Establishing Current ‘Reference’ Conditions

Rates and concentrations of suspended-sediment transport vary over time and space due to factors such as precipitation characteristics and discharge, geology, relief, land use and channel stability, among others. There is no reason to assume that “natural” or background rates of sediment transport will be consistent from one region to another. Within the context of clean-sediment TMDLs, it follows that there is no reason to assume then that “target” values should be consistent on a nationwide basis. Similarly, there is no reason to assume that channels within a given region will have consistent rates of sediment transport. For example, unstable channel systems or those draining disturbed watersheds will produce and transport more sediment than stable channel systems in the same region. This reflects differences in the magnitude and perhaps type of erosion processes that dominate a sub-watershed or stream reach.

In order to identify those sediment-transport conditions that represent impacted or impaired conditions, it is essential to first be able to define non-disturbed, stable, or ‘reference’ conditions. For the purposes of this study, stability is defined in geomorphic terms; that is, a stream in dynamic equilibrium, capable of transporting all sediment delivered to the system without altering its dimensions over a period of years. This is not to say that the stream is static but that short-term, local processes of scour and fill, erosion and deposition, are balanced through a reach such that the stream does not widen, narrow, degrade or aggrade.

Rapid Geomorphic Assessments: RGA’s

To evaluate channel-stability conditions and stage of channel evolution of a particular reach, an RGA was carried out at each site using the Channel-Stability Ranking Scheme. RGAs utilize diagnostic criteria of channel form to infer dominant channel processes and the magnitude of channel instabilities through a series of nine unique criteria. Granted, evaluations of this sort do not include an evaluation of watershed or upland conditions; however, stream channels act as conduits for energy, flow and materials as they move through the watershed and will reflect a balance or imbalance in the delivery of sediment. Given the large number of USGS gages in EPA Region 8, it was not feasible to perform detailed, time consuming field surveys at every site, RGAs provided an efficient alternative, enabling the rapid characterization of stability conditions.

Four steps are completed on site:

1. Determine ‘reach’. The ‘reach’ is described as the length of channel covering 6-20 channel widths, thus is scale dependent and covers at least two pool-riffle sequences.
2. Photograph the reach, for quality assurance and quality control purposes. Photographs are used with RGA forms to review the field evaluation
3. Carry out RGA. Make observations of channel conditions and diagnostic criteria listed on the channel-stability ranking scheme (Figure 8).
4. Sample bed material.

CHANNEL-STABILITY RANKING SCHEME

River_________________________ Site Identifier____________________________________

Date _____________ Time_______ Crew _______________ Samples Taken_________________________

Pictures (circle) U/S D/S X-section Slope__________ Pattern: Meandering
Straight
Braided

1. Primary bed material							
	Bedrock	Boulder/Cobble		Gravel	Sand	Silt Clay	
	0	1		2	3	4	_____
2. Bed/bank protection							
	Yes	No	(with)	1 bank	2 banks		
				protected			
	0	1		2	3		_____
3. Degree of incision (Relative elevation of "normal" low water; floodplain/terrace @ 100%)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
	4	3	2	1	0		_____
4. Degree of constriction (Relative decrease in top-bank width from up to downstream)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
	0	1	2	3	4		_____
5. Stream bank erosion (Each bank)							
	None	Fluvial	Mass wasting (failures)				
Left	0	1	2				_____
Right	0	1	2				_____
6. Stream bank instability (Percent of each bank failing)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
Left	0	0.5	1	1.5	2		_____
Right	0	0.5	1	1.5	2		_____
7. Established riparian woody-vegetative cover (Each bank)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
Left	2	1.5	1	0.5	0		_____
Right	2	1.5	1	0.5	0		_____
8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
Left	2	1.5	1	0.5	0		_____
Right	2	1.5	1	0.5	0		_____
9. Stage of channel evolution							
	I	II	III	IV	V	VI	
	0	1	2	4	3	1.5	_____

Figure 1 – Channel stability ranking scheme used to conduct rapid geomorphic assessments (RGAs). The channel stability index is the sum of the values obtained for the nine criterion.

