Hydrological Science and Technology, Volume 23, No. 1-4
Proceedings of the 2007 American Institute of Hydrology
Annual Meeting and International Conference
"Integrated Watershed Management: Partnerships in Science, Technology and Planning"
Reno, Nevada, April 22-25, 2007

WARSSS – WATERSHED ASSESSMENT OF RIVER STABILITY AND SEDIMENT SUPPLY – AN OVERVIEW

DAVE ROSGEN
Wildland Hydrology, Inc.
11210 N. County Rd. 19, Fort Collins, CO 80524, USA
Phone: 970-568-0002 Fax: 970-568-0014
Email: wildland@wildlandhydrology.com

ABSTRACT

WARSSS integrates the disciplines of hydrology, geomorphology, geology, engineering, soil and plant science into a watershed assessment methodology. *WARSSS* is a three-phase methodology that:

- Identifies specific locations and processes adversely affected by various land uses
- Provides a consistent, quantitative analysis of sediment supply and channel stability
- Predicts hillslope, hydrologic and channel processes contributing to sediment yield and river impairment
- Establishes a basis for site- and process-specific mitigation
- Documents a better understanding of the cumulative effects of various land uses on the water resources

The EPA has supported and peer reviewed *WARSSS* as an alternative to numeric standards for "clean sediment TMDLs." *WARSSS* is also used in river restoration by documenting the cause and consequence of impairment and establishing criteria for natural channel design.

Key Words: Geomorphology, Hydrology, River Stability, Watershed Assessment, Sedimentology and Cumulative Watershed Impacts

INTRODUCTION

Watershed management has historically placed more emphasis on project planning and design than on project response or evaluation. Sediment and stream reach stability problems have traditionally been treated by "patching symptoms," rather than by addressing the ***cause*** of the problem.

The *WARSSS* methodology provides a procedure to assess large watersheds with a practical, rapid screening component that integrates hillslope, hydrologic and channel processes. It is designed to identify the location, nature, extent and consequence of various past, as well as proposed, land use impacts. Before changes in land use management are implemented, it is of utmost importance to first understand the cause of the impairment. A good assessment can lead to more effective solutions, including ***preventive strategies*** that may be cheaper and more effective than restoration.

The *WARSSS* procedure helps scientists to integrate existing resource inventory information into a structured, reproducible analysis. The underlying purpose of the method is to better understand the four "C's" of river/watershed assessment:

1. The ***cause*** of the impairment (problem)
2. The ***consequence*** of change
3. The ***correction*** (prevention, mitigation, stabilization, restoration) of the problem
4. The ***communication*** of assessment results and recommendations

This paper provides a broad overview of the detailed reference textbook "WARSSS," which includes a case study (Rosgen, 2006b), and the first version is also available on the EPA's interactive *WARSSS* Web site (www.epa.gov/warsss) (USEPA, 2006). The impetus to develop and test a watershed sediment assessment procedure came as an alternative method for developing "clean sediment TMDLs." The EPA completed an external formal peer review of *WARSSS*; as a result, the EPA recognized that implementing this pro-active approach would be an acceptable method for clean sediment TMDLs for impaired rivers listed under Section 303(d) of the Clean Water Act.

WARSSS is also used in river restoration by documenting the cause and consequence of impairment and establishing key criteria for natural channel design. The majority of the procedures contained in *WARSSS* have been implemented in both formal training courses, management applications and restoration projects for many years.

WARSSS identifies the hillslope, hydrologic and channel processes responsible for significant changes in erosion, sedimentation and related stream channel instability. It uses a three-phase assessment process to quickly separate areas into low, medium and high risk landscapes. The three levels of assessment include: 1) the Reconnaissance Level Assessment (*RLA*), 2) the Rapid Resource Inventory for Sediment and Stability Consequence (*RRISSC*) and 3) the Prediction Level Assessment (*PLA*). The combination of these levels provides a practical means of assessing large watershed areas and river reaches through a series of initial screening levels to prioritize potential problem areas associated with specific land uses. High-risk sites are then evaluated at a more detailed level to quantitatively determine disproportionate sediment source(s) and stream channel stability.

THE PROBLEM

The 1996 National Water Quality Inventory (USEPA, 1997) indicates that sediment is ranked as a leading cause of water quality impairment of assessed rivers and lakes. Accelerated erosion and deposition from hillslope and channel processes have impaired designated uses in rivers in many ways. Stream channel instability caused by excess deposition of sediment can severely impact aquatic life including the food chain, spawning and rearing habitat, in-stream cover, water temperature extremes and other related adverse impacts. Existing inventories that document watersheds and river reaches with obvious water resource-related problems, such as 303(d)-listed streams and rivers in need of restoration for either physical and or biological reasons, are prime candidates for the *WARSSS* assessment.

