US Army Corps of Engineers ®
Portland District

Summary Report

Sustainable Rivers Project

Integration of McKenzie and Santiam Rivers for Basin-wide Implementation

January 2017

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ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
BA	Biological Assessment
BiOp	Biological Opinion
BPA	Bonneville Power Administration
cfs	cubic feet per second (ft^3/s)
COP	Configuration/Operation Plan
Corps	U.S. Army Corps of Engineers
E flows	Environmental flows
EA	Environmental Assessment
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ft	foot (feet)
ft^3/s	cubic feet per second
FY	fiscal year
GIS	Geographical Information Systems
hr	hour
M&I	municipal and industrial
NMFS	National Marine Fisheries Service
ODFW	Oregon Department of Fish and Wildlife
O&M	Operations and Maintenance
OMET	Operational Measures Evaluation Team
PHABSim	Physical Habitat Simulation System
PDT	Project Delivery Team
POR	period of record
ResSim	Reservoir System Simulation
RM	river mile(s)
RM&E	Research, monitoring, and evaluation
SRP	Sustainable Rivers Project
sq. ft.	square foot (feet)
TDG	total dissolved gas
TNC	The Nature Conservancy
U of O	University of Oregon
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WCM	Water Control Manual

1. INTRODUCTION

Environmental flow (e-flow) implementation and monitoring in the Willamette River Basin has primarily focused on the Middle Fork sub-basin as a pilot project. To achieve basin-wide implementation of an adaptively managed environmental flow program, the Sustainable Rivers Project (SRP) in the Willamette Valley, needed to bring the McKenzie and Santiam River sub-basins up to the same level of development as the Middle Fork Willamette River.

Two recently developed basin-wide products, the “environmental-flows implementation guidance” and the “environmental-flows monitoring framework”, were used as the basis for expanding implementation and monitoring to the other sub-basins. The work performed to accomplish this task included the following:

1. Evaluated annual flow operations in all sub-basins since initiation of the SRP program to determine the level of achievement of e-flow targets and to identify critical gaps
2. Expanded the development of baseline monitoring datasets and short-term monitoring goals for key areas of the McKenzie and Santiam sub-basins
3. Compared Corps hydro-regulation operations to implementation guidance and identified opportunities to better meet e-flow objectives
4. Engage Willamette Basin experts to review recent monitoring findings and identify potential refinements to flow and ecological objectives for high-priority river reaches. This was accomplished by conducting a workshop with the Corps, TNC, and regional experts.

The product of this effort is the subject summary report outlining e-flow implementation to date, initial results of monitoring, and refined e-flow objectives for the Middle Fork, McKenzie, and Santiam sub-basins.

2. BACKGROUND

Formal adoption and implementation of environmental flows (e-flows) into US Army Corps of Engineers Willamette Valley (Valley) water management operations was made by the Portland District in July 2015. The approval signaled a change from a focus on achieving implementation of environmental flows to one of integrating and sustaining those operations. Going forward, the SRP required a systematic approach to managing future SRP e-flows activities in the Middle Fork Willamette, McKenzie, and Santiam river basins.

Early on, adaptive management was identified as the best management approach for the Willamette SRP, post implementation. For the SRP, adaptive management, is an organized and goal driven approach for attaining e-flow objectives through systematic monitoring, synthesis, and feedback that informs planning SRP’s future actions. It is “doing, while learning in the face of uncertain outcomes”. The need for an adaptive management plan (AMP), arises from several requirements for future management of the Willamette SRP program, post implementation phase, including:

1) Plan and manage future Willamette SRP activities.
    a) Coordinate SRP funding (e.g. data collection, etc.).
    b) Coordinate with Willamette Valley stakeholder and their efforts to maximize efficiencies.
    c) Prioritize SRP reaches based on opportunity and need.
    d) Coordinate with Portland District water management section on refining e-flow targets.

2) Manage and schedule on-going SRP monitoring activities, such as:
    a) Recording of streamflow and water stages (e.g. data logger collection and synthesis, hydrograph comparison analyses, etc.).
    b) Collection of aerial photography showing geomorphic floodplain planform changes over time (e.g. gravel bar creation and movement).
    c) Collection of riparian vegetation succession and extents data (e.g. Black cottonwood).

3) Manage the development and implementation of future SRP monitoring and emerging science studies.

Adoption of an adaptive management strategy is an appropriate response for meeting these requirements. Adaptive management for the Willamette SRP program would be characterized as:

1) Addressing uncertainty over time through systematic monitoring, feedback, and response using the best available and evolving science.
2) Structured and iterative in nature.
3) Focusing on specific flow objectives as well as other metrics described in monitoring plans.
4) Collaborative to maximize Valley stakeholder resources.

A Willamette Valley SRP adaptive management program would provide a logical, systematic, and sustainable structure for e-flow operations into the future.

The foundation of Willamette SRP adaptive management would be the monitoring plans developed by the University of Oregon (U of O) and the US Geological Survey (USGS), with assistance from The Nature Conservancy (TNC) and the Corps. The U of O developed the first monitoring plans, concentrating in the Middle Fork Willamette. The USGS built on this work and prepared a comprehensive monitoring plan that included all three Willamette River SRP subbasins. The SRP monitoring plans are:

1) "*Willamette Sustainable River Project Phase 1: Development of a Monitoring Plan for the Environmental Flow Recommendations on the Middle Fork Willamette River, Oregon*". (2012).

2) "*Willamette Sustainable River Project Phase 3: Development of a Monitoring Plan for the Environmental Flow Recommendations on the Middle Fork Willamette River, Oregon*." (2013).

3) "*Monitoring Framework for Evaluating Hydraulic, Geomorphic and Vegetation Responses to Environmental Flow Releases in the Middle Fork Willamette, McKenzie and Santiam River Basins, Oregon"*. (In Press).

The USGS monitoring report built upon the U of O monitoring reports for the Middle Fork Willamette River. The USGS added the McKenzie and Santiam reaches into their comprehensive report, and included recommendations for future studies that could fill existing data gaps and integrate emerging science into the SRP program. A list of other monitoring efforts in the Valley was provided in the report that represented opportunities for the Willamette SRP to leverage those efforts against SRP monitoring efforts.

The USGS and U of O monitoring plans will provide the basis for Willamette SRP adaptive management efforts. The monitoring plans identify linkage metrics between flow regimes and habitat improvement.

3. EVALUATION OF ANNUAL FLOW OPERATIONS

Annual flow operations were evaluated to determine if water management operations resulted in flows that achieved e-flow target flow rates and durations. The e-flow targets were initially developed in the SRP sub-basin workshops, then refined and documented in the Corps' July 2015, e-flow implementation memorandum. TNC prepared hydrograph analyses for the period from water year 2008 through 2015 for the Middle Fork Willamette, McKenzie River, and North Santiam.

Flow data for each subbasin river reach of interest was downloaded from USGS National Water Information System (NWIS) databases as daily average flows from October 1, 2008 through September 30, 2015.

USGS provisional data (i.e. subject to revision) was used for mid-2015 data. There was some missing data (occurred rarely) that was not included in the comparison analysis. Daily average data were used for the analysis, but instantaneous data sets for limited periods, do exist. It was noted that the use of daily averages "dampened" the effect of intra-day events.

Some observations of the data relative to the 2015 e-flow Implementation MFR are summarized below:

North Santiam at Mehama:

- In cases where the target duration was >1 day, the magnitude/timing criteria were frequently met, but the duration was not met. This occurred in 66% of the water year-goal combinations with >1 day duration.
- The high-flow, 1-day duration event targets in summer and winter were met more often than in the McKenzie or Middle Fork Willamette.

McKenzie near Rainbow:

- Met noticeably fewer e-flow targets than the other two subbasins, indicating that discharge was typically too low in the periods of interest to meet the e-flow criteria.
- Only met a high-flow, 1-day duration event target in either summer or winter in one year (2008).
- The spring flow target (between 1,500-2,500 cfs, >=4 day duration) was the only goal that was met the majority of the time.

Middle Fork Willamette at Jasper:

- Targets met falls between North Santiam and McKenzie rivers; mixed success
- Partially met most of the 4-day duration flow targets in winter and spring, because there usually weren't enough consecutive days to fully meet the criteria.

Hydrograph comparisons highlighted some apparent differences between SRP workshop metrics and those identified in the Corps' July 2015 implementation memorandum. The differences arose primarily as a result of the SRP e-flow objectives developed during the workshops, being used by subsequent analyses. The original flow targets were modified to achieve Corps implementation requirements, including:

- Demonstrate that a project e-flow operation was feasible.
- Demonstrate quantitative benefits.

- Verify that all Project authorities were met and that the e-flow operation fell within the constraints of the current water control manual constraints.

To meet these requirements, objectives were necessarily tailored to be more specific and conform to constraints of actual water management operations. A summary of how e-flow targets evolved during the implementation process, is attached as an appendix to this document.

The primary lessons learned from this task and were discussed with the regional experts at the workshop as shown below

- The record showed that many e-flow release and duration targets had been realized during wintertime operations in the Willamette Valley. This meant that there were adequate hydrologic opportunities conducive to SRP e-flow goals. It was pointed out that the observed level of attainment was often due to the fact that water managers were familiar with the development of SRP objectives and conceptual operations that would satisfactorily achieve SRP goals.
- Hydrograph comparisons highlighted apparent differences between original SRP workshop target metrics and those identified in the Corps' July 2015 implementation memorandum. The workshop attendees recommended that the differences be better reconciled and that final e-flow target metrics be more clearly identified.
- The goal of a specific e-flow target was not clear. Future work should clarify and refine a target to better reflect how a specific ecosystem benefit function was achieved by an e-flow release.
- It was also not clear how changes/refinements to e-flow targets might be applied retroactively to the current e-flow water control manual updates. Workshop attendees suggested that a similar level of effort that was taken for the Corps' July 2015 implementation memorandum, might be necessary. This was identified as a substantial multi-year effort.

4. DEVELOPMENT OF E-FLOW MONITORING FRAMEWORK

The USGS monitoring framework report (to be completed in 2017) is comprehensive and builds upon the U of O reports by the addition of the McKenzie and Santiam subbasins. The report will be used as the starting point for adaptive management in the Willamette SRP.

The draft report, titled "*Monitoring Framework for Evaluating Hydraulic, Geomorphic and Vegetation Responses to Environmental Flow Releases in the Middle Fork Willamette, McKenzie, and Santiam River Basins, Oregon*", is intended to be a tool for adaptively managing the Willamette SRP and is attached as an appendix to this report.

The monitoring framework report laid out an approach for monitoring hydrologic, hydraulic, geomorphic, and vegetation responses to adaptively managed environmental flow releases implemented by the Willamette SRP. The USGS report noted that with refined objectives in place, a comprehensive monitoring program could be developed with the methods outlined and used to provide critical information for tracking progress towards SRP goals.

The USGS report recommends the following:

1) Sustain SRP's diverse floodplain ecosystems through an adaptively managed environmental flow program.

2) Perform periodic hydrograph comparison analyses to characterize success of meeting e-flow targets, such as flow magnitudes, duration, and number of events.

a. Standardize and simplify flow, geomorphic, and biological objectives.
b. Contextualize the metrics and clarify what is important for attaining specific ecosystem function and habitat improvements.
c. Identify an agreed upon mechanism for incorporating monitoring and emerging science feedback into the Willamette SRP e-flow water management by the Corps.

3) Perform analyses to characterize habitat availability/refugia for different e-flow releases (e.g. flow depths and inundation extent analyses)

4) Perform repeat mapping for:
    a. Channel and floodplain planform features using LiDAR and aerial photographs (e.g. gravel bar movement).
    b. Channel bathymetry survey to determine sediment transport and channel geometry response to e-flows (e.g. bank erosion and occlusion).
    c. Perform vegetation analyses using aerial photographs, site monitoring, and GIS analyses to identify potential recruitment for Black cottonwood and other floodplain plant species
    d. Plot cottonwood seedling survival and succession, and determine causal relationships to differing e-flow regimes.
    e. Evaluate cottonwood stand diversity from field observations and repeat land cover mapping.

The USGS also suggested developing processes for data syntheses, reporting, and adaptive assessment. They proposed:

1) Annual assessments of environmental flow implementation to document flow conditions and identify which targets were achieved.

2) Detailed reports summarizing short-term hydraulic, geomorphic, and vegetation responses to streamflows could be issued every 5 years or after a large-magnitude flood event that triggers major changes to the study area.

3) Longer term assessment reports could be issued every 10 years which synthesized the annual and short term trends (5-year) monitoring reports. These would be reach-scale status and monitoring trend reports.

Finally, the framework report identified the importance of developing a multi-organizational monitoring program. An adaptive management plan for the SRP should include a robust cooperation and coordination aspect to ensure a "maximization of efficiencies" for Corps and other stakeholders in the Willamette SRP basins.

5. IMPLEMENTATION IMPROVEMENTS AND OPPORTUNITIES

In 2016 the USGS conducted an assessment of alluvial sections of the Middle Fork Willamette and McKenzie Rivers. The study, titled "Summary of environmental flow monitoring done in 2014-2015 for the Sustainable Rivers Project", provides an example of emerging science and monitoring that can be used to support SRP adaptive management activities.

The goal of the study was to assess the changes from e-flow releases on channel planform elements (e.g. gravel bar creation and movement) as well as comparing the effects to vegetation succession and dispersion. Site monitoring was conducted for Black cottonwood succession and dispersion in the Middle Fork and McKenzie River alluvial reaches.

The report provided insight into the effectiveness of the target e-flows, and identified where more information would be useful. The report included future monitoring considerations for streamflows, mapping, geomorphology, sediment movement, Black cottonwood, and invasive plants.

The basis for monitoring and future adaptive management of the Willamette subbasins will be the creation of baseline datasets and evaluation and analysis reports. The USGS monitoring framework report, provided information about establishing recurring site-monitoring and data recording, and highlighted ways the SRP knowledge base could be expanded and developed further under adaptive management. In that vein, the USGS study was an initial attempt at performing comparisons between target and actually implemented e-flows, with an assessment of the "on the ground" impacts from e-flow operations. The synthesis and discussion resulting from this study provides the adaptive management process with the mechanism for identifying opportunities to better meet e-flow objectives. An excerpt from this report is attached as an appendix to this document that includes useful, future environmental flow monitoring considerations and recommendations.

6. EXPERT REVIEW AND DISCUSSION

In March 2016, the Corps and TNC conducted a small group workshop with Willamette basin experts to discuss preliminary assessments of e-flows implemented to date and to solicit feedback on how to proceed in the future. The group was updated on SRP work accomplished since the last workshop in 2012.

Experts in biology, hydrology, geomorphology, vegetation, planning, and engineering from TNC, the USGS, Oregon Department of Fish and Wildlife (ODFW), and the Corps participated. A focus when establishing the list of attendees was to ensure that the group included persons who had significant experience on the Willamette SRP. Notes of the meeting are provided as attachments to this document.

The goals of the workshop were:

1) Update participants on the status of Willamette SRP
2) Share Analyses of e-flows
3) Discuss e-flow strategies

Workshop discussions centered on how e-flow metrics evolved from the three (3) subbasin workshops to the final Corps implementation memorandum, analysis of peak flows and durations of observed streamflow record, an overview by USGS of basin geomorphological and plant monitoring indicators, and responses to streamflow fluctuations.

The background information formed the basis for further group discussion concerning adaptive management activities. These discussions involved prioritization of efforts and identified the possible focus on some subbasins over others, data gap studies, and collaborating with other environmental programs and studies to be efficient.

Training of regulators was also a discussion point. Currently, only one Portland District water management regulator has experience with the SRP workshops and possesses practical operational knowledge for implementing e-flows in the Willamette. The group suggested additional training for regulators and management. The first phase of training should be dedicated for regulators and the regulatory chief. A second phase of training would focus on project operators in the Valley.

Monitoring discussions focused on hydrograph evaluations, (e.g. were targets met?) as one monitoring parameter for defining “success”. Habitat response to e-flows was the other primary evaluation success metric category. The USGS and U of O studies exemplified the approaches and also pointed out the complexity of the interplay between e-flows and geomorphic and planform response. Both are important. Future adaptive management strategies will need to include a mutually agreed upon plant or suite of plants to monitor and report on to determine the success of e-flow operations.

Funding for future SRP work was discussed. The Corps currently funds many studies in the Willamette through the Research, Monitoring, and Evaluation (RM&E) program. Some of this research may be applicable to SRP monitoring needs. It was asked, how SRP monitoring could better align with RM&E monitoring to better take advantage of the work being done. The USGS and others pointed to on-going data collection efforts and programs in the basin. SRP management could and should focus on developing agreements to maximize the efficiencies of the various agencies efforts in the Valley and within the Corps. For example, there is an “instream flow” regional group reviewing ecological needs and developing recommendations for alternative flows for the Willamette Biological Opinion. This group is working to meeting both the NMFS Reasonable and Prudent Alternative, RPA and for the Willamette Basin Review project objectives. Soon there will be recommendations that include a framework to annually adapt flow management associated with the Willamette Valley Project. The SRP e-flow recommendations and efforts should be aligned with the efforts by others.

7. Conclusions and Recommendations

The Willamette SRP has accomplished much. TNC and the Corps, along with very important contributions from the USGS and Willamette basin regional experts, produced a comprehensive monitoring plan and framework study for all three SRP Willamette sub-basins, the Middle Fork Willamette, McKenzie, and Santiam Rivers. The USGS open file report, “Summary of Environmental Flow Monitoring for the Sustainable Rivers Project on the Middle Fork Willamette and McKenzie Rivers, Western Oregon, 2014-2015”, https://pubs.usgs.gov/of/2016/1186/ofr20161186.pdf, was an initial step to understanding e-flow impacts at the site-level and for identification of opportunities to better meet e-flow objectives. An excerpt from that study, outlining future opportunities and suggestions for follow-on tasks and improvements, is provided as an attachment to this study.

The follow-on workshop in March 2016, solicited regional expert opinions and discussion on the status of the e-flow program and future management.

From that workshop, an adaptive management approach for the Willamette SRP was recommended to implement future SRP e-flows. The management approach would be a structured response, yet flexible and resilient to address future habitat and human induced changes in the Middle Fork, McKenzie, and Santiam River watersheds.

The final implementation of adaptive management into the SRP will necessarily be a collaborative effort taken on by the Corps, TNC, and SRP stakeholders.

General suggestions for an SRP adaptive management approach are outlined below.

1. Use the USGS report, *"Monitoring Framework for Evaluating Hydraulic, Geomorphic and Vegetation Responses to Environmental Flow Releases in the Middle Fork Willamette, McKenzie and Santiam River Basins, Oregon"* as a basis for SRP monitoring and adaptive assessment activities.

2. Perform recurring hydrograph comparison analyses to characterize success of meeting e-flow targets, such as flow magnitudes, duration, and number of events.
    a. Standardize e-flow targets criteria.
    b. Agree on mechanisms to refine and revise e-flow targets.

3. Prepare "water plane" analysis (e.g. flow depths and inundation extents) to characterize habitat availability/refugia for different e-flow releases.

4. Perform repeat mapping and data collection for:
    a. Channel and floodplain planform features using LiDAR and aerial photographs (e.g. gravel bar movement).
    b. Channel bathymetry survey to determine sediment transport and channel geometry response to e-flows (e.g. bank erosion and occlusion).
    c. Perform vegetation analyses using aerial photographs, site monitoring, and GIS analyses to identify potential recruitment for Black cottonwood and other floodplain plant species

5. Plot cottonwood seedling survival and succession, and determine causal relationships to differing e-flow regimes.

6. Evaluate cottonwood stand diversity from field observations and repeat land cover mapping.

7. Clearly outline the SRP management structure at the Corps. The efforts and activities leading up to implementation were managed by the Districts Project Management Branch (CENWP-PM). Currently, e-flow operations are managed by the Portland District H&H branch, water management section (CENWP-EC-HR).
    a. Portland District project management should continue as lead for SRP program studies, planning, and implementation and to secure funding for repeat monitoring and data recording.
    b. Portland District water management section should manage the day to day implementation of e-flow operations.
    c. Provision for an updated SRP point of contacts (POC) list would be useful.

8. Prepare a Corps SOP describing external communication procedures for reporting of e-flow operations by Portland District water management section. A short section is provided in the Corps' implementation memorandum, and could be expanded upon.

9. Prepare annual assessments of environmental flow implementation to document flow conditions and identify which targets were achieved.

10. Create detailed reports summarizing short-term hydraulic, geomorphic, and vegetation responses to streamflows every 5 years or after a large-magnitude flood event that triggers major changes to the study area.

11. Prepare longer term assessment reports every 10 years that synthesize the annual and short term trend (5-year) monitoring reports. These would be reach-scale status and monitoring trend reports.

12. Develop a multi-organizational monitoring program that would be collaborative, to ensure a "maximization of efficiencies" for Corps and other stakeholders in the Willamette basin.

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Appendix A

USACE Implementation Memorandum
(July 2015)

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS, PORTLAND DISTRICT
PO BOX 2946
PORTLAND OR 97208-2946

17 JUL 2015

CENWP-EC

20150717 Approved as requested

MEMORANDUM FOR Jose L. Aguilar, Colonel, EN, Commanding (CENWP-DE)

SUBJECT: Implementation of Environmental Flows in the Willamette Valley

1. Attached herein is a Memorandum for Record (MFR) that provides detailed guidance for implementation of environmental flows in the Willamette Valley. This document demonstrates our compliance with Corps guidance to implement environmental flows where feasible at Corps projects and meets Corps commitments in agreements signed with The Nature Conservancy (NWP, NWD, National agreements). Environmental flows are part of the Sustainable Rivers Project (SRP) that these agreements created.

2. The MFR discusses the analyses, evaluations, and determination of low risk associated with implementation of environmental flows and identifies the conditions and constraints reservoir regulators should follow during implementation of SRP environmental flows in the Willamette Valley.

3. With your concurrence, this guidance will be added to several Willamette Valley water control manuals for future implementation. For additional information regarding the MFR, please contact Chris Budai, project manager, at extension 4725 or Keith Duffy, technical lead, at extension 4969.

Signature redacted

Signed

Lance A. Helwig, P.E.
Chief, Engineering & Construction Division
Portland District

2 Encls
1. E-Flow Implementation Guidance
2. REC

CENWP-EC-HY 7 July 2015

MEMORANDUM FOR RECORD

SUBJECT: Implementation of Environmental Flows in the Willamette Valley

1. Purpose. This memorandum summarizes guidance for implementing environmental flows (e-flows) in the Willamette River Basin reaches; specifically the Middle Fork, McKenzie and the North and South Fork Santiam Rivers.

The U.S. Army Corps of Engineers Portland District (Corps) with the Nature Conservancy (TNC) developed an implementation plan for environmental flows at multiple projects within the basin. The SRP's goal is to 'operationalize' the environmental flow recommendations into acceptable guidance and recommendations for Willamette reservoir regulators and project operators for implementation. In order to achieve the project goal, this project's objectives were twofold:

1) Identify biological criteria and priorities (e.g., e-flow targets and benefits).
2) Given biological understanding and priority of different biological goals, outline the relevant items important to regulators tasked with implementing e flows.

The proposed environmental flow implementation described in this MFR has been found to conform to operational constraints as outlined in the Water Control Manuals. This has been verified through previous studies and analyses described in greater detail below.

Environmental flow implementation falls under the range of flood reduction operations outlined in the Water Control Manuals. Flood reduction operations occur primarily in the wintertime period (December through February). E-flow releases are not to be performed if they contradict NWP flood operation constraints. Flood operation considerations applicable to the e-flow implementation are summarized in Tables 1 through 4 below.

Upon acceptance of this Memorandum for the Record (MFR), the Water Control Manuals will be updated to incorporate operations for environmental flows.

