A Model for Adaptive Management for the Front Range Collaborative Forest Landscape Restoration

DRAFT, April 9, 2013

The Front Range Collaborative Forest Landscape Restoration Program has developed an adaptive management (AM) model to incorporate data to be developed by its Multiparty Monitoring Program (Clements and Brown 2011) into future goals and treatment actions (Figure 3). The model assumes a definition of AM provided by the National Research Council (2004):

> *Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.*

The key feature of this definition is the acknowledgment that AM is an active process ("learning by doing") that requires monitoring actions and adjusting future actions as knowledge is gained. As the definition suggests, it is not simply *ad hoc* course corrections made as past mistakes become undeniable. As DeLuca et al. (2010) write:

> Adaptive management is an iterative approach to management that is based on a series of feedback mechanisms in a continual cycle of evaluation, planning, action, and monitoring... Under adaptive management, learning is accelerated because management is conducted in a framework of experimentation, where cause–effect relationships between management actions and outcomes are treated as hypotheses to be tested. Each element of this process is fundamental to the success of the approach, and exclusion of any one element, including monitoring, scuttles the entire process and prevents learning.

Typically, AM is represented as a closed loop involving planning, implementing, monitoring, and adjusting (Fig. 1). The value of such a representation is that it makes clear that every step is necessary. Unfortunately, such a representation also implies that the process is sequential, when in fact, monitoring, to be effective, must be done throughout the AM cycle. So important is this concept that Bliss et al. (2001) represented adaptive management as two cycles, interlocking as gears, comprised of a "monitoring cycle" and an "adaptive decision-making cycle" (Fig. 2), with monitoring engaged continuously throughout the adaptive management process. Figure 2 also makes clear that monitoring itself must be self-reflective – continuously planning, implementing, and re-evaluating.

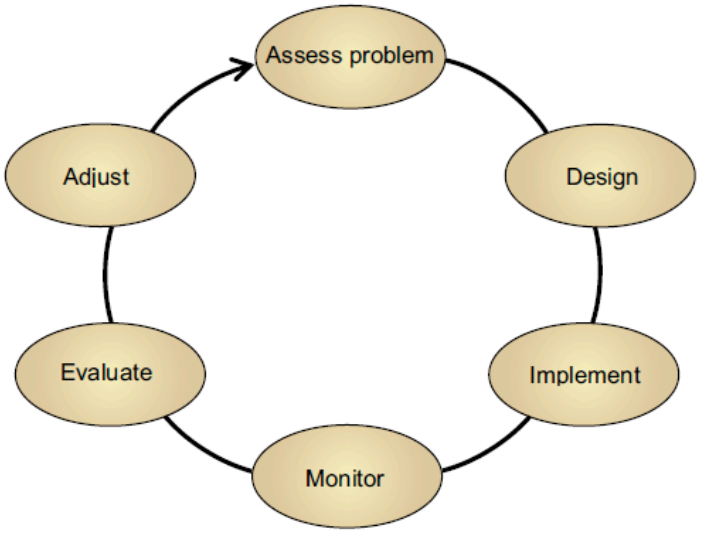

Figure 1. Typical representation of the adaptive management cycle as a closed, step-wise loop (from Williams et al. 2009)

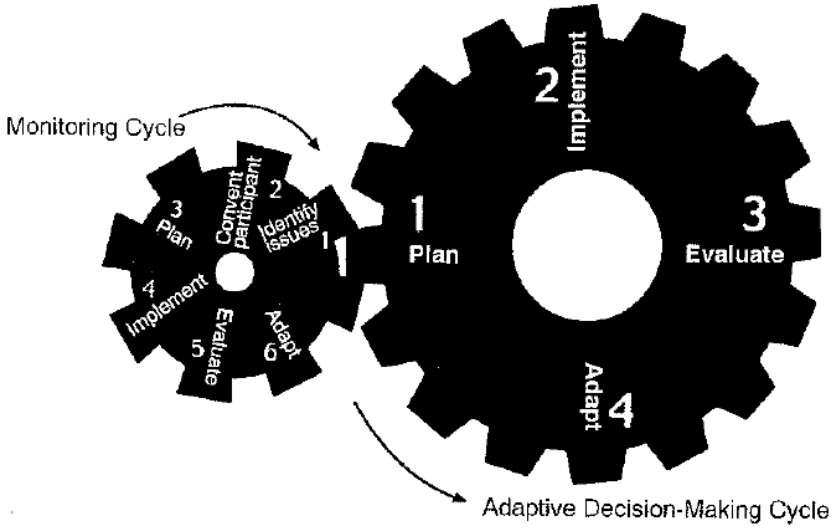

Figure 2. Adaptive management represented as a combination of two cycles of continuous monitoring and decision-making (from Bliss et al. 2001)

