The Natural Channel Design Method for River Restoration

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Abstract

Research and restoration implementation of nearly four decades has resulted in the development of the principles and procedural sequences of natural channel design. The procedure includes the implementation of fluvial geomorphology relations to assist in stability assessments, as well as the application of sedimentological, hydraulic and morphological relations. Procedures for natural channel design include *analog, empirical,* and *analytical* methods. The proper implementation of this approach requires fundamental training and experience using this Fluvial Geomorphology method. Experience and formal training in geomorphology, hydrology and engineering is required to implement this method. The restoration specialists must also have the ability to integrate principles from multiple disciplines, such as fishery biology and plant science, and most importantly, they must be able to implement the design in the field. Sediment competence and capacity computations are key parts of the assessment and design phases. The methodology is broken into eight major sequential phases: I) Define specific restoration objectives associated with physical, biological and/or chemical process; II) Develop regional and localized specific information on geomorphologic characterization, hydrology and hydraulics; III) Conduct a watershed/river assessment to determine river potential, current state and the nature, magnitude, direction, duration and consequences of change. Obtain concurrent biological data (limiting factor analysis) on a parallel track with the physical data; IV) Consider passive restoration recommendations based on land use change, in lieu of mechanical restoration. If passive methods are reasonable to meet objectives, skip to the monitoring phase (VIII). If passive efforts and/or recovery potential do not meet stated multiple objectives, then proceed with the following phases; V) Initiate natural channel design with subsequent analytical testing of hydraulic and sediment transport (competence and capacity) relations; VI) Select and design stabilization/enhancement/vegetative establishment measures and materials to maintain dimension, pattern and profile to meet stated objectives; VII) Implement the proposed design and stabilization measures involving layout, water quality control and construction staging; and VIII) Design a plan for effectiveness, validation and implementation monitoring to ensure stated objectives are met, prediction methods are appropriate and the construction is implemented as designed. Finally, design and implement a maintenance plan.

Contrary to popular misconception, this method is not a "simple cookbook" approach. Users of this method will find sufficient complexity involved in the detailed, quantitative assessments of the cause(s) of river disequilibrium and the field measurements and models used to predict the morphologic, hydraulic and sedimentological relations of the proposed design.

Introduction

River restoration is a popular and noble notion; however, its successful accomplishment is a great challenge. The uncertainty of prediction, the complexity of river systems, the various knowledge and experience levels of professionals assigned to do restoration, and conflicts with traditional river controls all contribute to the difficulty of successful river restoration. Rather than utilizing the collective expertise from many disciplines to standardize restoration procedures, great controversy has arisen of late among academics and various professional disciplines. These controversies are notably between geomorphologists and engineers, as they attempt to define standards for their respective disciplines.

Adding to the complexity is the fact that any restoration approach should be a watershed-based procedure, although stabilization often occurs on local or individual river reaches. The watershed context allows critical information to be assessed regarding the cause of disturbance or disequilibrium to river channels. Often the cause, beyond the more obvious direct disturbance to river channels, is associated with changes in flow magnitude, timing and duration due to vegetative management/storage and/or diversions within the watershed. Changes in sediment regime influencing size and/or load from erosional and depositional processes in the watershed need to be understood and predicted. Land use history, including time-trends and the consequences of change, are key questions that must be answered in any river restoration design.

This paper presents river restoration methods using Natural Channel Design (NCD) that have been developed, tested, implemented and monitored by the author for nearly four decades. The procedure is a geomorphic approach that integrates many disciplines, including geomorphology, engineering, plant science (riparian and silvicultural management), fishery science, soil science and landscape architecture. It has been referred to by many as a simple and inappropriate "cookbook" procedure (Miller and Ritter, 1996; Kondolf, 1995; Kondolf and Downs, 1996; Juracek and Fitzpatrick, 2003; Simon et al., 2005; and Hilderbrand et al., 2005). Described as a "form-based" design approach, its use is discouraged in favor of a "process-based" approach (Wohl et al., 2005). It is apparent, based on a review of the critical comments, that there is not a clear understanding of the NCD method, as many of the reviewers' interpretations appear misinformed. For example, *both* form-based and process-based procedures are used as part of the "Geomorphic Approach" to the NCD methodology. While an overview of the NCD procedure is presented below, space does not allow for substantial details to be presented for each of the various components. This procedure is outlined in more detail in the USDA, NRCS *Stream Restoration Design Handbook, Chapter 11*, (2005). The procedure has been applied by the author on multiple miles of river restoration projects over a 35-year period, where post-project monitoring has provided the data to continually revise both field and analytical methods. Training courses over the last 20 years require a minimum of 400 hours of training for professionals to learn watershed and river stability assessment and stream restoration methods. Additional information on procedures used for restoration can be obtained from the EPA's interactive web page *Watershed Assessment and River Stability for Sediment Supply* (*WARSSS*), (Rosgen, 2006a), at http://www.epa.gov/warsss.