2. Background. The Sustainable Rivers Program (SRP) began in 2002 as a partnership between TNC and the Corps with the objective of developing, implementing and refining a framework for beneficial flows downstream of dams. TNC and the Corps have signed memorandums of agreements (MOAs) at the national level as well as the district level to study current hydro regulation operations. SRP efforts in the Willamette River Basin focus on identifying opportunities to improve overall downstream ecosystem health and resiliency by modifying dam releases within the existing operational constraints. The releases that benefit downstream ecosystem health are termed environmental flows (e-flows). The e-flows targets were developed through a process of collecting and synthesizing relevant hydrologic and ecological information and expert knowledge into a set of e-flow recommendations.

a. Purpose of E-flows. Flow recommendations focused on fall flows (October-November), winter high flows (November-February) and smaller spring bankfull flows (flows at Action Stage, as identified by the National Weather Service) (March-June). Each seasonal flow is important to some aspect of ecosystem health. Fall flows enhance channel habitat and provide flows for outmigration. Winter high flows provide benefits to habitat by modifying channel features and recruiting large woody debris. Spring time flows are important for providing out-migration flows as well as scouring and flushing during bank full events.

b. Environmental Flow Recommendations. Environmental flow recommendations have been developed for the Middle Fork Willamette River, McKenzie River and the North, South and mainstem Santiam Rivers. The flow recommendations were defined by 1) event duration; 2) number of events per year; 3) range of flow magnitude; and 4) frequency. Summary reports were completed for each river system (also see References):

- Santiam Basin: *Summary Report: Environmental Flows Workshop for the Santiam River Basin, 2013.*
- Middle Fork and Coast Fork: *Summary Report Environmental Flows Workshop for the Middle Fork and Coast Fork of the Willamette River, 2007.*
- McKenzie River: *Environmental Flow Recommendations Workshop for the McKenzie River, Oregon, 2010.*

c. Constraints. The e-flow operations are constrained by Water Control Manual operational requirements for each project and the system as well as the Willamette Biological Opinions (BiOp) (National Marine Fisheries Service and U.S. Fish and Wildlife Service) implementation.

d. Forecast Uncertainty Analysis. The forecast uncertainty analysis performed by the Corps in 2011suggests that maximizing the number of e-flow discharges is feasible; however, evaluations of forecast error indicate that the release of e-flows should not be taken lightly. If anything, the modeling exercise emphasized the intricacy of the hydrologic and operational complexities of the Willamette system.

e. HEC-ResSim Analysis. HEC-ResSim was used to model potential operational changes to provide e-flows. The resulting report prepared in 2013, *Evaluation of E-Flow Implementation and Effects in the Willamette Basin using ResSim Modeling,* addressed concerns about potential increased flood risk and other adverse impacts from e-flow operations and provided recommendations on potential operational approaches. Two approaches were evaluated to determine how Willamette Valley Project operations could be modified to realize e-flow benefits within the constraints of the WCM: 1) Release More and 2) Store More. Both approaches modified the maximum evacuation release rule, as a function of elevation, from the baseline condition at the three projects, Lookout Point/Dexter on the Middle Fork Willamette, Cougar on the South Fork McKenzie River, and Detroit/Big Cliff on the North Santiam River.

The Release More scenario was recommended as a starting point for a strategy to implement e-flow releases in the Willamette River basin. The Release More scenario provided an overall increase in e-flow events (benefits) while affecting minimal change to flood risk reduction, water quality, hydropower and meeting BiOp targets. An unforeseen benefit from implementing the

Release More option was that flood storage availability increased under this alternative. The Store More option did not produce significant changes to total e-flows compared to the baseline. Further, the Store More option potentially increases flood risk by holding water longer and reducing the flood storage space during the wetter times of the year.

3. Implementation. The general intent is to maximize opportunities for achieving e-flows at the Willamette Valley projects considering operational constraints and forecast uncertainty. The following discussion of implementation provides guidance for reservoir regulators and project operators; however, implementation of e-flows is based on regulator/operator judgment and is not a highly prescriptive process.

E-flow operations require use of stored water to achieve environmental goals. The e-flow operation absorbs the incoming event then releases post event to minimize downstream flood risk. Once downstream gages have peaked and are receding below action stage (bankfull) levels, e-flow operations can commence. All intentional e-flow operations must operate below flood stage and within action stage (bankfull) constraints. That is, it is ok to release to bankfull, with some allowance for exceedance, but not to release to flood stage for e-flow purposes.

Just as for any high flow release scenario, error in forecasts should be considered when implementing e-flow operations. Release of large volumes of water combined with an error in the forecast can unintentionally result in reaching flood stage downstream. Previous SRP work has more fully quantified forecast uncertainty in the Middle Fork/Coast Fork Willamette and ReSim modeling has shown that e-flow releases are feasible within the uncertainty of forecasts without exceeding project water management constraints.

There may be high flow events where a sufficiently high volume will have to be passed with the result that the project release 'naturally' exceeds action stage (bank full)/flood stage. Although this could result in e-flows benefits, it is not the intent of e-flow operations to realize benefits in this manner (i.e., to purposely exceed action or flood stages). Rather e-flow operation seeks to obtain benefits while operating under the WCM and other operational constraints.

Flow recommendations focus on winter high flows (15-November through 15-February) and spring bankfull flows (15-March though 30 June). It is cautioned that e-flows cannot be guaranteed every year. The e-flow operations are 'opportunity driven' and would first be indicated by a forecast of a substantial weather system headed for the Willamette Valley and the three sub-basins of interest.

Overall, the e-flow benefit expected from the preferred e-flow operation is an increased number of wintertime events. Spring time e-flow events are expected to be minimally increased. Table 1 lists the range of e-flow operation goals downstream.

Maximizing e-flows is important to effectively manage aquatic habitat. The higher flows provide the mechanism for creating and managing fish spawning/incubation and other aquatic habitat needs over time. Salmon populations and other aquatic organisms are adapted to these variable flow conditions. Active management by fisheries and other technical experts should be part of the protocol.

Table 1. MF WILLAMETTE AT JASPER Maximum Flow and Duration E-Flow Objectives below Projects

Middle Fork Willamette River at Jasper USGS 14152000		
Winter E-Flow Target 1		
(15-Nov through 15-Feb)		**Operational Considerations**
Flow Above (cfs)	17,000	Releases from Fall Creek and Dexter may be combined to achieve these flows at Jasper.
Duration (days)	1	
Winter E-Flow Target 2:		
Min Flow (cfs)	15,000	
Max Flow (cfs)	17,000	
Duration (days)	3	
Winter E-Flow Target 3:		
Min Flow (cfs)	12,000	
Max Flow (cfs)	15,000	
Duration (days)	4	
Spring E-Flow Target A		
(15-Mar through 30 June)		**Operational Considerations**
Flow Above (cfs)	15,000	Releases from Fall Creek and Dexter may be combined to achieve these flows at Jasper.
Duration (days)	1	
Spring E-Flow Target B		
Min Flow (cfs)	12,000	
Max Flow (cfs)	15,000	
Duration (days)	3	
Spring E-Flow Target C		
Min Flow (cfs)	10,000	
Max Flow (cfs)	12,000	
Duration (days)	4	

Table 2. SF MCKENZIE AT COUGAR DAM Maximum Flow and Duration E-Flow Objectives below Projects

<table>
<tr><th colspan="3">South Fork McKenzie River below Cougar Dam
USGS 14159500</th></tr>
<tr><td colspan="2">Winter E-Flow Target 1</td><td></td></tr>
<tr><td colspan="2">(15-Nov through 15-Feb)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>6,000</td><td rowspan="11">Outflow above 5,000 cfs will inundate the adult fish collection facility's facility water system (FWS) intake structure which includes electrical gear and air burst system equipment.

Outflow above 5,000 cfs may scour redds (October – January).</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Winter E-Flow Target 2:</td></tr>
<tr><td>Min Flow (cfs)</td><td>4,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>6,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Winter E-Flow Target 3:</td></tr>
<tr><td>Min Flow (cfs)</td><td>3,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>4,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Spring E-Flow Target A</td><td></td></tr>
<tr><td colspan="2">(15-Mar through 30 June)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>4,000</td><td rowspan="10"></td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Spring E-Flow Target B</td></tr>
<tr><td>Min Flow (cfs)</td><td>2,500</td></tr>
<tr><td>Max Flow (cfs)</td><td>4,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Spring E-Flow Target C</td></tr>
<tr><td>Min Flow (cfs)</td><td>1,500</td></tr>
<tr><td>Max Flow (cfs)</td><td>2,500</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
</table>

Table 3. NO SANTIAM AT MEHAMA Maximum Flow and Duration E-Flow Objectives below Projects

<table>
<tr><th colspan="3">North Santiam River at Mehama
USGS 14183000</th></tr>
<tr><td colspan="2">Winter E-Flow Target 1</td><td></td></tr>
<tr><td colspan="2">(15-Nov through 15-Feb)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>15,000</td><td rowspan="10">Fishermen's Bend resident owners should be notified by the shift operator via phone when Big Cliff (BCL) outflow will exceed 10,000 cfs.

E-flow operations necessitating releases at BCL greater than 10,000 cfs should not be undertaken because this MAY cause adverse flooding downstream at Fishermen's Bend. It should be noted that BCL outflow may exceed 10,000 cfs as part of normal flood operations.

Operational Considerations for Fishermen's Bend may be amended pending future analyses to quantify potential impacts.

High flows may impact the Minto Facility. Notify ODFW prior to increasing outflow.</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Winter E-Flow Target 2:</td></tr>
<tr><td>Min Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>15,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Winter E-Flow Target 3:</td></tr>
<tr><td>Min Flow (cfs)</td><td>10,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
<tr><td colspan="2">Spring E-Flow Target A</td><td></td></tr>
<tr><td colspan="2">(15-Mar through 30 June)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>12,000</td><td rowspan="10">From March 15 – May 15 flows above 3,000 cfs will require a higher incubation release during the summer which would impact keeping the lake full for recreation and operational temperature control.

E-flow operations necessitating releases at BCL greater than 10,000 cfs should not be undertaken because this MAY cause adverse flooding downstream at Fishermen's Bend. It should be noted that BCL outflow may exceed 10,000 cfs as part of normal flood operations.

Releases higher than 3,000 cfs are allowed in the BiOp only if the lake elevation is above rule curve</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Spring E-Flow Target B</td></tr>
<tr><td>Min Flow (cfs)</td><td>10,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Spring E-Flow Target C</td></tr>
<tr><td>Min Flow (cfs)</td><td>8,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>10,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
</table>

a. Operational Details. Implementation of e-flows is event driven, based on regulator/operator judgment and is not a highly prescriptive process. The preferred e-flow operation is to release stored flood water during the high water months (usually the winter and early spring). Under this operation, stored flood waters are released earlier by allowing the maximum outflows to go higher when the lake elevation is lower than current practice. This e-flow operation does not change project operating rules, in terms of release rate and normal operations during flood control season as identified in the Water Control Manuals.

Ramp rates must also be monitored to not exceed those identified in the Water Control Manuals and the Biological Opinions. If ramp rates are excessive, there may are adverse biological impacts.

The regulator should always exercise discretion. For example, it may be that the start of release be at an elevation above the secondary flood control pool. For example, Lookout Point elevation would be 856 feet and at Detroit reservoir, 1484.5 feet. Releases below these elevations should be capped at powerhouse capacity. Also, when scheduling releases one has to assure that there is enough stored water to ramp flows back down to inflow without drafting into the power pool and without violating ramp rates.

4. Communication. Normal coordination and communication procedures shall be followed as outlined in the *Standard Procedures for Regulation of the Willamette Basin Projects*.

a. Internal Communication. EC-H will pre-coordinate e-flow operations similar to how it coordinates operations related to BiOp implementation. Notification of pending opportunities for e-flow releases will be included in the normal Corps communication channels such as the Corps Weather and River Updates which indicate expected increases in river flows, such as bankfull or flood levels.

Each year, hydrologic conditions and information on fish spawning activity should be reviewed prior to initiating a high e-flow by consulting technical experts (hydrologists, biologists and operating engineers) in order to balance mission needs within and across years. This could be accomplished in a meeting at the start of each hydrologic year.

During e-flow releases, Corps staff may be directed to monitor downstream conditions to minimize any potential adverse impacts such as bank erosion. It is assumed that notifications may be updated frequently due to changing weather and river conditions.

b. External Communication. Additional external parties may desire to be notified of pending e-flow releases. For example the environmental flow representative at the TNC should be contacted when e-flow releases are likely, in order to monitor potentially beneficial downstream impacts. Other interested parties may be added upon request.

5. Monitoring. Monitoring of ecological benefits is part of the adaptive management process to help inform and refine e-flow targets over time. The SRP team is in the process of developing a monitoring plan for the Middle Fork, McKenzie and Santiam Rivers that focuses on geomorphic and vegetative responses to e-flow implementation. This includes development of a geodatabase and evaluation of indicators (e.g., channel bar formation, side channel inundation, vegetation changes, etc.) using aerial photos, ground survey and LiDAR. In order to maximize the monitoring process, it is foreseen that the Corps/stakeholder interaction should be more collaborative and informative. To this end, Corps reservoir regulators will provide early

indication when e-flow operations are pending in sufficient time for others to set up monitoring of specific indicators of interest.

6. Environmental Considerations. In a memorandum dated 2 June 2015, the implementation of the Sustainable Rivers Project Environmental Flows in the Willamette River was reviewed by PM-E.

7. References.

a. Bach, L., Nuckols, J. and Blevins, E. 2013. Summary Report: Environmental Flows Workshop for the Santiam River Basin, Oregon. The Nature Conservancy, Portland, OR.

b. Gregory, Stan, Ashkenas, Linda and Nygaard, Chris, 2007a. Summary Report to Assist Development of Ecosystem Flow Recommendations for the Coast Fork and Middle Fork of the Willamette River, Oregon. Oregon State University, Corvallis, OR.

c. Gregory, Stan, Ashkenas, Linda and Nygaard, Chris 2007b. Summary Report Environmental Flows Workshop for the Middle Fork and Coast Fork of the Willamette River, Oregon. Oregon State University

d. Risley, John, Wallick, J.R., Waite, Ian and Stonewall, Adam. 2010a. Development of an environmental flow framework for the McKenzie River basin, Oregon. U.S. Geological Survey Scientific Investigations Report 2010-5016, 94 p.

e. Risley, John C., Bach, Leslie and Wallick, J. Rose 2010b. Environmental Flow Recommendations Workshop for the McKenzie River, Oregon. The Nature Conservancy, Portland, OR.

f. Risley, J.C., Wallick, J.R., Mangano, J. F.,and Jones, K. L. An Environmental Streamflow Assessment for the Santiam River Basin, Oregon. U.S. Geological Survey Open File Report 2012-1133, 60 p. plus appendixes.

g. Risley, John., Wallick, Rose, Waite, Ian and Stonewall, Adam, 2010. Development of an environmental flow framework for the McKenzie River basin, Oregon. U.S. Geological Survey Open File Report 2010-5016, 94 p.

h. U.S. Army Corps of Engineers. 2013. Final Report Sustainable River Project Evaluation of E-Flow Implementation and Effects in the Willamette Basin using ResSim Modeling. Portland District, Portland, OR

i. U.S. Army Corps of Engineers. 2012. Standard Procedures for Regulation of the Willamette Basin Projects. Portland District, Portland, OR

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k. U.S. Army Corps of Engineers. 2011. Technical Memorandum. Middle Fork/Coast Fork Willamette Uncertainty Forecast Analysis Portland District, Portland, OR.

l. U.S. Army Corps of Engineers. 2012. Willamette River Basin Operational Measures Evaluation Report. Portland District, Portland, OR.

Signature redacted

Signed

Lance A. Helwig, P.E.
Chief, Engineering & Construction Division
Portland District

CENWP-EC-HR (Nicholas)
CENWD-PDW-R (Proctor)
CENWP-OD-V (Petersen, Bengtson, Bardy)
CENWP-PM-FP (Budai)

Appendix B

E-flow Evolution

US Army Corps
of Engineers ®
Portland District

Supplemental Report

Sustainable Rivers Project

Evolution of SRP E-flows

September 2016

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1. INTRODUCTION

This document is intended to provide an overview of how e-flow target flows and durations evolved from the SRP workshops conducted for the Middle Fork Willamette, McKenzie and Santiam Rivers to the Corps July 2015, implementation of e-flows memorandum for the record (MFR).

Environmental flows have evolved from the SRP e-flow workshops begun in 2010 through the Corps implementation memorandum for the record (MFR) signed in July 2015. E-flow objective flows and durations were modified for use in Corps e-flow validation modeling (i.e. HEC-ResSim) performed in 2012-2013. The Corps reservoir modeling of the Willamette Valley projects confirmed operational feasibility of e-flow releases by the Corps as well as making an initial assessment e-flow "success" in terms of flow quantity and duration metrics.

The success criteria for computer modeling necessarily focused on flow quantity (peak flows), duration and number of events achieved, for a given e-flow operation scenario. The efforts began with SRP workshop targets as basis but were altered for modeling purposes, using best engineering judgment and input from Corps biologists. Assessment was made on what e-flow/duration combination might benefit ecosystem function. The nature of the changes were towards higher level of resolution in terms of peak flow and duration combinations as well as more specific quantification of seasonal flow rates.

The modeling effort also emphasized metrics that were useful from a water management and operations perspective. Therefore, flow objectives were generally reported at control points, used by Portland District water managers. Details are described in the *"Final Report: Evaluation of E-Flow Implementation and Effects in the Willamette Basin Using ResSim modeling"* (2013).

The flow targets were again slightly modified during the formulation of the subsequent July 2015 MFR, *"Implementation of Environmental Flows in the Willamette Valley"*. Similar to the previous efforts, the e-flow target guidance focused on water management activities. However they were derived from metrics found in the SRP workshop and modeling studies documentation.

In order to "operationalize" proposed e-flow operations, the flow objectives were tailored to meet the needs of water management. Therefore, only sites that corresponded to regulation control points were addressed by the MFR.

The subsequent Corps biological and legal reviews of the MFR, also contributed to influencing the development e-flow operational targets. For example, some SRP targets in the memorandum exceeded maximum or were under than minimum flows used by the Corps. Adjustments were therefore made with judgments being as to what flow quantity and duration would meet both SRP intents and not violate the water control manual or Corps standard operating procedures.

The purpose of this document is to summarize the details of the progression of e-flow objectives over time. This is done to partially address the apparent ambiguity between the original SRP workshop targets and the MFR guidance. It is also prepared to help inform the questions regarding how the SRP stakeholders should define successful e-flow implementation.

This document should not promote a perception that the flow objectives discussed are the "final versions" to be used by all SRP stakeholders for regulation purposes and/or evaluation of "success". The MFR guidance were developed for a singular purpose, to be a starting point for how Corps water management could implement e-flows. They were not seen as specifically

providing the metrics for success. This is a subtle but important distinction. It should be recognized that there is room for change, especially in the context of future SRP adaptive management activities.

2. EVOLUTION OF E-FLOW CRITERIA

Environmental flows are central to the SRP and e-flow recommendations formed the starting point for the adaptive management plan. Flow recommendations focused on fall flows (October-November), winter high flows (December-February) and smaller spring and bankfull flows (March-May). Each seasonal flow was important to some aspect of ecosystem health. Fall flows enhance channel habitat and provided flows for outmigration. The highest annual peaks occur during the winter and historically provide watering for rearing/spawning habitat in side channels and provide additional ecosystem complexity by recruiting large woody debris and providing flushing flows in off channel areas. The higher peak flows are geomorphically significant and provide motive power for transport of gravel sediments. Spring time flows are important for providing out migration flows as well as scouring and flushing during bank full events.

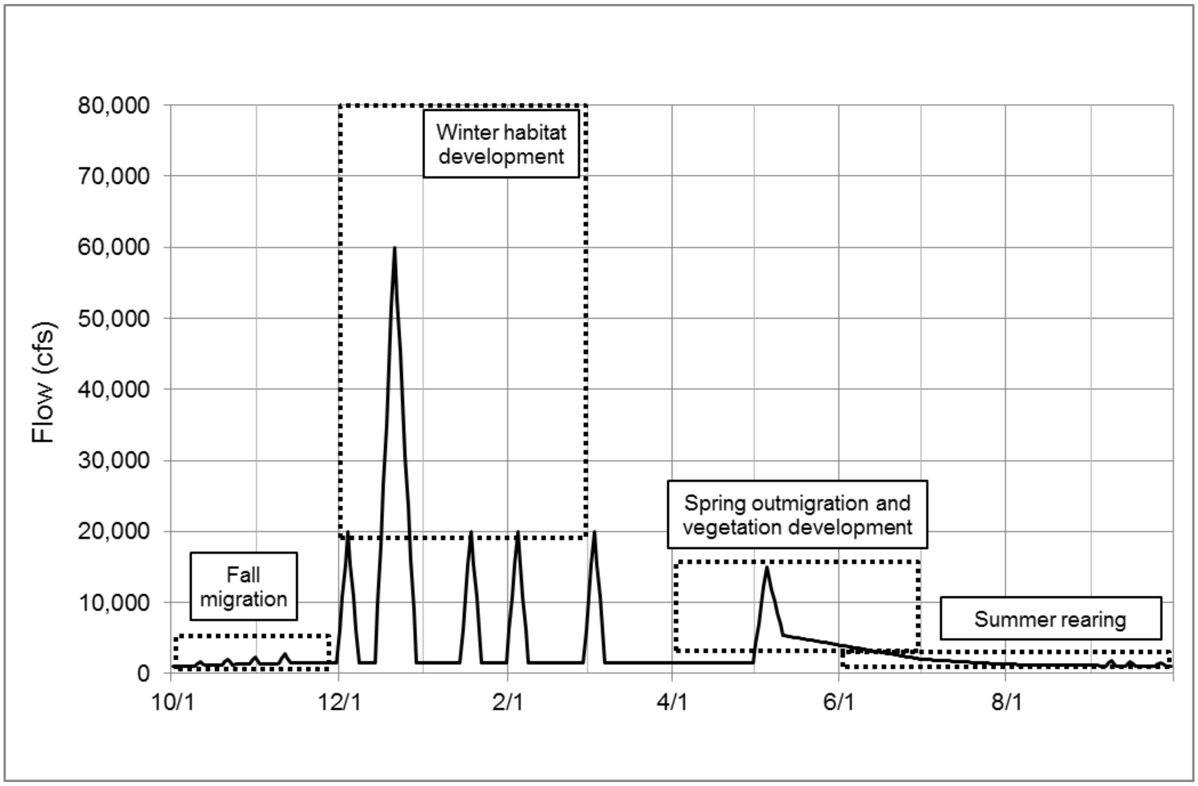
During the workshops the environmental flow recommendations were defined by the following categories 1) time period; 2) number of events per year; 3) range of flow magnitude; and 4) duration and frequency.

The relevant workshop e-flow recommendations are summarized below. The workshop e-flow objectives were the starting point in the evolution of those parameters.

2.1. SRP WORKSHOP MIDDLE FORK WILLAMETTE RIVER E-FLOWS

For the Middle Fork winter high flows generally occurs from mid-November through mid-March. The events are rain driven and usually occur 1 to5 times per year. The resultant flow range is 19,000 to 25,000 cfs. The biological benefit from fall/winter season e-flows are associated with opening and maintaining side channel and backwater habitat for a number of species, including Chinook salmon, lamprey, and chub. The “high winter flow event” serves as flushing flow and helps create important ephemeral habitats. The flows also serve to facilitate wood recruitment and increase ecological complexity. Flows are high enough to mobilize gravel sediments and help in the formation of channel and bar formations which improve habitat value. A visual plot summary of the e-flows is provided in Figure 1 below.

