SEDIMENT IMPACT ANALYSIS METHODS (SIAM): OVERVIEW OF MODEL CAPABILITIES, APPLICATIONS, AND LIMITATIONS

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Abstract The SIAM (Sediment Impact Analysis Methods) model is a recent addition to the Corps modeling suite. It was developed to evaluate watershed and reach scale sediment processes, and has some unique capabilities. SIAM integrates watershed-scale sediment continuity concepts into stream rehabilitation and management. The model provides an intermediate step between qualitative computations and numerical mobile boundary sediment transport models. It also provides a framework to combine hydrology, hydraulics, and sediment supply into a geomorphic assessment and rehabilitation design. This paper discusses the theoretical basis and historical background of SIAM. It provides an overview of the SIAM model capabilities and limitations, and a treatment of how SIAM fits into the arena of sediment transport and watershed modeling tools. With sediment as the number one ranking pollutant in streams and a contributing agent in many others, the addition of SIAM into the river-engineering toolkit will empower designers and planners to more easily consider sediment supply and transport in management and rehabilitation of channel systems.

INTRODUCTION

What is SIAM? The Sediment Impact Analysis Methods (SIAM) has been developed as a one-dimensional (1-D) sediment continuity model that provides the field with a useable tool for conducting rapid assessments and design of water resources projects. SIAM provides a framework to combine channel morphological, hydrologic, and hydraulic information for a series of reaches representing a network of channels. The algorithms use sediment continuity and the connectivity between reaches to evaluate the impact from local changes in flow and/or sediment inputs on the system. SIAM develops a map of potential imbalances in a channel network to provide the first step in identifying design or remediation needs. A key component of SIAM is its ability to track sediment through the system by grain size and to account for the spatial variations in the wash load/bed-material load thresholds. This allows SIAM to not only quantify the bed material-driven morphologic impacts, but also to route the wash load through the system (Little, 2007).

For ease of use, SIAM has been embedded into HEC-RAS as a hydraulic design function. This allows the user to take advantage of existing HEC-RAS hydraulic models, provides a stream network framework, expedites data entry, and provides a mechanism for technical support, documentation, and training.

Genesis of SIAM The initial development of SIAM was through the joint efforts of the Engineering Research and Development Center (ERDC) and Colorado State University research effort on channel stability as part of the Mississippi Delta Headwaters project (then known as the

Demonstration Erosion Control project). The original computer programming was done by David Mooney (USBR) as part of his PhD work at Colorado State University (Mooney, 2006). It has been incorporated into HEC-RAS through a collaborative research effort between ERDC and the Hydrologic Engineering Center (HEC) under the System-Wide Water Resources Management Program.

Need for SIAM As stated in Biedenharn et al (2006), "In many rivers and streams, management of downstream sediment loads is far from straightforward. The risk exists that a scheme designed without consideration of catchmentwide [watershed-wide] sediment dynamics will solve one sediment related problem at the expense of creating new sediment imbalances and unintended morphological responses elsewhere in the fluvial system." As an increasing number of projects seek to evaluate or implement modifications to reduce watershed sediment loads, it is imperative to define and analyze system-wide sediment processes and linkages in order to achieve the desired benefits without causing unanticipated or unacceptable negative impacts.

IMPORTANCE OF WASH LOAD AND BED-MATERIAL LOAD CONCEPT

The Two Systems A watershed can be seen as a channel network that conveys both water and sediment. Sediment is transported in two ways, as wash load and as bed-material load. In regard to sediment, the channel network can be conceptualized in two different ways:

- For wash load, as a network of channels with essentially fixed beds that carries fine sediment (wash load) without channel erosion or deposition, and
- For bed material load, as an alluvial channel network carrying bed material sediment, where the channels are formed of the sediment they carry, and react by changing their shape in response to changes in incoming sediment load or other factors.

Wash Load Any channel reach carries the finest material as wash load in quantities limited by the supply of material rather than the transport capacity of the channel. (The transport of wash load is supply limited, rather than hydraulically limited.) The wash load is finer than the material found in the stream bed. It does not interact with the bed. From a transport point of view, the wash load is carried through the stream reach without bed interaction or deposition.

