Interim Report to The Nature Conservancy and the Illinois Nature Preserves Commission

Development of Illinois Stream Management Strategies Modeled on the Mackinaw River

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August 31, 1995

Introduction

This document summarizes the results of literature review and preliminary field testing of methods for classifying and assessing stream geomorphology and aquatic habitat quality. These methods are being developed to provide management guidance for aquatic ecosystem protection and restoration efforts by The Nature Conservancy and other organizations within the Mackinaw River Basin. These methods are also intended to be usable in other regions of the midwestern United States.

The literature review performed for design thus far is much more extensive than is described here--this report should be considered an interim document only. In a later phase of this study, an exhaustive review of the literature and methods rationale will be prepared.

Classification is an ordering of objects according to their characteristics. Managing a large, complex ecosystem with limited resources requires organization of data so that river reaches with common characteristics can be managed similarly. An important benefit of applying a classification system is the understanding it fosters among those using it (Naiman et al. 1992). Classification also helps to prevent the misapplication of management techniques by illustrating the important differences between river reaches and the different management approaches required. Ideally, classification can help us determine a stream's present state, its response to disturbance, and its ability to recover (Gordon et al. 1992), or its "possible state." Classification may also be thought of as a means to diagnose and treat disturbed ecosystems. This idea will be familiar to managers of terrestrial ecosystems, especially prairie restorationists, who use soils classification and assessment to determine the past and potential ecological states of a landscape. This research is directed toward development of a river classification methodology because we have no analog for river ecosystems.

Classification suggests that sets of observations or characteristics can be organized into groups based on similarities and differences (Gauch 1982). The simplest systems are already in wide use. Examples are classification of streams or stream reaches by drainage area or stream order (Naiman et al. 1992). River ecosystem researchers and managers often classify streams by hydrologic regime as perennial or intermittent.

As used here, the term *assessment* means the process of measuring and characterizing stream habitat and biota, and *classification* is the process of ordering this information. In much past work, these areas have not been properly integrated, that is, stream habitat assessment protocols are designed and carried out with little thought given to how the information will later be organized and analyzed (pers. comm., John Lyons and Mike Wiley).

In this process, I've sought to integrate the entire assessment, classification, and management process. I have also considered efficient use of assessment resources, including existing information, and the skills, resources and data commonly available in the midwestern US.

River assessment and classification

In an review of river classification theory and methods, Moseley (1987) identifies basic rules for classification:

--Classification should be designed for a specific purpose.
--Objects which differ in kind will not fit easily into the same classification.
--The system should not be absolute, but allow change as more information becomes available.
--Differentiating characteristics should be properties of objects classified rather than factors assumed to affect or determine the objects.
--The system should be exhaustive (i.e. include all objects in a given class) and exclusive (objects should fit into only one class).
--Classification should proceed at every stage as far as possible on a single characteristic.
--Differentiating characteristics must be important or relevant to the purpose of classification.
--Properties used to classify at the broader scale levels must be more important for the purpose of classification than those at the finer scale (more detailed) levels.

Mosley notes that few classification systems are likely to conform to all of these rules, and that river systems are particularly difficult to classify because they tend to present features on continuum.

Frissell et al. (1986) offer what is perhaps the most complete published conceptualization of river habitat classification to date. (Rosgen, as reported in Rosgen (1994) apparently has developed an exhaustive system, but it is as yet

unpublished, and will be available in late 1995 at the earliest. His methods are accessible only through a series of several commercial workshops.) They advocate a hierarchical system in which the highest level is the stream system (an entire watershed) with an approximate linear spatial scale of 10^3m, followed by stream segments (10^2m), reach systems (10^1m), pool/riffle systems (10^0m), and microhabitat systems (10^{-1}m). Frissell et al. offer an important concept in linking classification with management: that observable geomorphic characteristics at a given level can be indicators of the potential capacity of the habitat system associated with that level. As an example, they note that reaches with uncohesive banks of sand and gravel have different potential for channel morphology than reaches with clayey banks, a common contrast seen on the Mackinaw River and other Midwestern streams. They offer a conceptual model for using classification in management based on potential capacity. By evaluating "control" reaches and comparing key physical properties of these reaches with other reaches of differing habitat quality, the relative potential states of the sites can be assessed. For example, reaches with uncohesive bank materials (sand and gravel) often depend on riparian trees for channel stability. By measuring and comparing vegetated and devegetated reaches, we can often see that the primary variable controlling habitat quality in such reaches is riparian trees. Typically, the devegetated reaches are laterally unstable, exhibit higher width:depth ratios, and less diversity in hydraulic habitat and instream woody cover. Reaches with more cohesive materials, particularly clay, do not show this response. In this case, bank materials are a clearly useful classification characteristic. Figure 1 gives data from Gough (1992), showing how channel morphology of Spring Creek, a small stream in the Missouri Ozarks, resonded to devegetation and restoration.

