STREAM SYSTEMS TECHNOLOGY CENTER

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station **April 1999**

Channel Maintenance Considerations in Hydropower Relicensing

by J.P. Potyondy & E.D. Andrews

Over 250 hydroelectric projects were licensed and constructed on the National Forests during the 1940s and 1950s. Although hydropower has played an important role in economic development, many projects have caused significant unanticipated adverse impacts to National Forest resources. During the next 10 years, many of these projects will be relicensed by the Federal Energy Regulatory Commission (FERC). The forthcoming relicensing will be especially important because the standards and rules governing new operating license were changed by the Electric Consumer Protection Act of 1986. In the future, the operation of hydropower facilities must consider impacts to federal lands and resources when a license is issued. The relicensing process affords the Forest Service a unique opportunity to assess and possibly eliminate or mitigate the negative environmental impacts of these facilities.

A thorough understanding of the impacts that the existing and alternative flow regimes may have on the downstream physical characteristics of the channel is essential during consideration of a new license. Channel morphology, especially the stability of channel banks and riparian vegetation, bed-material composition, water table influences, and bedload transport can be important issues. Understanding channel change is important because the condition of the channel directly influences the biological sustainability of aquatic and riparian ecosystems.

Existing channels below hydropower facilities are frequently damaged due to either too much or too little water. Although the impact to a given site is highly variable and site dependent, a desired goal for the downstream channel is to reestablish proper channel function and thus assure channel maintenance. On National Forests, a key objective is to manage regulated rivers to mimic natural geomorphic processes to the greatest extent feasible.

Proper channel function enables the Forest Service to meet in part the "favorable conditions of water flows" reservation purpose of the Organic Administration Act. Forest Land and Resources Management Plans provide additional guidance for protecting and improving resource values. These plans often identify resource objectives that may require modifications to regulated flow regimes to achieve multiple use purposes such as sustaining fisheries, providing recreational opportunity, or maintaining riparian vegetation.

Channel maintenance flow regimes must meet the following criteria to achieve the desired properly functioning condition:

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1. Move bed-material to maintain a long-term sediment balance;
2. Maintain streamside vegetation and the structural stability of streambanks; and
3. Prevent vegetation encroachment in the channel.

In summary, an analysis of flow and bedload sediment must be conducted to assure sufficient sediment is conveyed to maintain channel capacity and prevent adverse impacts to banks and riparian vegetation from sediment accumulation in the channel.

The objective of geomorphic analysis during the relicensing process, therefore, is to analyze the existing sediment and flow regime to understand the existing condition and predict changes to the downstream channel under a variety of alternative flow regimes. Major factors to consider include: (1) Channel characteristics, (2) the operational hydrology (flow regime), and (3) the sediment regime.

Channel Characteristics

A stream classification system is beneficial to begin to understand the physical characteristics of stream channels involved in a relicensing project (Figure 1). Classification schemes developed by Rosgen (1996) or Montgomery and Buffington (1997) are examples. Mapping the spatial distribution of stream types allows for a focused analysis of sensitive reaches.

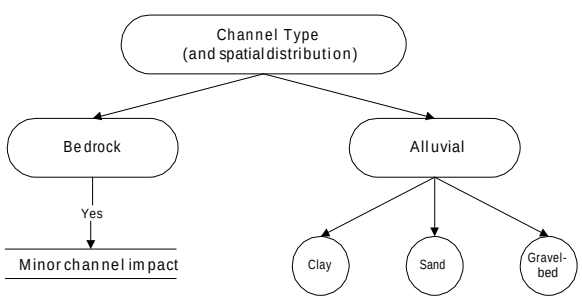

Figure 1. Channel characteristics.

Many hydropower projects are situated on bedrock-controlled reaches of streams. Such channels are inherently stable and are less susceptible to alteration. Under certain circumstances, however, impacts on bedrock stream channels can be quite dramatic, e.g., where the hydroelectric facility significantly reduces peak discharges while tributaries continue to supply large quantities of coarse sediment.