Figure 1. Middle Fork Willamette River Wintertime Flow Recommendations Plot



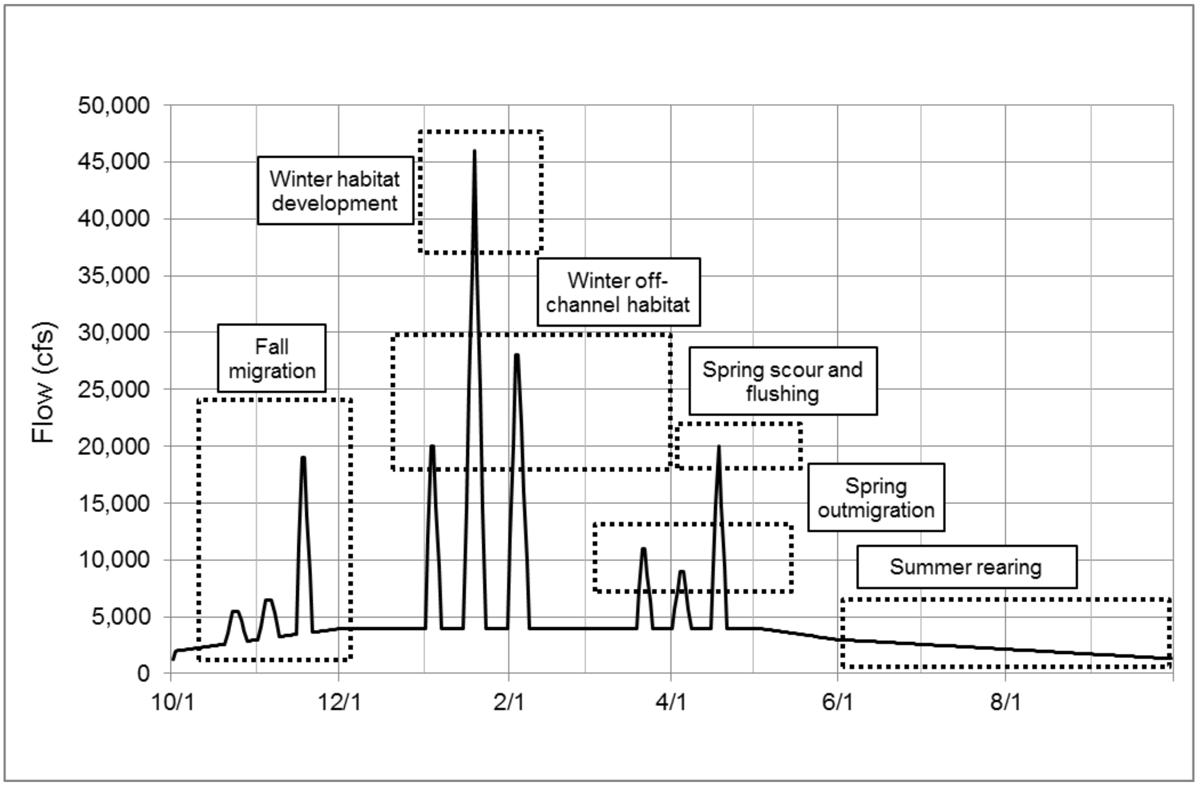
2.2. SRP WORKSHOP MCKENZIE RIVER E-FLOWS

Environmental Flows were established for four reaches of the McKenzie River, the South Fork McKenzie (Cougar Dam to mainstem McKenzie River confluence), Middle McKenzie (South Fork confluence to the Leaburg canal diversion dam, a stretch of 22 miles), McKenzie reach with Eugene Water & Electric Board (EWEB) canals and Lower McKenzie River (the lower 21 miles from the confluence with the Willamette River). The McKenzie above the South Fork confluence is unregulated and historic flow conditions have not changed. Therefore this reach was not evaluated during the workshop.

The winter high flows in the McKenzie primarily occur from mid-December through the end of February and generally occur about once per year. The flow range is 6,000 to 8,000 cfs with a typical duration of less than 5 days. The return frequency is once every 2 years or less.

SRP recommendations aim to restore some of the small wintertime floods which have been eliminated from the ecosystem in the post-dam period. These floods are important for connecting and wetting side channels, opening up new habitat, forcing gravel movement, and flushing sediment and wood into side channels. Newly connected side channels provide spawning and rearing habitat for spring Chinook. Resident trout, macroinvertebrates, and other species also benefit by increased habitat diversity and clean, unarmored substrates. A visual plot summary of the e-flows is provided in Figure 2 below.

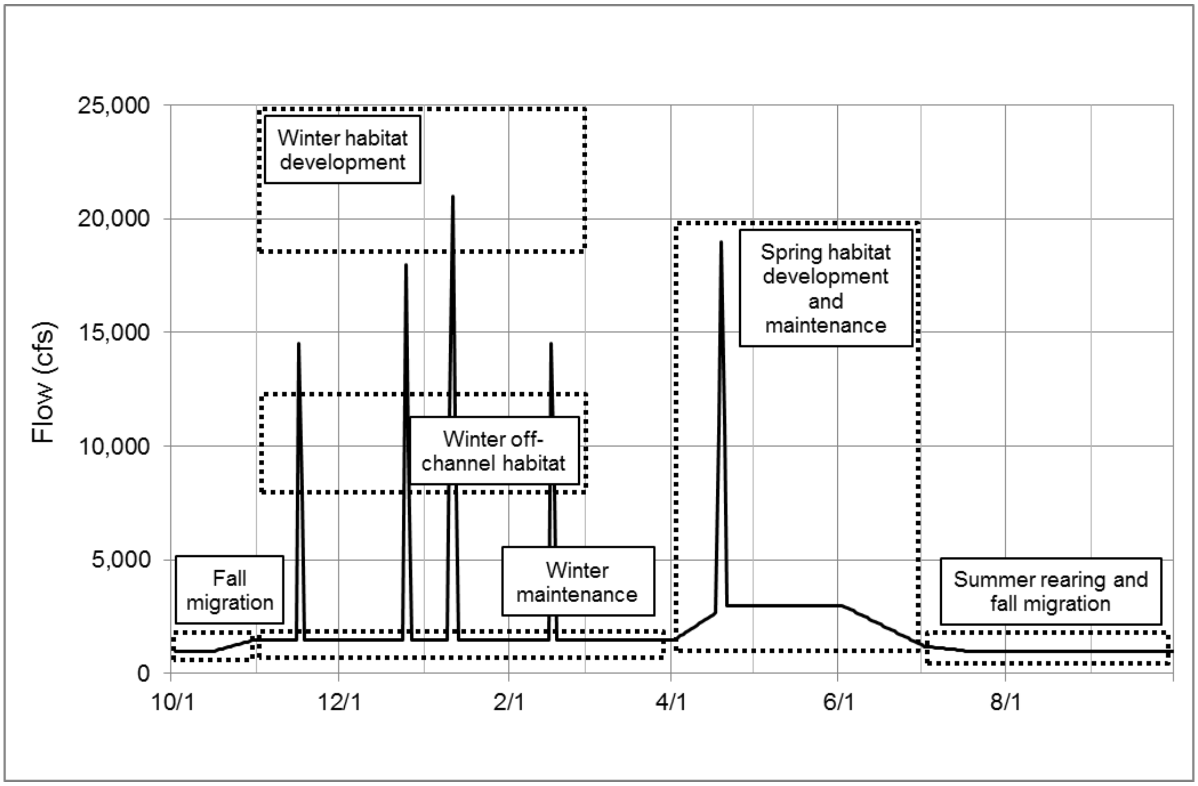
Figure 2. South Fork McKenzie River Flow Recommendations Plot



2.3. SRP Workshop North Santiam River E-flows

Environmental Flows were established for the North Santiam River, the South Santiam River and the mainstem Santiam River below the confluence of the North and South. Wintertime flows occur primarily in the November 1 to March 3 timeframe. Winter base flows consist of sustained flow rates at 1,000-1,500 cfs for 150 days on an annual basis. Winter events up to bankfull historically occurred about 2-5 times annually and are 13,000-18,000 cfs in magnitude over a 3-5 day event duration. For winter events above bankfull, the flow rate is 18,000 cfs for 3-5 days with a frequency of 1 in 10 to 3 in 10. A visual plot summary of the e-flows is shown in Figure 3 below.

Figure 3. North Santiam River Flow Recommendations Plot



2.4. CORPS RESSIM MODELING STUDY (JULY 2013)

The Corps prepared reservoir regulation modeling in July 2013. The study used the Corps reservoir modeling program, HEC-ResSim to perform simulations with the goal of confirm feasibility of SRP e-flow strategies. Modeling was also used to determine whether e-flow operations could be performed without violating operational constraints as outlined the Corps Water Control Manuals. The proposed e-flow operations in each basin were evaluated at the Middle Fork Willamette at Jasper, McKenzie River at Vida and North Santiam at Mehama for potential impacts to flood risk at the downstream control points. The combined flows were also evaluated for flood exceedance at the Willamette River at Salem flow gage. Water quality, hydropower, BiOp flow targets and recreation were also evaluated at the reservoirs. In the course of the study, the original SRP workshop flow recommendations were modified to meet the study requirements. The modeling analyses began with the e-flow recommendations as basis for defining the ecological objectives of altering dam outflows. Although the e-flow criteria were a good basis for evaluating success, it was still too broad for the quantitative modeling task conducted for this study. Therefore the study modelers elicited further expert opinion from biologists who were versed in the dam projects as well as the biologically important processes and species in the Middle Fork, McKenzie and Santiam Rivers to help refine the e-flow evaluation targets.

The study project delivery team (PDT) developed a range of environmental target objectives. The approach evaluated 3 levels of winter and spring e-flows in the Middle Fork, McKenzie and the North Fork Santiam River basins. At each of the three locations, e-flow regimes varied by combinations of season, flow magnitude and duration. The consensus of the study team and others was that each e-flow regime category had equal weighted ecosystem value and positive benefit lift was defined as an increase in any of the categories relative to the baseline condition. Note that the outflow at Cougar was used as the e-flow target because it is a 'controllable' flow while flood risk was checked at McKenzie River at Vida gage. Table 1 summarizes the e-flow targets used as success criteria.

Table 1. 2013 ResSim Study: E-Flow Criteria

Location	MF WILLAMETTE AT JASPER	MCKENZIE AT COUGAR DAM (OUTFLOW)	NO SANTIAM AT MEHAMA
E-Flow Target 1 Definition (Winter):			
Start Date	15-Nov	15-Nov	15-Nov
End Date	15-Feb	15-Feb	15-Feb
Flow Above (cfs)	17,000	6,000	15,000
Duration	1	1	1
E-Flow Target 2 Definition (Winter):			
Start Date	15-Nov	15-Nov	15-Nov
End Date	15-Feb	15-Feb	15-Feb
Min Flow (cfs)	15,000	4,000	12,000
Max Flow (cfs)	16,999	5,999	14,999
Duration	3	3	3
E-Flow Target 3 Definition (Winter):			
Start Date	15-Nov	15-Nov	15-Nov
End Date	15-Feb	15-Feb	15-Feb
Min Flow (cfs)	12,000	3,000	10,000
Max Flow (cfs)	14,999	3,999	11,999
Duration	4	4	4
E-Flow Target A Definition (Spring)			
Start Date	15-Mar	15-Mar	15-Mar
End Date	31-Jul	31-Jul	31-Jul
Flow Above (cfs)	15,000	4,000	12,000
Duration	1	1	1
E-Flow Target B Definition (Spring)			
Start Date	15-Mar	15-Mar	15-Mar
End Date	31-Jul	31-Jul	31-Jul
Min Flow (cfs)	12,000	2500	10,000
Max Flow (cfs)	14999	3999	11,999
Duration	3	3	3
E-Flow Target C Definition (Spring)			
Start Date	15-Mar	15-Mar	15-Mar
End Date	31-Jul	31-Jul	31-Jul
Min Flow (cfs)	10,000	1,500	8,000
Max Flow (cfs)	11,999	2,499	9,999
Duration	4	4	4

2.5. CORPS IMPLEMENTATION DOCUMENTATION (JULY 2015)

The ResSim modeling study e-flow criteria was carried forward into formulation of the Implementation MFR that was approved in July 2015. This signaled a formal adoption of the environmental flow operations in the Willamette Valley by the Corps.

For the implementation effort, the Portland District's water management section, environmental branch and the Office of Counsel performed review and critiques of the proposed e-flow operations. These review comments were incorporated into the final implementation language of the MFR. The changes were driven primarily by additional operational and biological constraints being identified. The MFR's e-flow targets were adjusted accordingly. The following tables summarize the final e-flow targets used by Portland District in the Willamette Valley.

It is emphasized that the guidance shown below is to be interpreted in the context of its usage for Corps regulation purposes. It should also be understood that the guidance below does not constitute a de facto metric for measuring an event's success.

For example, other SRP workshops contain additional information at other downstream locations. These have specific e-flow targets but are not reported in the subject MFR because they are not required for hydro-regulation purposes. However, the SRP workshop targets are still pertinent and useful in reporting out a successful e-flow operation to the broader stakeholder community.

Table 2. Implementation Memo (2015): MF WILLAMETTE AT JASPER E-flow Criteria

<table>
<tr><th colspan="3">Middle Fork Willamette River at Jasper
USGS 14152000</th></tr>
<tr><td colspan="2">Winter E-Flow Target 1</td><td></td></tr>
<tr><td colspan="2">(15-Nov through 15-Feb)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>17,000</td><td rowspan="10">Releases from Fall Creek and Dexter may be combined to achieve these flows at Jasper.</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Winter E-Flow Target 2:</td></tr>
<tr><td>Min Flow (cfs)</td><td>15,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>17,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Winter E-Flow Target 3:</td></tr>
<tr><td>Min Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>15,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
<tr><td colspan="2">Spring E-Flow Target A</td><td></td></tr>
<tr><td colspan="2">(15-Mar through 30 June)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>15,000</td><td rowspan="10">Releases from Fall Creek and Dexter may be combined to achieve these flows at Jasper.</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Spring E-Flow Target B</td></tr>
<tr><td>Min Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>15,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Spring E-Flow Target C</td></tr>
<tr><td>Min Flow (cfs)</td><td>10,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
</table>

Table 3. Implementation Memo (2015): SF MCKENZIE AT COUGAR DAM E-flow Criteria

<table>
<tr><th colspan="3">South Fork McKenzie River below Cougar Dam
USGS 14159500</th></tr>
<tr><td colspan="2">Winter E-Flow Target 1</td><td></td></tr>
<tr><td colspan="2">(15-Nov through 15-Feb)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>6,000</td><td rowspan="10">Outflow above 5,000 cfs will inundate the adult fish collection facility’s facility water system (FWS) intake structure which includes electrical gear and air burst system equipment.

Outflow above 5,000 cfs may scour redds (October – January).</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Winter E-Flow Target 2:</td></tr>
<tr><td>Min Flow (cfs)</td><td>4,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>6,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Winter E-Flow Target 3:</td></tr>
<tr><td>Min Flow (cfs)</td><td>3,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>4,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
<tr><td colspan="2">Spring E-Flow Target A</td><td></td></tr>
<tr><td colspan="2">(15-Mar through 30 June)</td><td>Operational Considerations</td></tr>
<tr><td>Flow Above (cfs)</td><td>4,000</td><td rowspan="10"></td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><td colspan="2">Spring E-Flow Target B</td></tr>
<tr><td>Min Flow (cfs)</td><td>2,500</td></tr>
<tr><td>Max Flow (cfs)</td><td>4,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><td colspan="2">Spring E-Flow Target C</td></tr>
<tr><td>Min Flow (cfs)</td><td>1,500</td></tr>
<tr><td>Max Flow (cfs)</td><td>2,500</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
</table>

Table 4. Implementation Memo (2015): NO SANTIAM AT MEHAMA E-flow Criteria

<table>
<tr><th colspan="3">North Santiam River at Mehama
USGS 14183000</th></tr>
<tr><th colspan="2">Winter E-Flow Target 1</th><th></th></tr>
<tr><th colspan="2">(15-Nov through 15-Feb)</th><th>Operational Considerations</th></tr>
<tr><td>Flow Above (cfs)</td><td>15,000</td><td rowspan="10">Fishermen’s Bend resident owners should be notified by the shift operator via phone when Big Cliff (BCL) outflow will exceed 10,000 cfs.

E-flow operations necessitating releases at BCL greater than 10,000 cfs should not be undertaken because this MAY cause adverse flooding downstream at Fishermen’s Bend. It should be noted that BCL outflow may exceed 10,000 cfs as part of normal flood operations.

Operational Considerations for Fishermen’s Bend may be amended pending future analyses to quantify potential impacts.

High flows may impact the Minto Facility. Notify ODFW prior to increasing outflow.</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><th colspan="2">Winter E-Flow Target 2:</th></tr>
<tr><td>Min Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>15,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><th colspan="2">Winter E-Flow Target 3:</th></tr>
<tr><td>Min Flow (cfs)</td><td>10,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
<tr><th colspan="2">Spring E-Flow Target A</th><th></th></tr>
<tr><th colspan="2">(15-Mar through 30 June)</th><th>Operational Considerations</th></tr>
<tr><td>Flow Above (cfs)</td><td>12,000</td><td rowspan="10">From March 15 – May 15 flows above 3,000 cfs will require a higher incubation release during the summer which would impact keeping the lake full for recreation and operational temperature control.

E-flow operations necessitating releases at BCL greater than 10,000 cfs should not be undertaken because this MAY cause adverse flooding downstream at Fishermen’s Bend. It should be noted that BCL outflow may exceed 10,000 cfs as part of normal flood operations.

Releases higher than 3,000 cfs are allowed in the BiOp only if the lake elevation is above rule curve</td></tr>
<tr><td>Duration (days)</td><td>1</td></tr>
<tr><th colspan="2">Spring E-Flow Target B</th></tr>
<tr><td>Min Flow (cfs)</td><td>10,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>12,000</td></tr>
<tr><td>Duration (days)</td><td>3</td></tr>
<tr><th colspan="2">Spring E-Flow Target C</th></tr>
<tr><td>Min Flow (cfs)</td><td>8,000</td></tr>
<tr><td>Max Flow (cfs)</td><td>10,000</td></tr>
<tr><td>Duration (days)</td><td>4</td></tr>
</table>

3. References

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Appendix C

USGS Monitoring Report (2016 - Draft)

Prepared in Cooperation with the U.S. Army Corps of Engineers and The Nature Conservancy

Monitoring Framework for Evaluating Hydraulic, Geomorphic, and Vegetation Responses to Environmental Flow Releases in the Middle Fork Willamette, McKenzie, and Santiam River Basins, Oregon

By J. Rose Wallick, Leslie Bach, Melissa Olson, Joseph Mangano and Krista Jones

Report Series XXXX–XXXX

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Elevation, as used in this report, refers to distance above the vertical datum.
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Monitoring Framework for Evaluating Hydraulic, Geomorphic, and Vegetation Responses to Environmental Flow Releases in the Middle Fork Willamette, McKenzie, and Santiam River Basins, Oregon

By J. Rose Wallick, Leslie Bach, Melissa Olson, Joseph Mangano and Krista Jones

Significant Findings

This report summarizes a framework for monitoring hydrologic, hydraulic, geomorphic, and vegetation responses to environmental flow releases in support of the Willamette Sustainable Rivers Program (SRP). The SRP is a partnership between The Nature Conservancy (TNC) and US Army Corps of Engineers (USACE) to provide ecologically sustainable flows below dams while still meeting human needs and congressionally authorized purposes. TNC, USACE and U.S. Geological Survey (USGS) developed this framework specifically for the lower, alluvial portions of the Middle Fork Willamette, McKenzie, North Santiam, South Santiam, and mainstem Santiam Rivers. The report has five main elements, which are summarized below.

General monitoring considerations

- Habitats along these rivers are influenced by streamflow and other factors, such as bank stabilization, bedrock outcrops, and sediment trapping by upstream dams. Accordingly, the monitoring approaches outlined here are useful for evaluating the relative influences of streamflow amid these other factors.

- The overall monitoring approach is broadly similar for the study area. However, some consideration of reach specific conditions will be needed when establishing basin-wide priorities and developing river-specific monitoring plans (Appendix A).
- Data collection will be needed at varying spatial and temporal scales, depending on the response and indicator being monitored. Reach-level tasks (spanning 10-30 km) are useful for assessing longitudinal trends at infrequent (5-10 yr) timeframes, whereas monitoring zones target shorter (0.5-2 km) sections of the floodplain for more frequent measurements (1-3 years). Floodplain transects co-located within reaches and monitoring zones would provide site-scale observations of hydraulic, geomorphic, and vegetation conditions observed on a more frequent basis (monthly or as needed).
- USGS streamflow gaging stations in or near each reach (Appendix A) can be used to determine which streamflow recommendations were achieved. Systematic protocols for defining and quantifying environmental components will need to be developed.

Approaches for monitoring hydraulic responses to environmental flows

Several SRP flow recommendations focus on water surface elevation and inundation extent. These two hydraulic variables capture habitat availability and areas that aquatic species can use for migrations during critical periods. These response variables can be evaluated by:

- Characterizing water depths and inundation patterns for different flows by establishing multiple measurement stations at floodplain transects distributed throughout the reaches or through longitudinal surveys of water surface elevations.
- Assessing longitudinal trends using a hydraulic modeling and field data for calibration.

Approaches for monitoring geomorphic responses to environmental flows

The Willamette SRP has many flow recommendations related to maintaining geomorphic processes that create and sustain important riparian or aquatic habitats. Approaches for monitoring geomorphic processes and morphological changes include:

- Evaluating changes in channel planform through repeat mapping of channel features from aerial photographs or lidar every 2-3 years within monitoring zones or less frequently at the reach scale.
- Measuring changes in bed elevation with repeat surveys every 10 years at the reach scale and more frequently in areas with suspected incision or aggradation.
- Characterizing changes in bed texture (such as fining or coarsening) with repeat measurements of bed-material sediment at floodplain transects every 10 years or following a large-magnitude flow event.
- Evaluating deposition and scour along floodplain swales at the reach-scale with repeat lidar surveys every 10 years or at site-scale with repeat ground-based surveys every 1-3 years (ideally at floodplain transects).

Approaches for monitoring riparian vegetation responses to environmental flows

Environmental flow recommendations also were developed to promote floodplain forest succession, focusing on black cottonwood because its life history is tightly coupled with floodplain hydrology and disturbance processes. Related monitoring approaches include:

- Identifying potential recruitment sites for black cottonwood by mapping unvegetated gravel bars from aerial photographs or lidar.
- Monitoring stand recruitment and early succession at the reach-scale by mapping seral stages of floodplain vegetation from aerial photographs and lidar every 10 years.

- Monitoring black cottonwood recruitment with monitoring plots at the site-scale during spring recession and summer flows.
- Monitoring stages of seral succession, including stem exclusion and early seral succession along transects of different ages. Reach-scale landcover mapping at decadal scales would complement site-scale observations.

Considerations for developing an adaptively managed monitoring program

Developing a cost-effective and efficient monitoring and assessment program that leverages resources from multiple organizations will be critical for tracking SRP implementation and success. Steps for developing this program include:

- Standardizing environmental flow recommendations across tributaries.
- Addressing outstanding research questions to refine environmental flow objectives.
- Developing a multi-organizational monitoring program to leverage the strengths of organizations and institutions collecting related data in the Willamette Basin.
- Developing processes for data synthesis, reporting, and adaptive assessment.
- Establishing a process for measuring progress and defining success.

Introduction

This study is a collaborative effort of The Nature Conservancy (TNC), U.S. Army Corps of Engineers (USACE), and U.S. Geological Survey (USGS) to develop a monitoring framework to inform adaptive management of environmental flows downstream of USACE dams on the Middle Fork Willamette, McKenzie, South Santiam, North Santiam, and mainstem Santiam Rivers.

