SPANISH CREEK VORTEX BEDLOAD SAMPLER
FINAL REPORT
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Summary:

The vortex bedload sampler (VBS) is a technology that has shown promise for both research and commercial applications. In 1996, the Feather River Coordinated Resource Management (FR-CRM) group applied for a grant of Clean Water Act 319h funds through the State Water Resources Control Board (SWRCB). The purpose of this grant was to demonstrate the efficacy of this technology for data collection, as a tool for stream channel restoration, and for off-channel, aggregate production for commercial purposes. Only one VBS had been implemented prior to this project. That VBS was designed and installed by David Rosgen on the Blanco River in southwestern Colorado. The Blanco River VBS has successfully removed excess bedload (Rosgen, pers. comm.) from the river to aid in restoring stream channel stability and fishery habitat.

The VBS mechanism passively shunts bedload out of the stream channel into a nearby storage pond. Bedload is the coarse component of a stream channel sediment supply that typically slides and bounces (saltates) along the streambed. In steeper gradient mountain streams bedload is comprised of particles ranging from 2 mm (coarse sand) to 256 mm (large cobble) in the same channel.

Bedload is the dominant channel-forming, channel maintenance portion of the sediment supply and is integral to project design for the restoration of stream channel processes. Ironically, bedload is the most difficult component of stream sediment to accurately sample with existing technology. These difficulties arise from the large range of particle sizes, the non-uniform rate of transport and the difficulty of accurately placing and operating portable sampling devices during floods. The VBS technology does appear to have some advantages beyond the more standard methodologies. The limitations with the two methods are similar, to a degree, and are detailed below in this report.

Design and Installation:

The Spanish Creek VBS was installed just downstream of the Snake Lake Bridge 7 miles west of Quincy on the Bucks Lake-Oroville Hwy. The installation occurred in November, 1997. This location was chosen for a combination of reasons as follows:

- snow-plowed road access to the monitoring site
- ease of construction and maintenance access
- bridge platform for Helly-Smith bedload sampling for calibration
- high bedload stream system
- the bridge provides a channel control feature in an alluvial channel reach

Several technical challenges were present at this site. The Snake Lake Bridge has an exposed steel superstructure. This superstructure made streamflow and sediment measurements more difficult. The bridge, while providing an effective control, also affected sediment transport at stages above bankfull due to channel constriction induced by the bridge abutments. The VBS was installed the fall after the 1997 flood (largest on record). As a consequence there were natural post-flood adjustments in bed elevation, slope and cross-section that had to be accommodated by the VBS, yet were not part of the design.

The VBS is constructed of schedule 80, smooth-wall, carbon-steel pipe that is 20 inches in diameter with 12 inch wide flat, steel flanges along both sides of the sampler (please see attached design sketches). The total length of pipe is 160 feet. 70 feet of pipe is buried at the elevation of the streambed across the channel at a 45^0 angle. Three 10-foot long, 10 inch wide openings were cut along the top of the channel section of pipe. These openings were separated by 3 feet of uncut pipe. The remaining 90 feet of solid pipe extends through the streambank, under the floodplain and ends in a pre-excavated storage pond located in the floodplain. The storage pond was excavated to a design storage capacity of 2500 yds^3 (see attached cross-sections). An outlet channel, for return water flows, was constructed from the down-valley end of the pond back to the main channel 400' downstream. The overall installation of the VBS, including pond excavation, took 5 days. The VBS itself was fabricated off-site and moved to the site on a low-boy equipment trailer in 4 pieces which were welded on-site.

The project required permits or review by the following agencies, all of whom are interested in the viability of the technology:

U.S. Army Corps of Engineers
Ca. Dept. of Mines & Geology
Ca. Dept. of Fish & Game
Central Valley Regional Water Quality Control Board
Plumas County Planning Department
USDA-Forest Service, Plumas National Forest- land manager

Monitoring:

The project had an ambitious monitoring program intended to track a number of parameters:

- stream channel stability
- total bedload quantity
- physical processes occurring in the sampler
- sampler trap efficiency
- streamflow
- sampler operating protocol

It was felt that the placement of this first VBS at the location chosen on Spanish Creek provided the best opportunity to effect the above described monitoring. Primarily this is due to the reliability of access during extreme flood events. Ironically, there have been only a few (4) minor, short duration streamflow episodes capable of transporting bedload in the four years since installation. Less than 50 hours of bedload-transporting streamflows have occurred through the course of this project. These have been monitored by a combination of FRCRM staff, consultants and USFS personnel. All effective monitoring consists of quanitative data leavened with good qualitative observation. This combination is presented throughout the discussion of project effectiveness. The results are presented later in this report.

