CHANNEL CONDITION AND STABILITY INDEX (CCSI): MPCA PROTOCOL FOR ASSESSING THE GEOMORPHIC CONDITION AND STABILITY OF LOW-GRADIENT ALLUVIAL STREAMS

I. PURPOSE

To describe the methods used by the Minnesota Pollution Control Agency's (MPCA) Biological Monitoring Program to assess physical indicators of channel condition and stability during biological sampling for stream assessments. This protocol was developed through consulting other existing channel stability assessments (Pfankuch 1975, Simon and Downes 1995, VANR 2007, Rosgen 2006, Ohio EPA 2007, Magner et al. 2010) and includes modifications that attempt to better characterize physical indicators of channel condition and stability observed in low- to mid-gradient streams in Minnesota.

II. SCOPE/LIMITATIONS

This procedure applies to all river and stream monitoring sites for which Phase I stream assessments are being conducted to assess stream health using fish and macroinvertebrate communities. Additionally, this assessment may be conducted during Phase II Stressor Identification sampling events in order to investigate potential stressors related to a loss of habitat quality and/or water quality (e.g., turbidity).

III. GENERAL INFORMATION

Sites are selected for stream biological assessment for various reasons, 1) EMAP random sampling, 2) intensive watershed surveys, 3) sites selected for the development and calibration of biological criteria, and 4) special investigations of suspected sources of pollution. Although the reasons for assessment vary, this protocol is intended to support the benefits of the intensive watershed surveys.

IV. REQUIREMENTS

A. Qualifications of crew leaders: The crew leader must be a professional aquatic biologist with a minimum of a Bachelor of Science degree in aquatic biology or closely related specialization and basic familiarity with alluvial stream characteristics and concepts in fluvial geomorphology.

B. Qualifications of field technicians/interns: A field technician/intern must have at least one year of college education and coursework in environmental and/or biological science.

C. General qualifications: All personnel conducting this procedure must have the ability to perform rigorous physical activity. Field work may involve hiking and wading in streams under various weather conditions over long time periods.

V. RESPONSIBILITIES

A. Field crew leader: Implement the procedures outlines in the action steps. Ensure that documentation collected meets the objectives and standards of the Biological Monitoring Program.

B. Technicians/interns: Implement the procedures outlined in the action steps, including managing documentation to ensure that it is properly archived.

VI. QUALITY ASSURANCE AND QUALITY CONTROL

The minimum QA/QC requirements for this procedure are as follows:

Verification: A field crew trainer will periodically conduct reviews of field personnel and documentation to ensure that the procedures are followed in accordance with this SOP.

VII. TRAINING

A. All inexperienced personnel will receive instruction from a trainer designated by the program manager. Major revision of this protocol will require that all personnel are informed and retrained as necessary.

B. The field crew trainer will provide instruction in the field and administer a field test to ensure that personnel can execute this procedure.

VIII. ACTION STEPS

A. Equipment list: Verify that a guidance manual, forms, clipboard, pencils, copper probing rod or wooden dowl, measuring tape, camera, and GPS are present before commencement of this procedure. If a Regional Hydraulic Geometry Curve is available for the region of interest, a list of field numbers with corresponding drainage areas (DA in mi^2) of the reaches being sampled and the RHGC will also need to be acquired before heading into the field.

B. Data collection method: The location and length of the sampling reach is determined during site reconnaissance (see SOP—**Reconnaissance Procedures for Initial visit to Stream Monitoring Sites**). The MPCA will be evaluating channel condition and stability during the sampling index period for macroinvertebrates (end of July to early September). Unless otherwise instructed, observations of physical channel condition should be limited to the sampling reach (35 times the mean wetted width, 150m up to 500m). The CCSI should be completed when streams are at or near base flow immediately after macroinvertebrate sampling. Physical stream characteristics are scored using a qualitative and semi-quantitative observation based method (modified from Pfankuch 1975, Simon and Downes 1995, VANR 2007, Rosgen 2006, Magner et al. 2010).

Measuring mechanical shear strength using a probing rod: To learn how to interpret the probe data you will need to spend some time in the field observing and learning from a geomorphologist the art and science of fluvial sediment dynamics, observations, and interpretations.

C. Worksheet: Observations are recorded on the ***Channel Condition and Stability Index*** (CCSI) field form. A copy of the form is attached (Table D-2) and guidelines for filling out the worksheet are described in this document.

The following items are filled out on the modified CCSI worksheet as follows:

C.1. Stream Documentation

A) *Field Number* – The designated MPCA site ID associated with the reach. This is a seven-digit code that uniquely identifies the station. The first two digits identify the first year the reach was sampled, the second two identify the major river basin and the last three are numerically assigned in sequential order (example: 98SC032).

B) *Stream* – The name of the stream from the AUID shapefile, most recent USGS topographic map, or county plat map.

C) *Date* – The date associated with completion of the CCSI assessment in month/day/year format (MM/DD/YY).

D) *Staff* – The name(s) of the personnel completing the CCSI assessment.

E) *Potential stream type* – The potential stream type using Rosgen Classification

F) *Total score* – The score for the site after all metric components have been evaluated and tabulated.

G) *Metrics and scoring* - Individual metrics comprising each of these regions and versions of the CCSI worksheet are included and described in the following section.

In addition to the CCSI metrics, a few additional observations will be recorded on the backside of the form to aid in channel typing: measurements of a *channel cross-section* and *substrate composition*. This information can be used by a Phase II assessor to characterize the stream using the Rosgen Stream Classification (1994).

Estimation of bankfull flow – A relatively close estimation of the bankfull flow line (1.5 RI flow) is needed in order to properly assess the CCSI metrics for Upper Banks verses Lower Banks and for determining the CEM stages observed. A RHGC developed for the region of interest, if available, will greatly assist in locating the height of bankfull. Before heading to the field, see if an RHGC has been developed for the region in which biological surveys are being conducted. Note: If a RHGC is available, it will also be necessary to have the DA (units in mi^2) of the surveyed reaches prior to heading into the field.

When in the field, use the DA of the reach to find the expected cross-sectional area (CSA) on the RHGC. After the CSA is determined, locate a riffle within or just upstream of the survey reach or, if there is no riffle, find the straightest, narrowest, and shallowest area of the reach. Besides cobble and boulder, riffles can also be comprised of gravel and larger sand particles. In sand and gravel bed streams, a shallow area with slightly faster flow can produce areas of clean gravel substrates. In low gradient sinuous streams, this type of morphology is generally found between two meander bends and is referred to here as a “cross-over” where the thalweg shifts location from one bank to another (VANR 2007). At the riffle or cross-over, see if you can first see any indicators of the bank-full flow line. Indicators of annual high flow may include: lateral banks with new deposition; the root line of willow, alder, or other riparian vegetation; stain lines on rocks (Harrelson et al. 1994) and inflection points along banks. To locate these bankfull indicators when tall grasses are dense, walk the bank and note the location of bank inflection which may indicate an active terrace or an abandoned floodplain terrace. Look for and note these locations as you are sampling for macroinvertebrates or conducting a pebble count.

Channel cross-section – After bankfull indicators have been located, estimate the bankfull width (BfW)and bankfull mean depth (MeanBfD). Compute the cross-sectional area (CSA) and then compare the field estimated CSA to the CSA on the RHGC. If the two CSAs are in agreement, record the cross-sectional dimensions on the backside of the worksheet and illustrate the cross-section with terraces and floodplain. Draw a line for the height of bankfull and check the box for the version of the curve that was used. If the instream bankfull indicators and bankfull flow line determined by using the RHGC are not in agreement, first see if when you adjust the bankfull height to correspond to the dimensions of the RHGC if you are able to find agreement with other bankfull indicators.. Be mindful that the stream may be incised or is under the influence of upstream or downstream wetland and lake storage that may cause the infield CSA to not perfectly match the CSA from the RHGC. In this case, it is acceptable that the infield CSA does not match the CSA of the RHGC. Note where the bankfull flow line falls in the field. This will be needed to assess the conditions of the UPPER BANKS verses the LOWER BANKS.

Substrate composition (%) - Conduct a pebble count or visually characterize the percent of substrate types observed in the spaces provided. Both mineral and organic fractions of the substrate are estimated. This information can be used to understand inherent differences in biological communities or habitat quality given the availability of coarse substrates and size classes or limitations to habitat potential due to high prevalence of silt. The substrate composition can also be used to characterize the stream using the Rosgen Stream Classification. Woody debris and muck are included here for Stressor Identification, since a large percentage of these organic materials can decompose and influence dissolved oxygen.

For reference, the substrate types are included below using the size descriptions from VANR (2007). The traditional pebble count sizes are modified here for a basic level generalization of substrate size for stream classification (Rosgen 1996) and habitat quality assessment (Kaufmann and Robison 1998):

<u>Bedrock</u>: larger than a car (Volkwagen Bug)

<u>Boulder</u>: >256mm (basketball to Volkswagen Bug)

<u>Cobble</u>: 64 – 256 mm (tennis ball to basketball)

<u>Coarse Gravel</u>: 16-64 mm (marble to tennis ball)

<u>Fine Gravel</u>: 2 to 16 mm (peppercorn to marble)

<u>Sand</u>: <2 mm (smaller than a peppercorn)

<u>Silt</u>: fine inorganic material that is dark brown and slightly gritty and greasy to the touch (smaller than sand). Will not hold its shape when compacted into a ball.

<u>Clay</u>: fine inorganic material that can form a ball and will hold its shape when pressed into a ball or band.

<u>WD/Detritus</u>: organic matter that forms a sizeable layer on the bottom to be considered part of the substrate composition (e.g., wetland with decomposing vegetation or stream with high volume of woody debris).

<u>Muck</u>: black, organic matter that is in the final stages of decomposition. Visual particles of muck will disintegrate when rubbed between fingers. Muck is typically found in channels through or downstream of wetlands.

General Comments – Describe stream observations on the general condition of the channel and riparian areas. Record if there were photos taken of conditions observed.

Guidance Manual for the Channel Condition and Stability Index

The Channel Condition and Stream Stability Index (CCSI) presented here is designed to be a fast and cost-effective qualitative screening tool that will be informative to staff involved in condition assessment and Stressor Identification (EPA 2002) of biological and chemical impairments. This protocol was developed through consulting existing channel stability assessments (Pfankuch 1975; Simon and Downes 1995; Rosgen 2006; VANR 2007; Magner et al. 2010) and includes modifications that attempt to better characterize physical indicators of channel condition and stability observed in low- to mid-gradient streams in Minnesota. The CCSI guidance manual provides a background in channel stability concepts and detailed descriptions of each metric.

Regional application

The CCSI was developed using generally low-gradient (< 2% channel slope) alluvial streams in geologic regions in Minnesota that are carved into deposits of loess, glacial outwash, and glacial till. These streams are typically comprised of finer materials such as silt, clay, sand, gravel with occasional cobble and boulder. Low-gradient, alluvial streams continue to rework the bottom sediment as they meander back and forth within their belt width over time and build low-flow channels and inner berms. The metrics are designed to detect local and watershed alterations that lead to aggradation or degradation. Due to the nature of fine, easily eroded and transported sediment that typically comprise the bed and banks, these low-gradient alluvial streams are generally more sensitive to changes in watershed hydrology and adjacent riparian vegetation than streams cutting through sedimentary limestone, carbonaceous rock, or bedrock. However, other stream types do occur in Minnesota, and refinement of the current CCSI may need to be considered and applied which includes basic level stream typing, metric scoring modifications or alternative stability indices.

