bedrock		0	0–10	0	0	0
Temperature (°C)		14–17	16–19	11–12	13–18	11–22
Width - mean (m)		1.8–3.4	0.96–1.7	1.4–3.0	2.2–4.4	1.9–6.9
Number of sites		2	4	3	3	4

Variable		Chippewa watershed	
		Como Creek	Lowes Creek
Bank cover - dominant		MD/OP	FO/MD/OP/WP
Bank stability (%)		80	85–95
Canopy cover/shading (%)		20	50
Clarity/Turbidity (NTU)		8.4	3.6–12
Depth - mean (m)		0.57	0.35–0.47
Depth - mean maximum (m)		0.75	0.45–0.61
Discharge (m^3/s)		0.10	0.68–0.74
Embeddedness (%)		10	20–30
Gradient (m/km)		2.03	8.70–11.8
Instream cover (%)		35	10–25
Oxygen - minimum dissolved (mg/L)		6.80	8.1
pH - mean		6.6	7.5–8.0
Pool length - total (m)		114	29.3–113
Pool quality (1–3)		2	1–2
Pool width mean - (m)		5.45	7.65–8.50
Riffle length (m)		0	0–300
Substrate type (%)			
Clay	(<.004 mm)	1	0
Silt	(.004 mm)	30	5–25
Sand	(.062 mm)	60	30–80
Fine gravel	(2 mm)	1	5–10
Coarse gravel	(16 mm)	1	0–5
Pebble	(32 mm)	<1	5–10
Small cobble	(64 mm)	0	0–5
Large cobble	(128 mm)	<1	0–5
Small boulder	(250 mm)	0	0–1
Large boulder	(<500 mm)	0	0–1
Bedrock		0	0–50
Temperature (°C)		14.7	16.5–17.0
Width - mean (m)		4.4	9.1–9.3
Number of sites		1	3

Table 3. Number of brook trout collected and results of Habitat Suitability Index model for brook trout in Kickapoo and Trempealeau watersheds in 1990 and Chippewa watershed in 1991 before and after computer-simulated modification of the percentage of fine sediment in spawning and riffle-run areas

[HSI, habitat suitability index percentage of fine-grained sediment refers to sediment <2 mm diameter]

Name of stream	Station number	Number of brook trout collected	Percentage of fine-grained sediment		Station HSI value	
			Initial	Optimal	Initial	After modification
			(Spawning/riffle run)			
1990 Kickapoo watershed						
Brush Creek	1	0	30/35	20/25	0.00	0.78
	2	0	40/45	20/25	.66	.68
	3	0	40/45	10/15	.00	.83
	4	0	5/10	5/10	.86	.86
			Overall HSI value		**.38**	**.79**
North Bear Creek	1	0	35/40	20/25	.00	.75
	2	0	20/25	20/25	.62	.62
			Overall HSI value		**.31**	**.68**
Otter Creek	1	0	20/25	20/25	.81	.81
	2	0	25/30	25/30	.67	.67
	3	0	40/45	25/30	.52	.59
			Overall HSI value		**.66**	**.69**
Warner Creek	1	0	5/10	5/10	.79	.79
	2	0	20/25	10/15	.78	.81
	3	0	35/40	25/30	.67	.68
	4	0	35/40	25/30	.35	.41
			Overall HSI value		**.65**	**.67**
1990 Trempealeau watershed						
Lewis Valley Creek	1	0	5/10	5/10	.47	.47
	2	0	40/45	20/25	.68	.80
			Overall HSI value		**.58**	**.63**
Newcomb Valley Creek	1	6	20/25	20/25	.50	.50
	2	0	15/20	15/20	.76	.76
	3	0	35/40	20/25	.51	.58
	4	0	5/10	5/10	.45	.45
			Overall HSI value		**.54**	**.56**
Reynolds Coulee Creek	1	0	1/1	1/1	.81	.81
	2	0	55/60	25/30	.00	.00
	3	14	55/60	25/30	.00	.60
			Overall HSI value		**.27**	**.47**
Swinns Valley Creek	1	0	55/60	20/25	.44	.57
	2	0	20/25	20/25	.56	.56
	3	0	1/1	1/1	.84	.84
			Overall HSI value		**.62**	**.66**
Turton Coulee Creek	1	0	55/60	20/25	.00	.00
	2	0	35/40	20/25	.00	.67
	3	14	20/25	20/25	.71	.71
	4	12	20/25	20/25	.48	.48
			Overall HSI value		**.30**	**.47**
1991 Chippewa watershed						
Como Creek	1	9	60/60	5/10	.46	.74
			Overall HSI value		**.46**	**.74**
Lowes Creek	1	ND	60/60	10/10	.00	.81
	2	0	31/31	10/10	.58	.81
	3	0	46/46	10/10	.64	.88
			Overall HSI value		**.41**	**.83**

Table 4. Number of brown trout collected and results of Habitat Suitability Index model for brown trout in Kickapoo and Trempealeau watersheds in 1990 and Chippewa watershed in 1991 before and after computer-simulated modification of the percentage of fine sediment in spawning and riffle-run areas

[Numbers of trout for Lowes Creek from Wisconsin Department of Natural Resources data for 1987; HSI, habitat suitability index; percentage of fine-grained sediment refers to sediment <2 mm diameter]