Monitoring Methodology:

Stream Channel Stability: A major concern of any sediment (bedload) harvesting in stream channels is the depletion of material necessary for channel stability and habitat quality. To this end, channel cross-sections were established to track changes in channel geometry parameters that resulted from the operation of the sampler. Pebble counts were also conducted to determine if any changes were occurring in substrate composition (see attached).

Total Bedload: Bedload quantity and particle size composition is a significant data collection need for understanding river dynamics in any given reach. In order to determine total bedload and VBS trap efficiency, a Helly-Smith bedload sampler was deployed from the Snake Lake Bridge during high flow events to gather bedload just upstream of the VBS installation. The Helly-Smith sampler is lowered via a cable from a portable bridge crane with a calibrated reel. The main limitation for this project is that the equipment was only capable of operating a 3-inch, square orifice sampler. A significant portion of the bedload at this location, possibly as much as 50% by weight, was larger that 3-inches (see attached).

Physical Properties of VBS: Some of the most critical information collected during this project was the actual physical properties of water and sediment inside the VBS. The 45^{o} orientation of the sampler to streamflow is the most crucial variable determining the energy vectors necessary to keep the entrapped load in suspension and moving down the pipe and into the pond. Natural channel velocities are strongly influenced by channel roughness, particularly near the bed.

As streamflows cross the sampler, a portion of it drops into the smooth-walled circular pipe. The lack of roughness causes a significant acceleration of velocity. The orientation of the pipe with streamflows initiates a helical flow pattern within the pipe. The pipe's upstream angle into the flows directs helical flows down the pipe. If the pipe were perpendicular to streamflow the helical flow would be nearly stationary. This creates the paradox of a flow pattern that seems both laminar and turbulent at the same time. This flow pattern is extremely effective at moving large quantities and large caliber particles. Another variable affecting sediment transport is the increase in hydraulic pressure and, therefore, tractive force, with an increase in flow depth.

VBS Trap Efficiency: Concurrent with bedload sampling from the adjacent bridge, efforts were made to sample bedload exiting the mouth of the sampler into the storage pond. Again, the existing technology was significantly challenged by the conditions. The velocity of flow from the VBS mouth and its helical nature literally twisted a hand-held Helly-Smith sampler from the grip of two men. However, sufficient samples were obtained to characterize the shunted bedload (attached).

Streamflow: Streamflow measurements, both stage and discharge, are crucial components of determining sediment transport rates and capacity. The difficulty in any natural channel measurement program is finding reliable, accessible, stable sites to conduct long-term flow measurements. The site, ideally, is composed of immobile bed and banks with a compact cross-section that contains all floods without inducing extreme turbulence. Spanish Creek is not wadable when measuring events at bankfull stage and higher. At bankfull stage, as bedload movement becomes fully initiated, streamflow measurements and bedload sampling necessitates that they be performed from a bridge (unless specialized cableways have been installed). Calculating flows after the event is over using indicators of stage and measurements of channel morphometry can also used.

This project used both methods. A cross-section located in a bedrock-bounded reach was established for moderate flows and a bridge site with an adjustable boundary was used for high flows. The bridge site, a cantilevered, steel superstructure bridge was difficult to measure from but fairly reliable data was collected. The staff-gage (a graduated metal plate permanently mounted to an immovable object and used to indicate flow stage) at both sites presented problems because they are prone to damage or loss during high flow events. As a consequence some data gaps occurred. However, the redundancy built into the system has allowed for a reliable integration of streamflow and bedload measurements. The most limiting factor in monitoring this project has been the paucity of high flow events since 1997.