The phases of river restoration using the Geomorphic Approach to NCD

There are eight phases associated with the Geomorphic Approach to NCD. Each phase is critical to the success of a restoration project and cannot be short-circuited. The conceptual layout of each phase used for NCD is shown in **Figure 1**. General descriptions associated with each phase are described as follows:

Phase I. Restoration Goals/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 stream to meet specific objectives must be assessed early on in the planning phase, 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 "natural stable" river; g) withstand floods; h) be self-maintaining; i) be cost-effective; j) improve water quality; and k) improve or create wetlands.

It is essential to fully describe and understand the restoration objectives. Often, the objectives compete or even conflict with one another. If this occurs, conflict resolution must be initiated and can often be offset by varying the design and/or the nature of stabilization methods or materials. The assessment required must also reflect the restoration objectives to ensure that related 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 the 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 includes constructing and/or assessing regional hydrology curves (bankfull discharge and cross-sectional area versus drainage area) (Rosgen and Silvey, 2005) and hydraulic calculations/validation at gage stations using resistance relations/roughness values.

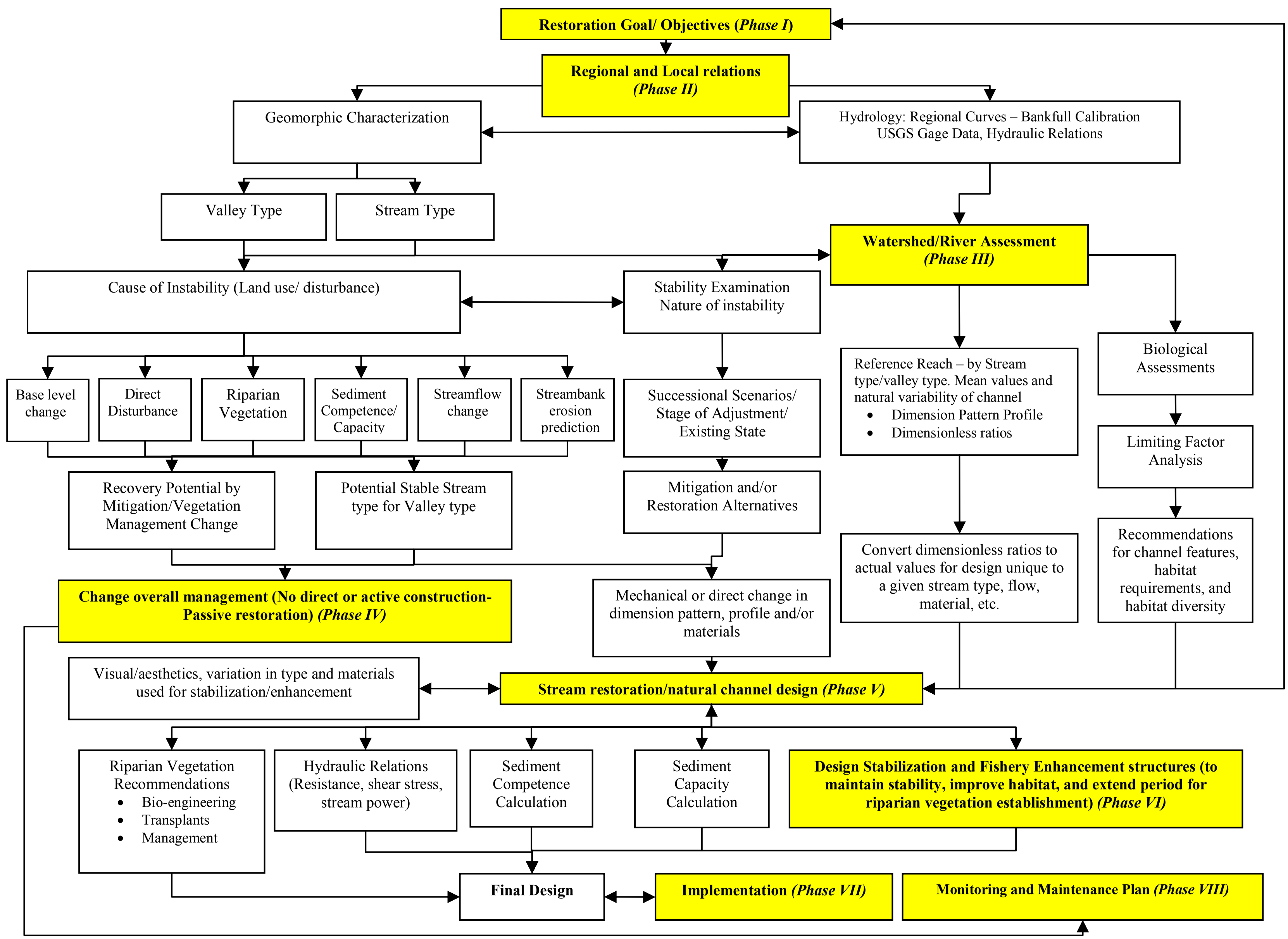

Figure 1. Flow chart depicting sequence of implementation of the 8 sequence phases associated with natural channel design using a geomorphic approach.

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*. This is a critical phase to understand the cause(s) and consequence of change. Without a good assessment, restoration designs may be misdirected. 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. In order to address each assessment, one must look at the watershed/river at both the micro- and macro-level involving the assessment of a range of watershed/river variables.

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, 1999, 2001a). To optimize river stability, one must inventory 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. Detailed procedures for this assessment are described in Rosgen (1996, 1999, Chapter 6; 2001b) and in *Watershed Assessment and River Stability for Sediment Supply* (*WARSSS*) (Rosgen, 2006).