Name of stream	Station number	Number of brown trout collected	Percentage of fine-grained sediment		Station HSI value	
			initial	Optimal	Initial	After modification
<u>1990 Kickapoo watershed</u>						
Brush Creek	1	2	30	5	0.00	0.00
	2	0	40	5	.10	.10
	3	7	30	5	.00	.00
	4	5	5	5	.43	.43
			Overall HSI value		**.21**	**.21**
North Bear Creek	1	1	30	20	.00	.00
	2	0	15	5	.00	.00
			Overall HSI value		**.00**	**.00**
Otter Creek	1	0	15	5	.43	.43
	2	0	20	5	.14	.14
	3	0	30	5	.00	.00
			Overall HSI value		**.33**	**.33**
Warner Creek	1	6	5	10	.00	.00
	2	41	15	10	.00	.00
	3	2	30	10	.14	.14
	4	0	30	10	.00	.00
			Overall HSI value		**.12**	**.19**
<u>1990 Trempealeau watershed</u>						
Lewis Valley Creek	1	0	5	5	.14	.14
	2	0	35	20	.15	.40
			Overall HSI value		**.32**	**.37**
Newcomb Valley Creek	1	0	15	10	.30	.30
	2	0	15	10	.38	.38
	3	0	30	10	.20	.30
	4	0	5	5	.14	.14
			Overall HSI value		**.28**	**.28**
Reynolds Coulee Creek	1	0	1	1	.50	.50
	2	0	40	10	.00	.00
	3	0	40	10	.00	.00
			Overall HSI value		**.17**	**.17**
Swinns Valley Creek	1	0	40	10	.10	.10
	2	0	20	10	.00	.00
	3	11	1	1	.50	.50
			Overall HSI value		**.23**	**.23**
Turton Coulee Creek	1	0	40	10	.00	.00
	2	0	30	10	.00	.00
	3	0	5	5	.00	.00
	4	0	15	10	.00	.00
			Overall HSI value		**.00**	**.00**
<u>1991 Chippewa watershed</u>						
Como Creek	1	0	40	5	.05	.05
			Overall HSI value		**.05**	**.05**
Lowes Creek	1		40	20	.00	.10
	2		36	20	.11	.25
	3		40	20	.10	.25
			Overall HSI value		**.10**	**.25**

5 percent at these stations increased the LRSI values for embryos substantially; however, neither the HSI values for these stations nor the overall HSI value for the creek improved because the embryo LRSI value was not limiting (table 5). Habitat suitability was limited by inadequate cover for adults at all stations, inadequate cover for juveniles at stations 1 and 2 and fry at stations 1, 2, and 3, and insufficient pool area for juveniles at station 3. Fine-grained sediment at station 4, estimated at 5 percent, was not limiting to brown trout. Low numbers of brown trout were found at stations 1, 3, and 4, and the largest number of brown trout was found at station 3. Brush Creek is stocked annually (Schreiber, 1991a).

North Bear Creek—Habitat was "totally unsuitable" for brook trout at station 1 and "average" at station 2, whereas the overall habitat for the creek was "below average" (table 3). The rating at station 1 was due primarily to a lack of winter and escape cover for fry and small juveniles. Relatively large percentages of fine-grained sediment in spawning and riffle-run areas also limited brook trout at this station. The station 1 HSI value increased from "totally unsuitable" to "good" and the overall HSI value for the creek increased to "average" when fine-grained sediment in spawning and riffle-run areas was decreased to optimal values (table 3). Although decreases in fine-grained sediment at station 2 did not affect the HSI value, an increase in fine-grained sediment in spawning areas to approximately 33 percent resulted in an HSI value of 0.00. No brook trout were found in this creek.

Habitat for brown trout was "totally unsuitable" at both stations sampled in North Bear Creek due to a lack of winter and escape cover for fry (table 4). Decreases in percentage of fine-grained sediment in spawning and riffle-run areas did not increase the HSI values for these stations or for the creek. Only one trout was collected in North Bear Creek although the WDNR stocked the creek in spring 1990 with brown trout (Schreiber, 1991a).

Otter Creek—Habitat for brook trout in Otter Creek ranged from "average" to "good" at the three stations sampled, and the overall HSI value for the creek was "average"; however, no brook trout were found (table 3). Decreasing fine-grained sediment at stations 1 and 2 did not result in substantial increases in the HSI values because of the importance of other variables. Brook trout at station 1 were limited by insufficient trees and shrubs on the streambanks. The primary limiting variable at station 2 was minimum flow and this was a secondary limiting variable at stations 1 and 3. Brook trout at station 3 were limited by a lack of winter and escape cover for fry. Percentages of fine-grained sediment in spawning and riffle-run areas were largest at station 3, and when fine-grained sediment was decreased to optimal values, the HSI value for this station and the creek improved only slightly.

The overall HSI value for the brown trout in Otter Creek was "below average" (table 4). At stations 1, 2 and 3, a 10 percent decrease in fine-grained sediment resulted in an increase in the LRSI values for embryos of 15, 10 and 30 percent, respectively. However, a decrease in fine-grained sediment to an optimal value of 5 percent did not result in an increase in the overall HSI value for the creek. Inadequate cover for adults and juveniles at station 2, and lack of winter and escape cover for fry at station 3 appeared to be more important in limiting brown trout (table 5). Similar to North Bear Creek, no brown trout were collected despite the fact that the WDNR stocked Otter Creek with brown trout in spring 1990 (Schreiber, 1991a).

Warner Creek—Habitat for brook trout in Warner Creek was "good" at stations 1, 2, and 3, "below average" at station 4, and the overall HSI value for the creek was "average" (table 3). Decreasing the percentage of fine-grained sediment in spawning and riffle-run areas did not substantially increase the HSI values for the stations sampled or the overall HSI value for the creek. At station 1, the percentage of fine-grained sediment was small, and decreases did not affect the HSI value. Percentages of fine-grained sediment were moderate (20–40 percent) at the other stations. Brook trout at stations 1 and 2 were limited mainly by a lack of winter and escape cover. Low minimum flow was the primary limiting variable at stations 3 and 4. No brook trout were collected.

HSI values for brown trout in Warner Creek were "totally unsuitable" at the four stations, as was the overall HSI value (table 4). Lack of winter and escape cover for fry and lack of cobble and boulder substrate in riffle-run areas were the most important variables limiting brown trout at station 1, where the percentage of fine-grained sediment in spawning and riffle-run areas was small. Decreasing the percentage of fine-grained sediment in spawning and riffle-run areas to optimum at stations 2, 3 and 4 did not change the HSI values (table 4). Lack of winter and escape cover for fry and inadequate cover for adults and juveniles were the primary limiting variables at these stations. The HSI values are in contrast to the fact that brown trout were

Table 5. Life Requisite Suitability Index (LRSI) and Habitat Suitability Index (HSI) values for brown trout in 11 Wisconsin streams during 1990 and 1991