Data Collection/Discussion:

Channel Stability:

The response of the stream channel to the removal of a portion of the bedload was monitored through a combination of permanent cross-sections and pebble counts. The intent was to determine if removal of bedload would result in adverse channel adjustments, specifically bed incision, and would coarsen the streambed. Cross-sections with pebble counts were established in 1994 and periodically re-surveyed and sampled. It should be noted that between 1994 and 1999 (the last re-survey) the channel had migrated from the north wall of the valley to the south wall. The comparative data is displayed on Figures ? & ?.

Bedload:

The project has enabled one of the most intensive, long duration, active bedload sampling efforts in the Feather River watershed. That said, seven (7) events were sampled from 1995-1999. Only one minor event has occurred since 1999. Several major events, before and during the contract period were not sampled for a variety of reasons. Most commonly, the storm events (3/95 and 1/97) were so extreme that personnel could not travel to the project area or velocities were so high, the equipment was incapable of operating within protocol. Other events developed and stop so suddenly that personnel could not mobilize quickly enough to catch the sample. The sedigraph in Figure ? illustrates the extreme variability of sediment transport volumes in natural channels.

The wide range of sediment volumes measured at similar discharges and stage can be attributed to a number of stochastic variables. These include but are not limited to:

1.) **Antecedent, in-stream storage volumes**
2.) **Nearby bed and bank erosion adjustments**
3.) **Contributing watershed event characteristics**
4.) **Local large particle motion**

Initially, sampling in early 1995 actually provided the highest volumes (tons/day) sampled during the entire project. This is attributed in part to in-channel storage accumulated through an extended drought period and to Wapaunsie Creek, a tributary immediately upstream, because it was straightened and moved the same season the sampler was installed. The channel section is still adjusting to that manipulation.

VBS Properties:

The following section addresses initial design criteria, what worked and didn't, and the modifications made to solve the problems. Incorporating these modifications into future designs is critical to the effectiveness and acceptance of the technology.

The VBS was designed to potentially "capture" material from 2/3 of the channel width. The remaining 1/3 was a hedge against bedload "starvation" downstream. The original design consisted of 3- 10' X 10" wide slots, separated by a 3' section of uncut pipe. This was to prevent the pipe from "spreading", which would impair the helical flow properties of the VBS. Understanding the complexity of flow, roughness and angle present in a working VBS is crucial.

> **The 3' straps separating the slots were too long. This minute detail impaired the first year monitoring effort. The action of water flowing into the open slots at a 45^0 angle initiates the downpipe helical flow. The resistance (commonly termed "roughness") created by the overlying water column (a factor of both velocity and pressure) modulates the in-pipe flow velocity. We theorize that when the helical flow reached the enclosed separation straps the reduction in roughness (no overlying water pressure/flow) caused an acceleration of the flow. This acceleration (in a distance of only 3') reduced the volume of water in the pipe which caused the water to lose contact with the top of the pipe interrupting the**

helical flow vector. This was compounded by the increased roughness provided by the inflow of water at the next downpipe slot. This VBS has 3 slots with 2 straps. Recruited bedload settled out at the downpipe end of each strap, plugging the upper two slots of the VBS. This phenomenon did not occur on the last slot before entering the solid pipe leading to the collection basin because there is no change in roughness to interrupt through-flow. In essence the VBS only worked at 1/3 of design capacity for the first season. The straps were shortened to one foot the next summer and this problem was eliminated.

The next two-part modification that became apparent was the need to lower the outlet channel elevation of the collection pond and move the confluence point of the outlet channel with Spanish Creek further downstream. Two processes have worked here to limit the design pond capacity. The first process is the elevation difference between the invert of the outlet pipe and the static water level of the pond. The greater the elevation, the steeper the slope on which the bedload moves away from the pipe as the pond fills. The second process hampering sampler operations is that at moderately high stages (< bankfull) channel water will back up the outlet channel, raising water levels in the pond. This further reduces the available slope moving bedload away from the outlet pipe.

The design elevation difference between the outlet pipe invert (bottom) and the outlet channel bottom was 12 inches. This provided for a .5% slope through the pond. This was found to be insufficient to move the material recruited (size/weight). The depositional feature that formed settled at no less than a 1% slope before the material began to back up in the pipe. This resulted in a depositional fan only 50 feet long rather than the designed 100^+ feet. Of note, the riffles in Spanish Creek have an average slope of 1.0%. The inference drawn from these observations is that the design slope for the effective pond area should mimic the average riffle slope of the contributing channel, matching existing hydraulics.