It is important to realize the difference between the natural, dynamic adjustment processes of streams 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 inadvisable 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 would not properly represent the natural stable form. Valley types are a key part of river assessment because it is important to understand stable stream types within their geomorphic settings. Further, reference reaches representing the stable form have to be measured and characterized for use in similar valley types. This prevents the application of good data to the *wrong* stream type.

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 rate, direction and consequence of channel change. The field inventory and the number of variables required for watershed and river stability assessment is substantial. **Figure 2** presents a general summary of the various elements used for assessing channel stability as used in the natural channel design methodology. Detailed assessment procedures are provided in Rosgen, Chapter 6 (1996) and in *WARSSS* (Rosgen, 2006a).

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. Streambank erosion rate (lateral erosion rate and sediment in 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 by increases in width/depth ratio due to lateral accretion. The prediction methodology is presented in Rosgen, Chapter 6 (1996), and in Rosgen (2001b), utilizing Bank Erodibility Hazard Index (BEHI) and Near-Bank Stress calculations (NBS) (Rosgen, 2001c).

Phase IV. Change Overall Management (No direct or active restoration – passive restoration) – *Initially 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), flood control measures, road closures/stabilization, hillslope erosional processes and other processes that affect river stability. Often, a change in management strategy can secure stability and function. This is usually determined based on the recovery potential of various stream types and the short- and long-term goals associated with the stated objectives (including cost).

The alternative to self-stabilization is always a key consideration in any stability assessment. The time-trend aerial photography from Phase III may provide insight into stream recovery potential. Successional stages of channel adjustment can also help to determine natural recovery potential. For passive restoration, it is very important to ensure that objectives are met through effectiveness monitoring. This requires documenting the nature, magnitude, rate and consequences of natural recovery. If natural recovery potential is poor and/or does not meet specific objectives, then stream restoration/natural channel design (***Phase V***) would be appropriate.