Impairment of river systems is also related to loss of riparian vegetation, accelerated streambank erosion, flow regime and sediment regime changes and past direct disturbance of the dimension, pattern, profile and materials of river channels. Such changes have led to a significant loss of land, channel instability, adverse downstream sediment consequences and loss of biological and physical function. Excessive sediment deposition and transport problems in surface waters have resulted in annual damage costs of approximately $16 billion (Osterkamp et al., 1992). River restoration projects have attempted to offset such adverse changes. However, if the *cause* of impairment is not understood, effectiveness of restoration may be limited.

PREDICTION EFFORTS – AVAILABLE TOOLS

In order to determine the cumulative effects of past and/or future land use activities for a watershed-based assessment, the processes that influence such change must be predicted. Land uses that result in changes in water yield and sediment supply, direct disturbance to stream channels, disturbance to riparian vegetation and other causal agents often result in accelerated streambank erosion, mass erosion, surface erosion, gully and channel bed erosion, channel instability, fish habitat loss, land loss and risk to development infrastructure. *WARSSS* establishes a prediction framework using a variety of models and/or prediction methodologies appropriate for given erosional/depositional processes.

Water Yield

Research efforts over many years to develop water resource-related prediction models have been extensive. Water yield models that predict a response to vegetative and/or landscape changes for both stormflow- and snowmelt-generated hydrographs are extensive and well documented The results of water yield changes in urban and timber harvest regions are documented in USEPA (1980), Bosh and Hewlett (1982), Sheppard et al. (1991), Haan et al. (1994), Troendle and Olsen (1994) and Troendle and Nankervis (2000).

Streambank Erosion

Streambank erosion prediction models are fewer in number than water yield models due to the complexity of the combined erosional processes involved. Process-specific methods using the *factor of safety approach* by Thorne (1999) and Simon et al. (1999) provide an output that identifies a quantitative index to risk of failure. A quantitative model predicting streambank erosion rates in tons/year (the BANCS model) is shown in Rosgen (1996, 2001a, 2006b).

Sediment Models

Sediment competence and transport capacity models have been around for some time. A review of many models is shown by Reid and Dunne (1996) and Yang (1996). Many of these models, however, predict sediment transport many orders of magnitude beyond observed values (Vanoni, 1975; Lopes et al., 2001). The application of a dimensionless sediment transport relation for both suspended and bedload sediment, as specified by stability rating and stream type, predicts sediment rating curves much closer to observed values (Troendle et al., 2001). Annual suspended and bedload sediment yield using the FLOWSED/POWERSED model (Rosgen, 2006a) utilizes dimensionless sediment rating curves and stream channel hydraulic relations by stage. The use of this model has shown excellent prediction accuracy comparing predicted-to-observed values on independent data sets from Alaska to Maryland (Rosgen, 2006a, 2006b).

Stability Evaluations

River stability is defined as "the ability of a stream, over time, in the same climate, to transport the sediment and flows produced by its watershed in such a manner to maintain the dimension, pattern and profile of the river without either aggrading nor degrading" (Rosgen, 1994). Various stability examinations are integrated into the *WARSSS* approach, including those developed by Pfankuch (1975) and Rosgen (1994, 1999, 2001b). These approaches utilize field indicators and various measurements to predict river stability.

IDENTIFICATION, PREDICTION AND MEASUREMENT OF SEDIMENT SOURCES

The most direct and definitive approach to quantify sediment contributions are direct measurements at the immediate location of obvious sources. Because sediment is associated with a great variety of temporal and spatial variability, it requires considerable effort to:

- Identify natural variability with flow, season and geology
- Determine contributing erosional processes
- Document land use influences on magnitude and duration
- Understand consequence of sediment change
- Assess departure from a stable "reference" condition
- Identify the relation of sediment measurement to past versus existing land use
- Quantify the influence of sediment source and stability on upstream and downstream reaches
- Conduct measurements of stream discharge, velocity, slope and channel characteristics to accompany sediment data for analysis

Thus, measurements must be accompanied by an assessment of hillslope, hydrologic and channel processes that identify the nature, extent and location of specific erosional processes linked to past and present land uses. The assessment of potential departure from a reference condition requires measurements of sediment from several source locations, including:

- "above" versus "below" specific channel/sediment source type and locations
- "before" versus "after" contributing source activities are initiated
- "control" or "paired" watershed with concurrent measurements
- reference stream that represents the stable form of the same valley type, stream type and vegetative type

Prediction of the sediment sources related to land uses by specific locations and associated stream channel stability consequences are key elements of the *WARSSS* methodology.