Naiman et al. (1988) propose that a classification system should categorize the types and frequencies of disturbance (or stress) that may impact the stream and allow prediction of adjustments in biological and physical characteristics. They note that such a system is necessarily process-oriented, that is, it takes into

account the fluvial processes that result in the physical characteristics of river habitat. Rosgen (1994) has applied this concept in his river classification methods. His classification system is intended to assist in prediction of a river's behavior from its appearance, provide a means to compare similar reaches, and provide a consistent means of communicating information about river systems among professionals. The last goal fills an important, previously unaddressed need.

A common theme in these approaches is the identification of key variables that determine habitat quality and potential states. Although this appears obvious, it is deceptively difficult to apply and is often overlooked or neglected. Most stream habitat assessment efforts have two serious limitations. First, they are not designed to allow classification of stream sections of any scale, and thus are difficult to use for a methodical comparison of reaches, even within a given watershed. Second, most systems are designed to measure habitat features that are thought to be important to stream biota, e.g. substrate size distribution and available overhead cover. However, since the processes that affect and are affected by habitat features are ignored, the capacity for prediction (determination of possible states) and understanding of changes in such elements is lost.

The goals of The Mackinaw Project include assessment of the entire Mackinaw River Watershed to determine the most effective means to protect and restore aquatic habitat. No single existing assessment or classification method do allows such a broad, holistic approach, in part because the process of site selection for detailed assessment is neglected. Although Rosgen's method (as described in Rosgen 1994) advocates watershed-scale assessment, only the preliminary steps for its application are published. As is typical of existing methods, his published methodology assumes that workers are starting with a river reach that has been selected to be assessed for an arbitrary reason, e.g. ownership, and provides no methods for initial site selection at a watershed scale. The US Environmental Protection Agency (USEPA) has recently developed

detailed protocol for aquatic habitat assessment that are described in Kaufmann (1994), but site-selection protocols for this method are not published. Part of the USEPA's Environmental Monitoring and Assessment Program (EMAP), this method has no accompanying classification system nor a methodology for analysis of the data collected (beyond multivariate analysis). This system also generally neglects assessment of fluvial process, and has come under criticism for its lack of clear methods for analysis or use of data for management (National Research Council 1994, Mike Wiley, pers. comm.) Indeed, it appears that many stream habitat assessment efforts have been developed from a rather simplistic approach that seeks to measure as many habitat variables as possible (or affordable, given the budget of an individual project), with little weight given to either fluvial process or methods of classification that allow sites to be meaningfully compared.

Rosgen's system, which is based on fluvial form and process, addresses this problem. By grouping streams into types based on fluvial form and process, we can compare reaches which are similar, and better understand what responses are possible under changes in stress to them.

Classification implies that distinct boundaries among the objects classified exist. Classification of streams, however, is complicated by linkages that are both lateral and longitudinal, by changes in physical characteristics over time, and by indistinct boundaries between habitat patches (Naiman et al. 1992). This complexity, along with neglect of process, has been a primary obstacle to development of stream assessment and classification methods. By neglecting the role of process and, often, fluvial morphology, aquatic ecologists have decreased their ability to find patterns and relationships between biota and habitat. This problem has also plagued fluvial geomorphologists who have assembled large data sets and attempted, through statistical analysis, to find consistent patterns in form among streams (Dave Rosgen, pers. comm.). For example, in a study reported by Wright et al. (1984), and also Furse et al. (1984), 268 sites on 41

British river systems were measured and the results statistically analyzed. Variables measured were mean bed sediment size, alkalinity, total oxidized N, discharge, width, depth, slope, and distance from headwaters. The researches had great difficulty classifying reaches by this method, and their results were somewhat disappointing. Cushing et al. (1983) performed a similar survey of 16 stream sites, and concluded that classification systems for physical habitat were of "little ecological value." Reports on both studies state that the lack of natural discontinuities between sites made classification difficult, but both research groups failed to adequately consider fluvial process in their sampling scheme and stratify their data accordingly. Their methodology also lacked the power to predict possible states, except perhaps for water quality or hydromodification. Rosgen's method is designed to solve this problem by first lumping stream reaches into groups of similar character, based on fluvial form and process, before proceeding to a finer level of examination (Dave Rosgen, pers. comm.). Although this sort of initial grouping by form and related process is common in terrestrial ecology and soils classification, it is a new development in stream ecosystem management.

Unfortunately, Rosgen's system, developed largely through his experience in the western US and most recently outlined in Rosgen (1994), has not been widely applied in the Midwest, and thus no reviews of applications are available in the literature. His system proceeds from what he calls "level I," which is a general description of the river system (much like that in Gough 1993), through level IV, which includes detailed measurements of sediment transport, biota, and riparian vegetation at specific reaches (Rosgen 1994). The system is thus hierarchical, a structure advocated by both Naiman (1992) and Frissell et al. (1986). Hierarchical structures put watershed elements in spatially nested levels of resolution (Naiman 1992).

