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In-Channel Sediment Basins: An Alternative to Dam-Style Debris Basins

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Abstract

In-channel sediment basins were designed, in lieu of a traditional debris basin, to capture large sediment loads at the upstream end of a proposed flood control channel. A numerical model, HEC-6, was used to size the basins.

Introduction

The US Army Engineer District, Los Angeles (USAEDLA), has proposed to improve a portion of San Timoteo Creek located in San Bernardino, California (USAEDLA 1990, 1991). The proposed channel improvement will convey the 100-year flood of 19,000 cfs with a concrete, supercritical flood control channel. The San Timoteo Creek watershed has the potential to supply a large amount of sediment during a storm event due to sparse vegetation, steep slopes, and easily eroded soils. Therefore, to assure that the proposed channel will function as designed, a debris basin is required.

Description of Study Area

The San Timoteo Creek watershed comprises about 126 square miles and is located southeast of the City of San Bernardino, California, in Riverside

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and San Bernardino counties. The creek is formed by three major tributaries and is itself a tributary to the Santa Ana River.

The proposed improvement includes the lower 5.2 miles of the creek as it flows from the foothills across an alluvial plain to the Santa Ana River. Upstream from the proposed channel improvements the bed is composed primarily of coarse sand with some gravel. The channel width varies due to extensive bank erosion, generally ranging in width between 100 ft and 300 ft. The average bed slope in the sediment supply reach is about 0.0145 ft/ft.

Debris Yield

An analysis was made to estimate the volume of debris delivered to the upstream end of the proposed project from the watershed. The debris yield was determined using the methods outlined in USAEDLA (1989). This method uses predictive regression equations which are based on watershed parameters and the combined probability of wildfire and flood.

This analysis indicated that the single-event, 100-year-frequency debris estimate is 700 acre-feet. Preliminary sediment transport analyses indicated potential problems with the channel inlet and outlet due to this large volume of debris.

Traditional Debris Basin Alternative

Initially, a traditional dam-style debris basin was designed to control debris and limit sediment inflow to the supercritical channel. However, due to the narrow canyon and further confinement by a railroad alignment, this structure had an embankment that was a maximum of 68 ft above the channel invert and was over 2 miles long. The spillway, designed to meet Corps probable maximum flood (PMF) criteria for dams, resulted in a 400-ft-wide spillway with a crest approximately 43 ft above the channel invert.

The local residents and flood control agency found this design unacceptable aesthetically and raised many concerns about dam safety. Thus, an alternative solution to the dam-style debris basin was sought.

In-Channel Sediment Basin Alternative

In-channel sediment basins were designed as the alternative. As shown in Figure 1, the in-channel alternative consists of eight sediment basins in series excavated 6 ft below the channel invert. Grouted stone stabilizers are located between the basins and rise to a height of 6 ft above the existing channel invert for a total height of 12 ft. The in-channel basins range in width from 250 to 500 ft and in length from 640 to 970 ft. The alignment of the basins generally follows that of the creek bed.

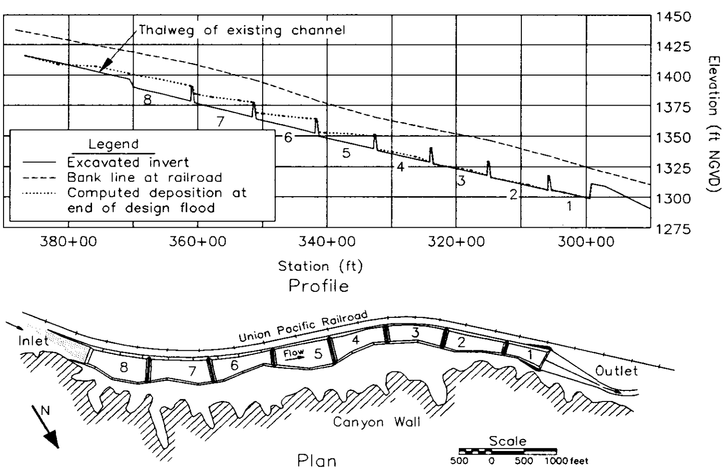

Figure 1. Plan and profile of in-channel basins

The proposed in-channel sediment basins for this project were designed to function basically the same as a larger, dam-style, single debris basin. With a single debris basin, sediment-laden flows are detained with a combination of above-grade embankment and below-grade excavation. The flow detention causes significant reduction in velocity, greatly reducing the sediment transport capacity of the flow and inducing deposition of most of the bed-material load. Only the wash load and a relatively minor amount of bed-material load are passed over the spillway of the debris basin.

The main difference from the concept involving a single debris basin is that instead of a combination of below-grade excavation and a substantially above-grade embankment, these in-channel debris basins are equally above and below grade. The height of the stabilizer at the downstream end of each basin was limited to 6 ft above the existing channel invert to keep it below the classification of a dam.

The system of in-channel sediment basins will significantly reduce the inflow velocities. At the design discharge for the existing natural channel above the project inlet, the flow velocities range from 12 to 18 fps, while the velocities within the basins will range from 3 to 8 fps. The design length of the basins will result in a typical detention time of 4 minutes, which is sufficient time to settle out even the finest classification of sand.