The various roles of monitoring have led to recognition of several types of monitoring (Table 1). As DeLuca et al. (2010) note, the most common form, called *implementation monitoring*, asks only whether

or not a management action was performed as designed. This helps establish accountability, but it cannot determine whether the action achieved its intended result. That takes *effectiveness monitoring*. Hutto and Belote (2013) parse monitoring even more finely, describing the concepts of *surveillance monitoring*, which establishes the baseline conditions of ecosystems, and *effects monitoring*, which tests whether treatments are having unintended negative effects on the system.[1] As is clear from Figure 2, there is a need also to monitor the monitoring program itself to ensure that it is meeting the needs of AM. Monitoring that evolves in response to new information is called *adaptive monitoring* (Lindenmayer and Likens 2009).

Table 1. Types of monitoring

Implementation monitoring	"[I]mplementation (or compliance) monitoring assesses whether or not a management action has been performed as designed" (DeLuca et al. 2010).
Effectiveness monitoring	"[E[ffectiveness monitoring determines whether an action has achieved its objective…[It] can provide data that specifically allow for the evaluation of the impact of the restoration activities on ecosystem attributes, diversity indices, wildlife health (e.g., fecundity, habitat quality, and migration activities), forest stand metrics, and socioeconomic variables (e.g., jobs, recreational opportunities, and tourism)" (DeLuca et al. 2010).
Surveillance monitoring	"Here, well-distributed (geographically stratified) locations are surveyed repeatedly across years in an on-going effort to uncover trends in target response variables...The purpose of this type of monitoring is to assess whether any change in a response variable exceeds some pre-determined threshold requiring management action" (Hutto and Belote 2013).
Ecological effects monitoring	"Ecological effects monitoring seeks to uncover unintended ecological consequences of management activity, and should be an integral part of any program designed to monitor management practices…Explicitly considering and monitoring potential ecological effects will help agencies and stakeholders make more informed decisions to minimize tradeoffs, seek complementarities among values, and optimize benefits among objectives" (Hutto and Belote 2013).
Adaptive monitoring	"A fundamental part of the adaptive monitoring paradigm is that the question setting, experimental design, data collection, analysis and interpretation are iterative steps…A monitoring program can then evolve and develop in response to new information or new questions" (Lindenmayer and Likens 2009).

Each of these types of monitoring applies to, and affects, different steps in the AM process. In Figure 3, we present a version of AM and show how monitoring answers different questions pertinent to the process. The figure shows the sequence of steps in AM, where monitoring is conducted in the process, and how the analysis of monitoring results links back to modify AM steps, if necessary. In this diagram,

[1] An important objective of our work is to articulate a process for a so-called "adaptive NEPA process," whereby projects can be modified based on monitoring results without having to initiate a new, costly, and time-consuming NEPA process.

we simplify the analysis of monitoring results into those questions that address longer-term, landscape-scale goals, which we call *effectiveness monitoring* (left side of the diagram), and those that address *adaptive monitoring* (right side of the diagram). *Implementation monitoring*, which is conducted by the Forest Service as part of contract oversight, is deserving of attention in its own right and so is not included in our diagram, and *surveillance monitoring*, as described by Hutto and Belote (2013), is beyond the scope of the CFLRP AM process.[2]. The process is represented as an inverted pyramid to emphasize the general trend from broad goals to specific outcomes – and back again. Below, we describe all the steps in the AM process and how they may be affected by monitoring results.

Problem: The first step in the process is to define the problem that stakeholders have gathered to solve. It is very important that all stakeholders hold the same understanding of the problem, lest they work at odds. A common understanding of the problem will help lead to a clear articulation of project goals, which is essential to collaboration. Stakeholders who do not share the same goal are engaged in negotiation, not collaboration. In the case of the Front Range Roundtable and the Colorado Front Range CFLRP, the problem is that the dry montane forests of the Front Range are not currently in a condition that can sustain desired ecosystem values.

