A Framework for Monitoring, Reporting and Managing Dam Operations for Environmental Flows at Sustainable Rivers Project Sites

Version 1.0

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Executive Summary

The goal of the Sustainable Rivers Partnership (SRP) is to improve the conditions of river, floodplain, and estuary ecosystems by managing dams owned and operated by the US Army Corps of Engineers for environmental flows, while maintaining or enhancing other purposes of dam management, such as flood control, hydropower generation, and recreational uses of reservoirs. Monitoring is necessary to determine if dam operations are having their intended results, and to adaptively manage environmental flows if possible and necessary. Reporting is necessary to summarize the status, progress, and results at site and programmatic levels.

Developing and implementing environmental flows and evaluating ecosystem changes in response involve: 1) defining an environmental flow prescription; 2) assessing the degree to which the prescription is implemented; 3) short-term monitoring of ecosystem responses to environmental flows; and 4) long-term monitoring of ecosystem status and trends that relate to flow. Adaptive dam management requires constructive, informative and timely guidance from scientists to dam operators, with periodic review and revision (if necessary) of the water control plan. In addition, work at SRP sites is designed to help catalyze agency-wide implementation of environmental flows by illustrating the benefits of their implementation, as well as to provide information for assessing progress toward this broader programmatic goal.

The primary purpose of this document is to assist practitioners in selecting a few well-considered indicators to monitor, as opposed to an exhaustive list that is expensive to implement and not necessarily more informative. This document provides a brief overview of approaches to strengthen and assist monitoring at SRP sites to collect information to evaluate the implementation, inform adaptive management, and assess the impacts of environmental flows. Examples are provided, as are links to web-based resources that provide details on developing, implementing and using monitoring information. Monitoring templates are also provided to highlight core questions and needs to address in a monitoring framework. A reporting template is provided to summarize the status of the work at individual sites for programmatic roll-up and reporting.

The Environmental Flow Prescription: Foundation for Monitoring and Adaptive Management
An environmental flow prescription consists of a set of hypotheses, each relating components of river flow to specific geomorphic processes, such as floodplain connection, or movement of sediment and woody debris, and ecological responses that result, such as seed dispersal and establishment, or fish spawning and recruitment. Environmental flow prescriptions are science-based and act as recommendations for how a dam should be operated to maintain or restore processes important to the condition of the downstream river and associated floodplain and estuary ecosystems. Individual components of environmental flow prescriptions are based on flow/environmental response models that provide the foundation for developing a monitoring plan.

Monitoring to Assess Environmental Flow Implementation
The overall environmental flow prescription consists of components that generally include low flows, periodic high flow pulses, and controlled floods that are within authorized dam operations. Each

component has a quantitative objective for magnitude, duration, seasonality and frequency. Typically in a given year, the prescription is not implemented in its entirety due to various constraints and uncertainties. Instead, select components of the prescription are implemented. A critical part of monitoring involves gauging river flows and characterizing the flow patterns as compared to the environmental flow prescription to explicitly identify which components are implemented, and to what extent the different objectives were met for those components.

Monitoring Short-Term Responses to Implementing Flow Prescription Components and to Support Adaptive Management

Short-term monitoring is designed to assess whether or not the implemented components of the flow prescription are resulting in the expected immediate and short-term geomorphic and biotic responses to specific components of flow, and if managing for environmental flows is having any impact on other designated dam operations. If the expected responses are not observed, or negative impacts to other dam operations are occurring, this monitoring supports refinements to the environmental flow prescription and dam operations.

Monitoring to Assess Long-Term Ecosystem Status and Trends

Long-term monitoring at SRP sites should be designed to track the status and trends (direction of change) in the condition of river, floodplain and estuary ecosystems in response to flow management. However, many ecosystem characteristics integrate environmental changes and multiple anthropogenic impacts that take place over time. Like short-term monitoring, the selection of specific indicators should be hypothesis-driven and flow-related. The strength of the cause and effect link between river flows and ecosystem trends will depend on the selection of appropriate indicators that account for ecosystem responses to environmental flow implementation in the context of natural variation and regional trends. Monitoring plans should be specific in terms of the connections between dam operations and programmatic reporting, and the data being collected. Monitoring plans should explicitly address spatial and temporal sampling configurations, statistical analytical approaches, reporting measures, and time frames for reports.

Programmatic Measures

Programmatic measures track and report the effectiveness of the SRP as a whole program. The SRP is required to report status, progress, and results, and can be more effective in obtaining continued support if summary measures are provided that are simple and easy to understand. Programmatic indicators include: the number of dams participating in the SRP, the stage they each are in developing/implementing environmental flows, which components of environmental flow prescriptions are being implemented, the estimated scope of impact (length of river, area of floodplain, estuary) that environmental flow management will have, and the number of ESA listed species and scope of critical habitats that are estimated to benefit from them.

Sites will report the types, degrees, and scope of impacts to verify the projected scope of impacts and to document those impacts. Results will also be used to illustrate the benefits of environmental flow management to other dam operators within and external to the Corps to expand the implementation of environmental flows more broadly.

Suggestions to SRP Sites for Developing Monitoring Plans

- Have a point person manage the processes to design, implement, analyze and report monitoring results.
- Involve water management (operations) personnel from Corps and other pertinent organizations in the development and analyses of flow prescriptions and monitoring plans
    - Corps staff must support proposed flows
    - Corps staff must recognize specific connections between monitoring and reservoir operations
- Involve regional scientists and monitoring experts. The group does not have to be large, but should consist of a diversity of expertise, including hydrology, fluvial geomorphology, ecology, and individuals with experience in monitoring and statistical analyses.
- Use the framework of the environmental flow prescription, monitoring for short-term validation and adaptive management, monitoring for long-term trends, and programmatic reporting to structure a monitoring plan and prioritize monitoring efforts.
- Coordinate with other agencies involved in monitoring and leverage funding and capacities to advance monitoring efforts. Support from water managers in performing experimental releases can attract monitoring and research funds from outside the SRP. However, focus monitoring to address specific needs, and do not expand monitoring to include everything that might be interesting
- Always keep the following principles in mind. Monitoring efforts should be:
    - articulated as part of a monitoring plan
    - directly linked to specific questions and information needs
    - clearly connected to dam operations and within the spatial zone of influence
    - scientifically credible, useful, efficient, and communicated in a timely fashion.

"Water managers and stakeholders are now demanding from scientists more than just a strong conceptual understanding of the likely ecological responses of river biota to managed flows"
(King et al. 2010)

"Management agencies need to be convinced their investments in environmental flows, and the monitoring of ecological outcomes are cost-effective and worthwhile activities"
(Arthington et al. 2010)

Overview

This document is intended to encourage more effective monitoring of the results of efforts to modify dam operations at Sustainable River Project (SRP) sites[1]. It provides a framework and approaches for monitoring environmental flow prescriptions and components of freshwater ecosystems that are expected to respond to them. This information can guide adaptive management of dams to be more efficient and effective in achieving near-term objectives for environmental flow releases, and to report on longer-term project effectiveness in conserving biodiversity/sustaining ecosystems where flow management has been in place. Methodological details on monitoring techniques and designs are not provided in this document, as monitoring plans should be developed with scientists who will be responsible for the work. Monitoring plans must address site-specific issues including the particular questions affecting water management decisions, methods for measuring local ecosystem responses, the sampling capacity given environmental heterogeneity and natural variation, and the resources and planning to support monitoring, statistical analyses, and reporting. This document focuses on ecological and environmental responses and does not address socioeconomic monitoring, which is important for evaluating the results of the SRP but requires the development of additional approaches and documentation.

The remainder of this document is structured in the following sections and appendices:

[1] In 2002, the US Army Corps of Engineers (Corps) and The Nature Conservancy (TNC) began collaboration on the Sustainable Rivers Project (SRP). This nationwide partnership aims to improve river, floodplain and estuary health across the United States by modifying dam operations to reinstate ecologically-important components of natural flow regimes ("flow interventions") while maintaining or enhancing traditional dam benefits such as flood control, hydropower production, water supply, and recreation. Most of the more than 600 dams owned and operated by the Corps are considered candidates for environmental flow management.

Appendix A: Links to useful resources for developing monitoring plans
Appendix B: Template for Monitoring for Adaptive Management, with examples
Appendix C: Template for Monitoring for Long-Term Ecosystem Status and Trends, with examples
Appendix D: Template for Reporting Site-Level Results for Programmatic Roll-up.

Sections III-V include criteria for and examples of appropriate indicators for monitoring. While it is recognized that many indicators could be appropriate, this guidance takes the position that monitoring to support adaptive dam operations need not be comprehensive or expensive, and that a few well-considered indicators can be effective and financially sustainable.

I. Introduction

All monitoring must begin with clearly articulated goals, management actions, and information needs. The goal of the SRP is to improve the conditions of river, floodplain, and estuary ecosystems by managing dams that are owned and operated by the US Army Corps of Engineers for environmental flows, while maintaining or enhancing other purposes of dam management, such as flood control, hydropower generation, and recreational uses of reservoirs.

For the context of this guidance document, the definition of environmental flows is: *"An environmental flow results from a management intervention that protects or modifies the flow regime of a river to achieve an ecological or environmental outcome". (Cottingham et al 2005).* "Improved" ecosystem condition may be rehabilitation of some characteristics of the historical ecosystem prior to dam construction, or development of new characteristics that have conservation or other social value (e.g., increase in native population of a fish that historically may have been lower, or improved water quality for drinking water supply which is a departure from historic, natural conditions).

While the SRP has the broad goal of improving freshwater ecosystems using environmental flows, site-specific objectives should be clarified using precise terminology (Schreiber and Cottingham, 2000):

"*Restoration* is defined as the act of restoring a system to a "close approximation of its condition prior to disturbance, with both the structure and function of the system recreated" (National Research Council 1992). *Rehabilitation* involves "the act of restoring a system to a previous condition or status". In contrast to restoration there is no underlying implication of a return to a state without any human disturbance. *Remediation* implies an attempt to improve a system in some way, but not necessarily to the full extent required by restoration or rehabilitation projects." (From King et al 2003).

