Columbia Estuary Ecosystem Restoration Program

2012 STRATEGY REPORT

FINAL

Prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland District

April 2012

Preface

The 2012 Strategy Report was produced by the Bonneville Power Administration (BPA) and U.S. Army Corps of Engineers, Portland District (Corps). A BPA/Corps committee developed a first draft, which was reviewed by staff from Columbia Land Trust, Columbia River Estuary Study Taskforce, Lower Columbia Estuary Partnership, Lower Columbia Fish Recovery Board, National Marine Fisheries Service, and Northwest Power and Conservation Council. Based on extensive, in-depth review comments, the draft report was revised to produce the final 2012 Strategy Report. BPA/Corps take full responsibility for the report's content.

The citation for this report is: BPA/Corps. 2012. *Columbia Estuary Ecosystem Restoration Program: 2012 Strategy Report*. Final report, prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

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Executive Summary

The 2012 Strategy Report for the Columbia Estuary Ecosystem Restoration Program (CEERP) was developed by the Bonneville Power Administration (BPA) and U.S. Army Corps of Engineers, Portland District (Corps) to establish the strategic, scientific basis for the ecosystem restoration and associated research, monitoring, and evaluation (RME) that they are funding in the lower Columbia River and estuary (LCRE) during 2012. The overall goal of the CEERP is to understand, conserve, and restore ecosystems in the LCRE. The CEERP's three main drivers are:

1. Northwest Power and Conservation Council (Council) Fish and Wildlife Program—the Council's program has strategies for estuary habitat reconnections, long-term effectiveness monitoring, estimation of juvenile salmon survival rates, impacts from estuary stressors, and partnerships.
2. Water Resources Development Acts (Sections 206, 536, and 1135) and the Lower Columbia River Ecosystem Restoration General Investigations Study—the Corps has authorities to restore LCRE ecosystems under various federal laws.
3. Biological Opinions for operation of the Federal Columbia River Power System—LCRE habitat restoration is an offsite mitigation action to help avoid jeopardizing Endangered Species Act (ESA)-listed salmonids by hydrosystem operations.

The Strategy Report is one of three inter-related, annual CEERP deliverables; the others are the Action Plan and Synthesis Memorandum. The Strategy Report contains strategies to implement restoration and RME actions outlined in the companion Action Plan, the results of which are evaluated in the subsequent Synthesis Memorandum, which in turn is used adaptively in the next Strategy Report. The CEERP deliverables are intended to guide or inform, as appropriate, the Actions Agencies, the National Marine Fisheries Service, the Council, restoration project sponsors, researchers, and various interested parties.

The 12-month period for the CEERP deliverables is a calendar year (CY) and starts with CY 2012. The 2012 Synthesis Memorandum, a comprehensive compilation of science to date concerning juvenile salmon ecology and ecosystem restoration in the LCRE, is currently under development and scheduled for regional release in June 2012. Rather than wait for one-half year, the BPA/Corps initiated the 2012 Strategy Report and 2012 Action Plan to jump-start the CEERP process. This 2012 Strategy Report, however, does contain a synthesis and evaluation "brief" to support strategies for restoration and RME actions during CY 2012. The 2012 Synthesis Memorandum will feed the 2013 Strategy Report and 2013 Action Plan. Within the CEERP's adaptive management process, the CEERP deliverables will be updated annually for applicability, transparency, and accountability.

The CEERP has four management questions. The first three are directly linked to the Council's 2009 Columbia River Basin Fish and Wildlife Program and the Biological Opinion (BiOp) on operation of the Federal Columbia River Power System (FCRPS). The fourth question is new and related to the support of the FCRPS BiOp. 1) What are the limiting factors or threats, i.e., stressors and controlling factors, in the estuary preventing the achievement of desired habitat or fish performance? 2) Which actions are most effective at addressing the limiting factors preventing achievement of habitat, fish, or wildlife performance objectives? 3) Are the estuary habitat actions achieving the expected biological and environmental benefits? 4) What adjustments should be made, if any, to improve the ability of the survival benefit unit crediting method to predict benefits to ESA-listed fish from ecosystem protection and restoration in the LCRE? The management questions are addressed through RME, the results of which are used to adaptively inform CEERP strategy and decision-making, particularly project development, prioritization, and design.

The CEERP knowledge base concerning juvenile salmon ecology and ecosystem restoration in the LCRE supports actions to restore shallow water habitats, such as hydrologic reconnections and riparian and channel improvements. The prevailing finding is that juvenile salmon tend to use restored areas. Bioenergetics research has shown potential benefits to juvenile salmon growth in shallow tidal freshwater water areas. These types of habitats produce prey that are consumed onsite or are exported to the main stem Columbia River to be consumed there. Restored habitats can help increase habitat diversity, which is hypothesized to contribute to increased early life-history diversity in salmon and, thereby, salmon population resiliency. The existing knowledge base provides a science-based, strategic foundation for CEERP restoration and RME actions.

The BPA/Corps strategy for LCRE habitat restoration is to use an ecosystem-based approach applying the best available ecological science for the CEERP. A formal adaptive management process is in place to implement the CEERP strategy through annual cycles of project development, prioritization, implementation, monitoring and research, and synthesis and evaluation, coming back to revisiting the strategy. The strategy involves making use of existing processes, programs, technical groups, and plans to avoid redundancy and increase efficiency, such as the Corps' Anadromous Fish Evaluation Program and the Council's Fish and Wildlife Program. The Expert Regional Technical Group for estuary habitat restoration provides guidance for CEERP projects. For example, bigger area is better than smaller area; close to the main stem is better than farther away; restoring remnant channels is better than excavating new ones; natural processes are preferred over engineered processes; and a holistic perspective from a landscape scale is better than narrow, site-specific perspective. CEERP strategy is informed by supporting resources, including a characterization of disturbance regimes, habitat suitability modeling, landscape change analysis, and the LCRE ecosystem classification system.

The BPA/Corps strategy for RME is to monitor compliance and implementation of CEERP restoration actions; monitor status and trends of LCRE ecosystems supporting juvenile salmonids; research, monitor, and evaluate juvenile salmonid performance in the LCRE relative to environmental, physical, or biological performance objectives; research, monitor, and evaluate LCRE migration and habitat conditions that may be limiting achievement of biological performance objectives; determine the effectiveness of restoration actions; and investigate critical uncertainties related to the scientific relationships between habitat conditions, including restored sites, and the survival, growth, and condition of fish residing and migrating in the LCRE.

In addition to guiding CEERP restoration and RME efforts, the Strategy Report will be incorporated into the BPA/Corps 2013 Comprehensive Report and 2014-2018 Implementation Plan. This work will be responsive to the 2011 U.S. District Court ruling on BiOp implementation. By describing the fundamental strategy for implementing estuary habitat actions and RME, the 2012 Strategy Report is one component of the BPA/Corps response to the ruling. Also, the 2012 Strategy Report and the 2012 Action Plan address the Council's and Independent Scientific Review Panel's programmatic issues concerning the LCRE restoration effort, including provisions of the Council's 2009 Fish and Wildlife Program and Recommendation 3 for monitoring and evaluating the effectiveness of habitat actions in the estuary from the Council's 2010 RME/Artificial Production Categorical Review.

In closing, the 2012 CEERP Strategy Report describes the BPA/Corps' fundamental strategy for estuary habitat actions and RME—apply an ecosystem-based approach to restore, enhance, or create ecosystem structures, processes, and functions in the estuary, and perform RME to assess the effectiveness of these actions, while building our understanding of ecosystems in the LCRE. The CEERP will use, as appropriate, information from projects funded outside CEERP for other purposes, such as predation, toxic contaminants, dredging, hydrosystem operations, and tributary habitat improvements, and other topics. The BPA/Corps intend for the CEERP to take advantage of lessons learned and knowledge gained from previous restoration and RME efforts in the LCRE and elsewhere as appropriate.

Acronyms and Abbreviations

AA	Action Agencies
AEMR	action effectiveness monitoring and research
AFEP	Anadromous Fish Evaluation Program
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CEERP	Columbia Estuary Ecosystem Restoration Program
Corps	U.S. Army Corps of Engineers
Council	Northwest Power and Conservation Council
CY	calendar year
EOS	Estuary/Ocean Subgroup
EP	Estuary Partnership (Lower Columbia Estuary Partnership)
ERTG	Expert Regional Technical Group
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FCRPS	Federal Columbia River Power System
GIS	geographic information system
ISRP	Independent Scientific Review Panel
JBH	Julia Butler Hanson (National Wildlife Refuge)
LCFRB	Lower Columbia Fish Recovery Board
LCRE	lower Columbia River and estuary
NMFS	National Marine Fisheries Service
NRC	National Research Council
RME	research, monitoring, and evaluation
SBU	survival benefit unit
SRD	Sandy River delta
SRWG	Studies Review Work Group
SWG	Science Work Group

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1.0 Introduction

This Strategy Report describes the Columbia Estuary Ecosystem Restoration Program's (CEERP's) science-based approach to restoring, enhancing, or creating ecosystem structures, processes, and functions in the lower Columbia River and estuary (LCRE)[1] (Figure 1)—especially those that support juvenile salmonid growth, fitness, and survival. The restoration strategy incorporates an ecosystem-based approach using supporting resources to develop on-the-ground projects both opportunistically and strategically. Concurrently, the research, monitoring, and evaluation (RME) strategy is to assess compliance, understand ecosystem status and trends, determine action effectiveness, and reduce uncertainty in the ecosystem restoration effort. The purpose of this report is to describe the strategies for ecosystem restoration actions and associated RME in tidally influenced areas of the LCRE floodplain.

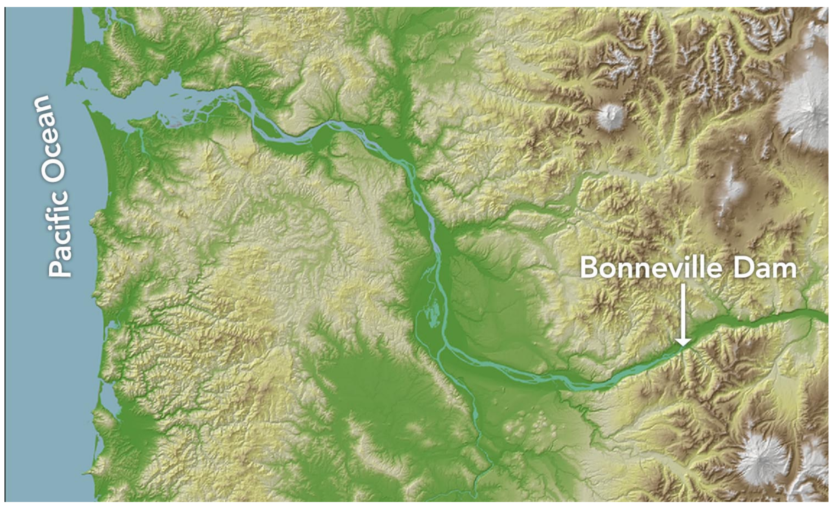


Figure 1. Map of Lower Columbia River and Estuary Study Area

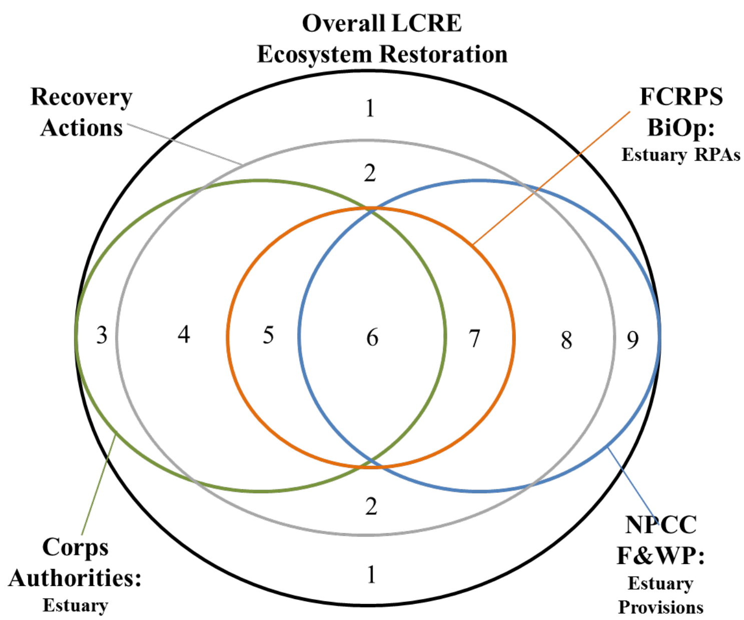
The Bonneville Power Administration (BPA) and U.S. Army Corps of Engineers (Corps) jointly established the CEERP to implement ecosystem restoration actions and RME in the LCRE in response to various requirements, mandates, and authorities.[2] CEERP's overall goal is to understand, conserve, and restore ecosystems in the LCRE. The CEERP is an important ecosystem restoration program, but is not the only one in the LCRE (Figure 2). Other restoration efforts include those of the Oregon Department of Fish and Wildlife, the Oregon Watershed Enhancement Board, the Lower Columbia Fish Recovery Board, the National Oceanic and Atmospheric Administration Restoration Center, the Washington Department of Fish and Wildlife, and otehrs. The CEERP's three main drivers are as follows:

1. Northwest Power and Conservation Council (Council) Fish and Wildlife Program (Council 2009)—the Council's program has strategies for estuary habitat reconnections, long-term effectiveness monitoring, estimation of juvenile salmon survival rates, impacts from estuary stressors, and partnerships.

[1] By definition, the LCRE includes tidally influenced areas of the floodplain from Bonneville Dam to the ocean.

[2] CEERP is an acronym coined in 2011 for the joint BPA/Corps efforts to restore LCRE ecosystems that started with the 2000 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) (NMFS 2000) and now is responsive to subsequent FCRPS BiOps, the Council's Fish and Wildlife Program, and various Corps restoration authorities.

2. Water Resources Development Acts (Sections 206, 536, and 1135) and the Lower Columbia River Ecosystem Restoration General Investigations Study—the Corps has authorities to restore LCRE ecosystems under various federal laws.
3. Biological Opinions (BiOps) for operation of the Federal Columbia River Power System (FCRPS) (NMFS 2000, 2004, 2008, 2010)—LCRE habitat restoration is an offsite mitigation action to help avoid jeopardizing ESA-listed salmonids by hydrosystem operations.



Legend: LCRE restoration funded by…
1 = Entities besides the BPA and Corps for ecosystem restoration, e.g., CREST at Sharnelle Fee
2 = Entities besides the BPA and Corps for recovery actions for listed fish, e.g., LCFRB at Lower Washougal
3 = Corps outside BiOp and recovery, e.g., Johnson Creek springwater
4 = Corps outside BiOp, e.g., Tenasillahe Island
5 = Corps for BiOp, e.g., Post Office Lake
6 = BPA+Corps for BiOp, e.g., Col. Stock Ranch
7 = BPA for BiOp, e.g., Otter Point
8 = BPA outside BiOp, e.g., Duncan Creek
9 = BPA outside BiOp and recovery, e.g., Shillapoo wildlife mitigation

Figure 2. Nested Relationships Among CEERP Drivers and Overall LCRE Ecosystem Restoration

The CEERP is relevant to other programs and needs as well. For example, it is pertinent to recovery plans (Lower Columbia Fish Recovery Board 2010; ODFW 2010; NMFS 2011) for salmon and steelhead species listed under the Endangered Species Act (ESA), because CEERP restoration actions are intended to benefit ESA-listed fish. CEERP work products (Strategy Report, Action Plan, and Synthesis Memorandum) will be important elements of the BPA/Corps implementation plans required by the 2011 U.S. District Court ruling (U.S. District Court 2011). The 2012 Strategy Report, in fact, will be one component of the response to address the Court's concern,[1] because the report describes the BPA/Corps fundamental strategy for implementing estuary habitat actions and RME. In addition, the CEERP is implementing the Council's RME/Artificial Production Categorical Review Recommendation Report's Recommendation 3 (ISRP 2010) to monitor and evaluate the effectiveness of habitat actions in the LCRE. Finally, the Council's and Independent Scientific Review Panel's (ISRP's) programmatic issues[2] concerning the LCRE restoration effort (Council 2011) are intended to be addressed by the 2012 Strategy Report (this document), the 2012 Action Plan (BPA/Corps 2012), and the 2012 Synthesis Memorandum (due in summer 2012).

[1] The Court was concerned about estuary habitat and RME actions and the plan for their implementation. These are described in detail in the 2012 Action Plan (BPA/Corps 2012).
[2] The Council was concerned about, "…lack of a clear synthesis or framework in the estuary linking habitat restoration actions to monitoring efforts to action effectiveness evaluations."

