Understanding Fluvial Systems

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

This technical note describes the physical processes that occur on landscape positions where moving water is the dominant force. It provides background information to those who develop plans and for the restoration of moving water systems to a more natural state. The landscape positions described include streams, floodplains, wetlands, stream corridors, and riparian zones. This document uses the term "fluvial system" to include these landscapes under a single term. Fluvial systems are described as a continuum longitudinally and laterally that grade across the various landscape positions and have common functions and attributes. A selection of classification and assessment methodologies currently available for various landscape positions is presented and the applicability of each described.

The fluvial system landscape

The fluvial system landscape receives surface and/ or groundwater and moves this water as surface and/ or subsurface flow under the force of gravity to a point lower in elevation (downstream). The system may receive inorganic sediment, organic matter, dissolved chemicals, and other materials (inputs). The downstream movement of inputs can be thought of as being longitudinal in direction. During the downstream movement of these inputs, they also move laterally across the system boundary as they are cycled between high-energy and low-energy flow areas in three dimensional space. Figure 1 shows the longitudinal and lateral directions on a typical floodplain. The systems boundaries are defined using stream reach, stream order, management area, landscape position, or other criteria. The definition can be further refined by currently available classification systems typically used by stream and wetland restoration practitioners. In fluvial systems, the wetlands, streams, and floodplains are hydrologically connected, to some degree. Stable systems usually provide the greatest ecological benefits, exhibit a high degree of connection, and are in a state of dynamic equilibrium.

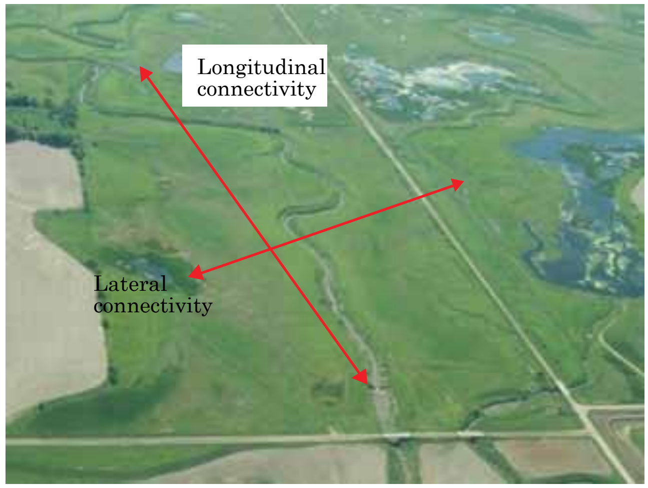

Figure 1. Lateral and longitudinal connectivity in a typical stream floodplain

Fluvial systems exist in a state of movement where physical processes are constantly underway. Many of these processes have a direct benefit to human society or are recognized by humans to have a direct benefit to the natural environment. In the literature, the wetland community often refers to functions and values. Values are societal values. Values are assigned by humans to natural processes based on human perception. To determine the degree of value, the processes must be quantified so that they can be measured. Processes that have been defined by a mathematical formula are referred to as “functions.” The formula consists of one or more measurable variables combined in an equation. An example of a function is floodplain groundwater recharge. This function may be assessed by measuring a single process or variable called flow duration, or flow duration may be combined with soil porosity and surface ponding potential. The level of function for floodplain groundwater recharge is a result of measurable variables.

The formula for this function is:

$$\text{Index of function} = \frac{(V_{dur} + V_{por} + V_{maco})}{3}$$

where:

V_{dur} = rating for flood duration

V_{por} = rating for soil porosity

V_{maco} = ratio for the presence of floodplain depressions, called macrotopography, that are available to pond water

In this formula, each of the variables is given equal weight. The index of function can give more weight to certain variables by using multiplication, division, squared, or other mathematical functions. For example, the formula

$$\text{Index of function} = \frac{(2 \times V_{dur} + (V_{por} + V_{maco}))}{4}$$

doubles the weight given to flood duration.

The measure of each variable is a value between 0 and 1. The function formulas are set up so that the results are a value between 0 and 1, as well. The user of the formula is provided a description of each variable so that values can be assigned based on observable or measurable parameters.

The use of the term “function” in this document is used in the context described.

All fluvial systems are capable of providing a certain level of function based on their capabilities. Human intervention to restore fluvial landscapes is done with the goal of maximizing functions. In broad terms, all natural functions in a fluvial system depend on connectivity and hydrologic complexity.

1. Connectivity

Connectivity is the degree to which water, organisms, and suspended elements and compounds can move across the fluvial system landscape. The degree of connectivity is based on the presence or absence of barriers. Barriers are features which interrupt connectivity. They may be natural or human induced. Human induced barriers can be hydrologic or structural. Barriers can also be natural. Barriers tend to reduce the ecological functions provided by the fluvial system, especially aquatic organism habitat functions. The number and health of fish and other aquatic organisms existing in the system is reduced when their opportunity to move freely is interrupted by a barrier.

The hydrologic analysis of connectivity focuses on the frequency, duration, and regime of water across the system. Frequency refers to the determination of how often water is present. Duration refers to how long water is present. Regime refers to the depth of surface water or the depth to groundwater. The most common data set used for these analyses is daily mean discharge data. Using these flows and hydraulic analysis of system capacity, a stage-discharge relationship can be developed. Frequencies, durations, and depths can be extracted to analyze the presence of surface water. The groundwater regime, duration, and frequency is more difficult to determine. This analysis requires the collection of data using groundwater monitoring devices such as monitoring wells and piezometers. With this data, correlations can be developed between stage and groundwater elevations for the determination of frequency, duration, and regime.

Longitudinal connectivity—Longitudinal connectivity describes the degree of connection along the main direction of flow for water, sediment, aquatic organisms, and other elements in the system, both living and inert. Its direction can normally be described as upstream and downstream. Some materials, such as sediment, may enter the system mainly as upstream inputs. Other elements, such as woody debris, may develop mainly within the system and either move downstream or remain close to the location they formed. Aquatic organisms may move into the system boundary from the upper end, lower end, or may spend their entire life cycle within the system. System functions are improved when all the elements, materials, and organisms are allowed to move unhindered from upstream to downstream. As stated, the frequency and duration of flow hydrographs can affect the degree of longitudinal connectivity. Consider the case of a perennial stream. The constant presence of water means that a continuous longitudinal connection exists. However, at low flows, the depths or velocities may not be adequate for suspended elements to move downstream or for fish to move upstream.

Waterfalls are natural longitudinal barriers that restrict the upstream movement of fish and aquatic organisms. Dams and diversions are human-induced longitudinal barriers that can interrupt the downstream movement of sediment, woody debris, and peak flow discharges, as well as the upstream movement of organisms. When planning to increase the system's function by increasing longitudinal connectivity, the capabilities of the system must be carefully assessed. Upstream movement of fish through a high natural waterfall is usually not within the system's capability. The lack of adequate flow in the system can constitute a barrier if the flow is not adequate for the movement of fish, sediment, debris, or other elements.

One case of special interest is the presence of large woody debris in the system (fig. 2). This debris can slow down flow velocity, increase flow depth, and cause sediment to deposit in a stream channel. In the past, many stream managers have considered this debris to be a barrier to upstream fish movement when it existed in the form of large log jams. Woody debris is now recognized by fishery biologists as an improvement to the ability of fish to move upstream. In other words, the woody debris creates an increase in longitudinal connectivity (at least for upstream movement for fish).

Figure 2. Woody debris can increase longitudinal and lateral connectivity

Lateral connectivity—Lateral connectivity describes the degree of connection laterally across the landscape. In general, this direction is normal to the direction of flow of water and suspended elements downstream. Water and suspended elements in a stream floodplain system move laterally only during flood events, for instance. The frequency and duration of flows affects lateral connectivity to a much larger degree than for longitudinal connectivity. This is because the degree of lateral connection is based upon the flow stage of the system, which is caused by varying flow rates. In other words, high flows place surface and subsurface water higher in the system landscape (higher stage). Conversely, low flows supply water to a smaller landscape area because they provide a lower stage. In most fluvial systems, the lateral connection is completely broken during significant periods in a normal annual hydrologic cycle, except for aquatic animals.

Human-induced lateral hydrologic barriers include water storage or diversion activities that reduce peak discharges. The reduced peaks reduce the system’s stage, which reduces the extent of the system supplied with water.

Human-induced lateral structural barriers are features such as dikes, levees, roads, and other infrastructure that prevent water from moving across the system.

Some fluvial systems in their natural condition have a high-capacity stream channel, which carries all but the highest discharges within the channel banks. Flow seldom accesses the floodplain, and the groundwater table in the floodplain is well below the surface. This situation can be considered to constitute a natural lateral connectivity barrier, and the system does not have the capacity for a high degree of connection.

The previous paragraph described the presence of large woody debris in a stream channel in terms of longitudinal connectivity. Since debris can cause an increase in the system's stage, it also has a positive effect on lateral connectivity.

2. Hydrologic complexity

Natural processes in fluvial systems function at their full potential when there is variability in the depth, duration, and areal extent of water in the system. Part of this variability is caused by variability of inflow hydrographs. This variability results in ranges of depth, duration, and frequency of flows that change spatially and temporally. Other variability is caused by the nature of the land surface within the system. Natural high and low surfaces create wetter and drier locations with different durations of flooding and/ or ponding. It is important to note that this range of variability is based on the system's natural climatic landscape, watershed, and other factors. For instance, the range of annual peak discharges in a typical stream west of the Cascades in the Pacific Northwest will be much smaller than a stream in the High Plains of western Kansas. The combination of variations in system inflow hydrographs and land surface variations create hydrologic complexity. Hydrologic complexity, in turn, creates spatial and temporal changes in the presence of water. These changes provide variations in vegetative plant communities, which provide complex variations in habitat for aquatic organisms. In practical terms, the systems inflow hydrograph cannot be changed without significant changes in the systems contributing watershed. However, the land surface within the system boundary can usually be modified to restore the original complexity. Land surface variability in a fluvial system can be described as microtopography and macrotopography. These terms are used by wetland restoration practitioners to plan and design wetland restorations.

