RECLAMATION

Managing Water in the West

Exploring Methods to Predict, Manage, and Control Alluvial Material Transport

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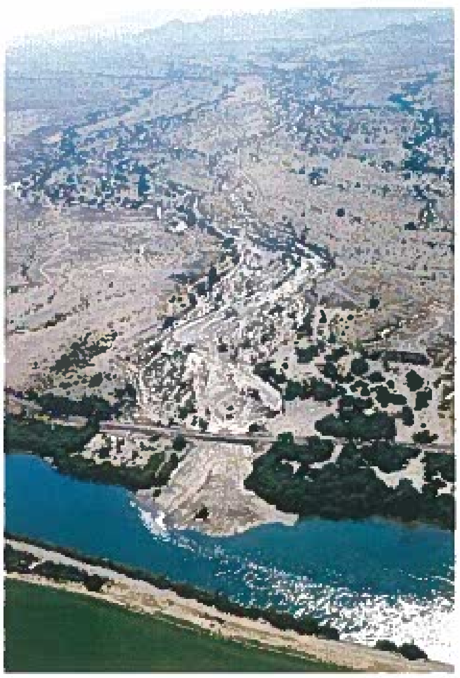
Science and Technology Program
Final Report 2014.7796



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Research and Development Office
Bureau of Reclamation
U.S. Department of the Interior

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Reclamation's mission is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Flows conveyed by ephemeral streams have damaged Reclamation infrastructure and deposited large amounts of material and debris into the river channel in the form of alluvial fans. Alluvial fans reduce channel capacities and have the potential to adversely impact water deliver operations and protective bank structures that guard adjacent lands and facilities. Reclamation is searching for proactive and cost effective solutions to ensure continued water operations. Control of alluvial material prior to its introduction into the Lower Colorado River is a potential best management practice and step forward in achieving such solutions. The research team conducted literature review to explore methods being used by Reclamation, private industry, and other public agencies to measure, capture, and control alluvial material transported during hydrologic events.

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Executive Summary

Rainfall events between 2003 and 2005 caused flooding within the Gould and Mule washes, ephemeral streams within the Cibola and Palo Verde Divisions of the Lower Colorado River (River). Flows exiting the termini of these streams washed out sections of Reclamation's operation and maintenance (O&M) roadways and protective river bank structures, depositing thousands of cubic yards of alluvial material and debris into the River channel. Reclamation's Yuma Area Office (YAO) personnel conducted emergency measures to repair said infrastructure and remove this alluvial material.

In October 2011, Reclamation personnel conducted a Review of Operation and Maintenance of the River from the Southerly International Boundary to Davis Dam and observed 10 large alluvial fans within the River channel that were deposited by ephemeral tributary flows. The alluvial fans constrict channel capacities and have the capability to erode and undercut bank structures that protect adjacent private, public, and tribal lands and facilities. Alluvial fans are potential navigational hazards to people using the river system for recreation. The Colorado River Indian Tribes (CRIT) have also experienced issues with alluvial fans and have contacted Reclamation's YAO for assistance (e.g. the Paradise Point Wash Fan, which reduced local channel capacity and impeded access to one of their boat ramps).

Ephemeral stream flooding and alluvial material transport are not unique to the Colorado River Basin are not solely a Reclamation issue. The Southern California floods of February 1969 resulted in more than $213 million in property damage and more than 100 lost lives. Ephemeral stream flows have the potential to transport large volumes of material and debris. As an example, runoff from heavy rains in the Huachucan Mountains deposited debris and boulders several feet in diameter south of Sierra Vista, Arizona in 1988.

For decades the Los Angeles County Department of Public Works, the U.S. Army Corps of Engineers (USACE), and other interested parties have utilized debris basins to capture and control material upstream of essential flood-control infrastructure and urbanized areas [1]. In the past, Reclamation has deployed heavy equipment within river channel boundaries to remove large alluvial fans. With constrained budgets, fish and wildlife considerations, permitting requirements, and a limited timeframe for removal (November through January, when River flow is typically low), addressing and removing alluvial fans in an effective manner has grown more challenging over time. Reclamation is looking for alternative methods to better manage alluvial material prior to its introduction into the river channel.