The 2012 CEERP Strategy Report has been informed by the Lower Columbia Subbasin Plan (Council 2005), previous synthesis and evaluation conducted in the FCRPS 2007 Biological Assessment and Comprehensive Analysis (Action Agencies 2007), the Council's 2009 Amendments (Council 2009), the ISRP's Review of Research, Monitoring, and Evaluation and Artificial Production Projects Recommendations of the Council (ISRP 2010), the National Marine Fisheries Service's (NMFS's) Estuary Module (NMFS 2011), and the Corps' Anadromous Fish Evaluation Program (AFEP) (Johnson et al. 2011a). The Strategy Report has four main sections after this introduction: CEERP Background, Synthesis and Evaluation Brief, Strategy for Ecosystem Restoration, and Strategy for RME. The report concludes with closing and references sections.

2.0 CEERP Background

In this section, we describe the CEERP goal, objectives, hypotheses, and management questions. We also explain CEERP's adaptive management process.

2.1 Program Goal, Objectives, and Management Questions

The CEERP is founded on a specific goal, principles, objectives, and management questions that are pursued within a specially designed adaptive management process. As stated previously, the overall goal of the CEERP is to understand, conserve, and restore ecosystems in the LCRE. The CEERP is also addressing a specific requirement from the 2008 BiOp (NMFS 2008) for the BPA/Corps to provide survival benefit units (SBUs)[1] for salmonids, i.e., 45 units for ocean-type and 30 units for stream-type salmon by 2018. The CEERP seeks to have restoration projects that, from Johnson et al. (2003), "…are founded on the best available ecological restoration science, implemented in an ecosystem context, and developed with the intent to restore relevant ecological processes…incorporate adaptive management practices with testable hypotheses to track ecological responses to a given restoration effort…are implemented in a coordinated, open process and scientific results from monitoring and evaluation are communicated widely and readily accessible." These principles are consistent with guidance from the Expert Regional Technical Group[2] (ERTG 2010a, 2010b, 2011a); a brief summary of the ERTG's guidance on project development to project sponsors is contained in Section 4.3.

The objectives of the CEERP reflect an ecosystem-based approach. They support and are consistent with the estuary strategies[3] in the Council's 2009 Fish and Wildlife Program (Council 2009) and

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[1] A survival benefit unit is an index intended to represent the effect of LCRE habitat restoration on juvenile salmon survival (ERTG 2010a). The SBU method uses an ecosystem-based approach to assess improvements to habitats supporting juvenile salmon and other species. SBUs are assigned on a restoration project-specific basis.

[2] The ERTG for estuary habitat restoration was established by the BPA/Corps in response to the 2008 FCRPS BiOp (Reasonable and Prudent Alternative 37). Its purpose is to provide assessment of the benefits for salmon populations from LCRE habitat restoration actions.

[3] Fish and Wildlife Program estuary strategies include habitat restoration work to reconnect ecosystem functions, long-term action effectiveness monitoring, evaluation of salmon and steelhead migration and survival rates, and evaluation of impacts from flow regulation, dredging, and water quality.

recommendations[1] from the 2010 Council RME/Artificial Production Categorical Review. The specific CEERP objectives are as follows (after Johnson et al. 2008):

1. Understand what effect primary stressors[2] have on ecosystem controlling factors[3], e.g., flow regulation, passage barriers.
2. Conserve and restore factors that control ecosystem structures[4]/processes[5], e.g., hydrodynamics, water quality.
3. Increase quantity and quality of ecosystem structures, e.g., estuarine habitat for juvenile salmonids.
4. Maintain and enhance LCRE food webs to benefit salmonid performance.[6]
5. Improve salmonid performance in terms of life-history diversity, fish condition, growth, and survival.

The objectives are based on the conceptual ecosystem model developed by Thom et al. (2004)—stressors alter controlling factors affecting ecosystem structures driving ecosystem processes producing ecosystem functions. The first objective relates to understanding the basic stressors and controlling factors affecting LCRE ecosystem structures and processes. This first objective is analogous to understanding limiting factors and existing environmental conditions, terminology from subbasin and recovery plans (Council 2005; LCFRB 2012; ODFW 2010; NMFS 2011). The second, third, and fourth objectives provide scientific direction for ecosystem restoration and conservation actions. Restoring ecosystem structures, processes, and functions for juvenile salmon will also benefit these ecosystems in general. The fifth objective focuses on one important outcome of the CEERP—salmonid performance.

Basically, limiting factors and existing environmental conditions in the LCRE affect juvenile salmonid performance and determine strategic priorities for mitigation actions. An important management concern is how well these actions are working relative to LCRE habitat and fish objectives and, most importantly, knowing which projects are the most effective to guide future project development and prioritization. Management concerns are addressed through RME, the results of which are used to adaptively inform CEERP decision-making. Related to the objectives, the CEERP has four key management questions (Figure 3):

1. What are the limiting factors or threats, i.e., stressors and controlling factors, in the estuary preventing the achievement of desired habitat or fish performance?
2. Which estuary habitat restoration actions are most effective at addressing the limiting factors preventing achievement of habitat, fish, or wildlife performance objectives?

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[1] A primary recommendation was, "The Council calls for the responsible entities to complete an estuary-wide synthesis prior to the initiation of the review of habitat actions."

[2] Stressors are external or anthropogenic entities or processes that affect ecosystem controlling factors.

[3] Controlling factors are the basic physical and chemical conditions that construct and influence the structure of the ecosystem.

[4] Ecosystem structures are the types, distributions, abundances, and physical attributes of the plant and animal species composing the ecosystem.

[5] Ecosystem processes are interactions among physicochemical and biological elements of an ecosystem that involve changes in character or state.

[6] Performance is an indicator of the state of anadromous salmonid populations and their habitats. Performance can be defined by growth, foraging success, spatial structure, life-history diversity, and habitat conditions.

3. Are the estuary habitat restoration actions achieving the expected biological and environmental benefits?
4. What adjustments should be made, if any, to improve the ability of the SBU crediting method to predict benefits to ESA-listed fish from ecosystem protection and restoration in the LCRE?

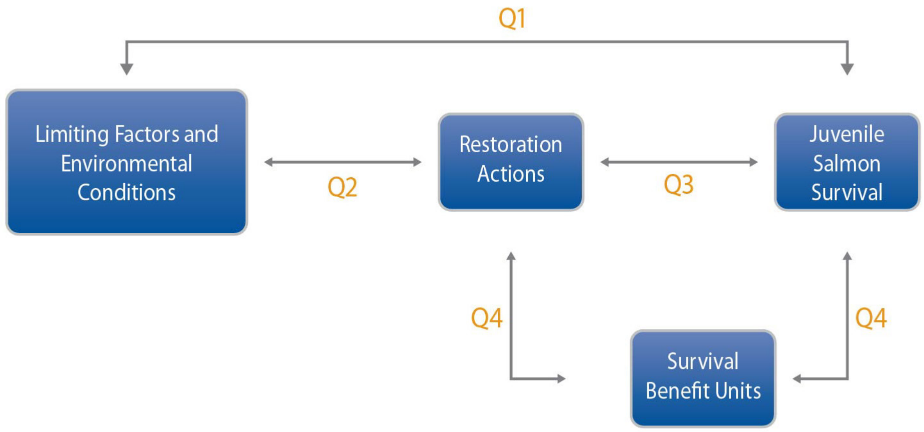

Figure 3. CEERP Management Questions Shown as Interactions Among LCRE Limiting Factors and Conditions, Restoration Actions, Survival Benefit Units, and Juvenile Salmonid Survival. Double-headed arrows represent two-way information flow. See the text for the management questions.

2.2 Adaptive Management Process

The CEERP adaptive management process is described in detail by Thom et al. (2011a). Briefly, this process involves five phases (Figure 4)—decisions, actions, monitoring/research, synthesis and evaluation, and strategy (Thom 2000). The CEERP proceeds through each of these phases adaptively based on the results from the preceding phase(s). Teams of key staff perform specific functions and assume certain responsibilities to produce desired outcomes (Table 1). The adaptive management process informs management decisions that can be reconciled relative to the context of the long-term CEERP goals and objectives. As management questions are answered by RME results, program objectives and strategies will be revised as necessary and inform future restoration and RME actions. The Strategy Report is the deliverable from the Strategize Phase in the CEERP adaptive management process.

Activities to support all phases of the CEERP adaptive management process are underway in the LCRE, thereby institutionalizing the process regionally across stakeholders/partners. Adaptive management, however, is only successful when the parties to the program commit to sustained cooperation and responsibilities. Adaptive management can be efficient if existing, required reporting functions are adapted to ensure the flow of information from project monitoring staff to project planning staff, and if RME is funded appropriately. The CEERP uses existing regional coordination efforts, such as the Corps' AFEP, the Council's Fish and Wildlife Program, and the Lower Columbia Estuary Partnership's (EP's) programs. Existing work groups contributing to CEERP purposes include the federal Estuary/Ocean Subgroup for Federal RME (EOS), the AFEP Science Review Work Group (SRWG), the Estuary Partnership's Science Work Group (SWG), the ERTG, the ISRP, and others. Many federal, state, and local agencies and non-governmental organizations are working to restore and understand estuarine and tidal freshwater habitats for juvenile salmon in the LCRE and are cooperating and collaborating within the CEERP.

Figure 4. CEERP Adaptive Management Process. Brown and blue boxes signify adaptive management phases and deliverables, respectively. CEERP adaptive management phases, responsible parties, and deliverables are listed in Table 1.

Table 1. CEERP Adaptive Management Phases, Responsible Parties, and Deliverables. See Section 1.3 of the 2012 Action Plan (BPA/Corps 2012) for descriptions of the responsible parties. (Abbreviated terms used in the tables are defined in the list in the front matter of this report.)

Phase	Responsible Parties	Function	Deliverable(s)
Strategize	AA, Council, SRWG, SWG, EOS	Provide strategic priorities on project types that will provide the most benefit	Strategy Report
Decide	AA (final decisions); Council, ISRP, SWG, SRWG, ERTG (inputs)	Select projects and identify RME for a given implementation year	Action Plan, Feasibility Studies
Act (Implementation)	AA; sponsors	Implement restoration projects	Design Memoranda, as-built drawings
Monitor and Research	AA; researchers	Study "on the ground" implementation	Site Evaluations, Technical Reports
Synthesize and Evaluate	AA, NMFS, Council, ERTG	Synthesis RME findings and make recommendations to inform following years' strategy	Synthesis Memorandum

3.0 Synthesis and Evaluation Brief

Over the past 30 years, much has been learned about juvenile salmonid ecology and its ecosystems in the LCRE and, especially in the last decade, much has been done to apply this knowledge to LCRE ecosystem restoration. Some of the important past contributions include Dawley et al. (1986), Borde et al. (2009), Bottom et al. (2005ab, 2008), Fresh et al. (2005), Roegner et al. (2004, 2008, 2009ab, 2010), Sather et al. (2009), Johnson et al. (2011a, 2011b), and Simenstad et al. (2011). The BPA/Corps intend to use knowledge gained from past work to develop the CEERP strategy for 2012. A comprehensive synthesis and evaluation, however, is beyond the scope of this Strategy Report. The upcoming 2012 Synthesis Memorandum (in preparation; due summer 2012) will be used to update the information in this section in the 2013 CEERP Strategy Report. For now, we present a synthesis and evaluation brief that includes some key scientific findings organized by management question, some implications to project design, and some uncertainties in the knowledge base as applied for CEERP purposes. This information demonstrates how the available science justifies LCRE ecosystem restoration.

3.1 Key Scientific Findings by Management Question

Management Question 1. What are the limiting factors or threats, i.e., stressors and controlling factors, in the estuary preventing the achievement of desired habitat or fish performance?

Loss of floodplain wetlands and other anthropogenic alterations of the LCRE have been substantial. In particular, tidal swamp and marsh habitats have suffered the largest relative declines based on a habitat change analysis (1890 vs. 1992 habitat maps for the lower 46 miles of the LCRE) (Thomas 1983). Dikes, levees, and armored shorelines are prevalent because lowland areas were disconnected from the river for economic development, resulting in the loss of shallow-water habitats (Thomas 1983; Kukulka and Jay 2003). Flow regulation has altered the hydrograph in the LCRE such that present flows are not as dynamic, have lower and more attenuated peak flood flows, and have less severe low-water periods than occurred historically (Kukulka and Jay 2003). Pile structures are hypothesized to have altered flow patterns and access to shallow-water habitats. In summary, development actions have adversely affected the formation and maintenance of wetland habitats, the historic access to wetland habitats by aquatic species, the food webs based on them, and the export of materials from these habitats, all of which support various life-history strategies for listed salmon and steelhead in the Columbia basin (Bottom et al. 2005; Fresh et al. 2005).

Limiting factors, also referred to as ecosystem stressors and controlling factors, affecting fish performance in the LCRE were identified in two important regional planning documents. In the *Columbia River Estuary ESA Recovery Plan Module for Salmon & Steelhead*, the NMFS (2011) documented numerous limiting factors in the LCRE adversely affecting ESA-listed salmon and steelhead in the Columbia basin, as did the recovery plans for Oregon (ODFW 2010) and Washington (LCFRB 2010). Similarly, in the *Lower Columbia Subbasin Plan* (Council 2005), limiting factors are identified and their effects on salmon and steelhead described. Besides habitat loss from diking and flow regulation, such limiting factors include invasive plant and animal species, toxic contaminants, pollution, sediment load, water temperature, and others. While limiting factors have been identified, scientific evidence of causal mechanisms and linkages between them and ecosystem processes and functions supporting juvenile salmonids is sometimes lacking. The state of the science, however, supports reconnecting diked and blocked shallow-water habitats to the main stem river to improve fish performance.

Management Question 2. Which actions are most effective at addressing the limiting factors preventing achievement of habitat, fish, or wildlife performance objectives?

Although the most effective actions are not definitive, it is generally accepted that the more complete the restoration of natural hydrologic connections, the better (Thom et al. 2011b; ERTG 2011a). Research generally supports the hypothesis that habitat restoration to reconnect shallow water, tidal wetlands off the main stem river can benefit various Evolutionarily Significant Units (ESUs) and size classes of salmon that reside, feed, and grow in the estuary before migrating to the ocean (Bottom et al. 2008). Findings suggest juvenile salmon of different life-history patterns can use LCRE areas differently (Johnson et al. 2011c). For example, ocean-type juvenile Chinook, chum, and stream-type coho appear to more directly benefit from restoration in the LCRE (feeding and growing) compared to stream-type Chinook, steelhead, and sockeye (that are actively migrating). Yearling emigrants could benefit indirectly from ecosystem services by restored areas to the overall LCRE system, such export of organic materials. Research also indicates that restored LCRE habitats could provide benefits to multiple life-history types year-round (Sather et al. 2011). Restoration benefits, however, can be site-specific. For example, a tide gate replacement in one location might not be effective (e.g., Roegner et al. 2010, Vera Slough), whereas in another location it is effective (Johnson et al. 2009, Julia Butler Hansen National Wildlife Refuge) because of availability of juvenile salmon to the area. Collectively, data on action effectiveness are limited and more monitoring and research are needed over a broader range of restoration actions and locations than are presently the case to better understand which actions are most effective at addressing the limiting factors preventing achievement of performance objectives.

Management Question 3. Are the estuary habitat actions achieving the expected biological and environmental benefits?

Through action effectiveness monitoring and research, habitat actions in the estuary are being evaluated relative to environmental, physical, or biological performance objectives. Some key findings and their implications for CEERP management are listed in Table 2. For example, initiation of sediment accretion after tidal reconnection has implications for site elevations previously lost through subsidence, for development of the ecosystem's vegetation community, and for the capacity of the area for juvenile salmonid feeding. An important uncertainty in the knowledge base, however, concerns the direct and indirect relationships between ecosystem restoration and effects on juvenile salmon production, condition, or health.

Management Question 4. What adjustments should be made, if any, to improve the ability of the SBU crediting method to predict benefits to ESA-listed fish from ecosystem protection and restoration in the LCRE?

Since 2009 when the ERTG was established, the BPA/Corps and restoration project sponsors have worked with the ERTG as the group reviewed and scored prospective restoration projects. The ERTG process to assign SBUs will be scrutinized. It is too early now to identify any adjustments, but in the future the BPA/Corps might eventually ask the ERTG to suggest how the SBU method might be improved.

Table 2. Key Scientific Findings from CEERP Action Effectiveness Research. The restoration actions included culvert replacements, tide gate replacements, and channel excavations. **Bold** font designates monitored indicators listed in footnote on page 21. (Based, in part, on Thom et al. 2011b.)