Alluvial channels by contrast are more adjustable. Nevertheless, gradients of adjustability exist for different stream types. For example, sand-bed channels are inherently more sensitive to change than gravel or cobble-bed rivers, while a different suite of channel processes operate in alluvial channels with cohesive clay banks.

Recognizing the major channel types and materials is especially important for the selection of appropriate sediment transport models. For example, the Ackers and White bedload transport equation (Ackers and White, 1973) is appropriate for sand-bed channels while the Parker equation (Parker, 1990) is best suited for gravel-bed rivers. A procedure for applying the Parker equation to the design of channel maintenance flows in gravel-bed rivers is illustrated in Andrews and Nankervis (1995).

Operational Hydrology

The water impounding structure and operational hydrology will typically have a significant effect on downstream impacts (Figure 2). In general, unregulated flows (run-of-the-river projects) will have fewer significant impacts and are more easily analyzed for channel maintenance flows. In contrast, projects which divert flows frequently have severe impacts. In such schemes, flow in the natural channel is diverted off-stream to the power generating facility with a diversion dam. These designs generally utilize flow from the diversion for as long as possible, limited by plant hydraulic capacity and energy demand. The impact of regulated flow systems is directly related to the size of the dam and the operation of the facility. Larger dams have the capacity to store almost all of the flow while smaller structures generally store and regulate a smaller percentage of the annual volume. Dams used for power peaking have the potential to be most destructive and issues related to ramping rates need to be

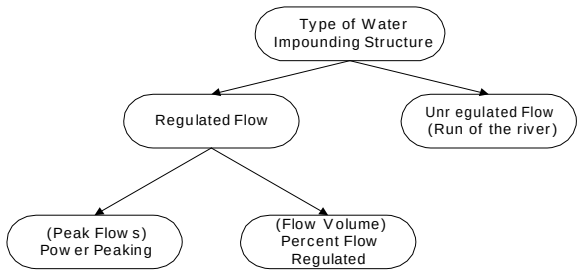

Figure 2. Flow considerations.

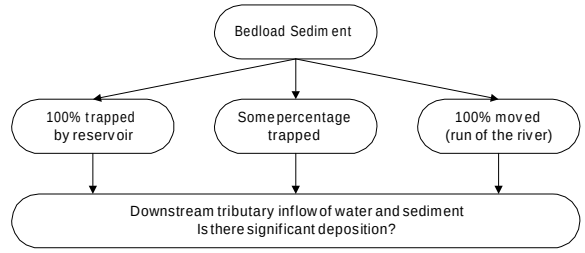

Figure 3. Bedload sediment considerations.

In all cases, the operational hydrology needs to be understood and analyzed. The "stop-and-go" nature of the flow regime compared to natural conditions changes flood hydrographs, sediment transport regimes, and alters channel morphology. It is crucial to understand when, how, and what magnitude of flows are diverted and recognize the range of usable flows that the facility accommodates.

Streamflow data are essential during the consideration of a new hydropower license. If streamflow data is unavailable, stream gages should be established as soon as possible. Streamflow data may be available from the project proponent. Streamflow analysis typically relies on developing existing and pre-project flow duration curves based on mean daily flows and analyzing low flow and peak flow frequencies. The Indicators of Hydrologic Alteration (IHA) analysis approach and software (Richter et al., 1996; see also STREAM NOTES, January 1999) is a tool for summarizing numerous hydrologic flow parameters and displaying changes to the hydrologic regime.

Sediment Regime

The several landforms, e.g., riffles, pools, point bars, etc., that make up a floodplain and river channel are composed of various sediment particle sizes. Typically, a hydroelectric facility will alter the supply and transport of the relatively fine sediment sizes differently than the coarse sediment sizes. The extent and stability of a landform will be impacted when the transport of the associated particle sizes is altered. The magnitude of channel response is largely a result of coarse sediment (bedload) trapped by the dam (Figure 3).

On the one extreme are run-of-the-river facilities that allow passage of all of the bedload sediment in the river. This is a common situation for small hydropower projects. The most probable response in the diverted reach with water removal is a decrease in channel size (aggradation) and an increase in surface/subsurface fines.