This version (2013) of the CCSI herein uses an original stream classification scheme that broadly characterizes stream types in Minnesota. This was done in order to advance the process of understanding the metrics and scoring modifications that may be required to characterize different stream types and inherent sensitivity to watershed or local disturbance and corresponding ratings of stability. The stream types are as follows:

1. **Higher-Gradient, Boulder/Cobble (HBC)** – Uncommon. Mostly found in Lake Superior Basin. Higher gradient streams with bedrock/boulder/cobble stream banks and/or bottom. Step-pool or plunge pool morphology in bedrock streams or long riffles (>50% of reach) in boulder/cobble dominated streams. Tend to be very stable, although increases in discharge from changes in watershed land use or uncharacteristically large rain events can make conditions unfavorable for fish eggs and YOY fish and certain macroinvertebrates taxa that are poorly equipped to cling on rocks or woody debris under high velocity conditions.
2. **Moderate-Gradient, High/Low Banks (MHL)** – Common. Moderate gradient, meandering, alluvial channels where the outside bend may have a higher bank than the depositional inside bend. Typically pool-riffle-run morphology with substrates comprised of cobble, gravel, sand or silt. Riffles typically present (5% -40% of reach).
3. **Low-Gradient, Low Banks (LGL)** – Fairly common. Meandering wetland or low-gradient stream with no or very low banks typically comprised of organic material (muck, detritus) or silt. Often lack riffle habitat (0 – 5% of reach). Substrate typically sand, silt or muck.
4. **Trapezoidal Channel (TC)** – Common. Streams that are mechanically channelized, typically with high banks on both sides of channel. Typically lack depth variability, no riffle habitat.
5. **Trapezoidal Channel, Recovering (TCR)** – Somewhat common. Streams that are mechanically channelized, but may not have been re-dredged in recent years allowing some habitat recovery. Stream may have a slightly meandering thalweg with inner berms and point bars present, or, at least some depth variability forming with the potential of riffle (0-15%) or pool habitat providing some flow variability.
6. **Channelized, Low-Gradient, low-banks (CLGL)** – Fairly common. Streams that are mechanically channelized through a wetland or low-gradient stream. Generally have low or no banks with emergent vegetation in channel. Banks typically comprised of organic material (detritus, muck) or silt. Often do not have riffle habitat (0-5%).

Training in Field Methods and Regional Context

The ability to distinguish between natural stream conditions and indicators of channel instability or disequilibrium (excess aggradation or degradation) requires more than one training event to develop. The trainings should involve readings and presentations on the basic principles of fluvial geomorphology and infield training with an experienced geomorphologist. The streams selected for training should include a range of stream sizes and types that a trainee will likely assess during that sampling year. Visiting multiple locations with a trained geomorphologist will assist the assessor in developing a perspective on what constitutes a stable verses an unstable channel under different geologic settings, climate regime, stream manipulation practices (i.e., channelization or damming) and scale (i.e. small or large rivers).

Initial Field Observations Prior to Rating the Assessment

A Channel Evolution Model (CEM) has also been included as part of the assessment process. Understanding the concepts and controls of the CEM will aid the assessor in determining whether conditions are considered part of the natural process of stream migration or are considered indicators of instability. Before starting the assessment, an assessor should first walk the stream and observe indicators of aggradation or degradation i.e., whether or not the sediment supply is in equilibrium with the sediment transport capacity.

The Channel Evolution Model (CEM)

Disequilibrium and channel instability occur when watershed disturbances are collectively magnified in the hydrologic regime and expressed in the channel. Disequilibrium often results in a change in stream gradient and/or sediment transport capacity (see Figure 1).

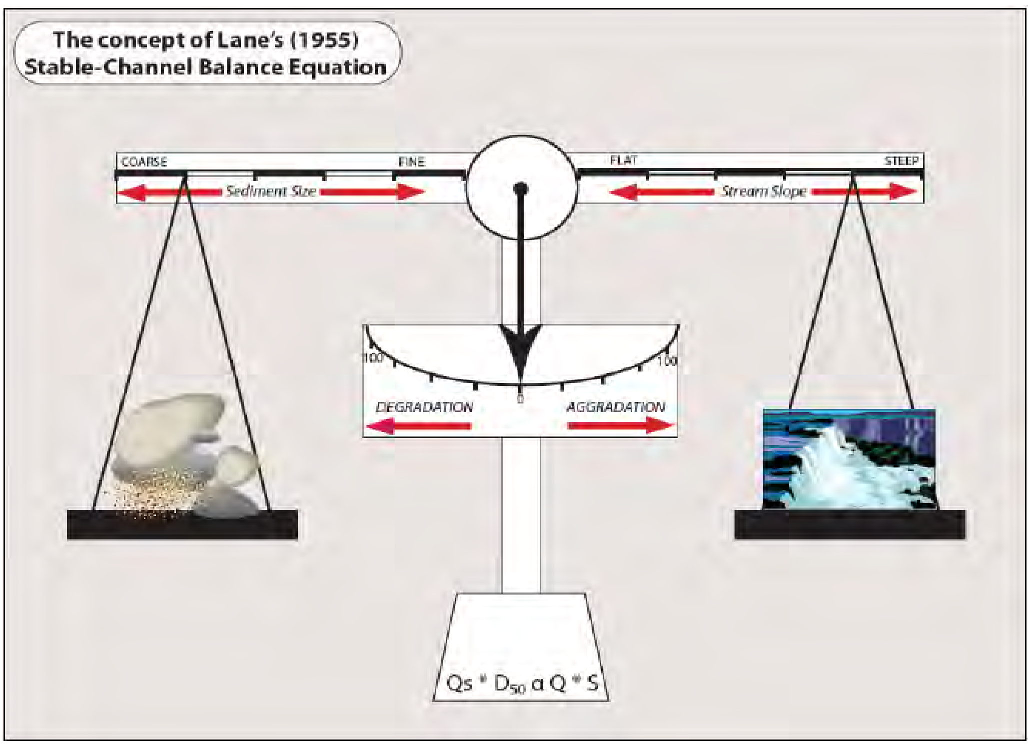
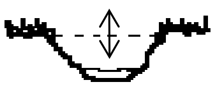
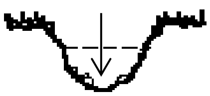
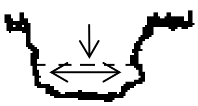
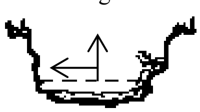
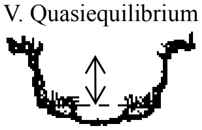


Figure 1. Lane's Balance (1955) demonstrating that a stream is considered in equilibrium when either the stream slope or flow volume are in balance with either the sediment supply or particle size. Figure adapted from Rosgen (2006) and recreated by B. Suppes. Permission granted by B. Suppes.

When the stream's ability to resist morphological changes is pushed past a natural background threshold, a stream may adjust its pattern (e.g., sinuosity), dimension (width and depth of cross-section), and profile (gradient, and longitudinal sequence of pool, riffle, run and relative depth) in order to accommodate the new regime being imposed (Rosgen 1996). In Minnesota, the new regime is often an increase in discharge (Q) from changes in land use, land cover, or climate change. Morphological changes in the stream's hydraulic geometry have been observed and described in channel evolution models (e.g., Schumm et al. 1984, Simon 1989, Rosgen 1996). These morphological changes may be observed in a longitudinal succession as knickpoints migrate upstream, or when a disturbance (channelization or stream alignment next to bridges) alters the local stream gradient and sediment transport capacity.

Table 1. Channel Evolution Model (CEM) stages. Modified from Schumm et al. (1984) and Thorne (1999).

I. Sinuous, premodified 	**I. Pre-adjustment** – Channel is in regime (processes of degradation and aggradation may occur between spring and fall, but remain overall consistent year to year and in balance). Channel exhibits little evidence of excessive bank erosion and cutting. For sinuous alluvial streams, the outside bends demonstrate some bank erosion and the inside bends some deposition. However, the degree of bank erosion and deposition is in balance and is characteristic of the natural hydrologic regime of alluvial streams.
II. Degradation 	**II. Degradation/Widening** – An increase in channel slope, discharge or decrease in sediment supply has tipped the scale toward degradation. The channel cross-section is deepening due to excess scouring. Channel has disconnected from the floodplain. Bank erosion and cutting is excessive along the inside and outside bends. Bank angles are starting to steepen. Trees may be seen leaning into the stream from one or both sides of the channel. Note: Degradation may not be observed when coarse substrates are armoring the channel bottom. In this case, channel widening will be the dominant process. Cutting along both banks may be observed.
III. Degradation and widening 	**III. Widening and Aggradation** – Banks have steepened to the point where the banks are destabilized and are collapsing. Cutting may be observed along one or both banks. New tree fall or areas of mass wasting/bank failure may also be observed. At this stage, the channel cross-section is overwidened and consequently, sediment transport capacity is reduced leading to excess aggradation in pools and runs.
IV. Aggradation and widening 	**IV. Thalweg Channel Adjustment** – During this stage, the stream may be re-developing a thalweg on the outside bend and a depositional bar on the inside bend. Consequently, some degree of cutting and bank collapse may still be observed as flow is directed along the outside bend by the developing point bar (Thorne 1999).
V. Quasiequilibrium 	**V. New Dynamic Equilibrium** – Thalweg reformed, banks stable, and sand bars revegetated. Smaller floodplain within active channel. Old terraces may be visible. Seasonal periods of degradation and aggradation are occurring; however, no net degradation or aggradation observed. Channel is once again in regime. However, due to the lower base level and channel confinement by relic terraces, stream is sensitive to high flows.

Note: The morphological adjustments observed may alternate back and forth between CEM stages within a given reach. For example, where coarse substrates are available and concentrated intermittently along the channel bottom, the stream may not have the ability to down-cut but will widen instead (CEM III). Where coarse substrates are not available, the stream may downcut considerably (CEM II) before breaching a critical bank repose angle at which point bank collapse could occur.

Channel Condition and Stability Assessment (CCSI) Metrics

The CCSI metrics rate channel stability indicators as they relate to channel form, function, and sediment continuity. The design of the CCSI worksheet and manual follows the Pfankuch guidance manual (Pfankuch 1975). Metrics from other channel stability assessments were consulted and incorporated into this assessment (Simon and Downes 1995, VANR 2007, Rosgen 2006, Ohio EPA 2007, Magner et al. 2010). Modifications to the original metrics and the scoring process have been introduced to broadly characterize stream conditions observed in Minnesota. Further research is needed to define the reference condition for various stream types so that calibration of scores and stability ratings will more accurately reflect deviations from the regional expectation. For some stream types in certain regions, the reference condition in the absence of hydrologic change due to changes in the rate of watershed evapotranspiration (e.g., perennial to annual crops) and/or hydrologic manipulation (e.g., drain tiling, storm drains, increase in impervious) may not be readily available, so a general interpretation on the conditions of stability will need to be matched with more detailed geomorphic surveys when feasible.