Microtopography—Microtopographic or micro features are defined as depressions and ridges less than 6 inches in height or depth from the average land surface. These features contribute to rapid changes in hydrologic regime during the system's annual hydrologic cycle. These changes provide diversity in vegetative plant communities and habitats for aquatic organisms. Microtopography is created by the actions of water, vegetation, wind, and animals. These features exist outside of the active stream channel. Definable floodplains in their natural setting always exhibit microtopographic or micro features. They tend to be ephemeral and are constantly created, modified, and destroyed by the dynamic interaction of water, vegetation, wind, and animals. They are more prevalent in systems with a high degree of lateral connectivity. These features can be mechanically created by machinery. However, the shape, pattern, and random frequency of natural micro features is hard to reconstruct. Figure 3 shows microtopographic features in a logged floodplain wetland.

Figure 3. Recently logged floodplain wetland with ponding in microtopographic features

Macrotopography—Macrotopographic or macro features are larger than microtopography. Macro features are common geomorphic features created by naturally occurring, but infrequent, adjustments in the fluvial system. In stream systems, they exist as oxbow cutoffs, scour channels, natural levees, and other erosional and depositional surfaces. Existence of macro features is proof that lateral connectivity exists or existed at some time in the past. Macro features provide longer term fluctuations in hydroperiod and hydrologic regime. Their form and dimensions tend to be similar within the same system, as they were created by the same distinct fluvial processes. For example, oxbow cutoffs have the same general dimensions, patterns, and frequency of occurrence as meander bends in the corresponding active stream channel. In practical terms, macro features can be constructed using engineering designs, drawings, quantities, and cost estimates. Macro features can be expected to last for a period of several years or decades. Their geometry can be based on the determination of reference sites, similar to the use of reference reaches in stream channel restoration. In natural landscapes, they are often large enough that NRCS soil surveys have mapped individual soil series in macrotopographic features. Figure 4 shows a macrotopographic feature formed from an oxbow cutoff.

Figure 4. Floodplain microtopography as an abandoned oxbow feature

Dynamic equilibrium—A system in dynamic equilibrium is capable of absorbing significant disturbances without changing its overall form. Such disturbance may lead to temporally short changes in the local geometry of the channel, macrotopographic and macrotopographic features, and vegetative plant communities. However, the system's functions are not decreased. Longitudinal and lateral connectivity and the associated frequency, duration, and hydrologic regime of water are not degraded. The system in dynamic equilibrium is resilient. Equilibrium is maintained by long-term continuity of hydrologic inputs, sediment inputs, vegetative structure, human management, and activities of aquatic and terrestrial animals. This system continues to be resilient as long as the temporal and spatial changes of a system in dynamic equilibrium occur within limiting threshold boundaries. Periodic stresses to the system are required for the long-term maintenance of many system processes. For instance, the creation of floodplain macrotopographic features and cycling of sediment between an active stream channel and the floodplain depends upon low-frequency catastrophic flood events, which deposit splays and natural levees, create and fill scour channels, form abandoned oxbow features, and return sediment back into the channel. These events also reset the succession of vegetative plant communities, remove decadent stands, and create habitat niches for new plant communities to start. Short-term changes occur in the stream channel, wildlife communities are stressed, and individual plants damaged, but the event is needed to maintain the long-term resilience of the system. If an event occurs that exceeds the resilience of the system, the system is no longer in a state of dynamic equilibrium, and a new set of limiting thresholds results. Figure 5 illustrates the concept of the response of a system to disturbances within limiting threshold boundaries.

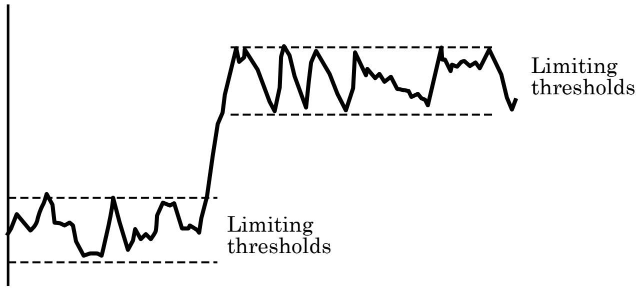

Figure 5. Dynamic equilibrium within limiting thresholds

(Thorne, Hey, and Newson 1997)

The challenge in using the concept of dynamic equilibrium is three-fold. First, a determination must be made as to whether the system is currently operating within a set of limiting thresholds. Decisions can then be made as to whether to maintain or reestablish the original thresholds or accelerate the establishment of new thresholds. Secondly, the magnitudes of the processes must be determined at the limiting threshold boundaries, not just on long-term, steady-state magnitudes. For example, the process of moving water and sediment downstream must be analyzed for its performance during catastrophic flooding, not just at baseflow or bankfull discharge. Otherwise, an action may be taken that lowers a limiting threshold boundary, even if it improves the function of the process at lower magnitude events. Finally, the value provided by the action of the process at near limiting threshold boundaries must be recognized. Often, these events create the greatest value for long system stability and ecological health.

Fluvial systems without a stream component

Before a fluvial system is analyzed as a stream system, a determination should be made as to whether it has a stream component or had one under a previous set of limiting thresholds. The lack of a stream channel must not be taken as evidence of low function, disequilibrium, or poor ecological health. These systems, when operating in a state of equilibrium, are capable of maintaining lateral and longitudinal connectivity, cycling nutrients and sediment, and functioning as resilient systems in dynamic equilibrium, as long as the limiting thresholds are maintained. In fluvial systems that did not originally exhibit stream morphological features, a common response to disturbances that reset limiting threshold boundaries, is the formation of stream morphological features. Such systems may have originally featured elements that appeared as channels, but these channel features did not operate hydrodynamically as streams.

There is no known set of common attributes which always separate fluvial systems that exist as stream systems from those that do not. Local climate, soils, geology, vegetation, wildlife, and other factors influence the system's morphology. Furthermore, there is currently no classification system or assessment model built specifically to deal with these systems. All the available models start with the assumption that the system either exists with a defined stream channel or is a wetland not dominated by flowing surface water.

One case of a fluvial system that does not have stream morphology is a system with low sediment inputs. In alluvial streams, the geometric features of the stream component of a fluvial system are formed from inputs of mineral sediment. If this supply is very low, fluvial systems may not exhibit stream features.

Figure 6 illustrates a fluvial system with low sediment inputs. This photograph shows the system at a transition point from a high-gradient stream system to a low-gradient landscape without a stream component.

Figure 6. Fluvial system transition point from reach with stream morphology to a reach without stream morphology. Flow is toward background

The low-gradient landscape can be described as a wet meadow. The active channel in the foreground maintained by the energy of the channel gradient disappears, and the flow transitions into the low-gradient landscape by forming multiple shallow flow pathways. Since the system is moving little or no sediment, the system does not have the raw materials needed to form an alluvial channel with bed and banks. However, this system is considered to be providing a high level of wetland function.

Stream classification systems are based on stream channel processes. Even in a fluvial system with a strong stream component, the system functions provided by the channel may be minor compared to the areal extent and functions provided by adjacent system components. Furthermore, the processes that occur on these adjacent components may be the determining factors that drive dynamic equilibrium and function. The following examples illustrate this point.

Systems that exist in organic soils or soils with a high organic content are low in sediment volume, low energy, and have a strong groundwater input provide a special case. Organic soils, by definition, were formed under conditions of near-continuous surface saturation across the extent of the fluvial system landscape. The conditions of the fluvial system required for this soil formation are not consistent with the hydrodynamics of a stream component. The processes occurring in a high energy portion of such a system (which may appear to be a stream channel) have little or no effect on the formation and maintenance of these soils (see Soil hydrodynamics for fluvial systems).

Another common case is represented by those systems that are dominated by very high loads of organic debris, referred to as "large woody debris." These systems also may have a high degree of impact by beavers. The morphology of the system in its original state is driven by the presence of debris and beaver dams. The surface geometry, hydrodynamics, and soil formation are the result of these factors. Often, these systems exist in high-gradient landscapes. In their natural state, these systems are usually very stable. These systems also may not have a stream component. Even if they do, channel processes do not determine the system's geometry and hydrodynamics. These factors are controlled by the recruitment, maintenance, and cycling of large woody debris in the system, along with the activity of aquatic organisms. Figure 7 shows a case where the fluvial system is dominated by beaver activity.

Figure 7. Fluvial system dominated by beaver activity

Hydrogeomorphic wetland classification system

Several wetland classification systems exist, but only the hydrogeomorphic (HGM) wetland classification system is addressed in this document. The HGM system is based on landscape position and hydrodynamics. It provides a parallel with stream classification systems. However, stream classification systems are based on the measurement of various geometric parameters, material found in the stream channel, and geometry of the landscape that contains the system (stream valley). The HGM system uses the broad landscape position and hydrodynamics of the system. Hydrodynamics are described by the source of the water inputs and outputs and the direction of water movement. The direction of water movement is described as horizontal or vertical and unidirectional or bidirectional. Stream classification systems address the water in the system that moves unidirectionally and horizontally (downstream). In addition, the source of the water input is surface flow from the upstream boundary, and the water leaves the system as surface flow at the downstream boundary. The HGM system forces the user to determine the relative magnitude of groundwater inputs, direction of flow both into and out of the system, and whether the source of water at a given location in the system landscape is surface inundation, groundwater flow, either, or both. Because of this, a large array of system functions that depend upon the hydrodynamics can be assessed.

