Restoration WARSSS
by
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Abstract

The four C's of river restoration...Cause, Consequence, Correction and Communication are better understood through the Watershed Assessment and River Stability and Sediment Supply (WARSSS) methodology. The WARSSS procedure involves a cumulative effects analysis of the watershed including the change in hillslope, hydrologic and channel processes influenced by various land use activities. Causes and consequences of instability related to specific processes are important to understand in order to "correct" the problem(s) rather than "patch" symptoms. Applying a geomorphic approach for river restoration and natural channel design is ***not*** a "simple cookbook" procedure contrary to recently published statements made by those unfamiliar with the method. Many river restoration projects that ignore the complexities inherent in assessment and geomorphic-based design are often the central cause of failure.

Conceptual outlines and examples are presented showing the watershed linkage to sedimentological, hydrological, morphological and biological process integration into river restoration. Applications for restoration are discussed utilizing; a) the WARSSS assessment, b) restoration alternatives, c) natural channel relations, d) design evaluation and "testing" methodologies and, e) implementation, effectiveness and validation monitoring.

Introduction

Numerous rivers of late, appear to be under a siege of "restoration". A great variety of river restoration approaches have been implemented, but even under the best of intentions, many failures have occurred. Many such failures are a direct result of the lack of a clear understanding of the cause and consequence of instability. The difference between success and failure in river restoration is often associated with the effort expended in watershed/river assessment.

There is no doubt as to the complexity as well as the risk in river restoration efforts. There are many potential solutions and a variety of appropriate methods in river restoration. Their use, however, is dictated by the project objectives and a detailed assessment of the problem(s). Many failed projects were the result of "patching symptoms" rather than addressing the processes leading to the source of river instability. Impaired rivers, those in obvious need of restoration, must be studied sufficiently to understand the underlying reasons for such instability and associated loss of physical and biological function. Potentially successful projects often result from directly addressing the major source(s) of impairment.

The first step toward successful river restoration is a rigorous watershed and river stability assessment. One such assessment methodology developed and utilized by the author provides a framework for assessing hillslope processes, hydrology and channel processes. The assessment methodology used is watershed assessment and river stability and sediment supply

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(WARSSS), a predictive tool to quantify the source, magnitude, direction and consequence of land uses, channel impacts, etc. on river stability (Rosgen, In press, 2004). A generalized flowchart (Figure 1) depicts the assessment categories of WARSSS. Regardless of the method or model used, it is imperative that a watershed/river assessment is a critical first step required for river restoration. Many of the field procedures utilized in WARSSS as a part of the assessment/stability analysis are summarized in Rosgen (2001a, 2001b, and 2001c).

Discussion of the major components of watershed/river assessment

Hillslope processes

Land uses leading to changes in vegetative composition, ground cover and soil compaction, can result in significant changes in streamflow response to precipitation as well as soil loss and delivered sediment to stream networks. Surface erosion and mass wasting processes that are disproportionately contributing sediment to stream systems must be identified. On-site mitigation and specific stabilization can be very effective in reducing accelerated sediment supply to the drainage networks. Roads in particular, not only contribute sediment, but intercept sub-surface flow and reduce evapo-transpiration. The results of these process changes can potentially result in peak flow magnitude and duration changes. Sloping road fills back to their original position, removing or re-designing and installing improved drainageway crossings can be extremely effective at reducing potential adverse channel and hydrology impacts. Assessment methods need to quantify the effects of roads such as channel degradation due to contraction scour, aggradation and lateral erosion due to backwater problems and accelerated sediment supply.

Hydrology

Streamflow magnitude, duration, timing and flood frequency changes must be understood. Channel instability often is not only a result of sediment increases or decreases, but can be related to changes in streamflow regime. An example of such water yield assessments are summarized in Treondle and Olsen, (1993). Diversions, impoundments and operational hydrology of reservoirs/hydro-power systems make substantial hydrology changes that often require modifications to the receiving channels to accommodate the new flow regime. The effects of concreted surfaces, structures, storm drains and other land use changes in urban watersheds create extensive impervious areas causing dramatic changes in the magnitude, duration and frequency of flood peaks. Channel dimensions must accommodate correct baseflow, bankfull and flood peaks, requiring detailed computations for design purposes. Examples of change in hydrographs and flow-duration curves for urban areas are demonstrated in Leopold (1994). If regulated main-stem reaches change the timing and/or magnitude of peak flows due to regulation, then the unregulated tributaries often cause aggradation and channel stability problems in the main-stem channel. This problem occurred in the main-stem of the Swift Current River in North Central Montana, located downstream of a major dam. The high bedload transport of Boulder Creek, an unregulated tributary deposited coarse sediment debris