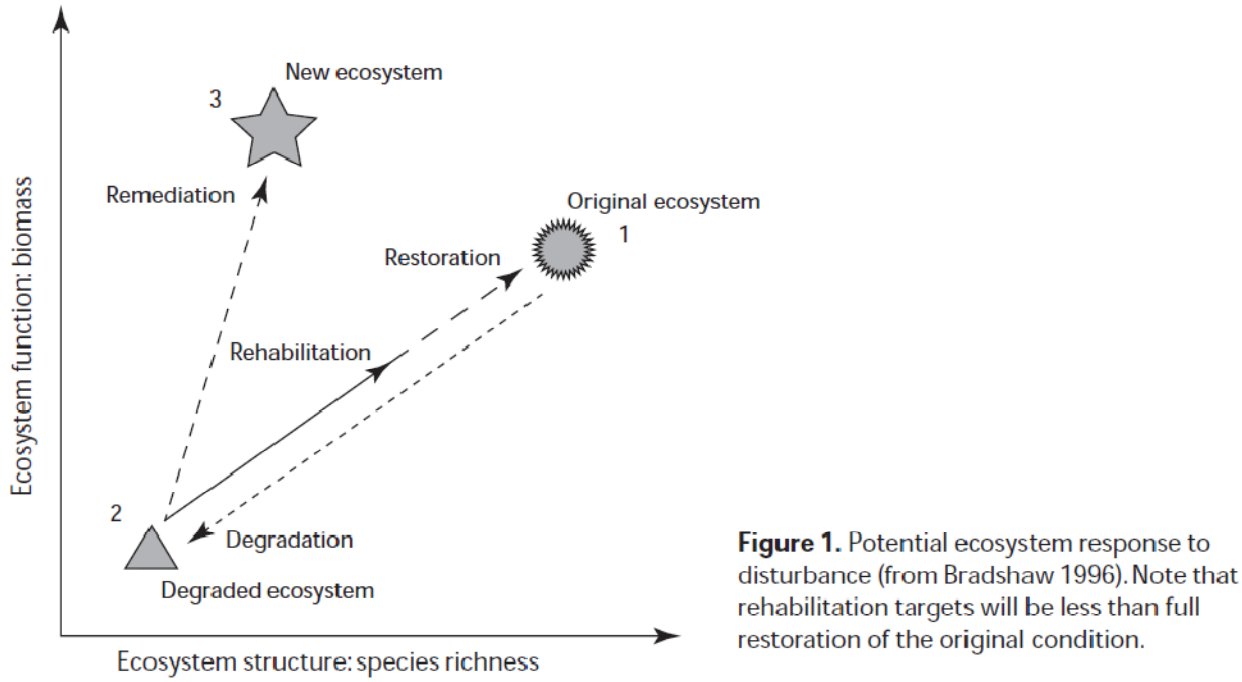

Figure 1. A conceptual framework for restoration, rehabilitation, and remediation (from King et al. 2003).

Given that Corps dams have authorized purposes other than ecosystem condition, and there are often multiple impacts to ecosystem condition from sources other than flow alteration, ecosystem "restoration" is generally not a reasonable objective for implementing environmental flows at an SRP site. Instead, work at SRP sites is focused on re-establishing critical components of flow regimes to help rehabilitate important aspects of river, floodplain and/or estuary ecosystems. Such goals are generally within the realm of the rehabilitation of components of ecosystem structure, function and condition.

Once goals have been articulated at a site, successful monitoring efforts depend on clearly defined ecological models that structure hypotheses and objectives for environmental flow/ecosystem response relationships, well defined information needs, and appropriately selected indicators to provide that information. Indicators should be responsive primarily or solely to environmental flow management and easy to quantify, interpret and report. The data to measure indicators should be collected through scientifically robust sampling designs, assessed through appropriate statistical evaluations, and communicated in a simple, clear and transparent manner that is appropriate for the given audience. Finally, sampling efforts can and should be cost effective.

II. Environmental Flow Prescriptions: Foundation for Monitoring and Adaptive Management

Sites in the SRP use an environmental flow prescription to identify a set of management priorities and objectives, proposed attributes of environmental flow components, and hypotheses about relationships among environmental flow components, ecosystem characteristics, and their responses. Therefore, the environmental flow prescription is the basis for developing a monitoring plan.

Figure 2 provides an example environmental flow prescription and expected ecosystem responses for the Savannah River, Georgia/South Carolina below Thurmond Dam.

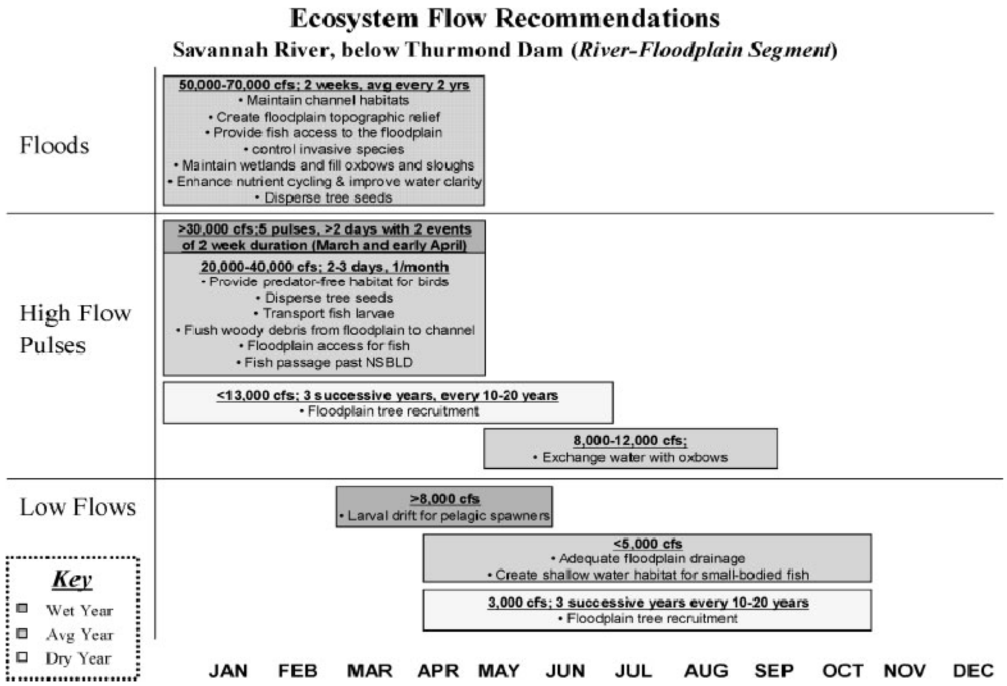

Figure 2. Recommended flow prescription for the Thurmond Dam on the Savannah River.

The individual components of the flow prescription (Floods, High-Flow Pulses, Low-Flows) have specific quantitative attributes defined for magnitude, duration, seasonality and frequency that serve as measureable objectives for achieving environmental flows. The desired attributes of flow to be achieved serve as the objectives for implementing environmental flows, and the indicators are the attributes themselves (cubic feet per second for flow magnitude, number of days for the given flow event, calendar period for the flow event, and the frequency that the flow event has occurred within and among years). The associated types of ecosystem attributes and the expected responses that result from environmental flow components (e.g. floodplain connectivity, inundation, access for fish, floodplain vegetation seed dispersal) are used to define indicators to inform short-term monitoring and adaptive management needs.

III. Monitoring the implementation of the flow prescription

It is critical to know which components of the flow prescription are being implemented and to what extent they are achieving objectives for magnitude, duration, seasonality and frequency. It should be know exactly what was done as compared to what was planned. This information is required to first understand to what extent environmental flow objectives were achieved. Then, it is possible to evaluate relationships between environmental flows and the ecosystem responses to them and to report on site-level and overall programmatic effectiveness of implementing environmental flow prescriptions. This requires evaluating and reporting the flow patterns that resulted from dam operations. Each component of the flow prescription can be evaluated as to whether it has been implemented, and if it is achieving flow objectives. Table 1 below provides an example of tracking implementation of individual components of the flow prescription from the Savannah River. This example includes the characterization of dry, normal and wet climatic years, but these attributes are not used universally in defining flow prescriptions.

Table 1. A record of the extent to which environmental flow components were implemented at the Strom Thurmond Dam on the Savannah River, USA (From Konrad, 2010).

Environmental Flow Component	Prescription (Objectives)	Water years
Floods	1,400-2,000 cms in January through April, 1 flood every three years in wet or average years lasting for 2 weeks	Not implemented
High flow pulses	570-1,100 cms in January through April, 5 pulses in wet years - 2 pulses lasting 2 weeks in March and April, 3 pulses lasting 2 days; 4 pulses (1 pulse per month) in average years lasting 2-3 days.	2006
	450-510 cms, early March and early April, 2 pulses in dry years lasting 3 days	2004-2005
	450-510 cms, early April, 1 pulse after three consecutive dry years lasting 2 weeks	2004-2005
	230-340 cms, May - October, 2-3 days per month in average years, no more than once every 10 days	2006
	<370 cms, January - July, 3 consecutive dry years after riparian seed dispersal	2008
Low flows	170-280 cms, January - May, wet years	Not implemented
	170-240 cms, January - May, average years	2005
	110-170 cms, January - May, dry years	2006-2007
	110-140 cms, Jun - Dec, wet years	2005-2006
	110-140 cms, October - Dec, wet years	2005-2006
	110 cms, Jun - Dec, average years	2005-2006
	> 76 cms, Nov and Dec, dry years	2005-2008
	> 76 cms, May through July, average and dry years	2005-2008
	>57 cms, July through October, dry years	2005-2008
	>230 cms, March-May, wet years	Not implemented
	<140 cms, April-October, average years	2008
	85 cms, April-October for 3 consecutive dry years	Not implemented
	In estuary	
	Monthly mean streamflow of 250-380 cms and instantaneous minimum of 170 cms in wet years; high end of range for January-May, low end of range for June-Dec, wet years	Not implemented
	Monthly mean streamflows of 230-340 cms and instantaneous minimum of 170 cms in average years; monthly mean streamflows of 170-230 cms and instantaneous minimum of 170 cms in dry years; high end of ranges for January-May, low end of ranges for June-Dec, average and dry years	2006-2008

IV. Monitoring Short-Term Responses to Implementing Flow Prescription Components and to Support Adaptive Management

Monitoring the immediate and short-term results from implementing different components of environmental flow prescriptions is done to validate or refine models of flow and ecosystem responses, evaluate whether implementing environmental flow components results in any confounding impacts to other dam operations, and how the flow prescription component should be adaptively managed, if necessary. If changes are needed, an alternative flow prescription should be defined and agreed upon, and information useful to dam operators should be provided to adapt flow management plans.

River and floodplain ecosystems are the "targets" of environmental flows. Indicators of their immediate and short-term responses to environmental flow management should include geomorphic and biotic indicators since flow/biotic linkages are often mediated by geomorphic mechanisms (Shafroth et al 2009), and improved understanding of these linkages could result in higher-confidence, shorter-term and less expensive monitoring of "leading" geomorphic indicators to inform adaptive management.

A detailed model of flow/ecosystem responses guides the selection of indicators to verify or adaptively manage environmental flow prescriptions. These models link flow, immediate and short-term geomorphic responses, and the resulting biotic responses. For instance, high flow events may be managed to inundate and connect floodplain ecosystems to river main-stems. Monitoring the magnitude and duration of a flow event, the extent and duration of floodplain inundation, and the extent and density of native vegetation seedling emergence allows the evaluation of whether flows were managed for sufficient magnitude and duration to achieve an appropriate hydro-period of floodplain inundation for seedling emergence to take place. Evaluating soil moisture in relation to low flow management, and tracking native vegetation seedling survival and juvenile growth would be appropriate for a low-flow period that would be managed later in the season. Both of these are examples of evaluating the relationships between flow, immediate geomorphic, and short-term biotic responses. This information is used to validate or adaptively manage the flow prescription component and dam operations.

