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

Cover photo: Crooked River arch culvert on the Payette National Forest, Idaho. Installed 2006.

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by

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Preface

This is a guide to stream simulation—a method for designing and building road-stream crossings intended to permit free and unrestricted movements of any aquatic species. The guide aims to help national forests achieve their goal of maintaining the physical and biological integrity of the stream systems they manage, including existing populations of fish and other wildlife species (see National Forest Management Act, 16 U.S.C. 1600-1616). Habitat fragmentation is an important factor contributing to population declines of many fish, and crossing structures that are barriers are a large part of the problem. Stream simulation provides continuity through crossing structures, allowing all aquatic species present to move freely through them to access habitats, avoid adverse conditions, and seek food and mates. Stream simulation applies to crossing structures on any transportation network, including roads, trails, and railroads. For brevity, the guide refers to all of these types of transportation infrastructure as 'roads.'

Whether culverts or bridges, stream-simulation structures have a continuous streambed that mimics the slope, structure, and dimensions of the natural streambed. The premise of stream simulation is that since the simulation has very similar physical characteristics to the natural channel, aquatic species should experience no greater difficulty moving through it. Water depths and velocities are as diverse as those in a natural channel, providing passageways for all swimming or crawling aquatic species.

Work on this guide began in response to a set of project proposals from engineers and biologists concerned with designing culverts for anadromous fish passage in the Alaska, Pacific Northwest, and Northern Forest Service, U.S. Department of Agriculture regions. During the initial project scoping process, it became apparent that many other fish and nonfish species across the country are also harmed by passage barriers. At that point, the project's focus expanded from anadromous fish to all aquatic organisms. Stream simulation is the technology most likely to achieve the goal of aquatic organism passage.

The idea of creating crossings that mimic the stream is not new (Katapodis 2005), but the technique was developed in its now best-known form in the Washington Department of Fish and Wildlife's 1999 "Fish Passage Guidelines" (Bates 2003). The present guide builds on that foundation, expanding our understanding of stream simulation and adding the results of several more years of design and construction experience, much of it by Forest Service engineers, biologists, and geomorphologists. The intent is to meet the needs of the Forest Service for a flexible design process for aquatic organism passage at road-stream crossings. The guide is for project teams that include members from several disciplines. It aims to help each team member better understand the challenges and considerations pertinent to the other disciplines, as well as their own. Although organized to suit the project design, construction, and management processes of the Forest Service, the guidance should also be helpful for other groups.

Stream-simulation technology is relatively new and changing rapidly. The bulk of the experience reflected in this guide's content comes from Alaska, and the Pacific Northwest coastal and inland States. The guide's authors, editors, and reviewers encourage practitioners in other landscapes to adapt the methods described here to local stream processes, and to contribute their findings to the expanding collection of experience and guidelines. We anticipate great strides in our ability to effectively and efficiently simulate streams through crossings, as forests apply, monitor, and modify the technology in vastly different areas.

Acknowledgements

Many people have contributed to this guide in a variety of ways. What started as a relatively restricted task—to collect design recommendations from a small group of people experienced in stream simulation—grew into a more extensive guide that now includes topics on final engineering design and construction. Because stream simulation is a relatively new way of handling the restoration of stream ecosystems during road-stream crossing projects, unknowns and debatable issues remain. As this guide evolved, these gray areas required clarification through lively discussions, debates, critiques, and the patient support of too many people to name here. We, the editors and principal authors, thank all who participated in this process.

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Purpose of the Guide and Its Intended Audience

Words shown in bold throughout this document are defined in the glossary

The intent of this guide is to:

- Explain to land and road managers and a general audience:
  - Why providing stream continuity at road-stream crossings is critical for maintaining aquatic animal populations and habitats.
  - How stream simulation works to provide stream continuity at road-stream crossings.
- Guide practitioners working in multidisciplinary design teams through the assessment, design, and construction phases of a stream-simulation project.