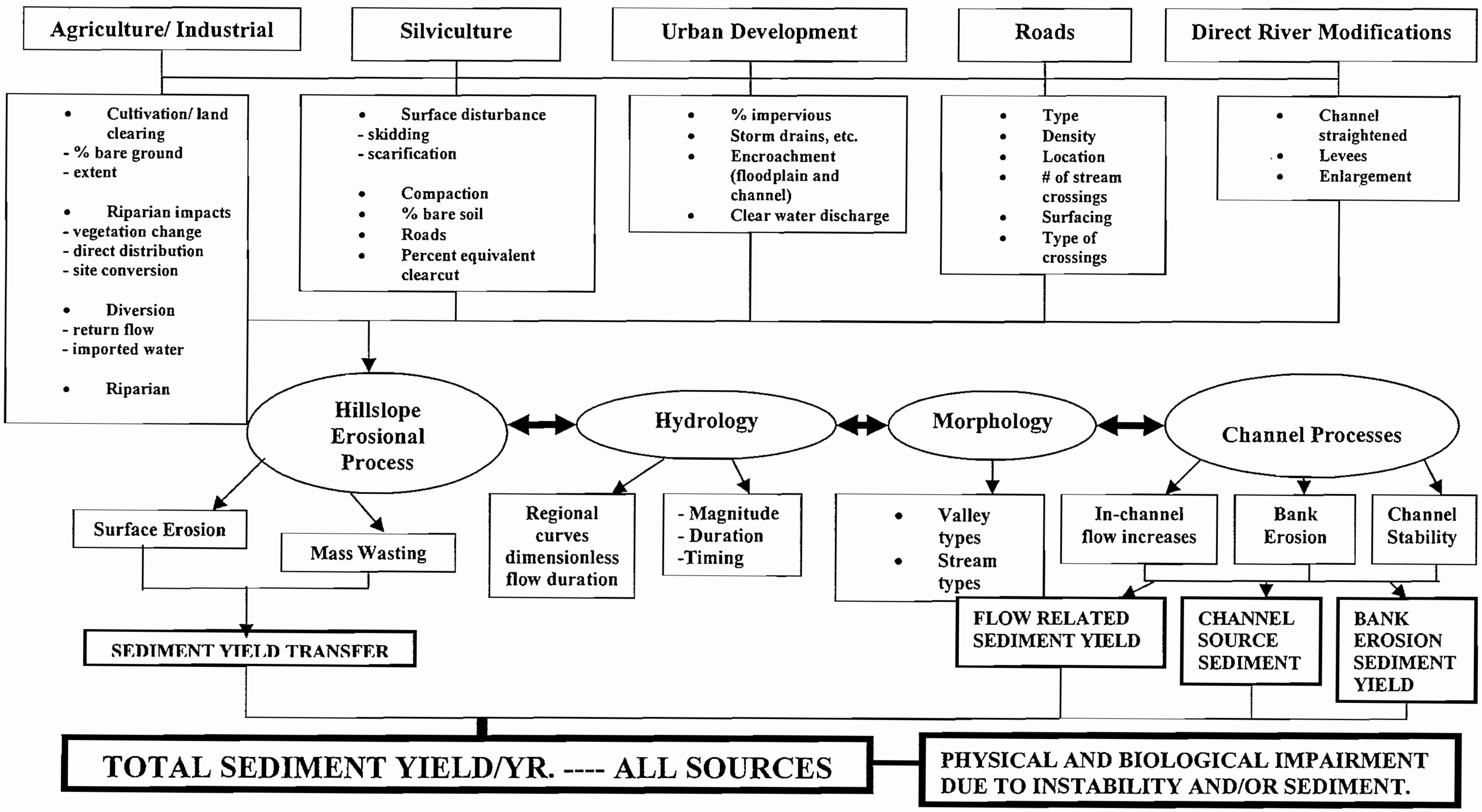

Figure 1. A generalized procedural analysis of the WARSSS assessment method for use in river restoration.