4.1.3 Channel-Stability Index

A scheme that assesses nine unique criteria was used to record observations of field conditions during RGAs (Figure 8). Each criterion was ranked from zero to four and all values summed to provide an index of relative channel stability. The higher the number the greater the instability: sites with values greater than 20 exhibit considerable instability; stable sites generally rank 10 or less. Intermediate values denote reaches of moderate instability. However, rankings are not weighted, thus a site ranked 20 is not twice as unstable as a site ranked 10. The process of filling out the form enables the final decision of ‘Stage of Channel Evolution’.

Characterizing Channel Geomorphology

1. Primary bed material

Bedrock	The parent material that underlies all other material. In some cases this becomes exposed at the surface. Bedrock can be recognized by appearing as large slabs of rock, parts of which may be covered by other surficial material.
Boulder/Cobble	All rocks greater than 64 mm median diameter.
Gravel	All particles with a median diameter between 64.0 – 2.00 mm
Sand	All Particles with a median diameter between 2.00 – 0.63 mm
Silt Clay	All fine particles with a median diameter of less than 0.63 mm

2. Bed/bank protection

Yes	Mark if the channel bed is artificially protected, such as with rip rap or concrete.
No	Mark if the channel bed is not artificially protected and is composed of natural material.
1 bank protected	Mark if one bank is artificially protected, such as with rip rap or concrete.
2 banks	Mark if two banks are artificially protected.

3. Degree of incision (Relative elevation of "normal" low water)

Calculated by measuring water depth at deepest point across channel, divided by bank height from bank top to bank base (where slope breaks to become channel bed). This ratio is given as a percentage and the appropriate category marked.

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

Often only found where obstructions or artificial protection are present within the channel. Taking the reach length into consideration, channel width at the upstream and downstream parts of the reach are measured and the relative difference calculated.

5. Stream bank erosion (Each bank)

The dominant form of bank erosion is marked separately for each bank, left and right, facing in a downstream direction.

If the reach is a meandering reach, the banks are viewed in terms of ‘Inside, Outside’ as opposed to ‘Left, Right’ (appropriate for questions 5-8). Inside bank, being the inner bank of the meander, if the stream bends to the left as you face downstream, this would be the left bank. Outside bank, being the outer bank, on your right as you face downstream in a stream meandering left.

None	No erosion
Fluvial	Fluvial processes, such as undercutting of the bank toe, cause erosion.
Mass Wasting	Mass movement of large amounts of material from the bank is the method of bank erosion. Often characterized by high, steep banks with shear bank faces. Debris at the bank toe appears to have fallen from higher up in the bank face. Includes, rotational slip failures and block failures.

6. Stream bank instability (Percent of each bank failing)
   If the bank exhibits mass wasting, mark percentage of bank with failures over the length of the reach. If more than 50% failures are marked, the dominant process is mass wasting (see question 5).

7. Established riparian woody-vegetative cover (Each bank)
   Riparian woody-vegetative cover is the more permanent vegetation that grows on the stream banks, distinguished by its woody stem, this includes trees and bushes but does not include grasses. Grasses grow and die annually with the summer and thus do not provide any form of bank protection during winter months whilst permanent vegetation does.

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)
   The percentage of the reach length with fluvial deposition of material (often sand, also includes fines and gravels) is marked.

9. Stage of channel evolution
   Stage of channel evolution are given by Simon and Hupp, 1986 (see diagram below). All of the above questions help lead to an answer to this question. Refer to previously determined criterion for guidance. See Table 3 for guidelines of features often found with each stage of channel evolution.

Total Score Total up the responses to the 9 questions.