The relevant monitoring question pertaining to this step is whether the problem is defined correctly. As monitoring data are collected and analyzed, it may be discovered that the problem is not as it seemed. For example, it is possible (though not likely) that monitoring will show that the condition of the forest has no effect on its resilience to fire. At that point, we would need to modify our understanding of the problem. It is essential to the success of the adaptive management process that the appropriateness of the problem statement be reviewed based on knowledge gained through monitoring.

Define Desired Conditions for Ecological Restoration and Define Uncertainties: If the problem is the condition of the forest, then solving the problem will require modifying that condition. In this step, stakeholders describe the kind of forest they want to see in the future. For the Colorado Front Range, conditions prior to about 150 years ago are believed to have supported fire behavior that, if it occurred today, would not threaten the sustainability of forest values. The Roundtable, in its 2006 report took an initial stab at defining desired conditions, describing "a complex mosaic of forest structures with patches of variable tree densities and ages that favor retention of the older trees." The CFLRP proposal expanded on this description, calling for work "to substantially decrease the density of ponderosa pine and Douglas-fir in the lower montane favoring ponderosa pine, create a more diverse age structure (sic). Treatments would increase meadows, patchiness and herbaceous understory across the landscape while maximizing ponderosa pine old growth."

In the adaptive management process, review of monitoring results would include evaluation of whether desired conditions have been appropriately described. Already, our work to develop monitoring protocols has revealed that more precision is needed in the characterization of desired conditions simply to facilitate evaluation of treatment success, and we have initiated a process to improve our

[2] What Hutto and Belote (2013) call "ecological effects" monitoring, we consider part of effectiveness monitoring because it is essentially monitoring for the absence of anticipated undesired effects, which should be described as part of the characterization of desired conditions.

characterization. In practice, monitoring plan design, project planning, and implementation are all likely to reveal whether desired conditions have been appropriately described; evaluation of monitoring results should explicitly consider whether modification is needed.

Characterization of desired condition is fundamentally a statement about how we want the world to be when it is functioning correctly. It is therefore implicitly a statement how we believe the ecosystem functions, and evaluation of desired conditions involves consideration of our understanding of ecosystem function. An extremely useful step in that evaluation is the explicit consideration of **uncertainties** in the function of the system. This acknowledgment of uncertainty both helps with the identification of variables to monitor and can help with the development of a research program to improve ecosystem understanding.

Define Restoration Areas: Once the problem and desired conditions have been defined, it is important to identify where work will be prioritized. Prioritization is essential because resources are simply too limited to address the problem everywhere it exists; they should be focused where they provide the greatest return on investment. The Front Range Roundtable identified 1.5 million acres that would benefit from treatment to improve community safety or the health of lower montane forests, 400,000 of which could be treated to achieve both goals. In its CFLRP proposal, the Roundtable modified the boundary of the restoration zone to include substantially higher elevation dry mixed conifer forest in the upper montane zone as well, adding an unspecified area to the 800,000 acres of restoration forest identified earlier. The precise location of treatments within this vast area should be determined by stakeholders based on careful evaluation of landscape condition.

Effectiveness monitoring, which examines effects only in the vicinity of a treatment, is a poor way to determine priority treatment areas, but it can tell whether treatments seem to be working. If they are not, either the treatment or the criteria for identifying priorities should be changed. The important step in the AM process is to ask, based on knowledge gained through monitoring, whether the criteria used to identify priority restoration areas are still appropriate.

Define Restoration Actions/Treatments: Once priority treatment areas have been identified, a general approach to forest restoration must be developed. This document describes the kinds of activities that will be used to achieve the desired conditions in general terms. It should document the silvicultural and other tools that will be used as well as constraints on the use of those tools (e.g., maximum opening sizes based on understanding of desired conditions) and restrictions on where those tools should be used (e.g., proximity to roads and communities). This step should yield a framework for restoration that will inform the public about the broad outlines of the project and help guide development of the monitoring plan and project plan. This is also the step where budgets should be developed, including the budget for monitoring. To date, the closest articulation of this framework is the CFLRP proposal. A worthwhile question to ask at this point is whether the proposal provides sufficient characterization of the project to serve as a basis for monitoring and project planning. If not, stakeholders should revise the plan to provide for these critical needs.

The monitoring question that applies at this step is whether the overall approach seems to be achieving the desired effect. In the case of the Colorado Front Range CFLRP, does the approach to forest restoration described in the document appear to sustain forest ecosystems without causing undesired effects? This is the essential question of effectiveness monitoring and should be the focus of the monitoring plan.