below the confluence with the regulated Swift Current River. The sediment deposition created aggradation and a braided river pattern, leading to accelerated lateral erosion of the river. Many wanted a restoration that would convert a braided river to a meandering single-thread channel. This design recommendation would be ill-advised, as the cause of the aggradation and corresponding braiding was due to a change in the timing of flow. A failure to return the timing of the historic flows with Boulder Creek would result in continued aggradation and a resultant failure of the restoration proposal. Calculations of the competence and capacity of the sediment transport of Swift Current River necessary to transport the size and load of Boulder Creek of Boulder Creek was made. The output of such analysis requires a bankfull flow released during the normal snowmelt season of Boulder Creek. The released flow would provide the hydraulics and corresponding magnitude, duration and timing necessary to move the bedload of the river to maintain channel stability. This example focuses on the value of understanding the cause of instability.

The analysis of streamgage networks is critical in assessment leading to the development of "Regional Curves" for specific hydro-physiographic provinces. Examples of "Regional Curves" show relations of bankfull discharge to drainage area (Figure 2) and bankfull dimensions related to drainage area (Figure 3), as developed by Dunne and Leopold, (1978). Additional hydrologic and hydraulic information is obtained including bankfull calibration, hydraulic geometry data, model calibration (such as the unit hydrograph model TR-55), and dimensionless flow-duration curves for sediment transport analysis (Figure 4).

Morphology

The morphology of valleys and stream channels within the watershed are described in assessment as unique valley and stream types (Rosgen, 1994, 1996). Due to the great diversity of valley and channel types, collected data must be stratified to identify "reference" or stable conditions within a particular valley type. The variability that exists within and between streams can often be explained by morphological "types". Dimensionless ratio relations are developed by reference reaches representing dimension, pattern and profiles unique to a valley and stream type. These ratios are used for comparative evaluations in departure analysis and for extrapolation for natural channel design applications. Morphology is also related to stability in the use of sediment transport relations.

Channel Processes

Specific assessments and channel stability examinations must be conducted to determine the degree or extent, direction, magnitude and consequence of departure from a stable "reference" condition (Rosgen, 1998, 2001a, 2001b). Riparian vegetation changes, direct disturbance factors and channel modifications including straightening, lining, leveeing, raising, lowering and/or widening must be assessed. Time-trend analysis using aerial photography is effectively used for this portion of the assessment.

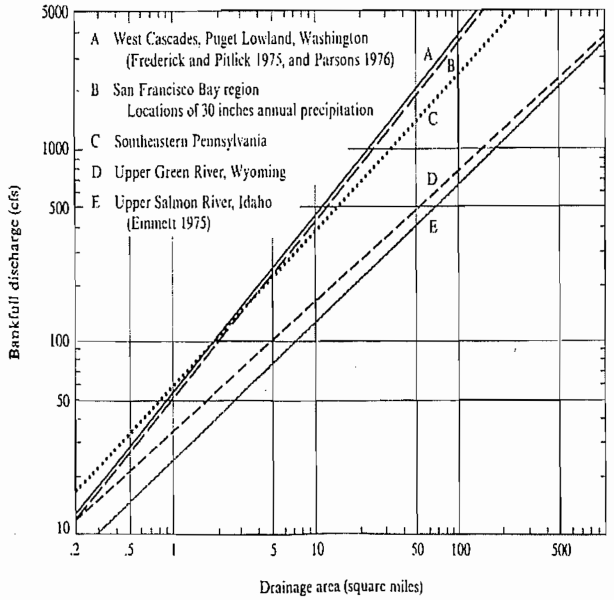

Figure 2. Regional curves showing relation between bankfull discharge and drainage area for selected watersheds. (Dunne and Leopold, 1978).