4.1.4 Stages of Channel Evolution

The channel evolution framework set out by Simon and Hupp (1986) is used by TMDL practitioners to assess the stability of a channel reach (Figure 9; Table 4). With stages of channel evolution tied to discrete channel processes and not strictly to specific channel shapes, they have been successfully used to describe systematic channel-adjustment processes over time and space in diverse environments, subject to various disturbances such as stream response to: channelization in the Southeast US Coastal Plain (Simon, 1994); volcanic eruptions in the Cascade Mountains (Simon, 1999); and dams in Tuscany, Italy (Rinaldi and Simon, 1998). Because the stages of channel evolution represent shifts in dominant channel processes, they are systematically related to suspended-sediment and bed-material discharge (Simon, 1989b; Kuhnle and Simon, 2000), fish-community structure, rates of channel widening (Simon and Hupp, 1992), and the density and distribution of woody-riparian vegetation (Hupp, 1992).

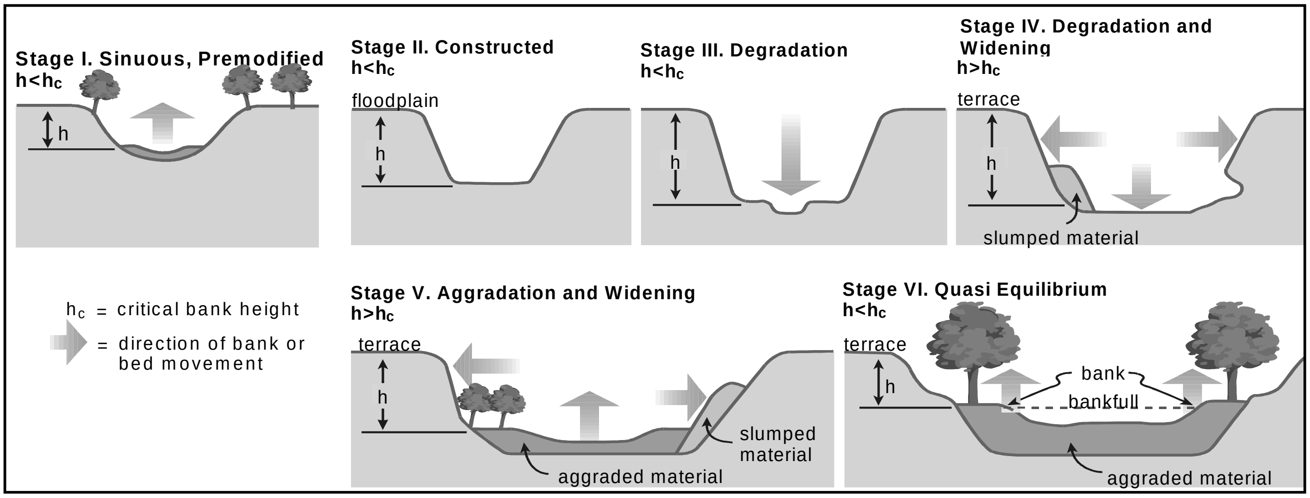

Figure 2 – Six stages of channel evolution from Simon and Hupp (1986) and Simon (1989b) identifying Stages I and VI as 'reference' channel conditions.

Table 1 – Summary of conditions to be expected at each stage of channel evolution.

Stage	Descriptive Summary
I	*Pre-modified* – Stable bank conditions, no mass wasting, small, low angle bank slopes. Established woody vegetation, convex upper bank, concave lower bank.
II	*Constructed* – Artificial reshaping of existing banks. Vegetation often removed, banks steepened, heightened and made linear.
III	*Degradation* – Lowering of channel bed and consequent increase of bank heights. Incision without widening. Bank toe material removed causing an increase in bank angle.
IV	*Threshold* – Degradation and basal erosion. Incision and active channel widening. Mass wasting from banks and excessive undercutting. Leaning and fallen vegetation. Vertical face may be present.
V	*Aggradation* – Deposition of material on bed, often sand. Widening of channel through bank retreat; no incision. Concave bank profile. Filed material re-worked and deposited. May see floodplain terraces. Channel follows a meandering course.
VI	*Restabilization* – Reduction in bank heights, aggradation of the channel bed. Deposition on the upper bank therefore visibly buried vegetation. Convex shape. May see floodplain terraces.