At the other extreme are structures that trap all of the bedload. The most common response with water removal is the "hungry water" phenomenon where clean water picks up sediment resulting in an increase in channel size (incision) and/or removal of gravels and fines (armoring).

Between these extremes are a vast array of complex, highly variable responses. These are due to the many possible combinations of altered sediment (changes in volume or size) and water discharge (changes in duration, timing, peak flows or volumes of flow) that are possible at hydropower facilities. While general response may be predicted, every river is unique. In the majority of instances, the site-specific circumstances of a project must be analyzed in detail. Numerous independent watershed variables (e.g., rainfall, geology, vegetation type, land use) combine in countless ways to produce different flow and sediment regimes. Numerous dependent channel variables (e.g., width, depth, bedforms, sediment transport) also adjust in many different combinations to any given regime. In addition, hydropower plant operating schemes and the physical layout of the facility and the stream environment are extremely variable.

A final important consideration in analyzing the sediment situation is the influence of downstream

tributary inflow of water and sediment to the by-pass reach. Generally, the critical location is the first major tributary below the dam. Other important factors to consider are the location of the tributary input with respect to accretion flows, the amount and size of material coming from the tributary, and the desyncronization of tributary inflow with the mainstem.

It is important to recognize that it is often impossible to restore channels to their pre-project condition simply by changing the flow regime. Novel approaches may be necessary to achieve satisfactory sediment balance. For example, lack of sediment input immediately below the dam may severely limit the rebuilding of channel banks and floodplains. Likewise, a goal of recapturing spawning habitat may be unattainable without artificial, annual introductions of gravel into the system.

Analysis Process

The technical analysis for hydropower relicensing can be very complicated. The following basic steps are suggested:

1. Determine **unimpacted** (baseline) conditions (flow, sediment, channel conditions) above project or pre-project.
2. Evaluate **existing** (current) conditions (below project).
3. Consider alternative **post-project** conditions.

Detailed flow and sediment information is essential to support any changes to the flow regime that might be proposed by the Forest Service to FERC. Three years of continuous streamflow record and at least 20 samples of bedload and suspended sediment over the full range of flows, including those above bankfull, are typically the minimum required during the relicensing process. This basic information is needed to validate any sediment transport modeling, understand local hydrology, and support flow change recommendations that may result. In many cases, specialized technical skills in sediment transport measurement and analysis will be required.

The need to build an adequate administrative and scientific record which contains "substantial evidence" of the facts supporting requested flow changes was reinforced by the *Bangor Hydro* decision on FERC relicensing (Pizzi, 1997). Well designed studies that link scientific evidence to management decisions are increasingly important for agencies to successfully recommend and implement flow changes designed to improve the adverse channel conditions that exist at many hydropower facilities.

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Habitat Modeling Not Enough to Save Fish ... or Rivers

by Sheri Woo

Interior Secretary Bruce Babbitt says he is trading in his fishing rod for a sledgehammer, "to celebrate destruction of dams." Okay, dam removal probably is the best way to restore rivers. I would love to see a dam blasted to bits, followed by a surge of impounded water pounding against relic river banks. But really, we can apply Edward Abbey's "monkey-wrench" to only a few selected dams, given our dependence on irrigated agriculture and hydroelectric power.

If we're serious about restoring river ecosystems, we need to answer two questions. First, how do biologists and engineers decide how much water a river "gets" after hydropower or agriculture diversions? And second, why do many of these same biologist and engineers – who are dedicated to preserving and protecting salmonid species – believe that they may have unwittingly hastened the decline in river ecosystem health?

In a recent ***Fisheries*** journal, (August 1996) twelve fisheries biologists sharply criticized a methodology, called the IFIM (Instream Flow Incremental Methodology). Biologists use the IFIM as a blueprint, or procedure, to decide how much water should be left in a river. The twelve scientists wrote "Our claim that there is now no scientifically defensible method for defining flow ... implies that … the IFIM is not such a method."

