Adapting Adaptive Management for Testing the Effectiveness of Stream Restoration: An Intensively Monitored Watershed Example

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ADAPTING ADAPTIVE MANAGEMENT FOR TESTING THE EFFECTIVENESS OF STREAM RESTORATION: AN INTENSIVELY MONITORED WATERSHED EXAMPLE

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A large effort is underway to test the effectiveness of stream restoration in the Pacific Northwest using intensively monitored watersheds (IMWs) to improve salmonid habitat with the expectation to increase salmonid production (Bennett et al. 2016). How, or whether, stream restoration can improve target salmonid populations and ecosystem functions remains equivocal despite the enormous efforts that have been expended in implementation of projects throughout North America (Bernhardt et al. 2005; Roni et al. 2008). Restoration efforts applied under adaptive management (AM) frameworks will likely be the most efficient way to better understand the effectiveness of stream restoration, promote accountability within the restoration community and document restoration effectiveness that will guide future restoration strategies (Downs and Kondolf 2002; Rieman et al. 2015). Yet, AM remains underutilized or misapplied in restoration (Allen and Gunderson 2011), and we suspect that this stems from a misunderstanding of what AM is and where it is appropriate to apply and/or a perceived difficulty in developing the framework.

Our goal in this essay is to clarify the application of AM and to promote its use in IMWs and restoration projects in general. We briefly review what AM is, the different approaches to implementing AM, and the key elements common to AM. We then provide an example of how we are using AM to test the effectiveness of adding large woody debris (LWD) to increase habitat complexity and increase production of steelhead *Oncorhynchus mykiss* in the Asotin Creek IMW in Washington.

Adaptive management is an iterative, structured way of "learning by doing," where testing of uncertain outcomes to management actions occurs while making progress toward broader management goals (Walters and Holling 1990). All AM

approaches have a similar iterative cycle: plan, do, evaluate and learn (Figure 1). The hallmark of AM is the flexibility to "adjust" either the plan or the actions based on an explicit evaluation and learning step, the "adjust" feedback loop (Figure 1). However, management adjustments without structured prediction of consequences and testing of those predictions with data derived from purposeful monitoring is just trial and error, which has lower potential for learning than AM (Allen et al. 2011).

A common delineation of AM approaches is passive versus active (Williams 2011). Passive AM uses existing knowledge and models to describe the most likely action to achieve management objectives—learning is an unintended consequence. Active AM implements actions with the goal to maximize learning or reduce uncertainties that will inform future management actions (Sabine et al. 2004). Hence, active AM is the most appropriate approach for IMWs to use because the goal of IMWs is to determine the effectiveness of restoration and the causal mechanisms of responses (i.e., learn) and to inform future restoration throughout the Pacific Northwest. Other dichotomies have been suggested to categorize different AM approaches (McFadden et al. 2011), but we feel that by emphasizing the elements common to all AM approaches and providing a clear example at the scale many management decisions are made (i.e., watershed scale), we can demonstrate how AM can maximize learning from all restoration projects.

