STREAM SYSTEMS TECHNOLOGY CENTER

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station

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Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings

Road-stream crossing structures should be designed to provide safe vehicle transportation across stream channels while not disrupting the movement and habitat needs of fish and other aquatic organisms utilizing the stream. Historically, many road-stream crossing structures were sized based on the hydraulic capacity of the structure for a specific design flood or the swimming and jumping abilities of target fish species. These types of design structures typically constrict the channel at the crossing, create flow hydraulics and channel conditions through the structure that are incompatible with those in the natural channel, and form barriers to the movement and habitat needs of fish and other aquatic organisms. For example, culvert assessments on National Forests and Bureau of Land Management Lands in Oregon and Washington found that more than 90 percent of culverts are barriers to the movement and habitat needs of fish and other aquatic organisms (GAO 2001). Moreover, hydraulic designs that focus on the passage of a target fish species during specific migration flows ignore the movement and habitat needs of other adult fish, juvenile fish, and aquatic organisms occupying the stream.

Stream simulation was adopted by the U.S. Department of Agriculture, Forest Service as a pragmatic approach and sustainable long-term solution to maintain passage for all aquatic organisms at all life stages at road-stream crossings while meeting vehicle transportation needs and objectives. Stream-simulation designs have a continuous channel through the structure with dimensions and characteristics similar to the adjacent natural channel (fig. 1). The premise of stream simulation is that since the design channel simulates the natural channel, fish and other aquatic organisms should experience no greater difficulty moving through the structure than if there were no crossing. Because the dimensions and characteristics of stream-simulation channels through the road-stream crossing are similar to those in the natural channel, stream-simulation channels are designed to laterally and vertically adjust to a wide range of floods and sediment/wood inputs without

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compromising the movement and habitat needs of fish and other aquatic organisms.

Although the concepts and overarching goals of stream simulation are easily understood, technical guidelines for collecting and interpreting channel data in the vicinity of the road-stream crossing, integrating those data to develop a stream-simulation design channel and structure/roadway design, and constructing a stream-simulation design had not been thoroughly developed. The Forest Service publication, ***Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings***, was written to provide resource specialists with detailed guidelines and examples for developing and constructing a design channel and structure that meets the ecological objectives of stream simulation (fig. 2).

The concept of stream simulation was first introduced by the Washington Department of Fish and Wildlife in 1999 (Bates 2003). The Forest Service publication, ***Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings***, builds on that foundation by expanding our understanding of stream simulation, providing detailed guidelines for achieving the goals of stream simulation, and adding the results of several more years of design and construction experience. One of the strengths and challenges of stream simulation is that it requires expertise in different technical fields. This guide does not teach all the technical concepts and methods needed for assessing, designing, and constructing a stream-simulation design channel and structure. Instead, it assumes that people skilled in engineering, hydrology, geomorphology, biology, and contract administration work together as a team throughout the stream-simulation process. The guide aims to help each member understand the challenges and considerations pertinent to the other disciplines, as well as to their own.

The publication, ***Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings***, consists of eight chapters and nine appendices. The first two chapters of the guide summarize the ecological consequences of habitat fragmentation

Figure 1. The replacement of the road-stream crossing structure on a tributary to the Middle Fork Salmon River (Olympic National Forest, Washington) using the stream-simulation approach. Upper Photo: Upstream view of the culvert outlet prior to replacement. The culvert was installed in the late 1950's, has a diameter of 1.83 m, a length of 27 m, and a gradient of 2.1 percent. The culvert outlet is perched 1.6 m above the pool. Middle Photo: Upstream view of the culvert outlet after the existing structure was replaced in October 2005. The open-bottom arch has a span of 5.49 m, a height of 2.25 m, a length of 29 m, and channel gradient of 4.1 percent. Lower Photo: The channel bed design through the structure contains a sequence of steps and pools, providing geomorphic continuity between the upstream and downstream channel.

caused by road-stream crossing barriers and outline the steps necessary for restoring ecological connectivity. Chapter 1, Ecological Considerations for Crossing Design, discusses the movement needs of aquatic species and the consequences of barriers to individual aquatic species and ecological communities. Chapter 2, Managing Roads for Continuity, briefly reviews the planning, design, construction, and monitoring practices that can address road-stream crossing barrier problems, including best management practices. This review is intended for land managers who participate in developing project objectives and make policy decisions that affect crossing projects.