Stream simulation is an approach to designing crossing structures (usually culverts), that creates a structure that is as similar as possible to the natural channel. When channel dimensions, slope, and **streambed structure** are similar, water velocities and depths also will be similar. Thus, the simulated channel should present no more of an obstacle to aquatic animals than the natural channel.

The first part of the guide (chapters 1 and 2) builds the case for stream continuity at crossings and gives a general overview of how to achieve continuity using stream-simulation methods. This part addresses a general audience, including managers responsible for roaded ecosystems. The remainder of the guide is for project teams responsible for either building a new crossing or replacing a crossing structure where full aquatic organism passage is a goal. This guide does not deal with the question of when full aquatic organism passage is necessary at a site. That decision depends on local policy and ecological needs.

Figure 1—Project team at a crossing site in New Hampshire.

The greatest challenge 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 designing and constructing a stream-simulation crossing. Rather, it assumes that people skilled in engineering, contract administration, hydrology, geomorphology, and biology work together as a team throughout the process. The guide aims to help each member understand the challenges and considerations pertinent to the other disciplines, as well as to their own. Although different specialists may take the lead at different times, the whole team should be available for consultation throughout the project.

Background

Streams and roads are long, linear networks whose functions include transporting material and organisms across the landscape. Being narrow and linear, both streams and roads are highly susceptible to blockages. The two systems frequently intersect, and at the junctions each can pose an obstacle to the other's continuity. In the past, most road-stream crossing design has aimed at protecting the road and minimizing traffic interruptions. Less attention has been given to protecting stream functions, such as sediment transport, fish and wildlife passage, or the movement of woody debris. Not surprisingly, many culverts disrupt the movement of aquatic organisms and impair aquatic habitats.

The numbers of road-stream junctions are huge. On National Forest System lands in Washington and Oregon, there are over 6,250 road-stream crossings on fish-bearing streams—approximately one crossing per every 3.6 miles of stream. According to Dave Heller, fishery biologist for the Pacific Northwest Region, in March 2004 about 90 percent of nonbridge (mostly culvert) crossings were considered to be at least partial barriers to anadromous fish passage. These barriers blocked about 15 percent of fish-bearing stream miles on national forest lands in the region (figure 2).

Until recently, where fish were a serious concern, designing culverts for passage of a target species (the "design fish") during its migration season was considered best practice. This practice, however, often does not achieve the best *ecological* results. For example, considerable resources have gone into facilitating passage of adult salmon and steelhead migrating to their spawning grounds, only for fishery biologists to find that accommodations made for adults did not even begin to cover the needs of juveniles of the same species. Sustaining a population demands that all life stages must succeed, and fry, juveniles, and adults have different movement needs and capabilities.