THE APPROACH

A quantitative watershed assessment procedure that identifies hillslope and channel processes influenced by specific land uses and that is consistently applied is key to help direct management to prevent further damage and/or to improve water resources. One application of the *WARSSS* methodology includes addressing "TMDLs for clean sediment." Great difficulty is associated with establishing "flat rate" or constant numeric water quality standards for non-toxic "clean sediment" due to the complexity and uncertainty of prediction under extreme natural variability over temporal and spatial scales. This complexity and variability has precluded the establishment of universal sediment standards. However the widespread adverse impacts on beneficial water uses due to sediment issues require an organized, consistent, quantitative assessment to address this nationally recognized river impairment and water quality problem.

The *WARSSS* methodology is intended to provide a:

- Mechanism to put fundamental geomorphic principles into practice
- Consistent, quantitative, comparative analysis that minimizes subjective bias
- Quantitative prediction of annual sediment yield and proportional contributions of the various sources
- Watershed-based as well as specific river reach assessment
- Linkage between various land uses and their associated source of accelerated sediment supply
- Procedure that rapidly prioritizes high-risk sub-watersheds and river reaches at broad "screening" levels, yet ultimately provides for a more detailed assessment
- Method to assess the probability, risk and potential consequence of sediment problems in the presence of imperfect knowledge, large uncertainty and spatial and temporal variability
- Basis for mitigation/restoration plans that isolates processes responsible for high-risk or adverse sediment-related consequences of watersheds/river systems
- Companion assessment that can be related to aquatic habitat/sediment relations
- Summary and nature of output parameters that is useable for assessment of sediment consequence
- Procedure to assess problems of the past, existing impairment and proposed projects to help set environmentally sound management direction for the future
- Database and analysis to direct river restoration projects

The procedure defines hillslope, hydrologic and channel erosional or depositional process relations to identify specific sediment sources and their locations that may potentially impair the physical and biological function of river systems. The *WARSSS* methodology for assessment of clean sediment TMDLs places emphasis on the specific location and potential, disproportional contribution of sediment sources by various processes influenced by land uses related to the total annual sediment yield. The sediment yield predictions assess potential adverse consequences as related to river impairment and stability. This emphasis allows for an assessment that can directly lead to appropriate management direction, improved design specifications and mitigation prescription.

Applications of this method are appropriate for evaluating physical water resources and their condition for watershed planning. The *WARSSS* methodology, which addresses the physical components of river channels, is also compatible for the integration of biological assessments, such as fish habitat indices. Restoration designs also require a stability assessment that addresses the cause, consequence and correction of river impairment. The majority of the procedures integrated into the *WARSSS* methodology have been developed and applied for stability analysis in river restoration designs.

The *WARSSS* methodology is not an exclusive office or modeling procedure, but rather relies heavily on the documentation of field observations and corresponding analysis. ***It becomes essential that due to the nature of this assessment methodology that the predictions be conducted by individuals with experience in geomorphology, hydrology, engineering and other scientific disciplines specifically trained in hillslope, hydrologic and channel processes.***

GENERALIZED FRAMEWORK OF *WARSSS*

WARSSS consists of six major categories: 1) Problem identification, 2) The Reconnaissance Level Assessment (*RLA*), 3) The Rapid Resource Inventory for Sediment and Stability Consequence (*RRISSC*), 4) The Prediction Level Assessment (*PLA*), 5) Management and mitigation implementation and 6) Monitoring (Figure 1).

The three distinct assessment levels (*RLA*, *RRISSC* and *PLA*) are shown conceptually in Figure 2. Each of the three assessment levels are discussed separately:

RLA: The Reconnaissance Level Assessment

The initial "screening" approach used in *RLA* is designed to eliminate areas that potentially are *not* contributors or do not require special study and/or mitigation. The initial "first screen," broad-level assessment is designed to a) identify obvious sediment sources/channel stability problems as influenced by land use activities linked to various erosional/depositional processes; b) refine, clarify and/or redirect problem identification; c) exclude sub-watersheds/areas/reaches from further assessment; and d) locate potential problem areas for the next higher level of assessment. The *RLA* requires the least time to provide the initial assessment.