Most classification methods (e.g. Rosgen's) are applied to management of river ecosystems in watersheds or river reaches that are largely controlled by a single entity, either large landowners or the government. The majority of land in the Mackinaw's watershed is privately owned and thus greatly affected by changes in landowner attitudes, government agricultural policy, and the agricultural economy. River management in this region is also hindered by a lack of coordination of the many public and private agencies, a role The Nature Conservancy hopes to fill in this project. Thus, although there are no complete models to follow, the assessment and classification approach used here should consider political, economic and social forces. In the Mackinaw Basin, riparian landowners are concerned with flooding and drainage, and with lateral channel stability. An assessment and classification system designed to direct management in such a river system should, at least, include process-oriented measurements important to both ecosystems and landowner values.

Links to biota

Assessment and classification schemes used for management of aquatic ecosystems depend on models that link biota and physical habitat conditions (Simonson et al. 1994). It appears that there are few such models for streams in the Midwestern US, and these models are directed toward management of a single or few species of fish, usually gamefish (e.g. Wisconsin's assessment program, described by Simonson et al. 1994). I was unable to find even a conceptualization of how an aquatic ecosystem might be modeled for management.

Variations of the Index of Biotic Integrity (IBI) are widely used (e.g. by the Illinois Department of Conservation and other agencies), but their limitations are serious and generally acknowledged. In general, these models are based on simple assumptions about fish community structure coupled with measurements of physical habitat data. The habitat data is not process-oriented, and all models depend on the assumption that presence of a fish species in a given habitat means

that habitat is preferred. For species that can use alternate habitat, for example, this premise may not be accurate (Rabeni and Jacobson 1993). Information on habitat needs for various life stages is also lacking--models that are gamefish-oriented tend to focus on habitat for adults (Rabeni and Jacobson 1993). Linking fish and habitat is also greatly complicated because species probably respond to combinations of habitat types (e.g. a pool adjacent to a riffle) rather than individual habitat units (Rabeni and Jacobson 1993). For this reason, reaches should be characterized with an understanding of process and morphology, because habitat units tend to occur in groups that can be identified in this way. Further, in disturbed systems, fish species may be displaced to habitat that is not optimum for them (Power et al. 1988). Finally, species presence/absence can be greatly affected by the presence of other species, regardless of habitat characteristics. Powers et al. (1988) note that certain species of water striders (an invertebrate) used pool habitat only when trout were absent, and researchers in the Ozarks of Missouri have noticed such relationships among species of fish (Terry Finger, pers. comm.).

Other habitat ranking systems, such as Wisconsin's Fish Habitat Rating system (FHR), or Missouri's Stream Habitat Assessment Device (SHAD) use estimated "optimum" conditions for fish, much as Instream Incremental Flow Methodology (IFIM) does. The FHR and SHAD systems score individual habitat elements (e.g. water depth) and sum scores to put reaches in qualitative rankings (e.g. poor to excellent). Simonson et al. (1994) offer an analysis of models and their use in Wisconsin streams. While such models can be powerful management tools, they depend on subjective estimates of habitat value, and thus must be applied with great care.

Rabeni (1990), who has done extensive research on fish-habitat relationships in the Ozark Mountains, states that "while our goal is to quantify critical factors of the stream environment, it does not appear that this goal can be attained in the near future." It appears, however, that stratification by geomorphic types, as is

done in Rosgen's system, may greatly enhance our ability to identify critical habitat, especially on a basin scale. A simple descriptive classification system, such as that used by Gough (1994) on the Mackinaw River, enables us to link geomorphic process with habitat elements, and thus account for previously ignored factors such as the expected stability of certain habitat elements within reaches. For example, it is clear that channels in the upper Mackinaw River are stabilized by well-consolidated bank and bed materials and beds composed of course (cobble to boulder) beds. The sandy-banked reaches of the lower Mackinaw River stand in contrast as reaches that are inherently unstable. Thus habitat characteristics in these reaches can be expected to change over time, while those in the upper Mackinaw should show little temporal variation in gross channel morphology.

Other gaps in existing methodology.

Existing methods (including Rosgen's) are designed to be applied to wadeable reaches. Nonwadeable reaches, with consistent lowflow thalweg depths of over 1.8 m or so, are much more difficult to assess. Assessment of these reaches is possible, but at greatly increased expense, and only through the use of special equipment, e.g. hydroacoustic devices.

This project, as does any the depends on voluntary cooperation from stakeholders, will greatly depend on education of nonprofessionals. No existing method of stream habitat assessment or characterization provides for simple presentation of data, particularly in graphic form. Thus a goal of this work will be to produce graphic representations of key data and concepts for use in general analysis and stakeholder education.