Finding	Implications for the Site	Implications for the Ecosystem	Implications for Salmonids	Citation
Initiation of **sediment accretion**	Will lead to restoring elevations lost through subsidence	Rapid vegetation assemblage development will extend for much longer than the 4 years of this study	Juvenile salmonid feeding and rearing capacity will change through time toward natural conditions	Thom et al. (2011b)
Redevelopment of historical tidal channels (indicated by **channel cross-sectional area)**	Development of productive marsh edges and natural wetland morphology	Increased channel area and productive marsh edges in the floodplain; enhanced area for nutrient processing and export of organic matter	Juvenile salmonid habitat feeding and rearing capacity increased; enhanced organic matter export to estuarine ecosystem salmonid food web	Diefenderfer and Montgomery (2008)
Exposure of buried large wood and development of stepped pools in tidal channels (indicated by **channel cross-sectional area)**	Development of natural wetland morphology to support microhabitat development, and natural biodiversity	Increased channel area in the floodplain; enhanced area for nutrient processing, organic matter deposition, secondary production	Enhanced quality for salmonid rearing and prey production in the floodplain	Diefenderfer et al. (2008)
Improved **water-quality** conditions (e.g., temperature) where substantial hydrological connectivity was restored	Development of natural wetland water properties and support of aquatic species	Improved water properties in estuarine ecosystem	Enhanced quality for salmonid rearing and prey production in the floodplain and estuary	Thom et al. (2011b)
Clear response of **vegetation** assemblage to restoration actions within 1 year following hydrological reconnection	Recovery of site habitat structure initiated quickly; restoration of natural biodiversity; enhanced site resilience	Processes associated with structure initiated within 1 year	Juvenile salmonid habitat access opportunity and feeding and rearing capacity are increased within 1 year	Thom et al. (2011b)
Demonstrated **material flux;** restoring site is a sink for total organic carbon, silicate, and total suspended sediments, and a source for nitrite.	Natural processes rebuilding the wetland site	Ecosystem services, i.e., nutrient export, from off-channel restoring wetlands	Nutrients to fuel main stem food webs for juvenile salmonids	Woodruff et al. (2011)
Modeling of particulate organic matter **flux** showed approx. 52% of the total mobilized material reached the main stem Columbia River and 48% remained in the restoring site floodplain and tributary	Restoring site functions as a net exporter of organic material	Restoring tidal freshwater tributary wetlands provides ecosystem services to the main stem Columbia River	Energy transfer to support main stem food webs used by juvenile salmonids from the entire Columbia basin	Woodruff et al. (2011)
Frequent, prolonged, and repeated between-year use of restored sites by **juvenile salmonids**	Natural biodiversity development	Natural ecosystem biodiversity development	Long-term enhancement of salmonid life-history diversity	Roegner et al. (2010)
Use of restoring lower Columbia River and estuary tributary wetlands by "out of basin" **juvenile salmonids**)	Natural biodiversity development	Natural ecosystem biodiversity development	Enhancement of salmonid populations and life-history diversity in the ecosystem	Roegner et al. (2010)

3.2 Implications for Project Design

The following lessons from RME are examples of applied learning from CEERP RME that could be included in the upcoming 2012 Synthesis Memorandum. This list is certainly not comprehensive. Our intent is to demonstrate the value of documenting lessons learned from restoration so that they are available to future restoration efforts. As examples, the following lessons learned were documented in a report from the Cumulative Effects project in which Johnson et al. (2011a) pointed out,

- "Potential sites for restoration are limited, even in an area as large as the LCRE floodplain, because of land-use practices, accessibility, suitability, among other reasons (Ke et al. 2011). Therefore, opportunities for restoration and conservation should be actively and aggressively pursued in a coordinated manner across multiple restoration funders and sponsors."
- "The ecosystem-based restoration prioritization strategy used by the EP—integrating stressors at the landscape and local scale in the LCRE—identifies areas where restoration is more likely to succeed relative to other areas (Evans et al. 2006). To our knowledge, likely areas for success have not been mapped back to opportunities for potential restoration sites identified by positive functional factors."
- "Alternative sources of large wood might need to be considered to meet restoration goals, even though some wood can become available to previously diked restoration sites through tree fall and re-exposure of previously buried wood due to changing hydrodynamics (Diefenderfer and Montgomery 2008). This is worth considering because ecohydrological processes that provide large wood and produce ecosystem structures in tidal channels could be important in the restoration of tidal forested wetlands (Diefenderfer and Montgomery 2008)."
- "Design should be informed by pre-construction topography and/or bathymetry because historical channel networks that remain in agricultural lands can achieve new purpose to convey flows after hydrologic reconnection (Diefenderfer et al. 2008; Thom et al. 2011b)."

3.3 Uncertainties in the CEERP Knowledge Base

Synthesis and evaluation of the scientific knowledge base as it applies to the CEERP goal and objectives will reveal areas where knowledge is lacking or deficient. Indeed, it is apparent now that uncertainties remain in the knowledge base regarding ecosystem restoration to benefit juvenile salmonids in the LCRE. The following list of uncertainties has not been prioritized and *does not imply intent to fund*. The list is presented to provide context for the CEERP by showing that there are risks to achieving the program's goal and objectives at this time. Uncertainties in the knowledge base include the following:

- ecological interactions between juvenile salmon and other aquatic native and non-native aquatic and plant species and the significance of these interactions and hybrid food webs (ISRP 2011)
- estuarine life-history contribution to adult returns, including interior basin and Willamette River stocks
- juvenile salmon passage through culverts and tide gates under roads, tracks, levees, dikes, and other obstructions between restored off-channel sites and the main stem river
- juvenile salmon residence times, growth rates, and bioenergetics in tidal freshwater, estuarine, and main channel habitats by species and stock
- ecological effects of reed canary grass, a prevalent invasive species

- relationships between restoration actions and juvenile salmon production or indices of the survival benefits of restoration and SBUs
- priority habitats and locations for restoration
- expected trajectories of restoration sites with different plant communities; e.g., time to reasonable functional equivalency with natural wetlands in the LCRE.

3.4 Conclusion

The CEERP knowledge base concerning juvenile salmon ecology and ecosystem restoration in the LCRE supports actions to restore shallow-water habitats, such as hydrologic reconnections and riparian and channel improvements. The prevailing finding is that juvenile salmon tend to use restored areas if they are available to the area and have access (Roegner et al. 2010; Johnson et al. 2011a). Bioenergetics research has shown the potential benefits to juvenile salmon growth in shallow tidal freshwater areas (Storch 2011). These types of habitats produce prey that are consumed onsite and exported to the main stem (Bottom et al. 2008; Roegner et al. 2008; Storch and Sather 2011). Restored habitats help increase habitat diversity, which is hypothesized to contribute to increased early life-history diversity in salmonids and, thereby, salmonid population resiliency (Bottom et al. 2005b; Waples et al. 2009). Although important uncertainties remain, the existing knowledge base provides a science-based foundation for CEERP restoration and RME actions.

4.0 Strategy for Ecosystem Restoration

The CEERP strategy for ecosystem restoration emphasizes hydrologic reconnections to restore the access to and capacity of habitats that have been cut off from the main stem river, while also working to improve the quality of existing habitats used by juvenile salmonids and other species (Simenstad and Cordell 2000; Johnson et al. 2003). Other actions are also possible, as described in the *Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead* (NMFS 2011). Johnson et al. (2003) in the “159 Plan” described the theoretical basis for the CEERP strategy, along with guidance for restoration project and program implementation, and included a seven-step ecosystem-based approach to restoration in the LCRE (Table 3). The material below on CEERP strategy for ecosystem restoration is organized into three main elements: ecosystem basis, supporting resources, and restoration project development (Figure 5).

Table 3. Seven Steps for an Ecosystem-Based Approach to LCRE Restoration (modified from Johnson et al. 2003)

Step	5. Description	6. Comment
7. 1	Describe the fundamentals of restoration science (as they apply to LCRE ecosystem restoration)	See Section 4.1 (ecosystem basis)
2	Determine usage of LCRE habitats by salmonid life-history type, i.e., determine which habitats are most important and why	Ongoing research; see the *2012 Action Plan* (BPA/Corps 2012)
3	Determine which LCRE habitats have been lost relative to historical conditions (pre-development in 1900s)	See Section 4.2.2 (habitat change analysis)

Table 3 (contd)

Step	Description	Comment
4	Identify and prioritize restoration strategies for the LCRE and establish a reasonable future condition, given constraints on the system (e.g., flow regulation)	See Section 4
5	Determine which specific habitats can be restored and where, i.e., develop an inventory of possible actions	See Section 4, especially Section 4.3 (restoration project development)
6	Implement locally supported and scientifically based restoration projects	See the *2012 CEERP Action Plan*
7	Monitor actions using standardized protocols and apply the results to adaptively manage future restoration actions	See Section 5 and the *2012 CEERP Action Plan*

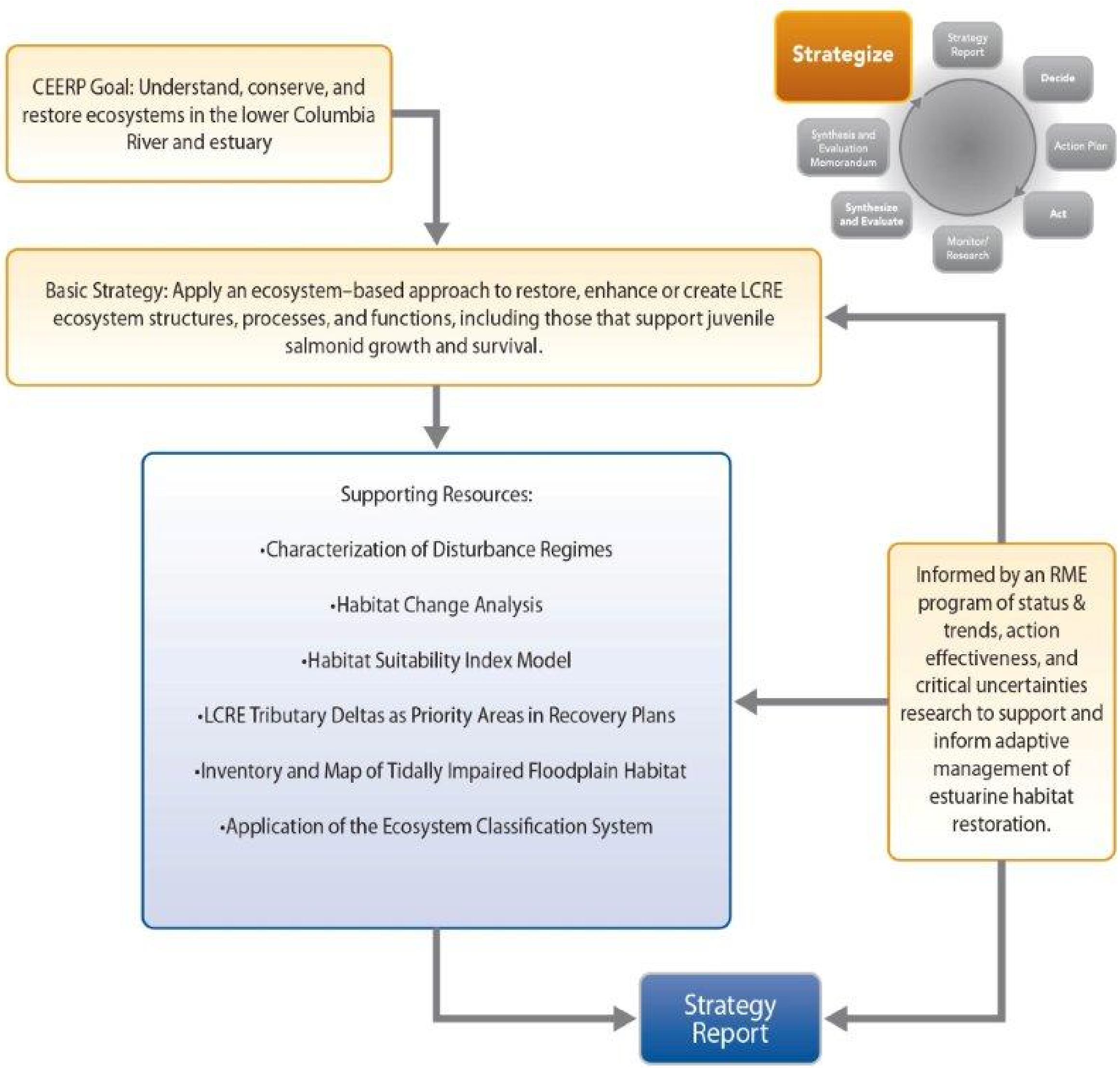

Figure 5. The Strategize Phase in the CEERP Adaptive Management Process (based on Thom et al. 2011a)

4.1 Ecosystem Basis

CEERP's ecosystem restoration strategy in the LCRE is founded on basic principles of ecological science, in particular, landscape ecology. The National Research Council (NRC 1992, pp. 347–348) viewed landscape ecology as a method for designing integrated aquatic ecosystem restoration projects. It concluded that, "*Wherever possible...restoration of aquatic resources...should not be made on a small-scale, short-term, site-by-site basis, but should instead be made to promote the long-term sustainability of all aquatic resources in the landscape*." Such a landscape approach was recently championed for the Council's Fish and Wildlife Program (ISAB 2011). Johnson et al. (2003) used these principles to develop an ecosystem–based restoration approach in the LCRE. Ecological science, as applied in the CEERP's restoration strategy, includes restoration guidance (Table 4) and the following principles:

- *Re-establishment of natural controlling factors*[1] *is required to build and maintain ecosystem structures,*[2] *processes,*[3] *and functions*[4] *that support juvenile salmon*. Re-establishing the factors that control the development, dynamics, and maintenance of natural habitat structures will result in restoration of natural habitat and ecosystem processes and functions, for example, salmon growth and increased survival/fitness. The CEERP ecosystem-based approach necessarily encompasses juvenile salmon habitats and the supporting ecosystems at site and landscape scales.
- *Returning the LCRE ecosystem to a less altered state is desirable*. The historical condition of the LCRE has been altered by agricultural and industrial development, and its current state is not entirely desirable from an ecological point of view. The structure and function of the LCRE is different than it was prior to hydrological modification and other anthropomorphic changes. The growing body of information indicates that improved survival/fitness of salmon may be dependent on return of the estuary to a less altered state (e.g., Bottom et al. 2005a; Fresh et al. 2005; Karieva et al. 2000), toward which the CEERP is essentially working.
- *The success of a restoration project will vary depending on the level of disturbance (anthropomorphic or natural) of the site and the landscape within which the site resides* (NRC 1992). Using the findings of the National Research Council and a review of the literature on estuarine habitat restoration, Shreffler and Thom (1993) concluded that different restoration approaches, such as enhancement[5] and creation,[6] should be applied depending on the degree of disturbance of the site and the landscape. For example, for sites with a high degree of disturbance, creation of a new habitat may be the only viable approach. In contrast, where the site and landscape are essentially intact, restoration to historical (i.e., humans present, but insignificant disturbance) or pre-disturbance (i.e., before man) conditions would be viable options and the probability of success likely would be high.

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[1] Controlling factors are the basic physical and chemical conditions that construct and influence the structure of the ecosystem.

[2] Ecosystem structures are the types, distribution, abundances, and physical attributes of the plant and animal species composing the ecosystem.

[3] Ecosystem processes are any interactions among physicochemical and biological elements of an ecosystem that involve changes in character or state.

[4] Ecosystem functions are defined as the role the plant and animal species play in the ecosystem, including primary production, prey production, refuge, water storage, nutrient cycling, etc.

[5] Enhancement is any improvement of a structural or functional ecosystem attribute (NRC 1992).

[6] Creation is bringing into being a new ecosystem that previously did not exist on the site (NRC 1992).