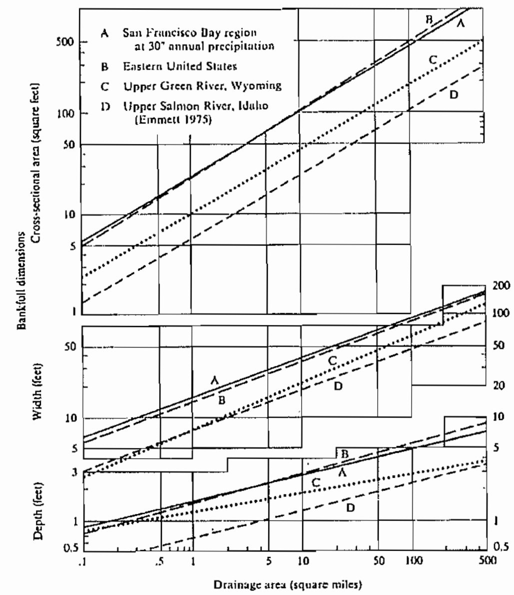

Figure 3. Regional curves showing relations of bankfull channel dimensions by drainage area for selected watersheds. (Dunne and Leopold, 1978).

Stability analysis quantitatively determines the extent, rate, and consequence of streambank erosion (tons/year) (Rosgen, 2001c), channel enlargement, degradation, aggradation, lateral accretion, pattern change, and successional stages of stream type change based on channel evolution (Rosgen, 1999, 2001a). Base level changes along the longitudinal profile are determined by bank height ratios (Rosgen, 2001a, 20001b).

Sediment analysis involves the computations of channel competency (ability to move the largest size sediment made available to the river channel), and sediment transport capacity (annual load). The assessment determines sediment supply from various sources, channel source sediment from increased flow, and changes in channel dimension, pattern and profile, leading to either degradation or aggradation. Sediment relations must be evaluated to properly understand the role of sediment in river stability problems.

Utilization of an assessment methodology for river restoration

River restoration is designed to "restore" natural stability and the physical and biological function. The definition of natural stability is "the ability of a stream, over time, in the present climate, to transport the sediment and streamflow produced by a watershed in such a manner that the stream channel dimension, pattern, and profile are maintained without either aggrading or degrading" (Rosgen, 1996).

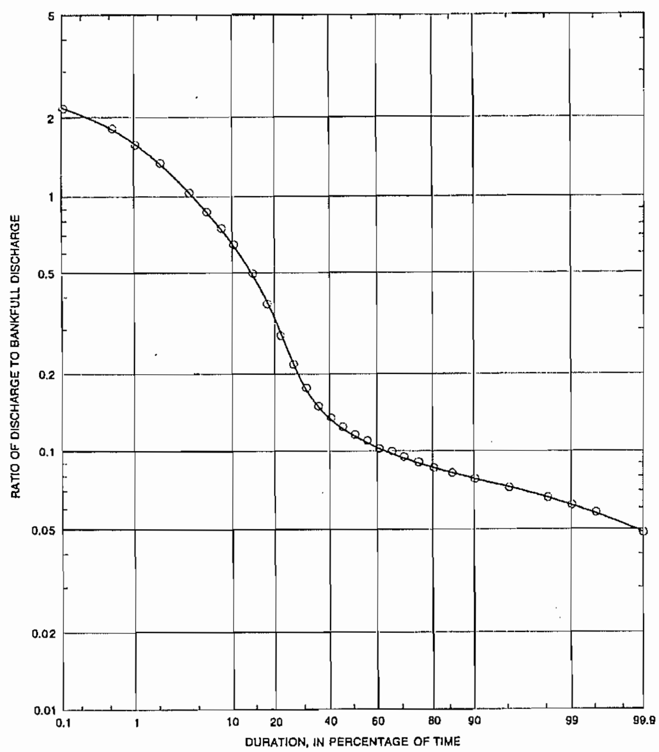

Figure 4. Dimensionless ratio flow-duration curves for the Salmon River drainage, Idaho (Emmett, 1975).

The watershed and river stability assessment provides a fundamental understanding of changes in streamflow magnitude, timing, duration and flood frequency, the size and amount of sediment from various sources, effects of past direct disturbance to stream channels, upstream and downstream constraints on base level, changes to the riparian corridor, etc, etc. So how is all of this information used?

Changes to the morphological, sedimentological, hydraulic and biological character of river channels must be compared to a stable reference stream representing the same valley type. Thus the nature, extent and consequence of departure must be understood to relate observed characteristics to "potential" states. If this information was not collected and analyzed…then how would a "river restoration designer" know how wide, deep, straight, crooked, steep, etc to make the stream? What is the appropriate stream type? What should be the stable dimension, pattern and profile? Can the "restored" stream move the largest sediment size, can it move the sediment load? These are not simple questions, nor are there simple solutions…however methods are available to make these assessments and calculations in order to reduce some of this uncertainty in river restoration.