An advantage of a process-based channel-evolution scheme for use in TMDL development is that Stages I and VI represent true 'reference' conditions. In some cases, such as in the Midwestern United States where land clearing activities near the turn of the 20th Century caused massive changes in rainfall-runoff relations and land use, channels are unlikely to recover to Stage I, pre-modified conditions. Stage VI, a re-stabilized condition, is a much more likely target under present regional land use and altered hydrologic regimes (Simon and Rinaldi, 2000) and can be used as a 'reference' condition. Stage VI streams can be characterized as a 'channel-within-a-channel', where the previous floodplain surface is less frequently inundated and can be described as a terrace. This morphology is typical of recovering and re-stabilized stream systems following incision. In pristine areas, where disturbances have not occurred or where they are far less severe, Stage I conditions can be appropriate as a reference.

4.1.5 Determining Historical Channel Stability

Unfortunately, it is not uncommon that suspended-sediment sampling was carried out over fifty years ago. Thus it may be the case that current channel stability was not relevant at the time of suspended-sediment sampling. Plotting certain stream morphology characteristics against a range of discharges over time can help us to establish channel stability during the period of suspended-sediment sampling, as it is both expensive and time consuming to establish current transport-ratings,. Figures 10 and 11 provide examples of using USGS stream-flow measurements to estimate channel stability at time of suspended-sediment sampling. A 2007 RGA judged the channel at station 06355500 on the North Fork Grand River near White Butte, SD to be unstable. Stream-flow measurement data was analyzed for this site as suspended-sediment sampling was carried out between 1949 and 1951, therefore current stability conditions of this channel may mean very little to the stability conditions fifty years ago. Analysis of stream-flow measurement data shows no bed movement during the time of suspended-sediment sampling, thus this channel is considered stable during that period. The stream-flow measurements at this station also support the present RGA, as the channel has exhibited continual incision since the early 1960s.

