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Guidelines For Evaluating Fish Habitat in Wisconsin Streams

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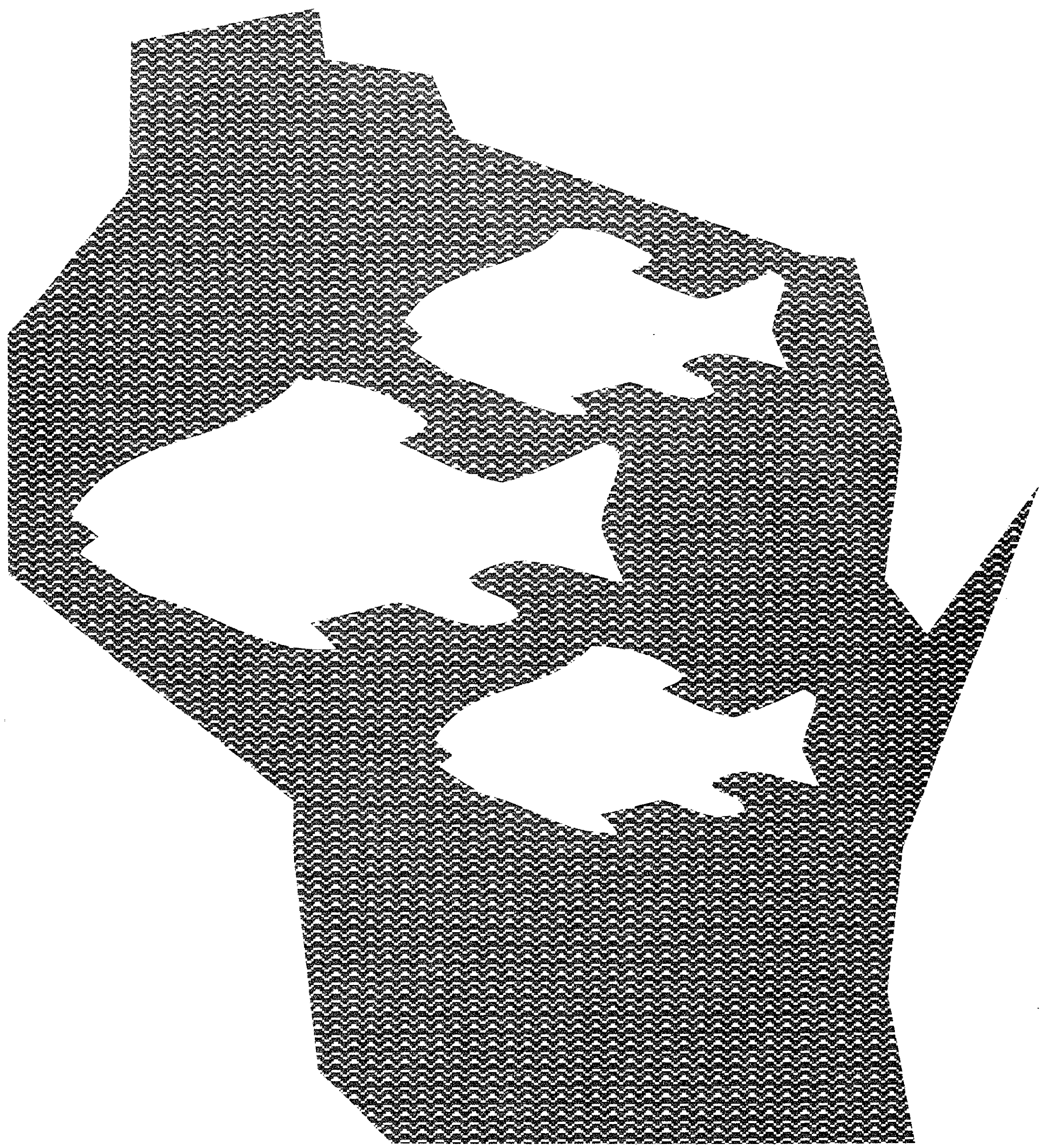

PREFACE

This manual is intended for use by biologists, resource managers, and field personnel when sampling fish habitat in streams in Wisconsin and nearby States. It contains a general protocol that can be used when conducting any stream habitat survey, evaluation, monitoring program, appraisal, or special project. Users should have a basic understanding and familiarity with stream habitat sampling techniques and variables. A bibliography of stream habitat sampling techniques, variables, and evaluations is included. Platts *et al.* (1983) attempted to "standardize" habitat evaluation procedures, and we have relied upon much of their information and definitions. If possible, users should take the time to review that publication.

Throughout this document, we have presented what we have found to be effective approaches to estimating various stream habitat variables, particularly those important for fish. We give preferences based on our research and experiences. This document is by no means the final word on habitat evaluation, and these guidelines may not provide the best approach for every situation. However, our goal was to begin to standardize habitat evaluations done in Wisconsin. Consistency in data collection will facilitate statewide comparisons of streams, will allow the development of statewide data bases of habitat evaluation data, and will foster cooperation among resource agencies and programs within these agencies.

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Guidelines For Evaluating Fish Habitat In Wisconsin Streams

Timothy D. Simonson, John Lyons, and Paul D. Kanehl

Aquatic habitat is generally recognized as all nonliving aspects of the aquatic ecosystem (Orth 1983), although living components (e.g. aquatic macrophytes) are also included. Stream habitat data are important because they largely determine potential fish species composition, abundance, and size/age structure (e.g., Gorman and Karr 1978, Binns and Eiserman 1979, Schlosser 1982, Lyons *et al.* 1988). The ultimate goals of stream habitat sampling are varied (e.g., to monitor habitat improvements, predict potential fish abundance or the success of introductions, identify limiting factors, etc.), but the immediate objective is typically to document the relative quality and/or quantity of habitat available for fish within a given segment of stream. Habitat measurements also allow the classification of streams into similar groups so that research results or management activities can be generalized. A "macrohabitat" assessment of physical habitat, the focus of this document, uses several values from a site to arrive at an overall picture of habitat conditions or availability for that segment. In contrast, a "microhabitat" assessment examines habitat features at several exact fish locations to arrive at the range of specific conditions used by the species of interest.

Given adequate chemical conditions such as pH, dissolved oxygen, and nutrients (Ryder and Kerr 1989), certain physical habitat features are particularly important in determining the occurrence and abundance of fish species at a given location within a stream. Current velocity, water depth, bottom substrate types, and cover are key habitat features, or variables, for most fish species (Fausch *et al.* 1988). Stream size, temperature, gradient, and bank conditions are also critical habitat features (Lyons 1989). Rankin (1989) and Lyons (1992a) found that substrate (type and quality), cover (type and quantity), channel features (sinuosity, development, modifications, stability), and pools or deep water (maximum depth, pool morphometry, velocity diversity) were strongly correlated with indices of biological integrity, which measure fish community health, structure, and function. Adjacent riparian features (width of riparian zone, quality, and bank erosion) were less strongly correlated with fish community integrity (Rankin 1989). Nonetheless, riparian conditions adjacent to and upstream of the site can have a profound influence (Vannote *et al.* 1980). Therefore, adjacent riparian conditions are usually determined, particularly in basin-wide evaluations (several sites within a watershed). The diversity or variety of these habitat features may be even more critical than the mean values for any single habitat feature, especially from the perspective of the fish community (Gorman and Karr 1978), and ultimately, biodiversity.

In measuring stream habitat quality and quantity, a set of key instream and channels variables are used to summarize general macrohabitat conditions for fish:

Stream feature

Stream size (e.g., width, drainage area, stream order, etc.)
Stream gradient
Stream temperature
Depth
Discharge
Substrate
Cover or shelter
Channel habitat units (e.g., pools, riffles, runs, etc.)
Bank erosion
Riparian conditions (e.g., adjacent land use, buffer width).

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These variables are measured or estimated within a representative stream segment. General conclusions about the stream segment's ability to support fish are then made. These conclusions can be applied to a larger segment of the stream, provided a sufficient number of representative sites are sampled.

PROJECT PLANNING AND OBJECTIVES

The objective of habitat evaluation is to document the relative quality or quantity of habitat available for fish. However, the sampling procedures used to attain that goal depend on the specific objective of the project. Before sampling methods are selected and a habitat evaluation is begun, a clear objective, or guestion to be answered, should be stated. Typical goals of habitat evaluations can be grouped into six major categories: **Status** (Is there a problem?), **Rating** (How bad is the problem?), **Monitoring/Trends** (Does the problem intensify or is it reduced over time?), **Evaluation** (Does the management approach reduce the problem?), **Prediction** (What might happen if the problem is intensified or reduced?), and **Research** (What factors cause the problems, and how can they best be reduced?).

The guidelines we present in this document can be used to meet all these major objectives with relatively high reliability. More- or less-intensive procedures than these may be used, depending on the accuracy and precision needed to achieve the objective. Accuracy, the correspondence between estimated and "true" values, is difficult to evaluate because "true" values are almost impossible to determine in natural systems (Platts *et al.* 1983). Bias, any consistent error in sampling that results in inaccuracy, is often caused by lack of randomization. Precision, the repeatability of a measurement technique, is better for systematic measurements or estimates made at a small spatial scale than for subjective visual "guesstimates" over a broad area. For example, depth of a stream reach can be rapidly estimated visually and may be accurate, but is subjective and depends on the experience of the observer. Estimates based on systematic measurements of depth within the reach will be more precise than visual estimates. Precision generally leads to accuracy, unless there is measurement bias (e.g., an improperly calibrated staff for measuring depth) (Sokal and Rohlf 1981). The objective should always include the spatial scale of interest and the level of accuracy and precision required.

When precise, defensible estimates are needed to substantiate management objectives, priorities, or effectiveness, the guidelines presented below should be used. However, if the objective of the study does not require a high level of precision, such as for reconnaissance surveys or identification of "good" or "bad" habitat conditions over a broad geographic area, then less intensive methods could be applied (e.g., Rankin 1989, Plafkin *et al.* 1989).

GUIDELINES

GENERAL SAMPLING PROCEDURES

Our habitat evaluation guidelines are designed for permanent, wadable [most areas < 1.2 m deep] streams that are large enough to support well-developed fish communities. More specifically, streams should be > 1.5 m wide with normal base flows > 0.03 m^3 sec^{-1} and watershed areas > 13 km^2. In Wisconsin, stations on many potential coldwater trout streams will be towards the low ends of these thresholds, whereas sites on warmwater streams may be much higher than these thresholds. Our guidelines should also be useful for streams that fall below these thresholds, but we have not tested them in such streams. Stations should have instream physical habitat, bank vegetation, and land-use characteristics typical of the stream segment of interest. This helps to ensure that results from the station can be more broadly applied. The entire station should be inspected before sampling to ensure that conditions are relatively uniform.

Mean stream width (MSW) is a very important characteristic of each station because it defines the length of the station and determines the spacing and boundaries of many habitat measurements. Mean stream width is based on the mean of at least 10 regularly spaced measurements of stream width taken from throughout the area of interest during the initial inspection. We define stream width as the width of the wetted surface of the stream, excluding islands, exposed bars, backwaters, and adjacent wetlands, measured from one bank to the other, perpendicular to the direction of the stream flow. Mean stream width should be determined at normal water level, i.e., near baseflow. If the actual water level is substantially above or below normal (0.15 m), then measurements should not be made. Once the MSW for a station has been determined, this value is used for all future habitat sampling, even if the MSW has changed. This ensures that the length of the station will remain constant over time.

A station should be approximately 35 times the MSW in length (Lyons 1992b). This approach provides progressively longer stations with increasing stream size. For streams with MSW less than 3 m, a minimum of 100 m, which is ≥ 35 MSW, should be sampled. If a stream has well-developed pool-riffle structure, then each station should start and end at the base of a riffle, even if stations must be somewhat longer than 35 times the MSW. Stations should not contain permanent tributaries or hydraulic controls (e.g., dams, bridge abutments, waterfalls), and should start and end at a distance of at least 10 times the MSW away from such features. Sampling a length of 35 MSW helps to ensure that the station is large enough to be representative of all habitat features within a longer segment of stream. Normally, at least three riffle/pool or two meander sequences will be sampled within a station 35 times the MSW (Leopold *et al.* 1964).

Habitat sampling should be conducted when streams are near baseflow. Summer is the most convenient time to sample, in terms of access and water clarity, although periods of floods, extreme low flows, ice formation, and acute toxic events may be more likely to limit aquatic ecosystems (Platts *et al.* 1983). Specific objectives of the habitat evaluation will dictate the time periods when sampling occurs.

Time of day for sampling is also an important consideration. Some habitat parameters, such as degree of shading, and air and water temperature, should be measured near midday to estimate maxima. Certain water quality features, such as dissolved oxygen and temperature, exhibit diel variation. Time of sampling for these parameters will vary with the objectives of the habitat evaluation, but should remain consistent among sampling locations or dates.

Parameters that are unlikely to vary substantially within a station, such as flow and water quality measures, need not be sampled repeatedly, but can be measured once, usually near the downstream end of the station.