Overview of the Sustainable Rivers Program

TNC and the USACE formed their national Sustainable Rivers Project (SRP) in 2002 to develop, implement, and refine ecologically sustainable flows downstream of dams while meeting human needs and congressionally authorized purposes (Warner and others, 2014). Defining flow recommendations involves developing environmental flow frameworks (or scientific assessments of a specific river system) and then determining flow recommendations through an iterative process that incorporates input from regional experts. Flow recommendations are then evaluated by dam operators for feasibility, implemented where possible, and monitored by scientists to evaluate their effects on the river ecosystem and dam operations (Tharne, 2003; Acreman and Dunbar, 2004; Richter and other, 2006; The Nature Conservancy, 2009). Because initial flow recommendations are often made using the best available knowledge of streamflow and ecological relationships, flow recommendations are implemented on a trial basis to test hypotheses and reduce uncertainties. As such, adaptive management and monitoring programs are necessary to determine the success of implemented flows at meeting stated ecosystem objectives and to refine the goals of the environmental flow recommendations over time (Higgins and others, 2011).

Implementation of the Sustainable Rivers Program in the Willamette River Basin

The Willamette River Basin in Oregon is one of eight demonstration sites in the SRP (Warner and others, 2014). The Willamette River and its tributaries support a rich diversity of aquatic flora and fauna, including important runs of salmon and steelhead. The river is also home to the majority of Oregon's population, and provides vital goods and services to the region and beyond. The USACE operates 13 dams in the Willamette Basin, including 11 multiple purpose storage reservoirs and 2 regulating reservoirs. All 13 dams are in the basins of major tributaries, including the Coast Fork Willamette, Middle Fork Willamette, McKenzie, and Santiam basins (Figure 1). The USACE operates the system of dams primarily for flood damage reduction as well as hydropower, recreation, water supply, and flow augmentation for fish and wildlife. Dam operations have changed the volume and timing of water flow in these regulated rivers, resulting in reduced peak flows, lower spring flows, increased low flows, and infrequent bankfull flows. Alterations to the natural flow regime affect the health and viability of the freshwater ecosystems and their associated aquatic and terrestrial species. To address these issues, TNC and USACE have used the SRP process to determine environmental flow requirements downstream of the dams and to identify opportunities to restore key aspects of the flow regime.

Figure 1. Map of the study area for the monitoring framework in the Willamette River Basin, Oregon.

Given that the dams are located on tributaries, the Willamette SRP process was phased. Environmental flow frameworks and flow recommendations were determined separately for the Coast Fork Willamette, Middle Fork Willamette, McKenzie, and Santiam River basins, and then combined and evaluated for basin-wide implementation. Gregory and others (2007a) summarized streamflow and ecological relationships for key Willamette species in the entire Upper Willamette River basin, and provided detailed hydrologic information for the Middle and Coast Forks of the Willamette River.

Subsequent reports compiled background information on hydrology, geomorphology, riparian vegetation, and biota for the McKenzie and Santiam Rivers (Risley and others, 2010, 2012). A series of expert workshops resulted in environmental flow recommendations for the Middle Fork Willamette (Gregory and others, 2007b), McKenzie (Risley and others, 2010) and the North, South and mainstem Santiam Rivers (Bach and others, 2012). The recommendations for each river focus on major seasonal components of the hydrograph, specifically fall transition and pulse flows, winter high flows, spring pulses and transition flows and summer low flows based on ecosystem objectives. By design, the recommendations are based on environmental needs, and therefore include flow conditions that cannot currently be implemented due to human constraints.

Figure 2 provides an example of environmental flow recommendations for the Middle Fork Willamette River (Gregory and others, 2007b). Initial implementation has focused on this tributary basin, which contains 4 of the 13 USACE dams. A subset of the environmental flow recommendations has been implemented in all years following the completion of the flow recommendations in 2008 (Konrad, 2010; Konrad and others, 2011b; Warner and others, 2014).

Figure 2. Environmental flow recommendations as described in Gregory and others (2007b) for the Middle Fork Willamette River, Oregon.

Study Purpose and Tasks

The purpose of this study is to develop a monitoring framework from which to assess the implementation of environmental flow recommendations in the Willamette River Basin and associated responses in streamflow hydrographs, inundation patterns, channel morphology, and riparian vegetation. This framework identifies measureable objectives and metrics related to environmental flows and methods for assessing these objectives and metrics. It then focuses on objectives and metrics capturing two key sets of processes influenced by environmental flows. Those two key sets of processes are: 1) hydraulic and geomorphic processes and 2) riparian vegetation. In the future, this monitoring framework will support ongoing adaptive management of the environmental flow program in the Willamette River Basin. It may also provide a platform for evaluating responses to restoration activities and other management practices. Specific tasks in developing the monitoring framework summarized in this report include:

1. Delineation of study reaches and zones for detailed monitoring in the Middle Fork Willamette, McKenzie, and Santiam River Basins;
2. Synthesis of existing information on hydrology, channel morphology, riparian vegetation, prescribed environmental flows, and anticipated responses to environmental flows for each study reach to create examples of measurable, narrowly defined objectives from which to compare findings from the monitoring program;
3. Identification of a set of indicator variables that can be used to assess hydraulic, geomorphic, and vegetation responses to environmental flows that are tailored and adapted to the unique conditions of each study reach;
4. Summary of the monitoring methods for assessing the indicator variables, including location, spatial extent, timing and frequency of measurements, thereby providing a basis for developing more specific monitoring plans along each study reach; and
5. Summary of the elements of an adaptively managed monitoring program, including data assessment, reporting, and considerations for defining success.

Report Organization

This report has the following sections:

- **Study Area and Reaches –** a description of the study area and reaches;

- **Background on the Middle Fork, McKenzie, and Santiam River** Basins **–** an overview of the key drivers shaping these basins and how they have changed over time;
- **General Monitoring Considerations –** a summary of the importance of spatial and temporal scales and hydrograph evaluations in relation to the monitoring framework;
- **Monitoring Hydraulic and Geomorphic Responses to Environmental Flows –** a summary of approaches to monitoring changes in water depth, inundation patterns, bed elevation, bed texture, and floodplain surfaces;
- **Monitoring Riparian Vegetation Responses to Environmental Flows –** a summary of approaches to monitoring vegetation recruitment and succession, geomorphic and hydraulic conditions that influence vegetation, and stand recruitment and succession; and
- **Developing an Adaptively Managed Monitoring Program to Track Progress towards SRP Goals –** an overview of some actions that would help with SRP monitoring and implementation in the Willamette River basin, including standardizing environmental flow requirements between the tributaries, addressing outstanding research questions, developing a multiple organization monitoring network, developing data reporting and assessment processes, and considerations for measuring progress and success.

The sections for monitoring hydraulic, geomorphic, and riparian vegetation processes include: 1) a description of the key responses that may result from environmental flows, 2) examples of testable objectives and associated indicator variables for the key hydraulic, geomorphic, and vegetation responses to environmental flows, and 3) brief summaries of approaches for efficiently monitoring these variables.

Study Area and Reaches

The study area for the monitoring framework is the lower alluvial sections of the Middle Fork Willamette, McKenzie, North Santiam, South Santiam, and mainstem Santiam Rivers (Figure 1). These alluvial sections are responsive to environmental flows because the beds and banks of the river channels in the alluvial sections are composed of river-transported gravel, sand, and silt. These relatively erodible bank and bed-material sediments allow alluvial channels to respond to environmental flows through adjustments in channel morphology or substrate characteristics. Such morphological adjustments have implications for riparian vegetation and the availability of aquatic and riparian habitats. Although many locations within the study area have been stabilized by revetments, overall, these alluvial sections still remain relatively dynamic compared with upstream bedrock sections and connections between the river and the floodplain still exist. In contrast, river sections that have high gradients and flow on or against bedrock are unlikely to be responsive to environmental flow releases. As such, these sections were excluded from the study area of the monitoring framework.

The channels within the study area do have some longitudinal differences in channel morphology, constraints on habitat-forming processes, and pragmatic considerations for monitoring responses to environmental flows. Thus, we defined distinct study reaches along the tributaries. The Middle Fork Willamette and McKenzie Rivers were each divided into two reaches (upper and lower) whereas the South, North and mainstem Santiam Rivers are treated as individual reaches (Figures 3-6; Appendix A). As summarized by Wallick and others (2013), the morphological characteristics of each reach are distinct and relate to overall differences in geology, physiography, flow, sediment transport, and bank stability. The longitudinal extent of each reach is defined by its alluvial characteristics, whereas its lateral extent is defined by its “geomorphic floodplain”. The geomorphic floodplain is the corridor of landforms and habitats that have been chiefly shaped by streamflow and sediment transport processes active during the Holocene climatic regime of the last 10,000 years. This process-based definition of the floodplain is distinct from definitions that are based on specific attributes such as inundation frequency and channel migration rates. We utilize the geomorphic floodplain because this corridor encompasses the diverse array of floodplain habitats that support different life stages for a variety of aquatic, riparian and terrestrial organisms. The geomorphic floodplain also provides a static reference frame from which to measure future changes in floodplain landforms and habitats. For each river in the study area, the geomorphic floodplain maps and floodplain kilometer (FPKM) reference system of Wallick and others (2013) is applied, where numbering begins at the mouth of each river and continues upstream.

This framework describes monitoring approaches for two main areas of the geomorphic floodplain: (1) the active channel area subject to frequent scour, bed-material transport, and sediment deposition during floods, and (2) the floodplain area (and associated surfaces) with occasional overbank inundation and fine sediment deposition. Active channel features include the primary (wetted) channel, secondary channel features (such as side channels, alcoves, sloughs and swales), in-channel elements such as pools and riffles, and gravel bars with sparse-to-dense vegetation. Floodplain surfaces are higher in elevation than active channel features, and contain a continuum of sloughs and swales intermixed with natural levees. Whereas active channel surfaces are underlain by coarser gravel and sand transported as bed-material sediment, floodplain surfaces are mantled with finer sands, silt, and clay transported as suspended load.

Figure 3. Map and images of the study reaches along the Middle Fork Willamette River, Oregon.

Figure 4. Map and images of the study reaches along the McKenzie River, Oregon.

Figure 5. Map and images of the study reaches along the North Santiam River, Oregon.

Figure 6. Map and images of the study reaches along the South and mainstem Santiam Rivers, Oregon.

Background on the Middle Fork, McKenzie, and Santiam River Basins

The Willamette Valley is a broad, alluvial plain flanked by two rugged and deeply dissected mountain ranges. The Willamette River flows through this valley, draining 28,000 km^2 of northwestern Oregon before joining the Columbia River near Portland, Oregon. The Coast Range forms the western boundary of the watershed, while the taller and broader Cascade Range forms the eastern boundary and contributes most of the flow and sediment to the Willamette River. Major tributaries to the Willamette River originate in the Cascade Range, and include the Middle Fork Willamette (3,530 km^2), McKenzie (3,450 km^2), and Santiam (4,550 km^2) River Basins (Figure 1).

The Middle Fork Willamette River begins near Timpanogas Lake, and flows about 185 km before joining with the Coast Fork Willamette River to form the mainstem Willamette River near Springfield. The McKenzie River begins near Clear Lake, and flows about 230 km before joining the Willamette River downstream of Eugene. The North Santiam River begins near Three Fingered Jack mountain, and flows more than 260 km before it joins with the South Santiam River near Jefferson to form the mainstem Santiam River, which flows about 23 km across the floor of the Willamette Valley to join the Willamette River south of Salem. The South Santiam River begins near Jumpoff Joe Mountain, and flows about 180 km to its confluence with the North Santiam River.

Climate, Geomorphology, and Riparian Vegetation

The Willamette Valley has a Mediterranean climate, with cool, wet winters and warm, dry summers. The valley floor receives 1,000 mm/yr of precipitation, mainly as rainfall during the winter. Headwater reaches that originate along the crest of the Cascade Range, like those in the North Santiam and McKenzie River Basins, receive as much as 2,600 mm/yr of precipitation, which falls as rain and snow mainly in the winter (Oregon State University, 2013a). Historically, peak flows generally occurred in winter, with major floods typically resulting from basinwide rain-on-snow events (Harr, 1981). Although precipitation is greatest along the crest of the Cascade Range, rainfall and snowmelt infiltrate through the young, porous volcanic rocks of the High Cascades geologic province, supporting steady year-round discharge at large spring complexes in this region (Stearns, 1928; Tague and Grant, 2004; Jefferson and others, 2006). In contrast, the older, less-permeable Western Cascades are steep and highly dissected, causing stream discharge to be much more responsive to storm runoff than in the High Cascades.

The Middle Fork Willamette, McKenzie, and North and South Santiam Rivers all originate in steep upper reaches of the Cascades and flow generally eastward through narrow bedrock canyons. As these rivers emerge from the foothills of the Western Cascades and traverse the floor of the Willamette Valley enroute to their confluences with the Willamette River, their floodplains widen downstream and are generally unconstrained, except where locally confined by valley geology. Within their alluvial sections, the overall planform of the study rivers can be characterized as those of “wandering gravel-bed rivers” (Church, 1983), which are dominated by a single channel but also contain multi-channeled reaches.

The Willamette River and its major tributaries have been incising through older Pleistocene sediments that compose the main floor of the Willamette Valley for about the last 10,000 years (O’Connor and others, 2001). As a result, the Holocene floodplains (or “geomorphic floodplain” described before) of these rivers are inset within topographically higher Pleistocene terraces and broadly corresponds with the extent of historical flooding and fluvial processes. Many surfaces within the geomorphic floodplain are vegetated with plant species that are dependent on fluvial processes and landforms. The width of the present-day riparian forest corridor within the floodplain varies throughout the study area and is up to several kilometers wide in some sites (Figures 3-6). In active alluvial sections, floodplain forests are composed of "pioneer" species like black cottonwood, willow, and white alder that colonize recently deposited gravel bars, whereas mature black cottonwood, Oregon ash, and big-leaf maple tend to occupy older, high-elevation surfaces.

Historical Alterations and Effects on Present-day and Future Conditions

Historically, the lower portions of the Middle Fork, McKenzie, North Santiam, South Santiam, and mainstem Santiam Rivers in this study were historically flanked by broad, forested floodplains (Gregory and others, 2002b). These rivers also had a complex assemblage of habitats and landforms created and maintained by interactions between four drivers; large floods, easily erodible bank materials, and substantial inputs of large wood and coarse sediment (Sedell and Frogatt, 1984; Benner and Sedell, 1997; Gregory and others, 2002b; Wallick and others, 2007; Gregory, 2008). These four drivers have fundamentally changed in the modern Willamette Basin. Flood control operations reduce inundation and the geomorphic effectiveness of present-day floods. The amount of coarse sediment entering the rivers in the study area is substantially reduced by trapping from upstream dams, and further reduced by revetments that restrict bank erosion and the subsequent liberation of sediment to the channel. Conversion of riparian forests to other land uses, combined with the removal of instream wood, has transformed historically multi-thread reaches into single-thread channels.

The rivers in this study are currently much more stable than they were historically, but also have varying levels of present day-dynamism (Figure 3-Figure 6; Appendix 1). Relatively dynamic valley segments like the North Santiam River have very little bank stabilization and experience active meander migration and avulsions, resulting in a nearly continuous band of actively shifting gravel bars and a diverse array of side channels (Figure 5). Artificially stable reaches like the Middle Fork Willamette, South Santiam, and mainstem Santiam Rivers are predominantly stable due to reductions in large floods and installation of bank revetments (Figure 3; Figure 6). These more stable rivers have very few actively shifting gravel bars, and most of the side channels along these reaches are relict features from the historical flow and sediment regime that are rarely scoured by modern-day floods.

Streamflows are measured throughout the Willamette basin at multiple USGS streamflow gaging stations, including the eight active gaging stations in the study area (Figure 1; Appendix A). The flows in this area are regulated by 10 of the 13 USACE dams in the Willamette Valley Project. Streamflows in the study area are also influenced by several smaller dams and projects, such as municipal and irrigation withdrawals from the North and South Santiam Rivers and McKenzie River (Appendix A; Risley and others, 2010; 2012). Regulated and unregulated flow data have been computed and analyzed for each of the main tributary basins to determine changes in key hydrologic statistics and environmental flow components and help with the development of environmental flow recommendations (Gregory and others, 2007; Risley and others, 2010; 2012).

General Monitoring Considerations

Monitoring hydraulic, geomorphic, and vegetation responses to environmental flow releases requires consideration of the spatial and temporal scales of monitoring activities and evaluation of hydrograph characteristics. Here, we outline key elements of these general monitoring considerations that should be integrated into environmental flow monitoring efforts.

Spatial and Temporal Scales of Monitoring Activities

The Willamette SRP environmental flow recommendations encompass a broad range of streamflows that are each intended to elicit a unique response from different features or topographic levels across the floodplain. Evaluating whether these objectives are met will entail strategically locating suitable monitoring activities and determining the appropriate spatial scale. For each expected hydraulic, geomorphic, or vegetation response to environmental flows, we identify the geomorphic domain for this response (active channel versus floodplain) and the specific landform or landforms of interest. For example, fall pulse flows are intended to inundate the margins of the active channel, specifically secondary channels. In this example, monitoring activities would seek to target inundation in secondary channels within the active channel.

Once there is a clear linkage between a particular environmental flow component and the location of the monitoring activity within the geomorphic floodplain, an appropriate spatial scale for the monitoring activity can be selected. In this monitoring framework, we focus on three spatial scales; reach-level, monitoring zones and static transects (Figure 7):

- **Reach-level monitoring** generates comprehensive data across an entire reach, which is useful for assessing longitudinal trends.
- **Monitoring zones** are shorter (0.5-2 km) sections of the geomorphic floodplain suitable for more in-depth monitoring because the hydraulics, geomorphology, and vegetation in these areas are likely to be more sensitive to environmental flows than areas that are geologically stable or stabilized with revetments. Candidate monitoring zones are identified in Figures 3-6 and Appendix A, and were divided into two categories:
    - **Dynamic monitoring zones** have actively shifting gravel bars and side channels, indicating frequent geomorphic adjustments in response to annual high flows.
    - **Stable monitoring zones** were historically dynamic and presently have secondary channels and large bars with mature vegetation, indicating they have been stable in recent decades due to flood reduction. These areas could potentially respond dynamically to future flood events because they lack revetment and are flanked by erodible, lower-elevation floodplain surfaces.

- **Static transects** traverse the entire lateral extent of the geomorphic floodplain (Figure 7) and are established for co-locating hydraulic, geomorphic, and vegetation observations. If located at a range of different sites along each reach (for example, stable and dynamic zones), the monitoring transects would aid in understanding longitudinal trends and could be used to identify areas where more detailed analyses are needed.

The monitoring activities described in this framework have unique considerations for the timing and frequency of data collection which reflects differences in a) the timescales over which different hydraulic, geomorphic, or vegetation processes occur, and b) pragmatic considerations for data collection. For example, some responses to environmental flows are immediate (like inundation) and may entail frequent, year-round data collection. In contrast, other responses are more gradual (like vegetation succession) and could be characterized by infrequent data collection every few years. Additionally, the timing of some monitoring activities is linked with flow conditions or safety considerations. For example, it is safest and most efficient to characterize bed-material substrate during low-flow periods when gravel bars are exposed. For each of the monitoring activities described in this approach, we provide general guidance as to the timing and frequency of data collection, which can be used to refine more specific monitoring plans for a particular reach.

Figure 7. Example of a static transect for co-locating monitoring activities to assess hydraulic, geomorphic, and vegetative responses to environmental flows.

Evaluating and Documenting Hydrograph Characteristics

Each of the environmental flow prescriptions has specific recommendations for the magnitude frequency, duration, and timing of different flow components. These in turn support key physical and biological processes. In some cases, it will be important to evaluate specific attributes of the flows and to compare these to the environmental flow components both to validate the environmental flow releases and to better understand hydrologic processes such as rate of change of flow conditions.

Evaluating the extent to which actual flows met these recommendations requires comparisons between observed streamflow and recommendations. The USGS streamflow gaging stations located in, or near, each reach can provide a basis for these comparisons (Table 1). At some locations, withdrawals for municipal or irrigation use must also be considered, especially during low flow periods when such withdrawals are likely to more substantially influence streamflow in the reach (Table 1).

Specific approaches for evaluating hydrologic characteristics and implementation of the environmental flow program could include:

- **Compiling daily streamflow data and then separating it into environmental flow components for each season.** Once the flow data are separated into individual environmental flow components, hydrographs can be analyzed to determine the frequency, duration, magnitude, and timing of each event. Recession rates for peak or pulse flows can also be computed. This hydrologic data can be used to assess streamflow conditions along specific reaches, or used in conjunction with hydraulic, geomorphic, or vegetation monitoring at specific monitoring zones or transects (Appendix A). Also, hydrological characteristics of environmental flow components can be compared against prescribed flows from the environmental flow workshops. To date, systematic and standardized protocols for defining and quantifying flow characteristics have not been development. SRP implementation and monitoring in the Willamette River basin would benefit from the development of standardized protocols.
- **Accurately characterize peak flows.** Accurate peak flow magnitude could be obtained by evaluating unit flow data, which is collected in 15 minute intervals rather than the daily mean flow data. Likewise, during extremely low flows, the unit flow data may reveal short periods where streamflows reach levels detrimental to aquatic organisms.

- **Comparing actual flow releases to unregulated conditions**. Unregulated flows have been determined by the USACE and USGS using a combination of pre-dam gage data and simulated unregulated flows (see for example, Risley and others, 2010). From these simulated flow data, a population of representative hydrographs and recession rates could be developed to represent each of the environmental flow components and their variation in different climatic scenarios like wet years and dry years. It would be helpful to refine the flow thresholds associated with specific ecological objectives so they are narrowly defined and directly linked to specific hydraulic, geomorphic, and ecological responses. For example, the Willamette SRP environmental flow recommendations describe bankfull discharge as a critical threshold for various hydraulic, geomorphic, and ecological processes. Currently, bankfull flood discharge is a regulatory target determined by the USACE (Keith Duffy, written commun., 2011), and is much smaller than the 1.5 year recurrence interval flow event generally used to define bankfull discharge from a geomorphic perspective (Wolman and Miller, 1960; Risley and others, 2010; 2012). These differences in terminology and flow magnitude could be clarified to better evaluate when this flow target is achieved and ensure realistic objectives are associated with this threshold.

Table 1. Examples of hydrologic objectives for different environmental flow components and approaches for evaluating whether targets are achieved.

Monitoring Hydraulic and Geomorphic Responses to Environmental Flows

As streamflows change, there are corresponding changes in water surface elevations or water depth, which varies with the geomorphic characteristics of the river and floodplain. Changes in flow, together with changes in sediment supply and large wood, create adjustments in river planforms, bed elevations, bed textures, and floodplain surfaces. These responses vary spatially according to inputs of flow and coarse sediment, which dictate the relative balance between transport capacity – the “maximum load a river can carry” (Gilbert and Murphy, 1914, p. 35) – and bed-material supply.

Geomorphic responses will also vary with factors like geology and physiography, which control large-scale patterns of bank erodibility, valley width, and valley slope, thereby mediating channel dynamism. In the Willamette Valley study area, geologic controls include the distribution of resistant lithologies like Western Cascades volcanic rocks and Pleistocene terraces that support inherently stable channel planforms. Revetments also impart local channel stability, whereas reaches flanked by erodible Holocene alluvium can respond more dynamically to changes in flow or sediment supply. Because changes in channel morphology and rates of erosion can reflect multiple influences, it can be challenging to establish clear linkages between environmental flows and resulting morphologic adjustments so the other factors like sediment supply and bank erodibility must be considered.

In gravel-bed rivers like those of the study area, the term ‘geomorphically-effective flows’ refers to streamflows that are able to transport bed-material sediment, a crucial threshold for initiating a wide range of geomorphic responses. Geomorphically effective flows are currently undefined for the study area but typically have recurrence intervals exceeding 1 year (Andrews, 1983, 1984). Because bed-material transport is required for gravel-bed rivers to create and rejuvenate fluvial habitats, we focus our discussion of geomorphic responses on geomorphically effective flows rather than specific environmental flow components (like bankfull flows or small floods) because the geomorphic responses associated with each of the environmental flow components are currently unknown. For this environmental flow-monitoring framework, we focus on summarizing methods for detecting changes in water depth, inundation patterns, bed elevation, bed texture, and floodplain surfaces.