Many freshwater biotic elements have complex life histories and needs for specific habitat and environmental conditions. It is common for different threats to be limiting different life history stages – creating "bottlenecks" for their life histories. It is critical to define the specific habitat and environmental conditions, and the life-history stage and bottleneck that is responding to the flow component in order to evaluate whether managing for that flow component is addressing the specific threat to the specific life history stage.

Each flow prescription component has specific hypotheses regarding ecosystem responses associated with them. In the Savannah River flow prescription, tree seedling dispersal is associated with floods and high-flows, and juvenile tree recruitment is associated with low-flows. These are all immediate and short-term responses to flow management. However, an overall response of "increase in area of native floodplain vegetation" is not provided. Such a long-term ecosystem response from comprehensive environmental flow management could be an indicator of longer-term ecosystem status and trends, but may not provide valuable information for adaptive management. Why? If there was no increase in the area of native floodplain vegetation over several years, it *might* indicate that something in the flow prescription needs to be changed, but it would not indicate *which* component of the flow prescription needs to be adapted and *how*. Evaluating each flow component separately is necessary to understand to what extent each component is resulting in the ecosystem responses they were designed for, within the context of background variation and regional trends.

Monitoring for adaptive management needs to provide useful information about specific types of flow events within appropriate time frames to dam operators, such as if flow management needs to change and how, not just indicate that more information needs to be collected because an objective was not met. Some flow events need to be adaptively managed as they are taking place, and monitoring, evaluation and feedback are necessary in real-time to inform their management.

Monitoring the responses of unplanned dam releases can result in opportunistic “flow experiments” to refine existing models and flow prescriptions, or to structure models for flow prescription development. For instance, weather events may result in unscheduled high-flow releases to provide reservoir storage capacity. This approach has been taken in the Bill Williams River in Arizona to develop models and flow prescriptions from empirical data collected during several dam releases to inform flow prescriptions for managing beaver dams, riparian vegetation, and macro-invertebrate communities (See Shafroth et al 2009).

Other issues relevant to adaptively managing dam operations is whether implementing the environmental flow prescription is benefiting or limiting the capacity for dam operations to meet other needs, and if the ecosystem responses can be achieved with different magnitudes or durations of flow that may result in less constrains or benefits for other dam operations. For instance, the magnitude for high-flow pulses initially prescribed in order to maintain connectivity of off-channel aquatic habitats in Big Cypress Creek was 6,000cfs. Monitoring during the implementation of this component of the flow prescription revealed that flows of about 2,500cfs were sufficient, so the high-flow pulse component of the prescription has been revised (B. Moring, U.S. Geological Survey, *pers. comm.).*

Many predicted responses from environmental flow components define the types and direction of change, but not specific objectives for end-points. There is often insufficient knowledge to generate accurate predictions and informed objectives for many future conditions that will result from large-scale ecosystem manipulations (see Welcomme et al 2006). Therefore, many indicators could be used to evaluate directional changes *from* a baseline as opposed to progress *to* a specific objective. This approach acknowledges our limited knowledge and the need to evaluate and manage through collecting and evaluating data to learn and adaptively manage. If quantitative objectives can be set in an informed manner, indicators can and should be used to measure progress towards them.

Indicators should provide information on dominant ecosystem attributes, such as critical processes, structures, patterns, and energy transfer, and generally not focus on individual species, especially those that are rare and endangered. Some individual species are indicators of ecosystem responses to flow, but they should be selected carefully, and consideration should be given to whether they are good indicators of ecosystem characteristics and condition. Rare and endangered species are often in such status because of an array of stressors from multiple sources in addition to those from flow alteration, they often have few individuals and it is difficult to sample sufficient numbers for statistical analyses, and they may not be very responsive to environmental flows. Rare and endangered species measures can result in further distortion of flows at the expense of other ecosystem components if flows are being managed just for them (Rood et al 2005). State and federal agencies often want to include rare and endangered species as indicators for flow management. An inclusive approach would be to monitor them to see if they respond to environmental flows, but not use them as a primary indicator for adaptive management of environmental flows.

Overall indicators of ecosystem integrity or health, such as the Index of Biotic Integrity (IBI) or species diversity often integrate many other factors, may not be responsive only to changes in flow, are generally not responsive in the short-term, and will generally not provide information on the specific components of flow that are being managed for. They are not good indicators of specific short-term environmental flow components/ecosystem responses necessary to inform adaptive management.

Indicator selection should result in as few indicators as necessary to answer questions critical to adaptive management of dam operations for environmental flows. They should be driven by focused need, and not by a broad array of research interests.

Suggested criteria for indicators to inform adaptive management

- Relevant to evaluating the need for adaptive management, and providing information on how to adaptively manage flows.
- Will respond quickly and significantly to the component of the flow prescription – at spatial and temporal scales useful for guiding operational changes.
- Relate directly to a flow-ecology relationship stated in the flow prescription, and/or to a related habitat condition.
- Strongly affected primarily from the environmental flow component and not controlled to a significant level from other environmental factors or anthropogenic impacts to the environment that will constrain or influence their responses.
- Quantitative, continuous measures (i.e. not qualitative or categorical), easily measured and interpreted in relation to environmental flow management.
- Represent important structural and/or functional component of river and/or floodplain ecosystems.
- Cost-effective.
- Have scientific justification.
- Indicate potential risk for any variety of reasons.
- Can be communicated to appropriate audiences.

Below are some suggestions for indicators to be used in conjunction with measures of flow magnitude, duration and seasonality for evaluating immediate and short-term responses to inform validation, refinement and adaptive management of flow prescription components.

1. Floodplain indicators

- Changes in area and hydro-period of floodplain inundation.
- Changes in spatial extent, density of non-native vegetation species
- Changes in spatial extent and density of seedling germination of native plants in floodplain habitats
- Changes in fish movement into floodplain habitat
- Changes in fish recruitment in floodplain habitats
- Changes in bird species composition and abundance on floodplain

2. Riverine indicators

- Changes in river bed composition and distribution (e.g. sediment, cobble)
- Changes in distribution and abundance of in-stream habitats (e.g. Pool, riffle, run)
- Length of re-creation of riverine habitat from lentic habitat
- Changes in number, area of off-channel habitats (e.g. oxbows, distributaries, etc).
- Changes in longitudinal migration – changes in number of fish accessing newly available habitat
- Changes in flow-dependent life-stage metrics (e.g., # smolt per redd, number of nests of flow-dependent species)
- Changes in relative abundance, composition of invertebrate species or guild structure (e.g. from lentic to lotic specialist species or guilds)
- Changes in flow-dependent invertebrate life stage metrics (e.g., mussel recruitment to 2^{nd} year class)
- Changes in recruitment of invertebrate invasive species (e.g., *Corbicula*)
- Changes in temperature, suspended sediments, sediment transport, conductivity, salinity, nutrients, dissolved oxygen, chlorophyll *a*.

Suggested additional reading relevant to model development and monitoring short-term responses to flow management:

Brierley G, et al (2010). What are we monitoring and why? Using geomorphic principles to frame eco-hydrological assessments of river condition. Sci Total Environ doi:10.1016/j.scitotenv.2010.01.038

King A.J. et al (2010). Adaptive management of an environmental watering event to enhance native fish spawning and recruitment. *Freshwater Biology* 55, 17–31. doi:10.1111/j.1365-2427.2009.02178.x

Merritt, D. M. et al (2010) Theory, methods and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds. Freshwater Biology 55: 206–225. doi:10.1111/j.1365-2427.2009.02206.x

E. L. Petticrew, E. L., A. Krein, and D. E. Walling (2007). Evaluating fine sediment mobilization and storage in a gravel-bed river using controlled reservoir releases. *Hydrol. Process.* 21, 198–210 DOI: 10.1002/hyp.6183

Richter, B. D. and H. E. Richter (2000). Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. *Cons. Biol.* 14:1467-78

Rood et al (2003). Flows for floodplain forests: successful floodplain restoration. *BioScience* 53:647-56.

Rood et al (2005): Managing river flows to restore floodplain forests. *Frontiers in Ecology and Environment* 3:4 193-201.
http://classes.uleth.ca/200803/geog3090a/Field%20Trip%20Rood%20et%20al%202005.pdf

Rosi-Marshall et al (2010). Short-term effects of the 2008 high-flow experiment on macroinvertebrates in the Colorado River below Glen Canyon Dam, Arizona: U.S. Geological Survey Open-File Report 2010-1031, 28 p. http://pubs.usgs.gov/of/2010/1031/

Shafroth, P. B., et al (2009). Ecosystem effects of environmental flows: modeling and experimental floods in a dryland river. *Freshwater Biology doi:10.1111/j.1365-2427.2009.02271.x*

Watts R.J., D. S. Ryder, and C. Allan (2009). *Environmental monitoring of variable flow trials conducted at Dartmouth Dam, 2001/02-07/08 - Synthesis of key findings and operational guidelines.* Report to the Murray Darling Basin Authority. Institute for Land Water and Society Report Number 50, Charles Sturt University, Albury, NSW.
http://www.csu.edu.au/research/ilws/research/docs/WATTS_MITTA_2008.pdf

Weisberg, S. B. et al (1990). Enhancement of benthic macroinvertebrates by minimum flow from a hydroelectric dam. *Regulated Rivers Research & Management*, 5:265-277.

V. Monitoring to Assess Long-Term Ecosystem Status and Trends

Long-term monitoring in the SRP is intended to track types and degrees of directional change ("improvements") of characteristics of river and floodplain ecosystem condition that result from implementing environmental flow prescriptions. It is critical to document project success and to illustrate the benefits of environmental flow management. Many ecosystem characteristics integrate environmental changes and multiple anthropogenic impacts that take place over time, such as those from climate, land use, altered hydrology from sources other than dams, etc. as well as from the flow prescription that has been implemented. The strength of inference in making cause and effect linkages of flow/ecosystem trends will depend on the selection of appropriate indicators and sampling frameworks to account for the environmental flow/ecosystem responses in the context of natural variation and regional trends (next section).

Monitoring to illustrate ecosystem responses from environmental flow management requires a hypothesis-driven monitoring approach, which is distinct from surveillance monitoring. Surveillance monitoring tracks indicators on a regular basis for reporting status and trends in ecosystem condition, such as water quality, overall fish community composition and abundance, or integrated indices of integrity (e.g. the Index of Biotic Integrity). Surveillance monitoring is more concerned with assessing overall shifts in ecosystem condition rather than those that responded to flow management (King et al., 2010). Hypothesis- driven, causally-linked monitoring should be viewed and conducted quite separately from surveillance monitoring. This separation may only be in the selection of indicators, and a significant amount of sampling for both approaches may be conducted simultaneously to be more efficient, and/or some information from surveillance monitoring can be used to address flow/ecology relationships.