The Transect Method

We recommend that habitat data be collected within the basic framework of the transect method (Platts *et al.* 1983). In general, **transects** are imaginary lines that span the stream from one bank to the other and are perpendicular to the flow. Various channel, stream bottom, or bank characteristics are measured or visually estimated along each transect. These transect assessments are repeated many times within a station to provide an overall picture of fish habitat. Transects, for our purposes, are just convenient reference points from which to take stream measurements. However, more detailed cross-sectional analyses can be done using permanently marked transects (e.g., Olson-Rutz and Marlow 1992).

Within each station, transects are established every two times the MSW, perpendicular to stream flow, with the first transect located one-half the MSW upstream from the downstream end of the station (Simonson *et al.*, unpublished data.). Subsequent transects are spaced 2 MSW's apart (fig. 1). Distances between transects are measured from the center of each transect in the stream. For example, for a 15-m-wide stream, the first transect would be 7.5 m from the downstream end of the station, and subsequent transects would be 30 m apart within a reach of 525 m. By spacing transects every 2 MSW in a station equal to or greater than 35 MSW in length, at least 18 transects will always be sampled regardless of stream size or the length of the station.

Stream habitat characteristics are measured at one or more of the following locations associated with each transect: (1) within a specified distance above and below the transect (**transect-reach** estimates), (2) along the transect (**transect-line** estimates), or (3) at positions along the transect-line (**transect-point** estimates) (fig. 1). We recommend estimating variables at the transect-point or transect-line scale rather than the transect-reach scale. It is usually faster, easier, and less subjective to estimate habitat variables within smaller transect-reach or transect-point areas versus larger transect-reach areas (Simonson, unpublished data).

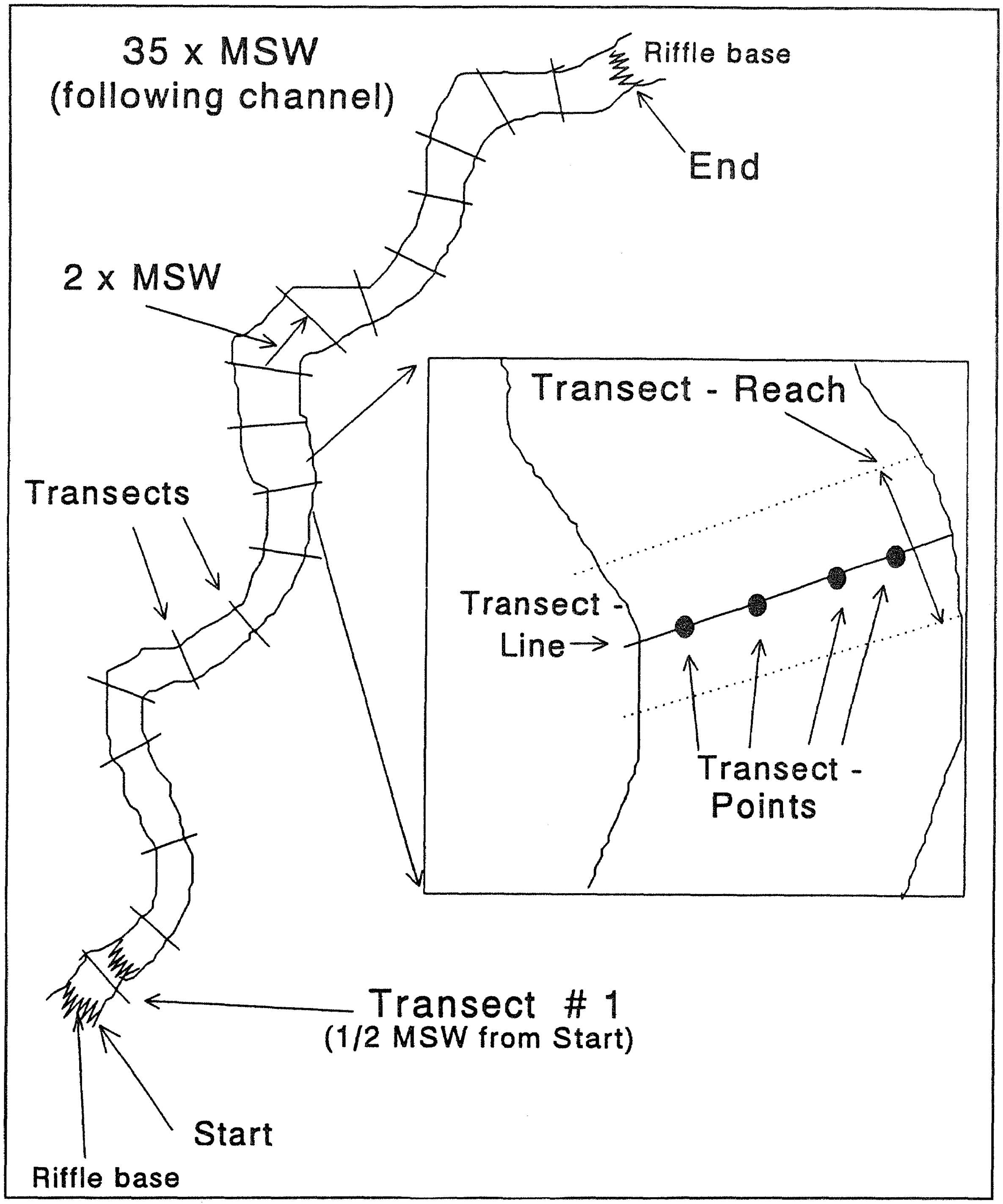

Figure 1.—*A typical stream reach, showing the start and end of a station (at the base of a riffle), and the location and spacing of transects within the station. A detailed view of a transect, showing the relative positions of the transect-reach and transect-points along the transect-line, is also shown.*

For transect-reach estimates, habitat conditions are estimated within a relatively large area centered on the transect. For example, the amount of gravel, visually estimated as the surface area within the transect-reach that is covered by gravel, is divided by the total surface area of the transect-reach to arrive at percent gravel. The surface area of the transect-reach can vary but is usually defined as the stream width at the transect times a specified distance (e.g. 2 m, 1 MSW, etc., but generally < 1 MSW) upstream and downstream from the transect. We recommend using a length of 5 m (2.5 m upstream and 2.5 m downstream) centered on the transect.

Transect-line estimates are made directly along the transect. For example, the actual length of gravel that intercepts the transect is divided by the total transect length (= stream width) to arrive at the percent gravel. In practice, we recommend making transect-line measurements within a narrow band (0.3 m wide) centered on the transect.

Transect-point estimates are made at several positions along the transect. We recommend four equally spaced points, with one additional position at the deepest point along the transect-line (the thalweg). In some instances, the deepest point will be located at one of the four equally spaced points, and thus the values will be the same. In other instances, the maximum depth of the channel may occur at two or more points. In this case, measurements should be made at the point of maximum depth that is closest to the middle of the channel. In practice, we make transect-point measurements within a small quadrate, or "plot," centered on the transect-point, rather than at an exact "point."

We recommend estimating each habitat type or class within the 0.3 m x 0.3 m quadrate centered on the transect-point (Simonson, unpublished data). For example, the area of gravel (m^2) within the quadrate would be divided by the total area of the quadrate (0.09 m^2) to obtain percent gravel. This procedure is repeated for each substrate category, and the sum of all substrate estimates within the quadrate would be 100 percent. This approach allows the flexibility of estimating all substrate categories (or other habitats) at each transect-point, and provides the greatest information in relation to effort (Wright *et al.* 1981). These data can easily be reduced to the dominant habitat, subdominant habitat, etc., later if desired. At each transect-point, several other methods may be used to estimate habitat variables. Occurrence of only the dominant habitat may be recorded at each point. For example, the number of points with gravel as the dominant substrate would be divided by the total points sampled to give percent gravel. A variation of this approach is to compute the Substrate Score (Crouse *et al.* 1981). At each transect-point, a score is recorded for the dominant substrate, subdominant substrate, size of fine substrate, and degree to which dominant substrate is surrounded or covered by fine substrate (embeddedness). These four values are summed to give the Substrate Score.

Other Methods

Other approaches available besides the transect method include **Site Assessments** and **Detailed Mapping**. The site assessment is a visual estimate that categorizes overall habitat conditions within the entire site based on a brief examination of habitat features (e.g., Rankin 1989). These assessments are qualitative and can be very subjective, but are easy to do, rapid, and relatively accurate (Hankin and Reeves 1988). However, precision of site assessments is usually low because observers generally are not consistent (Orth 1983). The transect method is also somewhat subjective, but less so than the site assessment method.

Another approach to estimating habitat in streams is to systematically map the entire reach of interest (Wright *et al.* 1981, Oswood and Barber 1982). This detailed mapping approach can be very time consuming. For example, a 50-m-long station can take up to 8 hours, even under good conditions, and can still be subjective (Wright *et al.* 1981). We recommend mapping only the habitat units (e.g., pools, bends, riffles, etc.) within each station to complement the transect sampling. Our mapping procedures are discussed in more detail under "Habitat Sampling Procedures."

Direct Measurements Versus Visual Approximations

Generally, most habitat features can be measured directly. For some variables, such as width, depth, and temperature, direct measurements are routinely made. However, for many variables, visual estimates are used as approximations due to time limitations or logistical constraints. For example, to estimate percent gravel, we could take several core or grab samples, sieve them through graded screens, and determine the percent of the samples composed of gravel. This might take several hours to complete. Alternatively, we could visually estimate the percent gravel covering the sampled areas. Such an estimate would require a few minutes at most; would require no equipment; would not disturb the site, which could be important if future sampling were planned at a station; and could be fairly accurate.

We evaluated the accuracy of visual substrate estimates made by six moderately to highly experienced observers through a comparison with direct measurements of substrate (Simonson and Lyons, unpublished data). Overall, most visual estimates were within 10 percent of the directly measured values, and heterogeneous habitats were estimated with more error than homogeneous habitats. On average, errors in visually estimating heterogeneous substrates were about 12 percent, while the errors associated with estimating homogeneous substrates were generally < 5 percent. Similarly, Crouse *et al.* (1981) obtained a high correlation (r = 0.96) between geometric mean particle size, based on time-consuming sieved core samples, and the Substrate Score, a visual estimate of substrate quality. Hankin and Reeves (1988) also found that visual estimates of habitat were similar to direct measurements. In summary, visual approximations of habitat features can provide relatively accurate estimates, provided observers are well trained and careful. Recently trained observers with no prior experience were generally as accurate as more experienced observers (Simonson and Lyons, unpublished data). Visual estimates, if systematically repeated at a spatial scale that is small relative to the reach of interest, will generally provide precise results.

Customized Evaluations

A typical habitat survey, following our guidelines, will take a trained crew about 2 to 4 hours to complete, depending on the size of the stream. Where limited resources prohibit a survey of this duration, portions of the survey may be streamlined. However, accuracy and precision are likely to be compromised, and the investigators' ability to identify changes in the habitat over time will be reduced.

One way to streamline the habitat survey is to sample fewer transects per station (Simonson *et al.*, unpublished data). We recommend sampling transects every 2 MSW, i.e., 18 transects, but our analyses indicate that sampling transects every 3 MSW, i.e., 13 transects, is sufficient on small streams (< 10 m wide) with no loss of accuracy. For medium to large streams (> 10 m wide), however, we do not recommend sampling fewer than 18 transects unless the habitat complexity is low (e.g., channelized streams, or streams with very little riffle/pool development), or the objectives of the project do not require robust estimates. In these cases, 13 transects spaced 3 MSW apart should be sampled.

The number of specific habitat variables, discussed in detail below, that are measured will influence the time and effort required for habitat surveys. Measuring only a subset of the recommended variables would reduce sampling time. This subset could be carefully chosen based on the specific goals of the habitat evaluation. For instance, if estimation of the effects of reduced sedimentation and improved bank stability are major objectives of a habitat evaluation, then variables such as percent embeddedness, substrate, bank erosion, and perhaps riparian land use might be measured. We recommend caution, however, when dropping variables from our recommended habitat evaluation. All the variables we recommend are key components of fish habitat. It requires much less effort to initially measure variables that may not seem directly relevant to evaluation objectives, than to have to repeat the field survey because a variable was incorrectly omitted from the first survey.

Photographic Documentation

An accurate series of photographs of the station is important for documenting habitat change that occurs over time. Photographs should be taken from the same point in the stream each time the station is sampled. If possible, successive photographs should be taken during similar light conditions and, depending on the time frame in which changes are being evaluated, at the same time of the day, month, year, etc. We photograph a data sheet bearing a description of the station first, so that subsequent photographs can later be identified as to location once the film is developed. Photographs taken at standard locations within the station should be described and recorded, along with their frame numbers. Two convenient locations, looking upstream at the station from the downstream end of the station and looking downstream from the upstream end of the station, are generally used. Additional locations, such as looking upstream from the upstream end of the station and looking downstream from the downstream end of the station, can be used to document conditions adjacent to the station (see example data sheet, Appendix table 1).

HABITAT SAMPLING PROCEDURES

A stream is made up of four components: the flood plain, the banks, the bed, and the water column (fig. 2). The stream proper is the column of water that is contained within the stream banks and covers the stream bed. The banks and bed together form the channel, while the flood plain and banks are generally thought of as the riparian zone (fig. 2). The banks are often difficult to identify but generally are defined as the portion of the channel that restricts the lateral flow of water. By convention, the channel, which includes the banks, is the portion of land that will contain flows with a recurrence interval of approximately 1.5 years or less (i.e., a 1.5-year flood).