The key elements of AM are stakeholder involvement, development of management objectives, identification of alternative management strategies, models of system function and key uncertainties, and a priori hypotheses of how management strategies will achieve their objectives, monitoring,
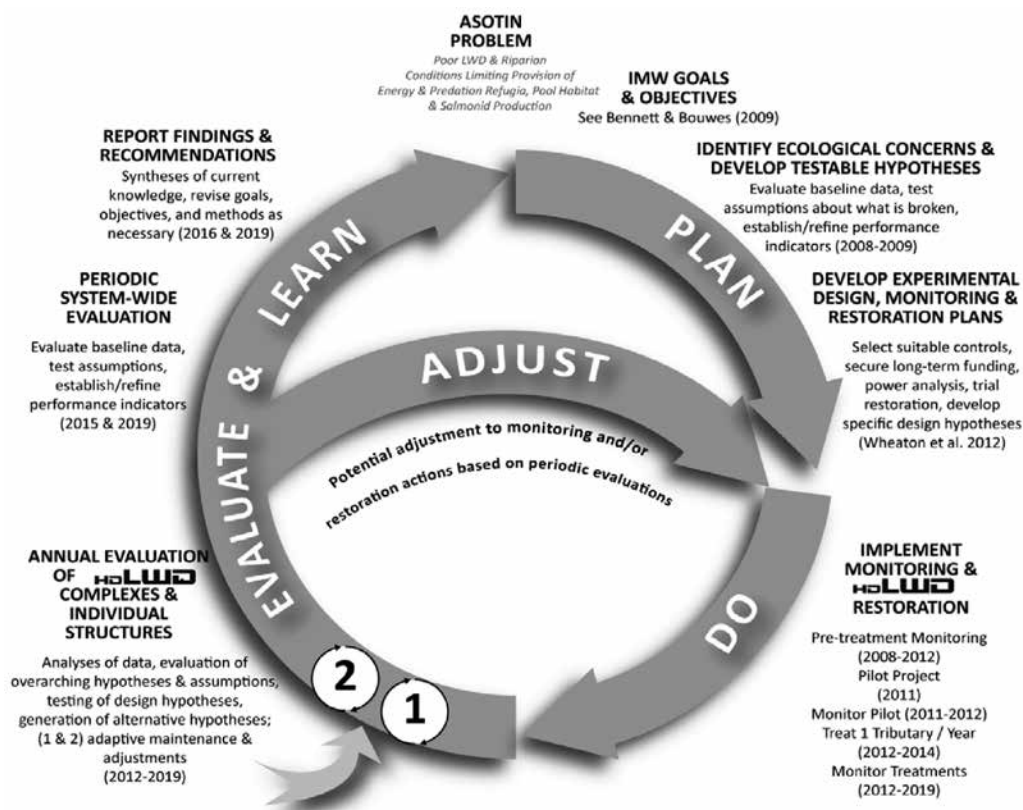

Figure 1. Primary adaptive management loop for Asotin Creek intensively monitored watershed (IMW). During the evaluation phase, detailed subloops are entered for (1) evaluation of individual large woody debris (LWD) structures (see Figure 4) and (2) how they work together as in the high-density large woody debris approach (HDLWD; see Figure 5).

and evaluation (Sabine et al. 2004; Williams et al. 2009). In the Columbia River Basin, much of the planning phase of AM has been initiated or completed within the context of salmon and steelhead recovery. Therefore, stakeholder involvement is often high, management objectives may already be defined (e.g., increase pool frequency by 50%), and management actions prescribed (e.g., establish 50 km of riparian buffers) that can be immediately incorporated into the AM process.

We suspect that many managers do not implement AM because they think that complex modeling is a prerequisite. Originally, complex modeling was encouraged in AM to help describe a study system, reduce uncertainties, and identify management strategies to test (e.g., Holling 1978; Walters 1986). However, often the ecological response cannot be predicted with current levels of knowledge or simulation models, or the funds and expertise to create meaningful ecosystem models are not available (Downs and Kondolf 2002). Experiments, directed studies, and intensive monitoring can compensate for not developing complex system models by (1) identifying mechanisms of responses to management actions to quantify parameter values lacking in the initial conceptual models, (2) identifying the causal mechanisms of responses to improve the ability to extrapolate learning to other locations, and (3) maximizing the chances of detecting harm and providing corrective adjustments should the actions not work. Prior to implementing restoration, a decision process of what conditions will be used to trigger potential adjustments to management should be articulated to help prevent the AM process from turning into the trial-and-error approach.

We focus on the AM steps that involve development of conceptual models, testable hypotheses, evaluation, learning, and a structured approach to adjustments because they are critical to maximize learning and these steps have not been implemented in many projects that purport to use AM (Gregory et al. 2006; Allen and Gunderson 2011). Our hope is that this example highlights that AM can be implemented in a relatively simple fashion and that it is tractable for IMWs and most restoration projects but still maximizes the opportunities for success and learning. Below, we describe the steps we followed in developing and implementing an AM plan for the Asotin Creek IMW. Asotin Creek is a direct tributary to the Snake River approximately 5 km upstream of Clarkston, Washington. The Asotin Creek IMW has added LWD to 4-km-long treatment sections within three tributaries to Asotin Creek (hereafter referred to as study creeks) and will be comparing the response of fish and habitat in two 4-km-long control sections in each study creek. The restoration uses a high density of hand-built LWD structures (i.e., ~135–208 structures within each treatment section) to minimize disturbance of recovering riparian vegetation and test the effect of many low-cost structures compared to a few expensive and hard-engineered structures.