The HGM system classifies wetlands in seven categories (always presented in capital letters):

RIVERINE
MINERAL SOIL FLATS
ORGANIC SOIL FLATS
ESTUARINE FRINGE
LACUSTRINE FRINGE
SLOPE
DEPRESSIONAL

In fluvial systems, the pertinent wetland types with added subtypes (always capitalized with lower case) presented here are:

- RIVERINE
  - Episaturated
  - Endosaturated
- SLOPE
  - Topographic

RIVERINE wetlands—Information on the use of HGM on RIVERINE landscapes can be found in U.S. Army Corps of Engineers (USACE) Wetlands Research Program Technical Report

WRP–DE–11, *A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands* (http://el.erdc.usace.army.mil/ wetlands/pdfs/wrpde11.pdf).

RIVERINE wetlands exist on fluvial landscapes that have a stream component. They receive water from the stream either as surface water, groundwater, or both. In broad terms, surface water creates conditions of episaturation, and groundwater creates conditions of endosaturation. The HGM system provides a methodology of assessing the functions of a subject wetland against the functions of a reference wetland. The reference wetland exists in a given reference domain. The system was developed for building a specific functional assessment model for a wetland or set of similar wetlands limited to a defined geographic region and a specific subtype. The functions provided by this specific type are defined, and the variables that can be measured to define these functions are determined.

The hydrologic functions described in WRP–DE–11 include all those associated with conditions of episaturation and endosaturation. In most cases, the dominant hydrodynamics are associated with one condition or the other, seldom with both.

The list of variables included in WRP–DE–11 include the following broken into those associated with epi- and endosaturation.

Episaturation:

V_{freq} — frequency of overbank flow

V_{inund} — average depth of inundation

V_{micro} — microtopographic complexity

V_{macro} — macrotopographic relief

Figure 8 shows a typical restored RIVERINE wetland with episaturated conditions.

Endosaturation:

V_{pore} — soil pore space available for storage

V_{wtf} — water table fluctuation

V_{subin} — subsurface flow into wetland

V_{subout} — subsurface flow from wetland to aquifer or to base flow

V_{micro} — microtopographic complexity

V_{macro} — macrotopographic relief

Figure 9 shows an example of an undisturbed RIVERINE wetland with endosaturated conditions.

Figure 8. Restored episaturated RIVERINE wetland

Figure 9. Endosaturated RIVERINE wetland

Note that the microtopography and macrotopography variables are common to both conditions. When building equations for wetland functions, it is suggested that an evaluation be made of whether the system is dominated by episaturation or endosaturation. Variables can then be selected from the appropriate hydrodynamic set. There are some cases when both hydrodynamic conditions exist, so variables from both sets may be needed.

The quality of microtopographic and macrotopographic features is important to the functioning of any fluvial system and is not included in any other classification system or assessment model other than HGM.

SLOPE wetlands

Stratigraphic SLOPE wetlands—SLOPE wetlands may occur as isolated landscape positions surrounded by non-wetland areas.

This is especially the case with stratigraphic SLOPE wetlands. These wetlands are formed where low-permeability, horizontally oriented strata force groundwater to the surface. They are typically not part of the continuum of a larger fluvial system and are not further addressed here.

Topographic SLOPE wetlands (fig. 10)— Commonly form the extreme headwaters of fluvial systems. These wetland areas exist as a first-order fluvial system. At this landscape position, there is a direct correlation between the first-order fluvial system in the modified Strahler classification system (as modified here) and a SLOPE wetland in the HGM classification system.

Topographic SLOPE wetlands in many areas occupy a relatively small part of the landscape and quickly transition into a stream channel, often supporting RIVERINE wetlands.

In other parts of the country, SLOPE wetlands exist with drainage areas of several square miles and a linear extent of several miles as shown in figure 11.

Common attributes of SLOPE wetlands are:

- Groundwater is the dominant water source
- Sediment delivery from the watershed is low
- Soils are organic or have a high organic content
- Wetland hydroperiod is continuous or nearly so

Figure 10. Topographic SLOP wetland as a first-order fluvial system

Figure 11. Large drainage area SLOPE wetland system

Defining the stream component of the fluvial system

Streams can be defined as separate fluvial system components that have definite geometric boundaries and hydrodynamics. These boundaries separate the stream component from laterally adjacent fluvial system components such as floodplains and from longitudinally adjacent components such as headwater wetlands. Geometric boundaries also separate features within the stream landscape position referred to with terms such as “channel bed,” “banks,” “floodplains,” “bars,” “pools,” and “riffles.” The geometry of these features is determined by the system’s response to its inputs of water, sediment, debris, and the vegetative plant community structure. In most cases, high discharges are the result of surface runoff from the watershed, and low discharges are provided by water stored within the system or adjacent landscape. In a stream system operating within a set of limiting thresholds, the sediment transported is in dynamic equilibrium with the rate of erosion of the stream’s bed and banks. Discharges in excess of a certain rate are too large to be handled by the stream component’s channel and enter into the floodplain. The discharge at which flows enter the floodplain is called the bankfull discharge, and the portion of the channel which carries this flow is the bankfull channel.

1. Use of stream order in fluvial systems

A method of classifying, or ordering, the hierarchy of natural channels within a watershed was developed by Horton (1945). Several modifications of the original stream ordering scheme have been proposed, but the modified system of Strahler (1957) is probably the most popular today. The Strahler system implicitly assumes that all parts of the fluvial system have a stream channel. Strahler’s stream ordering system is shown in figure 12.

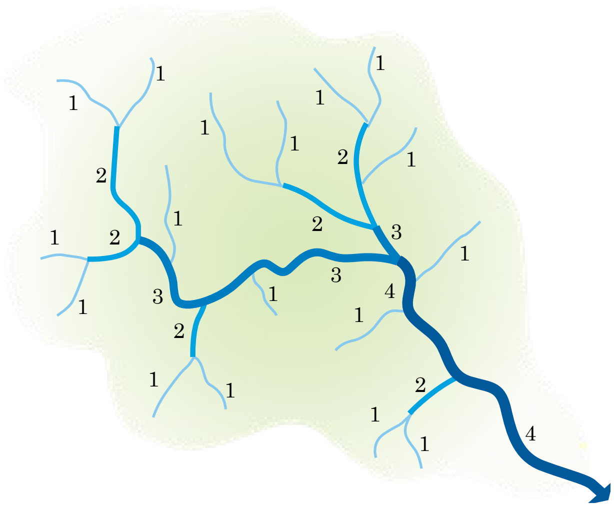

Figure 12. Strahler stream order system

The uppermost channels in a drainage network (headwater channels with no upstream tributaries) are designated as first-order streams down to their first confluence. A second-order stream is formed below the confluence of two first-order channels. Third-order streams are created when two second-order channels join, and so on. In figure 12, note that the intersection of a channel with another channel of lower order does not raise the order of the stream below the intersection (a fourth-order stream intersecting with a second order stream is still a fourth-order stream below the intersection).

Modified Strahler stream order model—Within a given drainage basin, stream order can correlate well with other basin parameters, such as drainage area or channel length. Consequently, knowing what order a stream is can provide clues concerning other characteristics such as the size of the system, geometric features, hydrologic and hydraulic parameters and the presence or absence of groundwater inputs.

The value of the system can be increased with following modifications and clarifications:

- The term "stream" is replaced with the term "fluvial system."
- The upper boundary of first-order streams is defined as the point where groundwater first begins to effect surface conditions (wetland hydrology), or the point where the stream component features described appear.
- The fluvial system is not required to exhibit a stream component.

With these modifications the following is meaningful. First- and even second-order fluvial systems are locations where the system may not have the stream component. However, fluvial systems described as wetlands or with a wetland component commonly exist in these low stream order locations if groundwater provides wetland hydrology. These first-order fluvial systems typically exist as SLOPE wetlands in the HGM wetland classification system. Furthermore, a fluvial system may begin in the first order without a stream component, exhibit a stream component in the second order, and then lose this component at the lower end of that order or higher orders.

In addition, streams are often defined in terms of the frequency and duration of flow; that is, ephemeral, intermittent, and perennial. These categories fit well with stream order, but the correlations are not the same for all regions. In the arid West, an ephemeral system may be a second or even third order, whereas in the humid East, a first-order fluvial system may be perennial. However, within a climatic region, stream order and fluvial system condition may correlate very well. For example, in the Great Lakes region, first- and even second-order fluvial systems commonly exist as SLOPE HGM wetland types.

Landscape positions that deliver surface runoff only and do not exhibit stream geometry features are not included in the system. These locations deliver water (and often sediment) inputs to the headwaters of a first-order stream. We can apply the limiting threshold concept to these landscape positions, as well. The original threshold boundaries may have provided a stable land surface where water moved off as sheet flow during precipitation events. If a disturbance allows a gully to advance into this landscape, it now may exist within new threshold boundaries as a first-order fluvial system because the gully introduces the stream component. The new threshold condition may even create a groundwater input if gully formation allows subsurface water to reach the surface through the gully banks.

Figure 13 shows a first-order fluvial system that exists as a wetland without a stream component.

The Strahler stream order model used with the modifications presented here has the advantage of including all fluvial system landscapes in a continuum. It incorporates the concept of longitudinal connectivity to that continuum. All fluvial systems are included, even those without a stream component. Systems that transition from SLOPE wetlands to fluvial systems with no stream component to systems with a stream and floodplain component (and back) can be analyzed as a single longitudinal system. It does not provide any clues as to whether the system is stable. Determination of stable limiting thresholds must be done by correlation between similar stream orders within the same region. One advantage is that large areas within a given region can be quickly assigned to a management or planning unit based on fluvial system order. This lends itself to geographic information system (GIS) applications, especially when used in combination with soils and land use information.

Figure 13. First-order fluvial stream system that is a wetland with no stream component

2. Classification systems for the stream component

Streams that have similar geometric attributes, sediment inputs, channel substrates, valley geology and geometry, watershed conditions, and are in a state of dynamic equilibrium often have common attributes. These similarities form the basis of stream classification systems. Stream classification systems were mainly developed for the purpose of analyzing the function of the stream component of the fluvial system and planning restoration or improvement activities.