The key data and interpretations provided by a watershed/river assessment utilized for restoration efforts are summarized as:

1. Identification and location of the *cause* of localized, disproportionate sediment supply/sizes, specific land uses causing instability, land ownership, processes affected and their locations,
2. Streamflow regime changes, regional curve development, hydraulic relations and bankfull calibration, and development of dimensionless flow-duration curves,
3. Departure analysis provides the extent, nature, rate and direction of change from potential or "reference" condition. Identification of stable stream types for respective valley types, successional states associated with channel evolution,
4. Spatial distribution of instability, base level changes, sediment supply changes by location that potentially influence upstream and/or downstream change.

Development of a restoration plan

The key ingredients in developing a restoration plan is to first have a full understanding of the restoration objectives. The objectives often have multiple facets including flood control, fisheries, aesthetics, streambank stabilization, sediment reduction, and recreational boating and safety issues. Some of these objectives often appear to have a conflicting and competing presence.

Once objectives are understood and agreed to, the summary from the assessment is used to develop the initial alternatives.

Formation of Restoration Alternatives

Often restoration can be implemented by a change in management. This potential is very important as a first priority, depending on the cause and consequence of change, the *recovery potential of the stream types* involved and land ownership. Mitigation of on-site impacts, management and protection of riparian corridors, revegetation efforts, and other "indirect" alternatives can be the least expensive with less risk, while potentially being the most effective in certain circumstances.

Other restoration alternatives sometimes must be considered if land ownership, recovery potential, extent of flow changes and other variables cannot be changed with management practices only. In these circumstances a more direct approach to river restoration is often required to meet objectives. Depending on the dimension, pattern and profile data from the assessment, bio-engineering or riparian plantings and native material streambank stabilization solutions can be very effective. Unfortunately, unstable channels often need to be re-shaped to secure the stable form, then stabilization methods can be used to "buy time" for the riparian vegetation to become effective. Often because of specific objectives, such as fish habitat enhancement, in-channel work must be undertaken to create such desired habitat.

Understanding the results and consequence of instability can help in formulating restoration alternatives. If degradation and/or vertical containment (entrenchment) results from disturbance, then a selection from the "four priorities" of incised river restoration may be considered (Rosgen, 1997). The results of the stability assessments as shown in Figure 5 are used to address the stability variables as part of the stable river restoration design.

Restoration Design

The resultant specific channel design and restoration plan must meet objectives, offset the instability variables, have the competence and capacity to move sediment, reduce accelerated streambank erosion rates, meet fish habitat requirements for diversity, etc., allow for the potential composition of riparian vegetation to be established. A flow chart depicting assessment integration for restoration is shown in Figure 6. It is readily apparent that the skills needed for assessment and design include engineering, hydrology, geomorphology, fisheries, plant physiology, soils, and other related disciplines. This does require an interdisciplinary effort. Not only should the designs meet objectives, they have to be commensurate with the information provided by the assessment. For example, if the flow regime cannot be changed, then it is often necessary to design the channel dimension, pattern and profile to match the new flow. The creation of multiple stage channels is often a very good solution in urban streams where the magnitude and frequency of flood peaks are increased. Rather than over-widening the channel to handle eventual "build out", flows of various magnitudes can be "stepped by stage". This allows for sediment transport and energy dissipation as well as biological function in changing flow environments. Without the hydrology assessment, regional curves and supportive data, dimensions of stream channels commensurate with the stable stream type would be difficult to select.