Table 4. Restoration Guidance from Ecological Science (derived from Johnson et al. 2003)

Factor	Restoration Guidance
Size	In general, larger size enhances habitat stability, increases the number of species that can potentially use the site, makes it easier to find by migratory species, and increases within-habitat complexity.
Complexity	As the number of habitat types increases, so does the number of species that can occupy the area, and the number of functions supported by the area. Higher complexity potentially results in greater biodiversity, and expression of multiple salmon life-history patterns (Bottom et al. 2005a,b).
Connectivity	Connectivity, the degree of connection and pathways between adjacent habitats or migratory corridors, means that an animal can move between adjacent habitats to derive the benefits of each habitat. It also allows for the flow of material such as organic matter between areas of production (e.g., a salt marsh) and areas of deposition (e.g., tidal channels and creek bottom where the materials are used by the ecosystem). Connectivity among habitats provides species areas in which to disperse and survive, as well as access to areas of high-quality habitat that is especially valuable to juvenile salmon.
Accessibility	The opportunity to enter and use an off-channel wetland site is fundamental to hydrologic reconnection restoration (Simenstad and Cordell 2002). Projects that restore or enhance access of juvenile salmon to important habitats would potentially enhance the feeding, rearing, and refuge functions of the site.
Areas of historic habitat loss	Areas where habitat loss has been greatest should be considered for restoration, depending on the nature of the loss and current uses at the site. These areas include forested and emergent wetland types that serve salmonids and birds.
Passive habitat restoration over creation	Areas where minor alterations would be needed to maximize ecosystem function should be prioritized over areas where massive alterations or creation of new ecosystems would be required. That said, active restoration in the form of channel excavations, scrape-downs, tide gate and culvert replacements, dike breaches, etc. will be essential actions for CEERP implementation.
Self-maintenance	Self-maintenance addresses the ability of a site to persist and evolve toward a natural (historical) habitat condition without significant human intervention. As a pre-requisite for this to occur, conditions for controlling factors in the reach and in the management unit must be appropriately developed and maintained. Self-maintenance means that the habitat can persist and develop under natural climatic variation, and that the system has a natural degree of resilience to natural perturbations. This criterion also takes into account the need to know the probable historical conditions, and the factors that produced the present conditions. This guideline represents the "areas of historic habitat type loss" theme.
Ecosystem functions	This acknowledges that some actions can result in greater enhancement of ecosystem functions than others. These projects may not be the largest or most complex projects. For example, the location may be more important than the size of a project. A medium-sized project in a location where an endangered species can directly benefit because of the proximity to its normal migratory pathway would be more important than a project far outside of the pathway.

- *Most elements within a landscape*[1] *function best when integrated with all other elements of the landscape*. Landscape ecology deals with the effect of the spatial extent, heterogeneity, and geometry of elements (e.g., habitats) of the landscape on the flow of energy, animals, and materials through the landscape (Forman and Godron 1986). One of the fundamental lessons of landscape ecology is that a landscape is a heterogeneous matrix of smaller elements, and that the arrangement, size, productivity,

[1] Landscapes are spatially heterogeneous geographic areas characterized by diverse interacting patches or ecosystems. The landscape scale is larger than the site scale and smaller than the estuary-wide scale.

resilience to disturbance, etc. of these elements within the matrix will affect the flow of energy, animals, and materials through the landscape. Removal or degradation of one or more elements may lead to the impaired performance of the remaining elements. In deciding on CEERP restoration strategies and sites, for example, it is useful to identify and consider the dysfunctional or absent elements.

- *Landscape ecology concepts such as minimum area,*[1] *shape,*[2] *corridors,*[3] *and buffers*[4] *are applicable to ecosystem restoration*. Of particular relevance to LCRE restoration are the related concepts of habitat size, accessibility, and capacity (Simenstad and Cordell 2000). These concepts are used by CEERP practitioners and managers to develop and design restoration projects. Also, the ERTG applies these concepts in its scoring process (ERTG 2010b).

4.2 Supporting Resources

During 2012, multiple tools and information resources are being used to support restoration planning and project development. These resources vary in their degree of development from completed to under construction. Resources described below are intended to support the CEERP restoration effort now or in the future. Results from these analyses as they become available will be shared with sponsors to ensure they have opportunity to consider the latest science in determining the best projects to develop. As much as the state of the science allows, we will strive to identify the most strategic habitats and locations for restoration.

Overlaying the results of the geographic information system (GIS) analyses will allow managers to map and identify areas critical for restoration and protection. A certain result might be used in combination with the others or be the sole analysis, depending on needs of the user. For example, recovery planners in Oregon and Washington may be mainly focused on priority tributaries for the LCRE salmonid populations or U.S. Fish and Wildlife Service managers may wish to identify specific types of riparian habitats that have been lost since the 1850s. Most of the resources below have been or are being developed as a GIS-based platform that can be easily updated as additional analyses come online. In addition, the resulting inventory of identified critical areas can be overlaid with the results of the disturbance analyses and land-use/land-ownership data sets to determine appropriate techniques and levels of effort needed to restore individual sites or combine multiple projects to restore larger areas.

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[1] Size estimates are a function of the minimum area needed to attract the species of interest, the size of the species, their behavior within the habitat, and required buffers. In addition, the habitat(s) must be stable over time, and with increased size comes stability.

[2] The shape of a patch or contiguous habitat affects the types and number of species in the patch. Species show preferences for edges or interiors of patches. In particular, juvenile salmon are believed to forage at the marsh-mudflat interface and at the edge of habitat patches (Roegner et al. 2011).

[3] A corridor is a narrow strip of habitat that differs from the habitats on either side. Corridors form very important routes of migration for many species. Corridors represent a more or less protected route of ingress and egress to habitats. Relative to restoration planning, corridors between sources of recolonizing species and the restored habitat are critical. If corridors are not present, the restoration effort has little chance of success no matter how well it is constructed. Corridors may also function as habitat for some species, and barriers or filters (e.g., riparian buffer zones) (Forman and Godron 1986).

[4] A vegetated buffer surrounding an aquatic habitat reduces disturbances from noise, wind, contaminated runoff, and movement. Without a high-quality buffer, the functions and stability of the aquatic habitat may be compromised.

- *Characterization of Disturbance Regimes*: Characterization of disturbance regimes is based on a landscape- and site-scale disturbance model (Evans et al. 2006). This completed tool (Figure 6) uses existing data about a series of stressors, e.g., diking, toxic contaminants, roads, population, flow restrictions, to categorize disturbances on individual site and landscape scales. This evaluation is useful in determining in general the types of restoration (preservation, conservation, enhancement, restoration, or creation) that are appropriate for a given area.

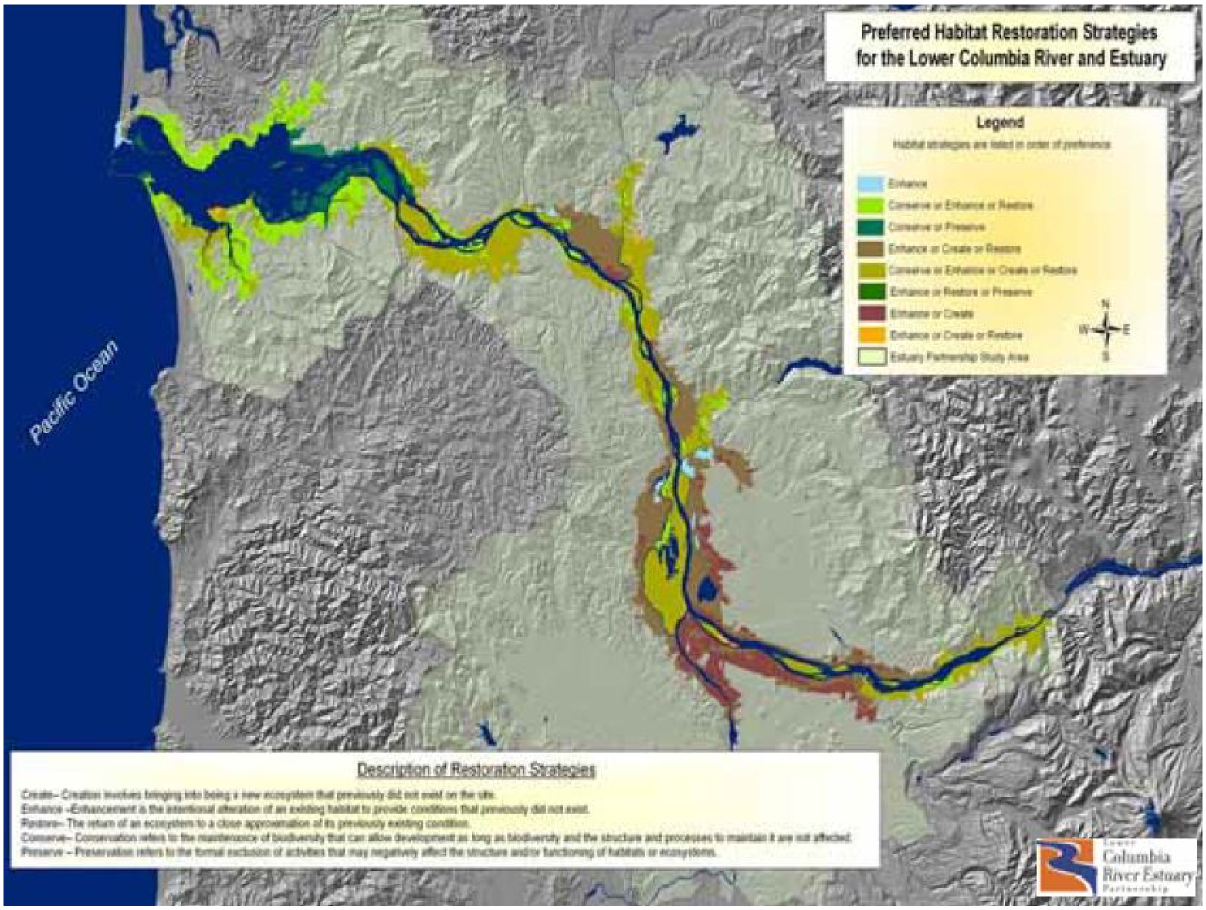

Figure 6. Assessment of Disturbance Across Landscape and Site Scales with Corresponding Restoration Approaches

- *Habitat Change Analysis*: This analysis compares habitats from historic topographic ("T") sheets and 1850s survey maps to 2010 land cover data. It assumes historic habitat coverage is a proxy for natural habitat diversity. The results generally showed losses, gains, and changes throughout the LCRE for various habitat types, e.g., tidal and non-tidal herbaceous wetlands, tidal and non-tidal wooded wetlands, forested areas, and shrub scrub areas. This analysis is ongoing with the intent to identify habitat areas where losses are coverable and overlay on public lands to determine potential areas for protection.
- *Habitat Suitability Index Model*: Focusing on yearling Chinook salmon, researchers used results from the Oregon Health Sciences University's SELFE model to determine the frequencies and locations that meet water temperature, depth, and velocity conditions favorable to yearling Chinook salmon, using criteria adapted from Bottom et al. (2005a). The research is ongoing, but preliminary results are indicating areas in the LCRE where the conditions favorable to juvenile salmon presence are met

consistently through time and those areas where they are not. For the latter, the analysis will attempt to identify areas where favorable environmental conditions can be restored.

- *LCRE Tributary Deltas as Priority Areas in Recovery Plans*: The rationale here is that fall, late fall Chinook salmon, and to lesser degree chum salmon can rear extensively in the tidally influenced habitats of LCRE tributaries. Such areas are important to Oregon and Washington salmon and steelhead recovery plans (ODFW 2010 and LCFRB 2010, respectively), as well as the CEERP. A systematic assessment of LCRE tributaries and their priority for supporting listed salmon and steelhead was conducted. This analysis is complete and produced a map and table of priority tributary habitats that is available from the EP.
- *Inventory and Map of Tidally Impaired Floodplain Habitat*: This GIS-analysis identified habitat currently disconnected or hydrologically impaired by dikes, levees, tide gates, and other structures. These areas could be reconnected, restoring natural ecosystem controlling factors and corresponding structures, processes, and functions. The results indicated over 63,000 acres of floodplain habitat could be pursued for reconnection.
- *Application of the Ecosystem Classification System*: The Columbia River Estuarine Ecosystem Classification is a tool that provides an opportunity to use best-science principles, information, and technology to select high-value restoration and protection actions to improve juvenile salmon habitat in the estuary. This application is being developed using the Classification as a foundation with the intent to apply knowledge from the Contributions to Salmon Recovery project by NMFS and collaborators and other projects, such as Historical Linkages (Bottom et al. 2008). For example, the application is intended to help with identification and prioritization of the type, location, and characteristics of estuarine habitat restoration and protection actions that would optimally benefit juvenile salmon of specific ESUs and life-history types.

4.3 2012 Restoration Project Development

Coordinated project development for CEERP relies on both opportunistic and strategic enterprise. During 2012, the approach to project development for the CEERP involved a “targeted” collaborative approach to identifying opportunities to satisfy strategic criteria (Figure 7). The approach was used to develop a living list of specific LCRE ecosystem restoration projects to implement in the 2014−2018 time frame. The result was a new methodology that considers a cost-benefit SBU assessment and allows for improved coordination among sponsors and funding agencies developing projects. As a matter of fact, the BPA/Corps and the EP, in collaboration with CEERP project sponsors, have set up a process to coordinate work to determine project opportunities. A map with relevant GIS layers of all possible sites in the LCRE is used to support this process. To focus the project development process, the EP applies the following layers to an LCRE GIS map: “tidally impaired” (current floodplain), public versus private (generally large tracts only) lands, and restoration inventory (existing projects already being tracked). A facilitated discussion about each “opportunity area” is then used to determine which sponsors may be already having discussions with the corresponding landowners. If none of the sponsors is holding discussions with the targeted landowners, the group discusses the pros and cons of doing work on that site as well as likely proposed actions. After all project opportunities are identified, the BPA/Corps start the prioritization and assignment stage with the following objectives in mind: identify cost-effective, high-value (SBU) projects; ensure that all partners have a full suite of potential projects based on their capacity; and assign projects that are a good fit for the sponsors' interests and skills. This step includes the following activities:

- Estimate potential SBUs, projected cost, and likelihood of success (see below).
- Prioritize the project opportunities based on cost per SBU, total SBU, and likelihood of completion.
- Request input from sponsors about their interest in the unassigned opportunities.
- Develop a draft version of sponsor (including the Corps through the Water Resources Development Acts Section 536 process) assignments to project opportunities with the goal of delivering the most SBUs in the shortest period of time.
- Where multiple parties are interested in the same projects, consider partnership opportunities.
- Share the draft assignments and then incorporate feedback from project sponsors to determine the final assignments.

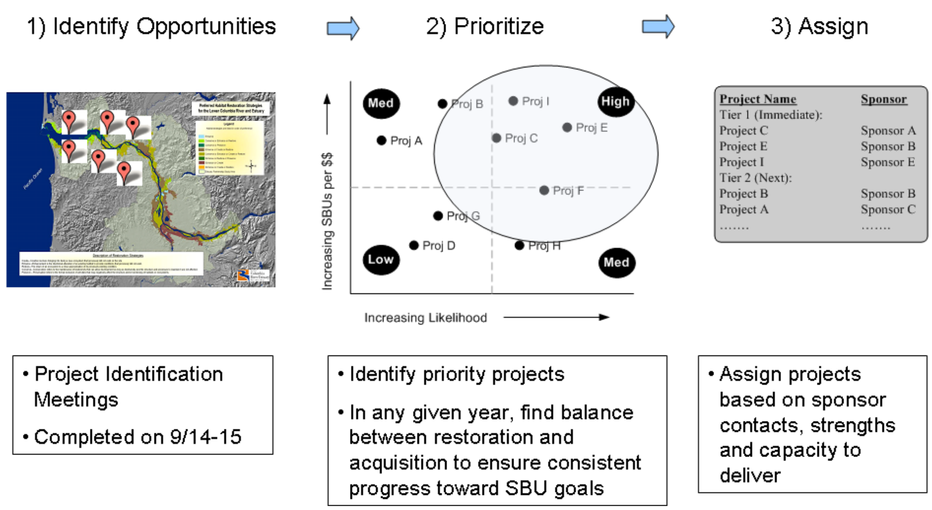

Figure 7. The 2012 Approach for CEERP Project Development

SBU assessment is an important step in the project development process. "Unofficial" SBUs can be calculated by any interested party to gauge benefits from a project. Here, the ERTG approach for calculating SBUs (ERTG 2010a) is used by non-ERTG parties to indicate SBU potential, with the caveat that there is limited information about a project at this early stage in the development process. In cases where the project is relatively costly or risky for other reasons, the ERTG may be asked to assign preliminary but "official" SBUs. Preliminary in this case means the project may need to be scored again at a later date if new information becomes available or the project design changes significantly.

The ERTG has provided guidance to restoration proponents that sponsors and the BPA/Corps applied for 2012 project development. This guidance includes (ERTG 2010b, 2011a, 2011b) the following: bigger area is better than smaller area; close to the main stem is better than farther away; restoring remnant channels is better than excavating new ones; natural processes are preferred over engineered processes; and a holistic perspective from a landscape scale is better than narrow, site-specific perspective. Based on this guidance, the BPA/Corps' approach has been modified to focus on restoration projects concerning floodplain reconnections and wetland channel improvements that have a significant footprint in tidally influenced areas relatively close to the main stem. Using a combination of best professional judgment and best available restoration science, the ERTG determined that the aforementioned actions provide the highest juvenile salmonid densities (ERTG 2010a, 2011a). Note that re-vegetation and invasive species removal are important complements to floodplain reconnection and channel habitat restoration actions, but they should not be the primary project focus to ensure delivery of the most cost-effective biological benefit.