PLANNING

During the planning phase we worked with the Snake River Salmon Recovery Board and their partners and used existing watershed assessments and literature reviews to identify the "problem(s)" in Asotin Creek (Figure 1). We followed up with our own field studies to corroborate previous assessments and identified simplified riparian and stream habitat, mainly from the lack of LWD, as the key ecological concern. We then developed an experimental design, monitoring, and restoration plan and detailed hypotheses to test the effects of LWD on hydraulic and geomorphic conditions and subsequently fish production

(snakeriverboard.org/wpi/library/reports).

A primary goal of management in Asotin Creek is to increase the production of wild steelhead to a level considered recovered and sustainable under the Endangered Species Act. Restoration actions in the 1990s focused on modifying upland farming practices to reduce sediment inputs into the stream and protecting and rehabilitating riparian areas. Inputs of sediment appear to have decreased and riparian areas are recovering; however, it will likely take several decades before instream habitat conditions improve and perhaps longer for fish populations to respond. Therefore, the objective of the restoration tested in the IMW is to use an active short-term, strategic restoration intervention with LWD structures to cause immediate hydraulic and short-term geomorphic responses that will increase velocity refugia, pool habitat, geomorphic diversity, bar development and sorting, and lateral exchange (i.e., floodplain connection). The hope and hypothesis is that this active intervention is a big enough disturbance to knock the system out of its stable degraded state and put it on a trajectory where passive recovery and natural recruitment of LWD take over. The IMW experiment will assess this active restoration strategy to provide immediate benefits to steelhead production.

We developed conceptual models for several aspects of stream dynamics and steelhead population life history. Figure 2 captures one example of a conceptual model of stream function. We used such models to help define testable hypotheses and highlight key uncertainties. The study creeks are bordered by relatively homogenous riparian age and species structure, which likely reflects a steady recovery following cessation and/or reduction in some of the previous land disturbances (e.g., logging, grazing, and/or floods). Unfortunately, this recovery has taken place around a heavily altered and relatively homogenized channel and has acted to stabilize the degraded condition of the channel. The current hydraulic and riparian conditions support the stability of this degraded state (Figure 2). We believe that the study creeks are locked in a state of low channel complexity due to a combination of a stable riparian corridor, an armored bed, and relatively modest mean annual floods that prevent the creeks from shifting to more dynamic, complex, but resilient states. Even when rare large floods do occur the creeks quickly revert back to degraded conditions. This conceptual model predicts that after the installation of a large number of LWD structures, floods of various magnitudes will promote recovery to a dynamic situation of switching between multiple stable states that have a more complex array of hydraulic and geomorphic features (Figure 2).