We recommend a holistic approach in assessing stream habitat quality or suitability for fish at a station. This approach includes measuring a key set of habitat features important for both fish community structure and function (Rankin 1989, Hunt 1991, Lyons 1992a). These features include riparian conditions, channel morphology, substrate, cover for fish, and features of the stream proper, all described in detail below.

Riparian Conditions

Among riparian characteristics, bank condition usually has the most direct influence on the quality of habitat for fish. Well-vegetated banks are stable and resistant to erosion.

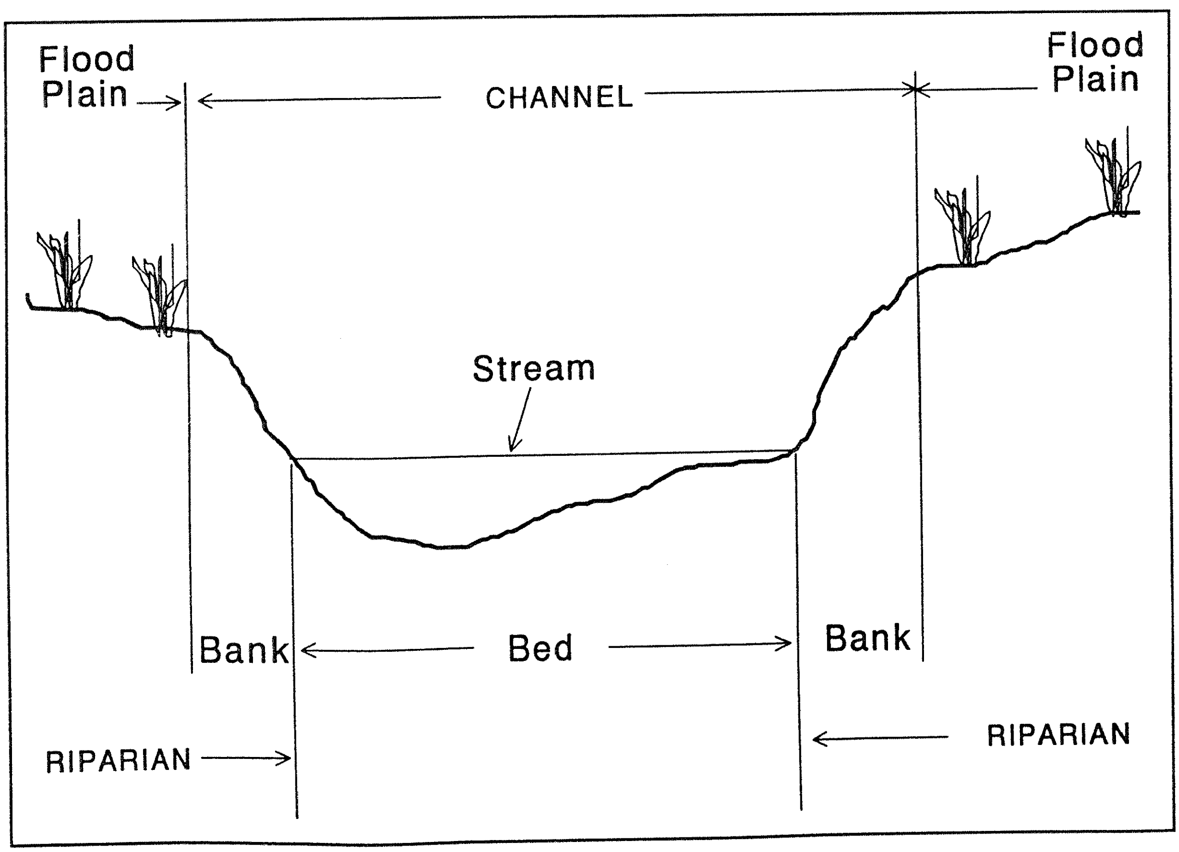

Figure 2.—*Typical stream cross section, showing the components of the channel and riparian zone (adapted from Platts* et al. *1983).*

They provide shading, which minimizes thermal stress from solar radiation, and overhead cover for fish, and serve as a source of woody debris, which can provide shelter for fish and their prey. A relatively wide (at least 10 m) buffer zone within the riparian corridor will protect and enhance stream fishes (Barton *et al.* 1985, Rankin 1989). Bank vegetation types and bank stabilities will usually reflect land uses in the riparian zone. Measurement of the types and amounts of land uses or vegetative cover can be made for the banks, for the riparian corridor, or for the flood plain. The specific riparian conditions we evaluate are as follows:

Riparian Land Use is the amount of various land uses on both banks. For this variable, we define "banks" as the land from the edge of the stream at normal water level to a point 5 m inland, following the contours of the land. This definition avoids confusion when identifying the actual banks, which can be difficult (Platts *et al.* 1983). There are generally two major types of potential land uses within the riparian zone. **Disturbed Land Uses** are unnatural, human-related uses, while **Undisturbed Land Uses** are characterized by relatively unaltered natural vegetation and soils. The type and age of the vegetation indicate how long the station has been undisturbed. Disturbed and undisturbed land uses can be broken down further into specific categories. A few common examples of the many possible land use categories, along with more detailed potential subcategories (underlined), are as follows:

Disturbed Land Uses

Agricultural - Includes land uses associated with rural crop or commodity production.

> **Cropland** - Land that is plowed and planted with <u>Rowcrops</u> and is harvested on a yearly basis, <u>Hayfields</u> that are regularly mowed, or <u>Orchards</u> that are intensively maintained and commercially harvested annually.
>
> **Pasture** - Land, either <u>Wooded</u> or <u>Open</u>, that is regularly grazed by livestock.
>
> **Barnyard** - Land that is used to confine and/or feed high densities of livestock; often referred to as feedlot. Usually contains little vegetation and large amounts of manure and mud.
>
> **Farmstead** - Buildings and other areas associated with a farming operation in a rural setting.

Silvicultural - Includes land uses associated with timber production.

> **Tree Plantation** - Lands where trees are grown for commercial use, including red or white pine plantations, Christmas tree farms, etc. Trees are generally planted in rows, are trimmed regularly, and have little underbrush.
>
> **Logged Woodland** - Lands where trees have been recently harvested. May include <u>Tree Plantations</u> that have been cut for pulp or Christmas trees, or otherwise wooded areas where obvious extensive tree cutting, brushing, or where <u>Clear Cuts</u> have occurred. Includes recently active <u>Unimproved Roads</u> used by logging vehicles.

Developed - Includes lands that have been modified for human use.

> **Commercial** - Buildings used for commerce or industry, including roads, <u>Parking Lots</u>, and other associated areas. Concrete, metal, or other non-natural <u>Revetments</u> along the stream are included. Usually situated in an urban setting.
>
> **Residential** - Houses and apartments and associated yards, roads, and <u>Parking Lots</u>. Includes individual houses and developments in urban, suburban, or rural settings.
>
> **Recreational** - Parks, playgrounds, golf courses, ball fields, and associated roads, <u>Parking Lots</u>, and other areas. Usually situated in an urban or suburban setting.
>
> **Right-of-way** - <u>Paved Roads</u>, heavily or regularly used <u>Unimproved</u> (unpaved) <u>Roads</u>, or active <u>Railroads</u> that do not occur in any of the other Developed Land uses. <u>Paved Paths</u> are considered a Developed Land Use, but unpaved trails, paths, horse trails, etc., < 2 m wide are not included.

Undisturbed Land Uses

Upland - Includes lands not greatly altered for human use that are in well-drained settings.

> **Meadow** - Land dominated by grasses, sedges, and forbs, with few woody plants; not subject to regular mowing or grazing.
>
> **Shrubs** - Land dominated by small (< 3 m high) woody plants, such as alders, honeysuckle, juvenile box elders, willows, etc.
>
> **Woodland** - Land dominated by trees, most of which are taller than 3 m. Includes Coniferous and Deciduous (Hardwood) Forests.

Wetland - Includes lands not greatly altered for human use in poorly drained settings that are covered with standing water for much of the year.

> **Swamp** - Low-lying forested land, either predominantly Coniferous or Deciduous Forests.
>
> **Shrub Marsh** - Low-lying land dominated by shrubs or small woody plants < 3 m high; covered by standing water for much of the year.
>
> **Open Marsh** - Low-lying land dominated by grasses, sedges, and forbs, with few woody plants.

Other - Includes undisturbed lands that can be found in either upland or wetland situations.

> **Exposed Rock** - Land covered by exposed bedrock outcrops, boulders, or other natural materials, or rip-rap or gabions along the banks.

Slumping or "cut" banks with little vegetation and exposed soil eroding into the stream are not considered a separate category, but are included with the land use found at the top of the bank. For example, an eroding, bare bank in an otherwise wooded area would be included as **Woodland** land use, while a severely eroding bank in a pasture would be included as **Pasture** land use. If a cut bank with a narrow band (≥ 1 m wide) of undisturbed land use (e.g., **Meadow**) at the top of the bank is followed by a disturbed land use (e.g., **Pasture**), the cut bank is included as **Meadow**.

Many other possible land use categories can be defined and evaluated. However, we have found that when many (up to 17) categories of land use are used, precision of these estimates among observers tends to be low, with 95 percent confidence intervals around the means that ranged from ±6 percent to ±30 percent. When fewer (< 10) categories were used (i.e., when some categories were combined), precision among individuals improved greatly; 95 percent confidence intervals around the means ranged from ±7 percent to ±13 percent. Most of our work has focused on evaluating streams affected by nonpoint source pollution in rural settings, so we have focused on the following categories, which were the result of combining or dividing the land use categories listed: **Cropland, Pasture, Barnyard, Developed, Meadow, Woody Vegetation (Shrubs** and **Woodland), Wetland,** and **Exposed Rock**. A good, all-purpose combination of categories useful for general surveys includes: **Agricultural, Silvicultural, Developed,** and **Undisturbed**. With the hierarchical organization of the various land use categories, some may be combined and others may be divided into more detailed categories, depending on the objectives of the habitat evaluation.

We visually estimate the percent of each **Riparian Land Use** category to the nearest 10 percent along the transect-line extended up the bank, following the contours of the land. This technique is rapid and fairly precise. A potentially more precise, but also more time-consuming method would be to measure the length of each land use category, following the contours of the land, to the nearest 1 m along the transect-line extended up the bank within 10 m of the stream. This length can be used to estimate the width of the riparian buffer strip (i.e., the width of undisturbed land uses, see below), and can be converted to a percentage by dividing its length by the total riparian corridor width (e.g., 10 m). For example, if the first 4 m from the water's edge along the transect-line were **Meadow** and the last 6 m of the corridor were **Pasture**, then 40 percent of the riparian zone would be **Meadow** and 60 percent would be **Pasture**; width of the riparian buffer (i.e., undisturbed land uses) would be 4 m.

Riparian Buffer Width is the length (m) of contiguous undisturbed land uses from the stream's edge out 10 m along the transect-line, following the contours of the land. If no undisturbed land uses are directly adjacent to the stream, then the riparian buffer width is 0 m; if undisturbed land uses are present from the stream edge to a point > 10 m, then the riparian buffer width is recorded as > 10 m. Riparian buffer widths ≤ 10 m from the stream should be measured to the nearest 1 m. We do not measure undisturbed land uses beyond 10 m, but for some studies it may be useful to do so.

Bank Erosion is the degree to which the stream banks are susceptible to the loss of material, particularly soil, when inundated by water (either from precipitation or from stream flow) or subject to heavy winds. Unstable banks supply sediment to the stream bed, provide poor conditions for plant growth, and provide little cover for fish (e.g., no undercuts or overhanging vegetation). Bank erosion can be estimated as a categorical variable at the intersection of the transect-line with the bank, e.g., record "bank erodible" or "bank stable." However, we recommend measuring the length of bare soil along the transect-line, within 1 m of the stream edge, extended up the bank. If there is no bare soil on the bank, then the length is 0 m. If bare soil is > 1 m up the bank, then the length is recorded as > 1 m. Lengths of bare soil > 0 m but < 1 m are measured to the nearest 0.1 m. For some studies, it may be useful to measure bare soil beyond 1 m from the stream edge. We also visually estimate the percentage of the bank along the transect-line that is bare soil. Determination of this percent bank erosion relies on an objective identification of the crest of the bank, which can be difficult in some streams. Visual estimates of percent bank erosion had excellent precision among individuals; 95 percent confidence intervals were generally less than ±5 percent. However, we did not test a very wide range of bank erosions, and we observed high among-year variability of bank erosion estimates. Platts *et al.* (1983) reported good precision among individuals (about ±3 percent) using a slightly different method, but they also found that year-to-year variability was high.

Shading is the degree to which the stream channel is shaded by vegetation and land formations (e.g., overhanging banks) at midday during the summer. Shading reflects the quality of the bank vegetation, and relates directly to the relative amount of solar radiation reaching the stream. We visually estimate this parameter to the nearest 10 percent within each quadrate at transect-points. Usually, the quadrate is either shaded (100 percent of the quadrate) or not shaded (0 percent of the quadrate). Precision of this variable among individuals, based on our data, was fair, with 95 percent confidence intervals ranging from about ±5 percent to ±17 percent.

