RIVER RESTORATION USING A GEOMORPHIC APPROACH FOR NATURAL CHANNEL DESIGN

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Abstract: River restoration based on the principles of natural channel design is most commonly accomplished by restoring the dimension, pattern and profile of a disturbed river system to emulate the natural, stable river. To "restore" rivers involves securing their physical stability and biological function, rather than the unlikely ability to return the river to a pristine state. Restoration is used synonymously with the term *rehabilitation*. Any river restoration design must first identify the cause and consequence of stream channel impairment (instability). The design must not only address the causes of instability, but also the rivers potential to balance the objectives, desires and benefits of the proposed restoration.

Natural channel design uses a geomorphic approach that incorporates a combination of *analog*, *empirical* and *analytical* methods for assessment and design. Because all rivers within a wide range of valley types do not exhibit similar morphological, sedimentological, hydraulic or biological characteristics, it is necessary to group rivers of similar characteristics into discrete stream types. Such characteristics are obtained from stable *reference reach* locations by discrete valley types, and are then converted to dimensionless ratios for extrapolation to disturbed stream reaches of various sizes. Hydraulic, sedimentological and morphological relations are obtained for both the reference and impaired conditions. Such values describe not only the average but the range of selected variables used for assessment as well as natural channel design. Sediment competence and capacity calculations are key to both the stability assessment and the design phases of the methodology.

The proper application of this approach requires extensive training and experience. A strong background in geomorphology, hydrology and engineering is required. The restoration specialist must also have the ability to integrate principles from fishery and plant science disciplines, and to implement the design in the field. The assessment methodology is broken into eight major sequential phases.

INTRODUCTION

The cumulative effects of long-term watershed development and "river works" have had extensive adverse impacts on our rivers. The effects of road construction, riparian vegetation change, in-channel gravel mining, logging, reservoirs/diversions, urban sprawl and other similar developments have significantly changed flow and sediment regimes and the boundary conditions associated with stable stream systems. Direct disturbance to channels by straightening, lining, draining, raising, lowering, clearing, dredging in the name of flood control, navigation and other single-purpose objectives have taken a serious toll on the physical and biological functions of our rivers.

Public awareness over the last decade has prompted federal, state, local jurisdictions and environmental groups to direct major efforts at preserving, protecting, enhancing, stabilizing, rehabilitating and restoring rivers throughout the United States. The pendulum is at least swinging the other way, albeit sometimes into a strong headwind. Great demands, as well as strong criticisms, are being directed to those who restore rivers. Society has spent the last 200 years changing landscapes: now, they want their rivers back. Often, the urgency to restore rivers comes at a price, as many rush into river restoration without the proper tools and/or the experience to properly use the tools. This paper provides a brief overview of the natural channel design method for river restoration. Space does not permit a full description of the methods here, nor does it allow for examples. Rather, this introduction is intended to build respect for the science and complexity behind river restoration using natural channel design procedures.

The river restoration dilemma reflects the complexity and uncertainty contained within the science. Although the study of rivers is not new, the science and art of river restoration is relatively recent in terms of addressing multiple objectives associated with physical, chemical and biological processes. Aesthetic considerations need to be balanced with efforts to provide a restoration that will be self-stabilizing over time. Some academics have become theoretical disciples of river restoration; others have become "prophets of doom." Many argue that rivers should be left alone to "do their thing." Others wonder, "What is the recovery potential of rivers? Are rivers really "trainable"? How do we define and implement ecological balance? If you cannot take care of the entire watershed, should local problem river reaches be left alone? How should property, road fills and homes be protected from erosion, other than with standard “hard control” practices? Ideal solutions make good sense, but practical realities, ownership boundary constraints and economics often preclude their implementation.

“Natural channel design” is a geomorphic-based method that is an obvious departure from traditional river engineering. Critics have labeled this methodology a “simplified cook-book” procedure that ignores process (Kondolf, et al., 2003). For example, Simon et al. (2005) stated “that natural channel design, using 50 year old technology, was never intended for engineering design, and the inability of the method to quantify the very variables and processes that control channel processes and morphology.” This dialog from those least familiar with the method will likely continue; however, it is increasingly important to familiarize those who are curious, yet unfamiliar, with the method.