Schumm Channel Evolution Model (CEM) – Conceptual models of channel evolution describe the sequence of changes a stream undergoes after certain kinds of disturbances such as channel straightening, increase in peak discharges, or decrease in sediment load. The changes can include increases or decreases in the width/depth ratio of the channel and also involve alterations in the floodplain. The sequence of changes is somewhat predictable, so it is important that the current stage of evolution be identified so appropriate actions can be planned.

Schumm, Harvey, and Watson (1984) and Simon (1989) have proposed similar channel evolution models due to bank collapse based on a “space-for-time” substitution, whereby downstream conditions are interpreted as preceding (in time) the immediate location of interest, and upstream conditions are interpreted as following (in time) the immediate location of interest. Thus, a reach in the middle of the watershed that previously looked like the channel upstream will evolve to look like the channel downstream. Downs and Thorne (1996) reviews a number of classification schemes for interpreting channel processes of lateral and vertical adjustment (aggradation, degradation, bend migration, and bar formation). When these adjustment processes are placed in a specific order of occurrence, a channel evolution model (CEM) is developed. Although a number of CEMs have been suggested, two models (Schumm, Harvey, and Watson 1984; Simon 1989, 1995) have gained wide acceptance as being generally applicable for channels with cohesive banks. Both models begin with a predisturbance condition in which the channel is well vegetated and has frequent interaction with its floodplain. Following a perturbation in the system (channelization or change in land use), degradation occurs, usually as a result of excess stream power in the disturbed reach. Channel degradation eventually leads to oversteepening of the banks, and when critical bank heights are exceeded, bank failures and mass wasting (the episodic downslope movement of soil and rock) lead to channel widening. As channel widening and mass wasting proceed upstream, an aggradation phase follows in which a new low-flow channel begins to form in the sediment deposits. Upper banks may continue to be unstable at this time. The final stage of evolution is the development of a channel within the deposited alluvium with dimensions and capacity similar to those of the predisturbance channel (Downs and Thorne 1996). The new channel is usually lower than the predisturbance channel, and the old floodplain now functions primarily as a terrace. Once streambanks become high, either by downcutting or by sediment deposition on the floodplain, they begin to fail due to a combination of erosion at the base of the banks and mass wasting.

The channel continues to widen until flow depths do not reach the depths required to move the sloughed bank materials. Sloughed materials at the base of the banks may begin to be colonized by vegetation. This added roughness helps increase deposition at the base of the banks, and a new small-capacity channel begins to form between the stabilized sediment deposits. The final stage of channel evolution results in a new bankfull channel and active floodplain at a new lower elevation. The original floodplain has been abandoned due to channel incision or excessive sediment deposition and is now termed a "terrace." The Schumm CEM is illustrated in figure 14.

The overlying assumption of the Schumm model is that a disturbance causes a series of changes resulting in channel incision. The model was developed for streams with cohesive banks. In large regions of the United States, this incision is the main cause of degradation of existing stream channels, and works well in channel assessments. The model, as used in the planning process, determines whether grade stabilization, bank stabilization, or both are appropriate. Another assumption is that the system originally exhibited a stream component, which equates with class I of the model.

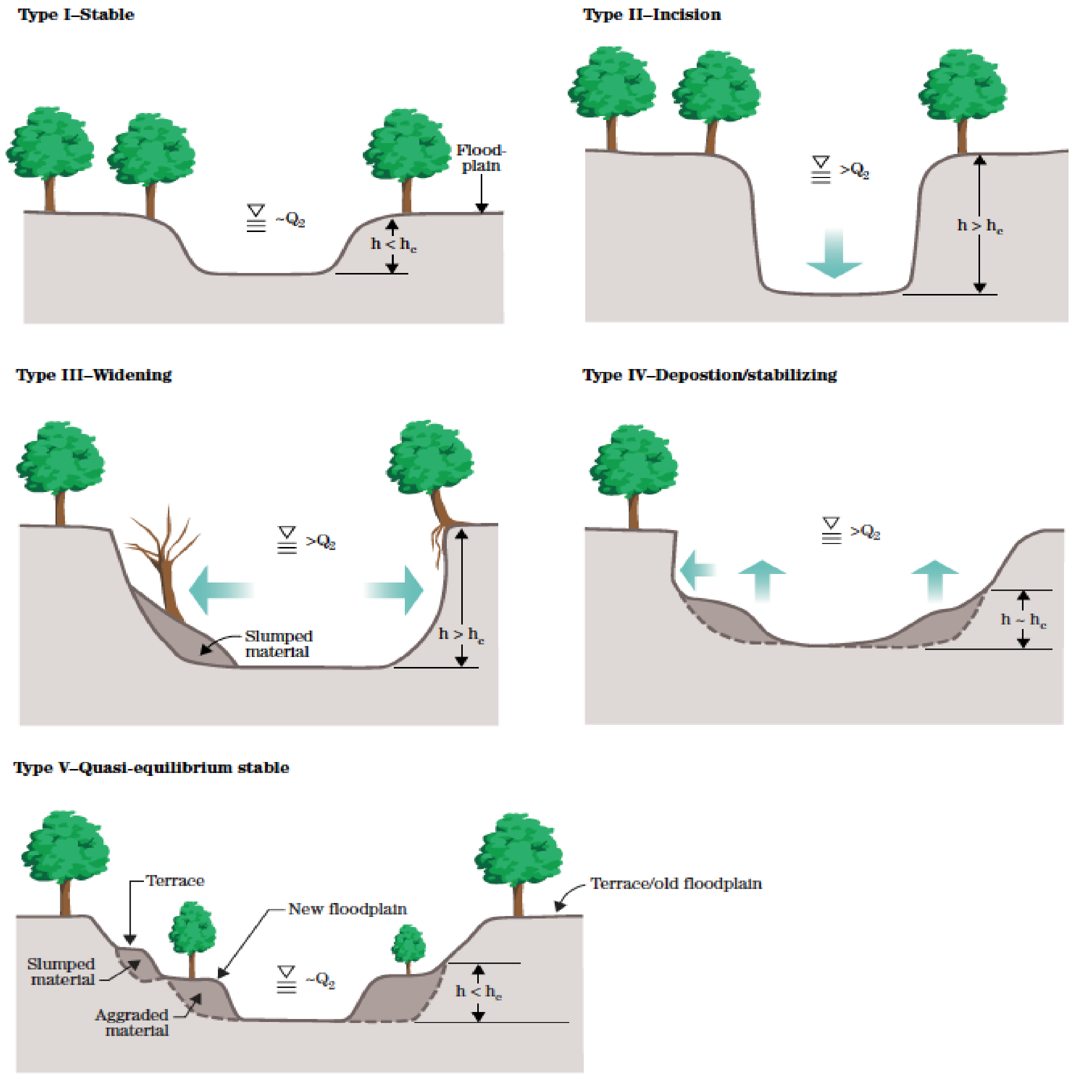

Figure 14. Schumm CEM

Channel incision can cause a fluvial system that formerly did not show evidence of a stream component to form one. In other words, the initial perturbation results in channel creation, which is often interpreted as a class I condition. This initial incision creates streambanks where they did not formerly exist. This case is shown in figure 15, where the class I channel foreground exists downslope of a fluvial landscape position with no channel. The stream channel is, in fact, forming through an existing system that did not have a stream component. This landscape is classified as a SLOPE wetland in the HGM system.

Figure 15. Schumm class I stream channel forming through a first-order fluvial system (SLOPE HGM wetland type)

Disturbances caused by excessive sediment supply that result in channel and floodplain accretion as the first perturbation to the system are not addressed by the model. Figure 16 shows a case where high, cohesive banks are the result of massive floodplain accretion. The stream channel grade has remained relatively constant, as evidenced by the layer of alluvial gravel on the channel bottom. This condition can be easily misinterpreted as a CEM class II or III condition caused by channel incision. In this case, the CEM is not an appropriate classification system.

Figure 16. Vertical accretion in floodplain, giving appearance of CEM class II channel

It is important to note that the CEM does not assign a value to channel class. The model is only a predictor of past conditions and future trend. In common usage, class I is usually assigned the highest value for system functions. It should be recognized that CEM does not provide a template for design of system geometry or analysis of system processes.

For systems operating with the processes assumed in the model, it is a valuable tool. For this reason, the first step in a fluvial system assessment should be to determine if the use of the Schumm model is appropriate. If not, its use should be ruled out. The use of the model provides ready determinations of the degree of lateral and longitudinal connectivity in the fluvial system. It also provides ready information about whether the system is still within original limiting thresholds. Table 1 is an example of the use of the CEM for an analysis of system function.

In table 1, class I is a channel that is not experiencing active incision, so the headcuts that advance headward and that might break longitudinal connectivity do not exist. In addition, the channel capacity is such that flows in excess of channel forming (assumed as the 2-year peak in the model) access the floodplain, so lateral connectivity is good. The system is still within its original limiting thresholds. In class II, incision is occurring, so incipient headcuts are lowering functions associated with longitudinal connectivity, and the increased channel capacity is decreasing the frequency of floodplain access (lateral connectivity). However, the channel can probably be brought back to its original geometry and function. Thus, it is still operating within its original equilibrium thresholds. In class III, the channel incision has reached its maximum, the original floodplain is now upland, and the channel will work to create a new floodplain at a lower landscape position. The system is operating with a new equilibrium threshold. Lateral connectivity is poor because there is no previous or new floodplain to allow flood flows into the system. However, longitudinal connectivity is improving as the headcuts associated with incision are decreasing. In class IV, lateral connectivity is still poor, with no floodplain access, but longitudinal connectivity is reestablished. As in class V, lateral connectivity is established to a new floodplain, and the system is operating within a new set of equilibrium thresholds.