RRISSC: The Rapid Resource Inventory for Sediment and Stability Consequence

The Rapid Resource Inventory for Sediment and Stability Consequence (*RRISSC*) is the "second screen" or intermediate assessment level. The three objectives of this assessment level are to 1) Exclude low-risk areas from further consideration; 2) provide management and/or mitigation recommendations for moderate-risk rating sites with monitoring; and 3) Identify high-risk sites, sub-watersheds and/or river reaches that rate as high risk requiring a more detailed assessment. Such high-risk sites advance to *PLA*.

PLA: The Prediction Level Assessment

The Prediction Level Assessment (*PLA*) requires the most field data and a rigorous analysis. *PLA* utilizes a consistent, quantitative, comparative analysis of potential impairment compared to a "reference" or stable condition. The analysis involves hillslope, hydrologic and channel processes utilizing models specific to various processes, site-specific locations and individual land uses. Management and process-specific mitigation recommendations can be designed to address the cause and consequence of impairment for individual land uses at a designated location. The outputs of all of the sediment sources, including hillslope, channel and flow-related sediment sources, are predicted in annual sediment yield in tons/year. The flowchart presented in Figure 3 shows the procedural sequence of this assessment.

The *WARSSS* methodology at the *PLA* level provides a "framework" for assessment in the manner that provides the users an option to select a model separate from those presented. The assumptions of various models preclude their universal applications to all conditions or sites; thus, it is important to be certain that whatever prediction model the user selects, it matches the specific processes and site conditions. Many professionals have had extensive, positive experiences with various models. The experience gained and validation efforts of certain models utilized within a given region can be substituted in place of a particular process-relation model contained in *WARSSS*. The data outputs, however, must be comparable for consistent, quantitative results. The units for the prediction of sediment sources from roads, streambanks, flow-related sediment, surface erosion and mass erosion are all in tons/year. The procedures offered in *WARSSS* are not intended to preclude application of other models, but rather to provide an example of how the relations presented can and have been successfully utilized for sediment and river stability prediction at the watershed scale.

The *PLA* analysis is designed to indicate spatially sensitive, diverse and disproportionate sediment sources. The results of *PLA* also indicate potential river instability due to a variety of processes. Site- and process-specific mitigation recommendations at this level can be effective to target identified stability and sediment source problems.

ASSESSMENT METHODOLOGY DISCUSSION

It is necessary to isolate and locate the various processes associated with accelerated sediment supply in order to identify relative proportional contributions and to appropriately prescribe effective and practical mitigation. Not all land uses potentially present a high risk for sediment problems or occur on unstable lands. Not all land uses are associated with poor practices; thus, it is necessary to have an inventory that identifies the location, nature and extent of land uses that allows for an initial assessment of potential sediment source problems. The assessment analyst must know a) How do various land use practices potentially affect streamflow and sediment production? b) How is increased sediment generated? c) Can stream systems accommodate sediment increases or decreases? and d) What are the consequences of changes in sediment and sediment-related processes? The *WARSSS* assessment methodology is designed to provide the tools to help answer these questions.

MONITORING

Validation monitoring is the means to extend the state of knowledge associated with the uncertainty of prediction. Effectiveness monitoring determines the success of management changes and/or specific mitigation to improve the water resources. Monitoring also provides the confidence of prediction and the basis of understanding river processes. The costs, necessary equipment and commitment to standardized measurement techniques often preclude proper sediment data collection and analysis. Sediment measurements, however, can and should be obtained to determine the reliability of prediction, calibration of specific models and to determine the effectiveness of management/mitigation and/or restoration efforts at specific locations. Sediment measurements are not required in every location but are necessary in those locations and specific river reaches where controversy, risk and consequences may be high.

Replicate surveys of stream channel cross-sections, longitudinal profiles and channel materials can validate stability predictions of dimension, pattern and profile. Annual resurveys of bank pins, bank profiles, scour chains and other field techniques can verify annual streambank erosion rates and sediment competence calculations. Sediment transport capacity is determined from both measurement of sediment rating curves and permanent benchmark sites to verify channel response (shift in bed material particle sizes, aggradation/degradation, enlargement, etc.).

Monitoring procedures to validate the various models used in *WARSSS*, including streambank erosion, sediment competence and capacity, vertical and lateral stability and channel enlargement, are discussed in Rosgen (1994, 1999, 2001b, 2006b).

SUMMARY

A consistent, quantitative, watershed assessment methodology is presented (*WARSSS*) utilizing broad screening levels up to and including a detailed prediction level. The procedure assists in determining the source, magnitude and physical consequence of land use activities and their proportional contributions of sediment and associated channel stability.

Site- and process-specific mitigation, restoration and/or changes in management practices can be designed utilizing the results of the *WARSSS* analysis. Adverse impacts of past and future development on river stability and function, including erosion and sediment consequence, must be identified to justify and redirect changes in management practices and site-specific mitigation.

