Debris Flow Magnitude and Mitigation

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Introduction

A debris flow is a mixture of granular solids, water, and air that flows over low to moderate slopes (Johnson, 1970). The flow is typically 70 to 90 percent solids by weight and carries large amounts of gravel, cobbles, and boulders with only minor amounts of clay and other cohesive materials. Debris flows occur on small watersheds. The potential for debris flow can be assessed by considering hydrometerorological, topographic, soil, and burn potential factors. In addition to the duration and intensity of a storm that ultimately produces debris flow, antecedent rainfall is an important meterorological characteristic (Keefer et al., 1988). The antecedent storm saturates the soil and reduces the frictional resistance at the failure plane, with the debris-generating rainfall serving as the trigger to failure.

Another factor that is an important determinant of debris movement is the land cover of the watershed, with special concern shown when fire destroys the vegetative cover. Erosion is greatly accelerated during the season following a fire (Wells, 1987). Postfire debris flows can occur during relatively small storms and require less antecedent rainfall. Helvey (1980) found that sediment production was increased more than eight times following fires in North Central Washington. Sidle et al. (1985) reports a three-fold increase in erosion rates for the southern California area.

Debris flows often require structural measures for control, with the debris basin being the most widely used structural measure for watershed level protection. The design of existing

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basins has often been based on the volume of a previous debris flow rather than on the basis of the potential magnitude of a future event. The maintenance of debris basins is extremely important since the risk of failure increases when debris is allowed to accumulate in the basin. A basin cannot function as designed if it is not properly maintained, i.e., it is allowed to fill with sediment and debris.

Magnitude and Frequency

The procedure that is widely used for the analysis of water-flood data was used to analyze the debris data from watersheds in the Los Angeles, California, area. (Johnson et al., 1988a). Specifically, the data at each site were analyzed using a frequency analysis with a log Pearson type III distribution. Since the skew was near zero, a log-normal population was assumed to underlie the physical processes. The means and standard deviations were used as parameters of the log-normal distribution to compute the debris flow volumes in cubic yards per square mile per year for exceedence frequencies of 2, 5, 10, 25, 50, and 100 years. For each exceedence frequency, the derived debris flows were regressed on watershed characteristics using the power model form. Values for the regression coefficients were obtained using a procedure based on both ordinary least squares with a logarithmic transformation and numerical optimization. The regression of debris yield on these variables indicated that the relief ratio and hypsometric index were the watershed characteristics necessary to predict the debris yield.

In order to determine the effect of burn, the debris yield was related to both the watershed characteristics and the interval since the most recent burn. A coefficient describing the relative effects of the years since the watershed burned was then incorporated into the six debris yield equations in order to account for the effect of burn. The prediction equations including the effect of burn are:

$$Y_2 = 485B^{-0.24} R^{0.75} H^{0.11} \tag{1a}$$

$$Y_5 = 675B^{-0.24} R^{0.93} H^{0.19} \tag{1b}$$

$$Y_{10} = 795B^{-0.24} R^{1.03} H^{0.26} \tag{1c}$$

$$Y_{25} = 940B^{-0.24} R^{1.13} H^{0.35} \tag{1d}$$

$$Y_{50} = 1080B^{-0.24} R^{1.20} H^{0.42} \tag{1e}$$

$$Y_{100} = 1225B^{-0.24} R^{1.26} H^{0.48} \tag{1f}$$

where B is the number of years since the most recent burn in which at least 40 percent of the vegetated area of the watershed burned, R is the relief ratio (ft/mile), H is the value of the hypsometric index, and Y_i is the magnitude of the debris flow for a return period of i years (cubic yards/square mile/year). To apply Eqs.1, a debris policy should specify the burn interval to be used and the risk (i.e., return period).

Debris Basin Design and Maintenance

A debris basin design procedure should be based on expected volumes of debris for a given seasonal event and hazard level. A systematic monitoring procedure to assess the need for maintenance of the basins should also be part of every policy.

Seasonal Debris Volumes

The volume of debris flow for an entire season may be estimated with Eqs. 1 for return periods of 2 to 100 years (Johnson et al., 1988b). Equations 1 provide seasonal volumes rather than volumes for a single event. To obtain the design volume of storage of a debris basin for a particular watershed, the yield from Eqs. 1 is multiplied by the watershed area and by the period, in years, over which debris flows typically occur, which is approximately the length of the rainy season, possibly 0.3 to 0.5 years.

Maintenance

In order to minimize the risk of failure of a debris basin, the debris basin must be maintained. A basin that is not maintained will not function as intended by the designer. The removal of accumulated debris and sediment is the primary maintenance requirement. Therefore, the accumulated material within the basin must be monitored and periodically dredged. A model to estimate the debris yield that can be expected to enter a basin during a single event, As, was developed by regressing the debris yield in cubic yards per square mile on the 24-hour raninfall depth (in):

$$A_S = 6600\ P^{1.158} \qquad (2)$$

Policy Recommendations

In order to ensure the safety of the community downstream from a debris basin, design standards and maintenance policies must be established by local jurisdictions. The selection of the debris flow return period and the design burn interval should be a function of the potential hazard. The risk of failure is greatest for a basin that is designed to control debris flows having a short exceedence frequency such as two years and an infrequent burn interval, greater than 10 years, since this design would specify a small volume of storage. The risk of failure will decrease if burn intervals less than 10 years are used and if the debris flow return period is increased.

Policies should also define the levels at which the basin should be dredged. The basin should be inspected following each rainy season (yearly) to determine whether or not the basin should be dredged. A systematic failure to maintain a basin essentially increases the risk of failure.

Conclusions

Rather than basing a debris basin design on the volume of a previous debris flow, a policy for debris flow return and burn interval could be established and the appropriate prediction equation used to compute the expected volume of storage necessary. The prediction equations may aid in the design and location of flood channels, culverts, roads, and other engineering structures. Local governments may also wish to use the predicted debris flow volume as a guide in land use planning and in determining areas that are inappropriate for land development. The prediction equations may be used to establish rates of liability insurance for the jurisdiction, as well as for homeowner's insurance.

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