The sampler has been subjected to one moderate flood event that backed water up the outlet channel and raised the pond water level over and into the outlet pipe. This immediately reduced sampler effectiveness since there was insufficient velocity and helical flow in the pipe to move material to the pond and the sampler plugged.

The CRM has designed and is ready to implement modifications that will lower the outlet channel elevation 1' and extend the outlet channel confluence point with Spanish Creek 800' down-valley. This proposal had to move through a lengthy review process with the USFS and was not approved until 12/2001. The work is planned for the summer/fall, 2002 using other funds. Monitoring will continue in order to document the response to the modifications and the ultimate efficacy of the device.

One of the crucial questions asked by interested parties was whether the sampler could move the larger particle sizes captured from Spanish Creek. The sediment load in Spanish Creek ranges in size from silts <.125 mm to small boulders >256 mm. The sampler effectively moved large quantities of large cobble (128 mm- 256 mm) as the attached photos illustrate. The largest particle shunted off the channel was a platter-shaped boulder measuring 371 mm X 371 mm X 159 mm that weighed 44 lbs. (19,976 gms.).

<u>VBS Trap Efficiency:</u>

Determining the trap efficiency of the VBS that correlates well with the available data is difficult. This is directly related to the sampling typologies of the VBS and the Helly-Smith methods. The VBS is a direct measurement tool in that it collects material (data) continuously throughout the period. The Helly-Smith bedload sampling, in contrast, gives indirect measurements because only a portion of the load is sampled for a portion of the time. Furthermore, the Helly-Smith sampler used to date has a 3-inch square orifice (80 mm). This means that the larger particles of the load are not being collected with the Helly-Smith.

> **The FR-CRM acquired a 6-inch sampler (160 mm) and a truck-mounted boom to operate it. This will make future comparative monitoring more representative of the actual load in particle size and weight.**

The other factor that influences the lack of correlation is that the smaller size fractions of bedload can become, intermittently or predominantly, part of the suspended load in flows above bankfull. This is due to the constriction of the channel formed by the bridge abutments, causing an increase in velocity and turbulence. This results in bedload particles moving over the sampler without capture. The outlet of the sampler is also difficult to accurately sample because of velocity and helical flow. A 6-inch hand-held Helly-Smith had to be specially adapted with handles to maintain its orientation in the flow. The helical flow twisted the standard sampler out of the grasp of two people.

<u>Streamflow:</u>

Streamflows directly measured as part of this and previous monitoring at the VBS site ranged from 32 to 1856 cfs. Streamflows measured using other methods (float, Slope/Area, etc.) extend the measured flows to 3886 cfs. (1997). As the sediment monitoring was affected by post-1997 channel adjustments, so to were streamflow measurements. The attached stage/discharge rating table illustrates the variability in measurement from both channel adjustment and standard operator differences. This rating will continue to be revised as additional flow events are monitored.

<u>Conclusions:</u>

The Vortex Bedload Sampler installed on Spanish Creek with the cooperation and support of numerous federal, state and local partners has demonstrated the potential for research and commercial applications. With the design modifications detailed above the VBS can shunt significant quantities of bedload, irrespective of size, from stream channels with minimal impact to channel morphometry and aquatic resources.

This project has sparked considerable interest from landowners/managers up- and downstream in attempting to work and restore Spanish Creek. Currently, the FR-CRM has submitted an application to Prop. 13 for a more comprehensive modeling of sediment transport in Spanish Creek in American Valley, downstream of the sampler site. The purpose of this grant is to develop a gravel management and channel restoration strategy that will accommodate the high volumes of bedload being transported through the channel system. This initiative is a direct off-shoot of the work funded by this grant. It has fostered a recognition by many local landowners that a collaborative approach that works with the river's streamflow/sediment dynamics is the optimal solution for their issues. The continued operation of the sampler will provide valuable data in the development of this strategy.

Additional Information Needs:

How should the sampler be designed and operated to handle loads exceeding the capacity of the storage pond?
What are the long-term maintenance and operational needs of the device?

How should the sampler be designed to limit the amount and/or caliber of the material to be sampled?