Ephemeral Tributary Sediment Loads

Overview

One common source of uncertainty in mobile-bed sediment transport modeling of a river is lateral sediment volumes delivered by tributaries. The uncertainty and error associated with tributary sediment loads is much larger for ephemeral non-armored tributaries as compared to perennial armor-bed systems. Many of the rivers in the western United States, especially in the southwest and central plains, have ephemeral tributaries which can be significant sources of sediment for the mainstem river. This is especially true in situations where an upstream dam cuts off mainstem sediment loads. These tributary sediment loads are very important for sediment management and river restoration purposes, and are often poorly estimated and can involve order of magnitude errors in their quantification (Reid and Laronne, 1995).

Current methods to estimate sediment transport involve estimating either: (1) the sediment supply or (2) the sediment capacity. Sediment supply estimates are usually of the Universal Soil Loss Equation types (USLE, MUSLE, RUSLE) and are understood to include significant uncertainties. Sediment transport capacity is typically estimated using a transport equation, which can be effective when the appropriate equation is selected to match the specific conditions. However, nearly all transport equations have been developed based on the energy in perennial systems, and bed load flux in an ephemeral channel has been shown to be "several orders of magnitude higher than maxima measured at similar levels of stream power in perennial counterparts" (Reid and Laronne, 1995). It is imperative that stream restoration studies, sediment management actions, and reservoir sedimentation studies conducted by or for Reclamation include tributary sediment estimates that are more accurate than what is currently being used.

Summary of Literature Review

Sediment input to a riverine system is one of two main drivers to geomorphic processes. “A river’s character is strongly influenced by the amount and timing of the water and sediment provided to it, and a change in sediment or water supply usually provokes a change in the river.” (Reid and Dunne, 2003). Similarly, “the dominant controls of channel form adjustment are discharge and sediment load (notably bed-material load), independent variables which integrate the effects of climate, vegetation, soils, geology, and basin physiography” (Knighton, 1998). Further, Knighton notes that “along many rivers the addition of water and sediment from tributary sources of variable size produces discontinuous changes in the controls, with parallel discontinuities in channel morphology. Excess or deficit of sediment in terms of a sediment budget implies different assumed responses in the channel morphology.” Similarly, stream “instability may result when the flow of water and transfer of sediment through the drainage network is disrupted or significantly perturbed. Adjustments involved in system instability typically involve aggradation (increasing bed elevation), degradation (decreasing bed elevation), or planform metamprhosis (abrupt alteration from one planform pattern to another)” (Watson et al. 2005).

Being able to predict geomorphic responses in the future, through the use of mobile bed numerical modeling, can depend highly on the lateral sediment input prescribed in the model, again even more so if the river reach is downstream of a dam. In addition, the design life of a reservoir depends on the ability to accurately estimate the rate at which it fills with sediment. Whether an ephemeral tributary contributes sediment to the river channel upstream of a reservoir or now directly into the reservoir since dam construction, the volume of sediment flux from the tributary needs to be accurately quantified for an accurate estimate of reservoir design. In predicting the life expectancy of a reservoir, "Due to lack of information, often the practice is to proceed by statistical or regression analysis, relating the short sediment concentration or sediment load record to a normally longer flow discharge record" (Frenette and Julien, 1996).