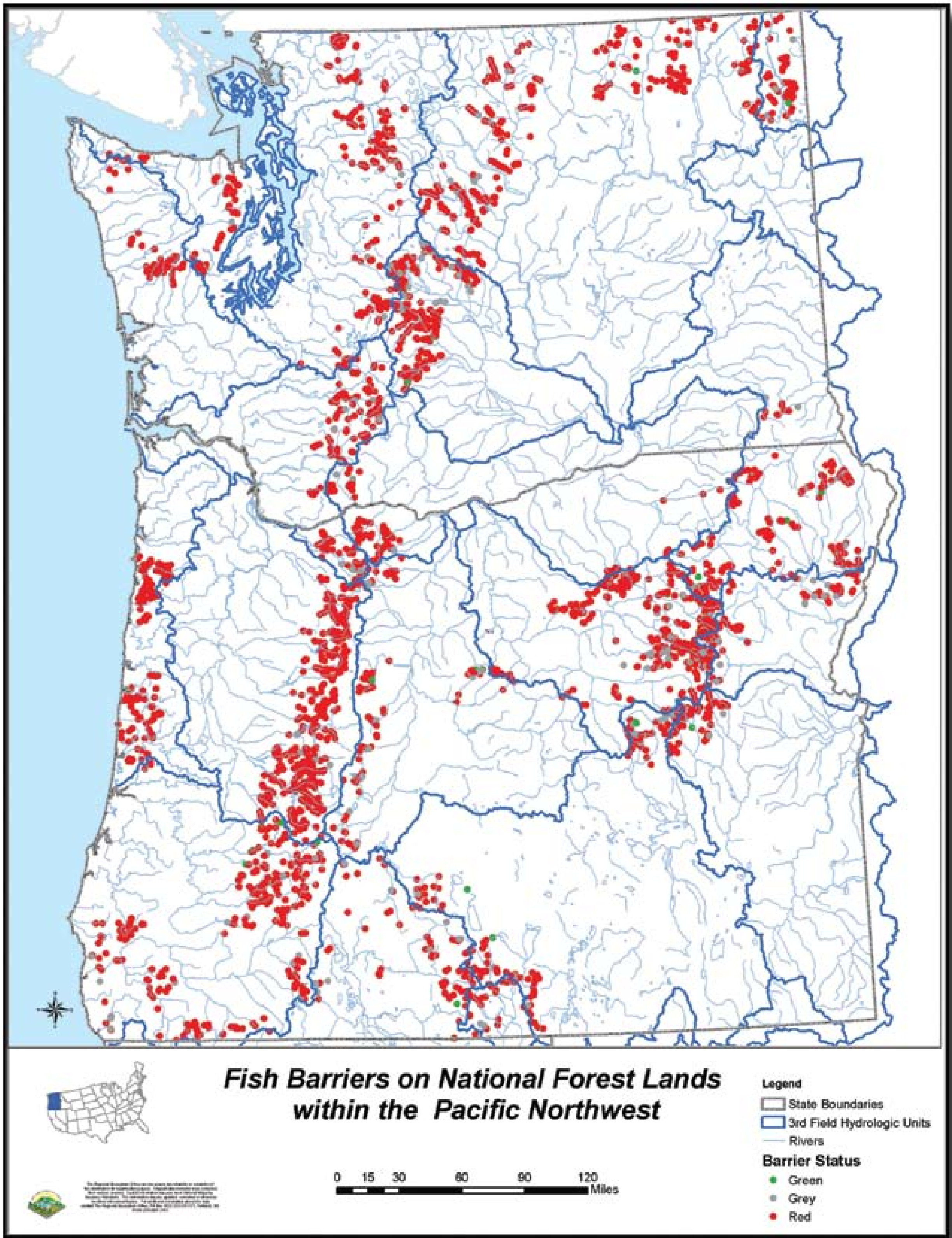

Figure 2—Forest Service Pacific Northwest Region map of road-stream crossing barrier status, 2005. Red dots indicate road-stream crossings that, at least partially, blocked passage of juvenile and/or adult anadromous salmonids.

As chapter 1 will show, focusing on a single desirable species is not enough: The entire aquatic ecosystem is linked, and all species depend on each other for food and other essential interactions. As survival of a "target species" depends on a healthy and diverse ecosystem, it is essential to focus on habitat quality and continuity for *aquatic communities* rather than for individual species. Without an ecosystem-based approach to road-stream crossings, we will be at risk of facilitating passage for particular fish species while at the same time undermining the ecological integrity of the ecosystems on which these fish depend.

Figure 3. Culvert on the Boise National Forest prevents migration of kokanee salmon.

Stream simulation supports the ecosystem-based approach to road-stream crossing design and aims to provide full aquatic organism passage; that is, all aquatic and semiaquatic species should be able to travel through the crossing structure with no greater impediment than the natural channel would offer. The crossing, therefore, acts as neither a barrier nor a filter that passes only certain individuals, species, or age groups (life stages). Moreover, because a stream-simulation crossing accommodates the full channel width, it does not impede the downstream transport of floodwater, sediment, or woody debris as much as narrower, traditional culverts do. Stream simulation thus provides for not only the long-term sustainability of the entire aquatic community, but also a more durable roadway that is less susceptible to damage by high flows and **debris** blockage.