Indicators should be sufficiently responsive to flow management to evaluate the success of the flow management project (Richter et al. 2006). Environmental flows may be necessary but not sufficient to result in significant changes in many ecosystem attributes. River and floodplain ecosystems often have multiple stressors, and flow alteration may be one of several affecting environmental and ecological patterns and processes. Selecting indicators that will illustrate long-term change resulting from flow management must take into account bottlenecks imposed by stresses other than flow alteration, and avoid selecting indicators of attributes that are constrained in their responses from other stresses not addressed solely or primarily by environmental flows.

Suggested criteria for long-term monitoring indicators

- Will respond significantly to the flow prescription within the time frame necessary to report on project success.
- Not strongly limited in response by factors other than flow.
- Relate to ecosystem "improvement" goals
- Provide incremental directional change over time (are quantitative, continuous variables).
- Easily collected, interpreted, and communicated to appropriate audiences.
- Cost-effective.
- Have scientific justification.
- Indicate negative consequences or conflicts of environmental flow management.

Below are some examples of indicators that can be used for evaluating and reporting long-term changes that result from environmental flow management.

1. Floodplain indicators

- Changes in spatial extent, distribution of native floodplain forest/wetland vegetation communities

- Changes in spatial extent, distribution, or age structure of invasive vegetation species
- Changes in spatial extent, density, or age structure of select, flow sensitive native riparian/floodplain species (e.g. Bald Cypress, Cottonwood)
- Changes in species composition or abundance of floodplain specialist bird species, (e.g. diving duck species, duck usage days).
- Changes in presence/absence or abundance of floodplain vegetation specialist bird species.
- Changes in abundance or average size/weight of floodplain dependent fish species

2. Riverine indicators

- Changes in abundance, biomass, age structure or spatial extent of flow-sensitive fish species.
- Changes in abundance, biomass or spatial extent of flow-sensitive invertebrate species.
- Changes in composition of community guild structure in relation to flow, e.g. shifts from lentic to lotic guild structure (e.g. flow-sensitive reproductive guilds in fish, invertebrate guilds sensitive to flow and sources of energy (e.g. filter feeders/scrapers, net spinners).
- Changes in spatial extent, age structure of invasive species.

Additional considerations for selecting indicators

The purpose of monitoring is not to track everything possible and hope for significant responses in a few indicators. Resources for monitoring are generally limited, and hypotheses-driven questions and responses should drive indicator selection. There is a tension between defining few, informative indicators for long-term responses and for adaptive management, with those that could be useful for contributions to basic understanding of the flow/ecology linkages in river and floodplain ecosystems, and those that could contribute to a growing body of evidence of benefits of environmental flow management. Given the limited data on environmental flow/response relationships, it seems reasonable to assume that any appropriate indicators and defensible results obtained from monitoring for adaptive management and long-term ecosystem improvements will contribute to basic science, and to evidence of benefits of environmental flow management. The latter requires reporting results in units common to other sites, and not necessarily additional monitoring.

Suggested additional reading on monitoring long-term ecosystem responses to flow management:

Connor and Pflug (2004) Changes in the Distribution and Density of Pink, Chum, and Chinook Salmon Spawning in the Upper Skagit River in Response to Flow Management Measures. *North Amer. Journ. of Fish. Manage* 24: 835-852.

King, A. J, Z. Tonkin and J. Mahoney (2010).Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. River. Res. Applic. 25: 1205–1218.
DOI: 10.1002/rra.1209

Opperman, J. J. et al (2010) Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale. Journal of the American Water Resources Association (JAWRA) 1-16. DOI: 10.1111 / j.1752-1688.2010.00426.x

Propst, D. L., and K. B. Gido (2004) Responses of native and nonnative fishes to natural flow regime mimicry in the San Juan River. Transactions of the American Fisheries Society 133:922–931 http://www.k-state.edu/fishecology/msreprints/Propst%20and%20Gido%202004.pdf

Robinson, C. T., and U. Uehlinger (2008) Experimental floods cause ecosystem regime shift in a regulated river. Ecological Applications, 18(2), 2008, pp. 511–526.

Rood et al (2003) Flows for floodplain forests: successful floodplain restoration. *BioScience* 53:647-56.

Rood et al (2005) Managing river flows to restore floodplain forests. *Frontiers in Ecology and Environment* 3:4 193-201.
http://classes.uleth.ca/200803/geog3090a/Field%20Trip%20Rood%20et%20al%202005.pdf

VI. Designs and Additional Considerations for Monitoring

The strength of evidence necessary for the task at hand, as well as accessible historic data, opportunities for control and reference sites, capacity, funding, and logistical constraints will determine monitoring designs. The degrees of required statistical rigor of results need to be determined with stakeholders and decision makers before designing a monitoring framework. Conflicts in expected rigor and the realities of constraints should be evaluated cautiously and resolved before moving forward.

Monitoring can be structured to make a variety of comparisons, resulting in different analytical strength. Several definitions are necessary before describing monitoring frameworks. The definitions below are derived from Cottingham et al (2005):

Impact/intervention sites are those sites where environmental flow management is implemented.

Control sites are those sites that are similar ecologically and have similar types of flow alterations to impact sites, but where environmental flows are not being implemented. Control sites are more useful if they are in neighboring rivers separate from the river with the impact site, but comparisons upstream/downstream from reservoirs can sometimes be used.

Reference sites are those sites that are similar ecologically to impact sites and are as near to natural conditions (undisturbed by human impacts) as possible. Reference sites are useful for providing indicator values for river restoration or for directional change for river rehabilitation.

Before/After monitoring is conducted to collect indicator data before and after environmental flow management has taken place. It can be conducted at impact, control, and reference sites for comparisons within and among them.

Cottingham et al (2005) provide 8 alternative monitoring frameworks to evaluate responses to environmental flows, listed in increasing strength of inference:

1) ***Intervention-only design***. An environmental flow prescription has already been implemented (no before-intervention data exist) and there are no spatial 'controls' or reference sites being used for comparison, monitoring is limited to the river where environmental flows have been implemented. These responses can be evaluated against specific predictions based on the conceptual model. Causal links between temporal change in ecological response and flow are difficult if not impossible to determine because the change might have occurred without the environmental flow.

2) ***Reference–Intervention design*****.** A modification of (1) above, where there are no before-intervention data but the same indicators are monitored through time in a reference system, i.e. one that is much less flow-modified and represents the desired direction of change for the intervention site. This design provides slightly better evidence for causal link between temporal change in response and flow, because natural changes through time can be measured at reference sites. It is also possible to assess whether the trend of change at the intervention location is towards the reference condition, if that is desired.

3) ***Control–Intervention design***. Similar to (2) above except that comparison is with a 'control' system, i.e. a river system similarly flow-modified to the intervention system but without environmental flows being implemented. This design provides stronger inference about causality because comparison with the spatial 'control' reduces the likelihood of flow effects being statistically confounded with natural change.

4) ***Control–Reference–Intervention design***. This is a combination of (2) and (3) above. Statistical analyses test for divergence in temporal trends between the intervention and the 'control', and for convergence in temporal trends between the intervention and the reference location. This design provides causal strength similar to (3), with the added advantage of assessing whether the trends are towards reference conditions, if that is desired.

5) ***Before–After–Intervention design***. This is a standard 'intervention analysis' design comparing indicator values before versus after intervention. The 'before' data provide baseline or temporal 'control' conditions. Evidence for causal links is limited by lack of spatial 'controls', therefore it is unclear whether or not the change after the environmental flow intervention would have occurred independently of the environmental flows. This design is also difficult to use if an environmental flow regime is implemented gradually, or if the flow prescription is not very different from the altered hydrologic regime, thus not providing a definitive point in time when flow regime is significantly changed due to environmental flow management.

6) ***Before–After Reference–Intervention (BARI) design***. This is similar to (5) but with a spatial component - a reference site that provides some measure of whether natural changes coincide with changes seen in the intervention site. This design also allows assessment of whether the trend of a response is towards the reference condition. The test of interest is whether any before–after difference at the intervention location is the same as at the reference location. The causal inference associated with this design is limited because the reference site and the intervention site have different conditions prior to the intervention. This makes it difficult to rule out a response to other factors at the intervention site coinciding with the start of the environmental flow.

7) *Before–After Control–Intervention (BACI) design*. Similar to (6), but using a spatial 'control' site instead of a reference site. This design provides strong inference about causality because comparisons with spatial and temporal 'controls' reduces the likelihood of confounding flow effects with natural spatial and temporal changes.

8) *Before–After Control–Reference– Intervention (BACRI) design*. A combination of (6) and (7) that provides strong evidence for causal links between flow management and response, and also measures whether the change is towards reference condition, if that is desired.

Note: Designs involving control– intervention contrasts are improved by having multiple 'control' streams, e.g. MBACI designs (see Downes et al. 2002).

In addition to the designs listed above, sampling in a spatial longitudinal series with increasing distance from the dam that is releasing environmental flows can be a valuable component of sampling design. This design component can contribute to pressure/response analyses, even for a single flow event within a single river system, as the impact from decays in magnitude of the flow event will change with distance from the dam. Additionally, it should be used to evaluate the spatial extent of the influence of environmental flows on river ecosystems.

There are obviously numerous experimental designs that can be chosen. Regardless of the one that is selected, it is critical to have a point person identified who will manage the process and communicate among participants, work with others to define the strengths and weaknesses of the design, understand the questions that can be addressed, and the statistical analyses that will be employed before collecting data. A statistician and experimental design expert should be consulted before monitoring begins in order to define the appropriate number of replicate samples and to ensure data independence where necessary.

Cottingham et al (2005) suggest 4 broad analytical approaches of indicators:

1) Detection of temporal trends in key response variables at selected locations. Analyses include time-series and linear model methods, where the response variable is modeled against time.
2) Specific temporal contrasts between sets of years or between before and after a particular flow event. Such temporal contrasts can be analyzed using ANOVA designs.
3) Comparison of reaches (spatial contrasts), which if incorporating 'before' and 'after' comparisons may also be analyzed using ANOVA designs.
4) Multivariate comparison of assemblages of organisms such as macro-invertebrates or fish. Ordination methods (e.g. multidimensional scaling using dissimilarity indices such as Bray–Curtis) with specific spatial (between reach) and temporal (between years or before and after events) contrasts using ANOSIM (analysis of similarity) or NPMANOVA (nonparametric multivariate analysis of variance).

In addition to the analytical approaches described above, Bayesian hierarchical analyses provide an approach that can increase inferential strength of environmental flow/ecological response relationships in data-poor situations using non- replicated sampling units (See Webb et al. 2010). However, even the most powerful statistics are limited by the amount of data that are available and the methods and framework in which they were collected. It is critical to plan for and design statistical approaches and monitoring frameworks before collecting data.