Develop/Modify Monitoring Plan: The monitoring plan should flow directly from the articulation of restoration actions and treatments. It should be designed to answer the fundamental question: Are treatments achieving desired effects without causing anticipated negative effects.

In our figure, we have drawn an arrow back here from the analysis/evaluation step to represent adaptive monitoring (see above). There are a lot of ways to approach adaptive monitoring, from periodic self-reflection of the monitoring committee to establishment of a monitoring program as a rigorous experiment itself, and solid arguments can be made for many of them. The important point here, though, is that stakeholders evaluate the monitoring plan to assess whether it is continuing to serve the needs of the project. If it is not, it should be revised

The question of who conducts monitoring should also be addressed in the monitoring plan. Depending on the desires and capacity of the collaborative, stakeholders may be very involved in the collection of monitoring data, or they may rely on the Forest Service to collect data. The Roundtable currently employs a hybrid approach, with the Forest Service collecting "Tier 1" data through Common Stand Exams and stakeholders augmenting other important "Tier 2" information through a separate process.

Project Planning, NEPA: Once the project framework and monitoring plan are in place, specific guidance to implement restoration should be developed in the form of a Project Plan. A project affecting federal land must adhere to the strictures of the National Environmental Policy Act and requires a Project Plan and environmental review that meet NEPA's requirements for specificity. The challenge here is to write a plan that meets those requirements but is still capable of improving over the life of the plan in response to knowledge gained through monitoring. The key to success of this so-called "adaptive NEPA" will be the inclusion of "triggers" that commit to changes in course depending on the results of monitoring (Nie and Schultz 2011). It is the responsibility of the U.S. Forest Service to develop the Project Plan with input from the public.

In our diagram, the effectiveness monitoring loop closes on this step only if treatments are effective. If monitoring shows them to be ineffective, a new restoration framework is needed, as is a new monitoring plan and new project planning. This would seem to defeat the purpose of "adaptive NEPA;" however, in our scheme, the triggers built into the plan come into play not through effectiveness monitoring, but through implementation monitoring conducted as part of contract oversight. If the triggers are set up correctly, they will allow for modification of restoration practices at the project implementation stage without modification of the plan. If, however, required changes are beyond the scope of the triggers in the plan, a new Project Plan will be needed.

Pre-treatment Monitoring: The monitoring plan should spell out the methods, intensity, and timing of pre-treatment monitoring, so this step should be one of implementation rather than planning.

However, the adaptive monitoring loop does encourage modification of monitoring methods throughout implementation of the project plan, and changes in monitoring methods should result in amendment or modification of the monitoring plan. The way the figure is drawn, changes to monitoring methods would also result in modification to the Project Plan/NEPA, which creates unnecessary complexity. Therefore, minor modifications to methods triggered by adaptive monitoring may be made at this step without triggering NEPA, with amendment of the monitoring plan affecting only development of the next project plan.

Project Implementation: Much could be said about project implementation, but it is largely outside the scope of this diagram. Also, most restoration activities will be conducted by contractors, either purchasers of timber sale contracts or contractors providing stewardship services, so there is little direct role for the collaborative in implementation. We include it in the diagram only to indicate that we understand implementation is an important part of the process.

Post-treatment Monitoring: See pretreatment monitoring.

Analysis/Evaluation: In their recent guidance for fuel management in dry mixed-conifer forests, Jain et al. (2012) consider a number of questions relevant to analysis and evaluation, including, "How, when, and by whom will monitoring data be analyzed? " and "Where will monitoring data be stored, archived, and documented?" They note:

> [T]aking time to ensure data integrity, security, and accessibility over time is critical. The data have to be: (1) accessible to managers and researchers; (2) archived in stable formats on stable media…; (3) resistant to corruption and accidental destruction; (4) accompanied by detailed metadata containing sufficient descriptive information about the data and their collection that others can use to interpret the data, possibly for purposes beyond what was initially envisioned; and (5) stored and archived as corporate data backed by a long-term information management commitment.

With regard to involvement in analysis, the authors explain:

> Ideally, when monitoring is an interdisciplinary enterprise with multiple constituencies, there will be multiple analysts representing a range of disciplinary expertise with a stake in analyzing the data to address different questions. If data are publicly available, there can be entire networks of university and agency research analysts that may be interested in exploring the data…, but building at least some analysis capacity in-house will likely lead to more timely results and provide the flexibility to employ exploratory analysis that ultimately addresses a broad range of questions about treatment effectiveness and efficiency.