Reclamation's mission is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. The YAO's mission is to manage and deliver water to its customers using technology and resources. Flows conveyed by ephemeral streams have damaged Reclamation infrastructure and deposited large amounts of material and debris into the River channel in the form of alluvial fans. Reclamation is searching for proactive and cost- effective solutions to ensure sustained water operations. Control of alluvial material prior to its introduction into the River is a potential best management practice and step forward in achieving such solutions.

The research team conducted a literature review to explore methods being used by Reclamation, private industry, and other public agencies to measure, capture, and control alluvial material transported during hydrologic events. The team documented successes, problems, and potential gaps in science through a midyear annotated bibliography which was submitted through the Science and Technology (S&T) Grant Program. Over thirty documents were read and examined as part of the literature review and subsequent annotated bibliography. Through this research, the team found that alluvial material and ephemeral stream flows are worldwide issues and are being studied closely. In particular, more studies were found to explore sediment transport models during hydrologic activities rather than mitigation of the consequences of major earthen transports into populated and traveled areas. Recognizing that the intent of the S&T Grant is to look at mitigation and preventative methods, only a portion of the researched material was applicable to Reclamation activities.

In reviewing the relevant literature, the team found that the Japanese have invested considerable efforts into implementing different experimental measures to try to reduce impact of sediment laden loads. Due to differing climate hydrology and geologic formations, the nature of Japanese concentrated sediment flows is different than that of flows examined on the River; however, some of the implementation measures cited in recent sabo dam studies could be applicable. These measures include screened basins, overflow stepped weirs, and staggered upland dikes. In applications related to the Desert Southwest, the Los Angeles County Flood Control District, Federal Emergency Management Agency (FEMA), and USACE have developed guideline documents for mitigation measures that are currently being practiced in the United States. In general, these agencies recommend avoidance of zoning and consideration of potential construction issues prior to building on or near an ephemeral stream. For the most part, research was focused around the impact that sediment-laden flows have on structures and was limited with regard to impact to waterways. The research reiterated consistently that ephemeral flows and resulting sediment loads are natural occurrences and that preventative measures are often costly to install and maintain.

Recognizing that the majority of Reclamation's issues in the YAO's jurisdiction are related to in-stream depositions from seasonal flow rather than direct impact to residential areas, the team believes it worthwhile to select a number of known seasonal flow and depositional areas for further study. While extensive modeling has been performed regarding the mechanics of sediment flow, scale model results of preventative and mitigation measures have not been directly applied or correlated to actual installation. To further implement the study measures, the team recommends that the YAO uses the Los Angeles County Flood Control District's debris dam and basin design to install and test several upland mitigation measures. These structures should be installed and studied over the course of several years to examine the effectiveness and applicability of structure sediment control structures upland of the depositional areas from the wash fans. Effectiveness of the structures can be measured after each major storm event through a visual inspection, and in-stream deposition growth may be monitored through the annual Colorado River O&M Inspection.

Contents

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Appendix A: Annotated Bibliography

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June 4, 2014

FY 2014 S&T Project
Exploring methods to predict, manage, and control alluvial material transport

Annotated Bibliography

Armanini, A., Dalri, C., & Larcher, M. (2006). Slit-Check Dams for Controling Debris Flow and Mudflow. Disaster Mitigation of Debris Flows, Slope Failures, and Landslides: Proceedings of the INTERPRAEVENT Intl. Symposium: Sept. 25-29, 2006 in Niigata, Japan (pp. 141-148). Tokyo: Universal Acadamy Press, Inc. Retrieved from http://www.interpraevent.at/palm-cms/upload_files/Publikationen/Tagungsbeitraege/2006_1_141.pdf