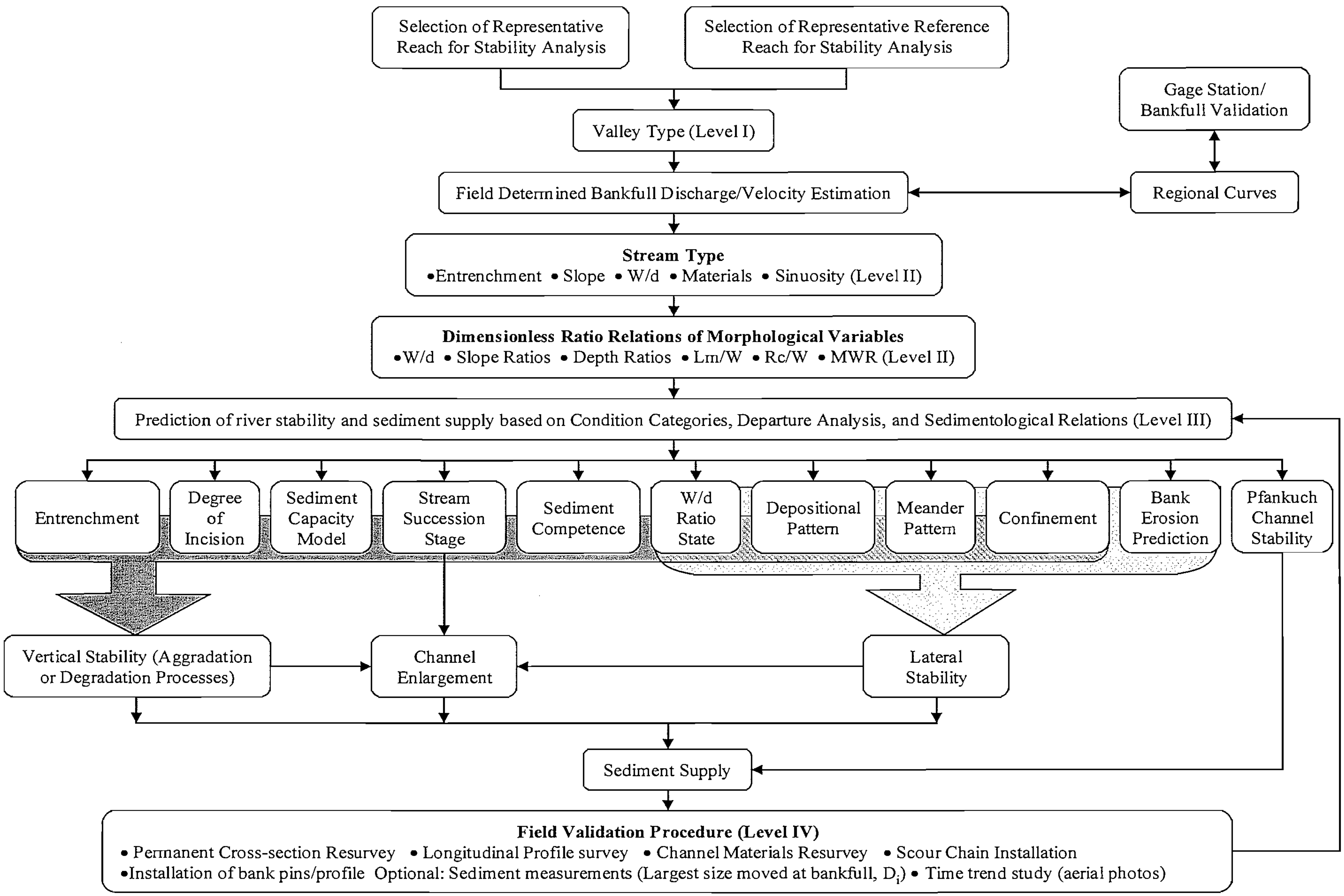

Figure 5. Summary of stability assessment, morphology and hydrology information used in restoration design.

Restoration designs need to not only correctly identify riparian species, selection of the correct range of channel dimension, pattern and profile by stream type, but select and locate stabilization methods and materials compatible with natural channel design principles. Aesthetics, biological function and other objectives have to be integrated at this stage.

There is a detailed analytical sequence in natural channel design utilizing *empirical, analog* and *analytical* approaches to accomplish the design. It is outside the scope of this paper to present this analysis as presently utilized. The reader should be aware, however, there is a very detailed, quantitative methodology available in natural channel design utilizing the assessment data and hydraulic, sedimentological and morphological relations. A minimum 40 step design process is required utilizing a geomorphic approach for river restoration.

<u>Design testing/evaluation</u>

Once the initial design is established it must undergo a rigorous review. Many failures of restoration projects occur due to the fact that the restoration channel could not accommodate sediment transport. One of the least understood but most important aspects of the design is to test or evaluate the proposed design for sediment competence and capacity (transport of annual load). The same methods used in the assessment and for the reference stream must also be implemented on the proposed channel. The use of reference dimensionless ratio sediment rating curves (Troendle, et al, 2001) and methods including "Power-Sed in the WARSSS methodology and methods included in Rosgen, (1998, 1999, 2001a, 2001b), are used in this sediment/stability evaluation.