We also estimate overhead canopy closure with a spherical forest densiometer (Lemmon 1956, Murphy *et al.* 1981, Platts *et al.* 1987) at each transect. The densiometer is a small, convex or concave mirror with a grid etched on its surface. The densiometer is held at a set distance above the stream, e.g., 0.3 m, and the number of squares in the grid containing obstructions to sunlight are counted. This number is divided by the total number of squares in the grid to arrive at the percent of the stream that is shaded. Densiometer readings should be made at each transect-point. This method will provide more objective and precise estimates than visual approximations of shade because densiometer readings of canopy will not vary with time of day.

Channel Morphology

Features of the stream channel reflect the health of the stream. For example, meandering channels (channels with many bends) tend to have a greater variety of habitats than artificially straightened channels, which generally have uniform conditions (Zimmer and Bachmann 1978). Diverse habitat generally supports more species, a greater variety of life-stages, and higher abundances of fish.

Habitat Units - Stream reaches are made up of a series of connected macrohabitat units (Frissell *et al.* 1986). These are relatively distinct longitudinal features of the stream, generally with lengths greater than the average channel width (Pearsons *et al.* 1992), that reflect differences in channel morphology. Visual determination of habitat units can be subjective, with poor precision, because they are rarely separated by clearly defined boundaries (Platts 1982). These macrohabitat components can be estimated as occurrence on the transect-line, or they can be mapped within the station. We do both, but obtain most of our information from mapping.

In mapping, we measure the length of each macrohabitat feature and its distance from the downstream end of the station. We also draw a diagram of the station and vicinity, showing the bends within and immediately upstream and downstream of the station, riffles within and immediately above and below the station, any runs, pools, islands, log jams, or dams within the station, and any specific habitat or environmental problems within or adjacent to the station. Definitions of some common macrohabitat units include:

Bends - Areas where the channel changes direction by at least 60 degrees. The outside of bends often have pools, which can have undercut banks if the bank vegetation is stable.

Riffles - Areas with shallower than average thalweg depths, obvious surface turbulence, and faster than average water velocities. In larger streams and rivers, deeper, faster riffles are called rapids. During high flows, some riffles may become runs. Generally, riffles are composed of coarse substrates and occur in relatively straight reaches between bends.

Runs - Areas with average thalweg depths and little or no surface turbulence. Water velocities may be fast or slow, but the water surface appears smooth. Generally, if it is not a riffle or a pool, we define it as a run. Shallow runs with slow, non-turbulent velocities are sometimes called glides. During droughts, shallow runs may become riffles. Runs tend to occur immediately upstream or downstream of riffles, but in some streams (e.g., channelized streams) runs can be a predominant macrohabitat.

Pools - Areas with deeper than average thalweg depths and little surface turbulence. Water velocities are always slow, and eddies are often present. The longitudinal profile of the stream bed in a pool is often bowl shaped, with wider than average widths. Pools usually occur at outside bends and around large obstructions to flow, with substrates of predominantly fine materials. "Pocket water" refers to groups of small pools located behind boulders or other obstructions, often in areas of otherwise fast or turbulent flow. Pocket water most commonly occurs in high gradient reaches of larger streams.

Islands - Areas of land between the stream banks that are surrounded on all sides by a substantial portion of the stream's water. We do not consider areas with nearly all the stream's flow on one side and just a trickle of water on the other to be islands. The number, position, size, and shape of islands may vary with water level. Islands must contain soil or numerous rocks; exposed sand or gravel/cobble bars are considered islands, but boulders that project above the water surface are not. Islands often occur at inside bends or in riffles.

Dams - Intentional structures (constructed by either humans or beavers) that, when in good repair, completely cross the stream channel and block flow. Usually, dams pool water behind them, and there is a sharp drop in water surface elevation at the dam.

Log Jam - A group of three or more large diameter (> 20 cm) intermingled logs partially or completely submerged in the channel that substantially alter stream flow and sedimentation patterns. When large and dense, log jams may be similar to intentional dams in their appearance and effect on the stream.

We use our map data to generate three summary statistics important for describing habitat quality and diversity. **Bend-to-Bend** ratio is the mean distance between the centers of adjacent bends, divided by the stream width. **Riffle-to-Riffle** ratio is the mean distance between the upstream end of one riffle and the downstream end of the next, divided by the stream width. **Sinuosity** is the distance between the upstream and downstream ends of the station following the stream channel, divided by the straight line distance between these two points. In some cases these statistics can be calculated from recent aerial photographs or topographic maps. These measures all reflect the morphological diversity of the channel. Another important feature derived from mapping the station is the percent of the stream in pools, or conversely, percent of the stream in riffles. When sufficiently deep, pools provide cover for fish, and their relative abundance also reflects the diversity of habitat. Riffles are important areas for the production of food and dissolved oxygen.

Stream Bed Features

Substrate refers to the materials that make up the stream bed. Substrate is important because it provides cover and spawning habitat for many fishes and benthic invertebrates. Substrate composition can be determined by a sieve method (Hamilton and Bergersen 1984) or visually estimated as a percent of the surface area of the stream bed. We recommend that each category of substrate be visually estimated to the nearest 5 percent at transect-points, within 0.3 x 0.3 m quadrates (Simonson, Unpublished data). Platts *et al.* (1983) record the dominant substrate type at 1-foot intervals along the transect. If the bottom cannot be seen, such as during above normal water levels or in turbid or stained water, hands and feet may be used to feel the stream bed. We use the following categories of substrate, modified from Platts *et al.* (1983) and Rankin (1989):

Bedrock - Solid, uniform rock bottom.

Large Boulder - Rocks with a maximum length of > 512 mm.

Small Boulder - Rocks with a maximum length of 256-512 mm.

Rubble/Cobble - Rocks with a maximum of 64-256 mm.

Coarse Gravel - Rocks with a maximum length of 16-64 mm.

Fine Gravel - Rocks with a maximum length of 2-16 mm.

Sand - Inorganic particles smaller than **Fine Gravel**, but coarser than **Silt**. The material typically found on a beach. Maximum length of 0.062-2 mm.

Silt - Fine inorganic particles, typically dark brown in color. Feels greasy and muddy in hands. Loose; does not retain shape when compacted into a ball. Will not support a person's weight when it makes up the stream bottom. Maximum length of 0.004-0.062 mm.

Clay - Very fine, inorganic, dark brown or gray particles; individual particles barely or not visible to the unaided eye. Feels gummy and sticky in hands; slippery when underfoot. Retains shape when compacted, and partially or completely supports a person's weight when it makes up the stream bottom. Maximum length of < 0.004 mm.

Detritus - Partially decayed organic matter such as leaves, sticks and tree branches, dead macrophytes, etc. When very fine, may appear similar to silt.

Marl - Deposits of calcium carbonate; often whitish in color. Individual particles very fine; sticky and muddy. Does not support a person's weight when underfoot; difficult to move through. Often found near springs and marshy areas.

These categories may be further subdivided (see Platts *et al.* 1983); however, precision among individuals is better with even fewer, broad categories, as long as they are relevant to the project and are believed to be biologically meaningful (Simonson and Lyons, Unpublished data). We usually combine small and large boulder into one category, termed **Boulder**. We also usually combine fine gravel and coarse gravel into one category, termed **Gravel**. Precision among different observers was better with seven broad categories than with nine more specific categories. In general, precision of the seven combined substrate estimates was good; all categories had 95 percent confidence intervals within ± 15 percent and most were within ± 10 percent (Simonson and Lyons, unpublished data).

Accuracy of substrate estimates made by several observers was not related to experience of the observer, but was influenced by substrate complexity (Simonson and Lyons, unpublished data). Recently trained personnel with no experience were as accurate or more accurate than personnel with moderate to extensive experience. Overall, 90 percent of substrate means for six different observers were within 10 percent of the "true" values. When the "true" value of a substrate was near 50 percent, the error in estimating it, on average, was highest (±4-12 percent), whereas for "true" values < 20 percent, the errors were, on average, lowest (±0-5 percent). This implies that heterogeneous substrates (two to four categories of similar abundance) are estimated with more error than are homogeneous (< four categories with one being dominant in abundance) substrates. We feel the observed level of error is acceptable and can be even lower with more intensive training. Regular review of sampling procedures will help maintain consistency among observers.

Embeddedness is the degree to which coarse gravel and rubble/cobble are surrounded by or covered with sand, silt, or clay. Embeddedness is an index of sediment deposition in the interstitial spaces of rocks, and high values negatively affect salmonids and other species (e.g., Crouse *et al.* 1981). High embeddedness is generally considered to be detrimental to the quality of stream habitat (Platts *et al.* 1983). Embeddedness values are only estimated for coarse gravel or rubble/cobble substrates; if these two substrates are absent, then embeddedness cannot be estimated. We visually estimate this parameter to the nearest 5 percent at transect-points within a 0.3 x 0.3 m quadrate. As a guide for estimation, if embeddedness is 100 percent, then rocks are completely buried by fine sediments. If embeddedness is 75 percent, then rocks are completely surrounded and half covered by fine sediment. If embeddedness is 50 percent, then rocks are completely surrounded by sediment, but their top surfaces are clean. If embeddedness is 25 percent, then rocks are half surrounded by fine sediment, and their top surfaces are clean. If embeddedness is 0 percent, then there is essentially no fine sediment surrounding or covering rocks. Do not confuse attached algae on rocks with fine sediment. Platts *et al.* (1983) reported fair to good accuracy and precision for this measurement and considered it fairly dependable. We found it to be fairly precise among individuals; 95 percent confidence intervals ranged from 12 to 16 percent. We have not evaluated the accuracy of embeddedness estimates.

Sediment Depth is the depth of fine sediments (usually sand and silt) that overlay or comprise the stream bed. Sediment depth, like embeddedness, is an index of sediment deposition. Sediment depth is measured to the nearest 0.01 m with a meter stick at four equally spaced points, and the deepest point, along transects. We have not evaluated the precision of sediment depth measurements among individuals. However, because sediment depth is actually measured rather than visually estimated, we suspect that it is often more objective and precise than embeddedness as an estimator of sediment deposition. However, in some instances deposition occurs only in the narrow crevices between rocks, and its depth cannot be easily measured. In these instances, embeddedness is a better measure of deposition.

Cover

Cover includes instream objects, channel features, or riparian/bank features that provide complete shelter from the current or visual isolation from predators or prey for fish. Cover can be an ambiguous feature, and its evaluation is subjective; no standard or commonly used method exists to quantify cover (Hamilton and Bergersen 1984). To reduce ambiguity and subjectiveness, cover should be clearly and explicitly defined (Kinsolving and Bain 1990). We specifically define cover as shelter for a fish that is at least 0.20 m in total length. In some studies, it may be useful to define cover differently (e.g., shelter for fish smaller than 0.20 m), in which case the dimensions used to specify cover will be different. To qualify as cover, potential cover features must be at least 0.3 m long, 0.3 m wide, 0.3 m high (equals about 1 cubic foot) and in or just above (≤ 0.1 m) water at least 0.3 m deep (other dimensions may be used but should be explicitly defined). We measure the length (m) of cover intersecting the transect-line (within 0.3 m). The percentage of the transect-line with cover is the length of cover divided by the length of the transect-line, or width of the stream, recorded to the nearest 1 percent. Cover can generally be visually estimated with good precision among individuals; 95 percent confidence intervals ranged from ±1.7 to ±7.9 percent along transects. Actual measurements of the objects that provide cover will be more accurate and precise than visual approximations of the surface area or percentage of cover. Other approaches for estimating and summarizing cover are also available (e.g., Kinsolving and Bain 1990).

Cover, as we define it, is generally an uncommon feature in most small to medium streams in Wisconsin. The sum of all cover types (see below) will typically equal less than 15 percent of the surface area of the reach, and cover may be missed entirely by transects. Therefore, if cover is an important component of the habitat survey, the surface area of all cover within the station can be measured and mapped, rather than estimated from transects. Some typical cover types are as follows (note that the depths and distances given all apply to normal water levels):

Undercut Banks - Banks that overhang the water by at least 0.30 m, at a point where the water is at least 0.30 m deep. To be considered cover, the bottom of the undercut bank must be no more than 0.10 m above the water surface.

Overhanging Vegetation - Thick vegetation overhanging the water that meets the above criteria for cover.

Woody Debris - Large pieces or aggregations of smaller pieces of wood (e.g., logs, large tree branches, root tangles) located in or in contact with water at least 0.30 m deep.

Other Debris - Pieces of human-made debris found in or in contact with water at least 0.30 m deep, that provide shelter or visual isolation for fish. Examples include old tires, abandoned farm implements, and discarded home appliances, although we do not encourage the intentional use of these to provide cover.

Boulders - Rocks that are ≥ 0.26 m long and that are located in or in contact with water at least 0.30 m deep. Large pieces of concrete and other artificial rocky aggregates also belong in this category.