Figure 8. Conceptual model of hydraulic and geomorphic processes shaping floodplain habitats in Willamette Basin and approaches for monitoring these processes.

Table 2. Examples of environmental flow objectives for hydraulic and geomorphic processes and approaches for evaluating whether targets are achieved.

Table 3. Summary of key activities for monitoring hydraulic, geomorphic, and vegetation responses to environmental flows in the Willamette River Basin

Water Depth and Inundation Patterns

Hydraulic characteristics, such as water surface elevations or water depth, spatial and temporal extent of inundation, and activation and maintenance of secondary or side channels, vary in response to specific flow characteristics. This has important implications for habitat availability, species movement and life-history patterns, and water quality conditions. Fall flows dictate the amount and suitability of spawning habitat for salmon, and control the depth of water over redds. Winter high flows inundate the floodplain and allow species movement into side channels. Spring flows, including rate of change, control downstream migration of salmon and access to off-channel habitat. Summer flows provide rearing habitat and influence water quality conditions such as temperature. Although this framework does not identify and address biological objectives, changes in hydraulic properties directly affect biological processes and conditions.

The approach outlined below utilizes a blend of site-scale (monitoring zones or transects) and reach-scale measurements for tracking lateral and longitudinal variation in flow depths and inundation extents (as described in Table 2 and summarized in Table 3). Each of the methods selected here have been recently utilized by USGS in the Willamette Basin and have proven to be efficient, reliable, and cost-effective. Datasets resulting from these approaches can be linked with habitat availability by combining information on flow depths and inundation extents with channel and habitat mapping (described later) and classifying habitats according to the level of discharge needed for inundation.

Studies have already been conducted in portions of the North and South Santiam, McKenzie, and Middle Fork Willamette rivers to evaluate relationships between streamflows and spawning habitat (R2, 2013; River Design Group, 2013).The datasets and approaches described below could be used to evaluate a much broader range of flows associated with other habitat needs and can also be used to understand linkages between streamflows and vegetation processes (see the "Monitoring Riparian Vegetation Responses to Environmental Flows" section).

Specific site-based methodologies for assessing water depths, elevations, and inundation extent at individual transects include:

- **Measuring water surface elevations and depths using repeat ground-based surveys.** This method is the most expedient means to directly evaluate water levels and inundation extent for a range of flows. The edge of water and depth of shallow areas can be directly surveyed if conditions allow (such as during low or moderate flows). In instances when it is impractical to directly survey the water surface (such as floods), flagging, pin flags, or other monuments can be used to note high water marks that can be surveyed later.
- **Recording maximum river stage using crest stage gages at a particular location.** This method is especially useful for obtaining high water marks along infrequently inundated side channels and sloughs and floodplain areas. Crest stage gages can also be located in more frequently inundated areas, but will require multiple site visits to determine flow-stage relationships. Crest stage gages should be surveyed upon deployment to provide a basis for converting stage to water surface elevation.
- **Monitoring continuous variation in water elevations using pressure transducers with automatic data loggers.** Many pressure transducers also record stream temperatures, which would be useful for characterizing habitat suitability for fishes. Pressure transducers should

be surveyed upon deployment and re-surveyed during seasonal site visits when the data are downloaded to determine if the instrument shifted during high flows. A permanent network of pressure transducers located at 2-10 km intervals along a reach would provide a robust framework for characterizing spatial and temporal variation in water surface elevations and stream temperatures and provide critical data for calibrating future hydraulic models.

- **Photographing inundation at a wide range of flow conditions from fixed cameras on timers or during site visits.** These types of photographs provide an in-direct method for tracking changes in stage and inundation over time. Pre-established photo points should contain a large, immobile target from which to reference repeat photographs (Shaff and others, 2007). If each photograph is attributed with a date and time, repeat photographs provide a platform for assessing qualitative differences in river stage at different discharges. More quantitative measurements can be developed by applying emerging techniques like ‘Structure from Motion’, in which digital elevation models are constructed from photographs, thereby providing a basis for measuring variation in water surface elevations from repeat photographs (Major and others, 2013; Fonstad and others, 2013). The main drawback to repeat photographs is that they must be taken during daylight and, unless fixed cameras are installed, the sites must be visited during the flow events of interest, requiring that the site be safe and accessible.

In conjunction with more site-scale measurements, reach-scale characterization of water surface elevations, depths, and inundation extent could be carried out using the following approaches:

- **Delineating the wetted channel from aerial photographs acquired at different flow conditions.** For example, publically available digital orthophotographs are generally acquired every 2-3 years by the National Agricultural Inventory Program (NAIP) during low to moderate flows. Repeat mapping from these and other photographs could be efficiently carried out using well-established protocols (for example, Wallick and others, 2009). The resulting maps would provide a basis for examining reach-scale inundation at a variety of discharges and could be readily paired with the surveyed transects to infer variation in flow depth and inundation at floodplain monitoring transects.

- **Commissioning aerial photography to coincide with peak discharge in the event of a particularly large flood or other flood event of interest.** This information can be used to document reach-scale patterns of inundation. The aerial photographs would need to be rectified and georeferenced, and flooded areas digitized, but the resulting datasets would provide a robust platform for evaluating reach-scale inundation patterns across a broad area and could inform a broad range of floodplain management issues.
- **Surveying water surface elevations and flow depths from boat-based longitudinal profiles surveys.** A highly accurate and efficient way to measure flow depths and water surface elevations along long reaches is through longitudinal profile surveys in which a jet boat is equipped with survey-grade GPS (to record boat position and water surface elevation) and Echo Sounder (to measure flow depths). Depending on river conditions, boat-based surveys can measure 10-40 kilometers of river channel in a single day and could be repeated for several distinct flows of interest. The resulting datasets would provide key information needed to understand longitudinal variation in flow, water surface elevation, and depth along diverse reaches. In addition, the longitudinal profile surveys can be paired with cross-section surveys in areas of interest (such as floodplain monitoring transects or critical habitat features) to evaluate lateral variation in flow depth for different discharges.

- **Mapping reach-wide patterns of inundation at different discharges using USGS stream gage rating tables, discharge data, and observed water surface elevations to create water surface elevation prediction trendlines (also called a "bath tub" analyses).** The resulting water surface elevations can be overlain on lidar topographic surface models to create inundation maps. Such analyses have already been completed for the 2-yr reoccurrence interval flow in the McKenzie and Middle Fork Rivers (River Design Group, 2012, 2013), are underway for the Santiam River Basin (Troy Brandt, oral commun. Sept 2, 2015), and could be repeated for other streamflows.
- **Using hydraulic models to develop relationships between streamflow, water surface elevations, and inundation extent.** For example, one-dimensional (1D) hydraulic models such as HEC-RAS can be used to examine variation in stage and channel width for flows confined to the channel banks (generally up to the bankfull flow), whereas two-dimensional (2D) hydraulic models more accurately characterize overbank flooding and side-channel connections in unconstrained floodplains. Both 1D and 2D models can also be used to evaluate reach-wide inundation patterns at different flows so that incremental changes in water elevation relative to discharge can be evaluated. Modeling could also help develop hydrographs of spring pulse flows, spring to summer transition flows, and summer base flows to support vegetation recruitment and succession. Many of the datasets needed to develop hydraulic models are already in-place in the Willamette Valley. For example, lidar is available for the entire study area and each reach has adequate streamflow gaging information. In addition, the monitoring activities described in this report would yield critical datasets, such as channel bathymetry and calibration data, that are necessary for model development and validation.

Channel Planform

In response to floods, coarse sediment transport, and erodible bank materials, the rivers of the study area move laterally across their floodplains through gradual meander migration and abrupt channel avulsions (Dietrich and Smith, 1983; O'Connor and others, 2003; 2013; Wallick and others 2006; 2007). Over time, migration and avulsions will lead to creation and subsequent abandonment of gravel bars, side channels, sloughs, and swales, so changes in channel position are often accompanied by adjustments in the size and position of other channel features. Changes in channel width may, or may not, accompany channel shifting but generally reflect changes in streamflow regime or sediment supply. As outlined in Table 2, geomorphically effective environmental flows could enhance meander migration and contribute to the formation of gravel bars, side-channels, and other features that support complex habitats.

The most expedient method for monitoring changes in channel and floodplain planform is through repeat mapping from aerial photographs and LiDAR. Repeat mapping could be used to document erosion and deposition resulting from different magnitude floods and subsequent changes in vegetation cover. The protocols for detailed geomorphic mapping of floodplain landforms are well established, and could draw upon the aerial-photograph mapping of the Middle Fork Willamette River (Jones and others, in prep), LiDAR-based mapping of the mainstem Willamette River (Wallick and others, 2013), and geomorphic mapping of other gravel-bed streams of western Oregon utilizing both LiDAR and aerial photographs (Wallick and others, 2010; 2011; Jones and others, 2011, 2012a,b,c). Key indicators of channel dynamism and habitat availability include the diversity and abundance of actively shifting bars and secondary channels, which together support a diverse array of species and life history strategies (for example, Shroeder and others, 2015). A mapping program for measuring these features and tracking overall channel conditions, including key metrics like side channel and bare gravel bar location and size, is summarized in Table 2 and includes the following components:

- **Developing detailed, reach-wide maps of channel and floodplain landforms using recently acquired LiDAR.** This dataset would form an inventory of landforms and habitats from which to evaluate future changes that may result from environmental flows.
- **Repeating reach-based mapping from LiDAR every 5-10 years (or following a large-magnitude flood).** The detailed LiDAR-based mapping could be carried out in conjunction with floodplain mapping (described later) and provides a basis for quantifying volumes of erosion and deposition.
- **Repeating mapping of the active channel every 1-3 years from publically available orthophotographs.** This more frequent mapping is necessary for linking channel change with specific flood events. The repeat mapping from air photographs would ideally be conducted for entire reaches, but could also be constrained to focus on monitoring zones.
- **Analyzing migration rates, avulsions, and bar building and bank erosion by comparing channel maps from multiple time periods to link channel changes with specific flood events or flow regimes.** To accurately compare mapped features from different time-periods, the features will need to be normalized to account for differences in streamflow at the time of photograph (or LiDAR) acquisition (Wallick and others, 2010; 2011).

Bed Elevation

Gravel-bed rivers, like those in the Willamette SRP study area, can adjust their depth in response to changes in streamflow and bed-material sediment supply. When transport capacity exceeds bed-material supply (which often occurs downstream of dams), an alluvial channel may incise, lowering its elevation relative to the flanking floodplain, which can have adverse effects on aquatic and riparian habitats (for example, Kondolf, 1997). Previous studies have documented historical incision at USGS gaging stations on the McKenzie, Middle Fork, and Santiam Rivers but the extent and magnitude of ongoing incision is unknown (Klingeman, 1979; Wallick and others, 2013). Conversely, when transport capacity is exceeded by bed-material supply, an alluvial channel may aggrade, or increase its bed elevation, which can reduce flow conveyance and increase flooding on adjacent properties.

Given our current understanding of bed-material transport and channel morphology in the Willamette Basin, we are not certain how environmental flows may affect current or future patterns of incision, nor can we anticipate how these adjustments might vary across the study area. Nevertheless, a possible objective for the Willamette SRP could be to reduce the potential for future incision along the main river channels of the study area to minimize associated reductions in aquatic and riparian habitats.

Assessing the locations and magnitudes of incision or aggradation will require repeat bathymetric surveys along each of the river corridors of the SRP study area. Incision and aggradation is generally a gradual process, so these bathymetric surveys could be carried out every 5-10 years or following a large-magnitude flood event. Sensitive habitats that are actively changing on an annual basis could be re-surveyed more frequently, perhaps every 1-2 years. Channel bathymetry resulting from these surveys could also be used to develop hydraulic models useful for evaluating reach-based variation in inundation and flow depths for different flows. A pragmatic approach for evaluating present-day channel bathymetry changes in channel elevations includes the following tasks (Table 2):

- **Comparing repeat longitudinal profile surveys along each river, supplemented with cross-section surveys at floodplain transects and other key sites.** These surveys could be efficiently obtained from a boat equipped with survey grade RTK GPS (to determine boat position and water elevation) and bathymetry obtained from either depth sounder or acoustic doppler current profile (ADCP). Depending on flow conditions and cross-section spacing, approximately 10-40 km of channel can potentially be surveyed in a single day. Repeat thalweg and cross-section surveys would reveal areas of incision or aggradation as well as changes in the locations and depths of riffles, pools, and secondary channels.

- **Utilizing water penetrating bathymetric LiDAR surveys, combined with conventional terrestrial LiDAR, to produce high-resolution elevation models of the channel and floodplain areas along entire reaches (WSI, 2013).** The depth of laser penetration depends on turbidity and suspended algae, and even in clear conditions, are best suited for areas less than 2 m deep, so deeper pools would require boat-based surveys.
- **Conducting ground-based surveys in wadeable areas like riffles, secondary channels or sections of the river with slow, shallow currents.**
- **Evaluating patterns of incision and aggradation by comparing survey data from different time periods.** The methods outlined here would provide baseline datasets from which to compare future changes. There are also multiple sources of recent and historical survey data from other organizations that could potentially be useful for assessing historical and recent trends (Appendix B). However, accurate assessment of incision or aggradation will require a) consistent vertical datum between time periods and b) coupling repeat surveys with channel maps from different time periods so that changes in bed elevation can be evaluated within the context of broader morphological changes.

Bed Texture

The streambed substrate of alluvial rivers can change in response to variations in bed-material supply or transport capacity. When transport capacity exceeds the available supply of bed-material sediment, bed texture can coarsen, which can decrease the availability of spawning habitats (Kondolf and Wolman, 1993) and contribute to channel stability. Conversely, when the available supply of bed-material sediment exceeds transport capacity, bar and bed surfaces can adopt finer textures in response to sediment deposition. While a local shift in particle size from coarse cobbles to smaller gravels may in some cases benefit stream ecosystems (for example, by enhancing spawning habitats), excessive deposition of fine sediments in gravel-bed areas could potentially have negative impacts on aquatic habitats (for example, Tappel and Bjornn, 1983; Everest and others, 1987; Roy and others, 2003). Within the study area, streambed coarsening has been noted in the McKenzie Basin (Minear, 1994) while streambed fining has been associated with reservoir management activities at Cougar Reservoir (Anderson and others, 2007) and Fall Creek Reservoir (Schenk and others, 2014). Evaluating current patterns of bed-material texture and monitoring future changes is critical for determining whether environmental flow releases could be implemented so as to minimize negative impacts such as armoring in main channel habitats and excessive fine sediment aggradation in off-channel habitats.

In gravel-bed rivers like those of the study area, bed-material textures can be highly variable between sites due to large-scale patterns like selective transport and attrition, as well as local hydraulics. The methods for bed-material sampling are well established and have been used extensively to characterize streambed textures on a variety of other gravel-bed rivers in western Oregon (Wallick and others, 2010; 2011; Jones and others, 2011; 2012a,b,c; Podolak, 2012). An efficient yet comprehensive approach to evaluate current conditions and monitor long term changes in bed texture is outlined in Table 2 and could have the following elements:

- **Establishing a network of sites for periodically sampling bed-material sediment sizes and tracking long term changes in bed texture.** Ideally, 10 to 20 sites could be established along each reach. Sampling sites should be located on the bar apex and selected on the basis of bar size, accessibility, and condition (such as little to no vehicle disturbance). Where possible, sampling sites should be located along large point bars or lateral bars formed by recent deposition events, as indicated by the absence or minimal coverage of vegetation. Bed-material sampling sites could coincide with other monitoring activities or high priority sites like floodplain transects (Figure 7) and monitoring zones (Figures 3-6).

  - At each site, sample the surface sizes of bed-material sediment using a modified grid technique (Kondolf and others, 2003) and a gravelometer measurement template (Federal Interagency Sediment Project US SAH–97 Gravelometer) which standardizes the measurement of sediment clasts greater than 2 mm in diameter.

- **Sampling the subsurface material of gravel bars to evaluate particle size differences between the surface and subsurface material (a measure of bar "armoring") at select sites**. Bulk samples could be collected from the same location that surface material was measured by removing surface material and then collecting a minimum volume of sediment, which is dictated by sediment size (Bunte and Abt, 2001). Bulk samples can be submitted to a sediment laboratory (such as the USGS Sediment Laboratory in Vancouver, Washington) to be dried and analyzed. Repeat sediment sampling could be carried out every 3-5 years, or following a flow event that meets a key threshold for a particular reach (for example, a small flood).
- **Analyzing particle size distributions and compute key metrics to characterize bed-material textures**. Examples include:
  - **Median grainsize diameter** (D50) from each site can be used to evaluate longitudinal trends and relationships between channel morphology and bed texture.
  - **Armoring ratios** (the ratio of D50 of the surface to subsurface layers) can be computed to provide an indication of the relative balance between bed-material

supply and transport capacity. The armoring ratio is typically close to 1 for rivers with a high sediment supply and approaches or exceeds 2 for supply-limited rivers (Bunte and Abt, 2001).

- **Mapping of sediment facies** could be used to supplement the grainsize measurements and would entail delineating areas with similar particle size distributions (Buffington and Montgeomery, 1999). Because bar shape changes over time, and sediment texture can varies across individual bars, facies mapping enables coupling between sediment size and bar morphology so that changes in sediment size can be related to variations in sediment supply or transport capacity (Podolak and Wilcock, 2013). Logical locations to focus this mapping effort would include the permanent floodplain transects where other monitoring activities are co-located.

Floodplain Surfaces

Floodplain surfaces are topographically higher than active channel landforms and encompass a variety of landforms like secondary channels, sloughs, and natural levees that are mantled with fine sediment (sands, silts, and clays). Floodplain landforms originate as active channel features, but when the channel shifts elsewhere due to meander migration or avulsions, these landforms begin to accrete fine sediment and become stabilized with vegetation. Floodplains continue to aggrade through occasional overbank deposition of fine sediments until erosion recycles these older surfaces and liberates sediment to be re-deposited downstream. Within the present-day study area, channel stability imposed by flood control, bank stabilization, and mature forest vegetation limits both floodplain erosion and the creation of new gravel bars that can evolve towards floodplain surfaces (Dykaar and Wigington, 2001; Wallick and others, 2013). In addition, reductions in flood magnitude and channel dynamism have caused formerly active bare gravel bars to become stabilized with mature forest vegetation.

Considering current patterns of streamflow regulation and bank stability, environmental flows are most likely to influence flood inundation and more fine-sediment deposition along higher-elevation portions of vegetated bars and low-lying floodplain surfaces like swales. These areas are inundated more frequently and, therefore, experience more fine sediment deposition and floodplain creation than topographically higher floodplain surfaces that may have been inundated during large historical floods but are seldom inundated by regulated floods (Figure 6). Environmental flows could also potentially influence the erosion of existing floodplain surfaces through lateral migration or avulsions, especially in areas with erodible banks and high supply of bed-material sediment such as the dynamic segments of the North Santiam River.

We focus these monitoring activities on tasks that track the three stages of floodplain evolution: 1) creation of new floodplain surfaces, 2) evolution of existing floodplain surfaces, and 3) floodplain recycling. Because these processes are gradual, and can potentially span tens to thousands of years, we identify activities that will yield practical information at timescales relevant to the Willamette SRP. A pragmatic approach for monitoring floodplain responses to environment flows could incorporate the following activities:

- **Mapping floodplain landforms from lidar to characterize existing conditions and provide a baseline for tracking future changes**. This mapping would build upon a similar effort for the mainstem Willamette River and would include delineation of ridges, swales, natural levees, meander scars, and sloughs, and characterizing the topography of these features. The lidar-based landform maps could be developed in conjunction with the aerial-photograph based maps of the active channel (described previously).
- **Mapping of floodplain landforms could be repeated 10 years or following a large flood event**. Changes to higher-elevation floodplain surfaces are typically gradual, so decadal-

scale mapping should be sufficient to characterize most features and could coincide with repeat mapping of active channel features.

- **Evaluating patterns of erosion and deposition could be carried out by comparing lidar-based mapping from different time periods to assess overall trends and underlying processes**. Geomorphic change detection software (for example, Wheaton and others, 2010) could expedite these analyses.
- **Surveying cross-sections along floodplain transects every 1-3 years (depending on flows).** This would enable aggradation and scour to be quantified in key habitat features like floodplain sloughs that are inundated more frequently (and likely subject to greater rates of aggradation) than higher-elevation floodplain surfaces. In conjunction with other data documenting the magnitude and frequency of inundation, repeat surveys could be used to document aggradation over the entire measurement interval or associated with individual flood events.
- **Measuring seasonal or event-based rates of floodplain deposition by installing deposition pads or plates along swales, vegetated bars, and other floodplain features to characterize rates and grain size distributions of newly deposited sediment**. Depending on site access, the pads can be visited between high flow events or annually in summer months when sediment is collected, dried, sieved, and weighed (as summarized by Steiger and others, 2003). Priority areas to deploy deposition plates include monitoring zones or other areas with distinct swales and minimal disturbance from agriculture or other land uses that are within the two-year flood inundation zone (as defined by presently-available inundation maps; River Design Group, 2012; 2013).

- **Measuring decadal-scale rates of fine-sediment deposition and floodplain creation in the post-dam era**. This could be done by identifying formerly bare gravel bars from recent (post-1970s) aerial photographs and measuring depths of fine sediment aggradation (oral commun., F. Fitzpatrick, USGS Geomorphologist, May 12, 2015). Because rates of floodplain development are likely to vary depending on local hydraulics, flood history, and site conditions, these measurements could be repeated at multiple sites along each reach to target areas with varying ages and stages of vegetation succession and floodplain development.
- **Evaluating rates and processes of floodplain creation, floodplain evolution and floodplain recycling**. This could be done by comparing datasets from the floodplain mapping, event-based deposition rates and decadal-scale deposition rates.

Monitoring Riparian Vegetation Responses to Environmental Flows

Through the environmental flows workshops, recommendations were developed to promote floodplain forest succession with an emphasis on black cottonwood and Pacific willow. The life history of black cottonwood (*Populus*) is tightly coupled with floodplain hydrology and disturbance processes. As such, there is a substantial amount of existing scientific literature on their flow requirements (for example, Bradley and Smith, 1986; Cooper and others, 2003; Rood and others, 2005). Therefore, we focus this section on monitoring the response of black cottonwood to environmental flow implementation even though other native tree species in the Willamette Valley floodplains are likely to benefit from these recommendations. These native species include many species of willow, Oregon ash (*Fraxinus latifolia*), big-leaf maple (*Acer macrophyllum*), Oregon white oak (*Quercus garryana*), hazel (*Corylus cornuta var. californica*), black hawthorn (*Crataegus douglasii*), and red alder (*Alnus rubra*).