The paper starts by defining slit-check dams, which are an open-type of check dam with one more narrow vertical openings beginning at the base of the dam and extending upwards to its weir elevation. According the document, "from a hydraulic point of view, open check dams are very often designed only on the basis of the designer's experience, who imitates similar structures built in analogous situations." The purpose of the study was to provide a rational criterion for designing slit dams to control debris flow and mudflow. The authors provide the reader with a theoretical approach and compare it to the results of a laboratory analyses. The results indicate a general agreement between the theoretical approach and the laboratory results. The study is beneficial in that it provides some guidance and equations to those who may otherwise rely on past experience or imitate other structures in similar areas. The paper did not provide specific examples of how to apply the equations, nor were there any examples of how structures designed using this outlined methodology performed in the field. A follow-up study to discuss how structures designed using this methodology, performed in the field would be enlightening and provide further validation of this study. Additionally, a single or multi-dimensional numerical analyses of these structures using different slit openings, channel widths, bed slopes, sediment concentrations, incoming hydrographs, etc., may be useful to obtain a better understanding of how these structures function in a more complex environment.

Chanson, H. (2004). Sabo Check Dams - Mountain Protection Systems in Japan. (P. Bates, R. Falconer, D. Garcia de Jalon, J. Imberger, & et. al., Eds.) Intl. Journal of River Basin Management, 2(4), 301-307. Retrieved from http://espace.library.uq.edu.au/eserv/UQ:9418/jrbm_04.pdf

The article provides the reader with a definition and application of sabo check dams and the different types that are being used in Japan. Also included within the article are generalized discussions on both proper and improper planning. Per the article: "The direct translation of Sabo (sa-bo) is "sand protection". The term "sabo works" refers to mountain protection systems." These systems are generally in the form of check dams, which are used throughout Japan to control sediment laden flows that could be catastrophic and detrimental to downstream infrastructure and individuals. The various types of Sabo check dams introduced and discussed within the article are vertical concrete walls, permeable type and slit-type sabo dams, and overflow stepped weirs. The author stresses the importance of proper planning, design, and long-term maintenance and cautions the reader against using "short-term and narrow-minded political 'reasoning'." In summary, the article is successful at defining sabo check dams, the different types that are available, and general wisdom for proper planning. The article is a great starting point for those new to sabo works or those interested in learning about other options for controlling debris flows.

Gonda, Y. (2009). Function of a Debris-Flow Brake. Intl. Journal of Erosion Control Engineering, 2(1), 15-21. doi: http://dx.doi.org/10.13101/ijece.2.15

The journal article provides a defition a debris-flow brake structure, its purpose, and how it functions. In essece, the debris-flow brake structure allows pore water to drain into a permeable catchment, thus removing the medium that transports debris. Said debris subsequently settles-out on top of the structure. The detailed mechanism of the debris-flow brake was not clear from a dynamic viewpoint; therefore, numerical simulations and expermiments were conducted to obtain a better understanding of said mechanism at the flow and structure interface. The journal entry discusses the dynamic model of debris flows on a debris-flow brake, provides an explanation of the numerical simulation and laboratory experiments, and outlines the results. The study indicates that the change in pore-water pressure plays an important role in how a debris-flow brake functions. The author successfully conveys the definition of a debris-flow brake structure (histroy, description, photographs), its purpose, and how it functions (discussion of governing equations, numerical simulations, and laboratory experiments). Upon a review of the article, it is evident that debris-flow brake structures require additional research. Studies to further analyze the performance of these structures under varying unsteady flow conditions, sediment and debris concentrations, and inlet and outlet geometry may be beneficial to parties interested in using the technology to control debris flows.