Chapters 3 through 8 describe the steps or phases of a stream-simulation design project. The stream-simulation process is applicable to new and replacement crossings, and to crossing removals. Although the discussion focuses on forest roads, the stream-simulation concepts and techniques discussed are applicable to crossings on other parts of the transportation system such as trails, highways, and railroads. Chapter 3, Introduction to Stream Simulation, provides a general overview of the stream-simulation design process from collecting and interpreting site data, developing a stream-simulation design, and constructing a stream-simulation design.

Chapter 4, Initial Watershed and Reach Review, describes the importance of documenting large-scale natural processes and management activities influencing channel conditions and geomorphic processes at the crossing, the value of aquatic resources at the crossing within the context of the watershed, current and future transportation requirements, and past road maintenance issues at the site. During this step, the team conducts a rapid reconnaissance of the project reach to verify that the road-stream crossing is well located, identify site risks and hazards, and formulate preliminary project objectives.

Chapter 5, Site Assessment, describes the process of collecting and analyzing the geomorphic and other site data that are the basis for developing a stream-simulation design. A site assessment involves the collection of channel and floodplain data that extends at least 20-30 channel widths upstream and downstream of the crossing, well beyond the influence of the existing roadway and structure. The site assessment characterizes the spatial distribution of channel and floodplain features, range of channel gradients, type and stability of grade controls, range of pool scour depths, spacing and length of channel units, dimensions of the channel cross section at various flows, and size of particles comprising the channel upstream and downstream of the road-stream crossing. These data are essential for quantifying channel characteristics and interpreting fluvial processes and potential channel responses in the vicinity of the crossing.

Figure 2. Cover page of publication, ***Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings.***

Chapter 6, Stream-Simulation Design, shows practitioners how to use the site assessment information to design a road-stream crossing that contains a natural and dynamic channel through the structure. The stream-simulation design approach requires measurements of site specific channel characteristics in the adjacent natural channel to ensure that an appropriate reference reach can be identified. Identifying a reference reach is a key concept and component of stream simulation as it provides the natural template for designing a channel through the crossing and determining the size and embedment depth of the replacement structure. A stream-simulation design determines the preferred alignment for the roadway and structure, selects a design channel gradient that provides geomorphic continuity between the upstream and downstream channel, develops a channel design through the crossing that is similar to channel dimensions and characteristics as those in the reference reach, determines the structure embedment depth based on pool scour depths along the channel, and assesses the mobility/stability of particles in the design channel and hydraulic capacity of the replacement structure for a range of design floods.

Chapter 7, Final Design and Contract Preparation, discusses structural design and contract preparation. It includes making the final decision on structure type, as well as on materials and contract requirements that are unique or that may need more emphasis in stream-simulation projects. During this phase of the stream-simulation process the design team finalizes details for the design channel, verifies the engineering plans for both the crossing structure and roadway, and prepares the documents necessary for soliciting bids for construction. The design details discussed in this chapter are unique to stream simulation or require more emphasis because the projects are bigger and take longer to construct than traditional culverts.

Chapter 8, Stream-Simulation Construction, discusses the construction planning and implementation actions that are especially important to both the successful completion of stream-simulation projects and the protection of aquatic species and habitats during construction. This chapter offers field construction experience on stream-simulation projects and aims to help new practitioners avoid common mistakes.

This guide only briefly discusses the last phase of the stream-simulation design process, maintenance and monitoring. Monitoring is especially important on stream-simulation projects, as it is the only way to collect the information necessary to improve the stream-simulation approach for conducting site assessments, developing channel and structure designs, and constructing those designs in various types of channels and environments.

There are nine appendices included in this technical guide that provide useful background information on geomorphic principles, other culvert design methods for fish passage, estimating design flows at road-stream crossings, methods for analyzing streambed mobility and stability, channel grade control structures, additional tips for developing design details and preparing contracts, examples of different contract provisions, and a checklist for collecting site assessment data.

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings was developed by the Forest Service Stream Simulation Working Group. The principal authors are Robert A. Gubernick (Forest Service, Tongass National Forest), Daniel A. Cenderelli (Forest Service, Stream Systems Technology Center), Kozmo Ken Bates (private consultant), David Kim Johansen (Forest Service, Willamette and Siuslaw National Forests), and Scott D. Jackson (University of Massachusetts, Natural Resources and Environmental Conservation Extension Program). The contributing editor for this document is Kim Clarkin (Forest Service, San Dimas Technology and Development Center).