Approach

The approach I propose to use for this basin resembles that proposed by Rosgen, in that it is hierarchical, and uses more detailed measurements on smaller

spatial scales at each level of analysis. This approach is also advocated by Frisell et al. (1986). The levels and measurements are:

Level of detail	description	information required	objectives
Level 1	broad morphological characterization	landform, geomorphology, climate, basin relief, river profile, general pattern and bank/bed materials	Describe general fluvial features, familiarize workers with basin, produce a general reference document, summarize existing data.
identify reference sites (not detailed in Rosgen 1994)			Identify sites of high ecological value, based on level 1 survey.
Level 2	morphological and process description (Rosgen's stream types identified)	channel patterns, entrenchment ratios, width:depth ratio, sinuosity, channel materials, slope	Using "reference reaches," against which other reaches can be compared, identifies homogenous stream types
Level 3	Rosgen's "stream state"	riparian vegetation, meander patterns, depositional patterns and other evidence of fluvial process, bank erodability	Provides information on possible states and impacts to both biota and stakeholders. Gives detailed information for comparison with other sites to determine possible states and suitability for restoration/protection.
Level 4 (not included in this study)	Rosgen's "verification" level	Direct observations of sediment transport, bank erosion rates, etc. (will be done in later phases of this study if funding allows).	Used to evaluate and verify prediction methodologies.
Compare reference reaches with other reaches		If "unifying variables" are found, a somewhat less detailed inventory that level 3.	Determine possible states for restoration/management decisions.

Table 1. Table of inventory hierarchy. Modified from Rosgen (1994). Note that this study will not include level 4 inventory, but that measurements and steps not used in Rosgen's method will be included. "Unifying variables" allowing us to determine possible states might include bed/bank materials, drainage area, channel modification, and riparian vegetation.

A level 1 inventory has been performed and is described in Gough (1993). Level 2 and 3 inventory methods for this study are based on information from several sources, primarily Rosgen (1994), Frisell et al. (1986), Lawson (1994), Meador et al. (1993), Kaufmann (1994), Simonson et al. (1994a, 1994b), and Simonson 1993. Specific steps proposed are:

- Overall geomorphic survey, compilation and synthesis of existing data including biological data. This step has been performed. Results are described by Gough (1994). Further information on socioeconomic characteristics, nonpoint pollution, and basin geomorphology was gathered by students at the University of Illinois and is reported in Farrell (1995). This work also included development of a hypermedia program to present basin data and production of 35mm slide copies of recent and historic aerial photographs of the basin.
- Stratification and classification of stream segments based on drainage area (and thus channel size), hydrologic regime, channel management and modification, fluvial form and process, and geology. This step has been performed and results are described in Gough (1994).
- Initial identification of high-quality reaches within each stratification/classification through use of remote sensing (including historical aerials), field reconnaissance, existing biological surveys, and other relevant information. Currently, existing Illinois EPA (IEPA) and Department of Conservation (IDOC) sampling sites are being assessed because fish and invertebrates have been intensively sampled at these sites in 1986 and again in 1994. Methods and site descriptions can be found in Short (1988).

- Intensive measurement of high quality reaches for level 2 (Rosgen) and more detailed classification, including some higher-order measurements, including
  - identification of key controlling variables, e.g. geologic control, channel modification.
  - determination of possible states through analysis of data and,
  - field examination of reaches of lesser quality and determination of key differences.
  - After the reference sites are measured we may be able to find "unifying variables," such as channel width, that allow us to compare other sites using rapid methods such as aerial photography. Possible unifying variables include width:depth ratio, bank and bed materials, riparian corridor vegetation, watershed size, and slope.
- Analyze data from reference reaches and develop classifications beyond the course level of classification used in Rosgen's system. Gough (1994) has offered a simple descriptive system for the Mackinaw Basin.
- Determine if differences seen between high-quality reference reaches and other reaches are due to manageable characteristics (e.g. riparian vegetation) or unmanageable features (e.g. bank and bed materials). Prioritize these sites according to manageability and economic viability of management, among other factors.
- As data from the reference reaches are analyzed, we will also search for patterns in channel history and management that indicate tendencies for either habitat destruction or recovery. In the Mackinaw, for example, there has been a strong tendency in recent decades to allow trees to invade riparian areas that were devegetated in the 1950's (as determined from aerial photographs). There appears to be "inertia" for certain kinds of management by stakeholders that is evidenced by similar management of similar river reaches, e.g. ditching of almost all low-slope upland areas.

Our analysis should be sensitive to such trends, and classification should include information that will allow us to identify them.

At level 2 and 3 analysis, field methods for use at reference reaches will include:

- Reference site location. The EPA's EMAP protocol provides the only systemic method for site location. I have requested the protocol (which is unpublished) but have not received it. Initially, all IEPA/IDOC sample sites within the basin will be assessed.
- General site description. Recent stereo aerial photographs (from 1988, 1993, and 1994) will be used qualitatively evaluate each site. Features of importance include unusual disturbance (e.g. riprap), floodplain configuration, and riparian vegetation patterns.
- Reach delineation. At each site, an initial reconnaissance will be done to establish a survey reach that is a multiple of channel bankful width as defined by Rosgen (1994, and pers. comm.). The sample reaches will be 20 times the mean bankful width (W_{bf}) as determined by 2 or 3 measurements of width. Reaches will begin at the margin of a geomorphic unit if possible (see Meador et al. 1993). Obvious disturbances such as bridges will be avoided. Figure 2 illustrates key steps and methods for the field work in schematic form.
- Thalweg profile and channel slope. Next the reach is laid out in multiples of mean bankful channel width W_{bf}. Depending on the width, small flags are set in channel banks at either 1 or 2 x W_{bf}. All longitudinal measurements are made with reference to these flags, which are numbered consecutively, beginning with flag 1, from 1 to 10 (or 20). Using an autolevel and level rod, the thalweg profile and water surface elevation is

measured for the entire reach. Elevations for key bankful indicators are also taken as possible, as are elevations for important breaks in channel slope (e.g. riffle heads and tails). Figure 3b shows a long-profile plot of site DK-21 on the upper Mackinaw.

- Woody debris. Woody debris within the reach is measured using a modification of the EMAP method described by Kaufmann (1994). The bankful channel is divided into two zones: within the lowflow channel and within bankful but outside the lowflow water surface. Length and diameter of all woody debris is recorded by reach subsegment (i.e. between transect (flag) 1 and 2, then between 2 and 3, etc.). Only debris with a diameter above 5cm is tallied. Overhanging rootwads of live trees are noted, as are whole trees, with rootwads intact, that lie in the channel. A length-diameter tally allows stratification of cover by size, analysis of variability within the reach and among reaches, and calculation of surface area of woody cover and large woody debris (LWD). Lengths and diameters are estimated visually, with periodic checks using a tape.
- Channel and riparian cross sections. Cross-sectional transects are next surveyed at 10 of the flags within the reach at 2 x W_{bf} intervals. Figure 4 shows plots of cross sections from site DK-21 on the upper Mackinaw River.
    - Channel cross section dimensions. First the lowflow width of the channel is measured using a tape. This section is then visually divided into 4 sections, and water depth measured at the 3 section boundaries within the channel. If the channel is highly asymmetrical, supplementary points may be taken between two of the points. This process gives a cross-sectional profile of the lowflow channel.
    - At each of these points, visual estimates of substrate type are taken. The dominant and subdominant particle sizes are noted, as is the

compaction of the substrate, as determined by whether or not is easily dislodged by the worker's feet, and is thus probably recently deposited. Substrate types are: thick organic matter, clay, silt, sand, gravel, cobbles, boulders, and junk (e.g. old car parts, which appear to be common in streambeds).

- Bankful channel dimensions. Using a clinometer and level rod, the height and angle of banks are measured and recorded. If significant features occur above bankful, these are measured as well, using a tape and level if necessary.
- Bank materials and stratigraphy (or absence of stratification) are noted on each bank. Bank materials are described and sketched and reference samples taken as necessary.
- Riparian vegetation is characterized as herbaceous or woody. At each transect end (i.e. at the right and left banks of each), the largest tree within 1/2 W_{bf} is noted and it's species and diameter at breast height (dbh) are recorded.

- Sinuosity and planform. Compass bearings are taken along the thalweg between each flag and plotted. Recent (since 1988) aerial photography is used to determine sinuosity for the reference reach and nearby reaches.
- Channel modifications or other human impacts are noted, e.g. channelization, levees, riparian corridor removal, drain tiles, dams, bridges.

- Hydraulic connection/disconnection with floodplain (or by Rosgen's definition, the "flood prone area) is noted by visual reconnaissance.
- Rooted aquatic plants are noted.
- Discharge measurements are made at each reference reach.
- Water temperature is recorded at the beginning and end of each day's field work. It appears that smaller sites take about a workday to complete, so

this measurement will give an indication of daytime temperature changes for the reaches.

- A pebble count is used to determine particle size distribution for the reach. Figure 3a gives a plot of pebble count data from site DK-21 on the upper Mackinaw River. Currently, the method used is a modification of Rosgen (unpublished workshop manual, 1995) in which 10 particles are sampled at each transect for a total of 100. I suspect, however, that sampling of certain fluvial features, perhaps riffles or gravel bars, will yield a more meaningful value. Many reaches in the Mackinaw, are lined with lag deposits of cobbles and boulders that are not transported by the current fluvial regime. Thus metrics like the D_{50} (the median particle size) are less meaningful that they would be if all bed material was being transported.
- Ground photographs for reference and as presentation tools are taken at each reach. At least two locations are photographed, and photograph locations are noted.
- Other obvious indicators, such as trashlines from floods are noted. We should also be aware of the energy and matter balance of the reach, i.e. the balance between what is entering and leaving the reach. Leveed sections, for example, tend to efficiently convey matter and energy downstream. Indicators of this are often obvious, even from aerial photographs, but require professional judgement to interpret, and are rarely quantifiable.