The CCSI rates current conditions related to channel form, function, and sediment continuity. Similarly to the PSI, the CCSI evaluates three regions of the channel and attendant floodplain: Upper banks, Lower Banks, and Bottom. Associated with each assessment region are individual metrics that score the ability of the stream channel to dissipate flow, resist detachment of bed and bank materials, and transport its annual sediment load. The magnitude of hydraulic forces that are at work during stream flows (< 2-yr RI) and the capacity of the stream to move sediment, will determine if the channel is stable or unstable.

There are 12 metrics. Make sure you are assessing the correct region for each metric (Figure 2). Each metric has 5 rating categories (excellent, good, fair, poor, very poor). The scoring strategy is intended to separate good sites from poor sites while allowing for sites that are in-between to be classified as moderately unstable (not good, not poor). Please note: The ratings provided were developed to rate 2nd to 4th order stream reaches. When scoring a 5th or 6th order stream, the metric scoring strategy may need to be rescaled using best professional judgment.

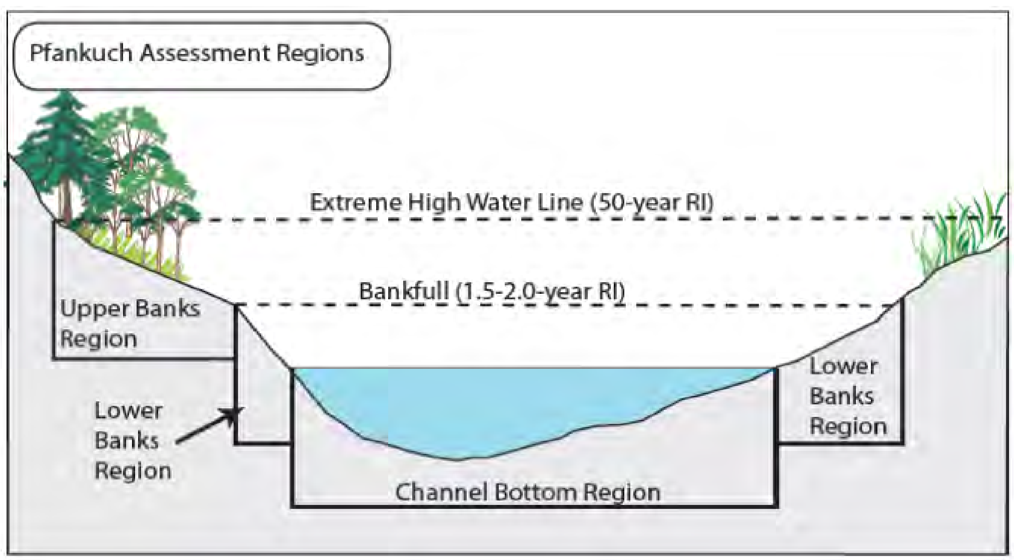


Figure 2. The three assessment regions. Illustration modified from Pfankuch (1975) by B. Suppes. Permission granted by B. Suppes.

The three assessment zones are broadly defined as follows:

Upper banks – The region above what is estimated as the bankfull flow (1.5-yr RI) (normal high water line to extreme high water line). In non-incised streams, this zone is the attendant floodplain that extends back to the valley wall, if present. In incised streams, this zone is above the bankfull flow line as indicated by high flow indicators (e.g., debris in tree limbs, inflection point on banks, height of depositional features) and verified with a regional hydraulic geometry curve.

Lower banks – The region between base-flow (indicated by water or at what is considered normal summer flow) and bankfull flow (1.5 to 2 yr RI flow, or high water line). This region is regularly submerged during annual high flow and generally becomes visible when flows reduce to seasonal base-flow. The metrics assess the ability of the banks to withstand the erosive force of high flows (i.e., the shear strength of the bank material to resist erosion). Additionally, the depositional metrics are used to infer whether the channel does not currently have the transport capacity to carry away the annual sediment load (e.g., when a stream cross-section is overwidened) or if the sediment load to the stream is overburdening the current transport capacity (e.g., when overland erosion has increased do to land use practices or from unstable stream banks upstream).

Bottom - The bottom or bed of the channel. This is the portion of the channel that encompasses the wetted width during base-flow (channel bottom to base-flow flow line indicated by water in the figure above). The metrics assess the degree to which the bottom substrates are resistant to movement by scouring flow, evidence of recent mobilization during annual high flow events, evidence of excess sediment in pools, and whether lateral riffles or tree limbs are positioned such that flow is directed into the banks causing erosion. Lateral riffles are also a sign that the erosive force of the annual high flow has increased in recent times and is therefore an indicator of instability (i.e., excess degradation).

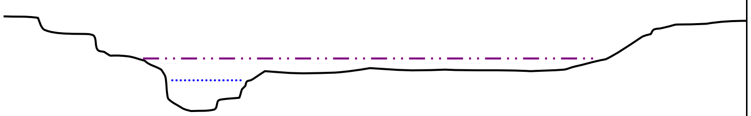
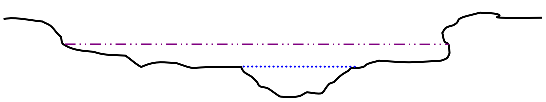
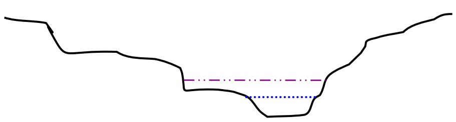
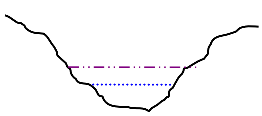
UPPER BANKS

This region is immediately adjacent to the channel and tends to be primarily a terrestrial environment. However, during high flows (1.5-yr RI or greater), this area can be inundated with water during which the stream flow interacts with trees, downed limbs, and upper bank vegetation. This zone is scored by assessing the degree to which energy from higher than annual flows has the opportunity to dissipate over the adjacent floodplain as well as the type and condition of vegetation available to protect banks and capture excess sediment and nutrients.

Intermediate Floodprone Width

The original Pfankuch (1975) metric assesses the degree of *landform slope* adjacent to the stream channel. This metric has been modified herein to rate the degree of floodplain connectivity for low-gradient streams (<2% channel slope). Floodplain connectivity is the interaction between the stream channel and the attendant floodplain (Kondolf et al. 2006). The *intermediate floodprone width* is defined as the ability of high flows to access attendant floodplains and dissipate erosive energy of relatively frequent high flow events (approximately 1.5 year RI to 10 year RI flows) and utilize the ecological benefits of healthy riparian vegetation to attenuate nutrients and sediment; or, the degree that similar flood-flow would be constrained within the bankfull cross-section and valley walls by relict terraces, modified bank heights (levies, retaining walls), or mechanical dredging and channelization. Ohio EPA (2009) characterize floodprone width targets for low gradient streams using three different flow heights in order to "reveal floodplain characteristics at low stages that have a strong influence on ecological services and riparian quality (Figure 1.5, Mecklenburg and Fey 2011)". Mecklenburg and Fey (2011) measure the high-flow stage using Rosgen's ER ($2xBfD_{max}$), the intermediate stage is measured at 1.5x bankfull max depth ($1.5xBfD_{max}$), and the low-flow stage is the bankfull flow ($1.0xBfD_{max}$). While the ER and bankfull flow are typically measured for geomorphic surveys, the intermediate flow is not. Mecklenburg and Fey (2011) consider the intermediate flow as being ecologically beneficial in that this is a more frequent flow (~5 to 10 yr RI) that can provide nutrient and sediment attenuation when this zone is inundated by high flows. A lack of a well-connected floodplain at this height may be identified as a cause of biological stress related to water quality and habitat issues related to excess nutrients and sediment as well as unstable habitat zones (e.g., mobilized rocks). Hence, this intermediate flood stage has been incorporated into the CCSI assessment (Table 2).

Table 2. Diagrams of cross-sections with the bankfull flow line (blue dotted line) and the *intermediate floodprone width* (purple dashed line) with descriptions of the metric ratings.

	**Excellent:** The ratio of the *intermediate floodprone width* (IntFpW) at 1.5 times the bankfull max height (1.5xBfH) to the bankfull width (BfW) is greater than 10 [IntFpW >10.0 x BfW]. For these streams, the floodplain is connected at bankfull flow and the energy from overbank flows (2-10 yrs) is largely dissipated. During extreme flood events the channel is likely to maintain existing channel dimensions with little sign of channel instability post-flooding.
	**Good:** These are fairly stable streams where the floodplain is connected at bankfull flow and the energy from overbank flows (2-10 yrs) is largely dissipated; however, high flows are slightly confined during very high flow events. A stream that is in the process of downcutting may still have a relatively high intermediate floodprone width ratio; however, when terraces are present, the small degree of confinement that now occurs may concentrate higher flows within a smaller area thereby increasing sediment transport capacity potentially resulting in an increase in scouring of bottom substrates.
	**Fair:** The ratio of the intermediate floodplain width at 1.5 times the bankfull height to the bankfull width is 3.0 to 5.0. This could apply where streams are beginning to downcut and adjust or where channels have downcut and adjusted but are still confined by relict terraces. Overbank flows at this stage may cause some minor channel adjustments during regular high flow events.
	**Poor:** The ratio of the intermediate floodprone width at 1.5 times the bankfull height to the bankfull width is 1.5 to 3.0. This could occur where channelized streams have adjusted to include a small connected floodplain within the trapezoidal cross-section or in a deeply incised stream that is confined by relict terraces. However, with this small floodplain there is still some limited benefit of sediment and nutrient attenuation by vegetation during overbank flows.
	**Very Poor:** The ratio of intermediate floodprone width at 1.5 x bankfull height to bankfull width is <1.5. This would largely apply to a very incised stream or mechanically channelized streams where the channel has not adjusted or is just beginning to introduce a low-floodplain within the trapezoidal cross-section. Ecologically, there is little opportunity for floodplain attenuation of nutrients or sediments.

Degree of Incision

This metric is not in the original Pfankuch (1975) but has been added to the CCSI. This metric assesses the degree to which higher than 1.5 RI flows are contained and magnified within a channel with a lower base-level due to downcutting (due to mechanical or hydrologic processes).

Incised streams that have down-cut to a lower base elevation will have contained flow that now erodes material below the observed top-of-bank. Evidence of this occurrence may be slumps of grass within the stream (greater than 1 meter by 1 meter), trees that have fallen into the stream from flows scouring below roots and undermining banks, and exposed soil surfaces between areas that still have vegetation overhanging banks.

In some instances, the degree of incision may not be uniform throughout the length of the reach. If this occurs, score one area of the reach and then score the other area. Afterward, average the scores and take note of this difference upstream/downstream in the UPPER BANK comments.