VII. Capacity, Managing Data, and Reporting Results

Given limited resources and capacities, monitoring and data analyses are generally achieved through collaborations. These collaborations should be managed to focus on specific questions and data needs, and not opened up to broader research interests unless the core needs are first met. Some institutional frameworks – such as a multi-agency technical committee – should be in place to help coordinate monitoring. Even where these are informal, they have been shown to be effective in coordinating with other monitoring efforts including allocation of resources, minimizing conflicts, and achieving more lasting and constructive changes in management.

A coordinator with a clear understanding of data needs should be selected to manage the process of bringing in experts in monitoring designs and approaches, statistical analyses, data management, and sampling logistics. Monitoring and analytical approaches should be peer-reviewed before initiating data collection. Results must be made available in time-frames sufficient to inform the needs identified in the monitoring plan. Funding to collaborators should be structured in contracts with clearly stated deliverables and time frames. Data storage and management should be addressed before monitoring is initiated, with access limitations clearly articulated if any issues are identified. Sites requesting funding from the Sustainable Rivers Project will be required to fill out a simple template as part of the proposal. See *Appendix A* for proposal templates for monitoring for adaptive management and monitoring for long-term ecosystem trends.

Results intended to inform adaptive management should be reported to dam operators in understandable language with proposed changes to flow prescriptions clearly defined. Results from long-term ecosystem responses should be reported to stakeholders and partners, and to the Sustainable Rives Project coordinator for inclusion in reports on overall project success. All results should be published in peer-reviewed journals to provide greater credibility and access to the broader environmental flow research and implementation community.

Suggested additional reading on approaches to developing and implementing monitoring plans for evaluating ecosystem responses to flow management:

Army Corps of Engineers, US (1995) Water Quality and Environmental Management for Corps Civil Works Projects (Reports Control Symbol DAEN-CWH-4) ER 1110-2-8154. Department of the Army, U.S. Army Corps of Engineers, Washington, DC 20314-1000. http://140.194.76.129/publications/eng-regs/er1110-2-8154/entire.pdf

Chee Y.E., J. A. Webb, M. Stewardson, and P. Cottingham (2009) Victorian environmental flows monitoring and assessment program: Monitoring and evaluation of environmental flow releases in the

Broken River. Report prepared for the Goulburn Broken Catchment Management Authority and the Department of Sustainability and Environment by eWater Cooperative Research Centre, Canberra. This document can be accessed at: http://www.ewater.com.au/reports/ewater-crc-report_VEFMAP_Broken-River.pdf

Cottingham P. et al (2005) *Environmental Flows Monitoring and Assessment Framework*. Technical report. CRC for Freshwater Ecology, Canberra. http://freshwater.canberra.edu.au/Publications.nsf/0/b217ed362dcbc90bca256fc7001cf693?OpenDocument

King, A.J., et al (2003) Monitoring programs for environmental flows in Australia – A literature review. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment; Sinclair Knight Merz; Cooperative Research Centre for Freshwater Ecology and Monash University. http://www.dse.vic.gov.au/CA256F310024B628/0/A38A91C573F7A831CA25714C0015F160/$File/Monitoring+Programs+for+Environmental+Flows+in+Australia-Literature+Review+2003.pdf

Manring, S., and S. Pearsall (2004) Creating an adaptive ecosystem management network among the stakeholders of the lower Roanoke River, North Carolina, USA. *Ecology and Society* **10**(2): 16. http://www.ecologyandsociety.org/vol10/iss2/art16/

Merritt D.M. et al (2010) Theory, methods and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds. Freshwater Biology, 55, 206–225. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2427.2009.02206.x/pdf

Nichols, J. D., and B. K. Williams (2006) Monitoring for Conservation. *Trends in Ecology and Evolution*. 22:12 668-673. doi:10.1016/j.tree.2006.08.007

http://www.restoresjr.net/flows/atr.html
The San Joaquin River Restoration Program is implementing and monitoring the ecosystem responses of flow prescriptions. This web-site provides access to information on organization, management, monitoring and reporting for the program. It illustrates good planning and transparency in how the project is planning and carrying out their work. It provides details on ecological models, monitoring approaches for flow, and for floodplain and river habitats and biota, and reporting summaries and communication materials.

Welcomme R.L., K. O. Winemiller, and I. G. Cowx (2006) Fish environmental guilds as a tool for assessment of ecological condition of rivers. River Research and Applications, 22, 377–396.

VIII. Reporting site-level results for programmatic roll-up

The SRP is required to report overall status, progress, and results to several managing entities, and can be more effective in obtaining continued support if summary measures are provided that are simple and easy for them to understand. Programmatic indicators do not provide site-level details. They summarize status and progress of all sites using common reporting units. SRP reports would be enhanced if they included: the number of dams participating in the SRP, the stage they each are in developing/implementing environmental flows, which components of environmental flow prescriptions are being implemented, the degree to which environmental flow prescriptions are being implemented, the estimated scope of impact (length of river, area of floodplain, estuary) that environmental flow management will have, and the number of ESA listed species and scope of critical habitats that are estimated to benefit from them. Each site in the SRP will report these attributes.

Sites will report the types, degrees, and scope of impacts to verify the projected scope of impacts and to document those impacts. Results will also be used to illustrate the benefits of environmental flow management to other dam operators within and external to the Corps to expand the implementation of environmental flows more broadly.

The process of defining and implementing environmental flows can be summarized as consisting of four stages, and any site can be categorized as to which stage it is in at a particular point in time. Sites should report which of stage they are in at the end of a reporting period (e.g., annually):

Initiating Process - An agreement is being developed between a Corps district or site, and partner(s) to collaborate on the ESWM process, and initial meetings are being held to engage partners and key stakeholders such as state and federal agencies, tribes, non-governmental organizations, academic institutions, and private industry.

Defining Environmental Flows - Critical components of natural flow regimes are described (e.g. floods, high-flow events, low flows) and flow/ecosystem response models are developed to describe hypotheses regarding relationships among flow, geomorphic, and ecological dynamics. A quantitative environmental flow prescription is defined (magnitude, duration, seasonality, and frequency within and among years) to achieve specified ecosystem responses associated with each flow component. Detailed flow/ecosystem response models and water management models are developed. A monitoring plan is developed to evaluate ecosystem responses to implementing environmental flows.

Validating/Adapting Environmental Flows - Components of the environmental flow prescription are implemented, monitored, and evaluated to validate/adaptively manage them to achieve desired short-term ecosystem responses in the context of other designated purposes of dam operations such as flood control, water supply, hydropower, and recreation.. Modifications are made to the flow prescription as needed.

Implementing Environmental Flows - The environmental flow prescription is incorporated into a revised water control plan for the dam. These flows are implemented and monitored, and long-term status and trends of ecosystem condition are reported in the context of environmental flow management.

The component of the flow prescription being implemented (e.g., a high-flow event) will be reported when sites are in the validating/adapting environmental flows stage. The degree to which environmental flow prescriptions are being implemented (% of each flow component implemented) will be reported for sites in the Implementing Environmental Flows stage.

In addition to the types and degrees of ecosystem responses, the observed scope of impact (responses) from environmental flow management should be assessed. Longitudinal monitoring along river length downstream from a given dam, and monitoring area of floodplain and estuary habitats are necessary to validate the projected scope of impact that are estimated, often using simulation models. Reporting the types and degrees of responses document the suite of benefits taking place at a site, and will be used to summarize the suite of benefits that are resulting from environmental flow management in the SRP. Additional reporting of ESA listed species and critical habitats that are benefiting from environmental flow management provides the Corps well deserved credit, and potential opportunities for additional funding.

A template for reporting site-level results is provided in Appendix D.

Citations

Cottingham P. et al (2005) *Environmental Flows Monitoring and Assessment Framework*. Technical report. CRC for Freshwater Ecology, Canberra.

King A.J. et al (2010) Adaptive management of an environmental watering event to enhance native fish spawning and recruitment. *Freshwater Biology* 55, 17–31

Konrad, C.P. (2010) Monitoring and evaluation of environmental flow prescriptions for five demonstration sites of the Sustainable Rivers Project, U.S. Geological Survey Open-File Report 2010-1065, 21 p.

Richter, B.D., A.T. Warner, J.L. Meyer, and K. Lutz (2006) A collaborative and adaptive process for developing environmental flow recommendations. *River Research and Applications* 22: 297-318.

Rood et al (2005) Managing river flows to restore floodplain forests. *Frontiers in Ecology and Environment* 3:4 193-201.

Shafroth, P. B., et al (2009) Ecosystem effects of environmental flows: modeling and experimental floods in a dryland river. *Freshwater Biology doi:10.1111/j.1365-2427.2009.02271.x*

Schreiber, S. and P. Cottingham (2000) *Approaches to validating the effectiveness of habitat rehabilitation in rivers: a literature review*. CRC for Freshwater Ecology. Murray-Darling Basin Commission, Canberra, Australia. Riverine Project R1.

Webb, A. J., M. J. Stewardson, and W. M. Kostner (2009) Detecting ecological responses to flow variation using Bayesian hierarchical models. *Freshwater Biology* doi:10.1111/j.1365-2427.2009.02205.

Welcomme R.L., K. O. Winemiller, and I. G. Cowx (2006) Fish environmental guilds as a tool for assessment of ecological condition of rivers. *River Research and Applications*, 22, 377–396.

Appendix A

Links to helpful guidance documents and web-sites for developing monitoring approaches for floodplain, estuary and river habitat restoration/rehabilitation projects

http://www.doi.gov/initiatives/AdaptiveManagement/TechGuide.pdf
U.S. Department of the Interior Adaptive Management Technical Guide provides technical guidance for monitoring and using adaptive management in decision making.

http://water.epa.gov/type/oceb/nep/upload/2009_03_13_estuaries_wholeguidance.pdf
This document provides guidance on the design, implementation, and evaluation of the required monitoring programs the National Estuary Program. This document should also be of use to others developing monitoring programs. The intended audience is the members of the management conference (i.e., the Management Committee, Scientific and Technical Advisory Committee, and the Citizens Advisory Committee) and the program coordinators and scientific staff of the individual estuary programs. The purpose of this document is to identify the steps involved in developing and implementing estuarine monitoring programs. Given the large number of participants in the management conference and the diversity of technical backgrounds, it is also intended to provide a technical basis for discussions on the development of monitoring program objectives, the selection of monitoring program components, and the allocation of sampling effort. While defined as outdated, it provides valuable guidance for developing a monitoring program.

http://www.pwrc.usgs.gov/monmanual/
This is designed to be a readily understood guide to the concepts, philosophies, and approaches that must be contemplated when designing a new monitoring program or in evaluating an existing one. The intended audience is biologists, managers, and anyone contemplating the creation of a monitoring program. The focus is on promoting a conceptual understanding of the "whys" and "hows" of monitoring the status of wildlife species and communities rather than on the details. It cover topics regarding site selection, layout of points/plots, numbers of samples to take, which species to choose, adaptive management versus status monitoring issues and an expanding listing of counting techniques, detailing the pros, cons, and biases associated with each. Subsets within this site, such as:
http://www.pwrc.usgs.gov/monmanual/management.htm provides approaches and examples of monitoring to support adaptive management.
http://www.pwrc.usgs.gov/monmanual/longtermchange.htm provides similar guidance for longer-term status and trends monitoring. While this manual is not focused on freshwater, it does provide excellent guidance on why and how to structure a monitoring program.

http://www.usace.army.mil/CECW/ERA/Pages/monitor_db.aspx
The Army Corps of Engineers provides monitoring criteria and links to guidance documents and tools for designing and implementing an estuary restoration monitoring program.

http://140.194.76.129/publications/eng-regs/er1110-2-8154/entire.pdf

Army Corps of Engineers, US (1995) Water Quality and Environmental Management for Corps Civil Works Projects (Reports Control Symbol DAEN-CWH-4) ER 1110-2-8154. Department of the Army, U.S. Army Corps of Engineers, Washington, DC 20314-1000.