Bed Material Load For bed material (the sediment sizes that are found in appreciable quantities in the bed of the channel), the channel response is entirely different than with wash load. Any stream reach can carry only a certain amount of inflowing bed material sediment. (Bed material transport is hydraulically limited.) Changes in the inflowing bed material load (or changes in the transport capacity of the reach) will result in changes in channel morphology: that is, aggradation, degradation, or planform changes. The changes in any given reach may affect reaches both upstream and downstream, having a ripple effect that can extend far from the original modification.

Systemwide Application of Wash Load and Bed-Material Load Concepts In any one reach, it is often possible to focus on either wash load or bed material load alone without sacrificing accuracy. However, the evaluation of impacts on a watershed basis requires that both wash load and bed material loads be evaluated together, and that the grain sizes be reclassified as one moves from one reach to another within the watershed. A simplistic paradigm in watershed evaluations is to assume that wash load is comprised of certain size classes (for instance, silts and clays) or derived from certain sources (e.g. surface erosion). However, a stream reach receives a total load that derives from multiple sources, each with its own annual load and gradation. Sediment that is carried as wash load in one reach, without morphological impact on the channel, is often bed material load further downstream in the watershed. This means that sediment reduction activities that have no impacts on local stability may have impacts on downstream reaches, causing channel incision or reducing the size of sand bars (or other features) in reaches downstream. Wash load (by definition) does not derive from the bed of the local reach, but it may come from sediment sizes eroded from the bed of upstream channel reaches. It is common for the threshold grain size between wash load and bed material load to change from reach to reach within a watershed (Biedenharn et al, 2006). It is important to address the changing grain size classification of bed material and wash load in any watershed study. In watersheds with system-wide instability, where a large percentage of the total sediment load derives from channel erosion, it is essential to evaluate wash load and bed-material loads in a single model.

WHAT DOES SIAM ADD TO OUR MODELING CAPABILITY?

Screening-level tool SIAM provides a screening-level tool to assess the impacts of alternative plans within a watershed on

- downstream sediment loads, and
- equilibrium of channel reaches.

All types of local sediment sources are included SIAM allows for the identification of individual sources of sediment (gullies, bank erosion, etc.) along with the gradation of each source. It allows the introduction of loads from different sources for each reach within the watershed. The sources are easily manipulated, so that sediment impacts can be tracked by source and grain size.

Unique linkage between sediment continuity computations and sediment sources in watershed SIAM is unique in bridging a gap between watershed sediment models and movable bed sediment transport models. Watershed sediment models often have a theoretical foundation linked to watershed hydrology, pollutant loads, and evaluation of sediment from a single source (surface erosion) as wash load. Sediment transport models which evaluate erosion/deposition and channel morphological response often focus on bed material loads, within a reach or set of reaches. SIAM links the evaluation of sediment continuity, sediment loads and channel equilibrium (computed for each reach) to the sediment sources throughout the watershed. SIAM is intended to provide an general representation of overall sediment transfer processes within a watershed, rather than a precise description of locally specific erosion and deposition. SIAM gives a picture of system-scale sediment processes and linkages. Its results are commensurate with the accuracy of data on sediment sources. (The magnitudes of the average annual contributions of sediment from various sources are often poorly known, and data on the gradations of these loads are even more scarce.)

Sensitivity Analyses The SIAM framework allows sensitivity analyses to be performed easily on each sediment source. Both natural and anthropogenic sources can be incorporated. The sediment contributions and gradations from each source (gullies, bank erosion, surface erosion, etc.) can be individually modified, and the impact on the outputs can be quickly determined. This capability is particularly useful when the sources are estimated, or the gradations are not well known. Sensitivity analyses can be performed for a reasonable range of variation in the sediment contributions or other data, and can establish whether additional resources should be dedicated to refining the input data.

System-wide Evaluation of Sedimentation Processes SIAM allows the user to evaluate sediment impacts on a system (watershed) scale by providing the mechanism for building an accurate conceptual model of sediment transfer processes within a watershed.

HOW DOES SIAM COMPARE WITH OTHER TOOLS AND MODELS?