Table 3. Diagrams of channel cross sections indicating the low bank height (LBH, green dotted line) and the bankfull height (blue dashed line) and descriptions of the ratings for the CCSI metric *degree of incision.*

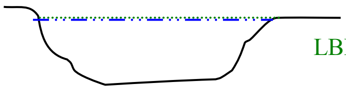
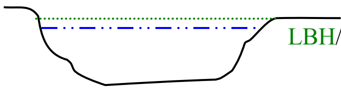
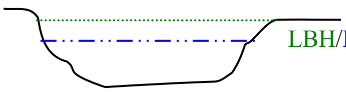
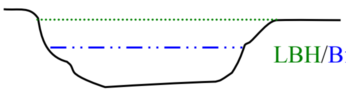
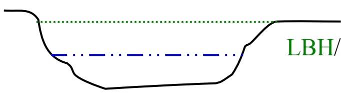
 LBH/BfH = 1-1.05	**Excellent:** Channel has access to floodplain regularly at bankfull flow (1.5 RI). Flow energy largely diminished during high flows. Low Bank Height (LBH) to Bankfull Height (BfH) ratio = 1 to 1.05
 LBH/BfH = 1.05 – 1.2	**Good:** Channel has access to floodplain in larger than 1.5 RI flows, but may no longer during annual or bi-annual flows. LBH/BfH = 1.05 to 1.2
 LBH/BfH = 1.2 – 1.3	**Moderate:** Channel is incised. Annual flows and some larger no longer accessing floodplain. Flows concentrated and downcutting likely. LBH/BfH = 1.2 to 1.3
 LBH/BfH = 1.3 – 1.4	**Poor:** Channel is severely incised. Cutting along both banks obvious. Critical height of bank surpassed, mass wasting /bank failure observed or likely. LBH/BfH = 1.3 to 1.4
 LBH/BfH = 1.4 – 1.5	**Very Poor:** Channel is deeply incised. Higher flows frequently contained and likely cause severe cutting on both banks and excess scouring on bottom. LBH/BfH > 1.5

Figure 3. Field example of *Degree of Incision*

Vegetative Bank Protection

Upper bank vegetation is considered anything above bankfull flow that is likely to support and maintain the integrity of the channel form. Consider bank vegetation from the bankfull flow line to at least 20 feet from the flow line, as a general rule. This metric assesses the degree that plant or tree roots are stabilizing banks and holding soil in place. Trees and shrubs generally have deeper roots than grasses and forbs. However, prairie grasses and the invasive Reed Canary Grass have very deep root systems (>12 inches) that can contribute greatly to the level of bank protection.

Activities within the riparian zone can introduce less protective, shallow-rooted vegetation (animal grazing, lawn care, golf-courses) or clear the banks of protective vegetation (dense grazing, row-crop cultivation). Consequently, the reduction in root protection can destabilize banks and lead to bank collapse. Consider the underling root depth, density, and amount of exposed soil within the riparian zone adjacent to the stream channel (within 10m) when scoring this metric. When scoring this metric, consider only the outside bends or banks that would likely experience erosive flow (not inside, depositional areas).

In addition to bank protection and stabilization, vegetation can also benefit the stream channel by dampening erosive overbank flows and reducing the velocity. The greater the density of stable trees and grasses along the banks, the greater the resistance to flow. Another factor to consider when scoring this metric is the variety and vigor of the vegetation being assessed. Vegetative variety and vigor (mixture of trees, shrubs, and grasses) afford greater bank protection than old decaying trees and sparse grass stands.

Excellent – Trees, shrubs, grasses and forbs together cover more than 90% of the ground. Openings in this cover exposing bare soil are rarely found or are small and evenly dispersed. A variety of species and age classes suggest a dense and vigorous soil binding root mass.

Good – Trees, shrubs, grasses and forbs cover 70 to 90 % of the ground. Shrub species and shallower grasses may be more prevalent than trees and deep rooted grasses. Openings in the ground cover are occasional but of fair size to be easily observed.

Fair – Plant cover ranges from 50 to 70%. Occasional deep rooted vegetation present, but most vegetation is shallow rooted and/or large bare spots are visible. There may be a lack of cover due to extensive shading by trees, dead vegetation or activities within the riparian zone (e.g., grazing, landscaping, row crops, etc).

Poor – 25-50% of the ground is covered with vegetation. Deep rooted vegetation is essentially absent or exists in scattered, discontinuous clumps. Shallow rooted vegetation is pulled loose from soil easily. Overall, vegetation provides little soil binding bank protection. Riparian land use will play a large role in the vegetative management.

Very Poor – <25% of the ground is covered with vegetation. Majority of ground bare or comprised of shallow-rooted grass or perennials. Little or no bank protection from vegetation.

Mass Wasting or Bank Failure (recent)

In the Pfankuch (1975), this metric assesses the existing and future potential of soil detachment and evidence of large landslide events. We have modified this metric here to account for only relatively recent events that may have occurred within the same year or previous year prior to the assessment and modified the characterization to account for smaller but still significant bank failures that may contribute excess sediment to stream channels.

In assessing this metric, consider the height of bankfull flow and the likelihood for sediment from nearby unstable banks to be carried into the stream channel during baseflow as well as high flow conditions. In meandering streams, focus the assessment to the outside bends that are likely to show signs of mass wasting and bank failure due to their exposure to the most erosive energy of higher flows. Where riparian is disturbed (e.g., grazing), evidence of mass wasting/bank failure may also be observed along the inside bends. Rate the occurrence and magnitude of areas of mass wasting/bank failure as follows:

Excellent - There is little or no evidence of mass wasting/bank failure that has occurred recently.

Good - There is evidence of infrequent (1 to 2 medium) and/or very small slumps (3 to 4). Occasionally, small areas of banks appear “raw” with exposed, unprotected soil. Where evidence of relatively recent slumps have occurred (same year or likely previous year), areas are re-vegetated and relatively stable.

Fair - Evidence of mass wasting/bank failure is more frequent (3 to 4 moderate occurrences, 1 or 2 large areas). Normal high waterline erodes soil at toe of steep banks, thereby causing banks above toe slope to become undermined and slump into channel periodically during the year.

Poor - Mass wasting/bank failure frequency and size is contributing large volumes of sediment to the stream channel yearlong (5 or more small occurrences, 2 to 3 large occurrences, or 1 severe). Normal high water line frequently erodes away toe slope and undermines steep banks above. Geotechnical instability also likely as wetted banks dry when high flows recede.

Very Poor – Mass wasting/bank failure is almost continuous along the outside bends of the channel and some on the inside bends of very incised streams. High volume of excess sediment from banks likely.

Comments Upper Banks

Include any pertinent descriptions of conditions observed for the *Upper Banks*. Also include any information related to whether or not the assessor experienced any confusion on bankfull indicators or any of the *Upper Bank* metrics. These comments will be reviewed during quality control CCSI revisits as well as to target metrics for additional review during training events.

LOWER BANKS

This channel zone is located between the normal high water line (1.5-yr RI flow line) and base-flow; the lower banks define the extent of the base-flow stream wetted width. Some plants may be able to grow on this region of the banks between high and low flows; however, plants may be relatively sparse depending on the energy regime.

For low-gradient streams under stable hydrologic conditions, the stream channel may migrate slowly side to side within the floodplain zone over time. Consequently, the outer bank of meander bends may show signs of bank erosion while the inside bends form point bars and accrue sediment. Unstable conditions can be observed when the outside bends show excessive cutting and mass wasting/bank failure, as the stream tries to increase sinuosity or when the channel is incised and widening. Evidence of incision and widening may include cutting along both the inside and outside banks of the stream channel and deposition along the inside bend or along both sides of the channel that is excessive compared with other streams in the region of similar geologic character.

Bank Materials/ Shear Strength

The composition of the bank material is related to the geologic history of the region (bedrock, glacial till, glacial outwash) as well as the history of the stream itself (alluvial deposition, lacustrine silts and clay), and protection afforded by vegetative growth (e.g., tree and grass roots) and human alterations (e.g., riprap).

This metric assesses both the composition of the bank materials and local conditions that will provide resistance to detachment by high, scouring flows as well as the ability of the stream banks to resist detachment and collapse under low flow conditions (e.g., silt banks with groundwater seepage). To assess this metric, focus on the exposed lateral surface of the bank on the outside bend of meandering streams that would be most affected by the scouring forces of high flows or would be most likely to collapse due to groundwater seepage during low flows.

Excellent – Rock, root, or cohesive materials makes up to 90% or more of the volume of the banks. Or, bank made of cemented clay and other cohesive materials that do not crumble when touched and would easily resist scouring during high flows.

Good – Banks are composed of 65 to 75% rock or mixture of roots or cohesive fine materials such as clay with gravel or sand that can resist detachment during high flows; however, slight crumbling to the touch when dry. Bank mostly stable during high flow conditions and when dry. No stratification observed.

Fair – 40 to 65% of the bank volume is rock, roots, or cohesive material. Bank is somewhat resistant to crumbling when touched. Bank would remain relatively stable during most flow conditions, however, fluvial action could slowly erode bank, stratification observed, or cracks could form when dry, leading to bank collapse.

Poor – 20 to 40% of the bank is composed of rock, roots, or cohesive material. Soil matrix crumbles easily when touched, or stratification of soil and/or silt/clay lenses present. "Pop-outs" or bank erosion during high flows or when dry likely or evident.

Very poor - <20% of the bank composed of rock fragments, roots, or cohesive material. Banks mostly sand or silt that crumbles easily to the tough when dry or easily dislodged by flows or groundwater seeps.

Flow Deflectors

Objects in the stream, both naturally occurring and human related, may locally change the natural longitudinal course of flow and lead to bank instability depending on their angle of flow deflection and associated velocity. The presence of numerous flow deflectors can greatly destabilize the channel reach. The flow deflection may occur only during high flow; therefore this metric requires the assessor to imagine the flow conditions at the bankfull elevation and higher.

Large woody debris (LWD)/ boulders - A large tree or branches may fall from one bank and stretch across only ¾ of the stream cross-section or boulders may be oriented in such a manner as to channel flow toward the banks. In this case, LWD or boulders may channel and "deflect" flow toward the opposite bank thereby causing localized bank erosion and bank collapse.

Lateral riffles - Lateral riffles form when previously horizontal riffles have been dislodged due to higher velocities or where local knickpoints are migrating upstream (this phenomena suggests bed instability that can also adversely affect the lower banks). In unstable streams, lateral riffles comprised of gravel or small cobble can form and deflect flow into stream banks and cause localized bank instability, as well as indicate an imbalance in the flow regime.

Center bars – In overwidened cross-sections, aggradation in the center of the stream may cause a mid-channel build-up of sediments that will begin to divert and concentrate flow to the outside banks. When this occurs, the center bar is acting as a flow deflector as well as is an indicator of channel instability related to excess deposition or a loss of sediment transport capacity due to an overwidened cross-section.

Point bars – Point bars, or lateral bars are natural features in stable, sinuous, low-gradient streams. However, in unstable channels, point bars or lateral bars can form on the inside bend and aggrade sediment in an overwidened cross-section as the thalweg begins to form on the outside bend. When this occurs, the point bar may act as a flow deflector and destabilize the outside bend and further destabilize the banks until the stream achieves an appropriate degree of sinuosity and slope for the new flow and sediment regime imposed upon the channel.

Excellent – Logs and other flow deflectors cause minimal bank erosion, if present. Riffles are stable and perpendicular to flow.

Good – Some minor flow deflectors present (1 to 2). These flow deflectors cause some cross-currents and minor bank instability, but very localized.

Fair – Moderately frequent flow deflectors (3 to 4 small or 1 large) likely to cause bank erosion during high flow. Lateral riffles may be observed which direct flow into banks.

Poor –Flow deflectors fairly frequent (5 to 6 small, 2 large). Cross-current pattern strong, deflecting into banks and creating extreme bank erosion, cutting back banks, adding sinuosity to the channel or creating avulsion.

Very poor – Frequent flow deflectors (6 or more small, 2 or more large) cause highly erosive cross-currents and severe bank erosion over a fairly extensive portion of reach (greater than 40% of reach length).