Stream	Station number	LRSI value					HSI value
		Adult	Juvenile	Fry	Embryo	Other[1]	
1990 Kickapoo watershed							
Brush Creek	1	0.14	0.33	0.00	0.20	0.30	0.00
	2	.14	.33	.20	.10	.60	.10
	3	.14	.22	.00	.20	.30	.00
	4	.43	.60	.81	1.00	.60	.43
						Overall value	**.21**
North Bear Creek	1	.60	.60	.00	.20	.30	.00
	2	.43	.60	.00	.50	.58	.00
						Overall value	**.00**
Otter Creek	1	.43	.60	.76	.50	.60	.43
	2	.14	.33	.65	.40	.60	.14
	3	.43	.60	.00	.20	.30	.00
						Overall value	**.33**
Warner Creek	1	.43	.60	.00	1.00	.30	.00
	2	.43	.60	.00	.50	.60	.00
	3	.14	.33	.47	.20	.60	.14
	4	.30	.30	.00	.20	.30	.00
						Overall value	**.12**
1990 Trempealeau watershed							
Lewis Valley Creek	1	.14	.30	.30	.80	.30	.14
	2	.60	.60	.33	.15	.60	.15
						Overall value	**.32**
Newcomb Valley Creek	1	.30	.30	.30	.50	.30	.30
	2	.38	.38	.38	.50	.60	.38
	3	.30	.30	.36	.20	.52	.20
	4	.14	.30	.38	.80	.60	.14
						Overall value	**.28**
Reynolds Coulee Creek	1	.60	.60	.50	.70	.60	.50
	2	.43	.60	.00	.00	.30	.00
	3	.60	.60	.00	.10	.30	.00
						Overall value	**.17**
Swinns Valley Creek	1	.14	.18	.18	.10	.30	.10
	2	.14	.33	.00	.40	.60	.00
	3	.60	.60	.50	.80	.60	.50
						Overall value	**.23**
Turton Coulee Creek	1	.10	.10	.00	.00	.21	.00
	2	.43	.48	.00	.20	.30	.00
	3	.24	.24	.00	.80	.30	.00
	4	.43	.60	.00	.50	.58	.00
						Overall value	**.00**
1990 Chippewa watershed							
Como Creek	1	.60	.60	.10	.05	.05	.05
						Overall value	**.05**
Lowes Creek	1	.60	.60	.00	.10	.11	.00
	2	.26	.26	.26	.11	.11	.11
	3	.69	.69	.20	.10	.12	.10
						Overall value	**.10**

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[1] All life stages.

found at stations 1, 2, and 3. The number of brown trout collected, especially the 41 trout collected at station 2, may simply reflect the large number of brown trout stocked in this stream in 1990 by the WDNR (Schreiber, 1991a).

Trempealeau River Watershed

Lewis Valley Creek—Brook trout habitat in Lewis Valley Creek received an overall rating of "average" (table 3) but no brook trout were found in the creek. At station 1, fine-grained sediment was minimal and not an important variable for brook trout populations. Shallow thalweg depth was the primary limiting variable at this station. Low minimum flows and shallow thalweg depth limited brook trout at station 2. Although only slightly sensitive to a 10 percent decrease in fine-grained sediment, the HSI value for station 2 increased by 17 percent, and the overall HSI value for the creek increased by 10 percent when fine-grained sediment in spawning and riffle-run areas was decreased to optimal values (table 3).

The overall HSI value for brown trout in Lewis Valley Creek was "below average" (table 4) and no brown trout were found. The creek had not been stocked (Schreiber, 1991b). At station 1, the percentage of fine-grained sediment in spawning and riffle-run areas was small and decreases did not affect the HSI value. The primary limiting variable for adults at this station was cover, and pool area limited juveniles and fry. Intermediate-function values indicated that fine-grained sediment in riffle-run areas limited all life stages at both stations. At station 2, a relatively large percentage of fine-grained sediment in spawning and riffle-run areas was the only limiting variable for fry and embryos and resulted in a "below-average" habitat rating for both life stages. A decrease in fine-grained sediment at station 2 to the optimal value increased the station HSI value from "totally unsuitable" to "below average" (table 4); however, the overall HSI value for the creek was still "below average" because of the importance of the other variables described above.

Newcomb Valley Creek—Although the HSI value for brook trout at station 2 in Newcomb Valley Creek was "good," values at the other three stations were either "below average" or "average," and the overall HSI value for the creek was "average" (table 3). Brook trout were collected only at station 1 and may have been from natural reproduction (Schreiber, 1991b). The creek is not stocked for trout. Decreasing the percentages of fine-grained sediment in spawning and riffle-run areas at station 3 to optimum values increased the station HSI value by 10 percent and the overall HSI value by only 3 percent. Decreases in fine-grained sediment at the other three stations or further decreases for station 3 did not substantially increase the HSI values. Low minimum flow at stations 2 and 3, and shallow thalweg depth at stations 1, 2, and 4, appeared to be the dominant limiting variables.

Newcomb Valley Creek had "totally unsuitable" or "below-average" habitat for brown trout at all stations (table 4), and brown trout were not found at any stations on this creek. The percentage of fine-grained sediment in spawning and riffle-run areas was a limiting variable for embryos at stations 1, 2, and 3 but was not important at station 4, where fine-grained sediment was minimal. Decreasing fine-grained sediment to an optimal value increased the LRSI value for embryos at stations 1, 2, and 3 but did not result in an increase in the overall HSI value of the creek (table 4). Inadequate pool area and poor pool quality resulted in low LRSI values for adults, juveniles, and fry (table 5). Fine-grained sediment in riffle-run areas at station 1 was an important limiting variable for all life stages. Also, high water temperature was limiting to all life stages at station 3, and the cover was inadequate for adults and juveniles at station 4.

Reynolds Coulee Creek—The overall HSI value for brook trout in Reynolds Coulee Creek was "below average" as a result of "totally unsuitable" ratings at stations 2 and 3 (table 3). Habitat at station 1 was "good," however. Percentages of fine-grained sediment in spawning and riffle-run areas were minimal at station 1 and not limiting to brook trout. Decreasing fine-grained sediment at station 2 did not increase the HSI value for this station due to a lack of winter and escape cover for fry and small juveniles and a lack of gravel substrate between 0.3–8 cm in spawning areas. Brook trout at station 3 also were limited by a lack of winter and escape cover. When fine-grained sediment in spawning and riffle-run areas was decreased to optimum values, the HSI value at station 3 increased to "average" and the overall HSI value for the creek increased from "below average" to near "average" (table 3). At station 3, the HSI value plummeted to 0.00 once the percentage of fine-grained sediment in spawning areas reached 44 percent. This stream is managed as a Class II trout fishery (Schreiber, 1991b) so the 14 brook trout found at station 3, in contrast to habitat model predictions, may represent stocked fish.