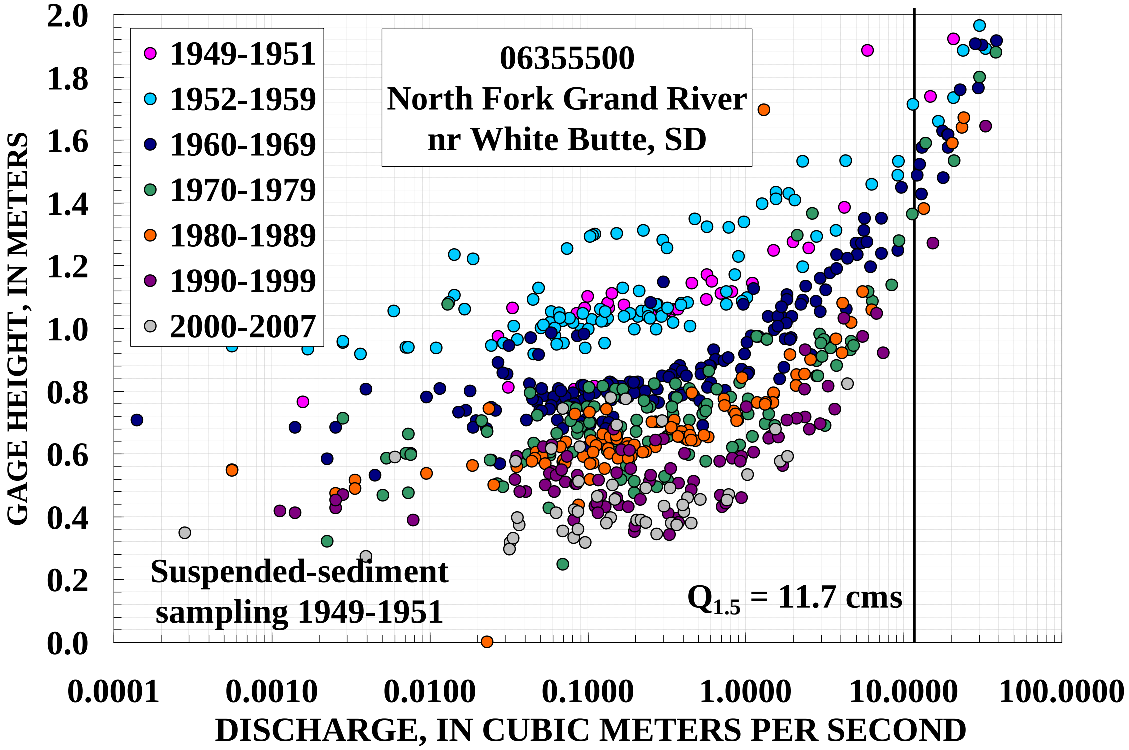

Figure 3 – Stream-flow measurements for the North Fork Grand River near White Butte, SD in Ecoregion 43 show that whilst the channel has degraded consistently since the early 1960s, it was in fact relatively stable during the period of suspended-sediment sampling, 1949 to 1951.

Stream-flow measurements were also analyzed for the Souris River near Sherwood, ND in Ecoregion 46. Photographs show outside bend mass wasting in 2007, therefore this channel is currently considered unstable (Figure 11). However stream-flow measurement data show no bed movement between 1974 and 1981, the period of suspended-sediment sampling (Figure 12), therefore the channel is thought to have been stable at this time.

Figure 4 – Present RGAs show both inside and outside bank mass wasting on the Souris River near Sherwood, ND gage 05114000, characteristics of an unstable channel.

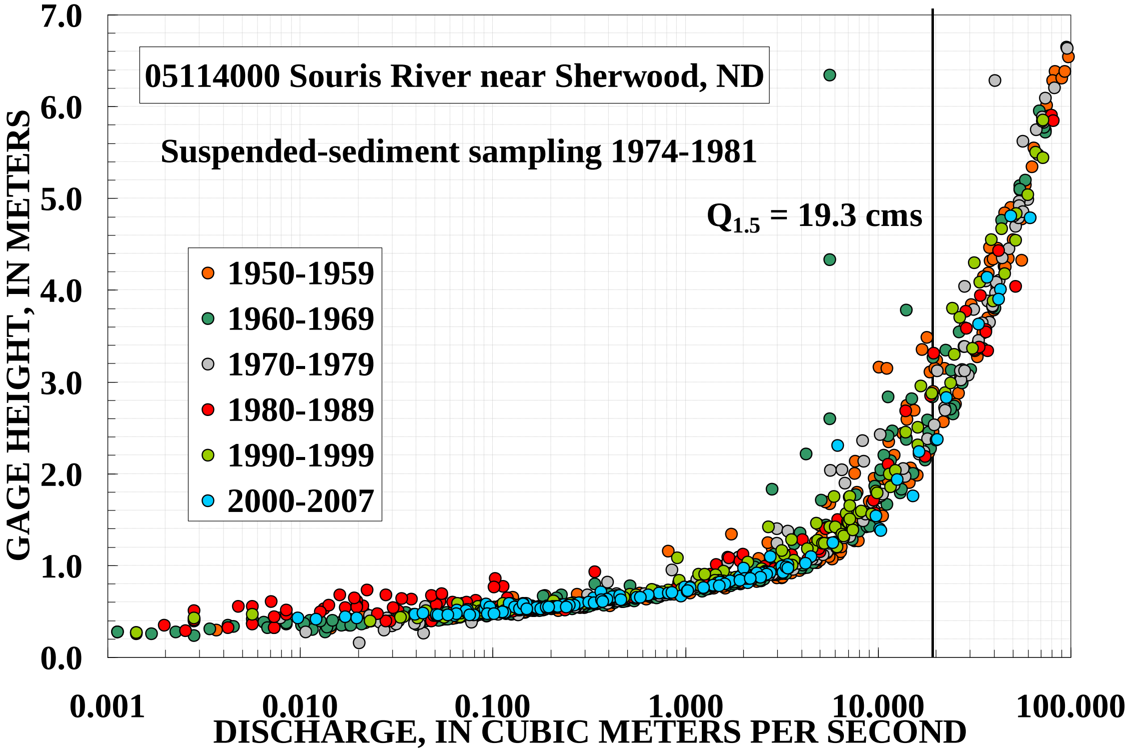

Figure 5 – Stream-flow measurement data for the Souris River near Sherwood, ND gage 05114000, show very no changes in bed elevation during the period of suspended-sediment sampling.