Obstructions to Flow/ Sediment Traps

Objects that block flow and locally slow the velocity of water tend to have a buildup of fine sediment behind them. Where this occurs, these objects are considered "sediment traps." For example, downed trees and branches may build up perpendicularly across the channel (log jams or beaver dams) and obstruct flow. This may cause a slowing down of water velocity as water backs up behind the jam. The sediment carried by higher velocity flows drops out and aggrades behind the dam at the start of the pool and "traps" sediment that would have otherwise been carried downstream. When a large volume of sediment is trapped, channel capacity can be reduced to the point where normal high flows now overtop the banks, thereby causing floods.

If water appears impounded but no large beaver dams or obstructions are observed within the reach being sampled, consider walking downstream of the reach a reasonable distance to see if obstructions are observed. If not, or time is limited, write in comments that the reach appears impounded and score according to the degree the reach appears to be impacted by very large impoundment from observation of velocity and sediment accumulation.

Excellent – No obstructions to flow observed. Normal sediment accumulation associated with boulders, woody debris, and instream vegetation.

Good – Some minor obstructions and sediment traps present (1 to 2 occurrences observed). Minor accumulation of sediment; sediment transport capacity minimally impacted.

Fair – Sediment traps moderately frequent (3 or 4 occurrences). Presence of obstructions contributing to measurable degree of pool infilling (1/4 to 1/3 of total depth), or noticeable slowing of water velocity behind obstructions causes some accumulation of sediment above what would be expected for natural conditions.

Poor – Sediment traps more frequent, cause infilling of pools and/or high degree of aggradation in runs. Sediment transport capacity moderately reduced from what would be expected of normal conditions.

Very poor – Numerous or large obstructions or sediment traps. Sediment transport capacity greatly diminished resulting in severe aggradation within pools and/or runs.

Cutting or Ground Water (GW) Seepage

Cutting is the degree the banks have steepened as a result of scouring flows and episodes of bank collapse. This may be due to channel base-level lowering during a stage of degradation where the scouring flows now erode under the rooting depth of vegetation, or when the channel is attempting to increase sinuosity by scouring into the outside bends. Some degree of cutting is likely to be observed under natural stream conditions along the outside bend of sinuous streams or along bottom of deep rooted vegetation during lower than baseflow conditions. Unless the channel encounters a resistant surface (bedrock, armoring of the channel bottom with coarse substrates), the channel will continue to degrade until the banks become nearly vertical and begin to collapse due to gravity (geotechnical failure).

Incised channels contain additional flow volume due to a now deeper cross-section and consequently, flow energy that previously overtopped the banks and dissipated is now held and magnified within the channel walls. The result is increased discharge and stronger erosive forces that will actively erode composite bank materials below the root-line, causing undermined banks eventually leading to bank collapse, even when the tops of the banks are well vegetated. Additionally, as the channel down-cuts, the profile may encounter stronger ground water discharge. Hydrostatic pressure being relieved during base-flow can create groundwater pore pressure seeps that push sediment out at the toe of the bank, thereby causing a "pop-out failure" and additional bank collapse (Cancienne et al. 2008).

Excellent – Very little or no cutting is evident. Raw, eroding banks are infrequent (1 to 2 small, localized occurrences), short and generally less than 6" high or less than ¼ of bank height. If GW seepage is present, seepage affects less than 5% of reach.

Good – Few locations of cutting evident (3 to 4 localized occurrences). Cutting occurs along the outside meander bend of sinuous channels and at areas of constriction. Raw, eroded areas are equivalent in length to one channel width or less. Vertical cuts are generally less than 12" high or between 1/4 to 1/3 of bank height. Groundwater seeps may be observed causing localized "pop-outs" but less than 5 to 10% of reach.

Fair – Bank cutting occurs frequently along the reach along one or both sides (5 to 6 occurrences if small and localized). Root mat overhangs and sloughing evident. Trees may lean in toward stream or collapse as roots are undermined by scouring flows or from groundwater driven failure. Raw vertical banks 12 to 24" or 1/3 to 1/2 of bank height. Ground water driven bank failure apparent but fairly localized (10 to 20% of reach).

Poor – Significant (5-6) cuts. Cuts up to 1/2 to 3/4 of bank height. Root matts may be overhanging with unstable cut banks underneath, with bank sloughing evident, or GW driven bank instability and failure occurring over 20 to 40% of outer banks.

Very poor - Bank cutting is nearly continuous along the outside bends of entire reach. Some cuts are over 24" high or greater than half of bank height. Undercutting of the vegetative root line, root overhangs, and vertical bank failures may also be frequent (greater than 50% of reach) or GW driven bank failure extensive (>25% of reach). New tree fall may also be evident.

Comments on Lower Banks

Include any pertinent descriptions of conditions of the *Lower Banks*. Also include any questions related to how the assessor viewed or scored the metric, and if the assessor experienced any confusion on how to score the metrics comprising this assessment zone; these comments will be reviewed prior to quality control assessment revisits as well as to improve and target future training opportunities.

BOTTOM

The bottom of the stream is largely an aquatic environment year round. The biological community of plants, fish, and macroinvertebrates are largely supported by the character of the substrate and the degree of movement during high flows. Large immobilizable substrates support the growth of diatoms, algae, moss and plants that provide food and protection for many species of fish and macroinvertebrates. Smaller, mobilizable substrates (sand, silt, gravels) may move often during high flows and typically do not afford opportunity for growth of vegetation and diatoms; however, sands may be also be firm and green with periphyton along the waters' edge. The degree of scour may be inferred from assessing the current condition rocks and rooted plants.

The following metrics consist of rock and plant indicators that provide evidence that substrates have been moved during high flow conditions. When possible, assessments within this zone should take place during base-flow conditions when the water is clear and not turbid.

Consolidation or Particle Packing (vertical)

When the sediment transport capacity is in regime, larger substrates may remain stationary during high flows. When a stream is experiencing excess scouring, rocks in riffles may be easily dislodged by kicking and sand and gravel substrates may feel spongy underfoot or easily penetrated with the copper rod. Cobble and gravel may appear "brighter" as the substrates have rolled during high flows and the unstained sides are now visible. For streams dominated by sand and fines, the probing rod will provide an estimate of bed material density if the rod is driven into the bed by applying a constant downward force. The depth of penetration may be influenced by ground water pore pressure; however, the end result will still point to the likelihood of mobility with an increase in stream power associated with a rise in water stage. Generally, cohesive till will be dense and if this high density sediment covers >80% of the channel bed the risk of bed mobility will be very low. Mixtures of sediment will likely occur in most streams, the challenge is to define the relative density as measured by mechanical shear and determine the spatial variability over the study reach. This will require the assessor to interpret probe contact with sediment and probe response to downward pressure.

Excellent – Probe depth minimal if any due to very firmly packed sediment. 0 to 1 inch or 0 to 2.5 cm.

Good – Probe depth 1 to 3 inches (2.5 to 8 cm) before encounters densely packed material or resistant surface.

Fair – Probe depth 3 to 5 inches (8 to 13 cm). Some evidence of underlain resistant material; however, overlain sediment relatively loose and likely to be easily transported with a small increase in water velocity. 3 to 5 inches or 8 to 13 cm.

Poor – Probe depth 5 to 8 inches (13 to 20 cm). Very loose bed sediment in many places but not all.

Very Poor - Probe depth > 8” or >20 cm. Sediment relatively unconsolidated; indicates that this is an actively mobile bed during high flows.

Evidence of Degradation/Excess Scouring & Evidence of Aggradation/Excess Deposition

The processes of scouring and deposition are scored together as one metric for the Pfankuch (1975), as they are considered as two interrelated processes as conditions of incision and channel instability (scour and bank collapse) upstream may translate into excess deposition downstream. However, it is unlikely that these two related processes may be observed together within the reach length being assessed (~150 to 300 m). For example, while conditions of scouring related to an incising stream channel are observed within the reach, the water velocity may be sufficient to carry the sediment downstream and outside the reach where aggradation will likely occur. Equally possible, conditions of deposition observed within the reach are the result of channel instability (scour and bank collapse) upstream of the reach and consequently may be outside of the area where observations are being scored. While both conditions (excess degradation or aggradation) are symptoms of channel instability, fish and macroinvertebrates may be affected by these two conditions differently directly or indirectly through alteration to habitat quality (e.g., scouring and mobilization of substrates verses excess sedimentation and embeddedness of coarse substrates). Therefore, the CCSI characterizes observations of excess degradation or aggradation independent of each other.

Evidence of Degradation/ Excess Scouring

Stream conditions related to excess scouring may be detrimental to biological communities. High velocities and associated shear stress may dislodge and mobilize organisms and the substrates that they are clinging to or using as protection. Events related to scouring may also dislodge recently spawned fish eggs, instream vegetation, and immature insect larvae. Rocks with periphyton that are scraped and consumed by algophytes may be tumbled so that the side with periphyton is turned upside down and unavailable to grazers. Metrics in the original PSI that score these conditions include: *rock angularity*, *brightness* and *clinging aquatic vegetation*, among others. The PSI guidance manual (Pfankuch 1975) suggests that these metrics be used to infer the degree of scouring observed. Since not all alluvial streams have coarse substrate to rate *rock angularity* and *brightness,* the CCSI does not rate these indicators as separate metrics, but includes them as evidence to rate the

CCSI metric *Evidence of Degradation/Excess Scouring* in streams where these indicators are present. Additional indicators of excess degradation/scouring include the presence of a knickpoint/knickzone and vertical composition of bar substrate material.

Knickpoint or knickzone observed- Knickpoints are more localized than knickzones. A point or zone where degradation and incision begins is likely to be found along the longitudinal profile of an incising stream. Upstream of the knickpoint the conditions may be stable, and downstream the channel conditions will likely demonstrate conditions related to excess degradation, before aggradation. Therefore, the presence of a knickpoint or knickzone is associated with degradation/excess scouring and channel instability.

Rock brightness - When stationary, rocks become stained with diatoms and algae. Rocks that are rolled by a recent high flow event, will be tumbled in such a manner that the unstained undersides of a percentage of rocks is now exposed, which appears lighter, or brighter than rocks that are darkened by periphyton. Since not all zones within a stream channel may be scoured during high flows (e.g., shallow-edge habitat), focus your attention on areas of the stream that would be likely to be scoured during high velocity flow events. In streams without large substrates, focus attention on sands and gravels. Then step-back and put the stream in context with its surrounding and stream size. Is the degree of brightness observed indicating normal annual bed movement or excess mobilization and therefore, excess scouring?

Bar substrate coarser on top than within - Streams that have recently experienced greater than normal velocity will likely demonstrate a substrate size difference in the vertical profile of deposited sediment on point and center bars. Locate a point or center bar and remove the overlaying 1 to 2 inches of sediment. If the substrate composition on top of the bar is coarser than what is buried, this may indicate that flow conditions are of higher velocities that the previous annual discharge regime.

Excellent – Little evidence of abnormal scouring observed (<5% of reach). Vegetation is well rooted, where water clarity allows for the growth of deep rooted plants and moss in areas that would characteristically experience swifter flows during periods of higher flow. Rocks, where present, are darkened from periphyton with few areas of bright substrates. Some fines are observed surrounding coarse sediments are would be expected for a stable stream in the region, for the stream type, and gradient of the reach.