The natural channel design method is continually updated based on post-project monitoring. The author has implemented this method on miles of rivers for more than 32 years. The method presently constitutes a chapter in the new *Stream Restoration Design Handbook* being developed by the USDA Natural Resources Conservation Service (NRCS, 2005; In review). The conceptual layout for the eight phases of the geomorphic approach to natural channel design is shown in Figure 1. The flowchart is indicative of the full extent and complexity associated with this method, including detailed, quantitative assessments of the cause(s) of river disequilibrium (stability); field measurements required to quantify hydraulic and sedimentological relations; and designs that implement *analog, empirical,* and *analytical* methods. The eight phases are detailed below.

METHODS

Sequential Phases: There are eight phases associated with the natural channel design method. Each phase is described below and corresponds to the outline in Figure 1.

Phase I: Restoration Goal/Objectives - *Define specific restoration objectives associated with physical, biological and/or chemical process*. It is very important to obtain clear and concise statements of restoration objectives in order to appropriately design the solution(s). The potential of a certain stream to meet specific objectives must be assessed early on in the planning phases, so that the initial restoration direction is appropriate. The following are common objectives: a) reduce flood levels; b) stabilize streambanks; c) reduce sediment supply, land loss and attached nutrients; d) improve visual values; e) improve fish habitat and biological diversity; f) create a “naturally stable” river; g) withstand floods; h) provide for self-maintenance; i) be cost-effective; j) improve water quality; and k) improve or create wetlands.

It is essential to fully describe and understand restoration objectives. There may be competing or even conflicting objectives. These conflicts must be mediated and can often be offset by varying the design and/or the nature of stabilization methods or materials planned. The assessment required must also reflect the restoration objectives, to ensure that all processes are thoroughly evaluated. For example, if improved fishery abundance, size, and species are desired, then a limiting factor analysis of habitat and fish populations must be linked with morphological and sedimentological characteristics.

Phase II: Regional and Local relations - *Develop regional and localized specific information on geomorphologic characterization, hydrology and hydraulics*. During Phase II, it is important to incorporate information on valley types, stream types and reference reach data representing the stable form in similar valley types. Preparation should include assessing regional hydrology curves (bankfull discharge and cross-sectional area versus drainage area) (Rosgen and Silvey, 2005) and hydraulic calculations and validation at gage stations using resistance relations and/or roughness values.