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Effects of Ski Slope Development on Stream Channel Morphology in Colorado

by Gabrielle C.L. David

The development of slopes for skiing involves tree-clearing, road construction, machine-grading, and snow-making, which in turn alters flow hydrology, geomorphic processes, and channel morphology in the watershed. These land-use activities in the watershed increase peak stream flow, water yield, sediment yield, and the size and quantity of sediment transported by the stream. The increase in discharge from tree-clearing and snow-making can cause bed coarsening, bank erosion, pool scour, and in extreme cases, incision of the channel. The increase in sedimentation from tree-clearing, roads, and machine-grading of slopes can cause channel-bed fining and infilling of pools, decreasing habitat quality and diversity for macroinvertebrates and fish. These potential channel changes interact in complex ways depending on the type, time, and extent of the land-use activity, underlying geology, channel characteristics and condition, and the type and density of vegetation adjacent to the channel.

The U.S. Department of Agriculture, Forest Service, Stream Systems Technology Center funded this study because of concern about the potential impacts of development on stream channels in national forest lands, where the majority of ski resorts are located. Channel morphology changes can decrease habitat diversity and water quality as the stream moves toward a new equilibrium. Understanding the combined effects of tree-clearing, road construction, machine-grading, and snow-making on fluvial processes and channel morphology can be used to develop better management practices to minimize those effects. Although each of these types of development has been studied individually, particularly the effects of tree-clearing and road construction, the combined effect of all four on channel morphology has not been investigated thoroughly.

Ski Slope Development Activities

Tree-clearing leads to a decrease in interception and transpiration, increasing the soil water content. The increase in soil water content results in higher water yields and peak flow in streams. Tree-clearing opens up large swaths of land to sunlight, affecting the rate of sublimation and snowmelt with north-facing slopes having a greater increase in water yields from tree-clearing than south-facing slopes because of a greater snowpack. Tree-clearing can also increase surface erosion and subsequently sediment yield in a basin during the initial phase of tree removal. As surfaces re-vegetate, the contribution of sediment from these areas decreases.

Forest roads increase overland flow and increase the drainage density of stream networks, leading to an earlier and larger peak flow. Drainage density is increased because the roads route the flow directly from water bars and ditches straight into the stream channel. Road cutbanks can also intercept slower moving subsurface flow, increasing the flow rate and changing the flow path of water being routed to the stream. The greater efficiency of flow being routed through the watershed increases the input of fine sediment to streams.

Machine-grading is the process of smoothing slopes by removing boulders, vegetation, and topsoil or adding material to swales. Machine-grading of ski slopes compacts the underlying material, decreasing its infiltration capacity and subsequently increasing runoff. Slopes in which topsoil has been removed by machine-grading are often not able to re-vegetate for long periods of time, increasing overland flow and sedimentation to the stream. Both machine-graded slopes and roads potentially have a persistent, long-term effect of increased flows and sedimentation to streams.

Snow-making is the process of mixing air and water in a snow gun under pressure and releasing it through a nozzle into the atmosphere. Artificial snow production can cause a variety of changes to the hydrology of the basin. Most artificial snow is found on cleared ski runs and is exposed to a greater amount of solar radiation than snow beneath a tree canopy, thereby allowing snowmelt to begin earlier and cause an earlier and larger peak flow in a stream. Conversely, the higher density of artificial snow because of its properties and compaction from grooming delays snowmelt.

Study Area and Methods

This study investigated the potential impacts of ski slope development on channel morphology using field data from 47 channel segments in or near the ski areas located in the White River National Forest and Arapaho-Roosevelt National Forest, central Colorado. The streams are confined, steep gradient, step-pool and cascade channels having low sinuosity and width to depth ratios. Vegetation along the channel banks consists mainly of pine, fir, aspen, and smaller shrubs such as willows, alder, and currants. The channel reaches are underlain by granitic or sedimentary rocks. The majority of precipitation falls in the form of snow during the winter months and is the major source of water to streams during spring snowmelt runoff.

Of the 47 stream reaches, 24 were project streams located on or immediately below ski slopes and 23 were reference streams located in watersheds with little to no development. To reduce variability between and within a reach, project and reference stream reaches selected were similar in slope aspect, gradient, confinement, elevation, geology, and vegetation. The channel variables measured were gradient, bankfull width, wetted perimeter, length of unstable banks, length of undercut banks, maximum depth of undercut banks, residual pool depth, channel-bed sediment size, and the number and size of instream wood. Vegetation was surveyed adjacent to the channels and stratified as overstory, understory, and ground cover. These variables were used in various statistical analyses (e.g., analysis of variance, analysis of covariance, analysis of similarity, classification and regression tree, cluster analysis, principal component analysis) to determine if there were any systematic differences between project and reference streams.