In conclusion, the strategy for restoration project development for CEERP 2012 used an ecosystem-based approach (Table 3) and involved a systematic, collaborative identification of potential restoration opportunities using GIS maps and knowledge of local communities to develop a list of potential projects. The list was culled and refined based on SBU assessments and strategic guidance provided by the ERTG and others. This work was fed into the CEERP process to make decisions about which projects to fund; the decision-making process is explained in the *2012 Action Plan* (BPA/Corps 2012).

5.0 Strategy for RME

The RME strategy is intended to support CEERP restoration actions and address the management questions (Figure 8). RME categories include the following

1. Implementation and compliance monitoring; e.g., were the projects implemented as planned?
2. Status and trends monitoring to provide ecological context from which to assess action effectiveness results; e.g., are estuary ecosystems degrading irrespective of CEERP restoration?
3. Action effectiveness monitoring and research to determine the success of the restoration effort; e.g., how effective is restoration and what are the most effective restoration actions?
4. Critical uncertainties research to build the state of the science in the estuary; e.g., what are the key limiting factors preventing the achievement of desired habitat or fish performance and the relationships between restoration actions and SBUs and survival/condition indices?
5. Synthesis and evaluation to roll up the results for strategists and decision-makers; e.g., what does the RME mean to the program? Projects are updated annually based on the synthesis of published research and/or meta-analysis of RME and project data.

To accomplish all of this, the BPA/Corps recognize and encourage continued partnerships in planning, monitoring, evaluating, and implementing activities in the LCRE.

The RME efforts are managed intentionally to address the four key management questions (Section 2.1). In the following material, we describe the strategy for RME activities to address the four management questions.

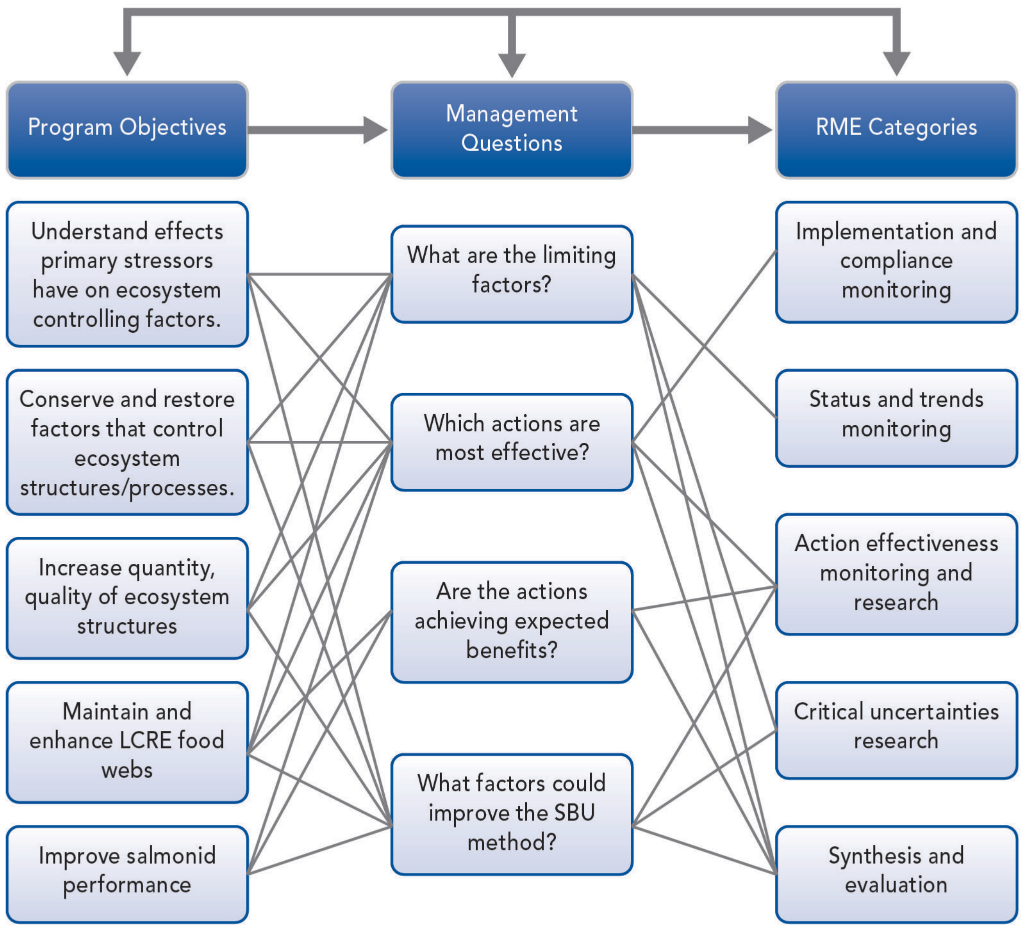

Figure 8. Relationships Among Program Objectives, Management Questions, and RME Categories

RME for Management Question 1 (What are the limiting factors or threats, i.e., stressors and controlling factors, in the estuary preventing the achievement of desired habitat or fish performance?)

Prior to 2002, scientists had not systematically surveyed fish use of tidal wetlands or most other shallow backwater habitats in the LCRE. More and more knowledge is being gained about the ecological functions or importance of these habitats to particular salmon stocks. For example, the BPA/Corps are working to evaluate controlling factors for LCRE habitats to better understand the relationship between habitat conditions and salmonid density, growth, diversity, and survival/condition. The BPA/Corps continue to address this management question through critical uncertainties research and status and trends monitoring. Topics of research and monitoring include the LCRE's contribution to fish growth and fitness/health at ocean entry and how that relates to the population structure of adult returns (population, age, etc.), and the effects of hatchery fish co-occurring with naturally produced fish. In addition to informing management of the Columbia River basin, research in the estuary is contributing to our base knowledge and understanding of how Willamette River basin and lower Columbia River basin juvenile salmon use and occupy the LCRE.

RME for Management Question 2 (Which actions are most effective at addressing the limiting factors preventing achievement of habitat, fish, or wildlife performance objectives?)

Action effectiveness research that has been accomplished to date shows that as floodplain habitats and wetlands are restored, juvenile salmon tend to use these restored habitats. This question (and presumption) will continue to be investigated through action effectiveness monitoring and research (AEMR), specifically by evaluating the effectiveness of habitat actions in the estuary relative to environmental, physical, or biological performance objectives, including long-term action effectiveness research at the landscape and estuary-wide scales for various types of habitat restoration projects in the LCRE. In addition, we will conduct site-specific action effectiveness monitoring of habitat restoration actions to reconnect ecosystems, such as removal or lowering of dikes and levees that block access to habitat or installation of fish-friendly tide gates, protection or restoration of riparian areas and off-channel habitat, and removal of pile dikes.

Beginning in 2009, the BPA/Corps began to develop the standardized methods and models to evaluate "ecological benefit" relative to improvements in habitat connectivity, juvenile salmon early life-history diversity, and survival benefit (fitness)—all defined below—as a result of habitat restoration in the LCRE (Diefenderfer et al. 2011a).

- Habitat connectivity represents a change in structural, functional, and hydrologic condition and is measured as a change in fish passage barriers at a site (width, area of restored passage, and area made available) and landscape scale (nearest neighbor distance).
- Life-history diversity represents a change in juvenile salmon estuarine use of the LCRE and can be measured as a change in spatial and temporal habitat use by juvenile salmon (species − body size – month).
- Survival benefit represents a change in juvenile salmon condition in different habitats (wetland channels, off-channel, and main channel) at different times of the year; this assessment is being developed to measure change in factors that promote fish production and indicate fish condition.

Research and development of these subjects will continue, including further implementation of AEMR to evaluate the "ecological benefit" of habitat restoration in the LCRE; methods to coordinate project-level, site-scale, and large-scale effects; and methods to define the statistical relationships between intensive action effectiveness research and extensive action effectiveness monitoring. When applicable, the approach will include other West Coast estuarine regional studies, as well as findings from the tributary habitat RME programmatic approach for project-level action effectiveness monitoring. This work will inform project selection and prioritization, project development, and alternatives formulation by testing/validating predicted ecological benefits.

RME for Management Question 3 (Are the estuary habitat actions achieving the expected biological and environmental benefits?)

CEERP RME addresses a hierarchy of hypotheses to answer this management question about the LCRE restoration effort, including an overarching working hypothesis, a landscape-scale hypothesis, and indicator hypotheses (listed below). The hypotheses are tested and assessed through RME, especially AEMR. The hypotheses are currently being evaluated and results will be reported in the 2012 Synthesis Memorandum.

- Overarching Working Hypothesis – Habitat restoration activities in the LCRE have a cumulative beneficial effect on salmon.
- Landscape-Scale Hypothesis – Restoration actions in the LCRE are producing increased habitat connectivity and an increased area of floodplain wetlands trending toward historical levels present prior to land conversion for agriculture and the construction of dams.
- Indicator Hypotheses – Indicators[1], as measured at restoration sites, are trending toward reference site conditions.

Therefore, through AEMR, we will continue to evaluate the effects of habitat actions on environmental, physical, or biological performance objectives. As indicated above, biological and environmental performance will be evaluated relative to "ecosystem benefit." However, to distinctly address this question, analysis will focus on the evaluation of biological community presence and response, specifically genetic stock identification, native and non-native species interactions, growth and diet, residence, migration, bioenergetics, mean fish density, and the LCRE's contribution to adult returns upriver. This focused area of research will allow managers to better understand how juvenile salmonids use and benefit from the Columbia estuary, and how these benefits contribute to adult survival and population diversity. Study findings will support CEERP habitat restoration planning and design.

RME for Management Question 4 (What adjustments should be made, if any, to improve the ability of the SBU crediting method to predict benefits to ESA-listed fish from ecosystem protection and restoration in the LCRE?)

RME is intended to provide the information necessary to answer this question. For example, the BPA/Corps plan continued research on salmon and steelhead migration pathways, residence times, and survival rates in the LCRE. A key consideration is that the region must use consistent data collection protocols and management systems to allow meta-analysis of RME data in the estuary. With these results, regional managers can be assured that SBUs are a meaningful measurement to evaluate the effects of habitat restoration in the Columbia estuary. To facilitate our ability to do this, we will begin by developing a regional database and establishing a proof-of-concept for synthesis and evaluation of project and RME data. Future RME should also update regional monitoring protocols, such as adding a protocol for data reduction and management, to facilitate our ability to relate observations back to the population level to the extent possible.

In conclusion, the CEERP will modify and expand specific topics of RME each year to best address programmatic needs and concerns. For example, investigations and analysis will be adapted to better index changes in early life-history diversity, habitat connectivity, and juvenile salmon survival benefits. AEMR will assess juvenile salmon density (#/m^2) to support comparative analysis through time and location. Critical uncertainties research will investigate species, populations, life-history patterns, and

[1] From Roegner et al. (2009a): Core Indicators (Ecosystem Controlling Factors and Structures): *Hydrology* − water-surface elevation, catchment area, tidal exchange volume, wetland delineation; *Water Quality* − temperature, salinity, dissolved oxygen; *Topography/Bathymetry* − elevation, sediment accretion rate, channel cross-sectional area; *Landscape* − photo points, aerial photos; *Vegetation* − percent cover, species composition, species richness, similarity index; *Juvenile Salmonids* − presence, abundance, species composition, size structure. Higher-Order Indicators (Ecosystem Processes and Realized Functions): *Habitat Availability* − area-time inundation, wetted-channel edge length, floodplain wetted area; *Material Flux* − flux rates for nutrients, chlorophyll, dissolved organic matter, plant biomass, total organic carbon, macro-invertebrates; *Juvenile Salmonid Usage* − residence time, diet, growth rate, fitness, prey availability, genetic stock.

habitat relationships such that restoration efforts strategically address the factors and threats that most prominently influence juvenile salmon survival and productivity. In addition, the CEERP will improve synthesis and reporting of key research findings to regional managers and stakeholders, including the ERTG, to inform restoration project assignment of SBUs. Strategic RME priorities address the four key management questions (Section 2.1). Specific RME projects to address the priorities are documented in the *2012 Action Plan* (BPA/Corps 2012). Strategic RME priorities will be updated annually as informed by the synthesis and evaluation of projects and RME information.

6.0 Closing

The overall goal of the CEERP is to understand, conserve, and restore ecosystems in the LCRE. The CEERP is a regional, collaborative program that involves using existing processes, programs, technical groups, and plans to avoid redundancy and increase efficiency. A formal adaptive management process is in place involving annual cycles of project development, prioritization, implementation, monitoring and research, and synthesis and evaluation.

This 2012 CEERP Strategy Report describes the BPA/Corps' fundamental strategy for estuary habitat actions and monitoring/research—apply an ecosystem-based approach to restore, enhance, or create ecosystem structures, processes, and functions in the estuary, and perform research, monitoring, and evaluation to assess the effectiveness of these actions, while building our understanding of ecosystems in the LCRE. The CEERP will use, as appropriate, information from projects funded outside the CEERP for external purposes regarding predation, toxic contaminants, dredging, hydrosystem operations, and tributary habitat improvements, and other topics. The strategy developed in *this 2012 Strategy Report* drives the actions outlined in the *2012 Action Plan*.

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Appendix

Programmatic Approach for Action Effectiveness Monitoring and Research for the Columbia Estuary Ecosystem Restoration Program

The purpose of this appendix is to describe the programmatic approach the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland District (BPA/Corps) are implementing to obtain useful and appropriate action effectiveness monitoring and research (AEMR) data to support the Columbia Estuary Ecosystem Restoration Program (CEERP). The BPA/Corps use this programmatic approach to guide their AEMR funding choices for the CEERP. The BPA specifically intends to incorporate programmatic AEMR into scopes of work for proposals during the Estuary/Lower Columbia River categorical review within the Northwest Power and Conservation Council's Fish and Wildlife Program Program in fall 2012. The programmatic approach to estuary AEMR is being coordinated with Columbia River tributary habitat AEMR and the overall federal research, monitoring, and evaluation (RME) effort under the 2008/2010 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NMFS 2008, 2010). The lower Columbia River and estuary (LCRE) environment is unique, but wherever possible we identify commonalities between the estuary and tributary habitats for restoration and RME to apply knowledge from one area to the other to reduce costs. In this appendix, we describe a step-by-step technical approach to programmatic AEMR for the LCRE, as listed below and described in the following sections.

Step	Description
1	Review previous work on programmatic AEMR planning and design.
2	Define the restoration actions requiring AEMR.
3	Establish the suite of monitored indicators by action.
4	Develop sampling designs, including power analyses by action.
5	Describe ongoing AEMR.
6	Determine AEMR priorities.
7	Develop standardized methods for restoration project proposals, AEMR plans, data reduction, and AEMR reporting.
8	Perform analyses to synthesize and evaluate AEMR results.

Step 1. Review previous work on programmatic AEMR planning and design

Fundamental elements of monitoring aquatic habitat restoration projects can be found in publications by Thom and Wellman (1996), Zedler (2001), and Rice et al. (2005). Previous work on programmatic AEMR by the BPA/Corps can be built upon for the CEERP. Three work products from BPA/Corps RME efforts are particularly pertinent: Johnson et al. (2008), Roegner et al. (2009a), and Johnson et al. (2011d).

A basin-wide, federal, BiOp RME effort, including estuary RME, commenced in 2000 (NMFS 2000). For the LCRE component of this effort, Johnson et al. (2008) produced a RME plan called the *Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program*. This plan developed the specific AEMR objectives that were incorporated into the 2008 FCRPS BiOp. At a programmatic level, AEMR was designed to use quantitative studies to demonstrate how habitat restoration actions affect factors controlling ecosystem structures and processes at site and landscape scales and, in turn, juvenile salmonid performance. Control chart (Burr 1976), hypothetico-deductive (Popper 1963), and meta-analysis (Johnson et al. 2011d) methods based on data from a suite of reference and restoration sites were recommended (Diefenderfer et al. 2011b). The plan recognized that pertinent elements of the data sets developed through status and trends monitoring, implementation and compliance monitoring, critical uncertainties research, and AEMR would need to be established, maintained, analyzed, synthesized, and evaluated. Data collection methods for action effectiveness, as well as the spatial and temporal scale of monitoring and example protocols, were also recommended.