This is the Corps' policy statement for protecting, maintaining and restoring freshwater resources as defined as "water Quality" (which includes chemical, physical and biological characteristics). It includes policy statements on commitment, management, monitoring objectives and efforts, engineering and design, uses of monitoring information, reporting, and funding. This provides very clear and explicit authority for managing freshwater resources, and collecting, evaluating and using monitoring data to support efforts to do so.

http://baydelta.ucdavis.edu/reports/final/chapter2
Floodplain Restoration Success Criteria and Monitoring. Joshua H. Viers, Ingrid B. Hogle, James F. Quinn
To better understand how restoration of riparian vegetation is influenced by a variety of factors, such as physical processes, especially inundation, and the multiple methods of restoration (both active and semi-passive) that land managers have used in the Cosumnes floodplain, we developed four complementary approaches to addressing different facets of assessing restoration outcomes. Embedded within this overall objective, we are interested in understanding of the spatial dynamics inherent to riparian vegetation across multiple scales, and how this information can help inform restoration efforts in the California Bay-Delta region.

http://baydelta.ucdavis.edu/files/crg/reports/Resto_Viersetal2006b.pdf
Monitoring Riparian Restoration: Making the most with limited data from the Cosumnes River Floodplain. Joshua H. Viers, Ingrid B. Hogle, James F. Quinn

Few of California's Central Valley riparian forests remain and are thus the focus of ongoing, large-scale restoration efforts. However, few formal programs are established to monitor restoration outcomes. We collected and synthesized planting and monitoring records from the last 20 years (1985-2005) of restoration actions conducted at the Cosumnes River Preserve, which has one of the largest extant riparian forest expanses in the Central Valley and has been the subject of ambitious efforts by multiple land managers to re-establish native riparian and floodplain vegetation. We cataloged and spatially indexed monitoring data from notes, reports, dissertations, publications and personal communications with reserve managers into a geographical information system (GIS). Our GIS-based retrospective analysis of restoration activities was enabled by collation of lists of species planted, methods of planting, and management methods, such as irrigation, weed control, and protection from herbivores. We analyzed germination rates, seedling survival, and growth rates for monitoring records across 76 separate restoration locations. Our results indicate that hydrologic regime, soil composition, and to a more limited degree management actions are instrumental in ensuring germination, survival, and rapid growth of riparian forests. Furthermore, the expansive effort required to capture these data retrospectively suggests that future and ongoing restoration efforts should be accompanied by robust monitoring programs with standardized data collection and storage requirements.

http://www.era.noaa.gov/information/monitor.html
NOAA developed standard monitoring protocols for estuary habitat restoration projects, as directed by the Estuary Restoration Act (ERA). These protocols allow for evaluation of restoration success. This web-site provides links to NOAA estuary ecosystem monitoring resources, ecological monitoring studies, and socioeconomic monitoring studies.

http://avianscience.dbs.umt.edu/documents/projects/Odell_2007_finalreport.pdf
EVALUATING HABITAT RESTORATION AT O'DELL CREEK USING BIRD COMMUNITIES: 2007 REPORT
AMY CILIMBURG, ROBERT FLETCHER, AND RICHARD HUTTO
Avian Science Center Division of Biological Sciences, University of Montana
This report provides a rigorous sampling and monitoring approach to evaluating riparian restoration at O'Dell Creek in Montana using bird community characteristics to interpret restoration success. It is a brief, yet well reported summary of the approaches and results. Although riparian habitats are generally restricted in Western river systems, they provide critical habitat for a wide variety of birds, many which are habitat specialists.

http://www.nwcouncil.org/dropbox/2008amend/cbfwa/Section_2/Sec2.1.5RM&E/Hillman_2005.pdf
PROJECT MONITORING: A GUIDE FOR SPONSORS IN THE UPPER COLUMBIA BASIN
Tracy W. Hillman, BioAnalysts, Inc. Boise, Idaho

This guide provides minimum monitoring requirements for assessing effectiveness of restoration projects. It provides techniques, monitoring plans and examples for monitoring restoration of riparian, floodplain, and in-stream habitats, connectivity, and diversions, and for acquisitions and conservation easements.

http://forestry.berkeley.edu/comp_proj/DFG/Monitoring%20the%20Effectiveness%20of%20Riparian%20Vegetation%20Restorat.pdf
Harris, R.R., S.D. Kocher, J.M. Gerstein and C. Olson. 2005. *Monitoring the Effectiveness of Riparian Vegetation Restoration*. University of California, Center for Forestry, Berkeley, CA. 33 pp.

This report includes recommendations for study design and methods for data collection. It is assumed that this report will be used as a guide for preparing monitoring study plans. The field methods presented are for monitoring the effectiveness of riparian restoration during the initial and intermediate stages of establishment and community development at the site and stream reach scales.

http://faculty.washington.edu/philroni/FSH428/Navigation%20Index/Assignments/Assignment%206/CH6_Pess_et_al_Floodplains.pdf
Chapter 6 - Monitoring Floodplain Restoration. In: Monitoring stream and watershed restoration. Philip Roni, Ed Quimby, American Fisheries Society

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The objective of this book chapter is to describe how to monitor the effectiveness of floodplain-associated projects that attempt to reconnect isolated habitats. The authors identify and briefly review common effects of anthropogenic disturbance to floodplains and restoration techniques used to reconnect floodplain habitats isolated by anthropogenic disturbance. Next, they discuss how developing a monitoring plan based upon clear restoration goals and objectives can be used to help guide the monitoring of individual or multiple floodplain reconnection projects. Then, they discuss the selection of physical and biological study parameters and sampling protocols that can be applied to different types of restoration approaches. Finally, they provide recommendations for applying these monitoring techniques to temperate rivers.

http://your.kingcounty.gov/dnrp/library/2008/kcr2017/Green-River-restoration-monitoring-report.pdf
Latterell, J. J., 2008. Baseline monitoring study of restoration effectiveness in the Green River (mile 32): processes and habitats in the channel and floodplain. King County Department of Natural Resources and Parks, Water and Land Resources Division, Seattle, WA
This report provides detailed information on monitoring approaches, techniques, and results for defining baseline conditions before restoration of channel and floodplain habitats from levee setbacks.

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15793.pdf
Roegner, G.C., H.L. Diefenderfer, A.B. Borde, R.M. Thom, E.M. Dawley, A.H. Whiting, S.A. Zimmerman, and G.E. Johnson. 2008. *Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary.* PNNL-15793. Report by Pacific Northwest National Laboratory, National Marine Fisheries Service, and Columbia River Estuary Study Taskforce submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.
In this document, the authors summarize the types of restoration strategies being planned and implemented in the CRE. They then propose a set of metrics and statistical design for restoration monitoring activities based on commonly shared ecological goals. Finally, they provide specific protocols for this set of estuary monitoring metrics. Monitoring protocols are provided for hydrology (water surface elevation); water quality (temperature, salinity); elevation (topography); landscape features (remote sensing); plant community (composition and cover); vegetation plantings (success); and fish community (species, temporal presence, size/age structure).

http://www.epa.gov/quality/qs-docs/g5s-final.pdf
This document, *Guidance for Choosing a Sampling Design for Environmental Data*

Collection (EPA QA/G-5S), will provide assistance in developing an effective QA Project Plan as described in *Guidance for QA Project Plans (EPA QA/G-5)* (EPA 1998b). QA Project Plans are one component of EPA's Quality System. This guidance is different from most guidance in that it is not meant to be read in a linear or continuous fashion, but to be used as a resource or reference document. This guidance is a "tool-box" of statistical designs that can be examined for possible use as the QA Project Plan is being developed.

http://www.epa.gov/nheerl/arm/
This Web-site provides information on monitoring of aquatic resources in the US, primarily focused on design and analysis of probability based surveys. Links are provided to other aquatic resources monitoring information available on the internet. This web site is designed to provide users needing information in several areas:

1. Introductory, conceptual and overview information on the overall approach, concepts and benefits.
2. Program level information on details of the approach, requirements, alternatives and examples.
3. Technical level information on the design and analysis details, including access to example data sets, results and statistical algorithms.
4. Implementation Issues, Indicators, and Field Manuals
5. Presentation and training materials
6. Reference information, internet links, brief descriptions of Federal, State, Tribal monitoring and research programs on aquatic resource monitoring.
7. Related publications and documents and program links.

http://www.nbii.gov/portal/server.pt?open=512&objID=819&mode=2&in_hi_userid=2&cached=true
The National Resources Monitoring Partnership is a web-based source of monitoring protocols, assessment methods, and locator of current monitoring and evaluation projects of members of the partnership.

http://search.usgs.gov/results.html?cx=005083607223377578371%3Ab5ixbbpqpx0&cof=FORID%3A11&q=monitoring+guidance&sa=Search#1010
This is a USGS web-link to a variety of monitoring guidance documents, technical reports, and project reports.

http://water.usgs.gov/nawqa/protocols/bioprotocols.html
Links to USGS National Water Quality Assessment program (NAWQA) laboratory and field sampling protocols for assessing stream biota and habitats.

http://www.cnr.usu.edu/wmc/
The Western Center for Monitoring and Assessment of Freshwater Resources web-resource sponsored by Utah State University. The Center provides three web-based resources to the ecological assessment community.

- The **Bioassessment** module provides a brief review of the ecological assessment literature as applied to freshwater ecosystems.