Submerged Macrophytes - Vascular plants that normally have all or nearly all their biomass below the surface of the water. To count as cover, submerged macrophytes must be rooted in water at least 0.30 m deep and must be thick or dense enough to provide shelter or visual isolation for fish.

Emergent Macrophytes - Vascular plants that normally have a significant portion of their biomass above the surface of the water. To count as cover, emergent macrophytes must be rooted in water at least 0.30 m deep and must be thick or dense enough to provide shelter or visual isolation for fish.

Features of the Stream Proper

Physical Features

Stream Width, as defined earlier, is the wetted width (from water's edge to water's edge) of the stream, perpendicular to the flow, at the existing water surface. "Normal" stream width is an estimate of the width when the stream is at a stable base flow and is not subject to surface runoff or drought. If the water level is normal, then the "current" and "normal" stream widths should be the same. "Bankfull" or "channel" width is the width of the channel, generally measured from the high water mark on the lowest bank horizontally to a point of equal height on the other bank (fig. 1). We measure width to the nearest 0.1 m using a tape measure along the transect-line. Precision of width measurements among observers was excellent; 95 percent confidence intervals were within 0.14 m (±2 percent of the mean width). Platts *et al.* (1983) also reported good precision and accuracy for width measurements. However, bankfull widths were very imprecise, and are not recommended for general surveys due to the difficulty in determining high water marks in many situations.

Depth of the stream is the vertical distance from the stream bed to the water surface. This should be determined with a meter stick or calibrated wading staff at each transect-point, to the nearest 0.01 m. Precision of depth measurements among individuals was excellent; 95 percent confidence intervals were within 0.03 m (±6 percent of the mean depth). Platts *et al.* (1983) also reported good precision for this variable.

Velocity is the speed at which the water is moving downstream, expressed as a distance per unit time (e.g., meters per second). Velocity can be estimated several ways. The easiest method is to time the passage of a floating object (such as an orange) or a dye over a known stream reach. The standard method would be to use rotating-element (e.g. pygmy meter) or electronic current meters to measure velocity at a standard point in the water column. Velocity estimates based on several measurements within a station generally have high variability when considered over the entire length of a station, resulting in very imprecise overall means. We do not recommend routine transect-point measurements of velocity for macrohabitat assessments because of the length of time required and the low precision (Simonson and Lyons, Unpublished data). We do, however, recommend the estimation of flow at each site (see below), which does require velocity measurements. If average velocity of the site is needed, it can always be calculated later based on the flow. We have not evaluated the precision of individual velocity estimates among different observers, but it should be high if a current meter is used.

Flow (or discharge) is the volume of water moving downstream per unit time, and is the product of current velocity and the dimensions of the channel. Discharge data may be obtained for some larger streams directly from the U.S. Geological Survey. Determining streamflow at a station is outlined in detail by USGS (1980) and Platts *et al.* (1983). We recommend that flow be measured at one cross section within the station.

Stage is the elevation of the water surface above some known or arbitrary level. Stage can be used to estimate flow once a relationship between stage and discharge has been established at a site.

Water Level is a visual estimate of the relative stage of the stream. When the water level is "normal," the stream is assumed to be at or near baseflow. If areas of the stream bed are dry but look as if they would normally be underwater, then the water level is "below" normal; measure the vertical distance (meters) between the current water level and the normal water level. If the stream is flowing over or through areas that have terrestrial vegetation (e.g., grasses, forbs, willows, but not bulrushes and cattails) then the water level is "above" normal; measure the vertical depth of water (meters) above the normal water line. Sampling generally should not occur if the water level is > 0.15 m above normal. Note: Channel characteristics, rather than the amount of precipitation in the recent past, should be used to determine water level. Streams with large amounts of ground water input may retain normal flows well into drought periods. Conversely, such streams may show little response to heavy rains, particularly if the local water table has been greatly reduced by prolonged drought. On the other hand, streams that are dominated by runoff may fluctuate greatly in water level in response to short-term wet and dry periods.

Water Quality Features

Chemical characteristics of water are extremely important for fish. However, because our goal is to characterize physical habitat rather than water quality, we measure only a few parameters: dissolved oxygen, temperature, conductivity, and turbidity. Various other water quality parameters can be measured, depending on the objectives of the project. See APHA (1992) for a complete description of other water quality parameters that can be examined. Certain water quality features exhibit diel and seasonal fluctuations (e.g., dissolved oxygen and temperature), so continuous monitoring may be required if changes are to be documented over time (Steven Greb, WI Department of Natural Resources, personal communication).

Dissolved Oxygen (DO) is one of the most important water quality indicators for fish. Concentrations less than 5 ppm are considered harmful to most aquatic life. The amount of DO that can be held by water varies with temperature, pressure, and salinity. We measure DO with a high-quality oxygen meter, which is air-calibrated before every use, and regularly wet-calibrated against a Winkler determination. A measurement of DO at the time of habitat sampling is recommended; but to fully evaluate DO conditions that may be affecting fish, continuous DO monitoring is recommended due to seasonal, diel, and flow-event related variability. Manufacturer's instructions provide details on calibration. To measure DO, place the probe in the sample, raising and lowering the probe about 1 foot per second, and read the DO value from the appropriate scale in milligrams per liter (= parts per million). If you carefully follow the manufacturer's instructions, you can obtain an accuracy of $\pm$ 0.1 ppm DO and a precision of $\pm$ 0.05 ppm DO (Hamilton and Bergersen 1984).

Water Temperature has a profound effect on the occurrence of many fishes due to their preferences and ranges of tolerance. In Wisconsin, daily mean temperatures in coldwater streams rarely exceed 22 C and daily means in coolwater streams rarely exceed 24 C, but daily means regularly exceed 24 C in warmwater streams (Lyons 1992a). Water temperature is generally measured in the shade at mid-channel with a hand-held glass thermometer. Immerse the thermometer for at least 60 seconds before reading. If possible, measure during the warmest part of the day to estimate maximum values. Measure water temperature away from any large objects that project above the surface. Such objects may efficiently transmit heat and influence local water temperature. Avoid areas of the stream where subsurface or bank springs may be present. Accuracy of hand-held glass thermometers is about $\pm$1 percent (Hamilton and Bergersen 1984). If longer term temperature records are needed, maximum-minimum thermometers or continuous recording thermographs must be used.

Conductivity is the ability of a solution to carry an electrical current. It is often measured before electrofishing to estimate effectiveness. Conductivity is also highly correlated with total dissolved solids (TDS), and is roughly correlated with the concentration of many substances. Conductivity can be used as a crude measure of stream productivity. Measure with a high-quality electronic meter. Most meters have built-in automatic temperature compensation to 25 C (77 F), but this should be confirmed before using the meter. On some older meters, the temperature compensation must be set by hand; and on others, there is no compensation. For these latter meters, the conductivity at 25 C can be calculated using procedures outlined in APHA (1992). Whatever meter you use, calibrate it before every use. Measure in µmhos/cm or µS/cm.

Turbidity is a measure of the scattering and absorption of light by particles suspended in water. Increased turbidity can reduce photosynthesis, disrupt visual and filter feeding species, and at extremely high levels, can interfere with oxygen transport and injure the gills of fish. In streams, turbidity generally increases with discharge. We measure turbidity with a high-quality electronic meter, which is calibrated before every use, in nephelometric turbidity units (NTU's).

DATA MANAGEMENT AND ANALYSIS

Data collected in the field should be recorded on pre-printed data sheets specific to the project or evaluation (e.g., see Appendix A). We recommend that data, once collected, be entered and stored on a computerized relational data base. Many data base software packages are commercially available. We currently use PC-SAS (SAS 1985), which is relatively expensive but has excellent customized data entry screens, and provides more flexibility than other data base software in terms of data analysis.

REPORTING AND SUMMARY STATISTICS

Results of habitat surveys should be summarized and reported promptly, and permanent paper and electronic records should be maintained. Summaries of habitat data should be accompanied by specific locality information, including stream name (from U.S.G.S. 7.5-inch topographic map), county and nearest road crossing or other landmark, location within the Public Lands System (township-range-section), latitude and longitude, as well as waterbody identification number (a unique number assigned by the Wisconsin Department of Natural Resources to each stream) and station mile, the distance of the station upstream from the mouth of the stream, following the stream channel (Appendix A).

Other useful information about the station may be included with a summary of habitat data. This information includes stream gradient, sinuosity, stream order, basin area, and general channel condition (i.e., natural, straightened or concrete channel), all of which can be determined using recent U.S.G.S. 7.5-inch topographic maps (Appendix A).

The mean or median of each habitat variable collected over all the transects should be computed. Clearly state whether the mean or median is reported. In the case of variables that are measured or estimated at five points or quadrates along each transect, the five values should be averaged for each transect and then averaged for all 18 transects. For categorical data, the frequency of each category can be divided by total counts. For example, if 5 of 18 transects traverse pools, then 5/18 x 100 = 28 percent of the station is pool.

MODELS AND INDICES

Once habitat data have been collected, it is often useful to summarize the information beyond simple averages. For instance, many field personnel find it convenient to compute one value that represents the condition or quality of habitat at a station. This value makes it easier to compare several stations, and facilitates communication with other professionals and the public. This value is usually the result of inputting habitat data into a model or index. Many models of habitat "quality" or "suitability" are currently available. However, models should be used with caution if they were not specifically developed for use in Wisconsin. Regional differences in habitat (i.e., limiting factors or expectations of "good" habitat) can result in poor applicability of empirical models (e.g., Bowlby and Roff 1986, Fausch *et al.* 1988).

The Stream System Habitat Evaluation, developed by Ball (unpublished manuscript) and modified by Plafkin *et al.* (1989), is a widely used habitat evaluation procedure in Wisconsin. This rating procedure is rapid and relatively accurate; and it focuses on water quality, water resource values, and ultimately, stream classification, rather than on fish habitat. This rating system is similar to the Qualitative Habitat Evaluation Index (QHEI; Rankin 1989); and both are generally well suited for synoptic surveys, but generally are not quantitative enough for evaluating specific sites over time.

The Habitat Suitability Index (HSI) models of the U.S. Fish and Wildlife Service (USFWS) can be successfully applied as a tool to rate relative habitat quality and potential (Pajak 1992), although we recommend against using them to predict fish abundance or biomass. These HSI models generally were not intended for quick assessments of fish habitat (Terrell *et al.* 1982), and one disadvantage of them is that the variables needed are often difficult to obtain and require intensive and extensive data collection efforts. It is often possible to "guesstimate" values for these variables and use HSI models to make a general estimate of habitat quality. However, HSI models are species-specific, which limits their use to species with existing published models. Furthermore, HSI's may need to be modified for different regions. The HSI modeling approach is well suited for efforts to predict changes in fish habitat suitability based on modifications to key habitat variables. For further information on HSI models or the Habitat Evaluation Procedures (HEP), see Terrell *et al.* (1982). HSI models are available for 32 species that occur in Wisconsin streams: paddlefish (Hubert *et al.* 1984), gizzard shad (Williamson and Nelson 1985), pink salmon (Raleigh and Nelson 1985), coho salmon (McMahon 1983), chinook salmon (Raleigh *et al.* 1986a), rainbow trout (Raleigh *et al.* 1984), brown trout (Raleigh *et al.* 1986b), brook trout (Raleigh 1982), northern pike (Inskip 1982), muskellunge (Cook and Solomon 1987), common carp (Edwards and Twomey 1982a), common shiner (Trial *et al.* 1983b), blacknose dace (Trial *et al.* 1983a), longnose dace (Edwards *et al.* 1983), creek chub (McMahon 1982), longnose sucker (Edwards 1983a), white sucker (Twomey *et al.* 1984), smallmouth buffalo (Edwards and Twomey 1982b), bigmouth buffalo (Edwards 1983b), black bullhead (Stuber 1982), channel catfish (McMahon and Terrell 1982), flathead catfish (Lee and Terrell 1987), white bass (Hamilton and Nelson 1984), green sunfish (Stuber *et al.* 1982a), warmouth (McMahon *et al.* 1984a), bluegill (Stuber *et al.* 1982b), smallmouth bass (Edwards *et al.* 1982a), largemouth bass (Stuber *et al.* 1982c), white crappie (Edwards *et al.* 1982b), black crappie (Edwards *et al.* 1982c), yellow perch (Krieger *et al.* 1983), and walleye (McMahon *et al.* 1984b).

One of the most comprehensive and complex systems for evaluating fish habitat is the Instream Flow Incremental Methodology (IFIM). The IFIM uses hydraulic simulation models to evaluate the availability of depths, velocities, and substrates at a variety of flows (Orth and Maughan 1982). Based on the microhabitat preferences of the species of interest, the amount of usable habitat for that species is then determined at various flows. The microhabitat preferences of species are input as habitat suitability curves. Therefore, use of this technique is limited to species for which habitat suitability criteria are available. In addition, the voluminous amounts of hydraulic data and the detailed microhabitat data required to develop suitability criteria for this approach are beyond the scope of techniques discussed in this manual. The IFIM is best suited for evaluating the effects of altered stream flow regimes on fish habitat. Although this methodology is very sophisticated, there are still questions about its accuracy and general. utility. For example, habitat suitability criteria may not be universally applicable, and may need to be developed for site-specific use. For further information on this approach, see Bovee (1982) and Orth and Maughan (1982).