The recognition of the sediment problem has been well accepted; however, the solutions are often constrained due to political and economic issues and scientific disputes of cause/effect relations. Guidance to assist agencies, states, municipalities and property owners on conducting sediment assessments is essential for consistency in the recognition and prevention of continuing sediment problems. These assessments can provide managers with a timely understanding to make informed decisions for management, mitigation and/or restoration. Both short- and long-term monitoring, however, should ease the anxiety of uncertainty for those who rightfully question such assessments, and the data obtained will continually improve our understanding and prediction of sediment relations. Another great benefit resulting from monitoring is the demonstration of the effectiveness of reduced sediment and improved river stability due to management/mitigation–the central purpose for watershed and sediment assessments. The cumulative watershed impacts from past land uses and the prediction of future development must be understood and documented to prevent a continuation of reoccurring impacts.

REFERENCES

Bosch, J.M., & Hewlett, J.D., 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration, *Journal of Hydrology, 55,* 2–23.

Haan, C.T., Barfield, B.J., & Hayes, J.C., 1994, *Design hydrology and sedimentology for small catchments*, San Diego, CA: Academic Press.

Lopes,V.L., Osterkamp,W.R., Espinosa, M.B., 2001, Evaluation of selected bedload equations under transport- and supply-limited conditions, *Proceedings of the Seventh Interagency Sedimentation Conference*, *1*, I-192–I-198.

Osterkamp, W.R., Day, T.J., & Parker, R.S., 1992, A sediment monitoring program for North America. In *Erosion and sediment transport monitoring programs in river basins* (IAHS Publication 210, pp. 391–396), Wallingford, Oxfordshire, UK: International Association of Hydrological Sciences.

Pfankuch, D.J.,1975, *Stream reach inventory and channel stability evaluation* (USDAFS No. R1-75-002, GPO No. 696-260/200), Washington, DC: U.S. Government Printing Office.

Reid, L.M., & Dunne, T.,1996, *Rapid evaluation of sediment budgets; Geo-Ecology Texts*, Reiskirchen, Germany: Catena Verlag.

Rosgen, D.L. , 1994, A classification of natural rivers, *Catena*, *22*, 169–199.

Rosgen, D.L.,1996, *Applied river morphology*, Pagosa Springs, CO: Wildland Hydrology Books.

Rosgen, D.L., 1999, Development of a river stability index for clean sediment TMDLs, In D.S. Olsen & J.P. Potyondy (Eds.), *Proceedings of Wildland Hydrology* (pp. 25–36), Herndon, VA.: American Water Resources Association.

Rosgen, D.L., 2001a, A practical method of computing streambank erosion rate, In Proceedings of the seventh Federal Interagency Sedimentation Conference: Vol. 1. (pp. II-9–II-15), Reno, NV: Subcommittee on Sedimentation.

Rosgen, D.L., 2001b, A stream channel stability assessment methodology, In *Proceedings of the Seventh Federal Interagency Sedimentation Conference: Vol. 1*. (pp. II-18–II-26), Reno, NV: Subcommittee on Sedimentation.

Rosgen, D.L., 2006a, FLOWSED-POWERSED: Prediction models for suspended and bedload transport, In *Proceedings of the Eighth Federal Interagency Sediment Conference*: Vol (pp. 761–769), Reno, NV: Subcommittee on Sedimentation.

Rosgen, D.L., 2006b, *Watershed Assessment of River Stability and Sediment Supply (WARSSS)*, Wildland Hydrology Books, Fort Collins, CO, 648 pp.

Sheppard, W.D., Troendle, C.E., & Edminster, C.B., 1991, Linking water and growth and yield models to evaluate management alternatives in subalpine ecosystems, In *Getting to the future through silviculture. Proceedings of the national silviculture workshop* (Gen. Tech. Rep. INT-291, pp. 42-49), Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Simon, A., Curini, A., Darby, S., & Langenden, E, 1999, Streambank mechanics and the role of bank and near-bank processes, In S. Darby, & A. Simon (Eds.), *Incised river channels* (pp. 123–152), New York: John Wiley and Sons, Inc.

Thorne, C, 1999, Bank Processes and Channel Evolution in North-Central Mississippi, In S. Darby, & A. Simon, (Eds.), *Incised river channels* (pp. 97–121), New York: John Wiley and Sons, Inc.

Troendle, C.A. & Nankervis, J.M., 2000, *Estimating additional water yield from changes in management of national forests in the North Platte Basin*, Final Report submitted to the Platte River Office, Bureau of Reclamation, March 2000, 51pp.