Stream-flow measurement data can also indicate aggradational channel beds, as is the case for the White River near Oacoma, SD gage # 06452000 in Ecoregion 43 (Figure 13). An aggradational channel with eroding banks is considered an unstable channel; stage V in the Channel of Evolution Model.

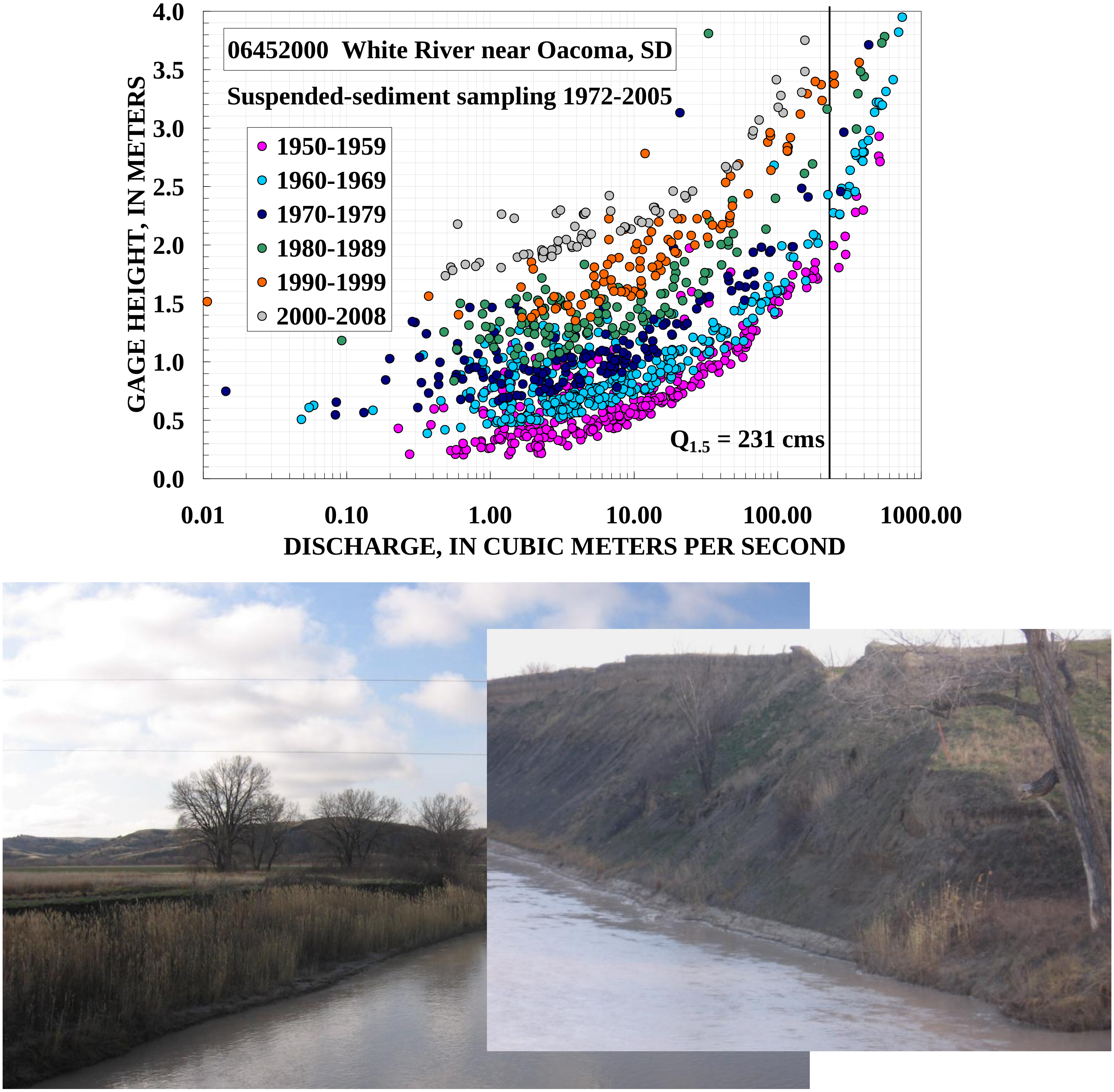

Figure 6 – The White River near Oacoma, SD is an aggradational channel with unstable banks, filling approximately 2 m since the 1950s.