Standard data collection protocols are critical to any programmatic approach to AEMR, because ideally the data so produced can be compared and integrated across locations and times. In the LCRE, Roegner et al. (2009) published protocols for “core metrics” (a class of monitored indicator) and provided recommendations for “higher-order” indicators and sampling designs for AEMR of habitat restoration projects. Categories of protocols included hydrology, water quality, landscape, vegetation, and juvenile salmonids. (For a list of monitored indicators covered by Roegner et al. 2009a, see the footnote in Chapter 5 of the Strategy Report.) Before-after-control-impact and before-after-reference-impact designs for the purpose of AEMR are described. The protocols and sampling designs are currently being used regionally in project-specific AEMR.

Johnson et al. (2011d) presented program- and project-level considerations for AERM. These authors established a methodology for specifying statistical relationships between intensive action effectiveness research and extensive action effectiveness monitoring, including a method to indicate how much AEMR sampling is enough. They also provided a statistical approach for quantitative meta-analysis of AEMR data and offered approaches to prioritizing AEMR and critical uncertainties research. For reporting and documentation, they developed templates for project descriptions, AEMR plans, and site evaluation cards. These works will not be reproduced here; the interested reader is encouraged to consult these references directly for more information.

Step 2. Define the restoration actions requiring AEMR

AEMR depends on the attendant restoration actions. LCRE restoration actions involve improving or creating habitat for juvenile salmon in migratory and rearing areas and reconnecting floodplain habitats to the main stem river (Table 1). A cross-walk between the LCRE and Columbia tributary restoration actions reveals mostly commonality, but some differences, between the two areas. The differences stem from structures and actions that are unique to the LCRE, e.g., dredged channel material and pile structures. In both areas, actions are undertaken to acquire and protect land, restore riparian habitats, reconnect and restore off-channel and floodplain habitats, and control invasive plant species.

Table 1. Restoration Actions for LCRE (categories from Estuary Module [NMFS 2011]) and Comparable F&WP Tributary Restoration Action Categories. "CRE" numbers are from the Estuary Module.

LCRE Restoration Actions	8. Comparable F&WP Tributary Restoration Actions
9. Acquisition and protection	Land acquisition or protection (category 3)
Restore riparian areas (CRE 1.4)	Riparian habitat (category 5; see invasive plants below)
Create habitat by applying dredged material to beneficial use, including notching and scrape-down (CRE 6.2 and 6.3)	Not applicable
Remove or modify pilings (CRE 8.2)	Not applicable
Restore degraded off-channel habitat (CRE 9.4)	Large woody debris (LWD) and boulder stability, sediment reduction (sub–category 2a) and LWD and boulder complexity/pools (sub-category 2b); side channel or connected wetland (sub-category 4b)
Breach dikes (CRE 10.1)	Floodplain enhancement/reconnection (sub-category 4a)
Remove tide gates or culverts (CRE 10.2)	Barrier improvements (sub-category 1b)
Upgrade tide gates or culverts (CRE 10.3)	Barrier improvements (sub-category 1b)
Control invasive plant species and plant native species (CRE 15.3)	Plant (sub-category 5a) and plant removal (sub-category 5b)

Step 3. Establish the suite of monitored indicators by action

The organizing framework for AEMR-monitored indicators is based on the LCRE conceptual model (Thom et al. 2004), as well as the estuary habitat capacity, opportunity, and realized function (defined below) model developed for salmonids by Simenstad and Cordell (2000) (Figure 1). The latter model was elaborated with respect to listed stocks of Columbia basin salmon by Bottom et al. (2005a). Realized function corresponds well to the viability concept as defined by Fresh et al. (2005) for the estuary, which includes four performance criteria: abundance, productivity, spatial structure, and life-history diversity. If monitoring shows that 1) through habitat restoration actions, habitat opportunity and capacity improve relative to present levels, and 2) that salmon exhibit improved realized functions associated with their use of restored habitats, then this information may serve as a basis for inferences regarding the benefits of LCRE habitat restoration actions to salmonids.

- Habitat Capacity: A category of habitat assessment metrics including "habitat attributes that promote juvenile salmon production through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality"; for example, invertebrate prey productivity, salinity, temperature, and structural characteristics.
- Habitat Opportunity: A category of habitat assessment metrics that "appraise the capability of juvenile salmon to access and benefit from the habitat's capacity"; for example, tidal elevation and geomorphic features.
- Realized Function: A category of assessment metrics that "include any direct measures of physiological or behavioral responses that can be attributable to fish occupation of the habitat and that promote fitness and survival"; for example, survival, habitat-specific residence time, foraging success and growth.

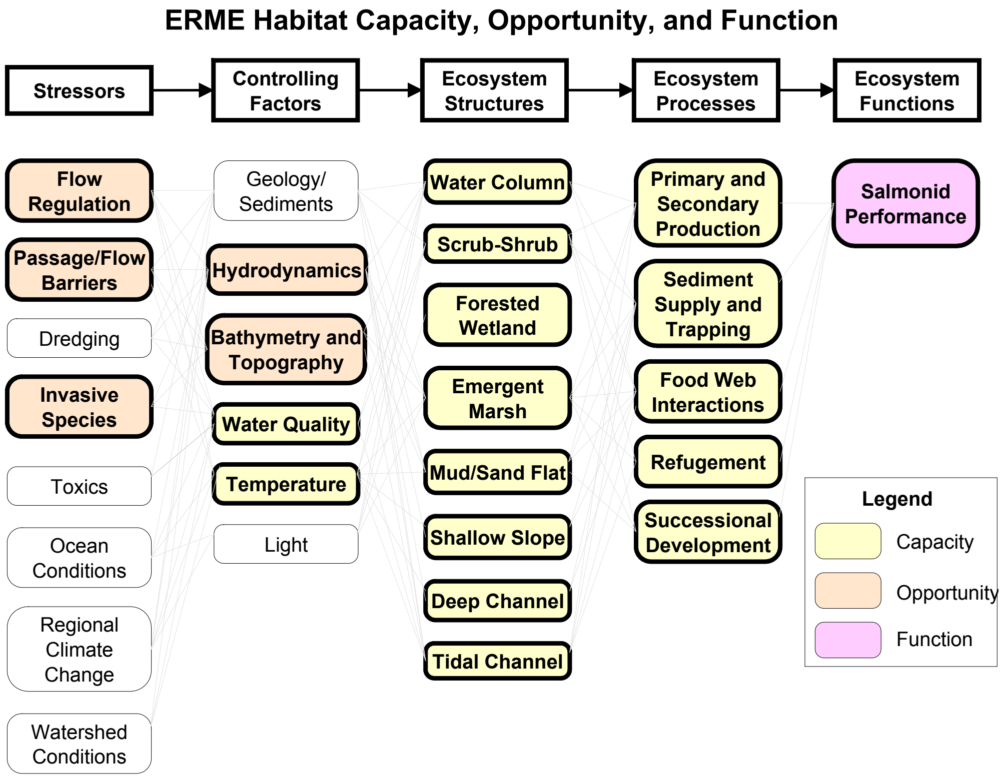


Figure 1. Estuary RME (ERME) Habitat Capacity, Opportunity, and Realized Function as Depicted in the Columbia River Estuary Conceptual Model. The conceptual model was adapted from Thom et al. (2004). The figure is from Johnson et al. (2008, Appendix B, Figure B.5).

Given this framework, the purpose of AEMR is to establish whether the restoration actions are having the desired effects on ecosystem controlling factors, structures, processes, and functions in terms of performance of targeted salmon populations. This requires deliberate selection of project-specific monitored indicators depending on project objectives, as well as program objectives. For example, at the project-level, a tide gate replacement could necessitate different monitored indicators than a riparian zone restoration. At the program-level, decisions are made about whether AEMR is needed for a given site (see below). The core metrics of Roegner et al. (2009) are monitored indicators intended for AEMR as necessary depending on project and program objectives. The selection of the core metrics was based on the following interrelated criteria:

- Metrics must be diagnostic of relevant ecosystem function and direct correspondence to common goals (i.e. hydrological reconnection) of CRE restoration projects (Thom and Wellman 1996)
- Three classes must be tracked: controlling factors (e.g., tidal regimes), structural factors (e.g., plant communities), and functional factors (e.g., salmonids age/size) (NRC 1992)
- Metrics must be applicable to all sites with measurements that result in comparable data sets relevant to present and future investigations (Tegler et al. 2001)
- Measurements and data analysis must be practical in terms of funding, manpower, and processing requirements (Callaway et al. 2001).

Monitoring the same core indicators using the same protocols at all selected LCRE restoration sites is part of the foundation for AEMR at the landscape and estuary-wide scales. These metrics were specifically designed to be feasible and economical for all projects. Other metrics in Table 2, which may require greater technical resources or costs to measure, are appropriate for directed research to reduce risk in decision-making regarding the LCRE restoration, for elucidating cause-and-effect relationships, and for assessing the cumulative effects of restoration projects on fundamental ecosystem processes (e.g., material flux). The suite of potential monitored indicators for each LCRE restoration action reveals that many indicators are applicable to a given restoration action depending on management needs (Table 2). Furthermore, a given monitored indicator is usually applicable to multiple restoration actions. The choice of monitored indicators will depend on project type, site, and objectives and program needs and priorities.

Table2. Potential Monitored Indicators by LCRE Restoration Category. The restoration categories have been condensed to simplify the presentation. The "X" signifies a potential AEMR application for the indicator. The monitored indicators are from Johnson et al. (2011d, Appendix F, Table F.1). The monitored indicators are in approximate order for a spectrum from action effectiveness monitoring (top) to action effectiveness research (bottom) and extensive (top) to intensive (bottom). The asterisk (*) signifies an indicator, called a "core metric" in Roegner et al. 2009a, that usually will be monitored at any site chosen for AEMR.

Monitored Indicator	Riparian Improvements	Habitat Creations	Pile Structures	Wetland Channels	Hydrologic Reconnections	Invasive Plant Control
*Photo Points	x	x	x	x	x	x
*Latitude and longitude	x	x	x	x	x	x
*Water-surface elevation (logger)	x	x	x	x	x	
*Temperature (logger)	x	x	x	x	x	
Salinity (logger)	x	x	x	x	x	
*Channel cross-sectional area	x	x	x	x	x	
*Sediment accretion	x	x	x	x	x	
*Elevation (bathymetry/ topography)	x	x	x	x	x	x
Catchment area				x	x	
*Plant species composition	x	x	x	x	x	x
Plant percent cover	x	x	x	x	x	x
Plant biomass		x		x	x	x
Aerial photo's	x	x	x	x	x	x
Fish presence/species/size	x	x	x	x	x	
Fish density	x	x	x	x	x	
Satellite imagery land cover						x
Water velocity	x	x	x	x	x	
Water properties (DO, TOC, chloro', etc.)	x	x		x	x	
Nutrients (NH_3, PO_4, SiO_3)	x	x		x	x	
Fish diet	x	x	x	x	x	
Fish residence time	x	x	x	x	x	
Neuston prey	x	x	x	x	x	

Table 2. (contd)

Monitored Indicator	Riparian Improvements	Habitat Creations	Pile Structures	Wetland Channels	Hydrologic Reconnections	Invasive Plant Control
Benthic invertebrate prey	x	x	x	x	x	
Insect fallout prey	x	x	x	x	x	
Fish condition	x	x	x	x	x	
Hypsographic curve of water-surface elevation	x	x	x	x	x	
Tidal exchange volume				x	x	
Image analysis	x	x	x	x	x	x
Area-time inundation	x	x		x	x	
Floodplain wetted area	x	x		x	x	
Wetted-channel edge length	x	x		x	x	
Plant similarity	x	x		x	x	x
Plant biomass flux	x	x		x	x	x
Material flux	x	x		x	x	
Fish growth	x	x	x	x	x	

Step 4. Develop sampling designs, including power analyses by action

Power analyses by restoration action will be determined for the draft 2013 Strategy Report in summer 2012. This step presents sampling designs for different approaches to AEMR depending on CEERP management needs and priorities. We preface the sampling design presentation with a discussion of the unique nature of evaluating the effectiveness of habitat restoration actions in LCRE environments and some of the relationships between recommended methods in the estuary and the tributaries. This section is based on material from Johnson et al. (2008, Appendix B.2, Action Effectiveness Research).

Action effectiveness research efforts in the LCRE and the Columbia Basin tributaries have differences and similarities. In terms of differences, the diversity of habitats and variability at multiple spatial scales are greater in the LCRE than in tributary areas, thereby affecting experimental designs. The aquatic environment is more dynamic in the LCRE than it is in the tributaries, with water-surface elevations, water currents, and salinities, among other variables changing on semi-diurnal tidal and time scales for other forcing factors (Jay et al. 2011). In terms of similarities, the tributary habitat AEMR has some of the same issues that are inherent to LCRE AEMR. For example, control or reference sites are difficult to identify and maintain through time, and adequate replication and isolation of individual action effects is difficult to accomplish. In the LCRE, data from restoration project sites may be compared with data from comparable trends monitoring reference sites to evaluate the trajectory of restoration progress. This melding of status and trends monitoring with AEMR is analogous to the integrated status and trends monitoring approach in the tributaries. Programmatic AEMR for the LCRE will continue to be coordinated with that for the Columbia basin tributary habitats to apply learning and reduce costs.

The general purpose of any AEMR sampling design is to enable assessment of whether restoration measures are achieving project and program goals and objectives. Testing for a simple change in ecosystem controlling factors is relatively trivial because a physical change was intentionally performed. A more difficult proposition is to assess whether the restoration action produced the desired shift in ecosystem structures, processes, and functions from some state A to desired state B. Auxiliary questions may include how rapidly the shift occurred and the relative costs of alternative restoration activities. The sampling designs described here are appropriate for testing these questions in the complex environment of the LCRE. No one design is recommended, however, because the monitoring design will depend on the project's objectives. Four sampling designs are presented below: control-reference, reference-only, control-chart method, and replicate restoration-reference. By sampling before and after restoration, these designs are specific subclasses of the general before-after-control-impact or before-after-reference-impact designs. The designs that follow, however, are based on the recovery model, which tests the parallelism hypothesis (Skalski et al. 2001) of how an impact site compares to an adjacent reference site, as opposed to comparing to "before" conditions at a control site. "Before" data for select monitored indicators are highly useful for documenting the initial response of the site to the restoration action and should be collected whenever possible. This is consistent with the sampling design recommendations by Roegner et al. (2009a).

Control-Reference Designs

This design for assessment of restoration effectiveness is based on evaluating whether a shift from a site's current state A to a desired state B in a natural system subject to spatial and temporal variability has occurred (Figure 2). Control sites are replicate locations with habitat traits similar to the subject site prior to restoration. These sites are sampled over time to monitor any temporal shifts in baseline conditions and how the subject area might have responded over time had no restoration action taken place. Reference sites are replicate areas considered representative of the desired outcome of the restoration action. These replicate areas are used to characterize the spatial heterogeneity of the target habitat and any temporal shift in the target over time due to climate shift, maturation, etc. Hence, the goal of the restoration may be best viewed as a range of ecosystem conditions, itself subject to natural change over time. A fully restored site might therefore be expected to be within this reference range and mimic any temporal pattern displayed by these reference sites (Figure 2).

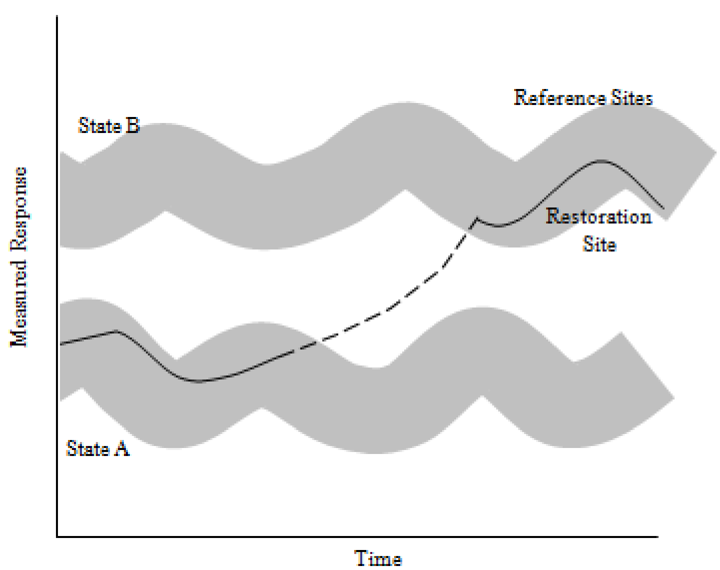


Figure 2. Conceptual Framework for Evaluating Restoration Effectiveness. The restoration site should shift from its initial state A to a desired state B over time. The successfully restored site should have response values within the range of reference sites and track their temporal pattern.