- The **Predictive Models** module describes the theory and application of predictive models as used in ecological assessments (Primer) as well as a summary of how to use existing models build custom models (Using and Building Models). The third component of this module (Predictive Models Software) provides a link to our web-based software that runs predictive models and generates both O/E and Bray-Curtis indices that quantify biotic condition at assessed sites.
- The **Data** module provides access to a query tool that allows users to download biological and environmental data associated with thousands of study locations that have been entered into their database. The database includes samples processed by the BML/USU Buglab, NAWQA stream reference site data, data used in the National Wadeable Streams Assessment, PACFISH/INFISH (PIBO) data, and various State data.

http://www.nwrc.usgs.gov/library.htm
The USGS National Wetlands Research Center Library holdings consist of approximately 11,000 books, documents, videos, sound records, maps, computer files/data bases, microfiche, directories, and technical reports; approximately 125 periodical subscriptions; and vertical files of pamphlets and resource materials for educators. The collection is comprehensive in U.S. Fish and Wildlife Service, National Biological Service, and USGS Biological Resources Division technical reports. Other state and federal reports considered as grey literature are included in the collection, and the entire collection is cataloged in the center's online library catalog and WorldCat, the Online Computer Library Center, Inc. (OCLC) Online Union Catalog.

http://www.usgs.gov/pubprod/
The USGS Maps, Imagery and Publications web-site provides links to technical approaches, tools and data useful for a wide-range of monitoring needs.

https://neri.noaa.gov/neri/index.htm
The National Estuaries Restoration Inventory (NERI) has been created to track estuary habitat restoration projects across the nation. The purpose of the inventory is to provide information on restoration projects in order to improve restoration methods, as well as to track acreage restored toward the million-acre goal of the Estuary Restoration Act. The purpose of the inventory is to provide monitoring and techniques information to advance restoration science track the acres of habitat restored toward the one million acre goal of the Act provide information for reports transmitted to Congress. The inventory contains information on projects funded through the ERA as well as other projects that meet minimum requirements. Project managers may submit data to the inventory through a user-friendly web site. Information on projects in the inventory is available to the public through project searches and reports, as well as through an interactive mapping application. Benefits of using NERI for project managers include:

- Track and manage your organization's projects
- Produce project-specific reports or generate summary reports based on selected criteria
- Increase public awareness and promote participation in restoration projects

- Maximize project partnership opportunities
- Use search capabilities and the Restoration Project Mapper to locate other regional restoration efforts to assist in future restoration planning and design

http://www.usace.army.mil/CECW/ERA/Pages/reps_congress.aspx
The Army Corps of Engineers provides reports to the U.S. Congress on estuary restoration projects. In response to section 108 of the **Estuary Restoration Act** (Act), as amended, the Secretary of the Army's designee submits periodic reports to Congress describing the activities carried out under the Act. These reports are prepared in consultation with the members of the **Estuary Habitat Restoration Council**. The reports contain information about projects funded, acres restored, the database established in response to this Act and other information related to implementation of the Act. It provides links to the three reports provided so far. It illustrates the reporting of length of river, area of wetland and estuary habitat, and phases of project implementation as central to the site-based and overall project measures reported to Congress.

Helpful Journal Articles

http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2008.01593.x/abstract

Paillex, A., Dolédec, S., Castella, E. and Mérigoux, S. (2009), Large river floodplain restoration: predicting species richness and trait responses to the restoration of hydrological connectivity. Journal of Applied Ecology, 46: 250–258. doi: 10.1111/j.1365-2664.2008.01593.x

http://forecaster.staging.gisinternet.nl/index.php?title=Main_Page
The FORECASTER web-based tool is a knowledge and information system relating hydromorphology and ecology of European rivers and has been developed as part of the project FORECASTER funded by the IWRM-Net and Delft Cluster. The system presents a compilation of case studies describing the output from restoration and rehabilitation projects and is intended to help practitioners by presenting experiences about success or failure of the application of different measures. The system is set up as a GEO-WIKI. Google maps are used as a gateway to the case studies and wiki pages are used to present relevant information about the implementation of the projects. Users can consult the tool either geographically or by theme using filter or free search options. Moreover, they can contribute to improve the information in the system by adding or updating relevant information in the wiki pages

http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2005.01004.x/full

PALMER, M., BERNHARDT, E., ALLAN, J. D., LAKE, P., ALEXANDER, G., BROOKS, S., CARR, J., CLAYTON, S., DAHM, C. N., FOLLSTAD SHAH, J., GALAT, D. L., LOSS, S. G., GOODWIN, P., HART, D., HASSETT, B., JENKINSON, R., KONDOLF, G., LAVE, R., MEYER, J., O'DONNELL, T., PAGANO, L. and SUDDUTH, E. (2005), Standards for ecologically successful river restoration. Journal of Applied Ecology, 42: 208–217. doi: 10.1111/j.1365-2664.2005.01004.x

http://onlinelibrary.wiley.com/doi/10.1002/rra.911/abstract
Florsheim, J. L., Mount, J. F. and Constantine, C. R. (2006), A geomorphic monitoring and adaptive assessment framework to assess the effect of lowland floodplain river restoration on channel–floodplain sediment continuity. River Research and Applications, 22: 353–375. doi: 10.1002/rra.911

http://www.mdpi.org/sensors/papers/s7091916.pdf
Assefa M. Melesse, Vijay Nangia, Xixi Wang and Michael McClain. 2007. *Wetland Restoration Response Analysis using MODIS and Groundwater Data*. *Sensors 7*, 1916-1933.

http://www.restoresjr.net/flows/atr.html
The San Joaquin River Restoration Program is implementing and monitoring the ecosystem responses of flow prescriptions. This web-site provides access to information on organization, management, monitoring and reporting for the program. It illustrates good planning and transparency in how the project is planning and carrying out their work. It provides details on ecological models, monitoring approaches for flow, and for floodplain and river habitats and biota, and reporting summaries and communication materials.

http://www.habitat.noaa.gov/restoration/techniques/srmonitoring.html
National Marine Fisheries Service provides a summary of monitoring approaches for structural and functional attributes of rivers and streams.

http://www-personal.umich.edu/~dallan/pdfs/Jenkinson_2006.pdf
This paper provides web-site addresses of databases that contain information on river restoration projects. The information in these databases varies, but can be useful in providing examples of what worked and what did not, costs, monitoring approaches, etc.

http://drc.ohiolink.edu/handle/2374.OX/6489
This paper provides modeling and remote sampling techniques to evaluate habitat suitability for fish and invertebrate species in relation to dam removal. While removal of a dam is not the intervention implemented in the SRP, it is relevant since the dam removal resulted in changes in flow and habitat suitability.

http://forestry.berkeley.edu/comp_proj/DFG/Monitoring%20the%20Effectiveness%20of%20Instream%20Substrate%20Restorati.pdf
Gerstein, J.M., W. Stockard and R.R. Harris. 2005. Monitoring the Effectiveness of Instream Substrate Restoration. University of California, Center for Forestry, Berkeley, CA. 53 pp.

This report provides an excellent example of an ecological model that illustrates relationships between salmon spawning and substrate requirements, questions that drive monitoring needs, and field data collection and data analyses techniques for evaluating responses of substrate to restoration projects. Whether a project site has salmon or not, this document provides a good conceptual approach to developing an ecological model and a monitoring approach to evaluate restoration responses.

http://www.nwp.usace.army.mil/environment/docs/afep/estuary/2004_CE_Final.pdf

Diefenderfer, HL, GC Roegner, RM Thom, EM Dawley, AH Whiting, GE Johnson, KL Sobocinski, MG Anderson, and BD Ebberts. 2005. *Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, Annual Report 2004*. PNNL-15102. Report to the US Army Corps of Engineers, Portland District, by Pacific Northwest National Laboratory, Richland, Washington.

The purpose of this study is to develop methods to measure and evaluate the cumulative effects of habitat restoration actions in the Columbia River estuary (CRE, river kilometers 0-235). By "cumulative effects" we mean the collective effects of numerous and varied estuarine habitat restoration projects aimed at improving the population viability of Columbia Basin salmon under the Endangered Species Act. Results from this study will ensure comparable monitoring data sets across multiple years and across multiple restoration projects estuary-wide. The management implications of this research are two-fold in that it will enable resource managers and decision-makers to 1) evaluate the ecological performance of the collective habitat restoration effort in the CRE and its effects on listed salmon, and 2) design, implement, and prioritize future habitat restoration projects.

APPENDIX B

TEMPLATE FOR MONITORING & EVALUATING SHORT-TERM RESPONSES

FOR ADAPTIVE MANAGEMEMENT OF ENVIRONMENTAL FLOWs

Provide the information below in a write-up when submitting a request for SRP funding for monitoring

When will results be reported:

ENVIRONMENTAL FLOW COMPONENTS AND THEIR ATTRIBUTES

Identify each environmental flow component that is being implemented and its hypothesized purpose(s) and response(s) or effect(s).

TYPE OF FLOW: (e.g. Flood pulse, High flow pulse, Low flow, other)
MAGNITUDE:

DURATION:

FREQUENCY:

CALNEDAR PERIOD:

PURPOSE:

RESPONSE(S):

*Generate as many of these necessary to explain monitoring plan

Describe the most important questions that monitoring is being carried out to answer and how the answers to these questions will feed back to inform water management. These typically will be investigations of direct impacts from implementing environmental flow components that will provide high-precision information and rapid feedback to water managers.

IMPLEMENTATION OF ENVIRONMENTAL FLOW COMPONENTS

(Provide as many environmental flow components as necessary)

ENVIRONMENTAL FLOW COMPONENT 1:

WHEN WILL IT BE IMPLEMENTED? :

DOES IMPLEMENTATION DEPEND ON ANY SPECIAL CONDITIONS (e.g., inflows?):

WOULD THIS FLOW COMPONENT HAVE BEEN IMPLEMENTED WITHOUT THE PRESCRIPTION (e.g., how is this different than normal dam operations?):

WHEN WAS THE LAST TIME THIS TYPE OF FLOW OCCURRED (either through a deliberate implementation of a flow prescription or as a result of normal dam operations):

INDICATORS OF ENVIRONMENTAL FLOW COMPONENTS

(Provide as many environmental flow components and indicators as necessary)

INDICATOR 1.1:

EXPECTED RESPONSE AND RESPONSE TIME:

OTHER FACTORS INFLUENCING INDICATOR RESPONSE:

METRICS USED TO EVALUTE RESPONSE AND ITS SPATIAL EXTENT:

BASELINE FOR EVALUATION:

HOW WILL THIS INFORM WATER MANAGEMENT:

INDICATOR 1.2 (as many additional indicators as needed):

EXPECTED RESPONSE AND RESPONSE TIME:

OTHER FACTORS INFLUENCING INDICATOR RESPONSE:

METRICS USED TO EVALUTE RESPONSE:

BASELINE FOR EVALUATION:

HOW WILL THIS INFORM WATER MANAGEMENT:

ENVIRONMENTAL FLOW COMPONENT 2:

WHEN WILL IT BE IMPLEMENTED? :

DOES IMPLEMENTATION DEPEND ON ANY SPECIAL CONDITIONS (e.g., inflows?):

WOULD THIS FLOW COMPONENT HAVE BEEN IMPLEMENTED WITHOUT THE PRESCRIPTION (e.g., how is this different than normal dam operations?):

WHEN WAS THE LAST TIME THIS TYPE OF FLOW OCCURRED (either through a deliberate implementation of a flow prescription or as a result of normal dam operations):

INDICATOR 2.1:

EXPECTED RESPONSE AND RESPONSE TIME:

OTHER FACTORS INFLUENCING INDICATOR RESPONSE:

METRICS USED TO EVALUTE RESPONSE:

BASELINE FOR EVALUATION:

HOW WILL THIS INFORM WATER MANAGEMENT:

INDICATOR 2.2: (as many additional indicators as needed):

EXPECTED RESPONSE AND RESPONSE TIME:

OTHER FACTORS INFLUENCING INDICATOR RESPONSE:

METRICS USED TO EVALUTE RESPONSE:

BASELINE FOR EVALUATION:

HOW WILL THIS INFORM WATER MANAGEMENT:

EXAMPLE

ATTRIBUTES OF ENVIRONMENTAL FLOW COMPONENTS

When will results be reported: December, 2010

TYPE OF FLOW: High flow pulse
MAGNITUDE: 10,000 cfs

DURATION: 10 Days

FREQUENCY: Once annually

CALNEDAR PERIOD: Mid April-Mid May

PURPOSE: Connect and inundate floodplain habitats, generate conditions for floodplain vegetation recruitment. Generate sufficient force to remove silt from cobble bed material in river main stem

PROPOSED RESPONSE: *Floodplain:* Connection and allow water inundation onto floodplain. Native floodplain vegetation seed germination occurs. *River main stem:* Clean bed materials in riffles to provide appropriate spawning habitat for fishes.