Another method of determining historical stability is to examine suspended-sediment sample data over a range of years, where long periods of record exist. Suspended-sediment was sampled between 1972 and 2005 at the above example, the White River near Oacoma. Analyzing the suspended-sediment data by decade shows a gradual increase in rating exponent and a decrease in coefficient (Figure 14). This change in rating relation with time implies channel instability and suggests that low flows are beginning to carry less sediment, but storm response is much greater. Alternatively, no change in rating equation with time can suggest a stable channel, as is the case at the Belle Fourche River below Moorcroft, WY (Figure 15). This analysis must be used in conjunction with stream-flow measurement data analysis and cannot be used as a sole indicator of relative channel stability.

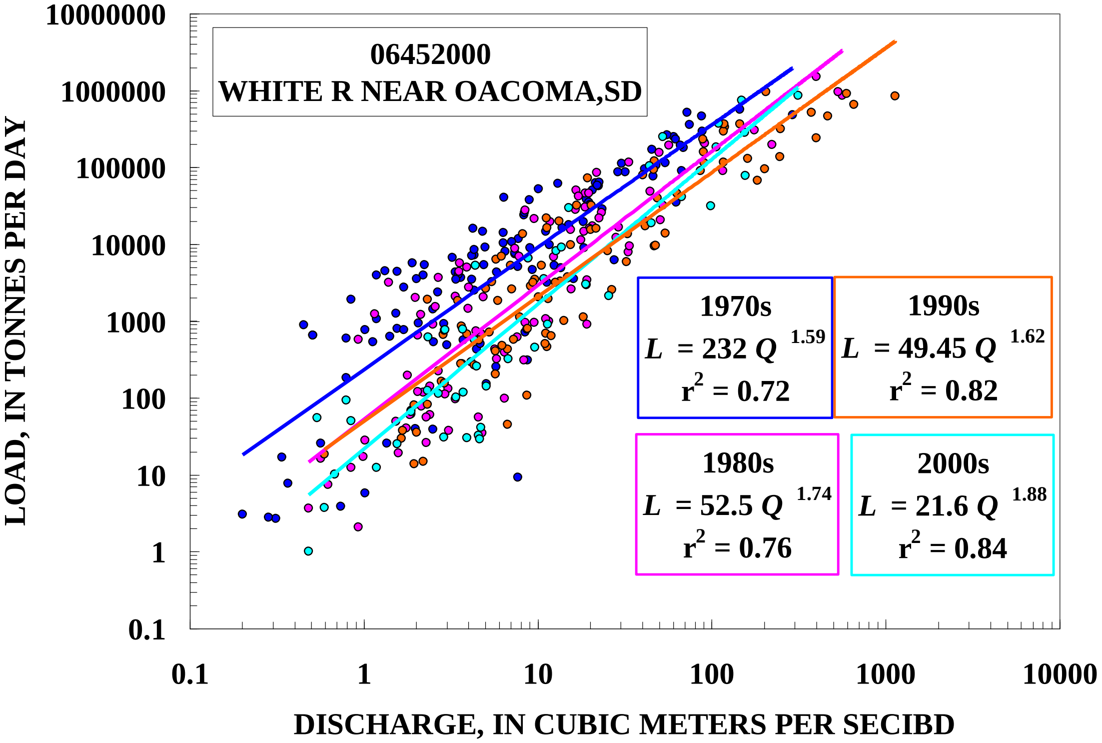

Figure 7 – Changes in suspended-sediment transport relations with time implies channel instability.