From the management objectives and conceptual models, we developed an extensive set of hydraulic and geomorphic design hypotheses for each type of LWD structure used in the restoration (e.g., Figure 3) and for the entire complex of LWD structures. We then generated a set of hypothesized fish responses based on the predicted habitat changes. For example, we demonstrated with hydraulic models based on current and restored channel topography (based on hypothesized responses) that eddy and scour pools would develop downstream of LWD deflector structures (Wall et al. 2016). We then used net rate of energy intake models to predict that these geomorphic and hydraulic responses would create "velocity refugia" habitat, which would increase foraging efficiency and overall carrying capacity of juvenile steelhead (Rosenfeld et al. 2014). Finally, we developed a set of triggers to determine when to change either our monitoring or restoration actions during our annual evaluations. An example of a trigger would be if the LWD
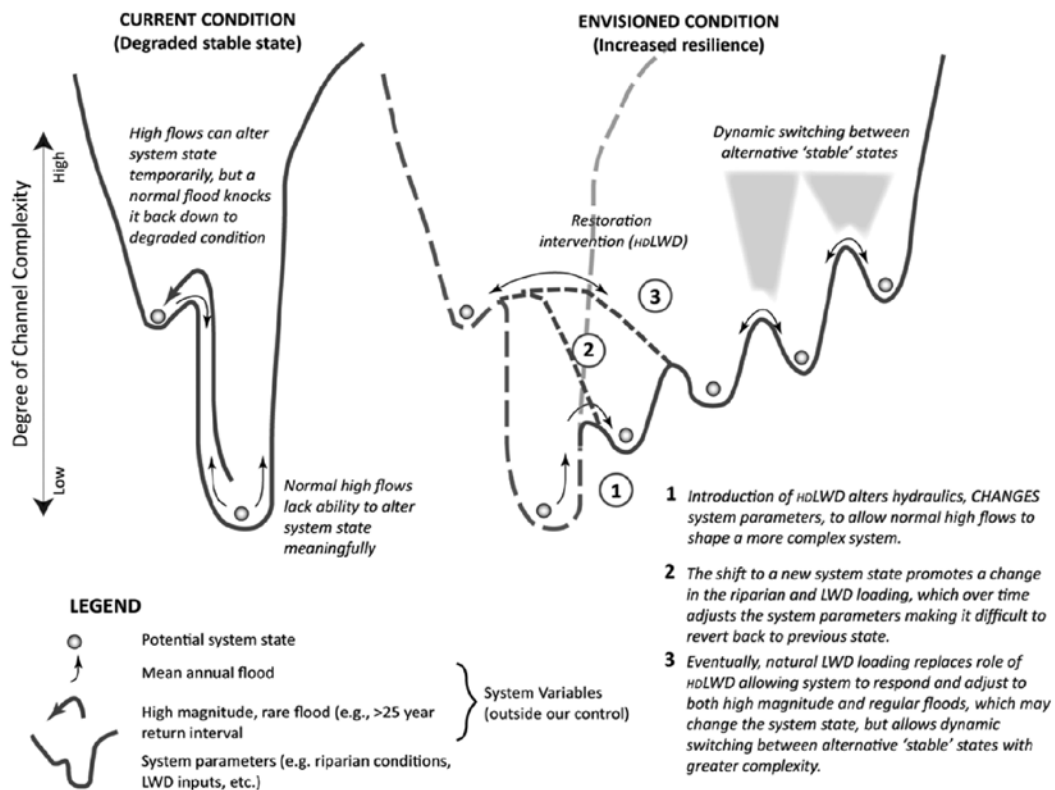
Figure 2. Conceptual model of current condition and envisioned condition postrestoration in response to the implementation of high-density large woody debris ($_{HD}$LWD). The system variables (e.g., hydrology) cannot be changed, but we can change the system parameters by increasing the loading of large woody debris (LWD). We hypothesize that $_{HD}$LWD will shift the creek into a number of more complex alternative stable states that are also more resilient to disturbance.

structures cause an overall widening of the stream channel at the treatment scale, resulting in a decrease in water depths and an increase in stream temperature above thermal optima for steelhead (i.e., "harm"; Figures 4 and 5). This would cause an "adjustment" in our actions, and we would consider removing the structures or other actions to reduce channel widening.

DOING

The "do" phase of the process includes the implementation of the monitoring and restoration. The information from monitoring is used to assess whether (1) objectives are being achieved and (2) unforeseen consequences are causing harm (or goals are not being met), which may require implementation of new management actions. By monitoring outcomes following management actions, AM can improve our understanding about which actions work and why. We monitor a wide variety of fish, habitat, and biophysical factors (discharge, temperature, water quality) across multiple spatial scales including at the LWD structure, site, treatment section, and watershed. For example, we monitor hydraulic and geomorphic changes around every LWD structure using a rapid habitat survey (Camp and Wheaton 2014), while a subgroup of the structures are monitored with detailed topographic surveys to quantify the amount of erosion and deposition occurring around each structure using the Columbia Habitat Monitoring Protocol (champmonitoring.org). Juvenile steelhead abundance, growth, movement, survival, and production are monitored at the site, treatment section, and watershed scale in all four seasons, and the adult and smolt migrations are monitored at the watershed scale by Washington Department of Fish and Wildlife.