Many sediment transport equations have been developed by data from, and are intended to be used for, perennial streams. However, "bed load sediment flux in an ephemeral channel… are several orders of magnitude higher than maxima measured at similar levels of stream power in perennial counterparts." (Reid and Laronne, 1995). These differences in flux rate between these two stream types can be attributed to a number of factors including armoring, supply, runoff frequency, and clay content. Having no surface course layer of ephemeral streams has been attributed to "the rapidity of flood recession and the complete absence of base flow, both of which minimize the opportunity for low-flow winnowing of finer grains." (Reid and Laronne, 1995). Rivers are typically classified as supply-limited or transport capacity limited. For ephemeral systems "the flux rates are not sediment supply-limited, as they are in perennial channels." (Reid and Laronne, 1995). The sediment available for supply is not fully evacuated in arid and semi-arid lands due to the infrequency and short duration of storm events. For example, the Nahal Eshtemoa "lies dormant for 99% of the year." (Alexandrov et al. 2009), and for the Barranca de los Pinos, "water was present in the channel during 1.98% of the monitored time, merely 11 of 556 days." (Lucia et al, 2013). In addition to quantity of water and sediment is the quality of the sediment. Clay content can stabilize streams (particularly stream banks), and "because of the lack of rainfall in desert regions, weathering is dominated by mechanical not chemical means, therefore, clay production is prohibited" (Scott, 2006).

Ephemeral systems are unparalleled relative to their perennial counterpart in terms of the variability in the relative ratios of bedload vs. suspended flux. "Bedload ranges from a few percent of total load in lowland rivers to perhaps 15% in mountain rivers, to over 60% in some arid catchments." (Kondolf, 1997). For the Nahal Eshtomoa "suspended sediment dominates the total yield." (Alexandrov et al. 2009) and similarly for 37 ephemeral channels in southwest Saudi Arabia, "The suspended sediment, especially that transported during flash flood events, is of high concentrations and is larger in amount that that transported as bed load." (Nouh, 1988). However, "…suspended sediment dominates the total sediment yield of dryland catchments whereas others found bedload to make up the most of sediment flux" (Billi, 2011).

Some of the uncertainty in quantifying bedload and suspended load sediment flux lies not only with the rarity of flow events, but also the difficulty in data collection in such rare events, especially surrounding instrumentation function and safety. While collecting suspended load data on the Cho-Shui river, it was documented that "The vertical concentration profiles of suspended load …are difficult to measure

during the floods…because it is hard to lower down the sediment samplers vertically through the highly turbulent rapid flows." (Su, Lu, Hong, 2012). The increased desire for safety can be seen by the desire to further develop surrogate methods which "show promise to enable relatively safe, quantifiably reliable and continuous monitoring of bedload transport in rivers." (Gray et al 2010). The Gereb Oda invokes a common reaction "while the limitations of such a small data set are evident, they are balanced by the lack of (and the difficulty of carrying out) field measurements on such dryland rivers" (Billi, 2011).

Planned instrumentation installation

There are some over-arching considerations for installing instrumentation on an ephemeral stream. First is the need for the system to be automated due to the infrequency of runoff events and the typically remote location of ephemeral streams. The likely remote location and infrequency of events to be measured dictates the need for solar power and batteries to provide energy for the data collection and logging instrumentation if they do not have adequate self-contained battery supplies.

Second is the type of sediment data to be collected. The installation described below focuses on bedload as bedload "provides the major process linkage between the hydraulic and material conditions that govern river-channel morphology" (Gomez, 2006). It is important to logically recognize that the sediment that gets delivered as suspended sediment from a high-energy tributary will remain in suspension (if washload) or more likely become bedload when introduced to the lower energy mainstem river. To that end, quantifying ephemeral tributary suspended load is not trivial. Additional instrumentation could be added to that which is outlined below to quantify the suspended load. However, an extensive dataset collected by Nouh and Jamjoom (1981) and used for formula development is described in Nouh (1988) is deemed an acceptable method for estimating suspended sediment flux for sand bed ephemeral systems.

Although this instrumentation installation is vaguely specific, further research and coordination with experienced field practitioners will be conducted to finalize a complete installation plan. We are fortunate that, in discussing the possibility of instrumentation installation on tributaries of the Rio Grande, Dr. John Laronne wrote in an email to Mr. (Robert) Hilldale "I shall willingly give from my experience to the oncoming monitoring plan for several ephemeral channels." (pers. comm. R. Hilldale). This conceptual installation will need to be further defined in terms of logistics, instrument communication, data logging, and site selection, among others.