The uppermost basin (basin 8 in Figure 1) will provide the initial trapping of sediment during the beginning of the design flood. As the basin fills up to the crest of the stabilizer, a condition of relative equilibrium will be attained between the rate of sediment inflow to the basin and the sediment transport capacity of the detained flow within the basin. Once the sediment storage capacity of the basin has been exceeded, additional sediment inflow will be transported to the next downstream basin. The process will be repeated sequentially through each of the basins. The series of basins is designed to provide a total sediment storage capacity equal to the entire volume of sediment expected during the design flood, plus an allowance for sediment from antecedent flows.

Because San Timoteo Creek is well entrenched in the canyon bottom, levees or other flow containment structures are not needed to line the basins. In most cases, the stabilizer crests between basins are still well below the banks of the channel. A small berm will be required along the downstream end of basin 1 (see Figure 1) to make sure the flows enter the basin outlet structure.

Although the concept of utilizing several small sediment basins in series may seem rather unorthodox at first, it actually constitutes only relatively minor variations of the same proven concept used in the USAEDLA, for many years to exclude large amounts of bed-material-sized sediment and debris from downstream channel improvements.

Sediment Transport Analysis

Numerical modeling, using a research version of the one-dimensional sediment transport model HEC-6, was performed by the USAEDLA, and the US Army Engineer Waterways Experiment Station to ensure that the debris basins would function as designed during a design flood. The numerical model was able to simulate the sequential filling of the basins, the variation of deposition rate as each basin filled, the size class distribution of the sediment that passed through the basin, and the slope of the deposited sediments. The one-dimensional model does not account for variation in deposition due to eddies or increased turbulence at the basin inlets.

Initial bed material gradations for the model were based on an extensive bed and bank sampling program that included over 100 samples. Most of the samples were taken in a representative supply reach upstream from the proposed sediment basins. Sufficient samples were taken to determine if there was any lateral, vertical, or longitudinal variation in the bed. The maximum size of material was about 64 mm with an average D_{50} of about 0.9 mm. An average normalized bed gradation was determined from the bed samples for use in the model (Figure 2).

Sand inflow to the numerical model was calculated using average hydraulic parameters in the supply reach and the average normalized bed material gradation. Silt inflow was estimated to be 20 percent of the total sand inflow. This percentage corresponds to the average percentage of silts from bank samples.

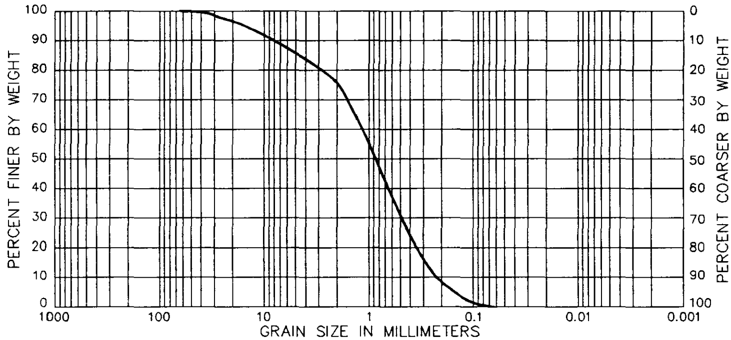

Figure 2. Average normalized bed gradation

It was especially important to determine the model's sensitivity to sediment inflow due to the lack of prototype sediment inflow data. Simulations of the design flood were conducted using three sediment transport equations. As expected, different transport equations produced different deposition rates and quantities. Since no suspended sediment data were available for comparison with calculated transport rates, numerical model results were interpreted considering the model's sensitivity to the transport function. Additional sensitivity tests were conducted; these included running the hydrograph twice to evaluate possible effects from the imposed initial conditions and increasing the sediment inflow of silt by one standard deviation.

Initially, the numerical model was run with basins that had a total storage volume of 700 acre-feet. However, upon running the HEC-6 model, it was determined that the stream was transport limited. Smaller basins were incorporated into the model and tested for reliability. As a result of the model study, the design volume of the sediment basins was reduced to 470 acre-feet.

The total calculated trap efficiency of the eight sediment basins for the 100-year hydrograph was 73.9 percent. Trap efficiency for sands was 94 percent, and for silts was 3.6 percent. 92 percent of the sand passing through the basins was smaller than 0.125 mm. Material passing through the basins will be easily transported in the high-energy concrete channel.

Conclusion

In-channel sediment basins are a viable alternative to larger, more traditional debris basins at the inlets to flood control channels. In this study it was demonstrated that the HEC-6 numerical model could be used to size sediment basins. Sensitivity tests are essential when insufficient data are available to substantiate model performance.

Acknowledgements

The contents presented herein were obtained from studies conducted by the US Army Engineer District, Los Angeles, and the US Army Engineer Waterways Experiment Station, Vicksburg, MS. Permission was granted by the Chief of Engineers to publish this information.

Appendix I. Conversion Factors from U.S. Customary to SI Units

To Convert	To	Multiply By
Acre-foot	Cubic metre (m^3)	1,233.5
Cubic foot per second (cfs)	Cubic metre per second (m^3/s)	0.028
Foot (ft)	Metre (m)	0.3048
Foot per second (fps)	Metre per second (m/s)	0.3048
Mile (U.S. statute)	Kilometre (km)	1.6
Square mile	Square kilometre (km^2)	2.6

Appendix II. References

US Army Engineer District, Los Angeles (1989). "Los Angeles District Method for Prediction of Debris Yield from Coastal Southern California Watersheds." Los Angeles, CA.

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