Prior to implementing a full-scale restoration treatment, we implemented a small trial restoration project in 2010. The goal of the trial was to test the logistical feasibility and hydraulic and geomorphic effectiveness of a modified LWD restoration method designed to minimize disturbance to recovering riparian areas. We installed five LWD structures in each study creek during low-flow conditions in the summer. We conducted topographic surveys 25 m upstream and downstream of each structure pre (2010) and post (2011) restoration. We were fortunate to have the largest spring flow in the last 15 years in 2011 that tested the ability of the trial structures to create hydraulic and geomorphic changes. The trial demonstrated that LWD could promote significant changes in hydraulic and geomorphic conditions as predicted. The trial also helped us learn how to build more efficient structures. Based on the trial, we then implemented the full-scale restoration plan in a staircase experimental design over 3 years (Walters et al. 1988). The three study creeks each had LWD added to a 4-km-long treatment section—one creek treated per year from 2012 to 2014, resulting in 12 km of LWD treatment (535 structures) and 24 km of control area.

EVALUATE AND LEARN—ADJUST IF NECESSARY

We conduct both short-term (annual) and longer-term (every 5 years) system-wide evaluations of the project (Figure 1). Annually, we evaluate whether (1) the right problem was identified, (2) restoration is achieving the predicted responses (e.g., hydraulic, geomorphic, fish), (3) restoration is causing harm (damage to infrastructure or decrease in fish production), (4) monitoring intensity is appropriate, and (5) the appropriate attributes are being monitored. We have two annual evaluation

PALS - Bank Attached

Hydraulic
1. Shunting Flow
2. Splitting Flow
3. Convergent Jet Downstream
4. Eddy Downstream
5. Eddy Upstream
6. Divergent Flow Downstream
7. Convergent Flow Downstream

Geomorphic
A. Deposition Upstream
B. Deposition in Wake
C. Deposition Downstream
D. Deposition Overbank
E. Erosion at Convergent Jet
F. Erosion by Plunge Hydraulics
G. Erosion Forming Chute
H. Erosion of Bar Edge
I. Erosion of Outer Bank

Eddy Pool
Deposition
Pool-Forming Erosion
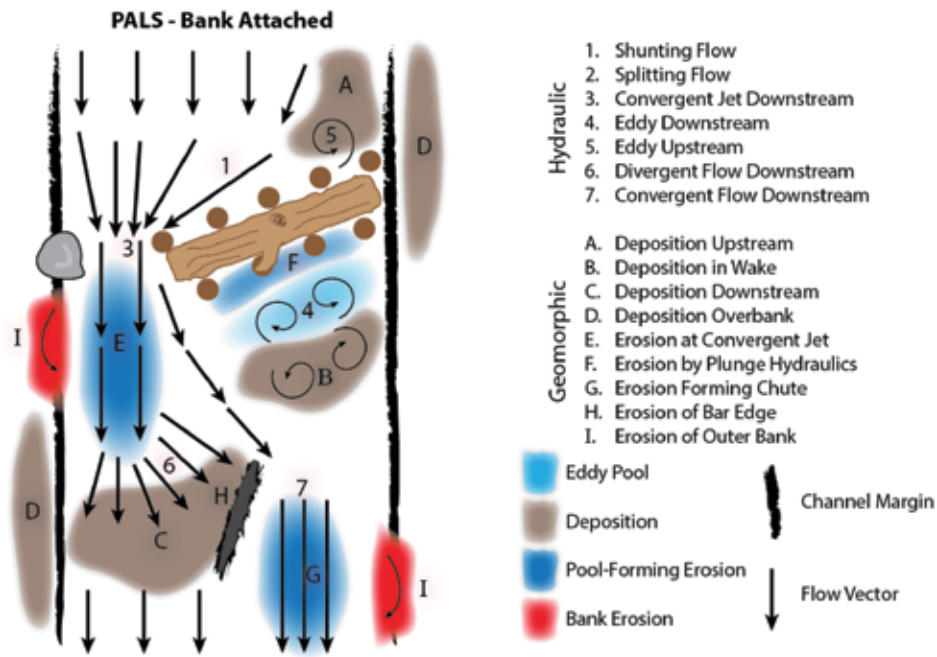Bank Erosion
Channel Margin
Flow Vector