Table 1. Use of the CEM

CEM class	Within threshold state	Lateral connectivity	Longitudinal connectivity
I	Yes	Good	Good
II	Yes	Medium/poor	Medium/poor
III	No	Poor	Medium/good
IV	No	Poor	Good
V	New	Poor	Good

The Rosgen stream classification system and natural channel design—This description is limited to the use of the Rosgen classification system (Rosgen 1994) as defined in Rosgen's Level II Morphological Assessment and its direct use for determining a natural channel design template. Additional information about the interrelationship of streams with their associated watershed and valley type, channel design, and assessment procedures is available in various other Rosgen publications. It is important to note that the reference material developed by Rosgen and Wildland Hydrology includes much more information that the Rosgen classification system.

In recent years, the Rosgen classification system has gained wide use in the United States. It provides a quantitative method for grouping similar streams. It was developed from an extensive data set of measured stream parameters and provides a useful means of communication. The system is also frequently used for planning stream restorations based on the streams current departure from its stable geometry. A full description of the Rosgen classification system can be found in the NRCS National Engineering Handbook, Part 654, Stream Restoration Design.

Application of the classification system relies heavily on the determination of the geomorphic bankfull indicators, which show the level of the bankfull discharge. Bankfull discharge is a concept used by many practicing fluvial geomorphologists, regardless of the classification system being used. The geomorphic bankfull discharge is that at which the flows just begin entering the floodplain. It is also an identified discharge, which over time does the most channel-forming work and carries the most sediment. High flows carry the most instantaneous sediment, but their frequency of occurrence is so low that the long-term volume of sediment is less than that of the bankfull discharge. In the bankfull discharge concept, the system geometry is formed and maintained by steady long-term processes, and not on discrete catastrophic events. In other words, frequent and long-duration flows define the shape and size of the stream and drive the dominant system processes. The effects of high-discharge, low-return period events, such as the 4 percent chance (25-year return period) peak discharge hydrograph, are assumed to be overridden by the cumulative effects of smaller bankfull discharge flows.

Bankfull discharge is commonly equated to a flow frequency. For instance, the discharge may be determined to be the 50 percent chance (2-year return period) peak discharge.

As already noted, many fluvial systems do not have a stream component. There are no Rosgen types for these systems. Also, fluvial systems that have steady long-term inundation events on an annual basis are hard to classify using the bankfull discharge approach. These systems are common in the Southeastern United States, where large stream systems have long-term winter flooding every year.

The application of the Rosgen natural channel design process requires that degraded systems must be compared with a reference reach. A reference reach is one that is in long-term dynamic equilibrium with the current watershed and climatic conditions. In many regions, these reference reaches are nonexistent. Also, fluvial systems in which large woody debris or beaver activity dictate the channel geometry may not fit within a Rosgen stream type. Accurate classifications in the Rosgen system require that the bankfull discharge stage be located in the field using bankfull indicators. These indicators are different for different systems, and require a considerable amount of expertise. Also, the indicators can give erroneous results if the stream being classified is not operating within a stable set of limiting thresholds. For this reason, the location and proper classification of a reference system is critical for determination of the proper stream geometry of the system being assessed. Bankfull discharge is a parameter based on the flow rate of water. The geometry of the stream channel component is actually created by the channel-forming discharge, which is the discharge that carries the most sediment over time, and does the most channel-forming work. In this context, the bankfull discharge serves as a surrogate for channel-forming discharge. The use of bankfull indicators provides a quick and repeatable method for determining this surrogate and, thus, has value for restoration practitioners. It is important to recognize that the bankfull discharge and channel-forming discharge may not be the same, even in stable systems.

The reference reach is assumed to be a system which is operating with a set of limiting thresholds provided by processes operating in a natural environment with no anthropogenic controls. This system may be in its original, natural condition, or one that is in a new equilibrium state. This new state is referred to as "stable analog." Stable analog conditions are not original conditions, but they are in equilibrium with new threshold boundaries. In systems with threshold conditions imposed by human infrastructure, land use restrictions, or human imposed uses, the reference conditions may not exist in a local reference reach. For projects with the purpose of increasing fluvial system function within anthropogenic limiting thresholds, a restoration to the reference condition may not be desirable or possible.

Procedures exist within the Rosgen methodology for these cases, but they are beyond the simple application of the classification system, and the use of a reference reach.

The Rosgen system, along with other stream classification systems, focuses most strongly on the processes of the stream channel component. The processes and functions occurring on the adjacent fluvial landscape are addressed mainly in the context of their effect on the active channel.

When used properly, with an appropriate reference system, the Rosgen classification system can provide the user with appropriate stream geometric parameters for use in restoration. The system being assessed must also be within the same limiting thresholds as the reference or stable analog. When the reference is operating in a stable manner within its limiting thresholds, the bankfull discharge determined by bankfull indicators can reasonably be assumed to be a good surrogate for channel-forming discharge.

Stream classification systems assume that the fluvial system consists of a defined channel associated with an adjacent floodplain. The geometry of the associated floodplain may be used in channel classification, but floodplain parameters such as morphology, soil hydrodynamics, and floodplain geomorphic features are not generally considered. Lateral interactions of surface water, groundwater, sediment, vegetation, and aquatic organisms are not addressed in channel classification systems and must be assessed using other tools. The fluvial system comprises the lateral and longitudinal continuum of the entire corridor. The interactions between stream, floodplain, wetlands, and floodplain dynamics must be addressed when planning the restoration of a fluvial system. Any single classification system must be used with a knowledge of the assumptions used within the system.

Stream classification systems use spatial relationships to place a system in a certain category. The CEM model is based on the temporal changes that the system undergoes, and no information can be directly inferred as to whether the system is operating within a set of limiting thresholds or moving to a new set of threshold boundaries.

Fluvial system assessment models

1. **Stream Visual Assessment Protocol (SVAP)**

The SVAP was designed for the user to make a quick visual assessment of wadeable streams. It incorporates the evaluation of system processes, and can provide information on whether the system is operating within its original set of limiting thresholds.

The method makes several assumptions that must be verified before it is applied to a particular system:

- The system has a stream component.

- The stream follows the CEM when it is degrading due to channel incision.
- The health of the riparian zone can be assessed based on the extent, diversity, and density of vegetation.

The SVAP focuses on the processes found in the stream component of a fluvial system, as it focuses mainly on in channel and near channel conditions. Conditions on floodplains are rated based on plant community health and extent. Thus, fluvial systems that do not have a stream component do not fit neatly into the system. The stream model presented in SVAP is the Schumm CEM. Channel processes that do not follow the assumptions of CEM may provide misleading results. The SVAP does address systems not fitting within the CEM progression because of channel aggradation. However, it does not include an assessment of the floodplain sediment dynamics, including the phenomenon of vertical accretion and the formation of macrotopography, which dominate the function of fluvial system wetlands. The state of the systems hydrology is based on whether the channel geometry is in equilibrium with current discharges. The depth, duration, and movement of water associated with wetland processes in not addressed. As mentioned, the bankfull discharge concept is not pertinent for fluvial systems without a stream component, so SVAP is not directly applicable.

SVAP is a useful tool and can be readily understood by those with limited training in geomorphology, hydrology, or biology. For the large number of fluvial systems that fit within the assumptions listed, the system provides a means for making accurate assessments with a limited amount of effort. The concepts incorporated, including the CEM, are intuitive and readily understood by conservation planners. However, for fluvial systems that fall out of the assumptions listed, other methods of assessment must be used.

2. **Proper functioning condition (PFC)**

The PFC assessment method is one which can be used to assess the condition of all riparian wetland systems. It divides wetland systems into lentic and lotic systems. Lentic systems are those where the water is static, and lotic systems are those associated with moving water.

The PFC method is outlined in the documents *A User Guide to Assessing Proper Functioning Condition and the Supporting Science for Lotic Areas* and *A User Guide to Assessing Proper Functioning Condition and the Supporting Science for Lentic Areas* (ftp://ftp.blm.gov/pub/nstc/techrefs/Final%20 TR%201737-15.pdf).

The assessment of both lentic and lotic systems are based on hydrology, vegetation, and erosion/deposition. One unique advantage of this tool is that it treats fluvial systems containing stream channels and riparian wetlands as a single landscape position. The hydrology of the stream and riparian wetlands are assumed to have a direct effect on each other, and it gives weight to the surface and groundwater interactions between the channel and floodplain. Within the PFC assessment method, the assumption is that a stream channel is associated with a wetland, even though it may be limited to a narrow linear belt green belt along the channel. All systems assessed as lotic systems are assumed to have a stream component. A fluvial system with pronounced flow not having stream morphology does not fit neatly within the PFC assessment procedures. All other HGM wetland types are assumed to be lentic and are assessed as such.

3. Summary of classification and assessment systems

The common classification and assessment systems used today are each based on a single component of a fluvial system and defined on a set of processes that is appropriate for a certain subset of fluvial systems. It is important to note that the popularity and widespread use of the systems indicates their applicability for a broad range of fluvial systems. Each, if applied to a system not featuring the processes, scale, and system component a particular system was designed for, can lead to misleading conclusions. Table 2 provides a comparison of each of these systems based on their scale of applicability, what fluvial system component they apply to, and the information they can provide.

In table 2, the scale decreases from watershed to intermediate to system reach to site scale. The intermediate scale includes the succession of stream reaches needed to describe the spatial extent of the channel evolutionary process in CEM. The other scales should be self-explanatory.

Table 2. Comparison of classification systems

System	Scale	Component	Information derived
Strahler	Watershed	Stream channel	Correlation of order with processes
CEM	Intermediate	Stream channel	Departure from limiting threshold condition
Rosgen	Reach	Stream channel	Restoration template
HGM	Site	RIVERINE wetland	Level of function, hydrodynamic processes
SVAP	Site	Stream/floodplain	Ecological health
PFC	Site	Stream/wetland	Ecological health

Table 2 shows that no system currently exists that covers the longitudinal continuum from headwaters to watershed outlet. No system fully treats the lateral continuum across all fluvial landscapes. No system is capable of treating commonly existing fluvial systems continuums that cannot be defined by all components or combinations of components possible.