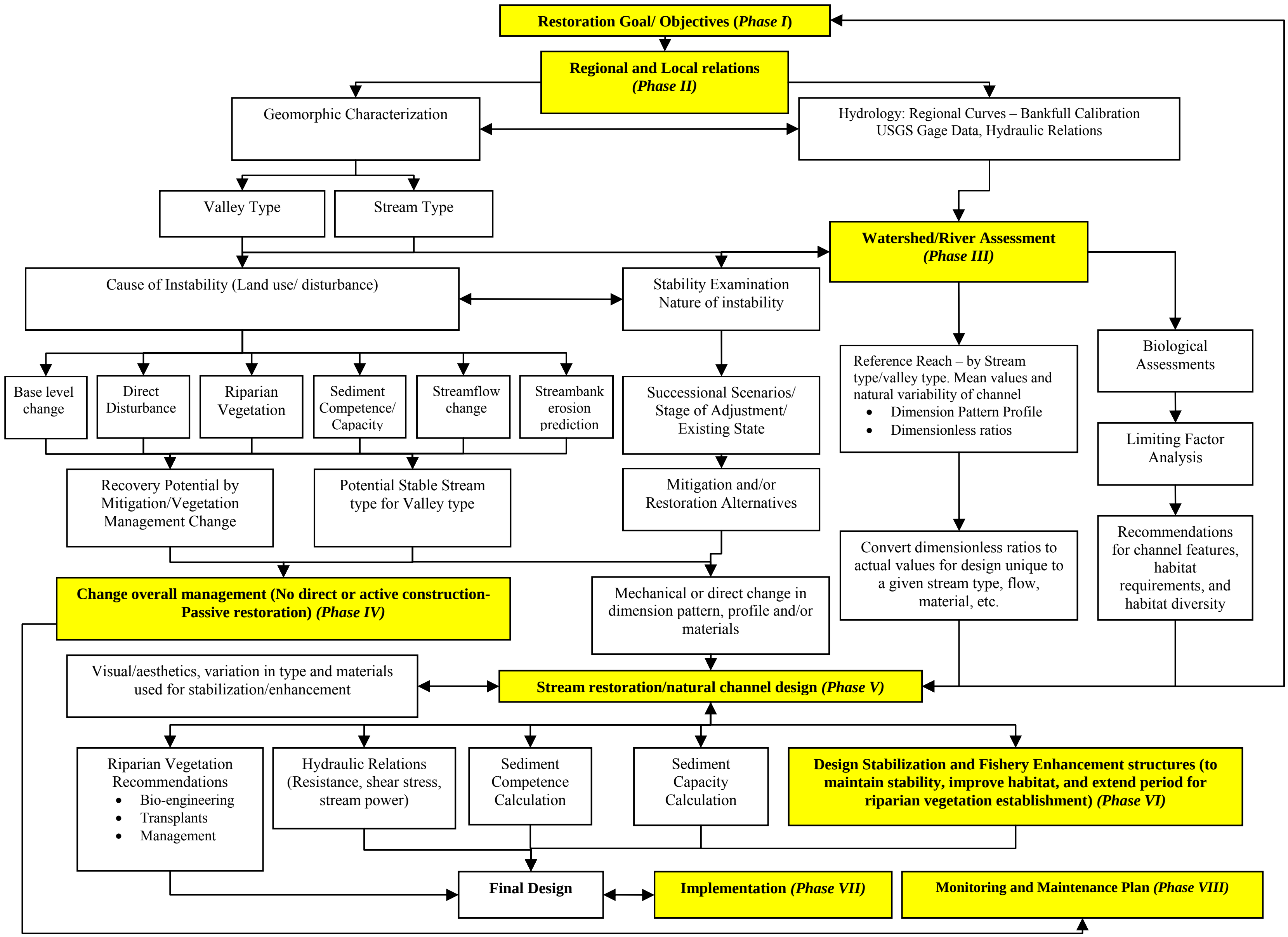

Figure 1 Flow chart depicting sequence of implementation of the eight sequence phases associated with natural channel design using a geomorphic approach.

Phase III: Watershed/River Assessment – *Conduct a watershed/river assessment to determine river potential, current state and the nature, magnitude, direction, duration and consequences of change.* Phase III, watershed/ river assessment, is one of the key procedural steps in a sound restoration plan because it identifies the causes and consequences associated with the loss of physical and biological river function. Phase III assesses the cause(s) and consequence(s) of change at both the micro and macro levels. During this phase, it is important to: a) review land use history and time-trends of river change; b) isolate the primary causes of instability and/or loss of physical and biological function; c) collect and analyze field data, including reference reach data, to define sedimentological, hydraulic and morphological parameters; d) obtain concurrent biological data (limiting factor analysis) on a parallel track with the physical data; and e) quantify streamflow and sediment regime changes.

It is important to realize the dynamic nature of streams, and the difference between the natural adjustment process and the acceleration of such adjustments. For example, bank erosion is a natural channel process; however, accelerated streambank erosion creates a disequilibrium condition. Many stable rivers naturally adjust laterally, such as the "wandering" river. While it may meet certain local objectives to stabilize high-risk banks, it would be unadvisable to try to "control" or "fix in place" such a river. In many instances, a braided river and/or anatomizing river type is the stable form. Designing all stream systems to be a single-thread meandering stream may not properly represent the natural stable form. Valley types are a key part of river assessment because geomorphic settings affect the characterization of a stable stream type. Further, reference reaches representing the stable form have to be measured and characterized for use with similar valley types. This prevents applying good data to the *wrong* stream type.

River stability (equilibrium or quasi-equilibrium) is defined as "the ability of a river, over time, in the present climate to transport the flows and sediment produced by its watershed in such a manner that the stream maintains its dimension, pattern and profile without either aggrading or degrading" (Rosgen, 1994, 1996, 2001a). To optimize river stability, one must take an inventory of riparian vegetation, identify changes in flow and sediment regime, compare limiting factor analysis to biological potential, and identify sources/causes of instability and adverse consequences to physical and biological function. Procedures for this assessment are described in detail by Rosgen (1996, Chapter 6; 2001a) and in the *Watershed Assessment and River Stability for Sediment Supply (WARSSS)* (Rosgen, 1999, 2006a, In press).

Streambank erosion rate (lateral erosion rate and sediment, tons/year) is predicted as part of the river stability assessment. The influence of vegetative change, direct disturbance and other causes of bank instability are quantitatively assessed. One of the major consequences of stream channel instability is accelerated streambank erosion and associated land loss. Fish habitat is adversely affected not only due to increased sediment supply, but also by changes in pool quality, substrate materials, imbrication and other physical habitat loss. Water temperatures are also adversely affected due to increases in width/depth ratio due to lateral accretion. The prediction methodology for streambank erosion is presented in Chapter 6 (Rosgen, 1996), and in Rosgen (2001a), using a Bank Erodibility Hazard Index and Near-Bank Stress calculations.