The Roundtable is fortunate to have an abundance of technical expertise to contribute to analysis and evaluation, but many details remain to be worked out. In our diagram, we have identified several of the key questions that must be evaluated and how the answers bear on different steps in the AM process.

External/Internal Research: Our figure also includes a two-headed arrow intended to represent the fact that research may inform and be informed by project development, implementation, and monitoring, and by activities external to the CFLRP. In some cases, this research may be identified by stakeholders and conducted under their auspices, or it may be conceived of and conducted independently. In either case, results could have important implications for any step of the AM process.

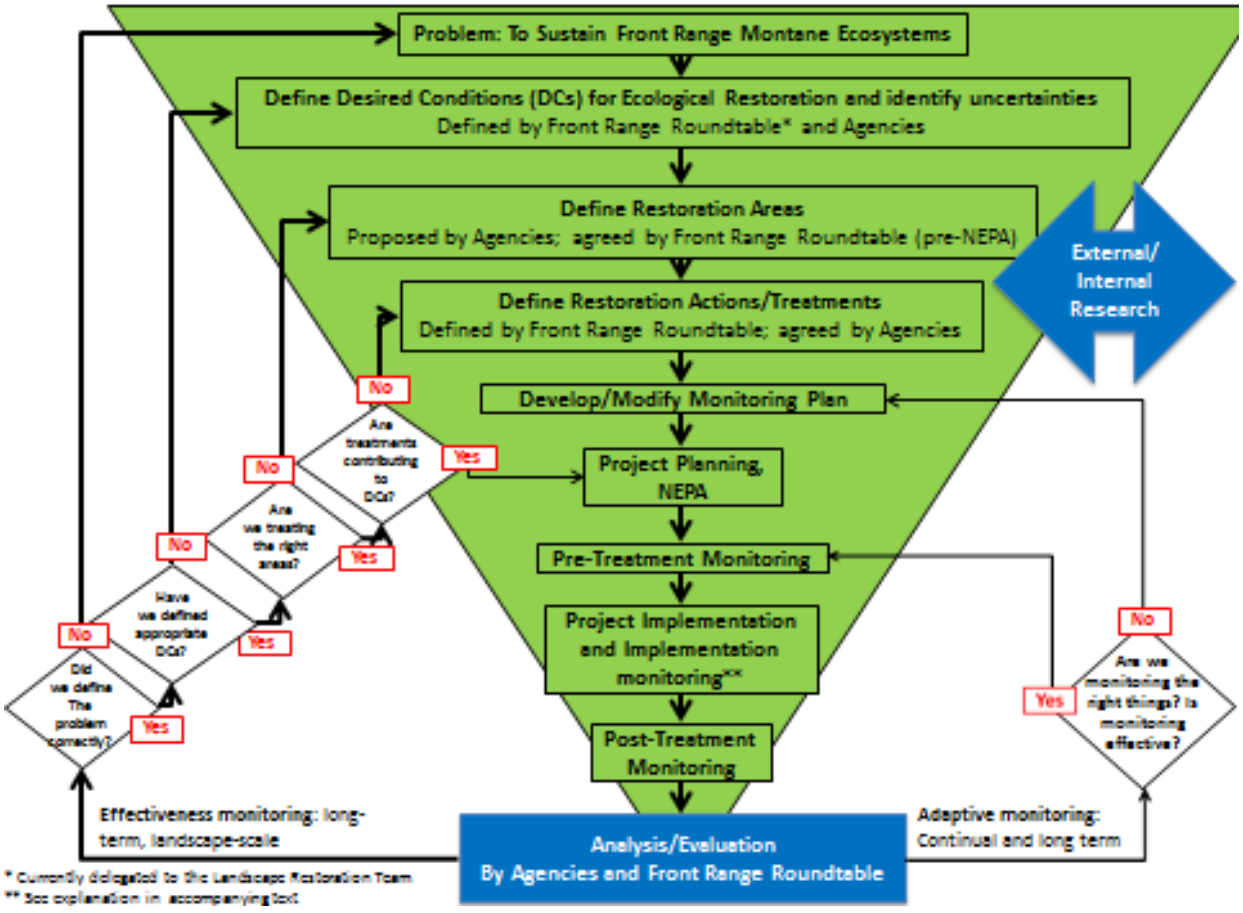

Figure 3. The Front Range Collaborative Forest Landscape Restoration Project Adaptive Management model.

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