Troendle, C.A., & Olsen, W.K., 1994, Potential effects of timber harvest and water management on streamflow dynamics and sediment transport, In W.W. Covington & L.F. DeBano (Tech. coordinators), *Sustainable ecological systems: Implementing an ecological approach to land management* (Gen. Tech. Report RM-247) (pp. 34–41), Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experimentation Station.

Troendle, C.A., Rosgen, D.L., Ryan, S., Porth, L., & Nankervis, J.M., 2001, Developing a "reference" sediment transport relationship, In *Proceedings of the seventh Federal Interagency Sedimentation Conference: Vol. 1*. (pp. II-73–II-80), Reno, NV: Subcommittee on Sedimentation.

U.S. Environmental Protection Agency, 1980. *(WRENSS) An approach to Water Resource Evaluation of Non-point Silvicultural Sources (A Procedural Handbook)* (EPA-600/8-80-012), Athens, GA: Environmental Research Laboratory.

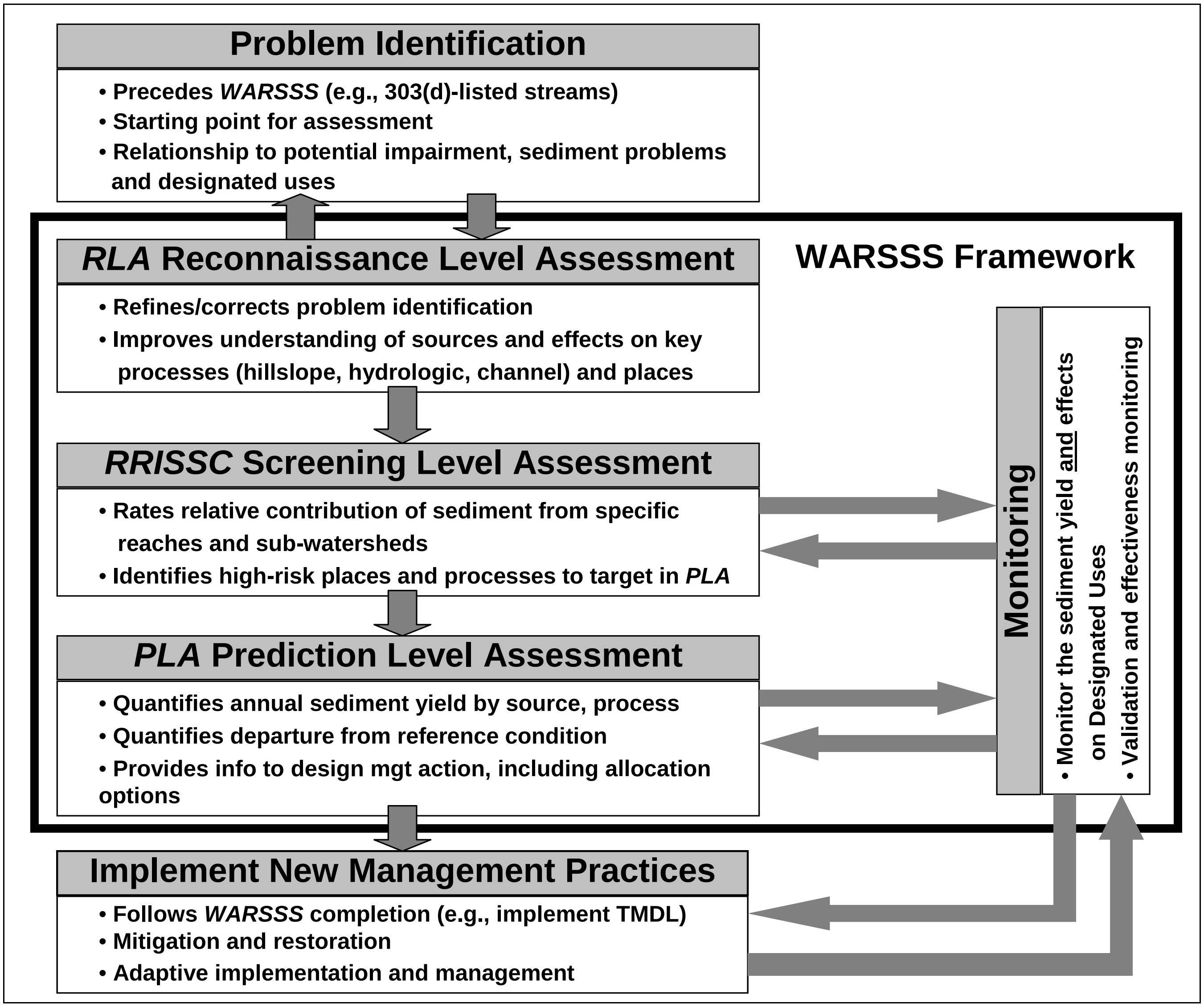
U.S. Environmental Protection Agency, 1997, *New policies for establishing and implementing Total Maximum Daily Loads (TMDLs)*, Washington, DC.