Our current conceptual model of floodplain forest recruitment and succession is described more fully in other texts (for example, Wallick and others, 2013). To summarize, there are four key phases to vegetation recruitment and succession that correspond with distinct environmental flow components (Figure 9, Table 4):

1. During seed and stem dispersal, black cottonwood seeds and stem fragments are spread by wind or water between May and mid-July (Dykaar, 2008). Spring flow pulses that coincide with seed release can disperse seeds throughout the river corridor, but cottonwood seeds require bare and moist gravel bar surfaces for germination. The amount of time a seed remains viable is dependent on exposure to moisture. If seeds remain wet, they lose viability within 2-3 days; but if dry, they remain viable for two weeks to a month. Flow conditions during this time are critical to successful germination. In addition, because cottonwood seeds require bare, exposed surfaces for germination, winter high flows may be needed to produce suitable locations for seed dispersal and establishment.
2. During stand initiation, shade intolerant pioneer species like black cottonwood germinate and grow rapidly on unvegetated gravel bars. As spring flows recede towards summer base flows, the roots of these young seedlings lengthen to access declining water tables. Recession rates that outpace root extension can cause seedling mortality, so gradually declining water levels that recede 0 to 2.5 cm/day are optimal for many species of cottonwood (Mahoney and Rood 1998). Summer base flows are also important for young seedlings because mortality can result from both drought conditions and inundation.
3. Continued establishment and survival of young forest stands requires suitable flow conditions for multiple years as the stand progresses through stem exclusion and early seral succession (Braatne and others, 2007). For example, seedlings that establish about 1-2 m

above the zone of repetitive scour are better able to withstand erosion from winter high flows and proceed to later phases of succession than seedlings on lower bar surfaces (Polzin and Rood, 2006; Cline and McAllister, 2012).

4. The ‘recycling’ of mature forest stands through floodplain erosion during floods creates bare patches that can be colonized by pioneer vegetation and liberates coarse sediment and wood that can be re-deposited in downstream habitats. Over the span of decades or centuries, floodplain recycling combined with vegetation succession creates a diverse floodplain forest mosaic of different-age classes.

Figure 9. Conceptual model of vegetation recruitment and succession and approaches for monitoring these processes.

Table 4. Examples of environmental flow objectives for black cottonwood and approaches for evaluating whether targets are achieved

One likely limitation to ongoing floodplain forest recruitment is a lack of bare gravel bars that support the colonization and continued establishment of pioneer species, such as black cottonwood and willows. Even in reaches with successful cottonwood germination on bare gravel bars, these seedlings are potentially subject to erosion by high flows. Studies on the Willamette River show that young seedlings are continually reset because channel stability confines erosive flows to a narrow corridor (Cline and McAllister, 2012). Channel stability also limits floodplain recycling, so mature forest stands are aging in place and relatively few places for the successful establishment of young stands presently exist. As a result, the river corridors throughout the Willamette SRP study area are flanked by dense, mature forest stands that are more homogeneous and on an overall trajectory towards late-succession species like maples than during historical periods. There are relatively few areas that support a more patchy mosaic composed of different successional stages (Wallick and others, 2013). Streamflows during spring and summer months can also potentially limit stand establishment. For example, spring recession rates can outpace root elongation while summer flows can inundate young seedlings. We do not currently know the relative importance of these factors, or how they vary from year to year or between reaches. Therefore, the monitoring approach outlined below would provide information critical for addressing these knowledge gaps.

The monitoring activities needed to assess vegetation responses to environmental flows are divided into two categories: 1) geomorphic and hydraulic tasks used mainly to identify and track likely sites for plant establishment and 2) vegetation monitoring tasks to track all phases of vegetation recruitment and succession (as described in Table 4 and summarized in Table 3). The vegetation monitoring tasks are further divided by scale. More detailed activities could occur along transects, primarily within dynamic monitoring zones, while reach-scale monitoring can detect status and trends in overall floodplain forest conditions. Because vegetation recruitment and succession is a gradual process, evaluation of the overall success of the Willamette SRP on cottonwood recruitment and succession will require a multi-year approach.

Geomorphic and Hydraulic Conditions that Influence Vegetation Recruitment

Because a lack of establishment sites is likely a key factor limiting vegetation recruitment throughout the study area, high priority tasks for all study reaches include:

- **Identifying unvegetated gravel bars that provide likely sites for seedling germination and establishment.** As described previously, bare gravel bars are readily mapped from LiDAR or aerial photographs.
- **Assessing bar inundation for different flows to evaluate how environmental flows will influence seed dispersal and stand establishment in a given year**. Inundation can be monitored using a broad array of methods described previously. For example, in the summer

of 2015, USGS and TNC staff developed relationships between low-flow inundation and discharge at sites on the Middle Fork Willamette and McKenzie Rivers by first surveying a transect and installing seasonal monuments, then measuring distance from the monument to the water's edge during subsequent site visits (Jones and others, In review).

- **Developing a hydraulic model to better understand longitudinal patterns of bar inundation at different discharges across entire reaches.** This reach-scale model could be developed utilizing data from each of the monitoring sites.
- **Developing reach-scale maps of potentially successful zones for cottonwood establishment by coupling maps of gravel bars with inundation patterns.** Previous studies have shown that cottonwood recruitment is most successful at elevations between 30 and 200 cm above the summer base flow stage (Mahoney and Rood, 1998). Repeat mapping every 3-5 years could be used to track changes in the abundance of establishment sites.

Along reaches such as the North Santiam where channel migration creates ample areas for successful stand establishment, the following tasks would enable us to evaluate the effectiveness of environmental flow releases designed to support seed dispersal and stand establishment:

- **Assessing the timing and magnitude of spring flow pulse hydrographs relative to seed release by comparing streamflow hydrographs from USGS gaging stations with observed patterns of seed release in each reach.** A goal for this analysis is to determine whether flows suitable for seed dispersal are occurring within the window of seed viability.
- **Comparing maps of seedling distribution with inundation maps to determine the range of spring flow levels that would support stand initiation.** Idealized recession rates can be computed by comparing the difference in stage between the elevation of seedlings and

typical summer base flows and assuming a gradual decline in water levels between 0-2.5 cm/day based on previous studies.

Stand Recruitment and Succession

Vegetation monitoring is divided into two categories: 1) reach-based mapping to provide broader context for evaluating the overall status and trends of floodplain vegetation in response to environmental flows and 2) site-based monitoring along transects and within zones to yield detailed information on stand establishment and succession.

Reach-based Mapping to Track Vegetation Recruitment and Succession

Because vegetation succession and stand recycling can encompass broad spatial areas and changes in one location may not be indicative of reach-wide conditions, a comprehensive approach for evaluating changes in floodplain vegetation would entail detailed landcover mapping for entire reaches of the Willamette SRP study area. The goal of this mapping would be to delineate different seral stages of floodplain forest succession and provide baseline datasets for evaluating future changes that may result from environmental flows or other influences. Landcover mapping would complement the geomorphic mapping described previously, providing a robust platform for evaluating coupled geomorphic and vegetation responses to environmental flows. Mapping could include the following tasks:

- **Mapping floodplain vegetation using methods currently under development for the Willamette River floodplain by the University of Oregon.** These methods are based upon previous efforts by the Pacific Northwest Ecosystem Research Consortium (PNW-ERC; *http://www.fsl.orst.edu/pnwerc/wrb/*). Mapping could utilize a combination of aerial photographs, LiDAR, and ground-truthing to map landcover, including different seral stages of floodplain forest vegetation similar to the effort underway for the mainstem Willamette River (D. Hulse, University of Oregon, written commun., 2013).

- **Conducting repeat landcover mapping for the whole floodplain every 10 years or following a large-magnitude flow event.** Analyses of landcover changes would depict areas where existing stands were reset by high flows and where young stands are being established. In conjunction with repeat mapping of channel and floodplain morphology (as described previously), repeat landcover mapping would permit linkages between flood magnitude, geomorphic processes, and vegetation succession.
- **Conducting repeat mapping of the active channel from aerial photographs every 3-5 years.** More frequent mapping would track changes in the availability of bare gravel bars that are suitable for vegetation recruitment and to identify areas where existing vegetation patches were eroded by high flows.

Site-based Monitoring Tasks

Site-based monitoring tasks could utilize vegetation plots to support statistically robust, repeatable observations over time. Vegetation plots would ideally be co-located with the established floodplain transects where hydrologic and geomorphic information is also collected (Figure 9; Figure 10). The exact approach for a particular site will depend upon site characteristics and monitoring objectives. In general, a successful sampling scheme for evaluating vegetation response to environmental flows would be a transect stratified by geomorphic landforms (such as gravel bars, young floodplain, and mature floodplain) that encompass key environments for different stages of vegetation recruitment and succession (Jonathan Friedman, USGS Ecologist, oral commun., May 7, 2014; Jones and others, In review). Along this transect, monitoring plots can be established to examine vegetation changes over time. Plot size will vary with the vegetation being targeted by the monitoring. For instance, smaller plots could be used to measure seedling density whereas larger plots may be needed to evaluate stand diversity in mature forests. Monitoring changes at the site scale can be very resource-intensive. The examples provided below may be considered if resources allow for field-based monitoring at this scale:

- **Monitoring seedling germination using repeat ground-based photographs or plot-based vegetation surveys.** Photographs would provide qualitative information for comparisons over time, whereas plot-based surveys could include species identification and provide a basis for quantitatively tracking seedling mortality and cover of native and invasive plants through summer months (Figure 10). Photographs and surveys can be taken one week to one month after seed release and spring pulse flows to ensure sufficient time for seed germination while minimizing effects of transition flows. Black cottonwood plants should be classified as seedlings or root sprouts to the extent possible. Photograph monitoring points could first be established in areas of dynamic monitoring zones where geomorphic conditions are suitable for seed dispersal and germination. If resources allow, photo monitoring points may be established at additional sites such as along permanent monitoring transects or stable monitoring zones along each reach.
- **Measuring seedling mortality periodically throughout the spring to evaluate seedling response to spring recession flows and establish a range of variability.** To do this, small plots are established along transects in areas identified as suitable for seedling establishment within each reach. Initial focus could be along transects within dynamic monitoring zones as well as in representative transects in areas outside of more stable zones. If resources allow, additional monitoring could be completed along transects in stable monitoring zones. These data may be coupled with other datasets, including air temperature, precipitation, bar

elevation, substrate, water level, presence and cover of habitat-altering invasive species, and browsing to account for other variables influencing seedling mortality (Figure 10; Jones and others, In review).

- **Continuing the field-based monitoring tasks described above into the late summer and early fall to evaluate seedling response to summer base flows and mortality associated with very low flows or inundation that may result from flow augmentation.**

Figure 10. Monitoring approaches used by TNC and USGS to evaluate black cottonwood establishment during summer months during summer of 2015. Methods included (a) initial survey of floodplain transect, followed by repeat measurements of water elevation to link inundation with flow (b) repeat plot-based measurements of seedling germination and mortality and (c) repeat landscape-scale photographs to document changes in overall vegetation across gravel bar.

If preliminary monitoring reveals that factors like seed dispersal, spring recession rates, or summer base flows are limiting vegetation recruitment on a particular reach, the following tasks could aid in tailoring spring and summer environmental flow releases:

- **Documenting the timing of annual seed release and developing a database to evaluate annual variability and long-term trends so that spring flows can be tailored to the period of interest.**
- **Evaluating relationships between seed dispersal, stream flows, and inundation patterns to assess patterns of seedling distribution for different flows.** Monitoring activities could include repeat photographs or surveys to document patterns of seed dispersal, which could be coupled with the inundation monitoring and streamflow analyses described previously.
- **Assessing seedling mortality in response to spring transition flows.** Recession rates can be computed using methods described previously, and compared with seedling responses and literature-based guidelines to determine whether guidelines developed for other regions are applicable to the study area.

Specific site-based activities to assess stand establishment and succession could include the following tasks, which would complement the reach-based repeat landcover mapping described above:

- **Establishing monitoring plots along transects within each reach that encompass a range of seral stages.** Some of these plots could include a subset of the sites used to track vegetation recruitment.
- **Monitoring phases of stem exclusion and early seral succession over 5-20 years in monitoring plots through repeat observations of size classes, age classes, vegetation types and densities, and other factors.**

Developing an Adaptively Managed Monitoring Program to Track Progress towards SRP Goals

Tracking the success of the Willamette SRP will be challenging, partly because the program encompasses three large, and diverse river basins and partly because dam operations are only one variable affecting these floodplain ecosystems. In addition, the flow prescriptions for these basins include dozens of specific recommendations for streamflows at different reaches of each basin. The recommendations were developed based on best available information and expert knowledge; however, there are substantial gaps in our understanding of the flow-ecology relationships including hydraulic and geomorphic responses, vegetation recruitment and succession, and biological processes. These flow-ecology relationships occur over different spatial and temporal scales, which need to be factored into monitoring and adaptive management. Developing a streamlined, cost-effective, and efficient monitoring and assessment program that leverages resources from multiple organizations will be critical for tracking program implementation and success. Below we describe considerations to help ensure such a program.

Standardizing Environmental Flow Recommendations across Tributaries

Environmental flow recommendations were developed independently for each of the major tributaries (Gregory and others, 2007b; Risley and others, 2010b; Bach and others, 2012). Although all of them include recommendations based on flow characteristics such as magnitude, frequency, and duration, the manner in which they were specified, and their linkage to specific ecosystem objectives, varies from tributary to tributary. This creates challenges in developing a basin-wide monitoring program that directly assesses the links between ecosystem objectives and observed flows. Specific refinements in environmental flow recommendations should include:

- **Streamlining the categories used in environmental flow recommendations.** Each of the Willamette SRP reaches have between 6 and 8 environmental flow recommendations. Although these recommendations fall into broadly similar seasonal categories, there are differences between basins. Recommendations that are designed to meet similar purposes, for example fall flows for upstream migration, should be described in the same manner across all basins. Some tributaries and reaches may have ecosystem objectives that are unique to that location, and their associated flow recommendations should be reviewed to ensure their description and linkage to ecosystem objectives are as clear and direct as possible.
- **Standardizing the criteria for flow duration and frequency.** Currently there are inconsistencies between the environmental flow recommendations developed for different basins that could result in an inaccurate portrayal of program implementation and success. Until there is additional scientific information to refine the recommendations, criteria such as duration and frequency for each reach should be based upon more general ranges that are linked with flow conditions and should be consistent across basins to permit comparisons.

Addressing Outstanding Research Questions to Refine Environmental Flow Objectives

The streamflow and ecological relationships that are the basis for the environmental flow recommendations are currently not well defined for the Willamette tributaries. To evaluate whether ecosystem objectives are being met, we need to ensure that each of the objectives are based on sound scientific relationships between streamflow and the ecosystem objective of interest. There are a number of outstanding research questions that, when addressed, will provide important data and information for refining the flow recommendations.

- Key Questions: Hydraulics and Geomorphic Processes:
    - **What is the floodplain area likely to be influenced by environmental flow releases?** Delineating an 'ecologically functional floodplain' would be helpful for defining the area where environmental flows are likely to have the greatest influence on hydrologic, hydraulic, geomorphic and vegetation processes.
    - **What is the relationship between streamflows and inundation patterns?** More information is needed on the discharges necessary to connect lateral habitats with the primary channel and for inundating floodplain sloughs. Along with direct measurements, hydraulic models could be used to refine and validate many of the connectivity and inundation objectives.
    - **What is the discharge necessary to trigger key geomorphic processes like bed-material transport or erosion of floodplain forest? What are the geomorphically-effective flows along each of the study reaches?** By documenting actual geomorphic responses to recent floods that meet the threshold for bankfull, small and large flood events, the Willamette SRP objectives could be refined so that

findings from future monitoring activities could be compared against realistic objectives.

- **What is the balance between sediment supply and transport capacity? How does this relationship vary across the study area? What are the implications for channel processes and resulting habitats?** For example, if a particular reach has excess transport capacity, it may be prone to incision and, therefore, future high flow releases could trigger negative impacts to aquatic and floodplain habitats.

- Key Questions: Vegetation Processes:
  - **What are the key factors limiting vegetation recruitment? How can environmental flows address these limiting factors?** Our understanding of these limiting factors is critical to setting pragmatic goals for floodplain forest regeneration. For example, if a particular reach lacks recruitment sites, then spring recession rates will not generate the desired response.
  - **What are the seasonal thresholds that support different stages of vegetation recruitment and succession?** We currently lack a refined understanding of the flow conditions that support different life stages of native vegetation and how these flows vary along the length of each river. For example, spring recession rates are largely derived from the literature and have not been verified against local observations to determine if they are applicable to the Willamette SRP study area.
  - **Is black cottonwood a suitable indicator species for the Willamette SRP? Would vegetation guilds provide a better indicator of forest response to environmental flows?** Using a guild approach would require new research to identify specific

reaches where this strategy is needed and groups of species that share similar life histories and reproductive strategies.

- **What is the relative importance of vegetative root sprouts versus seedling establishment for Black Cottonwood in the Willamette Valley?** Initial research indicates that root sprouts could potentially be a robust pathway for black cottonwood regeneration (Jones and others, In review). This process is not currently reflected in the environmental flow recommendations. Further research is needed to potentially link this process with streamflow characteristics.

Developing a Multi-organizational Monitoring Program

Considering the large spatial area of the study area, and the many stakeholders (including watershed councils, land trusts, and local and federal governments, as outlined in Appendix B) that are actively engaged in floodplain restoration within this area, there are many opportunities to leverage resources and distribute data collection activities. To facilitate monitoring, a small committee could develop a more detailed monitoring plan, oversee the monitoring program, and be charged with data assessment and reporting.

According to Higgins and others (2011), a detailed monitoring plan is a critical component of the environmental flow monitoring program and should describe:

- What is being monitored, and how data collection relates to recommendations, flow conditions and dam operations
- Multi-organizational strategy for data collection (who is measuring what, when, where, and the roles and responsibilities for each organization)

- Specific strategies for each phase of the monitoring program including evaluating program implementation, determining short-term responses to environmental flow releases, and evaluating long-term status and trends.
- Methods and protocols for data collection
- Site-specific issues relative to local dam operations and water management decisions.

As described previously in this report, well-defined protocols are essential for ensuring consistent data collection over time and across different reaches of the study area. Some protocols (especially those for geomorphic mapping and sediment size characterization) are well-documented and ready for broader implementation, but protocols for other tasks (like evaluating recession rates and vegetation recruitment) will need to be defined. Prior to implementation of the monitoring plan, all protocols should be clearly described and publically available.

A critical first step in tracking success of the Willamette SRP is to evaluate program implementation, such as which flow targets have been achieved, as this provides a basis for evaluating the corresponding hydraulic, geomorphic, and vegetation responses to observed flows. Although the environmental flow recommendations have been developed for each of the Willamette SRP river basins, there has been no comprehensive assessment to evaluate which targets have been met, nor has there been assessment to determine how patterns of implementation success vary between basins with varying hydrological conditions or reservoir operations.

Determining short-term responses to environmental flow releases could focus on evaluating hydraulic responses (including changes in wetted width and stream depth as outlined in this report) that result from environmental flow releases. In addition, many of the shorter-term (1-5 year monitoring frequency) tasks described in the previous sections would also satisfy objectives for short-term monitoring.

Long-term monitoring of status and trends is important since many of the geomorphic and vegetation processes described in this report are slow and responses may take several decades to occur. For example, processes like incision, aggradation, floodplain evolution, and vegetation succession are typically gradual, so monitoring activities to track these processes (bathymetric surveys, mapping of floodplain morphology and vegetation) are best conducted at decadal intervals. In addition, monitoring and data collection over the span of many years or decades is needed to evaluate the effects of infrequent events like larger floods, extreme droughts, or anthropogenic activities that may not occur within short-term monitoring timeframes. Long-term status and trends monitoring of the Willamette SRP could dovetail with similar monitoring efforts along the mainstem Willamette River (Gregory and Hulse, 2002).

Developing Processes for Data Syntheses, Reporting, and Adaptive Assessment

Successful implementation of the Willamette SRP would also benefit from having an established process for reporting and adaptive assessment. One possible approach is that annual assessments of environmental flow implementation could be reported so as to document flow conditions and identify which targets were achieved. More detailed reports summarizing short-term hydraulic, geomorphic and vegetation responses to streamflows could be issued every 5 years or after a large-magnitude flood event that triggers major changes to the study area. Each monitoring report could compare observed responses against stated goals, and identify lessons learned and recommendations for future phases. Reports describing reach-scale status and trends monitoring could be produced every 10 years.

Monitoring data and interpretations should be publically available for the benefit of all stakeholders interested in floodplain processes and streamflows. In addition to technical reports, a website could be established to display objectives for the environmental flow program and findings from the monitoring program. Because many different organizations may be assisting with monitoring, the website could potentially also serve as a portal for data sharing, methodology dissemination, and collaboration among organizations.

Considerations for Measuring Progress and Success

Context is critical for evaluating SRP implementation and program success. As described throughout this report, implementation of the environmental flow recommendations and resulting hydraulic, geomorphic, and vegetation responses to these flows will depend upon many variables. The following examples illustrate considerations that may help provide context when interpreting monitoring data and evaluating program outcomes.

- **Dam operations:** Considering current USACE reservoir management guidelines, some flow targets are more likely than others to be implemented during typical years. SRP implementation may benefit from consideration of flows that can be met on a regular versus irregular basis. For example, larger-magnitude flows may only be possible during rare hydrologic conditions like those experienced in winter of 1996-97.
- **Hydraulics:** Channel and floodplain geometry vary substantially along the length of the large Willamette Basin SRP reaches. This variation influences the spatial patterns of water depth and inundation extent. Artificial features like levees, revetments, bridges, and other structures also locally influence flow patterns. Understanding local controls on inundation extent and flow depths will help to set realistic targets and aid in interpreting monitoring data and evaluating success.
- **Geomorphology:** The present-day floodplain geomorphology and physical habitats of the Willamette Basin SRP study area reflect major reductions in floods, sediment supply, bank erodibility, and large wood compared with historical periods. Considering these major

alterations, flow releases from dams are unlikely to achieve historical habitats and ecosystem services (Wohl and others, 2015) so it is critical to develop realistic goals for geomorphic processes that are in sync with present-day habitat forming processes.

- **Vegetation:** Air temperature, precipitation, other weather patterns, site conditions, channel morphology, and other factors can all influence timing of seed release, viability of seeds, and patterns of seed dispersal, germination, and early establishment. For example, a period of hot, dry weather could lead to seedling mortality even if flows meet SRP recommended targets. High mortality is expected for cottonwood and other early pioneer species, so this could be anticipated when interpreting early survival of young stands.

Conclusions

This report summarizes an approach for monitoring hydrologic, hydraulic, geomorphic, and vegetation responses to adaptively managed environmental flow releases implemented by the Willamette SRP. Although this monitoring program is intended to provide a basis for tracking progress towards stakeholder-developed objectives in the Willamette SRP, the multi-disciplinary monitoring approaches outlined here could also be applied to a wide range of other floodplain management issues including hazards associated with floodplain inundation, channel migration, or habitat changes resulting from restoration activities.

High priority monitoring activities are in Table 3 and include:

- Hydrograph analyses to characterize flow regimes and determine which flow targets were achieved;
- Measurements of flow depths and inundation extent to characterize longitudinal patterns of habitat availability for different discharges;

- Repeat mapping of channel and floodplain features from lidar and aerial photographs to characterize existing conditions and evaluate patterns of channel change associated with different magnitude flow events;
- Repeat surveys of channel bathymetry to track the magnitude and extent of incision or aggradation that could impact sensitive habitats;
- Repeat mapping of unvegetated gravel bars from aerial photographs to identify potential recruitment sites for black cottonwood and other floodplain plant species and to evaluate how these zones respond to different flow regimes;
- Plot-based observations of seedling survival and early establishment to evaluate black cottonwood responses to seasonal flows and other factors; and
- Evaluation of stand diversity from field observations and repeat landcover mapping to characterize current and future forest diversity and assess streamflow-forest interactions.