Fish Habitat Rating System

The Fish Habitat Rating (FHR) System consists of models we developed to provide a summary of habitat data and to compare the quality of fish habitat in streams and rivers throughout Wisconsin. At present, this system consists of two indices: one developed for small (< l0 m wide) streams, termed the Fish Habitat Rating - Streams (FHR-Streams), and one developed for small to medium rivers (10 - 50 m wide), termed the Fish Habitat Rating - Rivers (FHR-Rivers; formerly Warmwater Physical Habitat Rating, Lyons 1992a). Separate indices were developed because expectations of "excellent" habitat (i.e., natural, undisturbed conditions) vary with the size of the stream and longitudinal position in the river system. The physical conditions of streams tend to exhibit continuous, longitudinal changes (Vannote *et al.* 1980). Small streams (first to third order) are generally of higher gradient, with larger substrates, better developed riffle/pool sequences, and more shade than larger, downstream reaches (> third order). Small streams are strongly influenced by riparian vegetation and allochthonous nutrient and organic matter input, whereas small to medium rivers rely more on autochthonous algal and macrophyte production. This shift from heterotrophy to autotrophy occurs approximately at stream order 3, which roughly corresponds to stream widths of 5 - 10 m in Wisconsin. Although there is no distinct break between small streams and larger streams exactly at a width of 10 m, a transition from small to medium streams exists for widths from about 5 to 15 m in Wisconsin. For streams in this transition zone, we suggest calculating both ratings and reporting the highest score.

The two Fish Habitat Ratings are similar in some ways to the Stream System Habitat Evaluation (Ball, unpublished manuscript). However, the two Fish Habitat Ratings presented here can be more objective and precise because scores are normally based on systematic, quantitative field measurements. Also, the Fish Habitat Ratings were designed specifically to evaluate habitat for fish communities, as well as selected gamefish (mainly trout and smallmouth bass), whereas the Stream System Habitat Evaluation is a general rating used to evaluate attainable stream-use designations based on watershed and instream conditions. The FHR System falls somewhere between subjective, largely qualitative habitat indices (e.g., QHEI, Rankin 1989) and quantitative, but very data-intensive procedures (e.g., Instream Flow Incremental Methodology, Bovee 1982).

The FHR-Rivers was evaluated using the Wisconsin version of an index of biotic integrity (IBI, Lyons 1992a). The FHR-Rivers scores were correlated with IBI scores, which measure fish community health. The FHR-Streams is difficult to evaluate at this time because we do not currently have specific biological expectations for small streams in Wisconsin, particularly coldwater and coolwater streams. The FHR's are meant to provide a relative score of overall habitat quality for fish and to facilitate comparisons among streams, not to provide a precise value that can predict fish occurrence or abundance.

Fish Habitat Rating - Streams

The FHR-Streams was developed to meet a fairly specific need, namely, to objectively assess the relative condition of fish habitat in small (< 10 m wide) streams throughout Wisconsin. Small streams can be divided into two broad groups; coldwater trout streams and warmwater nongame (or forage) streams. This index was designed to evaluate habitat in both types of streams. The underlying assumption of this index is that habitat quality and diversity influence fish population and community structure and diversity. The FHR-Streams score is intended to rate the ability of the physical habitat to support a diverse, healthy fish community. Therefore, variables for the FHR-Streams were based on a composite of habitat requirements for several species found in small Wisconsin streams, but focused on trout because they tend to be the primary game species. Habitat features important for fish community health (e.g., those correlated with an Index of Biotic Integrity; Rankin 1989) are generally similar to conditions important for trout in small Wisconsin streams (Hunt 1991).

Variables in the FHR-Streams were based on the following metrics of the QHEI (Rankin 1989): substrate, cover for fish, channel features, riparian conditions, and pool/riffle quality. We selected specific variables representing components of these metrics that could be easily measured and that could be used to identify habitat features that may require management. Precise definitions, the corresponding QHEI metric, and optimum levels based on a composite of several sources, are described below.

The FHR-Streams form (fig. 3) provides a convenient means of summarizing and rating the selected habitat variables. Optimum levels are assigned the highest scores; less desirable habitat conditions are assigned progressively lower scores. For each habitat variable, potential levels are categorized as excellent, good, fair, or poor, with the corresponding score directly below the potential levels. For example, a mean **Bank Erosion** of 0.30 m indicates limited erosion, corresponds to a rating of good, and is given a score of 10. The scores of each variable are added to arrive at a total score, ranging from 0 to 100. An Overall Rating of poor, fair, good, or excellent can be assigned based on the total score, with 0 being worst and 100 being best.

Riparian Buffer Width - The width of the riparian zone comprised of contiguous undisturbed land uses (meadow, shrubs, woodland, wetland, or exposed rock). This variable corresponds to the QHEI riparian conditions metric, and is considered an important component of small "headwater" streams for shading and a source of allochthonous detritus (Vannote *et al.* 1980). A mean value of > 10 m is assumed to be optimal (Barton *et al.* 1985).

Bank Erosion - The length of the bank (within 1 m of the water) that is bare soil (essentially, susceptible to, or shows evidence of, loss of material). This variable corresponds to the QHEI riparian conditions metric, and is an indicator of stream channel and flow stability, and availability of local fine sediment to the stream bed. A mean value < 0.20 m is assumed to be optimal. This corresponds to < 10 percent of the bank susceptible to erosion (bare soil), assuming an average bank height of 2 m for streams < 10 m wide.

Pool Area - The percentage of the stream length in pools. This variable corresponds to the QHEI pool/riffle quality metric, and is indicative of shelter/resting cover for fishes, particularly predators or other large fish. A pool area of 40 percent to 60 percent is assumed to be optimal (McMahon 1982; Raleigh 1982; Stuber *et al.* 1982a; Trial *et al.* 1983a, 1983b; Raleigh *et al.* 1984; Twomey *et al.* 1984).

Width-to-Depth Ratio - The average width divided by the average thalweg (maximum) depth of run and pool habitats. This habitat feature corresponds to the QHEI pool/glide and riffle-run quality metric, and is indicative of whether the stream is relatively deep and narrow or shallow and wide. An optimum value of ≤ 7 was selected (Ball, unpublished manuscript) and corresponds to an average thalweg depth in run and pool habitats of about 1.2 m for 10-m-wide streams and an average thalweg depth of about 0.25 m in runs and pools of 2-m-wide streams. Optimal width-to-depth ratios were < 17 for brook trout (Raleigh 1982), but 4 to 14 for creek chub (McMahon 1982).

Riffle-to-Riffle or Bend-to-Bend Ratio - The average distance between riffles or between bends divided by the average stream width. The option of using either bends or riffles allows the rating of low gradient streams with very few riffles. If you can calculate both ratios, use the better of the two scores on the rating form. Bend-to-Bend Ratio can sometimes be determined from recent aerial photographs. This variable corresponds to the QHEI channel features metric, and is an indicator of habitat diversity. An optimum value of ≤ 7 was selected for this variable (Ball, unpublished manuscript).

Fine Sediments - The percentage of the stream bed made up of sand, silt, and/or clay. This variable corresponds to the QHEI substrate metric. Fine sediment is detrimental for spawning, available shelter, and food supply of

Stream: ______________________ Waterbody ID: __________ Station: ______ Site Mile: ________

Year: _______ Month: _______ Day: _______ Personnel: ______________________

Total Score: ____________ Qualitative Rating: ______________________

Rating Item	Excellent	Good	Fair	Poor	Score
Riparian Buffer Width (m), width of contiguous undisturbed land uses; meadow, shrubs, woodland, wetland, exposed rock	Riparian zone well protected; buffer wide (> 10.0 m) 15	Riparian zone protected, but buffer width moderate (5.0-10.0 m wide) 10	Riparian zone moderately disturbed, buffer narrow (1.0-4.9 m) 5	Most of the riparian zone disturbed, buffer very narrow or absent (< 1.0 m wide) 0	
Bank Erosion, (width of bare soil on bank, along transects)	No significant bank erosion; < 0.20 m of bank is bare soil 15	Limited erosion; 0.20-0.50 m of bank is bare soil 10	Moderate erosion; 0.51-1.0 m of bank is bare soil 5	Extensive erosion; > 1.0 m of bank is bare soil 0	
Pool Area, % of stream length in pools	Pools Common; wide, deep, slow velocity habitat, balanced by other habitats; 40 to 60% of station 10	Pools present; not frequent or over-abundant; 30 to 39% or 61 to 70% of station 7	Pools present, but either rare or overly dominant, few other habitats present; 10 to 29% or 71 to 90% of station 3	Pools either absent or dominant, not balanced by other habitats; < 10% or > 90% of station 0	
Width:Depth Ratio, average stream width divided by average thalweg depth in runs and pools	Stream very deep and narrow; width/depth ≤ 7 15	Stream relatively deep and narrow; width/depth 8-15 10	Stream moderately deep and narrow; width/depth 16-25 5	Stream relatively wide and shallow; width/depth > 25 0	
Riffle:Riffle or Bend:Bend Ratio, average distance between riffles or bends divided by average stream width	Diverse habitats; meandering stream with deep bends and riffles common; ratio < 10 15	Diverse habitats; bends and riffles present, but not abundant; ratio 10 to 14 10	Habitat diversity low; occasional riffles or bends, ratio 15 to 25 5	Habitat monotonous; riffles or bends rare; generally continuous run habitat; ratio > 25 0	
Fine Sediments, % of the substrate that is < 2 mm (sand, silt, or clay)	Fines rare or absent, < 10% of the stream bed 15	Fines present but limited, generally in stream margins or pools; 10 to 20% of stream bed 10	Fines common in mid-channel areas, present in riffles and extensive in pools; 21 to 60% 5	Fines extensive in all habitats; > 60% of stream bed covered 0	
Cover for Fish (% of the stream area with cover)	Cover/shelter for fish abundant; > 15% of stream 15	Cover common, but not extensive; 10 to 15% of stream 10	Occasional cover, limited to one or two areas; 5-9% of stream 5	Cover rare or absent; limited to < 5% of stream 0	

Qualitative Ratings: Excellent ≥ 75; Good 50 to 74; Fair 25 to 49; Poor < 25

Total Score: __________

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Figure 3.—*Form used to characterize the quality of physical habitat in small (< 10 m wide) streams, based on the Fish Habitat Rating System.* ***Waterbody ID*** *- A unique seven-digit identification code assigned to each stream, river, and lake in Wisconsin.* ***Site Mile*** *- The distance in miles (via the stream channel) between the mouth of the stream and the down-stream end of the site.*

fish. Fine sediment, rather than rocky substrate, was used because it directly addresses substrate problems in small streams. An optimum value of < 10 percent was chosen. The HSI models for brook trout (Raleigh 1982), rainbow trout (Hickman *et al.* 1984), and brown trout (Raleigh *et al.* 1986b) all suggest that < 10 percent silt and sand is optimal.

Cover For Fish - The percentage of the stream area having shelter for fish. This variable measures the abundance of physical objects that provide shelter for trout or other large fish, in addition to deep, slow velocity habitat measured by Pool Area. An optimum of ≥ 15 percent of the stream area was selected for this variable based on our observations in small Wisconsin streams, which was much lower than in other habitat rating systems (e.g., Rankin 1989, Binns and Eiserman 1979, Twomey *et al.* 1984). However, cover was generally not explicitly defined in these ratings in terms of size of cover or depth of water.

Fish Habitat Rating - Rivers

The FHR-Rivers was developed specifically to evaluate the relative quality of habitat in small to medium rivers (10 - 50 m wide). In Wisconsin, these rivers are generally warmwater, and thus this rating was developed to address habitat requirements of warmwater fishes. The rating focused on smallmouth bass because they tend to be the predominant gamefish in many small to medium rivers. A high FHR-Rivers score reflects habitat capable of supporting a balanced, healthy fish community (Lyons 1992a).

The FHR-Rivers form (fig. 4) provides a convenient means of summarizing and rating habitat data. Optimum levels were assigned excellent ratings; less desirable habitat conditions were assigned progressively lower scores. For each habitat variable, potential levels are described as excellent, good, fair, or poor, with corresponding score ranging from either 0 to 12 or 0 to 25, depending on the variable. For example, a mean **Bank Stability** of 95 percent corresponds to a rating of excellent and would be given a score of 12. The scores of all variables are summed to arrive at a total score. An overall rating of poor, fair, good, or excellent can be assigned to the station based on the total score, with 0 being worst and 99 being best.

The structure and variables of the FHR-Rivers are similar to those of the FHR-Streams. Some variables or optimum conditions differ to reflect changing expectations of excellent habitat with larger stream size.

Bank Stability - The percentage of the bank that is protected by stable rock or vegetation and not susceptible to, or shows evidence of, loss of material, particularly soil. This variable corresponds to the QHEI riparian conditions metric, and is an indicator of stream channel and flow stability, and availability of local fine sediment to the stream. A value of > 90 percent was assumed to be optimal.

Rocky Substrate - This corresponds to the **Fine Sediments** variable of the FHR-Streams. The optimal level, 65 percent, reflects the importance of rocky substrate to smallmouth bass (Lyons 1991). Under natural conditions, larger streams tend to have smaller sediment sizes than smaller streams, and large substrate becomes increasingly important as stream size increases.