A high flow pulse is being managed to connect and inundate floodplains and provide sufficient flow mechanics to remove silt from riffle habitat. There are models of flow and floodplain inundation, and flow forces that have been generated. The primary purpose of this first managed high flow pulse event is to see if the objectives for floodplain inundation can be achieved without damage to private and public property, and if sufficient flow force results from risk-free high flow levels resulting in removal of silt from riffle habitats.

IMPLEMENTATION OF ENVIRONMENTAL FLOW COMPONENTS

1 (High flow pulse**):**

WHEN WILL IT BE IMPLEMENTED? : April 21, – May 1, 2010

DOES IMPLEMENTATION DEPEND ON ANY SPECIAL CONDITIONS: Requires sufficient reservoir storage.

WOULD THIS FLOW COMPONENT HAVE BEEN IMPLEMENTED WITHOUT THE PRESCRIPTION: Normal operations would not result in sufficient reservoir storage to let out this volume of water.

WHEN WAS THE LAST TIME THIS TYPE OF FLOW OCCURRED:

April 25-28, 2009 (managed flow event).

INDICATORS OF ENVIRONMENTAL FLOW COMPONENTS

<u>INDICATOR 1.1</u>: Change in area of floodplain inundation and extent of hydro-period

EXPECTED RESPONSE AND RESPONSE TIME: Floodplain reconnection and inundation during flow event

OTHER FACTORS INFLUENCING INDICATOR RESPONSE: levees, floodplain topography

METRICS USED TO EVALUTE RESPONSE AND ITS SPATIAL EXTENT: Spatial extent and duration of inundation at 10 floodplain sites using satellite and photo imagery, and staff gages to ground-truth imagery data.

BASELINE/COMPARISONS FOR EVALUATION: Extent and duration of floodplain inundation will be monitored at sites prior to implementation of high flow pulse, and compared to the same areas from previous calendar year(s) when similar natural flow conditions would exist but were not achieved through dam operations.

HOW WILL THIS INFORM WATER MANAGEMENT: Results will be used to verify or revise the high flow pulse prescription (magnitude and duration) of release needed to inundate floodplain for at least 7 days, and evaluate risks to and real impacts to property.

<u>INDICATOR 1.2</u>: Difference in area of floodplain vegetation seedling establishment

EXPECTED RESPONSE AND RESPONSE TIME: Seed dispersal during flow event, seedling germination 10 days later during moist soil conditions

OTHER FACTORS INFLUENCING INDICATOR RESPONSE: Other high flow events after germination, deer browsing.

METRICS USED TO EVALUTE RESPONSE AND ITS SPATIAL EXTENT: Number of seedlings per $1M^2$ plot, minimum 10 random plots in previously inundated areas per floodplain site.

BASELINE/COMPARISONS FOR EVALUATION: Seedling establishment (using same assessment techniques) in same floodplain sites not inundated in previous year(s) when similar natural flow conditions would exist but were not achieved through dam operations, and at similar floodplain sites at same elevations during managed flow event but not inundated due to structural limitations (e.g. levees).

HOW WILL THIS INFORM WATER MANAGEMENT: Results will be used to verify or revise the high flow pulse prescription (magnitude, duration, calendar dates of releases needed to inundate floodplain soils for appropriate hydro-period and appropriate seasonality).

<u>INDICATOR 1.3</u>: Change in % embeddedness of river bed material in riffles.

EXPECTED RESPONSE AND RESPONSE TIME: Lowering of embeddedness in riffles during flow event. Monitor week after flow event.

OTHER FACTORS INFLUENCING INDICATOR RESPONSE: Input of sediment from watershed, river banks, floodplains, and/or reservoir during flow event.

METRICS USED TO EVALUTE RESPONSE AND ITS SPATIAL EXTENT: % Embededdness (measured using visual estimates) at 10 riffles increasing distance from dam with greatest distance 40 miles.

BASELINE FOR EVALUATION: % Embededdness of riffles before flow event

HOW WILL THIS INFORM WATER MANAGEMENT: Results will be used to verify or revise the high flow pulse prescription (magnitude, duration) for lowering embededdness to appropriate levels, and to evaluate potential sources of sediment during high flow pulse events.

APPENDIX C

TEMPLATE FOR MONITORING & REPORTING

LONG-TERM ECOSYSTEM TRENDS

Provide the information below in a write-up when submitting a request for funding for monitoring

INDICATOR 1:

CONCEPTUAL LINK TO FLOW MANAGEMENT (REFER TO CONCEPTUAL MODEL):

MAJOR FACTORS INFLUENCING INDICATOR:

RESPONSE TIME AND OTHER FACTORS INFLUENCING INDICATOR:

METRIC TO BE USED TO EVALUTE RESPONSE INCLUDING SPATIAL EXTENT:

SAMPLING FREQUENCY:

INDICATOR 2:

CONCEPTUAL LINK TO FLOW MANAGEMENT (REFER TO CONCEPTUAL MODEL): MAJOR FACTORS INFLUENCING INDICATOR:

RESPONSE TIME AND OTHER FACTORS INFLUENCING INDICATOR:

METRIC TO BE USED TO EVALUTE RESPONSE INCLUDING SPATIAL EXTENT:

SAMPLING FREQUENCY:

Provide as many indicators as necessary

EXAMPLE

TEMPLATE FOR MONITORING & REPORTING

LONG-TERM ECOSYSTEM TRENDS

INDICATOR 1: % Change in area of native floodplain forest vegetation

CONCEPTUAL LINK TO FLOW MANAGEMENT: High flow pulses will allow germination of floodplain trees while low summer base flows will allow seedlings to become established (see ecological model in flow prescription report).

MAJOR FACTORS INFLUENCING INDICATOR: Structural constraints (Levees) to floodplain connectivity with river, implementation of flow prescription, deer browsing.

RESPONSE TIME AND OTHER FACTORS INFLUENCING INDICATOR: 5 years to achieve sufficient vegetation density for accurate satellite imagery assessment.

METRIC TO BE USED TO EVALUTE RESPONSE INCLUDING SPATIAL EXTENT: Change in area of dominant native vegetation in floodplains located laterally from 5 miles below dam to 38 miles below dam.

SAMPLING FREQUENCY: Every 5 years for on-the ground sampling (ground-truth imagery and evaluate species composition) and satellite imagery processing.

INDICATOR 2: % Change in density of riffle-spawning river main stem fish species

CONCEPTUAL LINK TO FLOW MANAGEMENT: Clean riffles provide necessary breeding habitats for riffle-breeding fishes resulting in increased fish species densities (bottleneck has existed because of high embeddedness of riffle habitats due to lack of high flow pulses). (See ecological model in flow prescription report).

MAJOR FACTORS INFLUENCING INDICATOR: Sufficient force and duration of high flow pulses, sources of sediment.

RESPONSE TIME AND OTHER FACTORS INFLUENCING INDICATOR: 1 year for recruitment, 3 years to use standard adult fish sampling techniques.

METRIC TO BE USED TO EVALUTE RESPONSE INCLUDING SPATIAL EXTENT: Change in densities of adult age classes of 2 riffle-breeding fish species over time.

SAMPLING FREQUENCY: Every 3 years

<u>INDICATOR 2</u>: % Change in Osprey reproduction

CONCEPTUAL LINK TO FLOW MANAGEMENT: More successful breeding because of increase in prey (fish) populations as a result of repeated high flow pulses that provide access to floodplain habitat and improvements of riffle habitat for fish reproduction/rearing. (See ecological model in flow prescription report).

MAJOR FACTORS INFLUENCING INDICATOR: fish productivity, changes in nesting habitat

EXPECTED RESPONSE AND RESPONSE TIME: Increased osprey reproduction within 3 years

METRIC TO BE USED TO EVALUTE RESPONSE INCLUDING SPATIAL EXTENT: Change in number/density of breeding pairs over time from river mile 5 to 38.

SAMPLING FREQUENCY: Ever 3 years

APPENDIX D

Reporting Site-Level Results for Programmatic Roll-up

Reporting year:

Site name:

Number of dams engaged in SRP:

Stage of environmental flow development or implementation:

Projected/actual scope of benefit:

ESA Listed species benefiting from flow management:

Scope of critical habitat benefiting from flow management:

Environmental flow prescription component implemented:

Degree to which environmental flow prescription was implemented:

Types and degrees of ecosystem responses documented:

Example
Reporting Site-Level Results for Programmatic Roll-up

Reporting year: 2011

Site name: Orange River

Number of dams engaged in SRP: 1

Stage of environmental flow development or implementation: Validating/Adapting Environmental Flows

Projected/actual scope of benefit: 60 miles of river habitat, 15,250 acres of floodplain habitat

ESA Listed species benefiting from flow management: None

Scope of critical habitat benefiting from flow management: None

Environmental flow prescription component implemented: Floods, High flows, Low flows

Degree to which environmental flow prescription was implemented: Floods (100%), High flows (25%), Low flows (50%).

Types and degrees of ecosystem responses documented:
Spawning habitat for salmon was improved through removing silt from gravel habitat from flood and high flow events, dewatering of active redds was avoided through maintaining minimum flows during low flow periods. Adult Chinook salmon densities have increased 15% in 5 years as a result of implementing comprehensive flow prescription. Native floodplain vegetation is establishing in larger areas due to comprehensive flow prescription. Exotic riparian vegetation species are decreasing in density and distribution due to floods (physical removal).