If you want to tick off a biologist, tell him his work is unscientific (or as it was gently phrased, "[not] scientifically defensible.") The authors knew they would raise the hackles of the fisheries scientific community. Consider: according to a 1991 U.S. Fish and Wildlife Survey, 71% of all water diversions were evaluated through the IFIM, in their Region 1, covering California, Nevada, Oregon, Washington, and Idaho. In other words, a lot of fisheries professionals are using the IFIM.

Since the mid-1980s, fisheries undergraduates learned the basics of the IFIM. For those who missed it in college, IFIM short-courses are available, and the present demand is higher than ever. And the use of IFIM is not limited to federal agencies; the environmental impact of any water diversion on most any stream or river in the western U.S. was likely evaluated through the IFIM.

But while intentionally shooting down many of their peers, the twelve authors should have lined up the crosshairs more precisely on target. It's not the IFIM procedure itself, but the misuse of the IFIM that should be under attack. To be even more precise, it's the substitution of a computer model, the PHABSIM (Physical Habitat Simulation System) for the entire IFIM procedure.

Whoa, overload on acronyms? Here's an analogy.

You have just smoothed your cloth napkin over your lap, anticipating a nine-course culinary experience. After reading "Tonight's Menu," you can almost taste the aperitifs, the bread, the soup, and the cleansing sorbet, not to mention the dessert and cheeses. With a flourish, your maitre'd and head waiter present … the second entrée. "Hey, where's the rest?"

If IFIM is the menu, PHABSIM is the second entre. That is, the IFIM is a plan of studies crafted by an interdisciplinary scientific team (including engineers, geologists, botanists, and fisheries biologists). The PHABSIM computer model is just one "course" of the complete IFIM "menu." Sure, the PHABSIM took many chefs much time to prepare, but it is just one course. The problem is that many fisheries biologists believe that only the second entrée is necessary and that the computer model is sufficient for recommending

environmentally "safe" river flows. Even the "IFIM Primer" (the handbook of the IFIM short-courses) states, "Many people confuse IFIM with the PHABSIM." Fisheries biologists run the PHABSIM model and believe they've performed the IFIM.

Well, so what? Is this just a bunch of academics throwing a hissy-fit?

No, because many scientists now believe that misuse of the IFIM has actually hastened the decline in river ecosystem health throughout the western U.S. The model's results allow fisheries biologists to recommend flows that are too low, and too uniform, such that river ecosystems can not be maintained. Dr. Clair Stalnaker is a "Founding Father" of the IFIM, working with the U.S. Geological Survey in Fort Collins, Colorado. I asked him to put the misuse of IFIM into perspective, considering other fish problems, such as water pollution, ocean over-fishing, or introduced predator species. Dr. Stalnaker said, "On big alluvial rivers, it [IFIM misuse] has been devastating."

Like wines, channel maintenance flow studies are somewhat subjective, open to interpretation and discussion. Like wines, they require experience

What's so devastating about low, uniform river flows? Let's do some armchair fieldwork. Picture yourself leaning over a bridge handrail, during a small flood. Not the kind of flood that carries away the bridge, but enough for us to comment, "Wow, the water's really up." Now picture the gravel and sand in the river – it's all moving, and in fact we can hear the "clunks" of heavier gravel and rocks bumping along the river bottom. The sand becomes suspended. As the flood develops, peaks, and ebbs, first the sand moves, then slightly larger gravel becomes mobile, and at the peak of this small flood, larger rocks are carried along. As the water recedes, heavy rocks settle first, then the gravel, and finally the sand.

When we see the S-shape of a river, with water flowing around river bars of rock, gravel and sand, we're looking at "the aftermath" of a flood. Without movement and deposition of the gravel, rocks, and sand, we wouldn't have sunny picnic spots on the river bars, nor the deep swimming holes scoured from behind large boulders. High flows are natural events, allowing the river to be in "dynamic equilibrium," meaning that the water and sediment move, yet the river form or shape remains the same. (Okay, now we can go back inside and warm up.)