Cover for Fish - This is the same variable included in the FHR-Streams. An optimal value of ≥ 12 percent was selected. This is somewhat lower than the optimum value selected for the FHR-Streams because, although larger streams can have larger amounts of debris and macrophytes, abundant cover should generally make up a greater proportion of the surface area of small streams.

Maximum Thalweg Depth - The average of the four deepest depths, measured throughout the station. This variable corresponds to **Width-to-Depth Ratio** in the FHR-Streams. An optimal value of ≥ 1.5 m was selected because this was considered an important component of smallmouth bass habitat (J. Lyons, unpublished data). Depths of 1.5 m are unlikely in small streams, thus a ratio of width to depth was used.

Riffle-to-Riffle or Bend-to-Bend Ratio - This is the same variable that was included in the FHR-Streams, except that the optimal value selected, ≤ 12, is somewhat higher than for small streams. Larger streams tend to be lower in gradient, riffle/pool development, and sinuosity than smaller streams.

Fish Habitat Rating - Rivers
(> 10 m wide)

Stream: ______ Waterbody ID: ______ Station: ______ Site Mile: ______

Year: ______ Month: ______ Day: ______ Personnel: ______

Total Score: ______ Qualitative Rating: ______

Rating Item	Excellent	Good	Fair	Poor	Score
Bank Stability (% of bank protected by rock or vegetation)	No significant bank erosion; ≥ 90% of bank protected; < 10% bare soil	Limited erosion; 70 to 90% of bank protected; 10-30% bare soil	Moderate erosion; 50 to 69% of bank protected; 31-50% bare soil	Extensive erosion; <50% of bank protected; > 50% bare soil	
	12	8	4	0	
Maximum Thalweg Depth (average of the four deepest depths recorded)	Stream very deep; ≥ 1.5 m	Stream relatively deep; 1-1.5 m	Stream moderately deep; 0.6-0.9 m	Stream relatively shallow; < 0.6 m	
	25	16	8	0	
Riffle:Riffle or Bend:Bend Ratio (average distance between riffles or bends divided by average stream width)	Diverse habitats; meandering stream with deep bends and riffles common; ratio ≤ 10	Diverse habitats; bends and riffles present, but not abundant; ratio 10 to 14	Habitat diversity low; occasional riffles or bends, ratio 15 to 25	Habitat monotonous; riffles or bends rare; generally continuous run habitat; ratio > 25	
	12	8	4	0	
Rocky Substrate (% of the substrate, by area, that is bedrock, boulder, rubble/cobble, or gravel)	Extensive rocky substrate; ≥ 65% of the stream bed	Moderate rocky substrate; 45-65% of stream bed	Limited rocky substrate; 15-44% of stream bed	Rocky substrate uncommon; < 15% of stream bed	
	25	16	8	0	
Cover for Fish (% of the stream area with cover)	Cover/shelter for fish abundant; ≥ 12% of stream	Cover common, but not extensive; 7-12% of stream	Occasional cover, limited to one or two areas; 2-6% of stream	Cover rare or absent; limited to < 2% of stream	
	25	16	8	0	

Total Score: ______

Qualitative Ratings: Excellent > 80; Good 60 to 80; Fair 20 to 60; Poor < 20.

Figure 4.—*Form used to characterize the quality of physical habitat in small to medium rivers (> 10 m wide), based on the Fish Habitat Rating System.* ***Waterbody ID*** *- A unique seven-digit identification code assigned to each stream, river, and lake in Wisconsin.* ***Site Mile*** *- The distance in miles (via the stream channel) between the mouth of the stream and the downstream end of the site.*

The FHR System does not currently address all conditions and stream types encountered within the state. For instance, large (>10 m wide) coldwater streams are not specifically addressed. However, these streams are relatively rare in Wisconsin, and the FHR-Rivers should work well for them. Another situation encountered in Wisconsin is very low gradient (marsh/swamp drainage) streams, where bottoms are naturally soft, channels are sometimes poorly defined, and the predominant gamefish is often northern pike. The FHR System does not effectively evaluate this kind of habitat, mainly because expectations of excellent habitat in low gradient streams are poorly understood.

No one index or rating will work perfectly in every situation. However, inherent biases associated with a habitat rating will be consistent, so a rating can provide a relative basis for comparisons among stations or at a station over time. One value of using an index is that habitat variables contributing to a poor rating are isolated and can be targeted for management. Finally, an index should not be expected to stand alone, but should be used in conjunction with all available information from the station to arrive at conclusions about the quality of the habitat at a site.

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GLOSSARY

Algae.—Simple plants, mostly microscopic, that form the base of the food chain in aquatic environments.

Allochthonous.—Food organisms, organic matter, and nutrients, usually terrestrial, originating outside and transported into an aquatic system.

Alluvial stream.—Named for the SEDIMENTS of river origin that compose the BED, BANKS, and FLOOD PLAINS. Alluvial streams are characterized by a distinctive S-shaped CHANNEL pattern that is free to shift slowly (MEANDER) in its valley.

Alluvium.—A general term for all SEDIMENTS transported and deposited by streams.

Area.—The quantitative measurement of the surface of an object.

Autochthonous.—Materials, such as nutrients or organisms, that are generated or originate within the aquatic system.

Bank.—The portion of the CHANNEL that restricts lateral movement of water at normal water levels. The bank often has a gradient steeper than 45° and exhibits a distinct break in slope from the stream BED. Also, an obvious change in the SUBSTRATE materials may be a reliable delineation of the bank.

Bankfull discharge.—The maximum FLOW that can be accommodated within the CHANNEL without overtopping the BANKS and spreading to the FLOOD PLAIN.

Bar.—A submerged or exposed accumulation of ALLUVIAL material formed in the CHANNEL, along the BANKS, or at the mouth of a stream where a decrease in VELOCITY induces DEPOSITION.

Base flow.—Stable DISCHARGE of a stream at normal water level; drought or runoff from precipitation is not affecting FLOW.

Bed.—The bottom of a lake, stream, or other body of water.

Bedrock.—Solid, uniform rock layer making up the BED or BANKS.

Bend.—Area where the CHANNEL changes direction by at least 60°. Outside bends are generally POOLs, which can have UNDERCUT BANKS if the BANK vegetation is stable.

Boulder.— Rocks that are ≥ 0.26 m long. Large pieces of concrete or other artificial rocky aggregates of this size are also considered boulder.

Braided.—A stream that divides into an interlacing or tangled network of several branching and reuniting CHANNELS separated from each other by ISLANDS or BARS.

Buffer.—Naturally vegetated strip maintained along a stream to mitigate the effects of actions on adjacent lands.

Calibrate.—To compare or standardize a measuring instrument or technique against a known value or standard, so as to correct errors or ascertain the proper correction factors.

Canopy.—The overhead branches and leaves of stream-side vegetation.

Channel.—That portion of the landscape containing the water that makes up the stream. Distinct from the surrounding area due to breaks in the general slope of the land, lack of terrestrial vegetation, and changes in the composition of the bottom materials. The channel is made up of stream BANKS and stream BED.

Channelization.—The mechanical alteration of a stream, which may include straightening or dredging the existing CHANNEL, or creating a new CHANNEL to which the stream is diverted.

Clay.—Very fine inorganic material with a maximum length of 0.00024 - 0.004 mm; individual particles, either dark brown or gray in color, are barely or not visible to the naked eye. Clay feels gummy or sticky, retains its shape when compacted, is slippery when underfoot, but partially or completely supports a person's weight when it makes up the stream BED.

Cover.—Organic or inorganic material under, at, or immediately above the water surface that provides shelter for fish. We define cover to include any material, object, or group of objects at least 0.3 m wide, 0.3 m long, and in or within 0.1 m of water that is at least 0.3 m deep.

Conductivity.—The ability of a solution to carry an electrical current. Depends on the total concentration of ionized substances dissolved in the water; the reciprocal of resistivity (ohms x unit length). When the concentration of ions is high, conductivity is high, and the resistance to electrical passage is low.

Crest.—The highest elevation reached by flood waters flowing in a CHANNEL during a specified time period.

Cross section.—The area of the CHANNEL in vertical cross section, perpendicular to FLOW, within the BANKS. Cross-sectional area is computed as the CHANNEL width times the mean CHANNEL depth.

Current velocity.—The speed at which water travels downstream from or to a given point, expressed in distance per unit time, usually meters per second or feet per second.

Dam.—A barrier obstructing the FLOW of water.

Debris.—Any material, especially human-made, moved by a flowing stream. Examples include old tires, abandoned farm implements, and discarded home appliances. See also WOODY DEBRIS.

Deposition.—The settlement or accumulation of material out of the water column and onto the BANKS or the BED. Occurs when the energy of flowing water is unable to support the load of suspended sediment.

Detritus.—A non-dissolved product of disintegration, usually pertaining to small organic particles such as leaves, twigs, tree branches, dead MACROPHYTES, etc. When very fine, may appear similar to SILT.

Discharge.—The volume of water that passes a given point in the stream per unit time; e.g., cubic feet per second (CFS) or cubic meters per second (CMS). The product of CURRENT VELOCITY, depth, and stream width, usually determined at several points within a CROSS SECTION and summed. Mean annual discharge is the mean daily discharge averaged over several years. Dominant (Formative) discharge is the level of discharge, usually the BANKFULL DISCHARGE, that is sustained over a period sufficient to alter a natural CHANNEL by dislodging, transporting, and distributing BED materials.

Dissolved oxygen.—A measure of the amount of oxygen present in a sample of water, usually expressed as weight of oxygen per volume of sample (milligrams oxygen per liter of water) or equivalently, parts per million.

Drainage basin.—The land area tributary to or draining to the stream (see WATERSHED). The basin consists of a surface stream together with all tributary surface streams.

Eddy.—A circular current of water diverging from and initially flowing contrary to the main current. Often forms POOLS.

Embeddedness.—The degree to which GRAVEL-sized and larger particles are surrounded, enclosed, or covered by SAND-sized and smaller particles.

Emergent macrophytes.—Higher aquatic plants with a significant portion of their biomass above the water surface.

Erodibility.—Susceptibility to EROSION.

Erosion.—The wearing away of the land surface by detachment and movement of soil and rock through the action of wind, moving water, or other physical agents.

Fine sediment (also Fines).—The fine-grained inorganic particles in stream BANKS and BEDS that are less than 2 mm in diameter. Includes CLAY, SILT, and SAND.

Flood.—Any FLOW that exceeds the bankfull capacity of a CHANNEL and flows out on to the FLOOD PLAIN; greater than BANKFULL DISCHARGE.

Flood plain.—Area adjoining a stream that may become inundated during periods of high water levels.

Flow.—See Discharge.

Fluvial.—Pertaining to streams, growing or living in streams, or produced by river action, as in fluvial plain. Synonymous with lotic.

Gaging station.—A selected CROSS SECTION of a stream CHANNEL where one or more variables are regularly measured over a long time period to index DISCHARGE or other parameters.

Gradient.—The difference in stream CHANNEL elevations divided by the distance between points where elevations were measured; the drop in the stream CHANNEL over a given distance, usually expressed as meters per kilometer or feet per mile.

Gravel.—Rocks with a maximum length of 0.002 to 0.064 m.

Habitat.—A specific type of place occupied by an organism, a population of organisms, or a community of organisms; the environment where a plant or animal will likely be found.

Headwaters.—The upper tributaries of a DRAINAGE BASIN.

Hydrograph.—A curve derived by plotting DISCHARGE against time.

Islands.—Areas of land between the stream BANKS that are surrounded on all sides by a substantial portion of the stream's water. Areas with nearly all of the stream's FLOW on one side and just a trickle of water on the other are not considered islands. Islands must contain soil or numerous rocks; exposed SAND, GRAVEL, or COBBLE are considered islands, but BOULDERS that project above the water surface are not.

Macrophyte.—Any multicellular (higher) plant that can be seen with the unaided eye.

Mainstem.—The principal, largest, or dominating stream of any given area or drainage system.

Marl.—A light gray to white material, primarily calcium carbonate, derived from the photosynthetic activity of ALGAE, decay of mollusk shells, or limestone deposits. Individual particles are very fine, sticky, and muddy. Marl does not support a person's weight when underfoot. Often found near springs and marshy areas.

Marsh.—A water-saturated, poorly drained wetland area, periodically or permanently inundated to a depth of up to 2 m, that supports an extensive cover of emergent, non-woody vegetation.

Meandering.—A winding reach of stream with many BENDS that is at least 1.5 times longer, following the CHANNEL, than its straight-line distance. A single meander generally comprises two complete opposing bends, starting from the relatively straight section of the CHANNEL just before the first BEND to the relatively straight section just after the second BEND.

MHO.—The unit of electrical conductance; reciprocal of the OHM.

Microhabitat.—HABITAT features in locations selected by organisms for specific purposes. Separated from adjoining microhabitats by distinctive physical characteristics such as VELOCITY, depth, COVER, SUBSTRATE, etc.

Morphometry.—Measures of the physical dimensions of an area or object.

