Reprinted from the North American Water and Environment Congress © 1996 American Society of Civil Engineers

Debris Basin Design Procedures

J. J. DeVries[1] and T. V. Hromadka[2]

Abstract

Debris basins are widely used in the southwestern areas of the United States, with the majority of the structures located in the Southern California area. More and more development is taking place on alluvial fans and on flood plains located at the outlet of streams from mountainous areas experiencing erosion. This paper reviews methods for estimating debris yield from watersheds and procedures for designing reservoirs to trap the sediment.

Introduction

Debris basins are reservoirs which control sediment discharged from a watershed. The role of the debris basin is to trap and store the sediment to separate sediment from the stream water flow to prevent damage to roads, buildings, and other downstream structures. Debris basins are widely used in the southwestern areas of the United States, with the majority of the structures in the Southern California area. In these arid regions there has been increasing development on alluvial fans and on flood plains located at the outlet of streams from mountain areas experiencing large amounts of erosion. The production of sediment is often associated with wildland fires which remove protective vegetative cover and produce changes in the surface soil layers which further contribute to conditions of rapid and severe erosion (Johnson, McCuen, Hromadka, 1991a).

An important consideration in the design of debris basins is the determination of the magnitude and timing of sediment inflows. Most debris basins are also designed to be maintained through removal of sediment to sustain an adequate volume of storage in the debris basin reservoir. The reservoir volume provided is designed to capture the sediment from a major flood event while allowing the water to be passed downstream. The entire volume of the reservoir may be filled by debris during a single season or a single large event.

The determination of reservoir capacity requires an estimate of the sediment reaching the basin associated with a frequency of occurrence. Sediment volume depends on a number of factors including the magnitude of the flood event, rainfall intensity, land use practices in the watershed, and the time since the last major fire. It is not possible to quantify these factors into a deterministic analytical procedure for the calculation of debris production from a watershed. Therefore, methods of estimating debris yield from watersheds typically employ empirical relationships such as the Universal Soil

---

[1] Boyle Engineering Corporation, Sacramento, CA, M. ASCE

[2] Boyle Engineering Corporation, Newport Beach, CA, M. ASCE

Loss Equation or use regression procedures to correlate debris volume to factors which significantly affect debris production. Computations may involve single-event analyses as well as longer-term estimates. Consideration of the coincident frequencies of wildfire and flooding may also be incorporated for either procedures

Two general types of debris basins are used; 1) reservoir-type basins which use a dam to create a reservoir to capture sediment, and 2) in-channel sediment basins which permit sediment to be deposited in stream channels, also with detention structures to create smaller reservoirs to permit sediment deposition and collection. The reservoir reduces the velocity of the water transporting the sediment and allows all but the finest sediment particles to settle to the bottom of the reservoir.

Types of Debris Basins

Dam and Reservoir-Type Basin—This is the type of debris basin which is most commonly used in the southwestern U. S. It requires the construction of a dam to produce a reservoir in which sediment can settle out and be captured. A large reservoir can provide very low water velocities and turbulence is very low. By providing a long distance between reservoir inlet and outlet all but the finest sediment particles have an opportunity to settle out and deposit on the reservoir bottom.

The dam must have an outlet works and a spillway for passing flood flows. Most dam-type of debris basins can be considered to be "major" hydraulic structures. They will be subject to the regulation of state dam safety agencies. They will be required to be designed to rigorous standards for structural and hydraulic integrity. One of the most restrictive factors in dam design is requiring the structure to safely pass the probable maximum flood (PMF). Because debris dams block the free flow of stream channels, they also pose a variety of environmental problems.

Provisions for removal of sediment trapped in the reservoir so must be furnished so that the effectiveness of the debris basin can be maintained. The average annual cost of maintenance of this type of basin is often quite high. When the value of the areas downstream which are protected by the debris basins is correspondingly high also the benefit-cost ratio for these projects becomes favorable. In some cases the sediment removed for the debris basins has economic value; in other cases disposal of the sediment can add greatly to the operation costs.

In-channel Sediment Basins—In-channel basins are suitable for certain situations in alluvial rivers. These are provided by constructing several small dams and reservoirs on a stream which trap sediment through a series of impondments An example of this type of system is described by Gist, Stonestreet, and Copeland (1992). In-channel basins have not been commonly used because the conditions which provide for their construction are usually not available. However, they may be useful and feasible in situations where conventional debris dams cannot be built because conditions for constructing a single large dam and reservoir are not present.

Reprinted from the North American Water and Environment Congress © 1996 American Society of Civil Engineers

Factors Affecting Debris Production from Watersheds

The sediment (debris) that reaches a debris basin site is produced by erosion from upstream watershed areas. Various physical processes are involved in producing and transporting sediment, including: 1) erosion from the watershed surfaces in the form of sheet erosion, rill erosion, gully erosion, and mass wasting of slopes, and 2) transport of sediment stored in the stream system and erosion of stream banks. Usually, not all of the eroded material is transported out of the watershed; some sediment will be deposited in various locations in the watershed before it reaches the watershed outlet. Material stored during some runoff events can be mobilized by later runoff events and carried to the basin outlet.