Time-trend data using aerial photography is very valuable for documenting channel change. Field evidence using dendrochronology, stratigraphy, carbon dating, paleochannels or evidence of avulsion and avulsion dates can help the field observer to understand the rate, direction and consequences of channel change. The field inventory and number of variables required for watershed and river stability assessment is substantial. Figure 2 represents a general summary of the elements used to assess channel stability in the natural channel design methodology. Detailed procedures for such assessments are provided in Chapter 6 of Applied River Morphology (Rosgen 1996) and in *WARSSS* (Rosgen, 2006b, In press).

Phase IV: Change overall management (Passive restoration) – *Consider passive restoration recommendations based on land use change prior to considering mechanical restoration.* A priority in restoration is to seek a natural recovery solution based on changes in the variables causing the instability and/or loss of physical and biological function. Changes in land use management can influence riparian vegetation composition, density and vigor, flow modifications (diversions, storage, reservoir release schedule modifications based on the operational hydrology),

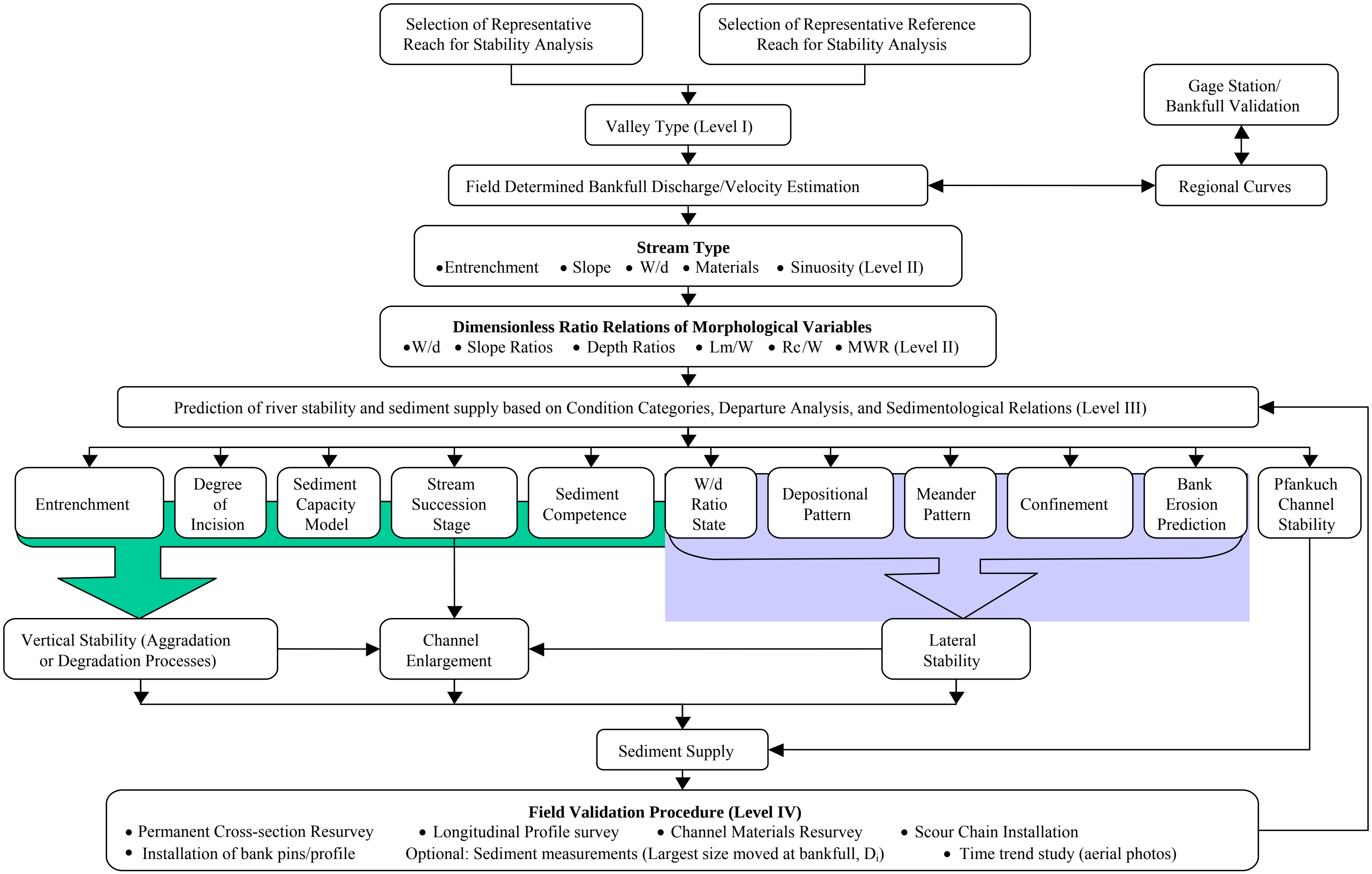

Figure 2 Generalized flowchart of application of various assessment levels of channel morphology, stability ratings, and sediment supply.

flood control measures, road closures/stabilization, hillslope erosional processes and other process influencing river stability. Changes in management strategies can be very effective in securing stability and function. This is determined based on the recovery potential of various stream types and the short- and long-term goals associated with the stated objectives, including costs.

The alternative to self-stabilization is always a key consideration in any stability assessment. The time-trend aerial photography from Phase III may help to provide insight into stream recovery potential following disturbance. Successional stages of channel adjustment can also provide clues to natural recovery potential. Passive restoration designs require effectiveness monitoring, including documentation of the nature, magnitude, rate and consequences of natural recovery, to ensure that objectives are met. If natural recovery potential is poor and/or does not meet specific objectives, then stream restoration/natural channel design (Phase V) is appropriate.