The overall HSI value for brown trout at the three stations in Reynolds Coulee Creek was "totally unsuitable" (table 4) and no brown trout were found in this creek. Habitat at station 1 was "good," whereas habitat at stations 2 and 3 was "totally unsuitable." Decreases in percentages of fine-grained sediment in spawning and riffle-run areas did not improve the HSI value for the stations sampled or the overall HSI value for the creek. At station 1, the percentage of fine-grained sediment in spawning and riffle-run areas was minimal, and any decreases did not increase HSI values. Although the percentage of fine-grained sediment was relatively large at stations 2 and 3, lack of winter and escape cover for fry was more important (table 5). Habitat at station 2 was also unsuitable for embryos due to lack of spawning gravel. Substrate at stations 2 and 3 was mostly clay, with some sand, silt, and detritus, and was a limiting variable for all life stages at these stations.

Swinns Valley Creek—Habitat for brook trout in Swinns Valley Creek ranged from nearly "average" to "good," with an overall habitat rating of slightly above "average" (table 3). Despite this model rating, no brook trout were found. Station 1 had the smallest HSI value and was limited primarily by the percentage of fine-grained sediment. When the average size of the fine gravel in spawning areas was assumed to be 1.6 cm and fine-grained sediment was set to optimal, the HSI value for station 1 increased by 30 percent (table 3). The overall HSI value for the creek increased slightly but was still "average" due to inadequate pool area and a predominance of fine gravel in spawning areas. Low minimum flow limited brook trout habitat at stations 2 and 3, and shallow thalweg depth was a limiting variable at station 3.

The overall HSI value for brown trout habitat in Swinns Valley Creek was "totally unsuitable" (table 4); however, habitat at station 3 was "average." The percentage of fine-grained sediment in spawning and riffle-run areas was relatively large at station 1 and was a limiting variable for embryos and fry. The dominance of fine-grained sediment in riffle-run areas was a limiting variable for all life stages at station 1, and large percentages of fine-grained sediment limited embryos at station 2. However, decreasing fine-grained sediment did not improve the HSI values for the stations or the overall HSI value because of the greater importance of other variables (table 4). Inadequate cover was the most important variable limiting adults at stations 1 and 2 and juveniles at station 2. Habitat for fry at station 2 was unsuitable due to lack of winter and escape cover (table 5). Fine-grained sediment was minimal at station 3, which was the only station where brown trout were collected from this creek. In addition, three age classes were found and indications of natural reproduction. This creek is managed as a forage fishery (Schreiber, 1991b) and is not stocked with trout. This information indicates that the HSI model predictions at station 3 did correctly assess station 3 as having the best brown trout habitat of all stations sampled on this creek and that it was suitable habitat.

Turton Coulee Creek—The HSI values for brook trout in Turton Coulee Creek stations ranged from "totally unsuitable" to "good," and the overall HSI value for the creek was "below average" (table 3). Percentage of fine-grained sediment in spawning and riffle-run areas was greatest at station 1, but decreasing fine-grained sediment did not change the HSI value for this station. Although a lack of winter and escape cover for fry and small juveniles was the major limiting variable at all stations, station 1 also was limited by a very large percentage of fine-grained sediment and a lack of gravel in spawning areas. Assuming the average size of fine gravel (not measured) was 1.6 cm, the HSI value at station 2 increased from 0.00 to "average" when fine-grained sediment in spawning and riffle-run areas was decreased to optimal values (table 3). The overall HSI value for the creek increased by 56 percent to achieve a nearly "average" rating. At stations 3 and 4, the percentages of fine-grained sediment were smaller, and decreases improved the HSI values by only 0.8 and 1.2 percent, respectively. However, the response curve for station 3 indicated a threshold at approximately 27 percent fine-grained sediment, above which the HSI value decreased to 0.00. Relative numbers of brook trout collected at the four stations in Turton Coulee Creek did support the model results for this stream. No trout were found at stations 1 and 2 where habitat was "totally unsuitable," and 14 and 12 brook trout were collected where habitat was rated approximately "good" and "average," respectively.

The overall HSI value for brown trout in Turton Coulee Creek was "totally unsuitable" (table 4) and no brown trout were found in the sampling at this creek. Intermediate-function values indicated that all stations lacked winter and escape cover for fry and station 1 also lacked spawning gravel (table 5). Inadequate pool area limited adults and juveniles at stations 1 and 3. Decreasing fine-grained sediment in spawning and riffle-run areas did not increase the HSI value for these stations or the creek overall (table 4).

Chippewa River Watershed

Como Creek—The habitat rating for brook trout for Como Creek was nearly "average" (table 3). Low minimum flow and inadequate winter and escape cover were the primary limiting variables. A large percentage of fine-grained sediment (sand) in both spawning and riffle-run areas was a secondary limiting variable. However, when the percentage of fine-grained sediment in spawning and riffle-run areas was decreased to optimal values, the HSI value for station 1 increased by 60 percent to "good" habitat (table 4). Nine brook trout were collected in 1991. This creek has historically had a reproducing population (K. Schreiber, WDNR, personal commun., August 1991).

The habitat rating for brown trout for Como Creek was "totally unsuitable" (table 4) and no brown trout were collected in 1991. Although habitat for adults and juveniles was "average," habitat for fry and embryos ranged from "below average" to "totally unsuitable" (table 5). Pool quality was the primary variable that limited adults and juveniles, and inadequate winter and escape cover limited fry. A large percentage of fine-grained sediment in spawning and riffle-run areas was also an important limiting variable for these life stages. Low minimum dissolved oxygen, 6.8 mg/L, was the dominant variable affecting embryos; low minimum dissolved-oxygen concentrations and a dominant substrate of sand and silt in riffle-run areas limited all life stages. For this reason, decreasing fine-grained sediment to an optimal value did not increase the HSI value for this creek (table 4).

Lowes Creek—The HSI values for brook trout at stations in Lowes Creek ranged from "totally unsuitable" to "average," and the overall HSI value for the creek was "below average" (table 3). No brook trout were found. Brook trout at all three stations were limited primarily by inadequate amounts of substrate for winter and escape cover as well as large percentages of fine-grained sediments throughout the sampled reaches, including spawning and riffle-run areas. Decreasing fine-grained sediment to an optimal value of 10 percent increased the HSI value at station 1 to "good," and the overall HSI value for the creek increased to "good." When fine-grained sediment was decreased to 10 percent at all stations, the overall HSI value for the creek increased to "good." At station 1, the response curve indicated a threshold value at approximately 18 percent fine-grained sediment, above which the HSI value was 0.00.