U.S. Environmental Protection Agency, 2006, September 27, *WARSSS–Watershed Assessment of River Stability & Sediment Supply | EPA*. Retrieved April 1st, 2007, from http://www.epa.gov/warsss/.

Vanoni, V.A. (Ed), 1975, Sedimentation engineering (Manuals and reports on engineering practice, No. 54), New York: American Society of Civil Engineers.

Yang, C.T. , 1996, *Sediment transport: Theory and practice*, New York: McGraw-Hill.

FIGURE 1. The general *WARSSS* process (Rosgen, 2006).



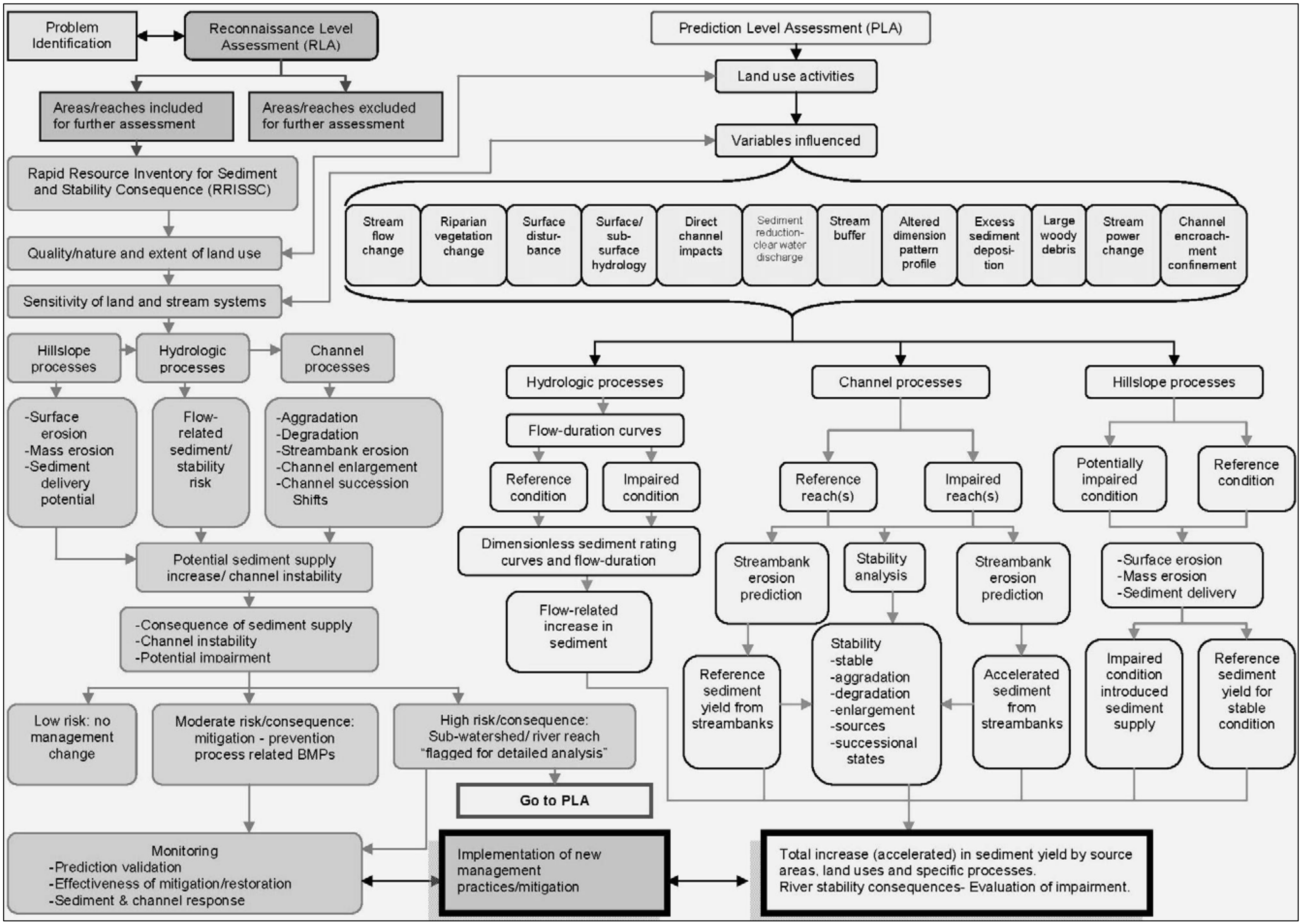


FIGURE 2. Conceptual model for *WARSSS* (Rosgen, 2006).