The monitoring approaches outlined in this study recognize that the alluvial, gravelbed portions of Middle Fork Willamette, McKenzie, and Santiam River Basins have many of the building blocks to support healthy floodplain and aquatic ecosystems despite the substantial historical and ongoing alterations (Wallick and others, 2013). For example, each reach has complex habitats that are stabilized by mature floodplain forest, but each reach also has relatively dynamic sections where channel migration actively creates and maintains habitats. Although the Willamette SRP aims to sustain these diverse floodplain ecosystems through an adaptively managed environmental flow program, other constraints may cause some sections of the study area to experience continuing habitat declines in coming decades. Some of these other constraints include local bank stabilization, trapping of gravel by upstream dams, and reductions in large wood. One approach to ensuring success would be for the Willamette SRP to set realistic, reach-specific targets for environmental flows and then to perform adaptive assessment of the program within the context of these other influences. To aid in this process, this monitoring framework provides examples of reach-specific objectives, based on current scientific understanding, which could be further refined by local experts and stakeholders (Appendix A). With refined objectives in place, a comprehensive monitoring program could be developed with the methods outlined in this report and used to provide critical information for tracking progress towards SRP goals. Data from this monitoring program could also be used to evaluating status and trends of important aspects of the floodplain system, like inundation patterns, channel morphology, and floodplain forests, which together support a complex mosaic of aquatic and riparian habitats.

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Appendix A. Reach characteristics and monitoring considerations

Reach name and boundaries	**Upper Middle Fork Willamette River:** Fall Creek Confluence to Dexter Dam (FPKM 15-22; Dexter reach from Jones and others, in review)
Hydrologic alteration and streamflow conditions	(See section for Lower Middle Fork Willamette River; streamflow in this reach is more adequately represented by the USGS gage at Dexter)
Geomorphic and vegetation conditions	This reach has very little revetment, but is geomorphically stable due to reductions in peak flows, coarse sediment inputs, and subsequent vegetation encroachment. The channel is largely a single thread with stable side channels near FPKM 15-17 and 20-22. Active gravel bars are small (less than 5,000 m^2) and sparse, so there are few areas for cottonwood recruitment. Mature forests are fairly homogenous, extending to the channel margin and covering relict gravel bars.
Pragmatic goal for monitoring based on present day (ca. 2015) conditions	Since reach stability may inhibit dynamic geomorphic or vegetation responses to typical high flows, a pragmatic goal may be hydraulic connectivity. Near term monitoring could determine key geomorphic thresholds and evaluate options for obtaining ecological and geomorphic benefits while maintaining flood protection. For example, monitoring could help determine whether multiple, high flow pulses have a similar effect as a single, larger magnitude flow. Long term monitoring could evaluate incision and evolution of key off-channel habitats.
Monitoring zones that are presently dynamic	FPKMs 15-17 near the mouth of Fall Creek have actively shifting bare gravel bars and secondary channels that were historically dynamic as well.
Monitoring zones with mature vegetation and relict side channels that may respond dynamically to future high flows	FPKMs 15-17 and 19-21 both have an extensive network of relict side channels flanked by dense, mature forest. Within both areas are lower elevation bars with moderately dense vegetation that established after the 1996-1997 floods.
Hydrologic and hydraulic response considerations	Inundation monitoring could focus on extent and duration of side-channel inundation at different flows and could incorporate ODFW, TNC, and USACE monitoring efforts. Streamflow in this reach is adequately represented by the USGS gage at Dexter (14150000).
Geomorphic response considerations	Repeat surveys of side channels could be coupled with inundation monitoring in key side channels important to Oregon chub and also used as rearing habitats. Given extensive vegetation encroachment, floodplains and stable bars will likely remain stable except in exceptional floods, so main monitoring focus should be active channel. Infrequent (every 3-5 years) side channels/sloughs outside of active channel should be monitored to evaluate how these important habitats are evolving, as they are probably not being renewed in current flow and sediment regime.
Vegetation response considerations	Vegetation recruitment appears particularly limited by a lack of bare bar surfaces that are suitable for stand initiation. Vegetation monitoring could focus on: 1) tracking areas of active vegetation recruitment and establishment, 2) evaluating trajectories of existing vegetation stands, and 3) determining flow needed to reset mature vegetation and create new bar surfaces.
References	Gregory and others (2007); Dykaar (2005, 2008a, 2008b); Wallick and others (2013); Jones and others (in review)

Reach name and boundaries	**Lower Middle Fork Willamette River:** mouth to Fall Creek confluence (FPKM 0-15; Jasper and Confluence reaches from Jones and others, in review)
Hydrologic alteration and streamflow conditions	Regulation has greatly reduced small flood (two year recurrence interval) and large flood (10-year recurrence interval) discharge at the Jasper gage. Large and small floods (previously 82,100 ft^3/sec and 39,300 ft^3/sec, respectively) have been eliminated so that the highest flows since 1965 were 23,300 ft^3/sec on December 25, 1996 (bankfull at Jasper gage is 20,000 ft^3/sec). Flows between 18,000-20,000 ft^3/sec have occurred every few years, but more typical peak flows are about 15,000-18,000 ft^3/sec. Regulated summer base flows have increased 2-3 times from the unregulated summer flows.
Geomorphic and vegetation conditions	This reach is more dynamic than the upper Middle Fork Reach, but stabilized by substantial reductions in peak flows, coarse sediment inputs, and local revetments. The channel is predominantly single thread with more bare, active gravel bars than upper segment. Bars range in size up to 6,000 m^2. Some channel shifting was observed in recent years near FPKMs 0, 4-7 and 15. The narrow active channel with few active gravel bars has limited cottonwood recruitment and decreased spatial heterogeneity of riparian plant communities. Vegetation consists mainly of mature trees along the channel margins and covering relict gravel bars.
Pragmatic goal for monitoring based on present day (ca. 2015) conditions	This lower reach displays more dynamism than the upstream reach, but is still relatively stable. Monitoring could focus on determining streamflows needed to maintain existing channel complexity and side channel/floodplain connectivity, and assessing cumulative effects of environmental flows, restoration strategies, and sediment delivery from annual drawdown operations at Fall Creek Reservoir.
Monitoring zones that are presently dynamic	FPKM 3-4 near the TNC Confluence site has bare, actively shifting bars and side channels and ongoing bank erosion.
Monitoring zones with mature vegetation and relict side channels that may respond dynamically to future high flows	FPKM 7 has a large bar with moderately dense vegetation established after the 1996-7 floods. This bar could be more easily mobilized by future high flow pulses than other areas with denser, more mature vegetation. FPKM 111 also has surfaces mobilized by 1996-97 floods, along with relict side channels.
Hydrologic and hydraulic response considerations	Inundation monitoring could focus on extent and duration of side-channel connectivity and newly connected floodplain inundation at different flows and could incorporate TNC monitoring efforts at the Confluence site. Streamflow in this reach is adequately represented by the USGS gage at Jasper (14152000)
Geomorphic response considerations	Repeat mapping of active channel in 2005 and 2011 by UO provides baseline datasets for evaluating future changes. Substantial sediment delivery from the drawdown of Fall Creek Reservoir in 2011-2015 obscures the effects of environmental flow releases. Priority tasks include: 1) assessing effects of Fall Creek sediment delivery; 2) evaluating changes in bed elevation; and 3) tracking changes in bare bars, and surfaces re-set by floods of 1996-7, as this will provide indication of future dynamism under current flow and sediment conditions.
Vegetation response considerations	Vegetation monitoring could focus on: 1) tracking vegetation recruitment and establishment along the new bars near FPKM 3-4, 2) tracking evolution of vegetation established after the 1996-1997 floods, and 3) calculating discharge needed to erode mature forest throughout the reach.
References	Gregory and others (2007); Dykaar (2005, 2008a, 2008b); Wallick and others (2013); Jones and others (in review)

Reach name and boundaries	**Upper McKenzie River:** Hayden Bridge to Dearhorn (FPKM 14-35; reaches 9, 10, 11 from Risley and others, 2010)
Hydrologic alteration and streamflow conditions	Regulation has reduced small flood (2-year recurrence interval) discharge at Vida gage (15 km upstream of reach) from 28,740 ft^3/sec to 17,210 ft^3/sec and large floods (10-yr recurrence interval) from 40,320 ft^3/sec to 27,400 ft^3/sec. Seven-day minimum annual streamflow increased 122 percent at Coburg gage after regulation; 125 percent at Vida gage. Small and large floods nearly eliminated in regulated era; daily mean streamflows at Vida have exceeded bankfull estimate of 20,000 ft^3/sec in only 5 years during 1969-2008 period.
Geomorphic and vegetation conditions	The channel is predominantly single-thread, with a combination of more dynamic sections and sections stabilized by revetments and naturally resistant bank materials. Floodplain surfaces are relatively low and easily inundated by 2yr recurrence interval flood (RDG, 2012a). Most of the reach is flanked by dense, mature riparian forest that varies from 300-700m in width, but dynamic areas like FPKM 19-24 have more patchy, diverse stands of vegetation at different seral stages.
Pragmatic goal for monitoring based on present day (ca. 2015) conditions	The existing channel complexity and relative dynamism of this reach make it a good candidate for evaluating year-round relationships between flow, geomorphology, and vegetation. Example goals might include determining flows necessary to: 1) inundate key side channels, 2) rejuvenate off-channel habitats, 3) recycle floodplains and re-set mature vegetation, and 4) support stand initiation and establishment.
Monitoring zones that are presently dynamic	Series of meander bends along FPKMs 19-24 have bare, actively shifting bars and side channels and limited revetment. The McKenzie Oxbow site near FPKM 25 is a long-term site for monitoring Oregon Chub, was studied by Jones and others (in review), and part of the area is managed for conservation by McKenzie River Trust.
Monitoring zones with mature vegetation and relict side channels that may respond dynamically to future high flows	FPKMs 19, 28 and 34 have secondary channels and low elevation bars that are mainly stabilized by mature forest. Limited revetment is in these areas. The Big Island site (FPKM 19) is a conservation site managed by McKenzie River Trust and other organizations and has baseline habitat and vegetation data.
Hydrologic and hydraulic response considerations	Two-year flood inundation maps shows widespread flooding between FPKMs 15 and 22, which differs from 1996 flood inundation patterns. Monitoring at multiple side channels could determine discharge when various off-channel habitats are inundated. Monitoring could target both newly formed and relict side channel areas. Discharge can be monitored using USGS streamflow gages on McKenzie River at Walterville (14163900), Hayden Bridge (14164900), and Coburg (14165500). Municipal and industrial withdrawals, including diversion of flow through the Walterville Canal, may influence summer streamflows.
Geomorphic response considerations	This reach has considerable channel complexity and lower elevation floodplains than the downstream reach. Monitoring could focus on: 1) repeat mapping to track morphologic changes and evaluate future losses and gains in riparian habitats, 2) determining discharge necessary to scour and rejuvenate off-channel areas that are presently or historically dynamic, and 3) evaluate future changes in bed elevation.
Vegetation response considerations	Several areas along this reach appear to support all phases of stand initiation and vegetation succession. (as described by Jones and others, in review). Future detailed, field-based studies at sites like FPKMs 19-24 could build upon these initial findings to evaluate conditions necessary for stand initiation, establishment and succession in different settings and findings could potentially be transferable to other sites along the McKenzie River and other tributaries.
References	Risley and others (2010); Wallick and others (2013); Jones and others (in review)

Reach name and boundaries	**Lower McKenzie River:** mouth to Hayden Bridge (FPKM 0-14; reaches 10, 11 from Risley and others, 2010)
Hydrologic alteration and streamflow conditions	(See section for Upper McKenzie River)
Geomorphic and vegetation conditions	Predominantly single-thread channel with few active gravel bars; somewhat dynamic by mouth, but elsewhere reach is stable due to local geology or revetments. Secondary channels most numerous at mouth and near FPKM 9. Floodplain relatively high compared to active channel with limited overbank flooding from 2-yr recurrence interval flood. The reach mainly contains of areas devoid of trees or areas where channel is flanked by dense, mature forest corridor that is up to 600m in width; there are very few areas with young or patchy vegetation. Cottonwood recruitment is limited by few bare bars for stand initiation, and most bare bars appear frequently re-set by high flows that hinder the establishment of young vegetation.
Pragmatic goal for monitoring based on present day (ca. 2015) conditions	Given current reach stability, monitoring could be used to evaluate whether environmental flows are maintaining and rejuvenating existing channel complexity. Monitoring is also needed to track potential losses in habitats and evaluate incision.
Monitoring zones that are presently dynamic	The Springfield Oxbow site near FPKM 8 is an excellent candidate for future monitoring because it has large, actively shifting bars flanked by stable mature vegetation, and is managed by McKenzie River Trust (MRT) who have been overseeing other monitoring at the site (J. Lemmer, MRT, oral commun. April 1, 2015). Dynamic areas in FPKM 0-5 are constrained by bank stabilization near gravel mining operations.
Monitoring zones with mature vegetation and relict side channels that may respond dynamically to future high flows	FPKM 5 and 7 have low elevation bars with mature vegetation that may get re-set by high flows. FPKM 7 has relict side channels.
Hydrologic and hydraulic response considerations	Much of floodplain is relatively high in elevation (compared to channel) and may not be inundated by 2-yr recurrence interval flood (RDG, 2013). Monitoring could confirm inundation patterns and identify key side channels that are inundated at different magnitude flows. Discharge can be evaluated using USGS streamflow gage at Hayden Bridge (14164900) in combination with flow inputs from Mohawk River (ungaged) and withdrawals for municipal and industrial uses.
Geomorphic response considerations	This reach has experienced substantial historical incision, which could influence current and future habitat availability. Priority tasks include: 1) reach-wide repeat mapping to track changes in channel features like bars and off-channel habitats and 2) monitoring bed elevation along entire reach and in select side-channels.
Vegetation response considerations	Currently there appears to be limited recruitment of young stands of riparian vegetation in this reach; therefore, detailed monitoring could focus on the upstream reach. More basic analyses (like mapping surfaces suitable for stand initiation) could be used to identify key factors limiting vegetation recruitment in this reach and determine how environmental flows may improve these limiting factors.
References	Risley and others (2010); Wallick and others (2013)

Reach name and boundaries	**South Santiam River:** below Lebanon (FPKM 0 - 20; reach 6 from Risley and others, 2012)
Hydrologic alteration and streamflow conditions	Regulation has reduced small flood discharge (1.5 year recurrence interval) at the Waterloo gage from 31,500 ft^3/sec to 14,200 ft^3/sec and large floods (10 year recurrence interval) from 65,600 ft^3/sec to 20,900 ft^3/sec. Seven day minimum annual streamflows have increased 335 percent after regulation. Prior to regulation, bankfull flows (18,000ft^3/sec at Waterloo) were exceeded about 4 days per year, but between 1967-2011, bankfull flows occurred less than once every 5 years. One flood (Feb 6 1997; 24,200 ft^3/sec) occurred within the regulation era.
Geomorphic and vegetation conditions	Predominantly single-thread channel with stable meander bends flanked by revetments; few side channels or active gravel bars except below confluence of Thomas and Crabtree Creeks. Much of the reach is stabilized by extensive revetments. Several individual bends near FPKM 10-11 have large (>10,000 m^2), active bars indicating active meander migration. Riparian vegetation varies from channel segments flanked by revetments and agricultural lands to segments like FPKM 10-12 where the riparian forest is 300-700 m wide. Most of forested areas are densely vegetated with mature trees and little spatial heterogeneity. The combination of few bare gravel bars and abundant mature trees indicate limited recruitment of young forest stands; exceptions include near FPKM 10-11 where bands of even-aged young woody vegetation indicate successful recruitment and succession with progressive meander growth.
Pragmatic goal for monitoring based on present day (ca. 2015) conditions	Given extensive revetments, and limited coarse sediment transport, this reach may be prone to incision and substrate coarsening during high flows. Alternatively, high flows could erode forested bars and enhance channel complexity. Monitoring could verify that environmental flows are enhancing existing habitats while minimizing negative impacts like incision.
Monitoring zones that are presently dynamic	FPKM 0-5 near confluence of Crabtree and Thomas creeks has active gravel bars and some active side channels. FPKM 11-12 has large bars and actively shifting meander bends.
Monitoring zones with mature vegetation and relict side channels that may respond dynamically to future high flows	Series of meander bends along FPKM 10-11 have wide (500m) corridor to migrate between revetments and relict side channels. Stabilizing vegetation could be reset by future erosion.
Hydrologic and hydraulic response considerations	Flood inundation will likely be restricted to riparian forest corridor (based on extent of 1996 flood inundation). Streamflows in this reach can be evaluated using the USGS streamflow gage at Waterloo (14187500; 10-km upstream of reach) and accounting for withdrawals from the Lebanon-Albany canal. Monitoring below FPKM 5 should account for inputs from USGS gage on Thomas Creek and Crabtree Creek (which is ungaged).
Geomorphic response considerations	High priority tasks for this reach would include: 1) monitoring habitats and channel change through repeat mapping off-channel features in dynamic areas to track losses and gains in off-channel habitats and 2) monitoring channel incision along the entire reach, but especially in dynamic areas where incision could reduce access to off-channel habitats.
Vegetation response considerations	The main factors limiting vegetation recruitment are poorly understood along this reach, but once these factors are better understood, future monitoring tasks could be tailored accordingly. For example, there are some areas of active meander migration that could support vegetation recruitment, but it is currently unclear whether recruitment is limited by high flows that re-set young vegetation or if flows during spring and summer limit recruitment.
References	Risley and others (2012); Wallick and others (2013)

Reach name and boundaries	**North Santiam River:** below Stayton (FPKM 0-36; reach 3 from Risley and others, 2012)
Hydrologic alteration and streamflow conditions	Regulation has reduced small flood discharge (1.5 year recurrence interval) at Mehama gage from 28,500 ft^3/sec to 17,800 ft^3/sec and large floods (10 year recurrence interval) from 58,300 ft^3/sec to 32,700 ft^3/sec. Seven day minimum annual streamflows have increased 95 percent after regulation. Prior to regulation, flow exceeded bankfull threshold (17,000 ft^3/sec) 3-4 days per year, but since 1952, bankfull flows occur slightly less than once per year. Floods occurred twice within the regulated era (Dec 22 1964 and Feb 7 1996) when peak flows were 36,200 and 46,700 ft^3/sec (respectively).
Geomorphic and vegetation conditions	This reach is more dynamic than other reaches with active meander migration and avulsions, especially between FPKMs 5-12. Revetments and resistant Pleistocene terraces limit local bank erosion in areas. There are extensive multi-channeled segments alternating with single-thread segments and a diverse array of secondary channels ranging from recently formed alcoves to more stable side channels. The reach has numerous active gravel bars ranging up to 60,000m^2, especially between FPKM 5-12; these are larger and more numerous than other study reaches. Aerial photographs indicate many areas with active vegetation recruitment and different ages of riparian forest. Channel dynamism on this reach creates more opportunities for cottonwood recruitment.
Pragmatic goal for monitoring based on present day (ca. 2015) conditions	Presently, the lower portion of the reach (FPKM 0-17) is relatively dynamic compared with other reaches, and a diverse array of habitats appear to be created and maintained under current conditions. Monitoring is needed to ensure that environmental flows will enhance geomorphic processes and all stages of vegetation succession so that this reach will continue to support diverse habitats in future.
Monitoring zones that are presently dynamic	FPKM 5-10 is the most dynamic of the whole reach, with continuous, large actively shifting gravel bars and numerous active side channels. Other segments like FPKM 17 also have bare bars and active bank erosion.
Monitoring zones with mature vegetation and relict side channels that may respond dynamically to future high flows	Much of the reach has minimal revetment, extensive relict side channels, and mature vegetation, but FPKM 17 and 25 are good candidates for monitoring because they have some bar growth and erosion. FPKM 17 coincides with a portion of the Chahalpam conservation site.
Hydrologic and hydraulic response considerations	Streamflows in this reach can be evaluated using the USGS streamflow gage at Mehama (14183000). Monitoring needs to account for irrigation and municipal water withdrawals which significantly influence summer streamflows. Flood inundation will likely be restricted to main channel and side channels (based on 1996 flood extent), but monitoring could help establish magnitude of discharge needed to inundate different types of side channels.
Geomorphic response considerations	Although this reach has experienced more dynamism than other reaches, the main channel in FPKM 5-10 is presently flowing along resistant Pleistocene terrace which could exert a stabilizing influence on channel morphology (Wallick and others, 2006). Repeat mapping of channel change and bank erosion would help verify that this segment is continuing to create and renew a diverse array of riparian habitats.
Vegetation response considerations	The North Santiam is a good reach to monitor all phases of vegetation recruitment and succession because there are many areas (such as FPKM 5-10) with vegetation at different seral stages. Channel dynamism in this reach makes this a good candidate for evaluating the hydraulic conditions necessary to re-set different stages of vegetation.
References	Risley and others (2012); Wallick and others (2013)

Reach name and boundaries	**Santiam River:** mouth to confluence of North and South Santiam Rivers (FPKM 0-11; reach 7 from Risley and others, 2010)
Hydrologic alteration and streamflow conditions	Regulation has reduced small flood discharge (1.5 year recurrence interval) at Jefferson gage from 62,400 ft^3/sec to 44,200 ft^3/sec and large floods (10 year recurrence interval) from 152,000 ft^3/sec to 102,000 ft^3/sec. Seven day minimum annual streamflows have increased 237 percent after regulation. Prior to regulation, bankfull flows (35,000 ft^3/sec at Jefferson) were exceed more than 7 days per year; but between 1953-2011, daily flows exceeded bankfull only about 4 times per year. There have been at least 4 floods exceeding 62,000 ft^3/sec since full regulation in 1967, including the Feb 7, 1996 flood of 115,000 ft^3/sec.
Geomorphic and vegetation conditions	This is a single thread channel with an extensive network of relict side channels along the entire reach. Active gravel bars are sparse except near FPKMs 0 and 7 where there are large active gravel bars. The narrow active channel with few active gravel bars and extensive revetment has limited cottonwood recruitment and decreased spatial heterogeneity of riparian plant communities. Although there are a few bare bars for vegetation recruitment, these surfaces are frequently mobilized, limiting cottonwood recruitment. Dense riparian forest varies from 400-700m in width and mainly consists of mature trees along the channel margins and relict bars, except for FPKM 0 where there are low bar surfaces with vegetation of varying ages.
Pragmatic goal for monitoring based on present day (ca. 2015) conditions	Monitoring could focus on determining level of flow needed to maintain and enhance existing habitats. For example: 1) inundate and rejuvenate relict side channels, 2) re-set mature vegetation on gravel bars, and 3) transport gravel and rejuvenate aquatic habitats like alcoves.
Monitoring zones that are presently dynamic	FPKM 0-3; bare bars and areas of active veg recruitment and succession.
Monitoring zones with mature vegetation and relict side channels that may respond dynamically to future high flows	FPKM 0-5 has numerous relict side channels and forested bars that may be sensitive to future flow fluctuations. FPKM 1 has low elevation bar with moderate vegetation and older alcoves.
Hydrologic and hydraulic response considerations	Overland inundation on broad, low elevation floodplain areas is affected by flow from the Willamette River, so inundation monitoring could focus on key side channels. Gage at Jefferson (14189000) is sufficient for evaluating discharge on entire reach.
Geomorphic response considerations	Priority tasks for this reach include: 1) repeat mapping of channel features from LiDAR or air photos, 2) repeat surveys of key side-channels to determine if they are filling with sediment, and 3) evaluate changes in bed elevation through repeat surveys to assess incision of main channel.
Vegetation response considerations	Vegetation monitoring could target dynamic monitoring zones where stand initiation and establishment are most likely to occur. Vegetation in this reach may especially benefit from the spring and summer flow prescription, so monitoring is needed to evaluate responses in this period.
References	Risley and others (2012); Wallick and others (2013)

Appendix B. Summary of existing monitoring data and outstanding data gaps

There are multiple ongoing data collection efforts by other agencies and organizations that could compliment the monitoring approaches outlined in this document. To our knowledge, existing efforts would not be redundant with the activities described in this report, but rather could be used to in conjunction with findings from these activities to evaluate ecological responses to environmental flows. Some key examples of monitoring efforts that are likely to persist into the future and have direct linkages to the habitats and processes of interest to the Willamette SRP are summarized below. This list is not exhaustive, and could be re-evaluated when developing reach-specific monitoring plans. An approach for maximizing efficiencies between different agencies and groups is described by Podolak (2012).