Analysis

As data collection proceeds, reaches will be classified according to Rosgen (1994, and pers. comm.) and according to trends in physical habitat and fluvial

process and morphology. For example, it is apparent that many of the Mackinaw's tributaries are heavily modified until they near the Mackinaw's valley, where they commonly become more sinuous and gain a healthy wooded riparian corridor. In this case, comparison with ditched and not ditched reaches will be done to determine if it is possible to better manage ditched reaches to resemble the healthier reference reaches downstream.

As data from the second IEPA sampling suite (in 1994) on established sites (also know as "DK" sites) becomes available, it will be analyzed to determine trends and, if possible, tie these trends to habitat data from this project and IEPA/IDOC habitat sampling data.

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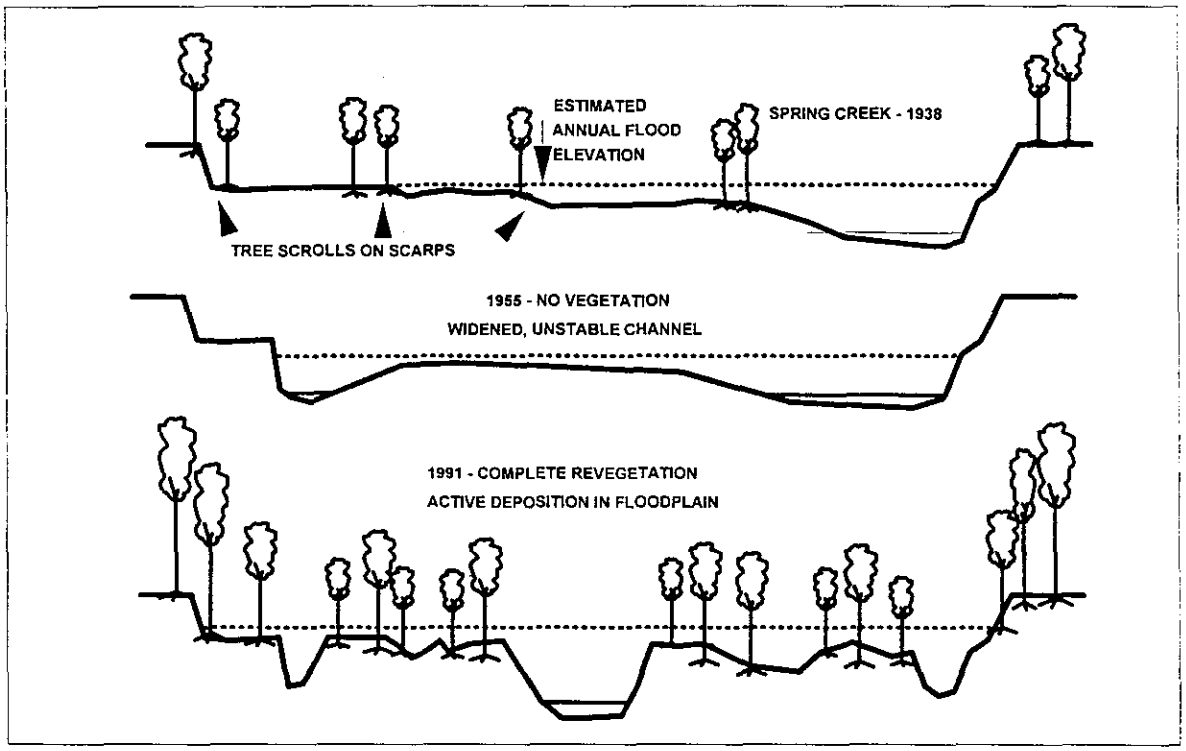


Figure 1. Cross sections of Spring Creek, near Rolla, Missouri showing channel response to devegetation in the 1940's and 1950's and response to removal of grazing pressure, which allowed riparian trees to regrow. Channel banks in this reach are composed of loose sand and gravel, which depends on tree roots for stability. Data from ground surveys and aerial photos. From Gough (1993).