Figure 3. An example of detailed design hypotheses for a postassisted log structure (PALS) used to increase large woody debris (LWD) in the Asotin Creek intensively monitored watershed treatment sections. Each number refers to either a hypothesized hydraulic or geomorphic response. Blue = scour, brown = deposition, red = undercut bank creation. Adapted from Camp (2015).

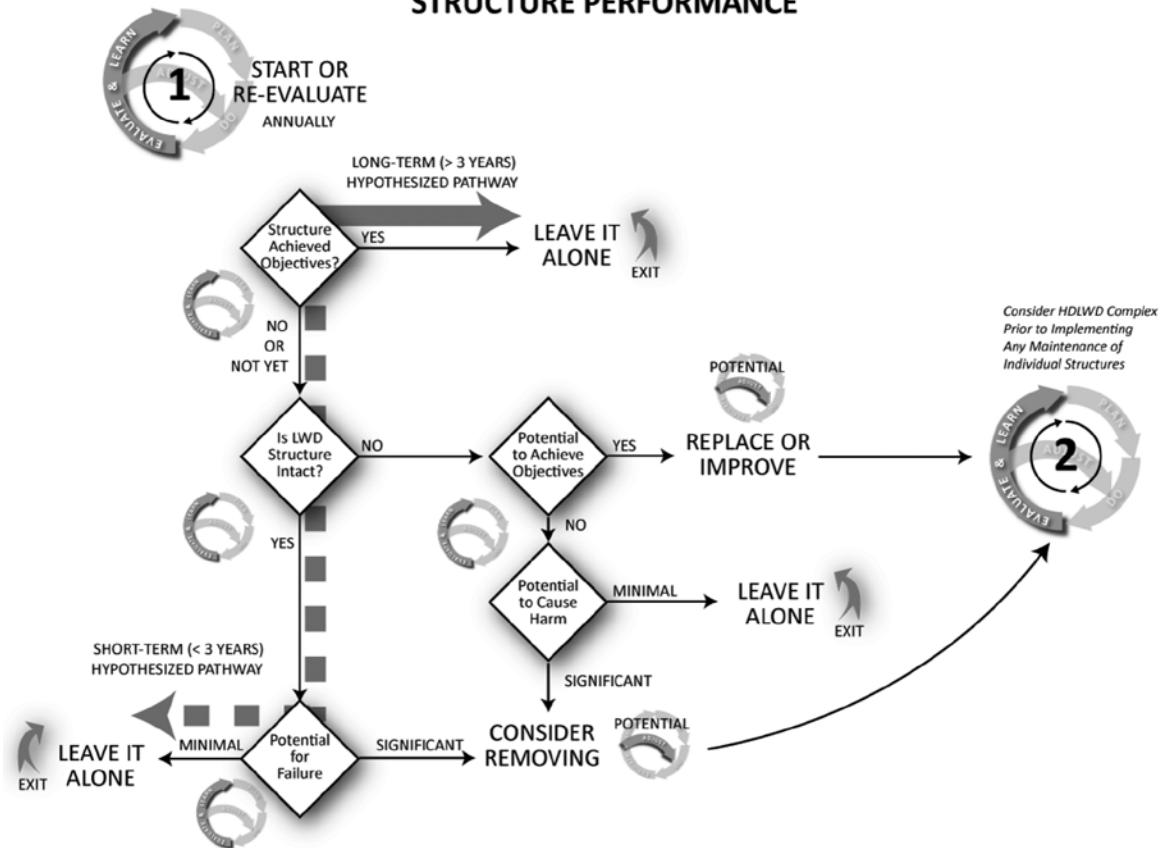**EVALUATION OF INDIVIDUAL LWD STRUCTURE PERFORMANCE**