Julien, P. Y., & Leon S., C. A. (2000). Mud Floods, Mudflows and Debris Flows - Classification, Rheology and Structural Design. Intl. Workshop on the Debris Flow Disaster of December 1999 in Venezuela. Caracas. Retrieved from http://www.engr.colostate.edu/~pierre/ce_old/Projects/index.html#Research

The three main types of hyperconcentrated sediment flows (mud floods, mudflows, and debris flows) are introduced, defined, and their dominating shear stresses explained. The reader is provided with guidance on how to determine what type of flow is dominate. Guidance is provided on how to select the appropriate types of mitigation measures depending on the flow type present. Said mitigation measures are discussed in cursory detail. The article does a sufficient job at emphasizing that there are different types of sediment laden flows, each behaves differently and that no universal method exists to control them all. However, the article does not document success stories or failures to reinforce recommendations for selecting a particular type of structure. Additional reading (USACE, 1993; Chanson, 2004) is recommended for more information on various mitigation methods and their performance during historic flood events. Upon reading the article, two questions arise regarding the authors guidance on prescribing mitigation measures: 1) Was the article written assuming that the reader was interested in protecting downstream infrastructure and lives in an urbanized setting? If so, 2) would the guidance change if the reader's interest was in managing sediment and debris that enters rivers or canal systems?

Mizuyama, T. (2010). Recent Developments in Sabo Technology in Japan. Intl. Journal of Erosion Control Engineering, 3(1), 1-3. doi:http://dx.doi.org/10.13101/ijece.3.1

The article outlines developments in sabo technologies in Japan from about the year 2000 to about the year 2010. Topics discussed within the report include: laws to promote better land use in areas prone to sediment deposition, inclusion of open-type sabo dams within technical standards; use of soil cement for dam construction, installation of hydrophones on river beds to measure bedload transport rates, use of airborne LiDAR to determine the scales of landslide events and volumetric estimates of debris flows, the development of more user friendly GUI programs to predict debris flow hazards and evaluate control structures, and the adoption of reinforced concrete to protect structures from debris flow impacts. The author makes it clear that much research is still needed and that a cross-discipline and collaborative approach should be taken. He concludes as follows, "Hopefully, effective mechanisms can be established to co-operate research and lessons learnt across the Asia-Pacific region, and beyond." The article displays that progress is being made in sabo technologies; however, it also indicates that there is still much to learn. The article sparks questions and ideas for further targeted research. 1) Can LiDAR and/or bed sediment sampling methodologies used in Japan, be translated to the Colorado River Basin so that Reclamation can estimate the volume of alluvial material that is being transported to the Colorado River via ephemeral streams? 2) Can Reclamation build its own GUI program targeted at predicting debris flow hazards and evaluating different types of control structures? 3) The author mentions collaboration within the Asia-Pacific region and beyond; therefore, can Reclamation reach-out to Japanese engineers to share knowledge. Reclamation could benefit from Japan's extensive experience using sabo works.

US Army Corps of Engineers. Hydraulic Engineering Center. (1993). Assessment of Structural Flood-Control Measures on Alluvial Fans. Davis: Federal Emergency Managment Agency.

The project report was prepared by the USACE for the FEMA and outlines 7 different case studies in the southwestern United States and two in Alaska. The information is based on past project reports and analyzes the performance of the various flood and debris control project features at each. Said project features include: levees, flood control channels, debris basins, and reservoirs. A specific section was dedicated to describing these features, the different options for their construction (concrete, wire mattresses, masonry block, loose riprap, grouted riprap, etc) and information on their past performance during flood events. If available, information on past hydrologic, hydraulic, sediment transport, and general design data was also shared. A case study of particular interest was the Las Vegas 1975 Flash Flood, which indicated that sediment deposition was actually more damaging than the erosional effects of the event. Though no specific quantities were documented, the report states that the storms deposited "probably several acre-feet of sediment" in the Caesar's Palace parking lot and several acre-feet of sediment at the Winterwood Golf Course in southeastern Las Vegas. One interesting quote within the report indicates that there is still need for further research: "Present state of the science methods depend on empiricism, experience, field observation, and the application of traditional clear-water assessment methods that have been modified to account for flow bulking and the unpredictable, and often episodic, nature of alluvial fan processes." The report is useful; however, it is becoming dated. The science is evolving and flow-measurement tools are improving. An updated report with new case studies, higher resolution photographs, tables, charts, and the assessment of different flood and debris control measures (e.g. slit-type and permeable type sabo dams) would be beneficial to those managing flood and debris events.