Habitat for brown trout at stations in Lowes Creek was "totally unsuitable," and the overall HSI value for the creek was also "totally unsuitable" (table 4). However, naturally-produced brown trout, including fingerlings, were collected from all sites in 1987. Winter conditions in 1986–87 were mild and may have provided favorable over winter conditions for fingerling and yearling trout (Doug Erickson, WDNR, written commun., March 1988). The HSI model indicated that poor quality of pools and a lack of substrate for winter and escape cover limited brown trout at station 1. At station 2, insufficient pool area, a large percentage of fine-grained sediment in riffle-run areas, and inadequate winter and escape cover were limiting variables. At station 3, the primary limiting variable was fine-grained sediment in riffle-run areas, and this is where the least number of trout were found. Low minimum dissolved-oxygen concentrations and a large percentage of fine-grained sediment in riffle-run areas were the primary variables affecting embryos at all stations. However, as mentioned earlier, dissolved-oxygen data for June were used in the HSI model because no data were available during embryo development (March through mid-April). It is possible that dissolved oxygen was not a limiting variable during embryo development. Decreasing fine-grained sediment to an optimal value at all stations did not substantially increase HSI values due to the importance of the other variables (table 3).

SUMMARY AND CONCLUSIONS

Habitat for brook trout and brown trout ranged from "unsuitable" to "good" at stations sampled in the 11 study streams. Results from the HSI models for brook trout suggest that fine-grained sediment was the primary limiting variable for brook trout at one or more stations in 8 of the 11 study streams. Although fine-grained sediment was not the primary limiting variable for brook trout in Otter and Warner Creeks, results from the HSI model suggest that an increase in fine-grained sediment would substantially decrease the habitat suitability for brook trout in Warner Creek. Lewis Valley Creek was the only study stream in which fine-grained sediment was the primary limiting variable for brown trout populations. Lack of winter and escape cover for fry was the primary limiting variable for brown trout at 20 of 33 stations and also limited brook trout at numerous stations. Other limiting variables for both species included inadequate pool area or quality, lack of instream cover and lack of trees and shrubs on streambanks for erosion control, low minimum flows, shallow thalweg depth, high maximum water temperatures, lack of spawning substrate, sand and/or silt as the dominant substrate in riffle-run areas, and low minimum dissolved-oxygen concentrations. The HSI values for brook trout were larger than those for brown trout at all but eight stations, where habitat was "totally unsuitable" for both species, suggesting that habitat at most stations was better suited to brook trout.

Except where stocking was likely, the HSI values were near "average" or better for those few stations where brook trout were collected. At Turton Coulee Creek, for example, the occurrence of brook trout at stations 3 and 4 but not at stations 1 and 2 was consistent with the HSI model output. The fact that most creeks did not have naturally-reproduced brown trout also was consistent with HSI model output indicating that habitat for early-life-stages was limiting. Brown trout, apparently naturally-reproduced, were found at the only station on Swinns Valley Creek where the HSI model output indicated "average" habitat and not at the other two stations where habitat was rated "totally unsuitable." At Lowes Creek, the only other creek where naturally-reproduced brown trout were collected, mild winter conditions might have mitigated the effects of limiting variables at stations 1 and 2 but not at station 3 where the fewest number of brown trout were found.

The two models differed in their sensitivity to fine-grained sediment impacts in the study streams. The brook trout model was more sensitive than the brown trout model and this likely reflects actual differences between the two species. Becker (1983) has suggested that brown trout are more tolerant than brook trout to turbidity, an indicator of the amount of suspended fine sediment in the stream.

HSI values for brook trout averaged slightly lower in the middle Trempealeau River watershed than the middle Kickapoo watershed. This may have reflected a higher percentage of agricultural land, especially cropland/grassland, in the middle Trempealeau River watershed. WDNR WIN analysis estimated a substantially greater upland sediment loading from cropland/grassland than from pasture (Wisconsin Department of Natural Resources, 1992a and 1992b). In the middle Kickapoo River watershed, creeks that had the lowest percentages of agriculture in their subwatersheds had better HSI ratings at most stations and overall when compared to the other creeks in the watershed. This relation was not found in the Trempealeau or Chippewa watersheds.

With regard to estimating sediment-reduction goals, an instream value of 20–25 percent fine-grained sediment on the stream bottom was generally optimum for most stations in our study and may be a reasonable instream goal to achieve. Pajak (1992) used HSI models to estimate sediment-reduction goals in the Milwaukee River watershed in Wisconsin. He found the models to be useful screening tools to generally assess which streams needed management action more then others and which habitat characteristics, such as fine sediment, were most limiting for fish species of interest in selected watersheds. Optimal values of fine-grained sediment projected by the models may be difficult or impossible to achieve in some watersheds. Projection of optimal fine-grained sediment percentages to subwatershed sediment-reduction goals is difficult without a great deal of assumptions, many of which may not be valid. It may be possible to develop a predictive relation between representative streams during installation of best-management practices (BMP's) in a watershed. It is not yet known how various BMP's quantitatively affect stream sediment delivery or retention.

Although the HSI models can be used to predict improvements in habitat suitability due to decreases in the percentage of fine-grained sediment on the stream bottom, the models do not attempt to relate sediment input or instream sediment transport to sediment that is present on the stream bottom. Other techniques and models exist that may be used to predict the effects of certain land uses on erosion and delivery of sediment to streams (for example, see Lisle and Hilton, 1991). Certain land uses such as logging, livestock grazing, and tillage have been shown to result in increased fine-grained sediment to the surface substrate of streams (Erman and Mahoney, 1983; Kauffman and Krueger, 1984; Armour and others, 1991). It is not yet possible, however, to make quantifiable determinations of how much a given change in sediment load will affect stream-channel morphology, flow conditions, and substrate (Lisle and Hilton, 1991) because a wide variety of factors influence the movement of sediment in streams (Beschta, 1987). There may be a poor relation between sediment supplied to the stream by upland erosion and sediment yield at the lower end of the basin (Trimble, 1981).