Reference-Only Designs

Control sites might be an unnecessary luxury if the difference between states A and B is great. In other words, if the ranges of characteristics at restoration and reference sites do not overlap, then there should be little or no risk of falsely concluding restoration (i.e., reaching state B) when the site is still within the range of the initial state A. In this case, only reference sites are needed to assess the status of recovery (Figure 3). Restoration success is still defined in this situation as the subject site merging into the range of reference conditions and tracking the site's responses over time. Using only reference sites as part of an effectiveness monitoring design is analogous in many ways to accident assessment designs (Skalski 1995). Recovery of affected sites after an environmental accident is defined by the affected site approaching the range of reference conditions and subsequently sharing their same temporal trajectory over time.

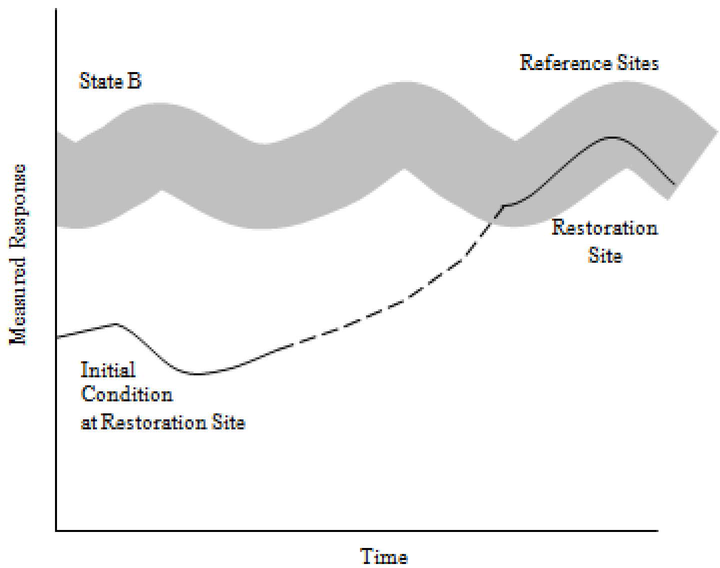


Figure 3. Conceptual Framework for Monitoring Restoration Effectiveness Using Only Reference Sites as a Target for Restoration

Control-Chart Method

In accident assessment, typically there are multiple reference sites and multiple potentially affected sites in the evaluation. Skalski and Robson (1992) suggested using repeated measures analysis in conjunction with a test for parallelism to assess recovery. Recovery was achieved when the reference and impact sites began tracking each other through time, i.e., parallelism (Skalski et al. 2001). However, in monitoring the restoration of a single site, standard tests of parallelism cannot be performed. There is no between-site, within-treatment variance, only within-site measurement error at the restoration site.

From the repeated sampling at the reference sites, upper and lower control limits for reference responses can be constructed (Figure 4). Control limits describe a range of population responses, such that a prescribed proportion of the population falls within their bounds. For example, the limits

$$\mu \pm 3\sigma$$

contain approximately 99.7% of a normally distributed population. Shewhart control charts (Grant and Leavenworth 1972; Duncan 1974; Burr 1976) use this principle to establish control limits to monitor production processes in manufacturing. A variation of this concept could be used to assess whether a restoration site merges into the range of reference conditions (Figure 4). Wheeler (1995; p. 205−225) provides statistical power calculations for control charts.

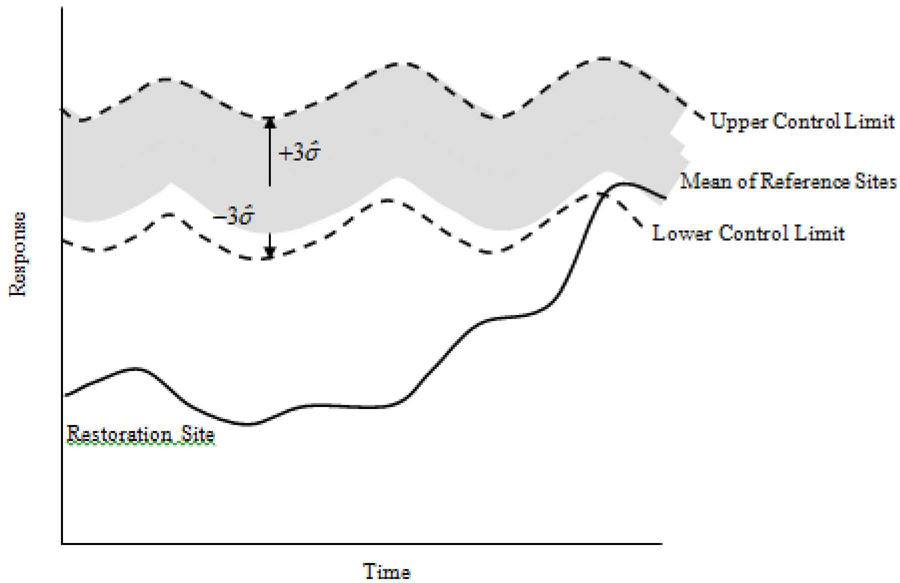


Figure 4. Illustration of Using Control Chart Methods to Monitor Recovery Success

Replicate Restoration-Reference Design

In many cases, intensive AEMR at the site level will be cost prohibitive. Therefore, the majority of restoration activities will go largely unmonitored. However, a regional effectiveness monitoring approach substituting extensive sampling for intensive, site-specific sampling may be used. A random sample (or stratified random sample) of restoration sites could be selected according to habitat type and restoration activity (e.g., rechannelization, dike removal, etc.). Each site would be paired with a nearby reference site, similar to matched pairs in biometrical studies (Fleiss 1985).

Indicators would be measured prior to restoration and periodically in subsequent years at each site within a pair (Figure 5). The replicated investigations would test whether there is an interaction between time (i.e., before-after) and treatment (restoration vs. reference site) as well as a convergence of responses over time. Site-specific covariates could also be used to determine which conditions are correlated with restoration success. This replicated trial would provide a region-wide assessment of restoration success. By blocking on different habitat or restoration practices, the analysis could also provide insight into which habitats or practices are best suited for restoration. In conclusion, the recommended AEMR sampling design uses a control chart method to document the condition of restoration sites relative to a suite of reference sites. All monitoring designs for AEMR described here would require a network or specially selected reference sites.

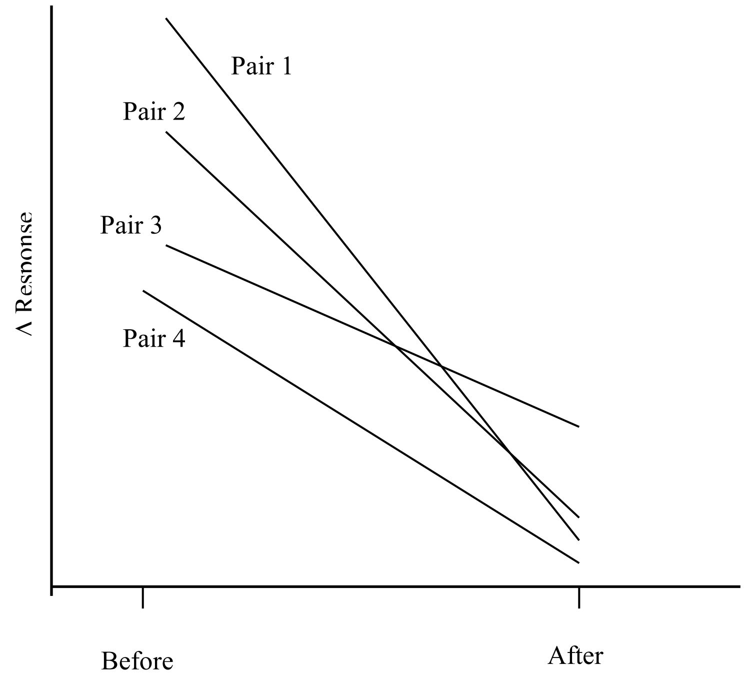


Figure 5. Graphical Representation of Before-After Response to Restoration at Replicate Restoration-Reference Sites Used in Regional Assessment. Measured response is the difference (Δ) between reference and restoration sites.

Step 5. Describe ongoing AEMR

Ongoing 2012 AEMR activities include one project under the F&WP (BPA) and five projects under the Anadromous Fish Evaluation Program (Corps) processes. Most BPA/Corps RME activities for the LCRE were placed with the Corps as part of the Washington Memorandum of Agreement (Washington-Action Agencies 2009). The Ecosystem Monitoring project (BPA 2003-007-00) is conducting AEMR at selected restoration projects being funded by the BPA. The restoration actions being monitored include riparian improvements, wetland channels, hydrologic reconnections, and invasive plant control. The Cumulative Effects project (Corps EST-P-02-04) is in the closeout phase, delivering its last annual report in April 2012 and producing a first-ever levels-of-evidence analysis in summer 2012. The Multi-Scale Action Effectiveness Research project (Corps EST-P-11-01) is conducting site-scale AEMR sampling at three sites (Sandy River delta [SRD], Julia Butler Hanson [JBH] National Wildlife Refuge, and Tenasillahe), fish density estimation to relate to restoration actions at the landscape scale (St. Helens to Longview), and preparing for eventual estuary-wide cumulative effects evaluations. At SRD, "before" sampling is underway for a proposed hydrological reconnection. At JBH and Tenasillahe, tide gate replacements are being studied using before-after reference-impact and recovery model sampling designs. The Salmon Benefits project (Corps EST-P-09-01) is a methods-development study that is producing indices for habitat connectivity, early life-history diversity, and restoration benefits to juvenile salmon. The BPA/Corps intend to apply these indices to measure and track restoration action effectiveness at site, landscape, and estuary-wide scales. The Synthesis and Evaluation project (Corps EST-P-11-01) has just begun to develop a geospatial database for the LCRE that will eventually include AEMR data from multiple sites, projects, and researchers to disseminate data and enable comprehensive syntheses and evaluations of AEMR in the LCRE. These projects are described further in the *2012 CEERP Action Plan* (BPA/Corps 2012).

Step 6. Determine AEMR priorities

From a programmatic point of view, CEERP managers are concerned about the following questions in order to help prioritize AEMR (Figure 6). These questions are addressed in a preliminary manner below Figure 6; much more detailed information is expected in the 2012 Synthesis Memorandum due in summer 2012.

- Which restoration actions (Table 1) are we least (most) certain about the potential for achieving project success and improving habitat access and capacity and benefits to juvenile salmon?
- Which reaches or habitat types are the highest priorities?
- Is there a solid statistical relationship between extensively and intensively monitored indicators that could be applicable?
- How much AEMR is enough?

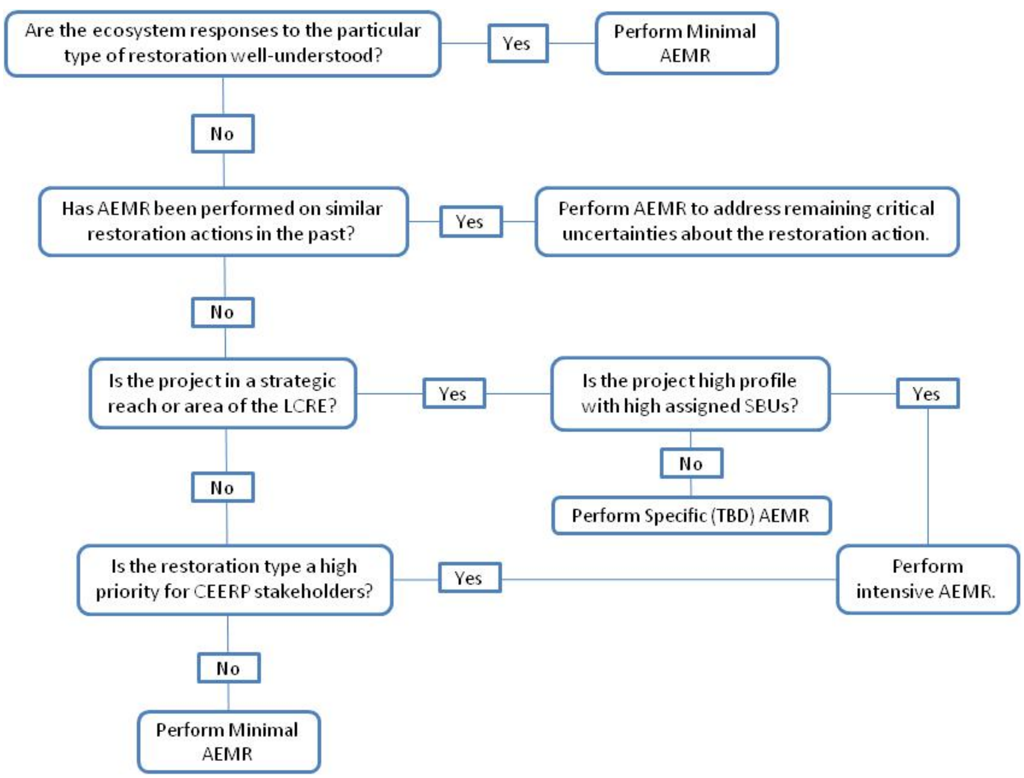


Figure 6. Example Decision Tree to Choose Between Intensive AEMR (research) and Extensive AEMR (monitoring). (From Johnson et al. 2011d.)

<u>Certainty of LCRE Restoration Actions</u>

The knowledge base is building regarding the ecological effects and benefits to juvenile salmon from LCRE restoration actions, but there is still much to learn. Each project site is different and the resulting effects of the restoration actions vary. Riparian improvements are being studied with results forthcoming in the next year. Purposeful habitat creation projects have not been attempted yet, but accidental habitat creation by placement of sediments dredged from the main Columbia River channel appears to have resulted in desirable habitats for juvenile salmonids (Borde and Diefenderfer 2009). Pile structures are being assessed for possible removal or modification. A plan for RME has been drafted for the pile structures (Johnson et al. 2010a). Hydrologic reconnections can change the water regimes at a site and provide new access to once blocked habitats (Roegner et al. 2010). Invasive plant control and associated plantings of native species is common to many restoration projects, but there have been few AEMR studies (Johnson et al. 2010b). Overall, we cannot say at this time which LCRE restorations actions are least (most) certain about the potential for achieving project success and improving habitat access and capacity and benefits to juvenile salmon. This means AEMR priorities for CEERP are wide ranging.

Priority Reaches or Habitat Types

At this time, the knowledge base does not support designating priority reaches or habitat types. Sather et al. (2011) concluded that juvenile Chinook salmon densities for unmarked fish did not differ statistically among wetland, off-channel, and main channel habitat types. Some have hypothesized that the reach between Bonneville Dam and the Willamette River might be a priority because it is the first area listed fish from upriver encounter when they enter the LCRE. CEERP research is underway to address the question of priority reaches or habitat types for particular genetic stocks.

Relationships Between Intensive and Extensive Monitored Indicators

As explained by Johnson et al. (2011d), "CEERP managers must make decisions about the trade-off between extensive and locally intensive sampling efforts. As part of the cumulative effects study, we ascertained which extensive restoration indicators to measure, and when and how often to measure them, from intensively studied reference and restoration areas. The Crims Island, Kandoll Farm, and Vera Slough sites were intensively sampled to develop effectiveness monitoring sampling protocols (Roegner et al. 2009a) and to map trajectories of physical and biological responses to restoration (Thom et al. 2011b). These intensively sampled sites provide a virtual model of the restoration process that we use to guide the selection of basic restoration indicator measurements at the extensively monitored sites and they provide the inferential framework to help assess the success of restoration from the cursory, extensive observations taken over time at individual restoration projects. By developing a proper mix of extensively monitored sites and intensively monitored sites in the CEERP, individual restoration projects may be surveyed with minimal effort while providing maximum opportunities to detect benefits at large spatial scales. The cumulative effects study developed several relationships between extensively and intensively monitored indicators (Table F.1 [Table 3 here]). More work remains to be done to provide peer-reviewed, statistically valid relationships."

Table 3. Example Relationships Between "Extensive" Independent Monitored Indicator(s) and "Intensive" Dependent Monitored Indicator(s). (From Johnson et al. 2011d, Appendix F, Table F.1)

"Extensive" Independent Variable(s)	"Intensive" Dependent Variable(s)	Reference
Water-surface elevation + land elevation	Floodplain wetted area; area-time inundation	Coleman et al. (in preparation)
Water temperature	Juvenile salmon presence	Roegner et al. (2010)
Land elevation + lateral and longitudinal location in floodplain + sediment accretion rate	Plant community composition	Borde et al. (in preparation)
Catchment area	Channel cross-sectional area at outlet; wetted-channel edge length	Diefenderfer and Montgomery (2008)
Tidal exchange volume	Material flux (chlorophyll, dissolved organic matter, nutrients, plant biomass, macro-invertebrates)	Woodruff et al. (2011)

AEMR Effort

The material in this section is from Johnson et al. (2011d).