OHM.—The unit of electrical resistance; equal to the resistance in a circuit in which an electromotive force of 1 volt maintains a current of 1 ampere.

Overhanging vegetation.—Thick vegetation overhanging the water surface.

pH.—A measure of the hydrogen-ion activity of a solution, expressed as the negative log (base 10) of hydrogen ion concentration on a scale of 0 (acidic) to 14 (basic), with a pH of 7 being neutral.

Point bar.—SEDIMENTS deposited at the convex (inside) BANK of a stream BEND.

Pool.—Portion of the CHANNEL with greater than average water depth, slow water VELOCITY, and no surface TURBULENCE; often wider than average.

Reach.—An arbitrarily defined length of stream, for example that portion of the stream between two tributaries, or the length of stream between two transects. The reach is made up of connected habitat units, such as POOLS, RIFFLES, RUNS, etc.

Riffle.—Portion of the CHANNEL with shallower than average water, relatively high GRADIENT, and greater than average current VELOCITIES, racing over stones to create much surface TURBULENCE.

Riparian.—Frequenting, growing, living on, or relating to the BANKS or FLOOD PLAINS of streams, rivers, or lakes.

Rubble/cobble.—Rocks with a maximum length of 0.064 to 0.26 m.

Run.—Portion of the CHANNEL with water of average width, depth, and CURRENT VELOCITY, with little or no surface TURBULENCE.

Sand.—Inorganic material with a maximum of length of 0.062 to 2 mm; smaller than GRAVEL but coarser than SILT.

Sediment.—Fragmental material that originates from weathering of rocks and decomposition of organic material that is transported by, suspended in, and eventually deposited or accumulated in BEDS and BANKS.

Sedimentation.—Deposition of organic or inorganic matter suspended in water.

Segment.—An arbitrarily defined length of stream, usually on the order of hundreds of MSW in length. Consists of multiple REACHES.

Silt.—Fine inorganic material, typically dark brown in color, with a maximum length of 0.004 to 0.062 mm. Feels greasy or muddy, but does not retain its shape when compacted into a ball. Silt will not support a person's weight when it makes up the stream BED.

Sinuosity.—The ratio of CHANNEL length between two points to the straight-line distance between the same points. CHANNELS with sinuosities $\geq$ 1.5 are termed "MEANDERING," while those close to 1.0 are "straight."

Stage.—The elevation, or vertical distance, of the water surface above a plane of known or arbitrary elevation.

Station.—The length of stream where detailed sampling occurs. The results of sampling in the station are extrapolated to a larger area that is similar to the station (e.g., a larger SEGMENT of the stream). There may be more than one station at a stream so that results may be extrapolated to a larger, more general area (e.g., the entire stream or WATERSHED).

Stream bed, Stream bottom.—See BED.

Stream order.—A method of classifying streams or REACHES of streams based on the number and size of TRIBUTARIES entering upstream. For example, a first-order stream has no TRIBUTARIES; two first-order streams join to form a second-order stream, two second-order streams join to form a third-order stream, etc. Larger streams increase in order downstream as the total number of TRIBUTARIES increases.

Submerged macrophytes.—Higher aquatic plants that grow or are adapted to grow beneath the surface of the water most of their life cycle.

Substrate.—The BED material of a waterway; also the base or substance on which an organism is growing.

Swamp.—Tree- or tall-shrub-dominated wetlands that are periodically flooded, with nearly permanent subsurface water FLOW.

Thalweg.—The longitudinal course connecting points of minimum BED elevation (greatest depth) along the stream BED. From the old-fashioned German: *Thal* = valley, *Weg* = way or path.

Thalweg depth.—The maximum depth of a CROSS SECTION.

Transect.—A line perpendicular to the FLOW of water, from one BANK to the other, along which samples are taken or measurements are made.

Tributary.—A stream feeding, joining, or flowing into a larger stream.

Turbidity.—An expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a sample of water, associated with the amount of fine particles suspended in the sample.

Turbulence.—The motion of water where local velocities fluctuate and the direction of FLOW changes abruptly and frequently, resulting in disruption of laminar FLOW. It causes surface disturbance and uneven surface level, often masking subsurface areas because air bubbles are entrained in the water.

Undercut bank.—BANKs that overhang the water surface.

Velocity.—See CURRENT VELOCITY.

Watershed.—All lands enclosed by a continuous hydrologic-surface drainage divide and lying upslope from a specified point on a stream (see Drainage Basin).

Woody debris.—Large pieces, or aggregations of smaller pieces, of wood (e.g., logs, large tree branches, root tangles).

APPENDIX A

FIELD DATA SHEETS

The following are data sheets used by the Fish Research Section of the Wisconsin Department of Natural Resources for habitat evaluations during Priority Watershed Projects. One **Station Summary** data sheet (fig. 5), one **Station Map** data sheet (fig. 6), one **Station Flow** data sheet (fig. 7), and several **Transect** data sheets (fig. 8) are completed for each station sampled. **Waterbody ID** is a unique seven-digit identification code assigned to each stream, river, or lake in Wisconsin. **Site Mile** is the distance in miles (via the stream channel) between the mouth of the stream and the downstream end of the site. **PW Basin Name** is the official name of the Priority Watershed being evaluated, as designated by the Nonpoint Source and Land Management Section, Water Resources Division, WDNR.

PW FISH HABITAT EVALUATION STATION SUMMARY WISCONSIN DNR

LOCATION

Stream Name: ____________ Waterbody ID Code: ____________ Site Mile: ____________

Station No: ______ Date (YY MM DD): ______ ______ ______ Starting Location: ____________

Township: ______ Range: ______ Section: ______ 1/16 Section: ______ 1/4 Section: ______

7.5" Quad Name: ____________ PW Basin Name: ____________ County: ____________

WATER CHARACTERISTICS

Time (24 hr clock): ____________ Air Temperature (C): ____________ Water Temperature (C): ____________

Conductivity (umhos @ 25 C): ____________ Turbidity (NTU): ____________ Dissolved Oxygen (mg/l): ____________

Flow (m3/sec - from Station Flow sheet): ____________

Water Level (check one - measure distance if Above or Below Normal): _____ Normal _____ Below: ______(m) _____ Above: ______(m)

CHANNEL AND BASIN CHARACTERISTICS

Stream Widths (m): ______ ______ ______ ______ ______ ______ ______ ______ ______ ______ ______ ______ ______ ______ ______

Mean Stream Width (m): ____________ Transect Spacing (m): ____________ Station Length (m): ____________

Channel Condition (check one): ______ Natural ______ Old Channelization ______ Recent Channelization ______ Concrete Channel

Gradient (m/km): ____________ Stream Order: ______ Shreve Linkage No: ______ Basin Area (km2): ____________

Mean Distance Between Bends (m): ____________ Mean Distance Between Riffles (m): ____________

Total (Sum) Length (m) of All: Riffles: ____________ Pools: ____________ Runs: ____________

Mean Length (m) of Individual: Riffles: ____________ Pools: ____________ Runs: ____________

PHOTOGRAPH DOCUMENTATION

Looking Downstream from the Downstream end of Station (from middle of stream): Frame #(s): ______ ______ ______

Looking Upstream from Downstream end of Station (from middle of stream): Frame #(s): ______ ______ ______

Looking Downstream from Upstream end of Station (from middle of stream): Frame #(s): ______ ______ ______

Looking Upstream from the Upstream end of Station (from middle of stream): Frame #(s): ______ ______ ______

Person(s) Who Collected Habitat Data: ____________

COMMENTS/NOTES (Continue on the back of this sheet if necessary):

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Figure 5.—*Station summary data sheet.*

PW FISH HABITAT EVALUATION — STATION MAP (p. ____ of ____) — WISCONSIN DNR

Stream: ______________________ Site Mile: ________ Station No.: _______ Date (YYMMDD): ______ ______ ______

DISTANCE FROM START (m)	STREAM FEATURE (Bend, Riffle, Pool, Run Log Jam, etc.)	Length (m)
0		

DISTANCE SUMMARY

Distances Between Bends (m):	Distances between Riffles (m):
Downstream - 1st: ________	Downstream - 1st: ________
1st - 2nd: ________	1st - 2nd: ________
2nd - 3rd: ________	2nd - 3rd: ________
3rd - 4th: ________	3rd - 4th: ________
4th - 5th: ________	4th - 5th: ________
5th - 6th: ________	5th - 6th: ________
6th - 7th: ________	6th - 7th: ________
7th - 8th: ________	7th - 8th: ________
8th - 9th: ________	8th - 9th: ________
9th - 10th: ________	9th - 10th: ________
10th - 11th: ________	10th - 11th: ________
11th - Upstream: ________	11th - Upstream: ________
Sum: ________	Sum: ________
Mean: ________	Mean: ________

Length (m) of Individual Riffles, Pools, and Runs

1st Riffle: ______	**1st Pool:** ______	**1st Run:** ______
2nd Riffle: ______	**2nd Pool:** ______	**2nd Run:** ______
3rd Riffle: ______	**3rd Pool:** ______	**3rd Run:** ______
4th Riffle: ______	**4th Pool:** ______	**4th Run:** ______
5th Riffle: ______	**5th Pool:** ______	**5th Run:** ______
6th Riffle: ______	**6th Pool:** ______	**6th Run:** ______
7th Riffle: ______	**7th Pool:** ______	**7th Run:** ______
8th Riffle: ______	**8th Pool:** ______	**8th Run:** ______
9th Riffle: ______	**9th Pool:** ______	**9th Run:** ______
10th Riffle: ______	**10th Pool:** ______	**10th Run:** ______
11th Riffle: ______	**11th Pool:** ______	**11th Run:** ______
Sum: ______	**Sum:** ______	**Sum:** ______
Mean: ______	**Mean:** ______	**Mean:** ______

DRAW MAP OF STATION ON BACK OF THIS SHEET

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Figure 6.—*Station map data sheet.*

PRIORITY WATERSHED FISH HABITAT EVALUATION   STATION FLOW   WISCONSIN DNR

Stream: ______________________ Site Mile: ________ Station No.: ______ Date (YY MM DD):_____ _____ _____

Stream Width:______________

Distance from Left Bank: (m)	Depth: (m)	Velocity at 60% of Depth: (m/sec)	Cell Width	Product (depth xvelocity x cell width)

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FLOW = Σ PRODUCTS = ______________________

Figure 7.—*Station flow data sheet.*

PRIORITY WATERSHED FISH HABITAT EVALUATION　　TRANSECT　　WISCONSIN DNR

Stream:__________________ Site Mile:________ Station No.:____ Date (YY MM DD):____ ____ ____

Transect No.:______ Distance from Start (m):________ Stream Width (m): ____________

Habitat Type (check): ____Riffle ____Pool ____Run

	Channel Position (fifths of current stream width and deepest point)				
	1/5	2/5	3/5	4/5	Deep
Water Depth (m)	______	______	______	______	______
Depth of Fines & Water (m)	______	______	______	______	______
Embeddedness (nearest 5%) of Coarse Gravel and Rubble/Cobble	______	______	______	______	______
Percent (nearest 5%) of Stream Bottom Covered by:					
BEDROCK (solid slab)	______	______	______	______	______
BOULDER (>.25 m)	______	______	______	______	______
RUBBLE/COBBLE (.065-.24)	______	______	______	______	______
GRAVEL (.002-.064)	______	______	______	______	______
SAND (.000062-.0019)	______	______	______	______	______
SILT (.000004-.000061)	______	______	______	______	______
CLAY	______	______	______	______	______
DETRITUS	______	______	______	______	______
OTHER (Specify-________)	______	______	______	______	______
ALGAE (attached & fila., %)	______	______	______	______	______
MACROPHYTES (%)	______	______	______	______	______
CANOPY/SHADING (%)	______	______	______	______	______

Cover for Fish (m): Length (nearest 0.01 m) of transect (within 0.15 m) with:

_____Undercut Banks _____Overhanging Vegetation _____Woody Debris _____Other Debris

_____Boulders _____Submerged Macrophytes _____Emergent Macrophytes _____Other-Specify________

Bank Erosion: Length (nearest 0.01 m), within 1 m of stream, and % of entire bank, along transect, with bare soil:

LEFT: _____ m _____ %　　RIGHT: _____ m _____%

Riparian Land Use (%): Percent (nearest 5%) of bank (within 5 m of stream edge, along transect) with:

_____Cropland _____Pasture _____Barnyard _____Developed _____Other-Specify__________

_____Meadow _____Shrubs _____Woodland _____Wetland _____Exposed Rock

Riparian Buffer Width (m): Length (nearest 0.1 m) of undisturbed Land Uses along transect, within 10 m of stream:

LEFT BANK: _____m　　RIGHT BANK: _____m

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Figure 8.—*Transect data sheet.*

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Simonson, Timothy D.; Lyons, John; Kanehl, Paul D.
1993. **Guidelines for evaluating fish habitat in Wisconsin streams**. Gen. Tech. Rep. NC-164. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 36 p.

Describes procedures for evaluating the quality and quantity of habitat for fish in small and medium streams of Wisconsin. Provides detailed guidelines for collecting and anlayzing specific quantitative habitat information.

KEY WORDS: Habitat, fish, bioassessment, biomonitoring.