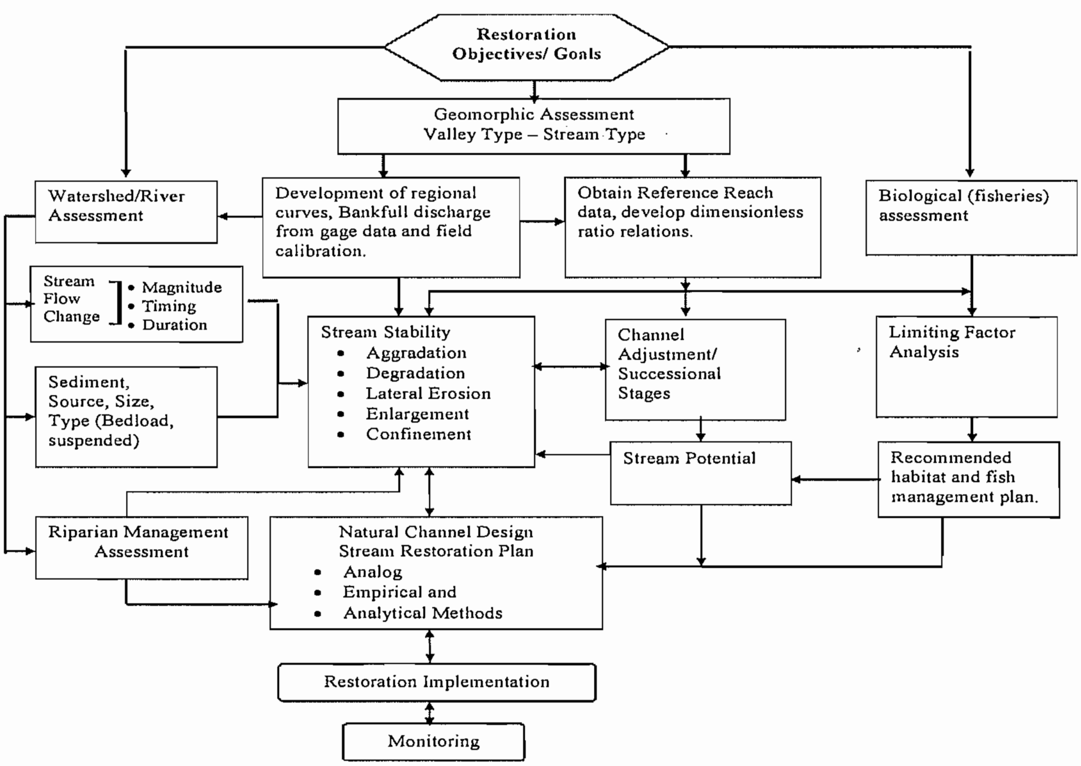

Figure 6. Integration of watershed/stability assessment for stream restoration using natural channel design principles.

Implementation, effectiveness, and validation monitoring

Due to uncertainty of prediction, potential problems in properly implementing the "best of plans", verification that objectives were met, makes monitoring absolutely essential. If prediction methods are questioned, which they should be, it is important to validate the relations so that predicted versus observed values can be compared. Permanent reference elevations for profiles and cross-sections will determine upon re-survey if the stream is maintaining its dimension, pattern and profile. Often, post-project monitoring documents that the design was not implemented correctly, thus, the fault was not in the design or in the model, but failure to get it constructed correctly.

If a restoration objective was to reduce accelerated streambank erosion, then an annual resurvey of bank and toe pins will verify post-restoration erosion rates. Bank erosion measurements not only assist in an accounting of meeting objectives, but can be used to compare predicted versus observed rates (Rosgen, 2001c). Monitoring provides an evaluation of stabilization and enhancement measures as well as validation of hydraulic and sediment models.

Summary

A good design for river restoration can only be accomplished following a good assessment. Assessment methodologies are becoming more sophisticated and have been validated and thus improved due to field observations. Documentation of such observations in a quantitative, consistent manner will help improve the tools that are used to accurately predict channel change. Amidst the complexity, there *is* knowledge...the challenge is to properly put this knowledge and associated principles into practice.

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