Structure and Scope of the Guide

The first two chapters of this guide summarize the ecological consequences of habitat fragmentation caused by road-stream crossing barriers, and outline the steps necessary for restoring connectivity. These chapters answer the following two questions: Why is stream continuity at road-stream crossings important? and, How do we create it? Managers faced with making fiscally significant decisions about providing habitat connectivity at crossings should find these chapters especially useful.

Chapter 1, Ecological Cosiderations for Crossing Design, discusses when and why aquatic species need to move, what they require to be able to move, and what the consequences of barriers to individuals, populations, and communities are. Biologists should note that this guide does not describe how to determine where, when, or for which species passage is required. This guide also does not cover setting priorities for barrier removal.

Chapter 2, Managing Roads for Continuity, is a very brief overview of the planning, design, construction, and monitoring practices that can solve road-stream crossing barrier problems, including best management practices (**BMPs**). This overview is intended for land managers who participate in setting project objectives and making policy decisions that affect crossing projects. The chapter places stream simulation in context within a range of crossing design approaches.

The next six chapters describe the steps or phases of a stream-simulation design project. The process is applicable to new and replacement crossings, and to crossing removals. The focus is on forest roads; however, the concepts and general approach are applicable to crossings on other parts of the transportation system such as trails, highways, and railroads.

Chapters 3 through 8 are addressed to members of multidisciplinary project teams responsible for the assessment, design, and construction of road-stream crossings. Readers who are unfamiliar with stream morphology and processes can refer to appendix A for a brief introduction to geomorphic terms and concepts used throughout the assessment and design process.

Chapter 3, Introduction to Stream Simulation, provides an overview of the process of stream-simulation design and construction. It defines and describes stream simulation and discusses limitations on its application.

Since this guide is intended as a reference, the descriptions of each phase of a stream-simulation project are comprehensive, including many complicating circumstances that may or may not pertain to a specific project. On any actual project, only factors and issues relevant to that project need to be considered. The level of detail in the assessment and design process should depend on the size, complexity, and risk of the project. Once teams gain experience, they can tailor the design process to the needs of each site.

Chapter 4, Initial Watershed and Reach Review, describes the large-scale assessments of watershed and aquatic resources and transportation needs that provide context for the project. At this stage, the project team takes a look at the "big picture." The team also conducts a rapid reconnaissance of the **project reach** to verify that the road and crossing are well located, to identify risks, and to 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 stream-simulation design.

Chapter 6, Stream-Simulation Design, shows practitioners how to use the assessment information in designing the simulated channel through the road-stream crossing. Note: To cover many road and stream settings with the design procedure, the authors have synthesized many years of experience in stream-simulation design and consulted experts throughout the country. Nonetheless, the guide primarily reflects experience in the Inland and Pacific Northwest. The technology is still in development. While culverts up to 15-percent slope have been constructed with these methods, such methods have not been used extensively on very low-gradient streams in fine sediments, cohesive soils, or densely vegetated streambeds.

Chapters 7 and 8 describe the final engineering design and construction phases. They are primarily directed to the project engineer and contract administrator, but all team members should find the material useful for understanding the elements and process of final design and construction. Consultation with the entire project team is essential in these final phases, especially when contract changes become necessary.

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.

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

This guide does not deal in detail with the last phase of all road-stream crossing projects—maintenance and monitoring (a brief discussion is in section 8.3.2). Monitoring is especially important on stream-simulation projects, since it is the only way to collect the information necessary for continually improving crossing design and construction practices. This guide is not the last word in this rapidly evolving field, and the authors anticipate with enthusiasm the growth of knowledge and experience that application of these principles in different environments will bring.

A glossary and a series of appendixes appear at the end of this guide. The glossary will be particularly useful for understanding terms used by a discipline in which the reader may not be well versed. As the material in certain chapters is directed towards team members with specific expertise, definitions of terms common within the discipline under discussion may not appear in the text. The glossary is therefore quite comprehensive, and readers should make good use of it.