SIAM compared to a Sediment Budget Analysis A sediment budget analysis compares the computed bed material transport capacity in the project reach to the inflowing bed material load (computed for the upstream supply reach) to evaluate the tendency for aggradation or degradation (USACE, 1994; FISRWG, 1998; Thomas et al, 2002; Copeland et al, 2001). SIAM uses the same theoretical evaluation, but extends the analysis in several ways. First, it enables the user to model a network of reaches, and automates the computation of bed material sediment balance at each reach. This allows the user to look at an entire watershed system. Second, it handles both wash load and bed material load, and allows sediments to be transferred from wash load to bed material load (or vice versa) as they move from reach to reach. Third, it includes inputs from sediment sources in each reach (with grain sizes) and allows tracking of sediment by grain size within a channel network.

SIAM compared to a Mobile Boundary Sediment Transport Model The strengths of SIAM as opposed to a mobile boundary sediment transport model are the following:

- SIAM separates sediment sources by type, rather than lumping sources into a single boundary supply (USBR, 2006). This enables the user to evaluate the impact of modifying a single source (for example, reducing streambank erosion).
- SIAM is designed for rapid evaluation of multiple alternatives, and comparison of the magnitude and direction of their impacts on sediment loads and channel equilibrium.

SIAM computes the difference between bed material supply and transport capacity, but does not adjust the cross section, update the hydraulics and re-compute sediment transport capacities. SIAM bases computations on reach-averaged properties (with reach lengths selected by the user), while a mobile-bed model bases computations on the properties at each cross section. A mobile boundary sediment transport model is recommended for determining intermediate and final stream profiles, and for evaluating selected design alternatives (Mooney, 2006). SIAM is recommended for screening alternatives, and for evaluating the sediment linkages on a watershed scale.

SIAM compared with Watershed Sediment Yield Models SIAM explicitly allows the incorporation of all sediment sources (bank erosion, gullies, mining, landslides, soil loss) separately by grain size in each reach. The magnitude and gradation of these sources must be determined by the user. SIAM evaluates multiple size classes (boulders through clay, using the American Geophysical Union Sediment Classification System). SIAM does not include information for the watershed hydrologic characteristics (and does not compute watershed sediment loads). SIAM focuses on channel properties, and allows a detailed tracking of sediment by grain size through the watershed. SIAM computes local bed material balance to assess potential impacts on channel stability.

LIMITATIONS OF SIAM

Limitations SIAM has the following limitations:

- not a sediment routing / erosion model (does not adjust cross section geometry and update hydraulics)
- model does not generate final or intermediate channel profiles
- model does not compute a time frame for sediment impacts
- computations are based on reach-averaged properties
- computations are steady state and one-dimensional only
- model assumes no limitation on bed material supply
- selection of reach length can affect reach-averaged values.

User Background SIAM requires a strong background in river engineering to develop the input data and to interpret the results.

Potential Additions to SIAM Capabilities The following are potential additions to the capabilities of SIAM:

- equilibrium (stable) slope computation,
- computation of effective discharge, and
- wider selection of sediment transport functions.

APPLICATIONS

SIAM (as embedded in HEC-RAS) has been applied in the Yalobusha River, Sabougla Creek, Hickahala Creek, Harlan Creek, Long Creek and Caney Creek (USACE, Vicksburg District), Arkansas River (USACE, Little Rock and Tulsa Districts), Toutle and Cowlitz Rivers (USACE, Portland District), Hawkcombe Stream (University of Nottingham, UK) and the Kankakee River (USACE, Rock Island District).

SUMMARY AND CONCLUSIONS

The SIAM model provides new capabilities suitable for modeling sedimentation processes on a watershed (systems) scale. It provides a method for inputting sediment loads by source, allowing for easy manipulation and tracking of impacts for various sediment management alternatives. The ability to track both bed material and wash load (and to reclassify sediment from reach to reach) gives the model the capability to accurately reflect morphological and sediment yield impacts within a large watershed network. SIAM is useful for modeling sediment continuity throughout a watershed, and for providing a conceptual model of sediment transfer processes on a watershed system scale. With sediment as the number one ranking pollutant in streams and a contributing agent in many others, the addition of SIAM into the river-engineering toolkit will empower designers and planners to more easily consider sediment supply and transport in management and rehabilitation of channel systems.

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