Phase V: Stream Restoration/Natural Channel Design – *Initiate natural channel design with subsequent analytical testing of hydraulic and sediment transport (competence and capacity) relations.* This phase combines the results from phases I through IV. It is important to remember that a good design stems from a good assessment. The goal of this phase is not to patch symptoms, but rather to provide restoration solutions that will offset the causes of the problem and allow the river be self-maintaining. To accomplish this goal, the practitioner must be very familiar with the processes involved in hydrology, hydraulics, sedimentology, geomorphology, soil science, aquatic habitat and riparian vegetation assessments. Due to the inherent complexity, it is usually necessary to obtain technical assistance for assessment and design, depending on the practitioner's experience and training.

The conceptual, generalized flowchart shown in Figure 3 depicts the general sequence of the mixed use of *analog, empirical*, and *analytical* methods in the natural channel design procedure. To determine the appropriate channel form, the existing valley type and potential stream type of the stable form must be available. The proposed natural channel design must be converted to a dimension, pattern and profile to determine if the hydraulic and sediment relations are compatible prior to completing the remaining procedural steps. A total of 40 analytical sequence steps generate and test restoration design specifications to determine dimension, pattern and profile relations as outlined in Chapter 11 of the NRCS (2005, In review). Sediment competence is determined with methods described in Rosgen (2001b, 2006a). Sediment capacity is calculated using FLOWSED and POWERSED models (Rosgen, 2006a) based on dimensionless sediment rating curve relations (Troendle et al., 2001). These models are programmed and made available by RIVERMorph$_{TM}$, version 4.0, FMSM Engineers, Inc., Louisville, KY.