Without high flows, riparian plants grow to the water's edge, and the plants' roots hold the rock and soil in place. Only high flows can rip out the plants, by setting the whole river bar in motion. If high flow water is diverted into storage ponds for irrigation or consumption later in the year, the riparian plants grow unchecked, and the stream banks become immobile, choked with stands of riparian bushes and trees. That's great if you're an animal that thrives in dense riparian forest.

But that's not so great for many other animals – notably the threatened coho salmon or the endangered Columbia River chinook.

And besides high flows, a river needs variable flows to create a number of habitats. For example, low flows provide "still water" areas for juvenile fish and aquatic insects. Medium flows uproot seedlings, allowing small mammals and birds to roam in open riparian areas. High flows flush out fine sand while mobilizing the river bars, creating "cleaner" spawning gravel, as well as open, sunny picnic spots. The result is a variable and complex river ecosystem, a "habitat smorgasbord" offering something for everyone.

How can we obtain this "habitat smorgasbord"? If the PHABSIM model encourages scientists to recommend flows that are too low and uniform, how can scientists recommend flows that will be sufficiently high and variable? Through a new kind of study which river ecologists call "channel maintenance flow studies."

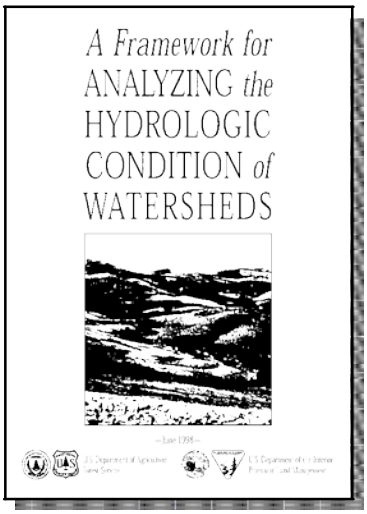
If IFIM is the menu, and PHABSIM modeling is the second entrée, then channel maintenance flow studies are the wines of our nine-course riverine feast. Like wines, channel maintenance flow studies are somewhat subjective, open to interpretation and discussion.

Like wines, they require experience (field experience) so that the ecologists can fully appreciate the complexity of river processes. And, stretching our dinner analogy a bit further, channel maintenance studies raise the tone and quality of the entire menu, that is, of the complete IFIM method.

You wouldn't serve a fancy meal without wine, and you shouldn't present an IFIM without a channel maintenance flow study.

Sheri Woo is a registered civil engineer and science writer, specializing in environmental engineering and natural resources. Her goal is to demystify scientific jargon for the general public, so that environmental policies are made by informed citizens and not by the scientific and political elite. She lives in Humboldt County, California.

This is an abbreviated version of two articles, "Dams Hastened Decline of River Ecosystem Health Throughout Western U.S." and "The Trinity River Train Gathers Steam, But Will Fish Be Onboard?" originally published in December 1998 and January 1999 in **U.S. Water News** and reprinted with permission.



A Framework for ANALYZING *the* HYDROLOGIC CONDITION *of* WATERSHEDS

by Bruce McCammon, John Rector, and Karl Gebhardt

The Bureau of Land Management and the Forest Service have developed a national framework for comprehensive interdisciplinary watershed analysis. Hydrologic condition analysis requires, among other things, obtaining information about precipitation, ground cover, vegetation, soils, geology, runoff, channels, floodplains, and riparian areas for each watershed. The analysis results in an understanding of the interrelationships among meteorological, surface and ground-water, and physical and biological factors that influence the flow, quality, and/or timing of water. The guidance outlines a process for identifying the essential factors needed to describe hydrologic conditions, with the flexibility to address site-specific characteristics.

The document can be viewed and downloaded from the STREAM Web Page (www.stream.fs.fed.us). Printed copies are available from the BLM's Printed Materials Distribution Section (303) 236-1975 or fax requests to (303) 236-0845.

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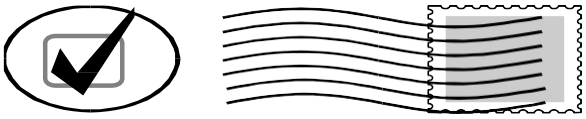

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