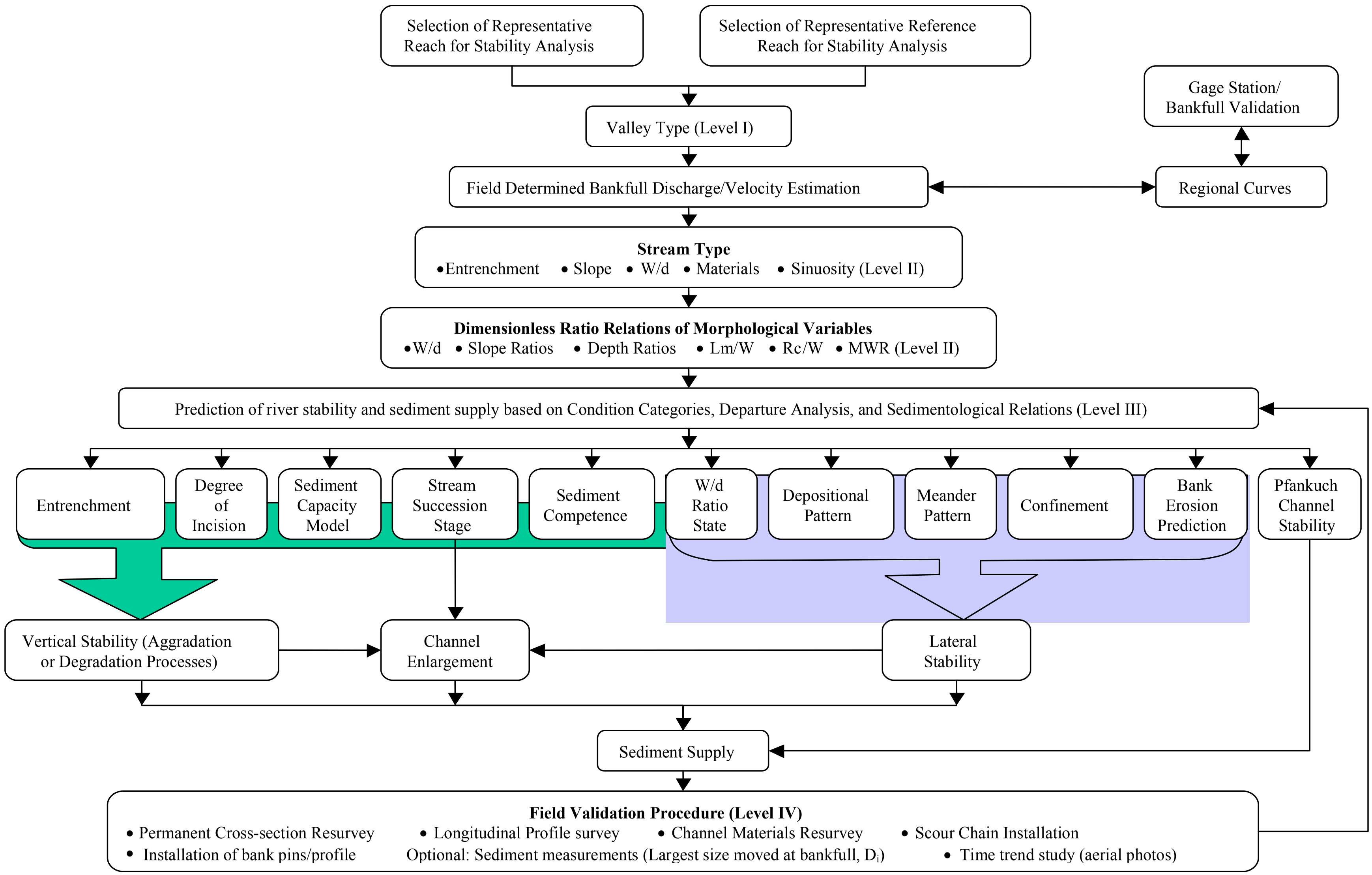

Figure 2. Generalized flowchart of application of various assessment levels of channel morphology, stability ratings and sediment supply.

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 involves combining the results of Phases I through IV. It is important to remember that good design stems from good assessment. The goal of this phase is not to patch symptoms, but rather to provide restoration solutions that will offset the cause of the problem and allow for a self-maintaining river. To accomplish this goal, the practitioner must be familiar with the processes involved in hydrology, hydraulics, sedimentology, geomorphology, soil science and aquatic habitat and riparian vegetation studies. Due to this inherent complexity, it is usually necessary to obtain technical assistance for assessment and design.

The conceptual flowchart shown in **Figure 3** depicts the general sequence of *analog (blue), empirical (green)*, and *analytical (pink)* methods in this natural channel design procedure. To determine the appropriate channel form, the existing valley type and potential stable form of the stream type must be available. The proposed natural channel design must be converted to a dimension, pattern and profile to determine whether the hydraulic and sediment relations are compatible prior to advancing through the procedural steps. A total of 40 analytical sequence steps are used to generate and test restoration design specifications to determine dimension, pattern and profile relations. Sediment competence is determined with methods described in Rosgen (2001a, 2006a). Sediment capacity is calculated using FLOWSED and POWERSED models (Rosgen, 2006a, 2006b) based on dimensionless sediment rating curve relations (Troendle et al., 2001).