Each system has a different set of uses. No system is capable of simultaneously analyzing processes, determining departures from limiting thresholds, assessing the level of function of processes, and providing the user with information on which to base decisions. This should not be taken as a sign that the set available tools is inadequate. It strongly suggests that those making management and planning decisions for fluvial systems be familiar with all the available classification and assessment models that are appropriate and carefully tailor the application of these systems on a site-by-site basis.

Soil hydrodynamics for fluvial systems

There is one physical resource common to all fluvial systems. The processes associated with the formation and maintenance of this resource are closely associated with the processes associated with fluvial system function. This resource is surface soils. The processes involving water, sediment movement, nutrient cycling, vegetative plant communities, and even aquatic organisms are the same as those that define the morphology and hydrodynamics of surface soils.

Soils data can greatly aid in understanding fluvial systems. It provides information on geomorphology and hydrodynamics. The morphological history associated with soil formation is intimately related to the morphological history of the system. It is critical that the soil morphology and the associated hydrodynamics be fully understood. Soils data also provides detailed information on physical properties such as rates of water movement and presence and depth of restrictive layers.

Soils data is readily available from the Web Soil Survey at http://websoilsurvey.nrcs.usda.gov/ and the Soil Data Mart at http://soildatamart.nrcs.usda.gov/.

1. **Soil taxonomy**

Each soil series is assigned a taxonomic name. These names are given based on a large range of properties, or absence of properties. Many of these taxonomic names are interpretative for soil hydrodynamics and morphology. The taxonomic hierarchy is order, suborder, great group, and subgroup.

Two orders are especially pertinent for taxonomic interpretations: Histosols and Entisols. Histosols are organic soils. By definition, they were formed under conditions of near-continuous saturation. Also, by definition, they are hydric (see Hydric soils). The most common source of water creating saturated conditions on Histosols is groundwater, meaning that they are endosaturated. Histosol wetlands described as bogs have direct precipitation as their water source. Entisols are those soils which do not show any distinctive soil horizons. They are commonly placed by wind or flowing water. They are usually young soils that have not been in place long enough to form soil horizons due to weathering and the action of vegetation. In the fluvial landscape position, Entisols were placed by flowing water, and their extent may be used to define the fluvial landscape.

Suborders pertinent to fluvial systems include Aquic, Histic, and Fluvic. Soils in Aquic suborders exist and were formed under saturated conditions. Soils with Histic soil horizons show organic soil attributes to a lesser extent than Histosols, but still indicate the same hydrodynamics and morphology. Fluvic soils were formed by the actions of flowing water.

Great groups with pertinent interpretative names are those with the prefix epi, endo, fluv, fibr, hemi, sapr, histo, aqu, and sphagn.

For detailed information on soil taxonomy, refer to ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/tax. pdf.

2. Hydric soils

The National Technical Committee for Hydric Soils has defined hydric soils as those with the following features (from http://soils.usda.gov/use/hydric/):

1. *All Histels except Folistels and Histosols except Folists. or*

2. *Soils in Aquic suborders, great groups, or subgroups, Albolls suborder, Historthels great group, Histoturbels great group, Andic, Vitrandic, Anpachic subgroups, or Cumulic subgroups that are:*

    a. *somewhat poorly drained with a water table equal to 0.0 ft from the surface during the growing season, or*

    b. *poorly drained or very poorly drained and have either:*

        i. *water table equal to 0.0 ft during the growing season if textures are coarse sand, sand, or fine sand in all layers within 20 in, or, for other soils*

        ii. *water table at less than or equal to 0.5 ft from the surface during the growing season if permeability is equal to or greater than 6.0 in/h in all layers within 20 in, or*

        iii. *water table at less than or equal to 1.0 ft from the surface during the growing season if permeability is less than 6.0 in/h in any layer within 20 in, or*

3. *Soils that are frequently ponded for long duration or very long duration during the growing season, or*

4. *Soils that are frequently flooded for long duration or very long duration during the growing season.*

This criteria includes soils that are not in a fluvial system landscape, but do occur in the remaining HGM wetland types. It does not include all soils that occur in fluvial system landscapes. For example, fluvents would logically be considered to be part of a fluvial landscape, but they are not hydric based on their taxonomy.

Readily available data useful for fluvial systems analysis is included in the Web Soil Survey under water features. This includes the upper and lower limit of water table fluctuations, duration and frequency of ponding and flooding, and months of year that ponding and flooding occurs. The distinction between ponding and flooding in itself is interpretative. Flooding is inundation that is the direct result of high stream stage flowing water. Ponding occurs in depressional areas in the fluvial landscape and continues after the end of the high hydrograph stages. The source of water for ponding may be surface or groundwater.

The great groups assigned the epi and endo modifiers are highly interpretative. Episaturated soils are wet due to surface water and commonly have a low permeability layer that supports a perched water table in the B horizon. The function of the system relies on maintaining the integrity of this layer. Endosaturated soils are wet because of groundwater movement vertically upward or horizontally into the system. The system function relies on the groundwater source and the ability of the soil to move water.

The presence of Histosols in the fluvial system landscape is highly interpretative. Histosols are formed under conditions of near continuous saturation. The saturation creates anaerobic conditions, which greatly diminish or stop the decomposition of the hydrophytic vegetation growing in the system. Since the material does not break down, it builds vertically upward and creates more soil storage volume for the excess groundwater available until an equilibrium point is reached. At this stage, the plant growth, decomposition, and water supply are in equilibrium. When a disturbance causes the level of saturation to decrease, the top layers of organic soil begin to decompose as aerobic bacteria have access. The organic soil is broken down and organic carbon is converted to carbon dioxide gas. Since the vast majority of the soil is made of carbon, this conversion to carbon dioxide causes the soil to disappear over time in a process called mineralization. The physical lowering of the landscape as mineralization occurs is referred to as "subsidence." Because of these phenomena, the presence of organic soils is a direct indicator of a long-term saturation level currently or in the recent past. The first objective in any restoration of these systems is to restore this regime or to raise the water level as high as possible to preserve as much of this soil as possible. In many cases, a water level that is significantly lower than the top surface of organic soils represents a new system threshold condition. If this is the case, it may not be possible to meet the restoration objective.

1. Importance of epi- and endosaturation interpretations

The determination of whether a fluvial landscape is dominated by epi- or endosaturation is critical to making proper decisions for restoration or management. The hydrologic functioning is distinct for each case. Improper assumptions can result in serious detrimental effects.

Episaturation—Figure 17 shows a schematic of an episaturated floodplain macrotopographic feature with the dominant water budget parameters.

A Web Soil Survey aerial map of an episaturated floodplain is shown in figure 18.

This feature is a large cutoff oxbow feature and is a good example of floodplain macrotopography. The soil taxonomy is Epiaquoll. This indicates that this feature is saturated for long periods of time during the growing season and that the dominant water source is from surface flooding. With no further investigation, it can be inferred that groundwater saturation is not a primary dynamic of this system. Lateral connectivity in this fluvial system is maintained by allowing high stream discharges to access the floodplain. Restoration measures for this system must ensure that the stream's capacity and flood frequency are sufficient to maintain the hydrologic connection with the floodplain macrotopographic features.

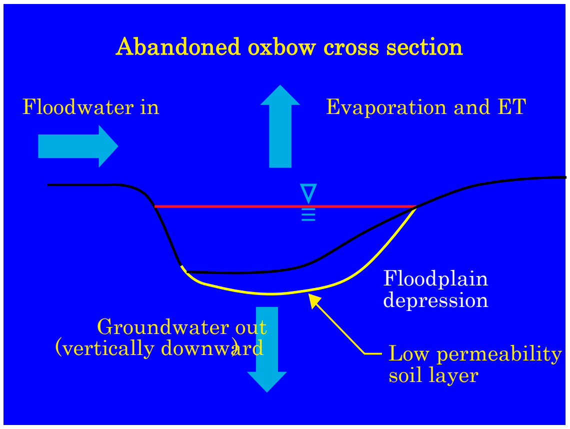

Figure 17. Episaturation floodplain macro feature

Figure 18. Episaturated macro feature

Episaturated soils in a fluvial landscape position commonly feature a low-permeability B soil horizon. In cases where the clay content of this horizon is very high, the epi prefix will be replaced with argi, meaning argyllic. Argyllic horizons are those where the high percentage of clay takes precedence over the episaturated conditions in the soil taxonomic naming rules. In both epi and argi prefixed names, the function of the clay horizon is to maintain a perched water table for a significant period after the stream's flood hydrograph has receded. The steam usually supports an alluvial aquifer, but it is more than 200 centimeters below the floodplain surface by definition and has no connection with the surface. It is the water table perched on top of the low-permeability clay horizon that dominates the surface hydrology. Because of this, the flood duration does not have a significant effect on the wetland function of these features. The instantaneous peak discharge during floods fills these features, and once full, the water is maintained by soil conditions, not the stream water surface. The maintenance or restoration of this soil physical property is the primary consideration to maintain the floodplain function.

Enhancement of macrotopographic features usually focuses on carefully increasing its depth or extent. Care must be taken when performing this activity. Any breach of the soil horizon can effectively "poke a hole" in the feature, allowing the perched water to rapidly drain out. If such a feature is to be created in this landscape, this layer must be provided, similar to providing a clay liner in a waste storage pond.

The formation of the low-permeability B horizon is usually caused by the presence of suspended colloids in the floodwater combined with the actions of hydrophytic vegetation, which grows in this feature. As the horizon gains more and more clay, the hydroperiod is extended, which further increases the formation of clay by extending the time hydrophytic vegetation can act on the soil.