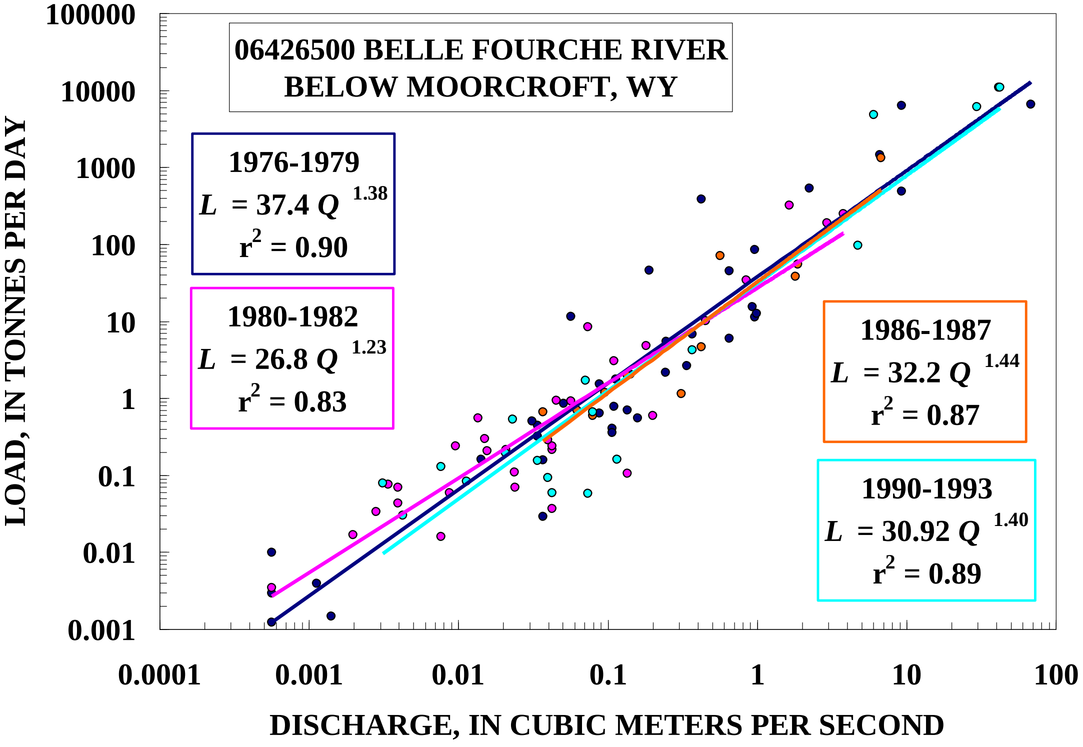

Figure 8 – Little change with time in the suspended-sediment transport relations derived for the Belle Fourche River below Moorcroft suggests a stable channel.

4.1.6 Bed-Material Conditions

As part of each RGA, bed material was characterized. If the bed material was dominated by gravels (2.00 mm or greater) or coarser fractions, a particle count was carried out. For a particle count, the intermediate axis of one hundred particles across the channel was measured, in order to represent a range of different particle sizes found across the width of the bed. Having carried out the particle count, if 16 % of the particles measured, had a median diameter of less than 2 mm, a bulk particle size sample of 100 g or greater was collected from the left, middle and right portions across the channel. This bulk sample was sieved to half-Phi intervals. Particle size data was combined with particle count data to give percentiles of class sizes and values for commonly used metrics such as the median particle size. If fines dominated the bed material, only a bulk sample was taken.

When concerned with water quality issues and their impact upon aquatic biota, the condition of the bed material is a key factor. One critical bed condition for biota is the filling of interstitial spaces between coarse particles (material 2 mm or larger; gravel, cobbles and boulders) with fines (material smaller than 2 mm; sand, silt and clay). This ‘filling of spaces’ reduces the habitat and breeding ground of macro-invertebrates. One way to examine this condition is through the “embeddedness” of the bed material. For this study we defined embeddedness by the percentage of material finer than 2 mm in an otherwise coarse matrix.