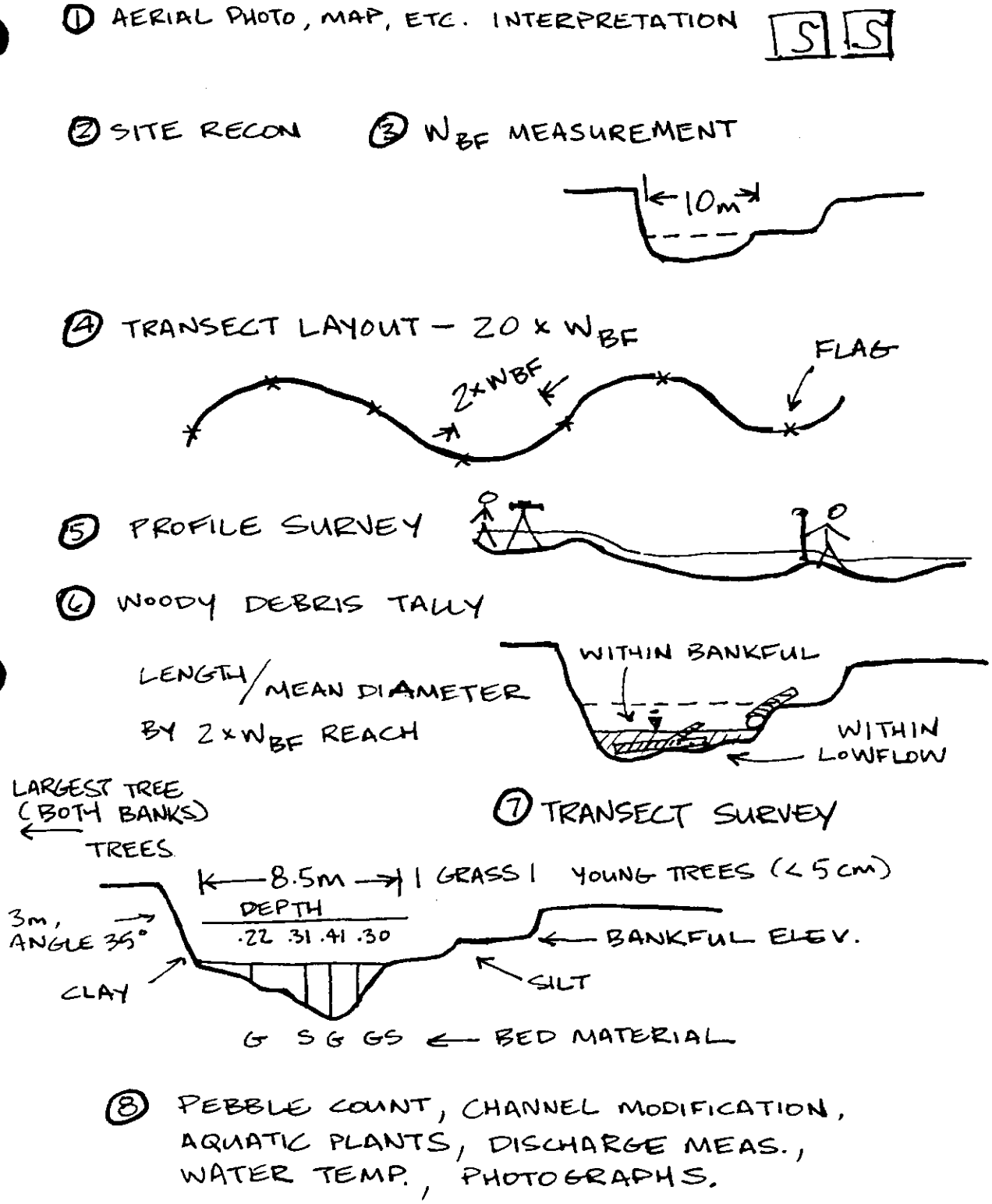
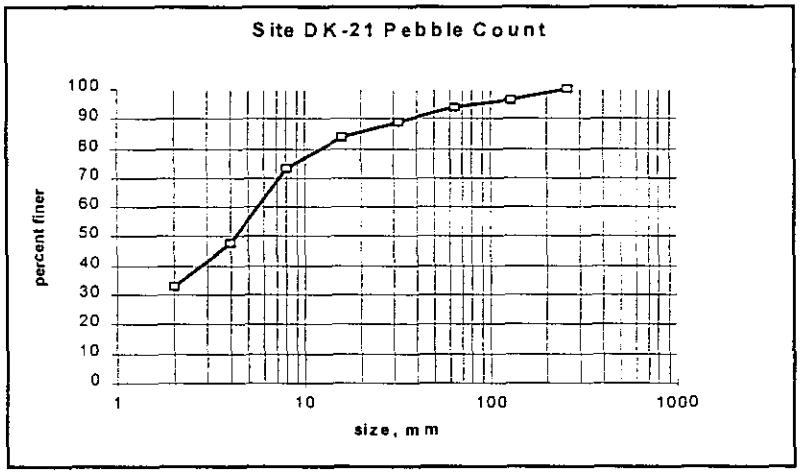


Figure 2. Schematic of steps for field survey of reference sites. The steps are listed in the order they are usually performed in the field. W_{bf} is average bankful width.