"In monitoring the estuary to estimate the salmon benefits of restoration activities, the question of sample size is two-fold. The extensive sampling and the site evaluation card were conceived to cover all restoration sites. From the perspective of tallying SBUs, site-specific information would be ideal. One could, however, envision representing sampling restoration sites to estimate total SBUs, but it's not clear all parties would accept anything less than a complete tally.

With regard to the number of intensively monitored sites, the intent is to select only a sample of the total restoration sites for such effort, say, n of N sites. At these sites, higher-level ecological responses would be measured along with correlated rapid assessment measurements. Then using the rapid assessment data at all or most sites, an estimate of estuary-wide, total higher-level ecological response would be estimated by either ratio or regression estimation (Cochran 1977:150–203).

Using the variance formula for regression estimators, the number of intensive monitoring sites that should be sampled can be calculated. Let $\hat{Y}$ represent the estimate of the estuary-wide, total response and Y be the true value. Furthermore, define precision as

$$P\left(\left|\frac{\hat{Y}-Y}{Y}\right| < \varepsilon\right) = 1-\alpha$$

where the desire is for the relative error in estimation $\left(\text{i.e.,} \left(\frac{\hat{Y}-Y}{Y}\right)\right)$ to be less than $\varepsilon, (1-\alpha)$ 100% of the time. For example, if you wish to be within ±25% of the true value 90% of the time, then

$$P\left(\left|\frac{\hat{Y}-Y}{Y}\right| < 0.25\right) = 0.90 .$$

Using the above definition of sampling precision, then

$$\varepsilon \doteq Z_{1-\frac{\alpha}{2}} \cdot \frac{\sqrt{\text{Var}(\hat{Y})}}{Y}$$

and in the case of regression estimation (Cochran 1977:192)

$$\varepsilon \doteq Z_{1-\frac{\alpha}{2}} \sqrt{\frac{\left(1-\frac{n}{N}\right)\text{CV}_{Y_i}^2\left(1-\rho^2\right)}{n}} .$$

Solving for n for given precision defined by ε and α

$$n = \frac{1}{\dfrac{\varepsilon^2}{Z_{1-\frac{\alpha}{2}}^2 \text{CV}_{Y_i}^2\left(1-\rho^2\right)} + \dfrac{1}{n}}$$

where ε = relative error size

$Z_{1-\frac{\alpha}{2}}$ = Z-value for a standard normal distribution at cumulative probability of $1-\frac{\alpha}{2}$

N = total number of restoration sites

ρ = correlation between higher level ecological response and rapid assessment variable,

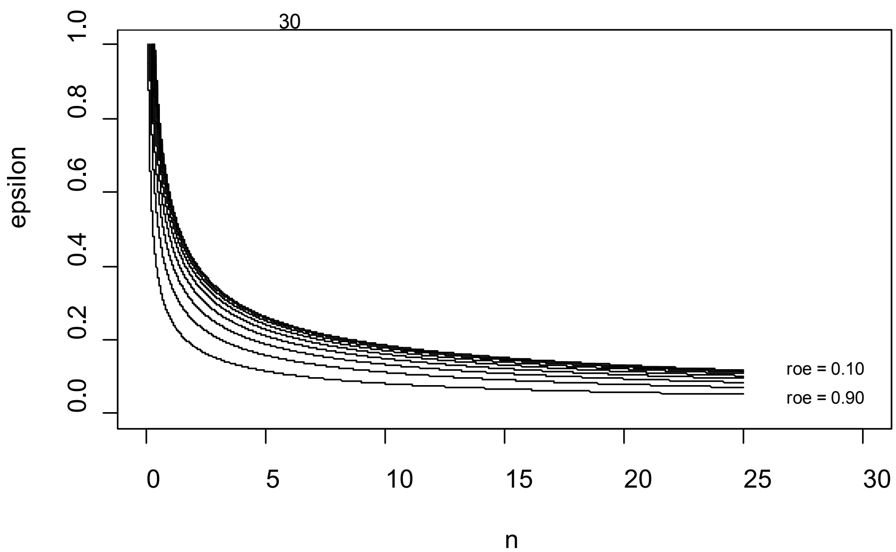
CV_{Y_i} = coefficient of variation in the higher level ecological response between restoration areas, i.e., $= \frac{\sqrt{\text{Var}(Y_i)}}{\bar{Y}}$.

Consequently, the number of intensively monitored restoration sites (n) will be a function of the desired level of precision (i.e., ε and $1-\alpha$); how correlated are the intensive and extensive responses $(\text{i.e.,} \rho)$ and how variable are the restoration sites $\left(\text{i.e.,} \text{CV}_{Y_i}\right)$.

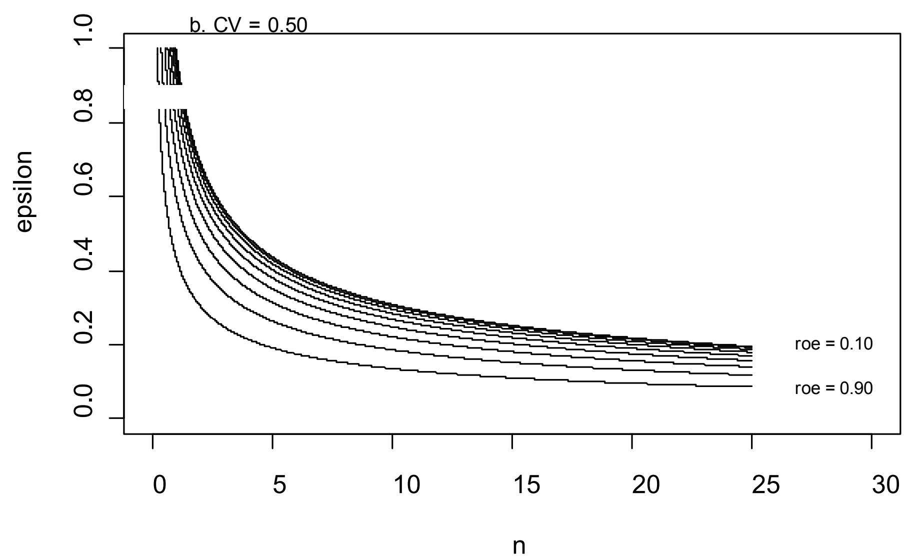
Robson and Regier (1964) recommended for rough management purposes precision should be ±50%, 95% of the time (i.e., ε = 0.50, $1-\alpha$ = 0.95)and for accurate management, ±25%, 95% of the time

$(\text{i.e., } \varepsilon = 0.25, 1-\alpha = 0.95)$. Figure 7 provides sample size curves for different levels of precision $(\varepsilon, 1-\alpha = 0.95)$, levels of environmental variability , and correlation in extensive and intensive measured responses. For example, if environmental variability has a CV = 0.50, and ρ = 0.50, then approximately n = 25 intensively monitored sites are needed (Figure7b) for accurate management. On the other hand, if CV = 0.30 and ρ = 0.50, this number of intensively monitored sites decreases to n = 6 for accurate management needs (Figure 7a).

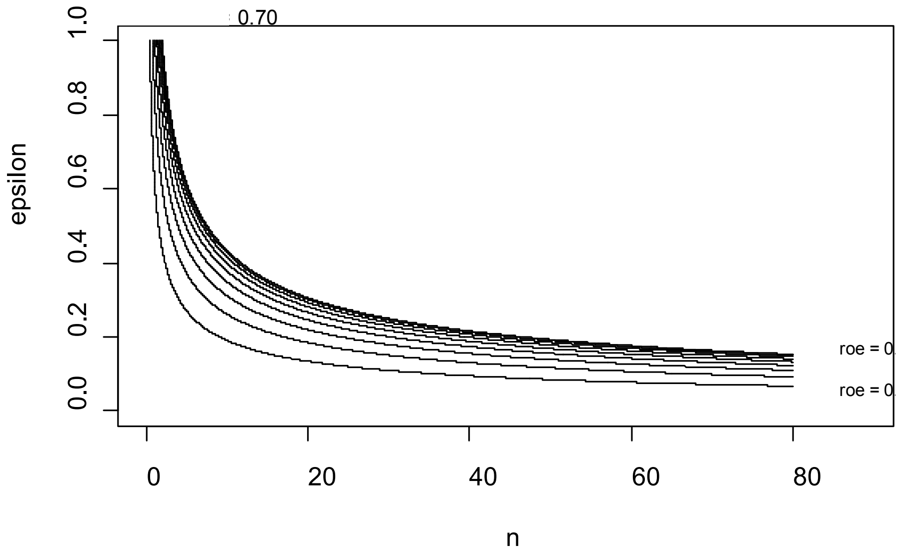
a. CV = 0.30



b. CV = 0.50



c. CV = 0.70



d. CV = 0.90

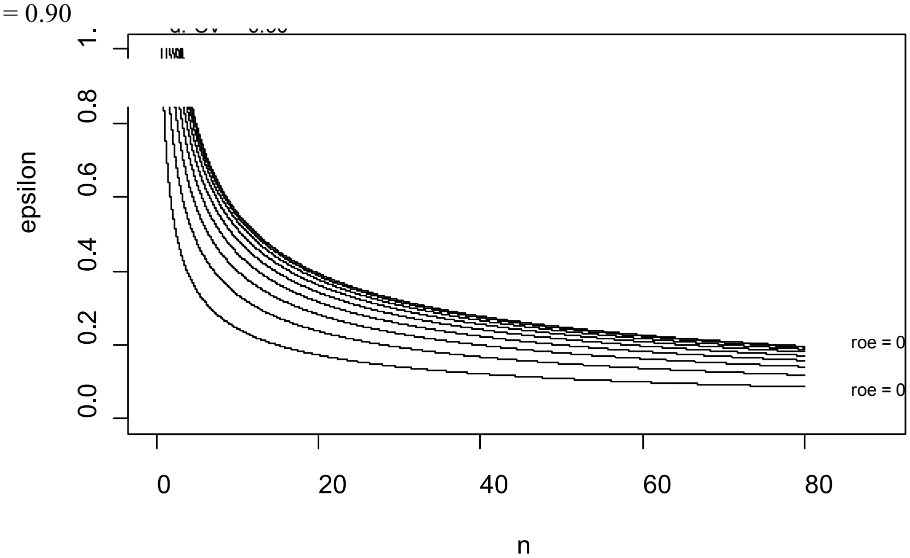


Figure 7. Sample Sizes (n) as a Function of Desired Precision (ε) at $1-\alpha$ = 0.95 and the Correlation Between Sites (ρ) When the Variability Between Restoration Sites Has a Coefficient of Variation (CV) of (a) CV = 0.30, (b) CV = 0.50, (c) CV = 0.70, and (d) CV = 0.90

In conclusion, this is just one possible quantitative framework that can be used to determine how much sampling is enough in the estuary. There are other possibilities as well. Using this framework, investigators should use preliminary data to estimate ρ and CV for important higher-level responses and work with management to select useful levels of ε and $1-\alpha$ all parties can agree upon."

Step 7. Develop standardized methods for restoration project proposals, AEMR plans, data reduction, and AEMR reporting

Templates have been developed for restoration project proposals, project-specific AEMR plans, and site evaluation cards (SECs) to support restoration practitioners and promote standardization and efficiency within the CEERP (Johnson et al. 2011d). For prospective restoration projects, the Expert Regional Technical Group (ERTG) for the CEERP created a project template to provide the basic content for each document. These templates are obligatory for all projects submitted to the ERTG for review.

Ideally, every restoration project would have a plan for AEMR. Such plans can range from a paragraph describing pre- and post-restoration site conditions coupled with photo points to an intensive research design to be carried out over 5 to 10 years. AEMR plans will be restoration project-specific, depending on local conditions, type of restoration, available funding and time, and other factors. Most importantly, however, AEMR will depend on the needs of the CEERP. The intent is to provide a template for project-specific AEMR plans consistent with the CEERP adaptive management process (Thom et al. 2011a).

Data reduction is the step between raw data after it has been screened through quality assurance and quality control procedures and data ready for uploading to the LCRE geospatial database that is currently under construction. Under the Synthesis and Evaluation project (EST-P-12-01), data reduction protocols are being developed for many of the action effectiveness monitoring protocols for data collection (Roegner et al. 2009).

SECs have been designed so that information in the project template and the AEMR plan can be copied and pasted directly into the SEC document. SECs were first proposed by Thom et al. (2008) as a mechanism for systematically recording AEMR data from restoration projects. The intent was and still is to use the SECs to synthesize AEMR data in periodic meta-analyses. The SEC template was designed with the context that its utility and value depend on the ability and ease with which it can be accurately completed by a wide range of restoration personnel. If the SEC were too large, too demanding, or too complicated it would decrease the chances of its being completed. However, without the SEC, the ability to systematically capture AERM data and use the data to respond to reporting requirements is diminished. In the future, SECs will be required for regular reporting by AEMR practitioners.

Step 8. Perform analyses to synthesize and evaluate the AEMR results

In practice, there will be a myriad of restoration projects, some of which may receive intensive site-specific AEMR evaluations. However, the cost of such studies is relatively high, so the number of such studies is necessarily limited. Meta-analysis will therefore be used to determine the consistency of effectiveness across studies as a whole. Ratiometric estimators using relationships between extensive and intensive monitored indicators will also be applied. If enough individual assessment studies exist, it may be possible to identify the factors shared by successful restoration and the traits common to failed attempts. The results of the meta-analysis would provide an overall assessment of the effectiveness of restoration projects and provide guidance on which proposed sites and methods have the greatest chance of succeeding. Johnson et al. (2011d) provided detailed methods for the meta-analysis of LCRE action effectiveness data.

Another approach the BPA/Corps intend to use to synthesize and evaluate CEERP RME data is the hypothetico-deductive method (Popper 1963, Figure 8). The approach begins with working hypotheses about the effects of restoration actions, e.g., tidal exchange is greater after the restoration action than before. Using multiple hypotheses and associated monitored indicator data, the preponderance of evidence for or against the effects of restoration on the habitat at restored sites can be gauged. Both meta-analysis and the hypothetico-deductive method will be included in the comprehensive, estuary-wide levels-of-evidence evaluation (Diefenderfer et al. 2011b) of the cumulative effects of CEERP restoration actions planned for 2016.

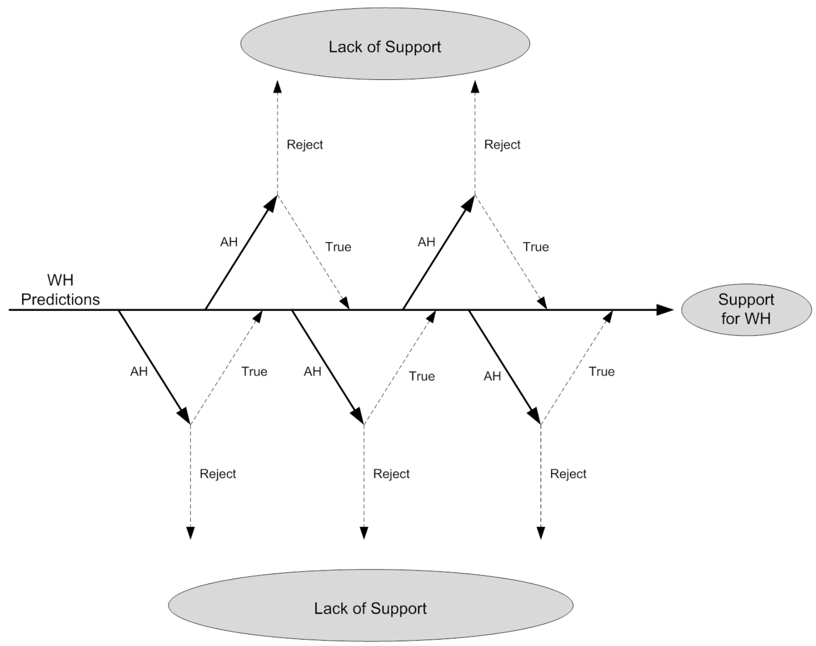


Figure 8. Conceptual Diagram for the Hypothetico-Deductive Method (reprinted from Johnson and Diefenderfer 2009, Figure 3.2.)

Conclusion

Action effectiveness is a critical element of the CEERP adaptive management process. It is important to monitor the effectiveness of restoration actions to know how well they are performing relative to their intended purpose. Funds for AEMR, however, are limited and need to be spent wisely to obtain useful, cost-effective information for management.