The USFWS HSI brown and brook trout models are useful and objective tools for identifying limiting variables and for assisting managers in prioritizing streams for management actions. This might include a determination of which streams should be nominated for priority watersheds. Although the time and cost required to measure all the chemical and physical variables included in the HSI models generally are prohibitive for most synoptic surveys, use of estimates or optimal values, as in this study, can allow for a general rating of habitat quality. Used in this manner, the HSI models could be valuable when time and funding constraints make it difficult, if not impossible, to make an in-depth examination of a large number of potentially limiting variables of all streams in a degraded watershed. Direct measurement and monitoring of fine-grained sediment in streams is difficult due to costly equipment and labor required for installation and retrieval. If a stream or stream reach is identified by HSI model as having sediment-related impacts, further study might include actual measurement of fine-grained sediment deposition in a number of pools and riffles along a reach and measurement of minimum and maximum flows during the year to see how the HSI value is affected.

Some modifications to the models are recommended in order to improve their utility for evaluating the effects of fine-grained sediment on brook trout and brown trout. Maximum values for percentage of sediment should be increased to 100 percent so that field observations could be input directly. Size categories in the models should be modified to reflect standard particle size categories (sand, silt, gravel, and so forth). Incorporation of embeddedness ratings should be considered. Detailed information of the life histories of the trout species in the study region is also necessary for correct input of data for seasonally affected variables. Fish-habitat-evaluation guidelines by Simonson and others (1994) include most brook trout HSI model parameters and are an additional reference for collection of accurate habitat data in Wisconsin streams. Finally, knowledge of habitat variability in a watershed is critical for selection of representative sampling sites (Frissell, 1986).

REFERENCES

Armour, C.L., Fisher, R.J., and Terrell, J.W., 1984, Comparison of the use of habitat evaluation procedures (HEP) and the instream flow incremental methodology (IFIM) in aquatic analyses: U.S. Fish and Wildlife Service Report FWS/OBS-84-11, Washington, D.C., 30 p.

Armour, C.L., Duff, D.A., and Elmore, W., 1991, The effects of livestock grazing on riparian and stream ecosystems: Fisheries vol. 16, no. 1, p. 7–11.

Avery, E.L., and Niermeyer, K., 1999, Timing of spawning and fry emergence of brown trout in a central Wisconsin stream: Transactions of the Wisconsin Academy of Sciences, Arts, and Letters, v. 87, p. 63–72.

Becker, G.C., 1983, Fishes of Wisconsin: University of Wisconsin Press, Madison, Wis., 1,052 p.

Berkman, H.E., and Rabeni, C.F., 1987, Effect of siltation on stream fish communities: Environmental Biology of Fishes, vol. 18, no. 4, p. 285–294.

Beschta, R.L., 1987, Conceptual models of sediment transport in streams *in* Thorne, C.R., Bathurst, J.C., and Hey, R.D., eds., Sediment transport in gravel-bed rivers: John Wiley and Sons Ltd., p. 387–419.

Bjornn, T.C., and Reiser, D.W., 1991, Habitat requirements of salmonids in streams *in* Meehan, W.R., ed., Influences of forest and rangeland management on salmonid fishes and their habitats: Special Publication 19, American Fisheries Society, Bethesda, Maryland, p. 83–138.

Brynildson, O.M., Hacker, V.A., and Klick, T.A., 1963, Brown trout, its life history, ecology, and management: Wisconsin Conservation Department Publication 234, Madison, Wis., 15 p.

Chapman, D.W., 1988, Critical review of variables used to define effects of fines in redds of large salmonids: Transactions of the American Fisheries Society, vol. 117, no. 1, p. 1–21.

Chutter, F.M., 1969, The effects of silt and sand on the invertebrate fauna of streams and rivers: Hydrobiologia, vol. 34, p. 57–76.

Cordone, A.J., and Kelly, D.W., 1961, The influences of inorganic sediment on the aquatic life of streams: California Fish and Game, vol. 47, no. 1, p. 189–228.

Crouse, M.R., Callahan, C.A., Malueg, K.W., and Dominguez, S.E., 1981, Effects of fine sediments on growth of juvenile coho salmon in laboratory streams: Transactions of the American Fisheries Society, vol. 110, no. 2, p. 281–286.

Erman, D.C., and Mahoney, D., 1983, Recovery after logging in streams with and without bufferstrips in northern California: California Water Resources Center Contribution No. 186, University of California, Davis, 50 p.

Frissell, C.A., Liss, W.J., Warren, C.E., and Hurley, M.D., 1986, A hierarchical framework for stream habitat classification—Viewing streams in a watershed context: Environmental Management, vol. 10, no. 2, p. 199–214.

Harshbarger, T.J., 1975, Factors affecting regional trout stream productivity *in* USDA (U.S. Department of Agriculture) Forest Service, Southeastern Forest Experimental Station, Proceedings of the Southeastern Trout Resource: Ecology and Management Symposium, Asheville, North Carolina, p. 11–27.

Hausle, D.A., 1973, Survival and emergence of young brook trout: Master's thesis, University of Wisconsin, Stevens Point, Wis., 66 p.

Hindall, S.M., 1976, Measurement and prediction of sediment yields in Wisconsin streams: U.S. Geological Survey Water-Resources Investigations 54–75, 31 p.

Holmstrom, B.K., and Erickson, R.M., 1990, Water resources data, Wisconsin, water year 1989: U.S. Geological Survey Water-Data Report WI–89–1, 436 p.

Holmstrom, B.K., Kammerer, P.A., Jr., and Erickson, R.M., 1991, Water resources data, Wisconsin, water year 1990: U.S. Geological Survey Water Data Report WI–90–1, 578 p.

Kammerer, P.A., Jr., and Batten, W.G., 1982, Sediment deposition in a flood-retention structure after two record floods in southwestern Wisconsin: Journal of Soil and Water Conservation, vol. 37, no. 5, p. 302–304.

Kauffman, J.B., and Krueger, W.C., 1984, Livestock impacts on riparian ecosystems and streamside management implications—a review: Journal of Range Management, vol. 37, p. 430–437.

Koski, K.V., 1966, The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams: Masters Thesis, Oregon State University, Corvallis, Oreg.

Lisle, T., and Hilton, S., 1991, Fine-grained sediment in pools—an index of how sediment is affecting a stream channel: U.S. Forest Service Pacific Southwest Region, FHR Currents, Fish Habitat Relationship Technical Bulletin 6, Eureka, Calif., 7 p.