Figure 4. Detailed adaptive monitoring and maintenance workflow for evaluation of individual large woody debris (LWD) structures (e.g., PALS; see Figure 3). This process is applied annually to all LWD structures. The primary hypothesized pathways result in no adjustment actions (i.e., "leave it alone") and are illustrated with the thick grey arrows. Alternative outcomes can result in potential adjustments, which are not acted on until the overall performance of functional high-density LWD ($_{HD}$LWD) complexes is evaluated (see Figure 5).
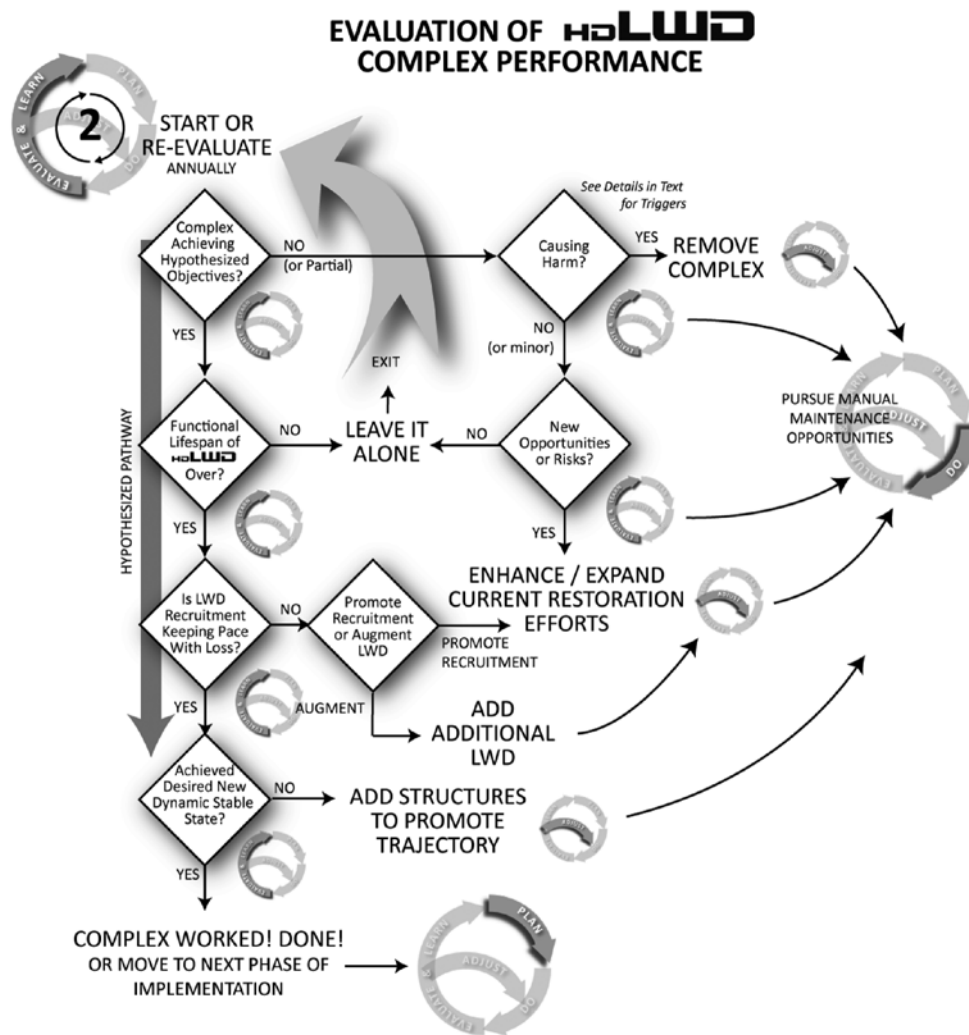
Figure 5. Detailed adaptive monitoring and maintenance for evaluation of high-density large woody debris (HDLWD) complexes. The primary long-term hypothesized pathway results in the achievement of a desired new dynamic stable state and is illustrated.