A variety of instruments are suggested for installation at an appropriately sited data collection location. The main instrument recommended at the site is Reid-type slot sampler. Although having high installation costs, the advantages of this type of device are numerous, including reliability; "Troughs and pits tend to produce the most reliable bedload data, provided that they are not full, have slots that span the channel, are capable of capturing the largest bedload particles, and possess a slot length that exceeds the maximum saltation length." (Gray et al 2010). The installation would be of the type with an outer liner and a set of load cells to measure weight of the collector box. A second installation to be incorporated in the data collection is a series of bedload-surrogate instruments; preferably hydrophones. The anticipated advantages to using hydrophones at this location include:

(1) installing one hydrophone upstream of the slot sampler, developing a relationship between the passive sensor signal and the physical sampler;
(2) installing an array of hydrophones across the channel, and utilizing the relationship developed in (1) to estimate total bed flux across the width of the channel;
(3) installing a single geophone well upstream of the main instrumentation site, to be used to 'alert' the downstream instrumentation of an event;
(4) using the relationship in (1) as one of many calibration datasets, where eventually only hydrophones could be used to accurately estimate the bedload flux of ephemeral tributaries in the arid southwest;
(5) And, to consider this effort in the larger context "The benefits of verifying and operationally deploying selected bedload-surrogate monitoring technologies could be considerable, providing for more frequent and consistent, less expensive, and arguably more accurate bedload data obtained with reduced personal risk for use in managing the world's sedimentary resources" (Gray et al. 2010). In addition, "…despite their shortcomings, and because of the small number of fixed field installations (pit samplers), it could be argued that one of the most significant stumbling-blocks for evaluating any instrument that purports to provide a surrogate of bedload flux is not development of the instrument itself, but rather the validation of its signal against bedload flux measurements that can be considered definitive." (Reid et al. 2010), and further "In this context, there has been a pressing need for simultaneous deployment of a means by which bedload can be sampled as definitively as is practicable in order to yield data against which the results of surrogate measures of flux and mobile grain size-distribution can be rated" (Reid, et al 2010).

In addition to measuring bedload, with both direct and surrogate methods, is the need to collect hydraulic data, scour data, and bed material data. The bed material data would be collected by conventional methods of bulk samples and/or pebble counts (depending on the stream chosen), and ideally will be conducted before any instrument installation and after installation, both upstream and downstream of the installation location.

The scour data could be collected using a scour chain field (Leopold et al. 1966, Foley 1975) but with the addition of accelerometers attached to the scour chains. The addition of accelerometers would "record the duration of streambed mobilization providing insight into bedload transport in the field" (Gendaszek et al., 2013). Accelerometer Scour Monitors (ASM) "recorded the time that scour lowers the streambed to the level where each accelerometer was deployed and the time of subsequent fill from the maximum scour level. Each accelerometer remained stable and at a constant tilt until it was scoured from the streambed as overlying sediment was removed," (Gendaszek et al., 2013). Although there has been controversy with scour chain data inferences (Colby, 1964), the addition of accelerometers, when coupled with bedload measurement, could yield an interesting dataset to add to the discussion.