Lyons, John, 1990, Appraisal-phase stream habitat sampling protocol—Priority Watershed Projects, Draft 1—June 1990: Wisconsin Department of Natural Resources, Madison, Wis., 19 p.

McFadden, J.T., 1961, A population study of the brook trout, *Salvelinus fontinalis*: Wildlife Monographs 7, 73 p.

Pajak, P., 1992, Developing integrated fisheries objectives for land and water resource management: The Milwaukee River Experience, *in* R.H. Stroud (ed.), Fisheries management and watershed development: American Fisheries Society Symposium 13, Bethesda, Maryland, p. 175–196.

Peters, J.C., 1965, The effects of stream sedimentation on trout survival *in* Seminar on Biological Problems in Water Pollution, 1962: U.S. Department of Health Education and Welfare, Public Health Service, Cincinnati, Ohio, p. 275–279.

Raleigh, R.F., 1982, Habitat Suitability Index models—brook trout: U.S. Fish and Wildlife Service, Biological Services Program and Division of Ecological Services, Biological Report FWS/OBS–82(10.24), Fort Collins, Colo., 42 p.

Raleigh, R.F., Zuckerman, L.D., and Nelson, P.C., 1986, Habitat suitability index models and instream flow suitability curves—brown trout: U.S. Fish and Wildlife Service, Division of Wildlife and Contaminant Research, National Ecology Center, Biological Report 82(10.124), Revised, Fort Collins, Colo., 65 p.

Ringler, N.H., and Hall, J.D., 1975, Effects of logging on water temperature and dissolved oxygen in spawning beds: Transactions of the American Fisheries Society, vol. 104, no. 1, p. 111–121.

Schreiber, Ken, 1991a, Middle Kickapoo River priority watershed water resource appraisal, final report: Wisconsin Department of Natural Resources, 16 p.

Schreiber, Ken, 1991b, Middle Trempealeau River priority watershed water resource appraisal, final report: Wisconsin Department of Natural Resources, 19 p.

____1992, Duncan Creek priority watershed surface water resources appraisal, final report: Wisconsin Department of Natural Resources, 19 p.

Simonson, T.D., 1993, Correspondence and relative precision of stream habitat features estimated at two spatial scales: Journal of Freshwater Ecology, v. 8, no. 4, p. 363–373.

Simonson, T.D., Lyons, John, and Kanehl, P.D., 1994. Guidelines for evaluating fish habitat in Wisconsin streams: General Technical Report NC–164, North Central Forest Experiment Station, USDA Forest Service, Rhinelander, Wis., 36 p.

Trimble, S.W., 1981, Changes in sediment storage in the Coon Creek Basin, driftless area, Wisconsin, 1853 to 1975: Science, vol. 214, p. 181–183.

Tschaplinski, P.J., and Hartman, G.F., 1983, Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival, Canadian Journal of Fisheries and Aquatic Sciences, vol. 40, p. 452–461.

U.S. Fish and Wildlife Service, 1980, Habitat as a basis for environmental assessment: U.S. Fish and Wildlife Service, Division of Ecological Services, ESM 101, Washington, D.C., 32 p.

____1981, Standards for the development of habitat suitability index models: U.S. Fish and Wildlife Service, Division of Ecological Services, Ecological Services Manual 103 ESM, Washington, D.C. [variously paged].

____1989, Micro-HSI version 2.1 software: Resource Evaluation and Modelling Section, National Ecology Research Center; U.S. Fish and Wildlife Center, Fort Collins, Colo.

Wang, Li, Simonson, T.D., and Lyons, J., 1996, Accuracy and precision of selected stream habitat estimates: North American Journal of Fisheries Management, v. 16, p. 340–347.

Waters, T.F., 1995, Sediment in Streams—Sources, biological effects and control: Monograph 7, American Fisheries Society, Bethesda, Maryland, 251 p.

Wesche, T.A., Goertler, C.M., and Hubert, W.A., 1987, Modified habitat suitability index model for brown trout in southeastern Wyoming: North American Journal of Fisheries Management, vol. 7, p. 232–237.

Wisconsin Department of Natural Resources, 1992a, A nonpoint-source control plan for the middle Trempealeau River priority watershed project. (Approved draft): University of Wisconsin Extension, Buffalo County Department of Land Conservation, and Trempealeau County Department of Land Conservation [variously paged].

____1992b, A nonpoint-source control plan for the middle Kickapoo River priority watershed project. (Approved draft): Monroe County Department of Land Conservation, Richland County Department of Land Conservation, Vernon County Department of Land Conservation, and Wisconsin Department of Agriculture, Trade, and Consumer Protection [variously paged].

APPENDIXES 1–2

Appendix 1. Locations of samples reaches for the 11 study streams in the Kickapoo, Trempealeau, and Chippewa watersheds of Wisconsin
[m, meters]

Stream Name	County	Township	Range	Section 1/4 Section	Reach Description
Middle Kickapoo River watershed					
Brush Creek					
1	Vernon	14N	2W	3NE	Hwy. 131 bridge; upstream 305 m
2	Vernon	14N	2W	4NW	Hoff Valley Road; upstream 305 m
3	Monroe	15N	2W	31SW	Valley Road bridge; upstream 305 m
4	Monroe	15N	3W	35SW	14th Drive first bridge; 92 m downstream, 213 m upstream
North Bear Creek					
1	Vernon	13N	2W	32NE/29SE	Hwy. 131 bridge; upstream 305 m (300 ft upstream of Kickapoo River)
2	Vernon	13N	2W	27SW	Hwys. 82 and D; downstream 305 m
Otter Creek					
1	Vernon	13N	2W	29SW	Hwy. 82 first bridge; downstream 305 m
2	Vernon	13N	2W	30NE	Off Puder Road, 305 m
3	Vernon	13N	3W	24SW	Hwy. 82 bridge; downstream 305 m
Warner Creek					
1	Vernon	14N	2W	35NW	Hwy. P first bridge east of Hwy. 131; upstream 305 m
2	Vernon	14N	2W	36SW	Hwy. P fourth bridge east of Hwy. 131; upstream 305 m
3	Vernon	14N	1W	33SE	Hwy 33; upstream 305 m from driveway culvert
4	Vernon	14N	1W	27SE	Fish Hollow Road; downstream 152.4 m from culvert
Middle Trempealeau River watershed					
Lewis Valley Creek					
1	Trempealeau	21N	9W	15SW	Private property; upstream 305 m
2	Trempealeau	21N	9W	6NW	Molitor Road bridge; downstream 244 m; upstream 61 m
Newcomb Valley Creek					
1	Trempealeau	21N	8W	32NW	Hwys. 95 and N; downstream 152.4 m; upstream 152.4 m
2	Trempealeau	21N	8W	32NE	Sorlie Road; private driveway; upstream 305 m
3	Trempealeau	21N	8W	33SW	Sorlie Road bridge and Hwy. 95; upstream 305 m
4	Trempealeau	21N	8W	33SE	Culvert on service drive; private property; downstream 305 m
Reynolds Coulee Creek					
1	Trempealeau	21N	7W	16SE	Hwy. 95 bridge; upstream 305 m through base of bridge
2	Trempealeau	21N	7W	29NE	Hwy 53; upstream 305 m; private driveway bridge
3	Trempealeau	21N	7W	29SE	Hwy. I bridge; upstream 305 m