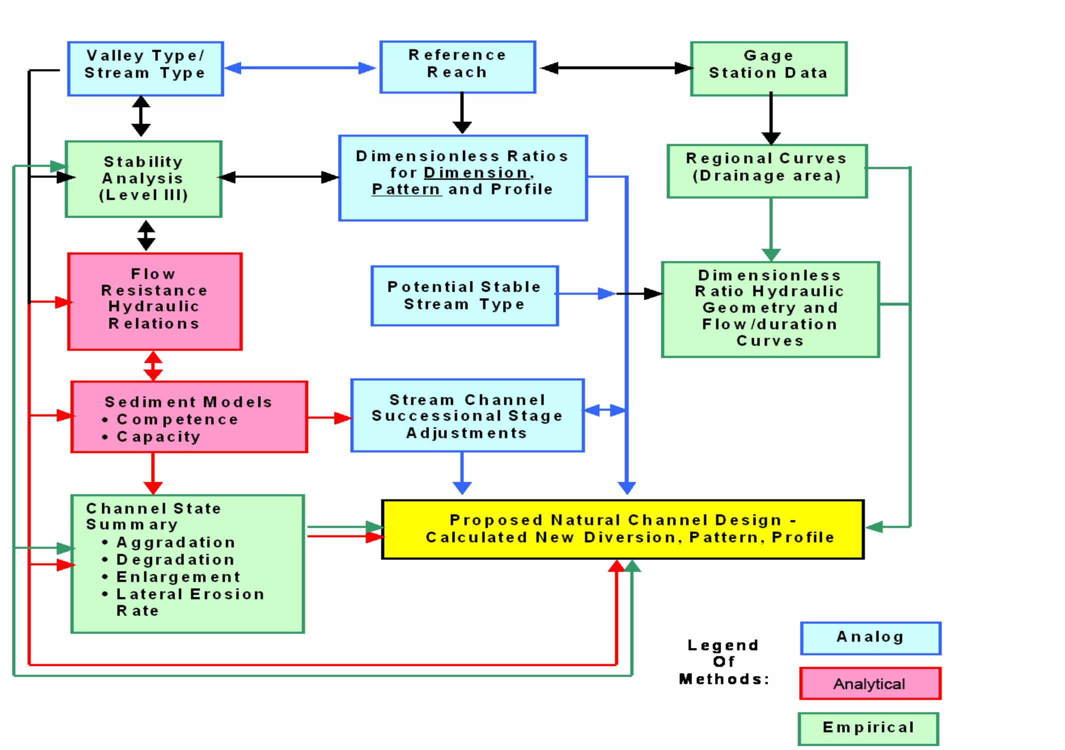

Figure 3. Flowchart representing natural channel design using analog, analytical and empirical methodologies.

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 to establish bed pavement. Selection of designs, materials and methods are critical to meet multiple objectives, including aesthetics. Various structures used in restoration are described by Rosgen (2001d).

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 be 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; 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 (2001d).

Phase VIII. Monitoring and Maintenance Plan – *Design a plan for effectiveness, validation and implementation monitoring to ensure stated objectives are met, prediction methods are appropriate and the 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 include the demonstration of the effectiveness of reduced sediment problems and improved river stability due to management/mitigation, which is 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 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; e) ease the anxiety of uncertainty of prediction; f) provide confidence in specific management practice modifications or mitigation recommendations to offset adverse water resource impacts; g) evaluate effectiveness of stabilization or restoration approaches; h) reduce risk once predictions and/or practices are assessed; i) build a database to extrapolate for similar applications; and j) determine specific maintenance requirements.

Conclusion

A full assessment and design often requires a team of trained professionals from different disciplines. Many of the tools described in this manuscript can be misused unless their proper use is understood. The most criticism of this geomorphic approach to natural channel design comes from those authors with the least familiarity with the method. Surprisingly, the most vocal critics also have the least experience in conducting river restoration projects. To gain such experience, it may be advisable for those individuals to seek available training to prevent "trial and error" impacts to river systems. The next logical step would be to personally conduct phase's I-VIII of a river restoration project. This may require working closely with experienced professionals as an apprentice. If all of the eight phases are accomplished by an individual including three to five years of post project monitoring, the resultant critique will undoubtedly improve subsequent projects.

Without training others, we will not meet the growing demands of our society to restore our rivers. Beyond the obvious complexity and uncertainty associated with river restoration additional constraints are still imposed that often limit ones effectiveness to properly implement a natural channel design. Some of these constraints are associated with:

1) A lack of understanding on what constitutes a successful river restoration project…what are reasonable expectations?
2) Confusion representing professional standards, minimum requirements, training and certification.
3) Limited scope of certain restoration projects only "patch symptoms" rather than deal with the cause of the instability.
4) What are the differences among the various approaches to river restoration, when or under what circumstances should a particular method be used?
5) The lack of specific training at Universities, technology transfer.
6) Lack of applied research in river restoration.
7) A lack of documentation and specific procedures for natural channel design in standard engineering field manuals or text books.

The tools described here will continue to be improved as we gain a better understanding of river systems through ongoing post project monitoring and implementation of applied research. A positive collaboration of efforts from many disciplines will be required for the advancement of the applied science, for the good of the rivers and for the success of those trying to help both.

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