Good – Some localized scour at constrictions, like under bridges or around downed trees (5-15% affected) or where grades steepen. Where water clarity allows, vegetation present in slower waters such as in shallower depths along the wetted edge or in slow velocity pools, as well some areas experiencing swifter velocity. Rocks and gravel, where present, are mostly dark with some light spots visible (<15% of reach). Some fines observed, but may be slightly less than would be observed for stable streams in the region, stream type and gradient.

Moderate – Evidence of areas experiencing scour noticeable or moderately frequent (15-25% of bottom affected). Examples of areas that might have evidence of scour would include zones of construction, such as downstream of undersized culverts and bridge passageways, where tree roots armour banks and the stream appears wider upstream and downstream of the zone of constriction, and bends. Where visibility allows for plants to anchor and grow, vegetation is less than would be expected and rocks and gravel may be mixed with dark and bright (<25%). Where applicable, there is less sand and fines surrounding coarse substrates than may be expected. Substrate size on bars somewhat coarser than within.

Poor – Noticeable scour pools at bridges, constrictions, and where knickpoints occur (25-40% of bottom affected). Cutting along both sides of the stream channel may also indicate that the channel is experiencing downcutting as the bottom is scoured away. Where water clarity allows, vegetation is spotty or found only in backwater areas. Where present, rocks may be relatively free of fine sediment or tops of bars coarser than within.

Very poor- More than 40% of bottom substrates moved due to excess scouring. Deep scour pools associated with bridges and constrictions. Dramatic knickpoint may be observed within reach or upstream of reach. Where stream is incised, severe cutting along both banks. Where applicable, rock and gravel may appear bright (>40%) and coarse substrate is abnormally clean of fines. Vegetation may be scarce and tops of bars much coarser than within.

Evidence of Aggradation/ Excess Deposition

Depending on the stream type, evidence of excess aggradation may be observed in the riffles, runs, and/or pools constriction where the banks are armored with riprap or tree roots, around obstructions such as downed trees, and along outside bends of sinuous streams. Where water clarity allows, vegetation observed is less than would be expected due to relatively recent scouring events (within year). Where applicable, less sand between coarse substrates than would be expected for this stream type or where there are lateral and center bars, the deposited material on top of bars is coarser than within.

Embeddedness in riffles/runs- The degree to which fine substrates surround and bury coarse substrates is embeddedness. Coarse substrates in pools tend to be embedded due to the slower flow velocities associated with these stream features. However, when embeddedness is observed in runs and riffles, excess sediment sources or loss of sediment competence is occurring within the reach. Embedded substrates may be the result of upstream pasture grazing, overland run off, mass wasting/bank failure in upstream reaches, and overwidened stream channels, among others. Regardless of the mechanism, embeddedness is a sign of excess deposition and is an indicator of channel instability.

Pool depth diminished- Streams that are experiencing an increase in sediment loading to the stream or a loss of sediment transport capacity (e.g., wigh overwidened stream channels) will display excess fine sediment collecting in pools. Consequently, the depth of pools is less than what would be expected under stable conditions.

Lateral bar or center bar build-up- Lateral and center bars that demonstrate excess new sediment deposition such as sand or gravel indicate that either the sediment load has increased or the sediment transport capacity has been decreased from the natural channel equilibrium (sediment in/stored > sediment out/mobilized). Where streams have access to their floodplains during high flows or have within channel bars, some sediment will be naturally deposited during the receding limb of the hydrograph; hence, a thin layer of new deposition is natural/expected. However, depending on the size of the stream, when the volume of new sediment is a few inches to a few feet, and appears larger than the normal amount of annual sediment deposition, excess aggradation is occurring. Center bars may also indicate an overwidened cross-section due to channel evolution. Sediment transported from upstream by higher velocity flows now enters the overwidened cross-section which creates a zone of slower velocity (diminished sediment transport capacity); consequently, suspended sediment settles out on the bottom of the channel and builds up on top of center or lateral bars, as well as embeds coarse substrates on the stream bottom and within pools.

Excellent – Excess deposition is minimal or non-existent. Where pools are present, pool depth/size not diminished by infilling of materials (<1/8 of total depth affected). Where rock present, cobble and gravel minimally embedded (<10% in runs).

Good – Slight embeddedness observed (cobble 10-15%, gravel 10-25% in runs). Where present, pool depth/size slightly diminished due to infilling (1/8-1/4 of total expected depth) but only in some localized areas of the reach (5-15% of total).

Moderate - Excess deposition is observed in patches along the reach (15-25% of reach affected). Deposition at obstructions and moderate embeddedness observed in runs (cobble 15-25%, gravel 50-75%). Where present, pool depth/size noticeably diminished (1/4-1/3of total) or some new material on bars. Some habitat conditions negatively affected but some pools with decent depths and good quality. Riffle quality also moderately affected, but still provides functional habitat.

Poor- Excess deposition is apparent (25 to 40% of the reach) and is negatively affecting habitat quality. Extensive embeddedness observed where coarse substrates are present (>25% for cobble, >75% for gravel). Where pools are observed, pool depth/size greatly diminished (1/3 to 1/2 of total) or bar build-up noticeable 25-40%. Extensive deposition at obstructions, on bars, and along bottom observed.

Very poor - Excess deposition is extensive (>40% of the reach). Pool depth almost non-existent or severely diminished, greatly limiting pool availability for fish. Some localized areas of scouring associated with woody debris or large boulders may be present, but large pools are greatly filled in with sediment (>1/2 of total depth). Where visible, lateral and center bars indicate substantial accumulation of new sediment.

Stage(s) of Channel Evolution

Indicators observed while walking the stream should provide indication of which CEM stage(s) appear to be active and prominent. To rate this metric, refer to the Channel Evolution Model (CEM) Figures (I-V) on the backside of the worksheet and ratings for previous metrics. Make a determination as to the degree to which channel adjustment is currently affecting the condition of the channel or is the dominant process of channel instability. Are the channel processes of aggradation and degradation in equilibrium (Stage I or V), are the processes of channel adjustment minor at this stage (just being initiated - Stage II, III) or in process of returning to equilibrium (Stage IV), or does the channel appear to be actively and noticeably downcutting (Stage II) or widening (Stage III), and are either degradation or aggradation the dominant process of instability (cause of mass wasting/bank failure, cutting, scouring, aggradation)? Use your interpretation of the erosional forces at work that are acting on the channel during bankfull conditions and how well sediment is effectively transported by the size of the cross-section. Record the stream stages observed in the location provided and circle the severity rating.

Excellent – Channel appears relatively stable (stage I or V); however, there may be small, localized instances where some bank erosion is observed. The nature of the bank erosion is from from natural flow deflectors or natural meandering. Overall, little evidence of channel instability is observed.

Good – Channel appears relatively stable, but some minor evidence of instability observed indicating that the channel has slightly downcut or is attempting to widen; or the channel is at the last stage of channel adjustment (stage IV to stage V) with some minimal erosion along outside bends due to lateral bar deflection. Lateral bars may now be well-vegetated.

Moderate – Channel appears to be in the process of evolving toward a more stable cross-section (stage III to stage IV). A thalweg is starting to form along the outside bend and sediment is being stored along the inside bend. Some grasses or vegetation starting to grow on the point bar.

Poor – Channel is actively downcutting and/or widening. Some lower bank and bottom metrics scouring in at least the moderate to poor range.

Very poor – Channel is actively in the process of rapidly downcutting or widening to such a degree that channel evolution is the dominant process of instability. Many banks demonstrating severe cutting or mass wasting/bank failure. Where applicable, new tree fall is evident as the channel is attempting to widen. The substrate is very uncompacted due to recent scouring events. Some lower bank and bottom metrics also scoring in the poor to very poor range.

Scoring and interpretation

Total score: The total score range is 14-147 where lower scores indicate stable conditions and higher scores indicate unstable channel conditions.

Stable 14–27

Fairly Stable 28–45

Moderately unstable 46–80

Severely unstable 81–114

Extremely unstable 115–147

Please note: Since this assessment tool and scoring strategy has not been fully tested in all stream settings, some score adjustments may be required.

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Channel Condition & Stream Stability Index (CCSI)

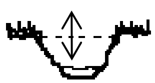
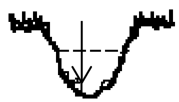
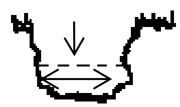
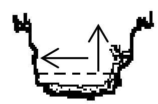
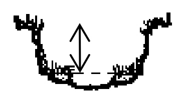
Field Number:______________ Stream:____________________________ Date: ______________ Staff: ______________ Stream Type: ______ Total Score: __________

		Stable (14-26)	**Fairly stable (27-44)**	**Moderately unstable (45-79)**	**Severely unstable (80-115)**	**Extremely unstable (116-147)**
1. Upper Banks For a. and b. Assess at riffle , shallow cross-over. or shallow, narrow run. Estimate bankfull using indicators and RGHC For c. and d. assess the outside bends or banks likely to receive erosive flows.	a. **Intermediate floodprone width** (1.5x BfH) IntFpW _____ BfW ____	Floodplain extensive. High flow energy (2-10yr RI) largely dissipated. IntFpW >10x BfW 1	Floodplain moderately extensive. IntFpW 5-10 x BfW 3	Floodplain wide, but limited. IntFpW 3-5x BfW 5	Floodplain narrow, minimal energy dissipation with high flows. IntFpW 1.5-3 x BfW 7	Floodplain almost non-existent, high flows contained. IntFpW <1.5 x BfW 10
	b. **Degree of incision** LBH ____ BfH ___	Channel not or minimally incised in some places. LBH/BfH = 1.0-1.05 (0-5%) 1	Channel is marginally incised LBH/BfH = 1.05-1.15 (5-15%) 3	Channel is slightly incised LBH/ BfH = 1.15-1.25 (15-25%) 6	Channel is moderately incised LBH/ BfH = 1.25-1.5 (25-40%) 9	Channel is deeply incised LBH/ BfH = >1.5 (>40%) 12
	c. **Vegetative bank protection** □ trees □ shrubs □ grasses □ perennials	90%+ plant density. Trees or thick grasses dominate; deep roots cover most of upper banks. Roots >10" deep, generally 1	70-90% density. Fewer trees and deep rooted grasses; roots 5-10" deep, generally 3	50-70% density; roots shallow (1.5 – 5") or discontinuous; bare spots may be visible 5	<25-50% density, plants or grasses with very shallow roots (0.5-1.5"), or bare ground between plants common 7	Very little root protection (<25%), majority of ground bare, vegetation with very shallow roots (<0.5") 10
	d. **Mass wasting or bank failure**	No or little evidence mass wasting or bank failure 1	Infrequent (1-2 medium) and/or very small (3-4). or mostly healed over. 2	Moderate frequency (3-4 medium) and size (1-2 large), some raw spots eroded by water during high flows (5-6) 4	Frequent (5 or more) or large (2-3 large, or 1 severe), banks contributes fair amount of sediment during high flows 7	Almost continuous mass wasting along channel, severe condition 11
	Comments on Upper Banks:					