Factors that can have a major influence on erosion and sediment production include land use conditions such as grazing by domestic animals, agricultural practices, logging, and road and building construction. In arid regions extreme drought conditions and watershed fires can have a major influence on sediment production. Following a major fire the erosion can be more than 20 times greater than prefire conditions.

As identified by MacArthur, Hamilton, and Gee (1995) the physical processes that produce sediment discharges from a watershed range from small-scale processes—including particle detachment by raindrops, erosion due to sheet flow, and rill formation— to much larger-scale processes. As the process scale becomes larger, formation and development of gullies occurs, and bed and bank erosion results in major production of sediment which then moves through the stream system. Additionally, landslides and mass wasting can produce very large amounts of sediment and initiate debris flows that transport very large volumes of sediment.

Debris Flows vs. Sediment Transport

It is worthwhile to consider the distinction between *debris flows* and general *sediment transport movement of debris* in evaluation of methods of predicting the volume of material that enters a debris basin. Many of the events which cause extensive damage and threaten life are not due to transport of large volumes of sediment materials by water from a watershed into developed areas. Instead they are debris flows, which are catastrophic movements of mud, sand, rocks, and boulders through the steep canyon channels of a watershed. These flows exit at the canyon mouth, and then create deposits of the debris materials on the flatter slopes of alluvial fans. Water has an very important role in initiating the debris flow process, but a smaller role in transport. In a debris flow the material being transported and the transporting medium are one and the same. Johnson and Rodine (1984) have made a detailed study of debris flows. They characterize a typical debris flow as "a large wave of admixed solid and fluid materials moving steadily through a channel with superimposed, smaller waves traveling at velocities higher than those of the debris flow itself." Debris flows in steep channels are comparable to the supercritical flow condition called a *bore*.

The behavior of a debris flow is similar to the flow of dry granular solids down a steep slope. When the debris flow is confined to a channel a helical pattern occurs in the flow. The helical motion tends to move the largest particles into the center of the flow. The large particles tend to move faster than the smaller sizes so that the largest particles tend to move to the front of the flow wave. Debris flows tend to be stopped, not by a process of the solids settling out from the water in the debris flow, but by a general cessation of movement of the entire flowing mass. Debris flows that enter a reservoir in which water is ponded do behave as water-borne sediment systems.

Johnson and Rodine (1984) point out that observation of debris flow deposits indicate that the coarsest material found in the deposit was carried nearly the same distance from its source as the finest material. Debris flows carry boulders and cobbles well beyond the points where these large-size materials can be transported by water.

The debris flow mechanism described above leads to the conclusion that calculations of sediment production from a watershed which are based on sheet flow erosion and water-borne sediment processes may not properly describe how the production of sediment is occurring and how much sediment may be produced. This makes the problem of predicting debris volumes a difficult one, especially when frequency of occurrence is also of interest. As pointed out by Johnson and McCuen (1992) debris flow frequencies do not generally coincide with rainfall frequencies.

Estimating Debris Yield from Watersheds

The discussion here is primarily concerned with procedures for computing debris yield from watersheds in the southwestern part of the United States. Debris problems exist in many other regions of the world, also. A review of the literature reveals papers describing this type of problem on all continents. Much of the literature is descriptive in nature, rather than quantitative, and procedures for estimation of sediment production volumes are limited. From a practical standpoint for the southwestern part of the US either the U. S. Army Corps of Engineers regression procedures or an estimate of erosion (such as the Universal Soil Loss Equation) or a combination of these must be employed. Some of these procedures are discussed below.

U. S. Army Corps of Engineers Regression Procedures—The Corps has developed the "Los Angeles District Method for Prediction of Debris Yield" as a standard procedure for debris basin design (U. S. Army Corps, 1992, Johnson, McCuen, Hromadka, 1991a). The procedure estimates the debris yield from a single large storm event. Because the entire debris production may not be the volume actually caught by a debris-catching structure, a "delivery ratio" (ratio between debris yield and debris production) is used. Delivery ratio is estimated from information about soils, climate, topography, and geomorphic characteristics of the watershed. Wildfire is also an important factor in debris production. The extent of brush and forest fires, time since last occurrence, and frequency of fires in the watershed affect total amount of runoff as well as debris yield.

Reprinted from the North American Water and Environment Congress © 1996 American Society of Civil Engineers

Soil Conservation Service— The Soil Conservation Service of the U. S. Department of Agriculture (SCS) has designed a number of debris basins in Southern California. The SCS does not have a general policy for debris basin design; each of their designs is very site specific (Schmidt, pers. comm. 1995). For general policy on debris basin design SCS engineers follow the guidelines given in the papers by Johnson, McCuen, and Hromadka (1991a, 1991b). The SCS typically designs a basin to store a 10-yr frequency hydrologic event. The volume of debris to be accommodated is based on site specific information about soils, climate, topography, and geomorphic characteristics of the watershed as well as fire information.