The analysis of stream hydrology is somewhat simplified for these systems. In most cases, instantaneous return period discharges during the growing season are the only needed data. Once the flood hydrograph recedes, the hydrology of the system is dominated by the ability of the soil to percolate water and the evapotranspiration of the vegetative plant community. The analysis can be further simplified if the peak discharges typically occur during the growing season months, as is the case in the Midwest and Plains States.

Endosaturation—Figure 19 shows a schematic of an endosaturated floodplain macrotopographic feature.

Figure 20 shows an aerial soils map from Web Soil Survey with soil map unit 179 highlighted. This soil is classified as an Endoaquoll and is the sole map unit for the length of the fluvial system corridor.

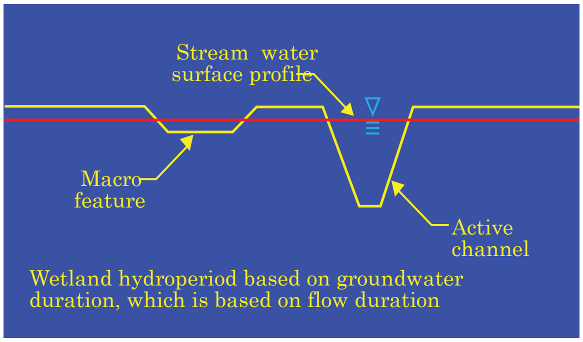

Figure 19. Endosaturated floodplain macro feature

With no other information than this, it can be determined that the floodplain is saturated to near the surface for long periods of time during the growing season and that the saturation comes from groundwater supplied by the stream water surface profile. In this system, maintenance of a water surface profile high enough to support the floodplain groundwater table is critical, and any system restoration measures should maintain this condition. The frequency of surface flooding is not known. However, surface flooding is not the condition that supports the hydrologic function of this system. Additional information that the system is supplied with long-term spring runoff from snowmelt completes the picture. Snowmelt runoff hydrographs lasting for several weeks provide steady, long-term, high-water conditions, which in turn support a high groundwater table. Wetland landscapes require that this saturation occur during the growing season. In figure 20, the green shading indicates that the fluvial system's soil is hydric.

Figure 20. Web Soil Survey map showing endosaturated soil

The effects of endosaturation in these systems are most pronounced in macrotopographic features such as the one shown in figure 21. The systems high groundwater table is supported by the stream water surface located in the background. It is expressed as surface water in the abandoned oxbow feature in the foreground.

In endosaturated systems, there is a high degree of connection between the stream hydrograph and the groundwater table, representing the lateral connectivity function. This connection can be analyzed and correlated as shown in figure 22. The graph plots streamflow versus groundwater level in a floodplain monitoring well in an endosaturated floodplain. The key point is that the duration of groundwater presence correlates with the duration of high streamflow.

The hydrologic analysis of streamflow is more complex than in episaturated systems because the duration of high flows is the important parameter. The duration of wetland conditions in the floodplain is dependent on the duration of the stream water surface.

Endosaturated fluvial systems are drained by providing subsurface drainage, which shortens the flow path for groundwater leaving the system. The subsurface drainage may be either buried conduits or surface ditches that intercept groundwater and convert it to surface flow. Naturally occurring macrotopographic features that have surface water are valuable for many floodplain ecological functions. When the surface water is static, it can be assumed to be at the same elevation as the groundwater adjacent to it. Subsurface drainage (either buried conduits or surface ditches intercepting the water table) lowers the groundwater table by allowing flowing water to leave the system. The original hydrodynamics can be restored by blocking or filling these drainage paths.

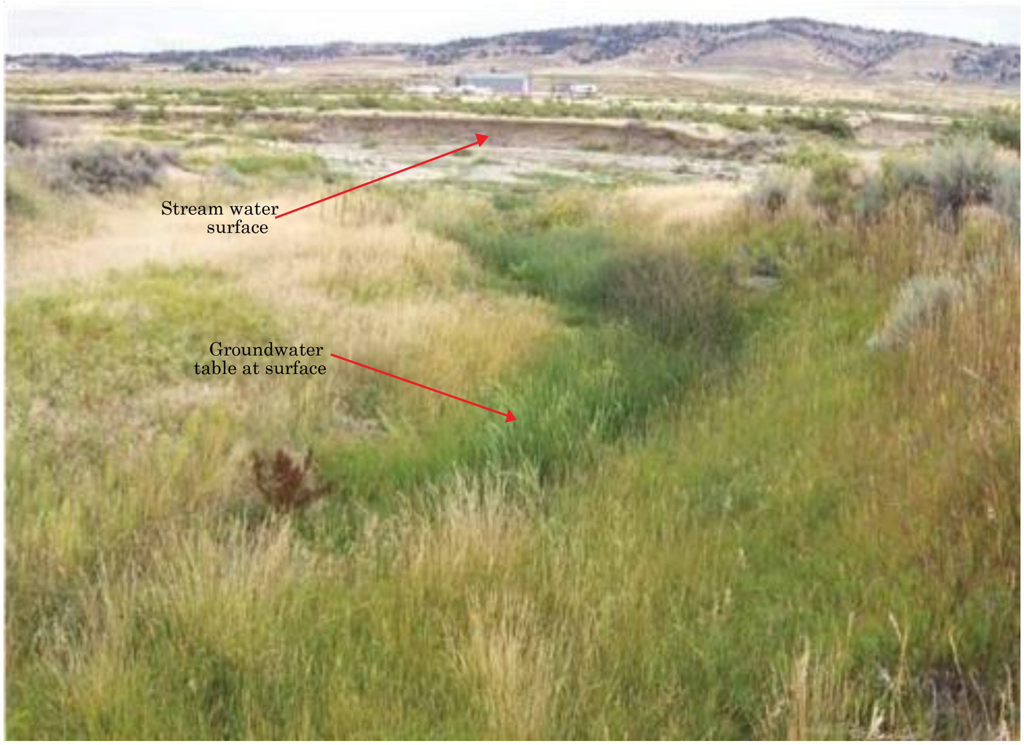

Figure 21. Endosaturated macrotopography feature

The restoration or enhancement of an endosaturated fluvial system must be done carefully. The creation of open water areas by excavation is usually a restoration goal. Any excavation with a bottom grade below the current groundwater level will force the groundwater flow lines to the excavation, at least until the excavation volume is filled. In many cases, the resulting surface flow will fill the excavation and flow out of the system, resulting in a net loss of stored water to the system. For example, a fluvial system that exists as a braided stream channel will often have remnant channel braids in the floodplain. These remnant macrotopographic features can be quite extensive in linear extent, but no surface water is present. The surface water can be exposed by excavation, but the process can essentially create a subsurface drainage ditch and cause a long-term surface flow out of the system. The energy for this flow is provided by the valley gradient. The upper end of the excavation will provide a source for groundwater flow, and the lower end of the ditch will exhibit a level ponded water surface, which spills out of the end and is lost from the system. This situation can be greatly reduced if excavations are conducted such that the bottom grade and elevation at the top of the cut are kept constant. This precludes the use long, linear features. Short, discontinuous excavations can be conducted with bottom grades that decrease at the rate of the valley slope.

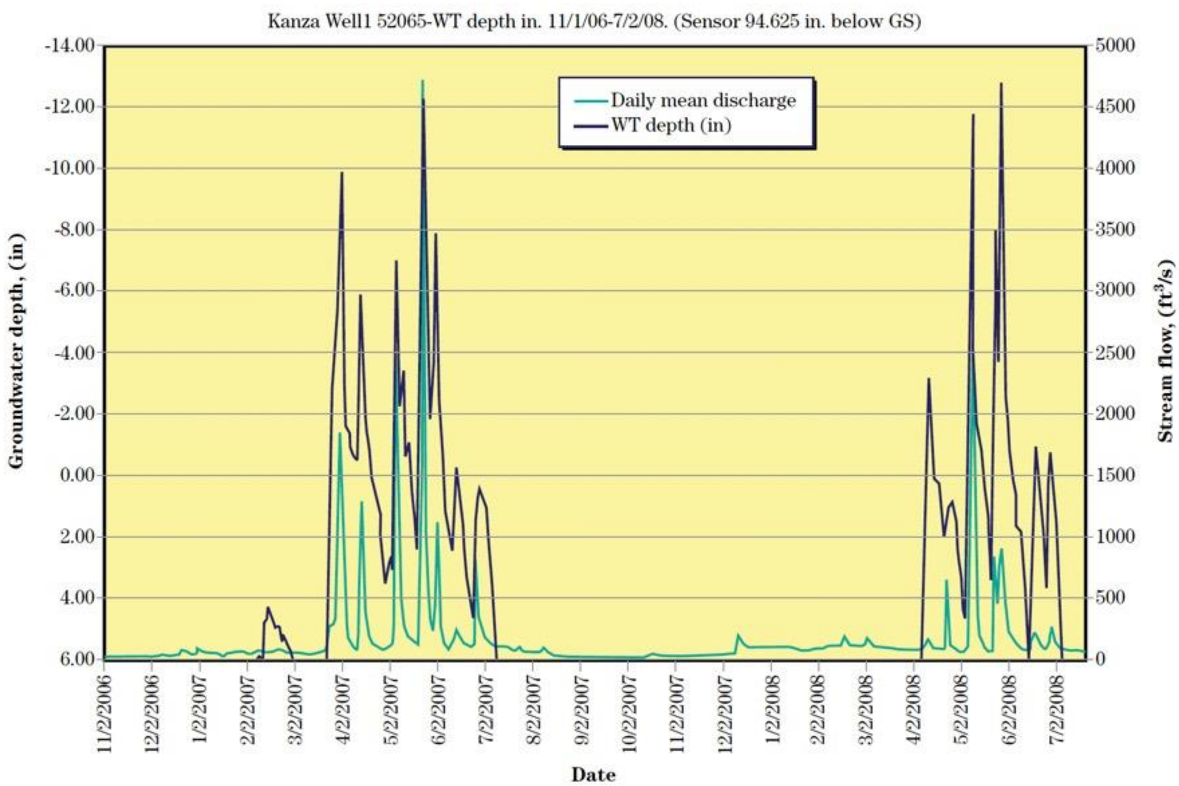

Figure 22. Correlation between streamflow and groundwater level in an endosaturated floodplain

2. Fluvial systems with organic soils (Histosols)

Systems dominated by Histosols are a unique case. The following examples show various systems dominated by the soils and use the previous descriptions for their interpretation.