2. Lower Banks Assess outside bends or areas that are likely to be scoured by flow.	e. **Bank materials/ shear strength**: □ rock □ sand □ silt □ riprap □ cohesive soil □ roots	Bank is largely comprised of rocks, roots or cohesive materials (>90%), or <5% of reach is moderately erodable	1	65-75% rock or mixture of roots or cohesive fine materials, some crumbling to the touch, minimally eroded by flow or GW (<10% of reach)	3	40-65% rock, roots or cohesive material. Some slightly friable locations present <25% can allow for some eroded spots	5	20-40% rock fragments, roots, or cohesive material. Moderately to somewhat friable mixture (25-50%), Erosion likely during high flows or when soil dries (geotechnical failure) or GW seeps	7	<20% rock fragments, roots, or cohesive material. Banks mostly sand or silt that crumbles easily to the touch when dry or easily dislodged by GW seeps	9
	f. **Flow deflectors**: □LWD □ boulders □ lateral riffles □ center bars □ point bars	Flow pattern without cutting or very minor. Pools and riffles stable	1	Some present (1-2 small), causing erosive cross currents and minor bank instability, very localized	3	Moderately frequent (3-4 small, or 1 large), cause erosive cross-currents and moderate bank instability (10 to 20% of reach)	5	Fairly frequent flow deflectors (5 to 6, 2 large), cause major instability in 20 to 40% of reach.	7	Frequent flow deflectors (>6 small, >2 large) cause highly erosive cross-currents and severe bank erosion (>40% of reach)	9
	g. **Obstructions to flow/ sediment traps**: □ WD □ boulder □ beaver dams □ check dams	No obstructions to flow observed; very minimal retention by sediment traps	1	Some minor obstructions and sediment traps present (1-2). Sediment transport capacity minimally impacted	3	Sediment traps moderately frequent (3-4), may cause some pool infilling (1/4 to 1/3 of total depth) or slowing of water velocity	6	Sediment traps entrain sediment and fill in pools (1/3 to ½ of pools depth). Sediment transport capacity moderately diminished	10	Obstructions large (block 2/3 to entire stream width) or sediment traps frequent (>4), severe loss in pool depth (>50%). Sediment transport capacity greatly diminished	14
	h. **Cutting/ scouring or gw seepage**	Infrequent (1-2) raw banks. Little evidence of undercutting (<1/8 of bank height) or seepage (<5% of reach)	2	Some (3-4), raw banks at outcurves and constrictions (1/8 to ¼ of bank height). Some toe slope erosion or seepage (5-10% of reach)	4	Moderate frequency (4-6), raw banks 1/3 to 1/2 of bank height. Toe slope erosion or seepage apparent (10-20% of reach)	6	Significant (5-6). Cuts 1/2 to 3/4 of bank height). Root mat overhangs and sloughing evident, or GW driven failure (20-40% of reach)	10	Almost continuous raw bank (>3/4 of bank height). Toe slope erosion fairly continuous (>40% of outside bend) or GW failure extensive (>25% of reach)	14
	Comments on Lower Banks:												

3. Bottom	k. **Consolidation or particle packing (vertical)**	Bed firmly packed. Probe depth 0-1" (0-2.5 cm) in runs 1	Bed fairly well packed. Riffles and pools stable. Probe depth 1-3" (2.5-8 cm) in runs 3	Bed moderately packed (3-5" or 8-13 cm) in runs. 6	Loose bed sediment. Probe depth 5-8" (13-20 cm) in runs. 10	Unconsolidated actively mobile bed. Probe depth >8" (>20cm) in runs 14
	l. **Evidence of degradation /excess scouring** □ knickpoint observed □ rock brightness □ bar substrate coarser on top than within	< 5% of the bottom affected by scouring. Where water clarity allows, vegetation abundant, algae clinging to materials, rooted plants visible in swifter waters 1	5-15% affected. Scour at constrictions and where grades steepen. Where water clarity allows, vegetation present in slower waters, algal forms in swift velocity and pool areas 3	15-25% affected. Scour at obstructions, constrictions, and bends. Vegetation less than would be expected due to local areas of scour. Where applicable, less sand between coarse materials or slightly larger materials on top of bars than within 5	25 to 40% affected. Scour pools at bridges, constrictions, and where knickpoints occur or cutting along both sides of channel in places. Where water clarity allows, perennial vegetation and algae spotty or mostly in backwater areas. Where present, rocks may be relatively free of fine sediment or tops of bars coarser than within 7	> 40% of bottom substrates moved annually. Extremely deep scour pools associated with bridges and constrictions or dramatic knickpoint within reach or cutting severe along both sides of channel. Where applicable, vegetation scarce, rocks clean of fines or tops of bars much coarser than within 9
	m. **Evidence of aggradation/ excess deposition:** □ embeddedness in riffles/runs □ pool depth diminished □ lateral or center bar build-up	<5% of the bottom affected by excess deposition (cobble and gravel minimally embedded, <10% in runs). Where present, pool depth/size not diminished (<1/8 of total) 1	5-15% affected. Slight embeddedness observed (cobble 10-15%, gravel 10-25% in runs). Where present, pool depth/size slightly diminished (1/8-1/4 of total) 3	15-25% affected. Deposition at obstructions and embeddedness (cobble 15-25%, gravel 50-75%) observed in runs. Where present, pool depth/size noticeably diminished (1/4-1/3 of total) or some new bar build-up 6	25-40% affected. Extensive deposition at obstructions, on bars, and along bottom. Extensive embeddedness (>25% for cobble, >75% for gravel) observed. Where present, pool depth/size greatly diminished (1/3 to 1/2 of total) or bar build-up noticeable 10	>40% of bottom demonstrating excess deposition. Pool depth severely diminished (>1/2 of total) or lateral/ center bars with substantial accumulation of new sediment 14
	Comments on Bottom:					

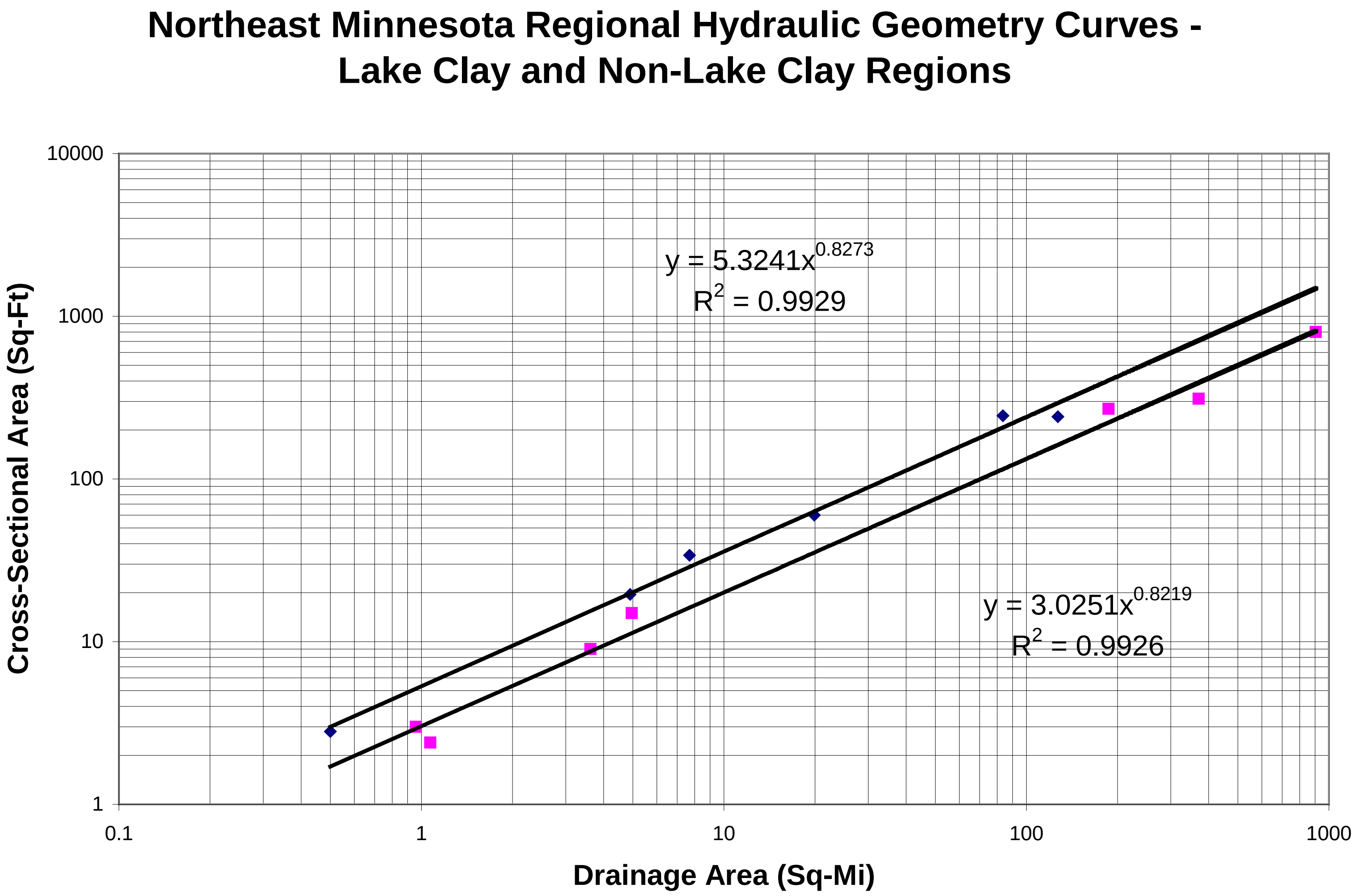
4. Stage of channel evolution: Stages observed: ___&____ &___&___	Channel appears to be relatively stable (stage I or V); □ however, some bank erosion observed, but mostly from deflectors or natural meandering	1	Channel adjustment appears to be: □ minor; slight downcutting or widening, not severe □ evolving from stage IV to V; thalwegs are fairly well established, little deposition in pools	3	Channel appears to be evolving towards a more stable cross-section (III to IV); thalweg beginning to form on outside bend sediment newly deposited along inside bend. □ some instability related to lateral bar build-up	5	Channel appears to be: □ downcutting (II) and/or □ widening (III) noticeable to severe fluvial bank erosion or cutting observed, trees may be leaning inward from one or both banks	7	Channel experiencing severe downcutting and or widening, which is the dominant process of instability. Many areas with highly eroded banks. New tree fall and mass wasting may be present	11
Comments CEM stage:										

CEM Stages	**I. Pre-adjustment**	**II. Degradation**	**III. Degradation and Widening**	**IV. Aggradation and Widening**	**V. New Dynamic Equilibrium**	**Cross section**
						