Appendix 1. Locations of samples reaches for the 11 study streams in the Kickapoo, Trempealeau, and Chippewa watersheds of Wisconsin—Continued
[m, meters]

Stream Name	County	Township	Range	Section 1/4 Section	Reach Description
Swinns Valley Creek					
1	Buffalo	21N	10W	26SE/35NW	Off County Road C; upstream 305 m; private driveway
2	Buffalo	21N	10W	11SE	Hwy C and Kunkel Valley Road; upstream 305 m
3	Buffalo	21N	10W	10SE	Sobotta Valley Road bridge; upstream 305 m
Turton Coulee Creek					
1	Trempealeau	21N	9W	32NE	Masever Street behind school, 305 m
2	Trempealeau	20N	9W	3NW	Thompson Valley Road bridge, upstream 305 m
3	Trempealeau	20N	9W	11NE/12NW	Hwy. T bridge, upstream 305 m
4	Trempealeau	20N	8W	7NW	Burlington Road bridge, downstream 305 m
Chippewa River watershed					
Como Creek					
1	Chippewa	30N	9W	6SE	Hwy. 53 bridge drain: access off Hwy. Q; upstream 305 m
Lowes Creek					
2	Eau Claire	27N	9W	32SW	Hwy. F/East Lowes Creek Road bridge, downstream 305 m
3	Eau Claire	27N	9W	4NW	South Lowes Creek Road bridge, downstream 305 m
4	Eau Claire	26N	9W	4NE	Hwy. 94 bridge, upstream 305 m

Appendix 2. Suitability index variables for the brook and brown trout Habitat Suitability Index models and sources of data

[%, percent; m, meter; mg/L, milligrams per liter; m^3/s, cubic meters per second; cm, centimeter; cm/s, centimeters per second; °C, degrees Celsius. The notation 1991-T indicates that cross-sectional transects were used in the 1991 sampling. Kickapoo and Trempealeau watershed: WDNR, 1990; Chippewa watershed: USGS, 1991 (except WDNR data used for Lowes Creek data on nitrate-nitrogen, maximum water temperature, and minimum dissolved oxygen).]

	Variable	Data Source
a,b	Cover of trees on streambanks (%)	Field measurements (1991-T)
a,b	Cover of shrubs on streambanks (%)	Field measurements (1991-T)
a,b	Cover of herbs on streambanks (%)	Field measurements (1991-T)
a	Cover instream for adults – late growing season/low-water (%)	Field measurements (1991-T)
a	Cover instream for juveniles – late growing season/low-water (%)	Field measurements (1991-T)
b	Cover instream for adults and juveniles – late growing season/low water (%)	Field measurements (1991-T)
a	Depth of stream – mean thalweg (m)	Field measurements (1991-T)
a	Dissolved oxygen – average minimum (mg/L)	1990: optimal value; 1991: field measurements
b	Dissolved oxygen – minimum (mg/L)	1990: optimal value; 1991: field measurements
a	Fine sediment <3 mm in spawning areas (%)	Field measurements (1991-T)
a	Fine sediment <3 mm in riffle-run areas (%)	Field measurements (1991-T)
b	Fine sediment <3 mm in spawning/riffle-run areas (%)	Field measurements (1991-T)
a	Flow – mean annual (m^3/s)	Estimated from nearby USGS gaged streams
a	Flow – minimum during the year (m^3/s)	Single base flow discharge measurement
b	Flow – average annual base as percentage of average annual daily (%)	Estimated from nearby USGS gaged streams
b	Flow – average annual peak as multiple of average daily	Estimated from nearby USGS gaged streams
b	Nitrate-nitrogen – late-summer (mg/L)	1990: optimal value; 1991: field measurements
a,b	pH – minimum during the year	1990: optimal value; 1991: field measurements
a,b	pH – maximum during the year	1990: optimal value; 1991: field measurements
a,b	Pool area as percentage of total reach area (%)	Field measurements
a,b	Pool class rating (1, 2, or 3)	Field measurements
b	Productive stream? (yes/no)	Field measurements
b	Shading of stream (%)	Field measurements (1991-T)
a,b	Stability of streambank (%)	Field measurements (1991-T)
a	Substrate size – average size of components that are 0.3–8 cm diameter (cm)	Field measurements (1991-T)
a,b	Substrate – dominant type in riffle-run areas	Field measurements (1991-T)
b	Substrate for spawning, 1–7 cm (%)	Field measurements (1991-T)
b	Substrate for spawning, 0.3–1 cm and 7–10 cm (%)	Field measurements (1991-T)
a,b	Substrate for winter/escape cover, 10–40 cm (%)	Field measurements (1991-T)
a,b	Velocity – average over spawning areas (cm/s)	Optimal value
a	Water temperature – average maximum during warmest period of year (°C)	Field measurements
b	Water temperature – maximum during warmest period (°C)	Field measurements
a	Water temperature – average maximum during embryo development (°C)	Estimated from nearby USGS gaged streams for April through early May
b	Water temperature – maximum during embryo development (°C)	Estimated from nearby USGS gaged streams for April through early May
a,b	Water temperature – where dissolved oxygen measured (°C)	1990: optimal value; 1991: field measurements
b	Water temperature – maximum during the year (°C)	Field measurements
a,b	Width of stream – mean (m)	Field measurements (1991-T)

a Brook trout variable.

b Brown trout variable.