loops: one for individual structures and one for the complex of structures, which we refer to as high-density LWD (HDLWD; Figures 1, 4, and 5). We began evaluating the first HDLWD treatment after construction in 2012. The spring flood was the lowest recorded in 9 years, and little geomorphic change was observed. Almost all of the structures were still intact in 2013, their potential for failure was minimal, and hence no adjustments were made to the overall treatment (Figure 4). Our first annual evaluation in 2013 of the effectiveness of the individual LWD structures informed each subsequent treatment design. For example, we noted that deflector structures that constricted a higher percentage of the channel increased the velocity of the hydraulic jet and subsequently increased the depth of the scour pool (Figure 3). This led to an "adjustment" of the structure designs to increase the constriction of the channel (i.e., 80%–90% constriction; Figure 4). We also noted that bars formed at many structures (both upstream and downstream) regardless of whether scour pools were created. This led us to develop alternative hypotheses about potential fish responses (i.e., creation of bars and increased sediment sorting could lead to better winter concealment habitat) and directed studies to further test these alternate hypotheses (e.g., winter mobile passive integrated tag surveys).

We also evaluate the complex of LWD structures in treatment sections annually (Figure 5). The HDLWD were explicitly designed to (1) force the current degraded, stable state of the creek into a more dynamic state that interacts with the riparian and floodplain habitat leading to natural wood recruitment and a greater diversity of channel habitats and widths and (2) work together as functional complexes or groups, thereby limiting the importance of any one structure. We evaluate how well the treatment complex is achieving the first goal by assessing how much of the wood in each treatment section is naturally recruited and how the LWD we placed moves. We tagged the LWD at each structure to differentiate it from naturally recruited wood. If each 4-km-long HDLWD complex does not promote natural recruitment of wood and the treatment sections start to lose wood, an adjustment that may be made is to add more wood assuming that data continue to support our conceptual model that LWD is lacking in the system (Figure 2).

After three restoration treatments we have increased the frequency of LWD by 185% in treatment sections compared to control sections. Our annual evaluations have not detected any harm associated with the structures, and we are detecting many of the hypothesized hydraulic and geomorphic responses around the structures. For example, some LWD structures are forcing

convergent hydraulic jets, scouring pools, and creating sediment bars (Figure 6). Changes in geomorphic features are also being detected with our topographic surveys using change detection methods (Camp 2015). We are seeing a greater diversity of geomorphic features in treatment sections after restoration compared to control areas (i.e., increase in total number of geomorphic features and increase in different types of features such as multiple pool and bar types). We have not evaluated the changes in steelhead production in treatment and control sections yet, but we have documented an increase in juvenile abundance in treatment sections compared to control sections. The remainder of the IMW experiment will focus on estimating changes in production and other life history characteristics (e.g., movement, growth, survival) and identifying the causal mechanisms of observed changes.

We implemented the Asotin IMW within an AM framework because we feel that it is the most efficient and powerful way to answer our primary question—is this restoration effective? Adaptive management can be complex and daunting, but the approach we have taken is relatively simple and has led to the purposeful and deliberate identification of the "problem," documentation of what we expect to happen, robust and frequent evaluation of our assumptions and system responses, and clear triggers for when to make adjustments. The AM example presented here has allowed us to learn more about the Asotin Creek watershed and incorporate this knowledge into the IMW implementation, which will ultimately lead to a better understanding of the effectiveness of a common restoration action at improving wild steelhead production.

We recognize that IMWs are expensive endeavors with the specific goal of testing the effectiveness of stream restoration; however, we have also demonstrated that AM need not be overly cumbersome. By using a rapid design and monitoring app, we managed to keep costs well below traditional approaches (Camp and Wheaton 2014). We conclude that variations of AM can be applied to many more restoration projects and should replace the trial-and-error approach to restoration actions that has been all too common in the past.

Figure 6. Example of changes to a plane-bed section of stream after construction of a large woody debris (LWD) structure: (a) bank-attached bar, (b) LWD structure, (c) eddy pool, (d) convergent hydraulic jet and scour pool, (e) new undercut bank, and (f) riffle bar.

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