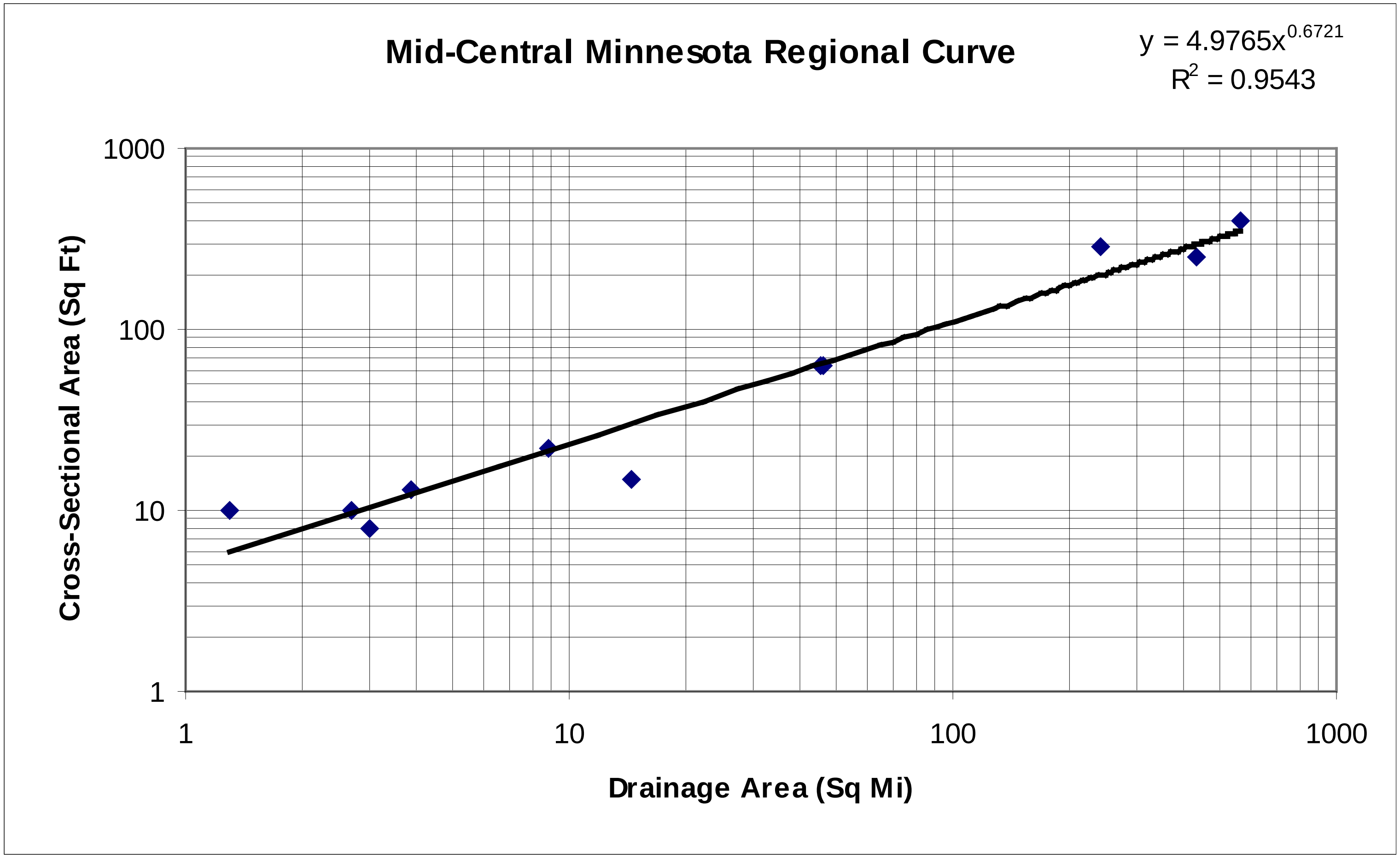
Substrate composition □ pebble count □ observation _____%bedrock _____%boulder _____%cobble _____%coarse gravel (16-64mm) ____%fine gravel (2-16mm) ____%sand_____%silt _____%clay ____%WD/detr. ____%muck	**Cross-section (at riffle, crossover, or straight: & narrow section):** BfW ______ BfD_____ BfW/D ______ CSA ______ ER______ Validated w/ RHGC? Yes ____ No _____ Version: □ Mid-Central MN □ East-Central MN □ NW-Central MN □ SE MN Till □ SE MN Karst
General Comments:	

Appendix: Regional Hydraulic Geometry Curves (RHGC) developed for Minnesota.

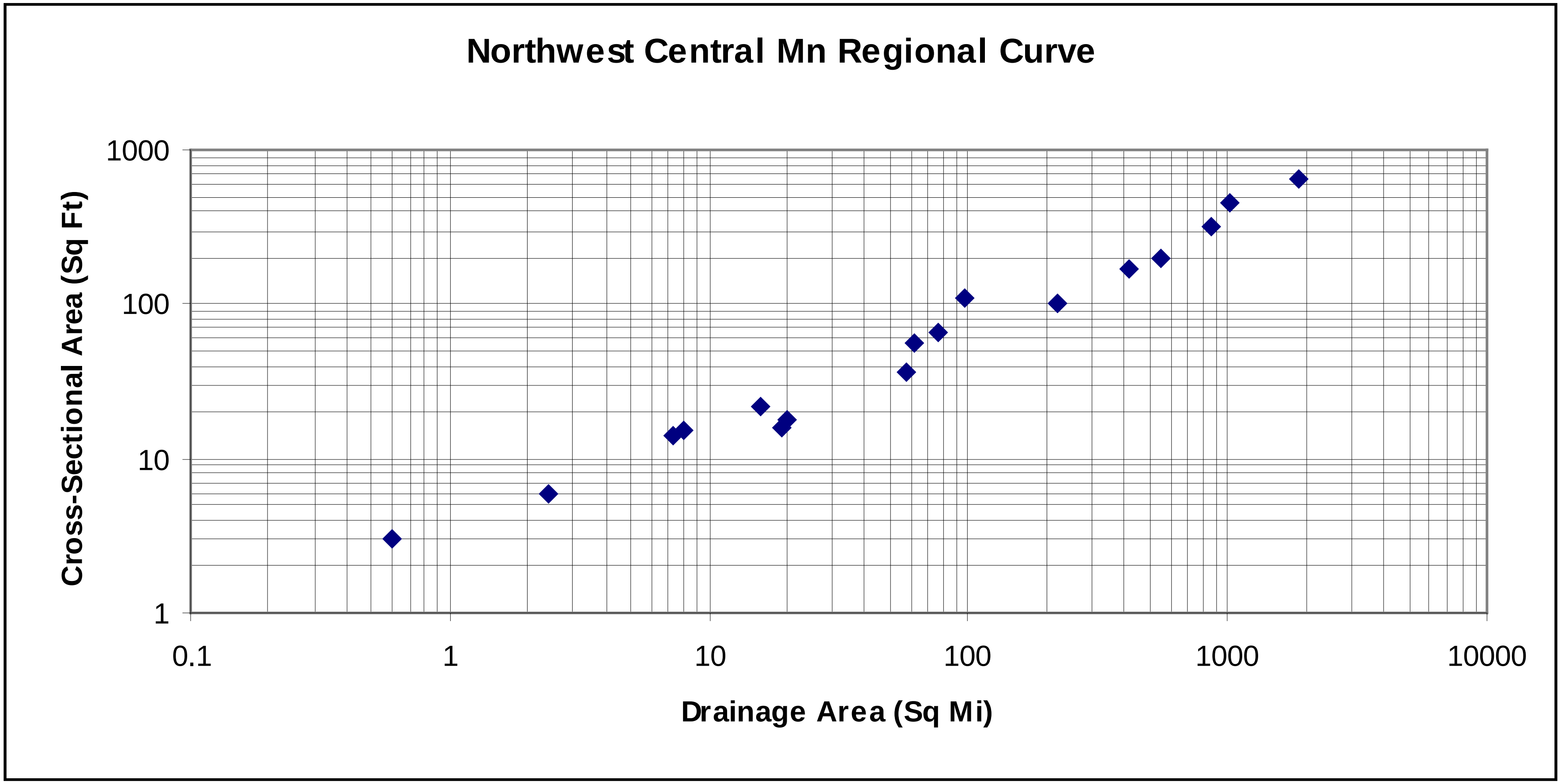
St Louis –
Lake Clay - North Shore Streams and Nemadji – lake clay and bedrock
Non-Lake Clay -



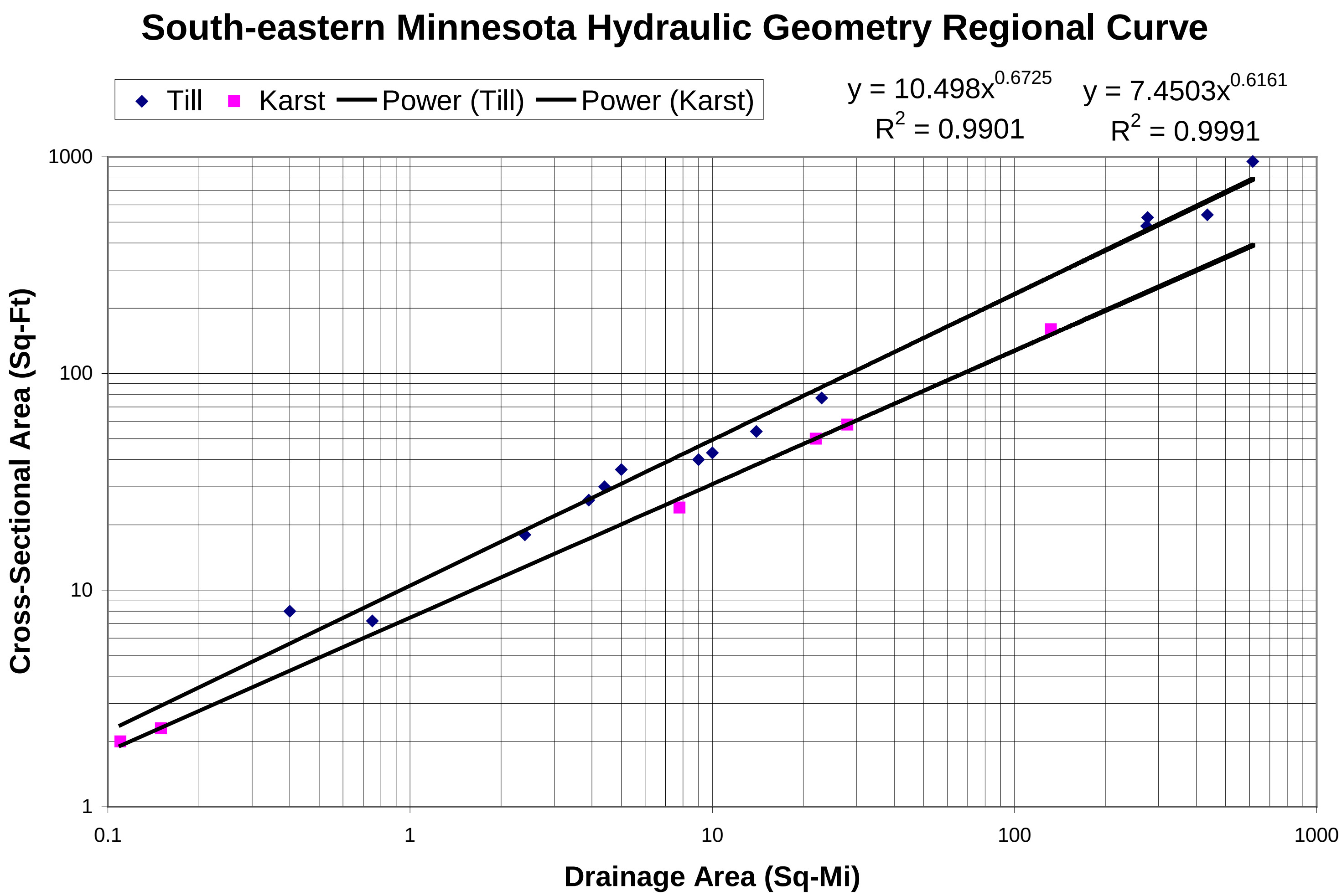
Mississippi – St Cloud



Buffalo
Chippewa



Cedar, Shell Rock (Till)



St Croix – Stillwater and Snake River