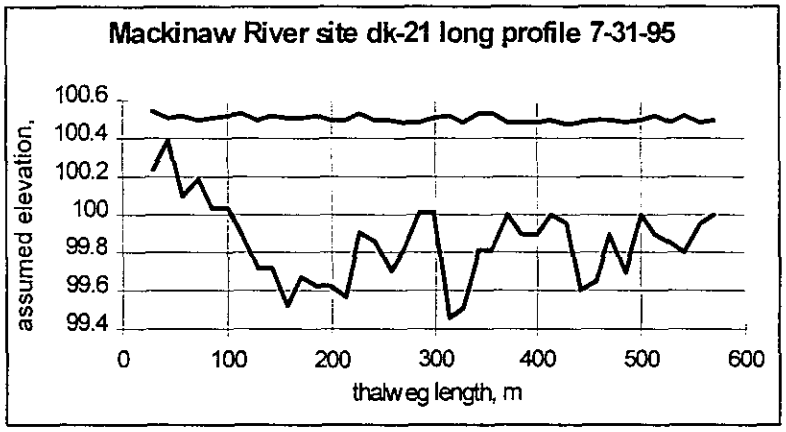
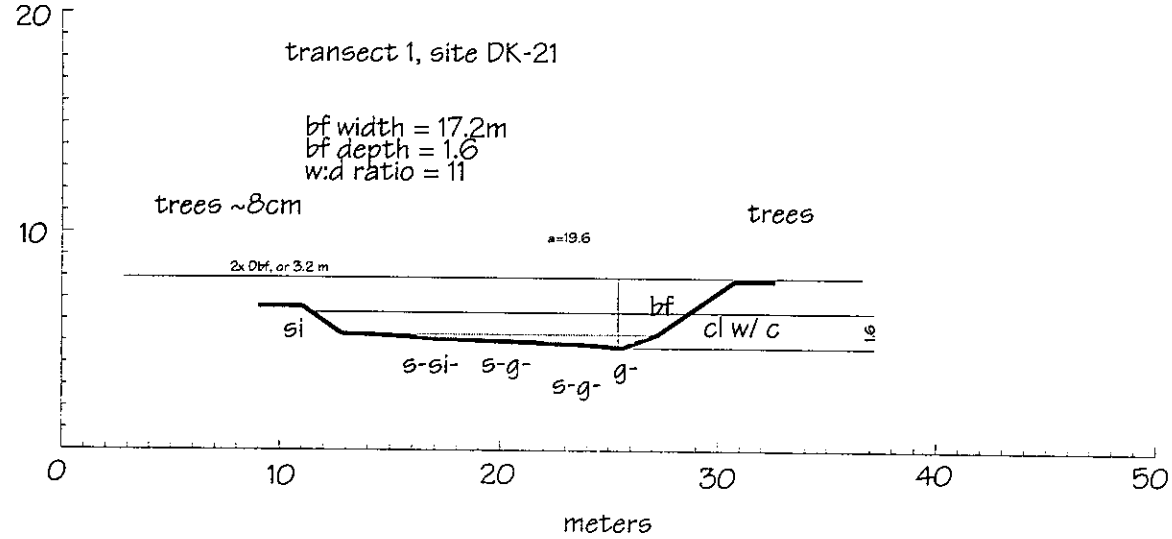


Figure 3a. Pebble count data from IEPA site DK-21 on the upper Mackinaw River. Figure 3b is a long-profile plot of thalweg bed elevation and water surface elevation from the same site.



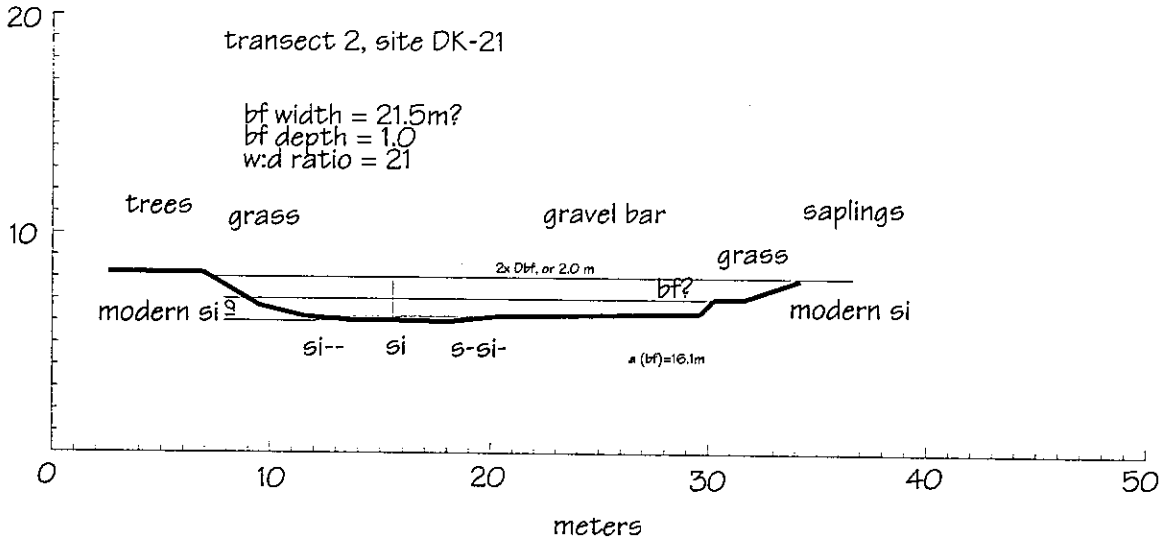


Figure 4. Example of plots from two transects at site DK-21. D_{bf} is average bankfull depth. This value is used in Rosgen's method to establish the "flood-prone" area for a channel. Letters below the plots are sediment type codes (e.g. si = silt, the "-" sign indicates that it is loose)