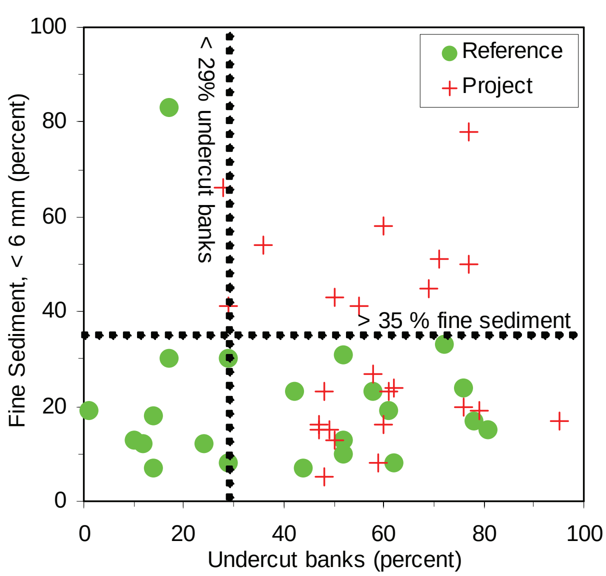

Figure 1. Relationship between project streams and reference streams for the variables of percent fine sediment and percent undercut banks.

Results and Discussion

The project streams differed significantly from reference streams for most of the channel variables measured. Of the channel morphological variables measured, percent fine sediment, percent undercut banks, and percent unstable banks differ most significantly between project and reference streams (fig. 1). Project streams had a greater range of percent fine sediment when compared to reference streams with many project streams having percent fine sediment exceeding 35 percent. All of the projects streams had percent undercut banks greater than 29 percent, whereas 22 of the 23 reference streams had percent fine sediment values less than 29 percent. Reference streams with percent undercut banks less than 29 percent and percent fine sediment less than 35 percent were larger, low-gradient streams with dense willow stands along the bank margins (fig. 1). The mixed population of reference and project streams with percent undercut banks greater than 29 percent and percent fine sediment less than 35 percent were generally smaller, high-gradient streams with dense willow stands (fig. 1). Streams flowing through materials derived from granitic bedrock have a higher percentage of fine sediment, undercut banks, and unstable banks when compared to streams flowing through material derived from sedimentary rocks, indicating streams in granitic material are more responsive to flow disturbances (fig. 2). Project streams underlain by granitic material, having steep gradients, and vegetated with a thicker spruce/fir overstory, but a low density of willow understory were found to have channel characteristics outside the range of variability of reference streams and are more sensitive to alterations in basin hydrology from ski slope development.

Figure 2. A comparison of undercut banks in reference streams and project streams flowing through material derived from granitic and sedimentary rocks. Upper left photo: Granitic material, reference stream. Lower left photo: Granitic material, project stream. Upper right photo: Sedimentary material, reference stream. Lower right photo: Sedimentary material, project stream.

The ski slope development variables that were most significantly related to changes in the stream channel were an increase in graded density, drainage density, and water yield. Water yield combines the effects from both tree-clearing and snow-making. An increase in water yield and drainage density were expected to cause project streams to have coarser beds and more deeply scoured pools than reference streams because of increased flow and sediment transport. However, many project streams were found to have a greater percentage of fine sediment when compared to reference streams, indicating that the input of sediment from roads and graded areas exceeded the increased transport capacity of the stream from higher peak flows and water yields.

The initial quantification of the effects of ski slope development on steep, headwater streams in the semiarid Rocky Mountains of Colorado suggests that development should be restricted or limited in catchments underlain by granitic geology and where stream corridors lack extensive stands of willows. Subsequent studies that apply the techniques discussed here to lower gradient streams and to other environments with ski slope development should prove useful in helping managers of natural resources to develop similar guidelines that identify stream catchments most likely to show changes in channel morphology as a result of ski slope development.

This article is adapted from the following publications:

- David, G.C.L. 2007. The impacts of ski slope development on stream channel morphology in the White River National Forest. Fort Collins, CO: Colorado State University. 219 p. Thesis.
- David, G.C.L.; Bledsoe, B.P.; Merritt, D.M.; Wohl, E. 2008. The impacts of ski slope development on stream channel morphology in the White River National Forest, Colorado, USA. Geomorphology. 103: 375-388.

Please refer to those publications for additional information and references.

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