Universal Soil Loss Equation—Estimates of sediment production can be obtained by use of the Universal Soil Loss Equation Method (USLE) and its modifications (MacArthur, Hamilton, and Gee 1995). This widely used method for estimating soil erosion was originally developed for estimating erosion from agricultural fields. Primarily because other techniques were not available its use has been extended to natural watersheds also. The USLE provides an estimate of annual average sheet and rill erosion as a function of rainfall, soil erodibility factor, a slope length and steepness factor, and a vegetative cover factor. There have been a number of experiments to determine these empirical factors (Haan, Barfield, and Hayes 1994), but the data were obtained for relatively uniform small catchments, and the appropriateness of applying of this method to large, complex areas is questionable.

Watershed Erosion Models—A number of investigators have attempted to develop physically-based models of the erosion process. Various researchers have developed hydrologic models that simulate sediment discharge, transport, and deposition within a watershed. A review of watershed erosion models was made by the Hydrologic Engineering Center (Fenske 1993). Over fifteen models were identified; six models were reviewed in more detail to determine to what extent they could be used to predict erosion and sediment yield from a watershed. The physically-based models are based on equations with constants and exponents that must be determined for each subbasin of the watershed. For large watersheds "the subdivision of the watershed into rill and interrill areas would require an enormous amount of time and effort." Fenske's conclusion is that empirical models require much less effort to apply because the required data on topography, soils, precipitation, and land use can be estimated from maps and simple field surveys.

Debris Basin Design and Maintenance

To establish policies governing design standards and maintenance requirements for basins it is necessary to first determine potential hazards to areas downstream from the basin (Johnson, McCuen, and Hromadka, 1991b). High hazard sites usually require return periods of 50 to 100 years, while a basin located above an area with a low hazard will permit a shorter return period and a smaller basin. As emphasized by many authors (*e.g.* Hungr, *et al.*, 1987), continuing maintenance and removal of debris deposits is essential for safe basin operation.

Conclusions

The volume of material moving as a debris flow frequently results from localized landslide mass moments from hill slopes, rather than general surface erosion of land surfaces. This indicates that models based on water-produced erosion may not accurately predict the amount of sediment that is produced and required to be stored in a debris basin for watersheds that experience this type of sediment production.

Physically-based models usually require a great deal of time and effort to apply and data are usually not available to properly use these models. Empirical models require much less effort to apply because the required data on topography, soils, precipitation, and land use can be estimated from a maps and from simple field surveys. Regression equations usually predict higher sediment yields than other analytic methods, but they may be the best indicators of sediment volumes for design of a debris basin, particularly when they are based on actual observations of sediment yield in a specific region.

References:

1. Gist, W., S. E. Stonestreet, R. R. Copeland. 1992. "In-channel Sediment Basins: An Alternative to Dam-Style Debris Basins," *Hydraulic Engineering; Saving a Theoretical Resource, In Search of Solutions,"* ASCE, New York, pp. 1000-1005.
2. Fenske, J. 1993. "A Review of Watershed Erosion Models," Appendix A, MacArthur, Hamilton, and Gee (1995), TD 36, Hydrologic Engineering Center, Davis, CA.
3. Haan, C. T., B. J. Barfield, and J. C. Hayes, 1994. *Design Hydrology and Sedimentation for Small Catchments*, Academic Press, San Diego.
4. Hungr, O., G. C. Morgan, D. F. VanDine, and D. R. Lister. 1987. "Debris Flow Defenses in British Columbia," *Reviews in Engineering Geology*, Vol. VII, Geological Society of America.
5. Johnson, P. A., and R. H. McCuen. 1992. "Effect of Debris Flows on Debris Basin Design," *Critical Reviews in Environmental Control*, 22 (1/2) pp. 137-149.
6. Johnson, P. A., R. H. McCuen and T. V. Hromadka. 1991a. "Magnitude and Frequency of Debris Flows," *Journal of Hydrology*, 123, pp. 69-82.
7. Johnson, P. A., R. H. McCuen and T. V. Hromadka. 1991b. "Debris Basin Policy and Design," *Journal of Hydrology*, 123, pp. 83-95.
8. MacArthur, R. C., D. Hamilton, and D. M. Gee. 1995. "Application of Methods and Models for Prediction of Land Surface Erosion and Yield," TD 36, Hydrologic Engineering Center, Davis, CA, March.
9. S. Army Corps. 1992. "Los Angeles District Method for Prediction of Debris Yield" Los Angeles District of the U. S. Army Corps of Engineers, Los Angeles, CA, Aug.