Example 1

The soil highlighted in figure 23 is Lupton Muck (L), a Histosol.

From the data in figure 23, the soil is organic and was formed under conditions of saturation. Being a Histosol, the dominant water source was most likely groundwater. The soil was formed under conditions that provided a water table that extended to the ground surface for most of the year. Even though it is adjacent to the stream channel, it may not be subject to flooding, but does (or did) experience long-term ponding due to groundwater saturation. Not shown is the system's watershed. It has very flat topography, good vegetative cover, and a large percentage of the area is in Histosols or soils of histic suborders and great groups. For these reasons, the groundwater supply to the system is quite high. The flow stage of the system is (or was) high enough to maintain a continuously high groundwater table, providing surface saturation (or was during the time of soil formation). The system is a third-order stream. The current Rosgen type is estimated to be C or E, although bankfull indicators are not strong.

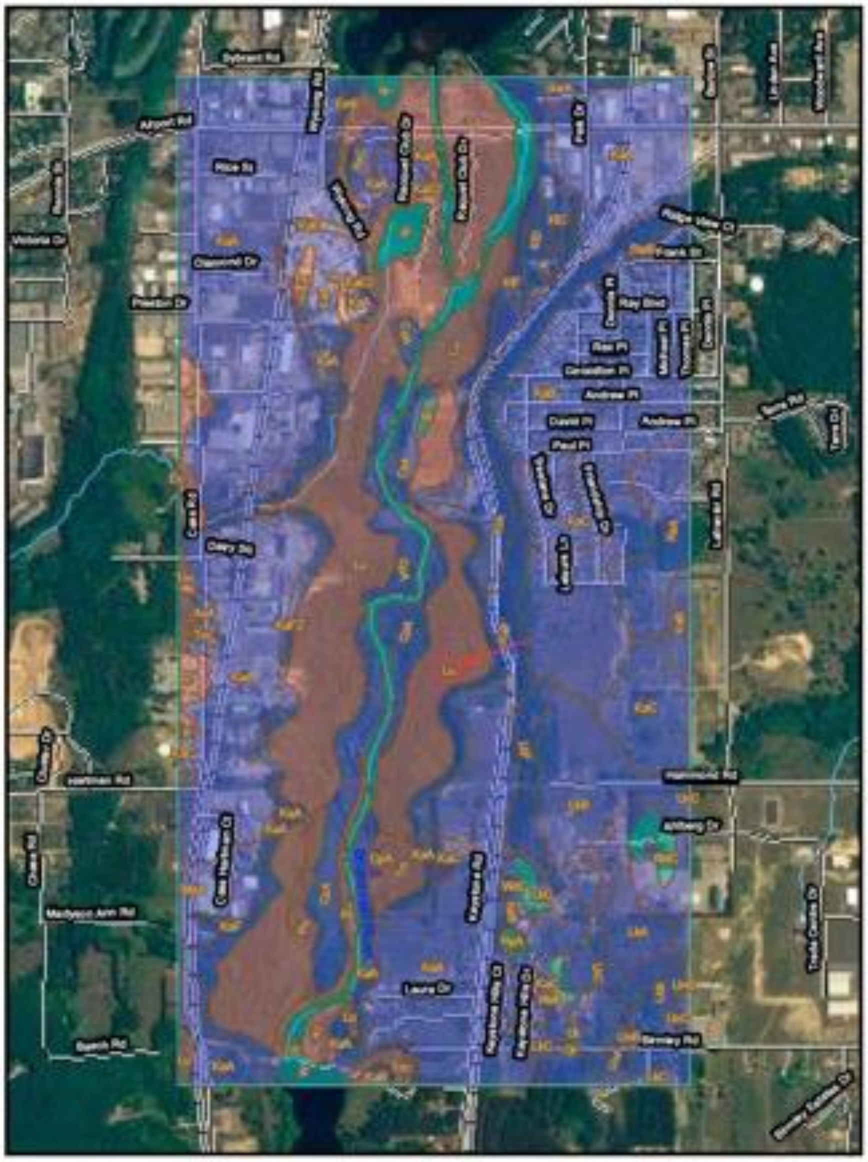

Figure 23. Soil map – hydric soils in green, partially hydric in brown, example 1

The HGM type is either RIVERINE or SLOPE, depending upon the correct determination of whether the system originally exhibited a stream channel with bed and banks. Assuming that stream channel morphology was not part of the original system's geometry, the system exhibits all the criteria for a SLOPE wetland. The main criteria is that the dominant water source is groundwater.

The area is mapped as partially hydric, not hydric. This is because the groundwater regime in existence when the soil was formed is no longer in place. This is a highly interpretative piece of information. It can be inferred that the system is operating within threshold boundaries that were different than those at the time of the formation of the organic soils. The system water surface is lower than at the time the soil was formed. If the objective of a restoration is to restore the original hydrologic regime, the current thresholds must be reset, in this case by raising the entire water surface profile back to past conditions.

The CEM may or may not be appropriate. The given information is not adequate to tell whether the system changed to a new set of thresholds by channel incision. However, the CEM was developed for systems with cohesive soils, and the initial disturbance caused an original stream component to undergo incision. In this case, it must be determined whether the original system had a stream component.

The Rosgen classification system may be used if a suitable reference can be found. Since it has been determined that the system shown is operating within different threshold boundaries than those that formed the current system elements, a stable reference with the same conditions must be found. If the objective is to restore the original hydrologic regime, a reference that is operating within those original threshold boundaries must be found. This can be a significant issue with the use of the Rosgen methodology.

Example 2

Figure 24 shows a similar system similar to example 1 that is a large wetland system with a significant drainage area.

Figure 24 shows an apparent stream channel with a high flow. In reality, there is no discernible break between bed, banks, and floodplain, and the flow area extends several hundred feet to either side of the obvious open water through the tussock sedge vegetation. Although the drainage area is more than 1 square mile, it is classified as a SLOPE wetland in the HGM system and is in very good condition. It is a first- or second-order system and does not fit within any common stream classification system. The area, like the previous example, is dominated by Histosols. Since the system does not have a stream component, no stream classification or assessment system is applicable. The HGM wetland classification system is directly applicable.

Figure 24. Large-scale SLOPE wetland, example 2

Example 3

Figure 25 shows an aerial photo of a drained fluvial system with the same soils and landscape features as example 2. The blue lines show locations of drainage ditches, and the center ditch carries the accumulated drained water downstream. Again, the soils are histic, the fluvial system has a continuous baseflow with no high flows at any time of the year, and the sediment component of the system is very low. It is further instructive to note that the area was drained successfully by installing the perimeter drains to cut off the strong groundwater component. The original system was similar to the one shown in figure 24.

Based on the organic soils and the successful drainage by cutting off the groundwater input, the system is classified as a SLOPE HGM wetland type. The large drainage ditch running through the center of the system (as well as the perimeter ditches) may appear to be stream, but in reality, it is not. It receives virtually no water from surface runoff, and it carries little or no sediment. A project objective may be to establish stream functions in this system within the current system thresholds, but this must be clearly recognized as one that does little to halt the mineralization of the Histosols or restore many of the other original system functions.

Figure 25. Aerial view of drained SLOPE wetland, example 3

Example 4

Figure 26 shows a streambank in a fluvial system that exhibits strong stream morphology features. Note the dark layers in the streambank, which are Histosols. These deposits must have been formed under longterm conditions of surface saturation. The loss of this saturation must have occurred fairly recently, as Histosols mineralize (convert to carbon dioxide) fairly rapidly. Based on this simple analysis, it can be concluded that at some time in the recent past, the fluvial system provided a water surface much closer to the floodplain surface. Also, note the strong interbedcarrying between the dark Histosols and deposits of sandy materials. This can indicate that the system was quite dynamic and prone to frequent shifts of the channel (s) carrying water downstream. Each floodplain location experienced frequent shifts between a high-energy flow regime and a still backwater regime required to form the Histosols.

Figure 26. Organic soil layers exposed in streambank, example 4

Historical research turned up maps dating to the early 1900s developed by the U.S. Geologic Survey (USGS) showing a well-defined stream channel with geometry similar to the single-thread stream existing today. However, written documentation found in Powers (1912) described the conditions at the time logging began in the stream watershed and provided the following account:

> *The next task performed, which proved to be of no small magnitude, was the clearing of the river, so that logs could be floated from the immense tracts of pine on the upper waters. It was not merely here or there that a fallen tree had to be removed. In some places the stream was so completely covered and hidden by a mass of fallen trees and the vegetation which had so taken root and was flourishing on the decaying trunks that no water could be seen. Ten long miles of the channel had to be cleared before the first pine was reached.*

These were the conditions that existed in the 1840s, before surface maps existed. These conditions were responsible for the formation of the large extent of organic soils on the current floodplain. It can be assumed that a large beaver population still existed and that beaver dams also provided a large extent of ponded water in the system.

CONCLUSIONS

There are many tools available to the restoration planner for use in fluvial systems. These tools are designed mainly for use in assessment or classification. None of these tools are comprehensive enough to be applied to all fluvial systems. The planner is challenged to select the appropriate tool or combination of tools needed for use in planning a successful restoration.

Stream and wetland classification and assessment systems can and should be used when appropriate. All have been shown to be useful in the specific fluvial system applications for which they were developed. Careful observation of the systems' soil, water, and vegetative resources combined with all available historical data is required to develop a successful restoration plan. These observations are needed so that the appropriate tools or combinations of tools are selected.

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