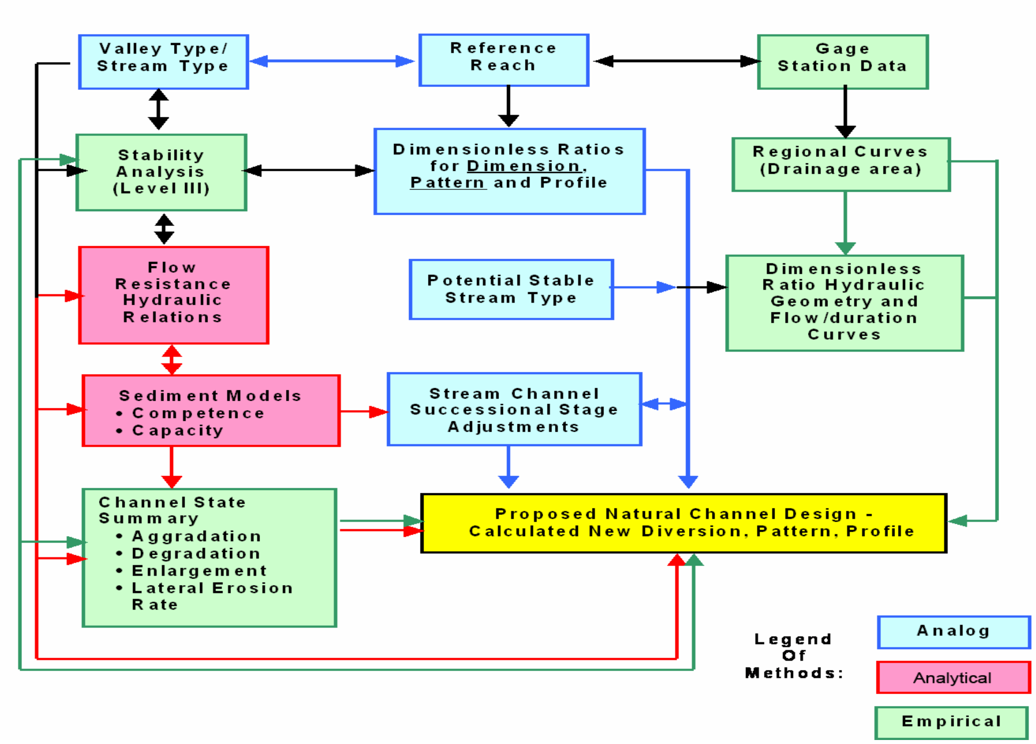

Figure 3 Flowchart representing natural channel design using analog, analytical and empirical methodologies.

Phase VI: Design Stabilization and Fisheries Enhancement Structures – *Select and design stabilization/ enhancement/vegetative establishment measures and materials to maintain dimension, pattern and profile to meet stated objectives*. Structures of native materials are used for energy dissipation, fish habitat enhancement, and near-bank stress reduction to extend time for vegetation response and establish bed pavement. Selection of designs, materials and methods are critical to meet multiple objectives including aesthetics. Various structures used for restoration are described by Rosgen, (2001c).

Phase VII: Implementation **–** *Implement the proposed design and stabilization measures involving layout, water quality control and construction staging.* River structures are often primarily designed to a) buy time to protect the new channel from excess erosion until significant riparian vegetation can become established; b) reduce accelerated streambank erosion; c) provide grade control; d) obtain stable flow diversions; e) enhance fish habitat, including in-stream cover, holding cover, spawning habitat, and habitat diversity, etc.; f) re-introduce and stabilize large wood for fishery, stability and aesthetic purposes; g) protect infrastructure adjacent to streams; h) protect bridges, culverts and drainageway crossings; i) reduce flood levels; j) transport sediment; and k) provide energy dissipation. Designs using native materials to meet these objectives are shown in Rosgen (2001c).

Phase VIII: Monitoring and Maintenance Plan – *Design a plan for effectiveness, validation and implementation monitoring to ensure stated objectives is met, prediction methods are appropriate and construction is implemented as designed*. Watershed and river assessments leading to restoration involve complex process interactions, making accurate predictions somewhat precarious. Continually measuring data after restoration will improve our understanding and prediction of sedimentological, hydrological, morphological and biological process relations. Additional benefits from monitoring include demonstration of the effectiveness of reduced sediment problems and improved river stability due to management/mitigation — the central purpose of watershed and sediment assessments and restoration. Without monitoring, the science behind river restoration cannot be advanced, nor can our understanding of these complex processes be improved.

The key to a successful monitoring program is to focus on the specific objectives of monitoring. Monitoring is generally recommended to: a) measure the *response of a system* from combined process interaction due to imposed change; b) document or observe the *response of a specific process* and compare it to a *predicted* response; c) prescribe treatment; d) define short-term versus long-term changes; e) document spatial variability of process and system response; f) ease the anxiety of uncertainty of prediction; g) provide confidence in specific management practice modifications or mitigation recommendations to offset adverse water resource impacts; h) evaluate effectiveness of stabilization or restoration approaches; i) reduce risk once predictions and/or practices are assessed; j) build a data base to extrapolate for similar applications; and k) determine specific maintenance requirements.

CONCLUSIONS

It is desirable that the individual(s) responsible for the project be involved in *all phases* of this methodology. If the same individual who conducts the assessment also completes the design, implementation and monitoring, then the desired restoration objectives are more likely to be accomplished. The complexity of this method requires great attention to detail, training and an understanding of processes. Involvement in the implementation, validation and effectiveness procedures is the best way to become experienced and knowledgeable about natural channel design methodology. Additional information regarding natural channel design river restoration methods can be found in Chapter 11 of the new USDA Natural Resources Conservation Service *Stream Restoration Design Handbook* (NRCS, 2005; in review).

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