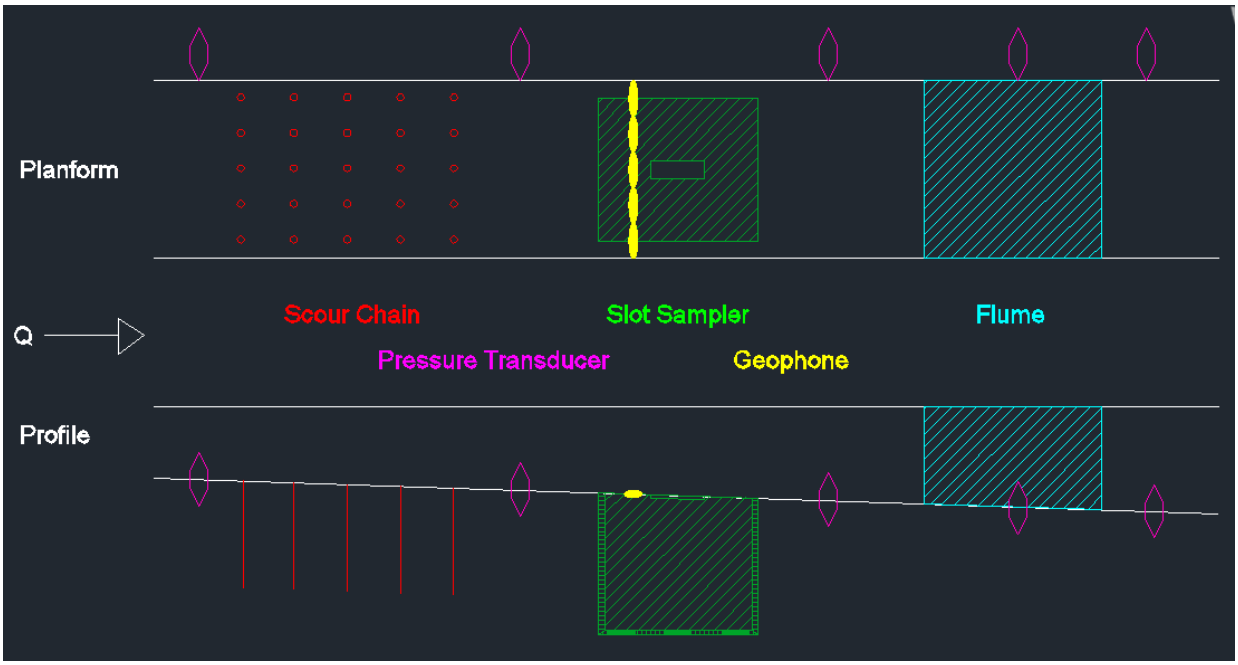
Capture of hydraulic data would be approached installing a fixed channel geometry, much like a flume, along with a pressure transducer. Although discussing infiltration rates in ephemeral streams, the implication by Stephens to stage-discharge relationship are obvious; "the influence of changes in channel geometry on infiltration may be more important than depth of water in the channel" (Stephens, 1988). The typical method for determining flow using a flume is to invoke an acceleration of flow to a supercritical state from an upstream subcritical state, such that the critical hydraulic control yields a unique flow-depth relationship; this may not be an option on ephemeral systems. As has been noted for

the Gereb Oda, “Froude number was constantly higher than one and supercritical flow conditions occurred also at shallow flow depths” (Billi, 2011). Although there is not a one-to-one relationship between Froude number and flow regime, they are related (Julien, 1998), and it has been noted that “for many sand-bed streams, at least part of the cross section will have a plane or an antidune bed at the highest flows” (Colby, 1964). However, having a good set of energy grade will allow for good inferential discharge estimates, which leads to more pressure transducers.

In addition to the pressure transducer at the fixed geometry, there would be additional pressure transducers located upstream, downstream, and throughout the data collection site to better estimate energy grade slope at the site. In addition to aiding in discharge estimation, an array of pressure transducers would be useful in that “water-surface slope is usually assumed to be constant when predicting bedload sediment transport in rivers despite its significance as a determinant of shear stress and the impact that variability would have on calculated sediment flux” (Meirovich et al. 1998).

The overall layout of this data collection site needs to be further refined, but the conceptual layout of the instrumentation is presented schematically below. The basic layout consists of:

1. A scour chains with accelerometers set up in a rectilinear field,
2. A Reid-type slot sampler with load cells for time-dependent weighing of the collector box,
3. A geophone array across the width of the channel, with one geophone directly upstream of the slot sampler,
4. A fixed geometry section, or flume, that will be used to infer discharge, and
5. A pressure transducers at the fixed geometry section, as well as at the beginning, end, and throughout the data collection site.



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