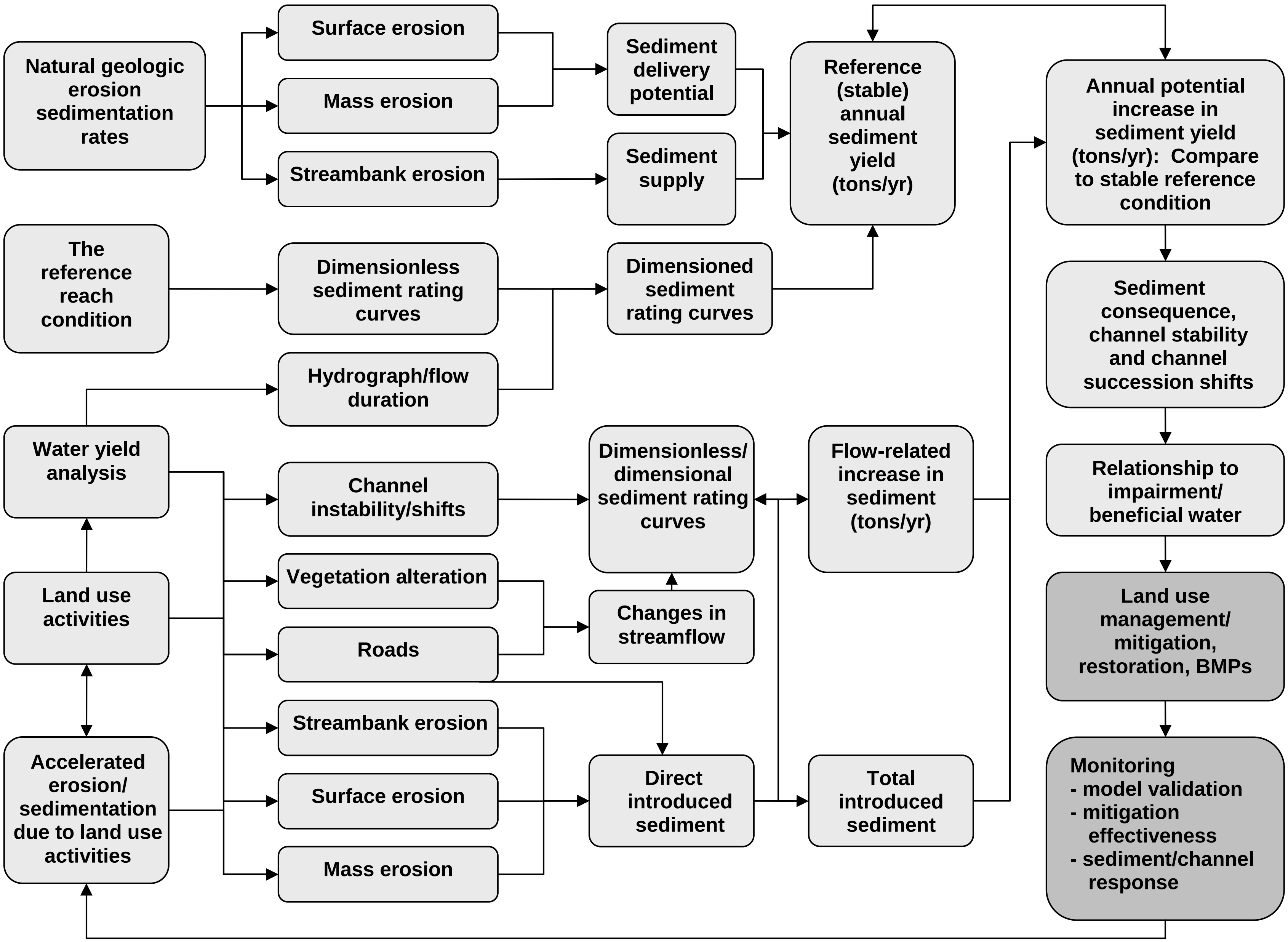


FIGURE 3. The general organization of the procedural sequence for the Prediction Level Assessment (*PLA*).