1. Oregon Chub monitoring conducted by Oregon Department of Fish and Wildlife (ODFW) is collecting an array of data to evaluate the floodplain slough ecosystems utilized by Oregon Chub. Data collection includes repeat surveys, water quality, water elevation, and fish communities at numerous sites throughout the SRP study area (Brian Bangs, ODFW Fish Researcher, written commun., Feb. 2014). These floodplain sloughs also provide key habitat for other important species like juvenile Chinook salmon, red-legged Frogs, and western pond turtles. Because ODFW monitoring will likely continue through 2023, these sites could be logical places to establish permanent floodplain transects for monitoring environmental flows.

2. The ODFW Willamette Salmonid Research, Monitoring and Evaluation Program evaluates juvenile life histories throughout the study area. As part of this work, the program periodically collects information on spawning sites, juvenile rearing habitats, and other information that would complement the hydraulic, geomorphic, and vegetation monitoring strategies outlined in this framework. Future environmental flow research in the Willamette Basin could aim to partner with ODFW to evaluate how fish are utilizing habitats shaped by the environmental flow releases (Tom Friesen, Program Manager, ODFW, writ. commun. Feb. 3, 2016). More information on this program is available at: *http://oregonstate.edu/dept/ODFW/willamettesalmonidrme*.

3. The USGS collects water quality and stream temperature data at streamflow gages throughout the study area. Continuous temperature measurements are available for each of the key streamflow gages in the study area (Figures 3-6; Appendix A) and other parameters like turbidity, dissolved oxygen, pH, and specific conductance are available at select sites (more information for each gage is available at: *http://waterdata.usgs.gov/or/nwis/rt/*)

4. The Nature Conservancy monitors stream temperatures, native fish, vegetation, and other parameters at its Confluence Island Preserve on the Middle Fork Willamette River (FPKM 2-3,

Figure 3). This site has also been used for other SRP monitoring (Jones and others, in review) and has been identified as high priority monitoring zone for future studies.

5. The McKenzie River Trust (MRT) oversees multiple properties along the McKenzie River and has baseline data on vegetation and habitat characteristics for these sites in addition to routine monitoring of site conditions. Because of their unique habitats and conservation status, these sites would make good candidates for long-term monitoring as part of the Willamette SRP (Jodi Lemmer, McKenzie River Trust, writ. commun., May 28, 2014).

6. The USACE operates pressure transducers along the Middle Fork Willamette River. Data generated from this program could be used to document the spatial pattern and magnitude of inundation associated with different magnitude flood events. Additional sites may be added along other rivers in the future (Jim Burton, USACE, writ. commun., May 23, 2014).

7. Watershed councils in the Santiam, McKenzie, and Middle Fork Willamette Basins may have baseline information and ongoing monitoring data that could inform the Willamette SRP. However, most of this monitoring is very site specific and may not coincide with the monitoring zones identified in this study. Examples of potentially useful monitoring information collected by watershed councils include water quality, macroinvertebrate, and riparian vegetation data gathered in the Santiam Basin by the South Santiam Watershed Council (Eric Anderson, South Santiam Watershed Council, writ. commun., May 20, 2014). The watershed councils also has in-depth knowledge of local habitat conditions and close working relationships with landowners and resource agencies, so they would be logical partners for future research and monitoring (R. McCoun, North Santiam Watershed Council, oral commun. Oct 2, 2015)

8. The Biological Opinion developed for the Willamette River Basin Flood Control Project (NOAA Fisheries, 2008) specifies a comprehensive Research Monitoring and Evaluation (RME) program to collect information needed for adaptive management of ESA listed fish populations and to track progress toward objectives specified in the Biological Opinion. RME research is intended to “inform decisions regarding the effectiveness of mitigation measures in the Proposed Action and Reasonable and Prudent Alternatives, including alternatives for downstream flows and ramping, fish passage, water quality, hatchery program operations, habitat restoration and other measures” (NOAA Fisheries, 2008, pg 9-83). To date, RME research has not been targeted by the SRP program, although some RME projects (such as studies to evaluate flows suitable for spawning) can directly inform the SRP process.

9. Hydraulic models have been developed for several of the rivers in the study area that could be updated and used to inform the Willamette SRP. For example, on the North Santiam River, USGS developed a HEC-RAS model for evaluating low flows (Stonewall and Buccola, 2015). This model would need updates in order to model floods, but would be suitable for evaluating

inundation patterns during spring and summer months. Smaller reaches have been developed for specific projects (for example modeling to inform restoration alternatives at the Chahalapam site on the North Santiam River; Troy Brandt, River Design Group, oral commun. Jan.7, 2015). Hydraulic models have also been developed for sections of the Middle Fork Willamette River by Tetra Tech (Ryan Kilgren, Tetra Tech, writ.commun. Jan. 15, 2016) and McKenzie Rivers by the USACE.

10. There are multiple sources of site-scale surveys collected by other organizations that would complement reach-scale repeat surveys described in this study. For example, Oregon Department of Transportation conducts routine surveys and scour assessments at several bridges in the study area. These cross-section based surveys are typically conducted every 1 to 5 years, and are useful for evaluating year-to-year changes in channel geometry (Jones and others, 2012a,b,c). Other sources of information to evaluate incision and aggradation include surveys conducted to support ecological assessments, stream restoration, infrastructure, or flood mitigation. For example, on the Middle Fork Willamette River, ODFW has repeat surveys of numerous off-channel habitats (Brian Bangs, ODFW, writ. commun., February 2014) and TNC has surveyed bathymetry near their Confluence Island Preserve site. Other organizations and municipalities could also be contacted to build a dataset of existing surveys, which could be periodically updated and reviewed as new data is collected. However, a challenge with utilizing multiple sources of survey data is to ensure that each dataset is referenced to a common vertical datum and meets certain standards for accuracy.

11. The Eugene Water and Electric Board (EWEB) has developed the Voluntary Incentive Program (VIP) to help protect drinking water quality in the McKenzie Watershed (*http://www.eweb.org/sourceprotection/vip*). A robust monitoring program will be developed to track progress towards program objectives, and preliminary discussions indicate that the SRP and VIP monitoring programs share many common elements, so there may be areas for future collaboration to ensure cost-efficiencies for both programs (K. Morgenstern, oral commun. April 2, 2015).

12. Changes in streambed elevation can be evaluated through specific gage analyses at USGS streamflow gaging stations whereby changes in water surface elevation for a particular discharge can indicate incision or aggradation. Specific gage analyses for rivers described in this study were originally developed by Klingeman (1973) and updated by Wallick and others (2013). These analyses could be updated every 5-10 years to determine trends.

13. Oregon State University (OSU) Department of Fisheries and Wildlife has led a long-standing program to sample and assess native fish communities along the Willamette River and its floodplain. In the summer of 2015, the program was extended to the major tributaries below USACE dams. Data from this research program can be viewed through the Willamette River

Fish Database, which provides information on the abundance and locations of native and non-native fish species. At each sampling site, habitat conditions (including variables like water depth, stream temperature, substrate, and riparian cover) are also recorded and published in the database. The OSU native fish research program thereby provides baseline data from which to measure future changes that may relate to a wide variety of influences, including dam operations. The SRP monitoring program could aim to partner with OSU so as to coordinate data collection activities and explore options for expanding the relationships between flows and geomorphic and vegetation responses (described in this report) to also include native fish communities. More information is available: *http://gis.nacse.org/wrfish/index.php*

14. The University of Oregon (UO) and OSU have developed the SLICES framework as a spatial template for tracking changes in the floodplain. The spatial framework delineates the historical floodplain into a series of 1km transects orthogonal to the floodplain axis, providing a static template for tracking changes in key aspects of the floodplain system. To date, GIS coverages of floodplain forest cover, channel complexity, two-year flood inundation, and cold water refuges have been developed and overlain on the SLICES framework, and all datasets are publicly available through a user-friendly web interface. As of early 2016, the SLICES framework is focused on the mainstem Willamette River, but expansion of these key spatial datasets to the Middle Fork Willamette, McKenzie, and South, North, and mainstem Santiam Rivers will likely be completed in the near future. The SLICES framework, together with reach-scale maps of channel complexity and floodplain forest cover, provide a framework for long-term status and trends monitoring. If a program is established to update SLICES datasets at decadal intervals, this effort could be executed in conjunction with the decadal-scale, reach-wide mapping of floodplain vegetation and channel features proposed in this monitoring framework. The SLICES framework could also potentially be used to store and share some of the SRP spatial datasets. Because many of the SRP monitoring activities are closely aligned with the status and trends monitoring datasets housed in the SLICES framework, the SRP monitoring program could aim to coordinate data collection and mapping activities with the UO and OSU. More information is available at: *http://ise.uoregon.edu/slices/main.html*

15. The Confederated Tribes of the Grande Ronde manages a large (more than 400 ac) parcel of land known as Chahalpam Wildlife Area on the North Santiam River. This property is managed for conservation and several restoration-related activities are underway, including habitat, vegetation, fish, and wildlife surveys; ODFW Chub research; and hydraulic measurements and modeling that are used to inform restoration strategies. The site also has suitable geomorphic and vegetation characteristics (namely broad floodplain with minimal revetments, diverse array of geomorphic surfaces, and stands of riparian vegetation). These characteristics, together with conservation status, make it an ideal candidate for future monitoring under the SRP program and The Grande Ronde Tribe is supportive of future SRP research taking place at this site (Lawrence Schwabe, Tribal Hydrosystems Compliance Specialist, oral commun., Aug. 27, 2014).

Appendix D

USGS 2014-2015 flow monitoring study–future considerations (2016)

Appendix A. Environmental Flow Monitoring Considerations for the Sustainable Rivers Project in the Willamette River Basin.

Table A-1. Future monitoring considerations related to streamflow.

[SRP, Sustainable Rivers Project; USGS. U.S. Geological Survey]

Streamflow monitoring considerations	Rationale
Compare observed streamflows with SRP flow recommendations	Analyses for Task 1 assessed whether streamflow magnitude exceeded SRP recommendations for WYs 2000–15. These analyses did not directly address flow duration, number of events per year, rate of change, spring flow recession, and seasonal flow conditions, all of which are important metrics for evaluating success toward meeting the SRP geomorphic and ecological goals. Quantitatively examining these types of flow metrics and making those analyses publically available would support flow implementation and adaptive management.
Determine geomorphically effective flow thresholds for the McKenzie River	This study identified geomorphically effective flow thresholds for the Middle Fork Willamette River. We were unable to determine similar flow thresholds for the McKenzie River because repeat channel mapping was done for a small reach that is not representative of the streamflow, coarse sediment inputs, and channel stability conditions throughout the entire alluvial section of this river. Comprehensive repeat mapping and field observations of the alluvial section of the McKenzie River are needed to determine geomorphically effective flow thresholds for this river.
Develop an approach for ranking flow events that do not meet SRP flow recommendations	Flow events can be geomorphically effective even if they do not exceed SRP flow recommendations in magnitude or timing. A methodology for characterizing these types of flows would inform SRP implementation, and provide the data needed for adaptive management and flow recommendation refinements.
Identify flow thresholds for synergy between flow events	Channel changes from the repeat mapping indicate that there may be cumulative and synergistic geomorphic effects resulting from sequential bankfull events. This is because the first event can scour vegetation and initiate new channels, essentially “priming” the floodplain for easier scour and notable reworking by sequential high-flow events. If periodic, sequential flow events maintain geomorphic complexity and dynamism, then SRP flow recommendations may not need to be met every year to provide the intended geomorphic and ecological benefits.
Collect stage and discharge data throughout the alluvial reaches in other years and seasons	SRP flow recommendations for inundation are based on discharge at USGS streamgages. If we could relate discharge and stage throughout the alluvial sections, then we could identify the channel and floodplain features that are inundated at specific discharges, assess the associated inundation effects on the recruitment of black cottonwood, and determine surface water connections between the mainstem, secondary, and floodplain channels. This study collected stage data at two sites from June to August 2015 on these rivers. More stage data collected over a range of flows and more locations are needed to develop robust stage-discharge relations.

Table A-2. Future monitoring considerations related to channel and vegetation mapping.

[SRP, Sustainable Rivers Project]

Mapping monitoring considerations	Rationale
Complete mapping of the alluvial section of the McKenzie River	This study mapped a short section of the McKenzie River that is not representative of the streamflow and sediment conditions throughout the alluvial section of the McKenzie River. Thus, mapping of the entire alluvial section is needed to determine thresholds for geomorphically effective flows. A logical starting point would be to map the alluvial section of the McKenzie River using the 2005, 2011, and 2012 aerial photographs and adding more photographs as needed.
Improve vegetation data in the mapping datasets	Mapping datasets produced by this study can be improved with field verification to classify vegetation types and age classes. These datasets would provide baseline datasets for future monitoring, assessments of vegetation, and tracking vegetation growing on bars in relation to SRP flow implementation.
Refine mapping of floodplain channels	Floodplain channels, such as sloughs and old secondary channels, are key habitats for Oregon chub, juvenile spring Chinook salmon, red-legged frogs, and other native species. However, channel stability limits the creation of new floodplain sloughs. There is no accurate inventory of current features, their dimensions, and their changes over time. Mapping for Task 2 showed that aerial photographs are not the best dataset for mapping these channels where the forest canopy is dense. Lidar would be a logical dataset for mapping the location and area of these landforms, whereas water-penetrating bathymetric lidar would be even better because it also provides the water depth (down to about1.5 meters).
Delineate channel and floodplain features from future aerial photographs	Additional mapping from aerial photographs taken before and after different types of flood events in low-flow and high-flow years would be helpful to document the range of geomorphic and vegetation responses to individual and sequential flow events, to refine the geomorphic thresholds for channel change and habitat creation, and to relate these changes to SRP flow implementation and success toward program goals.

Table A-3. Future monitoring considerations related to geomorphology and sediment

[SRP, Sustainable Rivers Project]

Geomorphology and sediment monitoring considerations	Rationale
Develop a coupled framework linking a bed-material budget with estimates of transport capacity	SRP flow recommendations focus on discharge magnitude and timing, which influence the supply and movement of bed material and values of transport capacity. Changes in bed-material transport and transport capacity can cause aggradation, incision, bed armoring, and changes in channel width. We do not have a framework for evaluating streamflow effects on these two variables in the Willamette River Basin. An efficient approach would be multi-faceted: (1) sediment volumes from Fall Creek Lake and reach aggregated bank erosion are computed using lidar differencing, (2) sediment transport rates are inversely computed using a "morphological approach," and (3) transport capacity is computed from equations of bed-material transport using a hydraulic model (Wallick and others, 2010).
Make repeat bed elevation surveys of channel and floodplain features to document patterns of aggradation and incision	Substantial increases or decreases in bed elevations can affect habitat restoration and infrastructure. Incision is a distinct possibility for bed-material limited rivers, such as the Middle Fork Willamette, and may lessen channel complexity. In contrast, fine sediment aggradation is the primary concern for floodplain sloughs where gradual filling will decrease flood storage and habitat for Oregon chub, red-legged frogs, and juvenile salmon. Incision and aggradation can be documented using repeat longitudinal profiles or water-penetrating lidar. Such data would be helpful for documenting reach-wide patterns of aggradation and incision, verification of the sediment budget and transport capacity framework, and tracking channel elevation changes over time.
Determine extent and integrity of natural and anthropogenic features controlling meander migration and channel avulsion	Meander migration and channel avulsion are an important geomorphic process for creating new gravel bars and secondary channel features, such as alcoves. Natural, non-erodible features, such as bedrock and Pleistocene gravel outcrops, as well as revetments and levees limit meander migration along the alluvial sections of the Middle Fork Willamette and McKenzie Rivers. Effort is needed to determine the extent and integrity of privately owned revetments and naturally resistant banks along these rivers and their associated effects on geomorphic and habitat responses to streamflows.

Table A-4. Future monitoring considerations related to black cottonwood and other vegetation.

[SRP, Sustainable Rivers Project]

Black cottonwood and invasive plant monitoring considerations	Rationale
Collect vigor data for black cottonwood and other plants early and later in the growing season and after high flows	We observed 190 seedlings and clones from vegetative sprouts from June to August 2015. We do not know if these black cottonwoods will survive the growing season and scouring in winter 2015–16. Repeat monitoring in 2016 would provide data on the survival of these plants. Also, it would help us evaluate whether or not clones are a more viable recruitment pathway than seedlings. We hypothesize that cottonwood clones may have a temporal and height advantage over seedlings because (1) clones can grow before seed release; (2) can draw on stored energy and moisture to survive drought, pest, and browsing stress; and (3) can grow rapidly and outpace shading by invasive plants. Future monitoring would benefit from revisiting the transects of this study and adding more transects on various bar types in geomorphically dynamic and stable zones along the alluvial sections of these rivers.
Continue to assess interactions between black cottonwood and invasive plants	We observed large coverages of marshpepper knotweed, white sweet clover, and bird's-foot trefoil that often were collocated with black cottonwood seedlings and clones in the monitoring transects. These invasive plants did not appear to suppress entirely the growth of black cottonwood. Conditions of when invasive plants do and do not suppress black cottonwood warrant further investigation.
Create an inventory of black cottonwoods and other plants in the alluvial sections of the Middle Fork Willamette and McKenzie Rivers	An inventory of black cottonwoods would help us identify existing stand locations and age classes, relate stands to streamflow and channel conditions (past and present), and verify whether vegetation mapped in Tasks 2 and 3 is composed primarily of native or invasive plants. This inventory could be repeated over time to assess the persistence of younger black cottonwood stands and other plants in relation to SRP flow implementation.
Track fine sediment releases from Fall Creek and relations with black cottonwood and invasive plants	Future drawdowns of Fall Creek Dam for fish passage will contribute fine sediment to the Middle Fork Willamette River. These inputs have ecological benefits, such as creating burrowing habitats for larval lamprey. They also may support black cottonwood and invasive plants when deposited on high elevation surfaces that are dry in the summer. Understanding the linkages between fine sediment releases, black cottonwood, and invasive plants would be helpful in identifying combinations of drawdowns and streamflow regimes that may benefit native plants instead of invasive plants.

Appendix E

Adaptive Management Workshop Minutes (March 2016)

Sustainable Rivers Project 2016 Workshop

Meeting Notes

When: March 31st, 11:30am to 4:00pm

Where: USACE Portland; 333 SW 1st Ave, 97204 BLDG 300

Attendees:

- Christine Budai, USACE, Project Manager
- Keith Duffy, USACE, H&H, Technical Lead
- Alex Farrand, ODFW, Biologist
- Zach Freed, TNC, H&H BioHydrologist
- Krista Jones, USGS, Hydrologist
- Elise Kelley, ODFW, Biologist
- Jason Nuckols, TNC, Willamette Basin Program Manager
- Melsissa Olson, TNC, Willamette Confluence Land Steward
- Rich Piaskowski, USACE, Fish Biologist
- Greg Taylor, USACE, Willamette Valley Project Fish Biologist
- Tina Teed, USACE, Water Management regulator
- Dan Turner, USACE, Water Quality Biologist
- Mary Karen Scullion, USACE, water management regulator
- Rose Wallick, USGS, Hydrologist and Geomorphologist
- Jeff Ziller, ODFW, Biologist

<u>WORKSHOP GOALS</u>:

1) Update participants on the status of Willamette SRP
    a. Explain E-flow strategies
    b. Share Analyses of E-flows
2) Solicit Feedback on Future Monitoring and Adaptive Management
3) Solicit Feedback on Possible Future Trainings for Operators and Regulators

<u>MEETING THEMES</u>

- Two questions recurred during the meeting.
    - What are the priorities for implementing e-flows across the system?
    - How are we defining success of e-flows?
- Objective e-flows were different between the original workshops and the Implementation Memorandum for the Record (MFR).
    - MFR focused on wintertime flood and spring bankfull flows.

    - Fall and summer low flows were not included in prescribed e-flow operations because Willamette Biop flows were greater than SRP workshop flow targets and fall flows had been tried previously and determined to be detrimental to redds as well as being too 'unnatural' in practice.
    - MFR e-flow target flow locations were developed for the regulators use, but specific monitoring sites, to comprehensively show benefit, will likely be more comprehensive.

- Future funding for SRP monitoring and adaptive management tasks is not assured.
    - Therefore, a strong monitoring and adaptive plan framework are required to support funding requests.
    - Collaboration and cooperation with regional stakeholders and with other projects in the Valley are integral to sustaining the SRP efforts in the future. Examples cited were:
        - Willamette Basin Review
        - ODWFW spawning monitoring, etc.

- There was a stated need for prioritization of basins and reaches based on monitoring metrics.
    - Regulators need prioritization for implementing e-flows of highest importance so they know what to implement when given choices.
    - To prioritize, there was a stated need to identify stable and unstable channel reaches.
- Preliminary feedback on basin prioritization was that:
    - McKenzie shows the most promise then the North Santiam and finally the Middle Fork.
    - McKenzie reaches of most opportunity are: Leaburg to the confluence

- SRP training in terms of the program background and what flow targets to regulate to was reiterated as a need in the future.
    - Training of regulators and the new reservoir regulatory chief would be most helpful as first phase.
    - A second phase that includes operators could be done at a later date.

<u>WORKSHOP NOTES (CATEGORIZED BY ASSOCIATED AGENDA TOPICSs)</u>

<u>WORKSHOP AGENDA:</u>

1) *Review of Process and Milestones to date – 20 Minutes – Chris Budai*

2) *Summary of the Workshops' and the MFR's Objectives – 30 Minutes Total*
    a. *How MFR objectives were created – 10 minutes – Keith Duffy*
    b. *Differences between MFR and Workshop Objectives - 10 minutes – Zach Freed*
    c. *Clarification and Questions – 10 minutes*

Milestones and Process

- We are first in nation to have gotten to phase (1) implementation of e-flows in water control manuals.
- By the end of the year there could be up to 30 total SRPs, in addition to the 7 or 8 original projects.
- We are moving into the operational phase (2) in which monitoring and adaptive management will become key.
- That being said, Greg Taylor said that the biological connections aren't laid out well. We should:
    - Consider things holistic, not fish centric.
    - Fish biologists need to prioritize (reaches, species, etc.).

MFR Objectives and Differences

- Going into the discussion the flow objective evolution, it was shown that going from the SRP workshops to the MFR, there were differences in e-flow targets.
- It was pointed out that the MFR focused on the operational aspects, how regulator and use by water management would actually be able to implement.
- One question that arose was why it appeared that high flow targets that would not be practically implemented because of operational (e.g. flood risk management) constraints, were still included in the final objective e-flows.
- SRP workshops ecosystem objective flow targets focused on pre-dam flows and were relatively unconstrained by operational considerations.
- MFR focused on wintertime flood and spring bankfull flows. Fall and summer low flows were not included in prescribed e-flow operations because Willamette Biop flows were greater than SRP workshop flow targets and fall flows had been tried previously and determined to be detrimental to redds as well as being too 'unnatural' in practice.
- MFR flow target locations differed compared to the workshop.
- MFR locations consisted of operational significant locations such as release points and or control points.
    - In the MFR: Jasper was used on the Middle Fork; Cougar dam for McKenzie and Mehama for North Santiam.
    - The MFR also dropped the South Santiam basin as an e-flow implementation basin. The rationale at the time was that the South Santiam would not be significantly benefitted

    from e-flow would not be as effective with some operational constraints in that basin. The details of the reasoning should be specifically identified and documented.
  - Future e-flow operations in the South Santiam is not excluded but as yet unspecified profess for showing efficacy would have to be done before adoption by CENWP-EC-HR.
- The MFR and SRP workshops differ in the flow durations called for.
- The MFR indicates durations of 1, 3 and 4 days. Workshops typically were less, 1 day.
- MFR included duration and flow peak ranges for wintertime, denoted as 1-3 and for spring period was A-C.
- For the McKenzie River, questions arose and points were made concerning:
  - Higher target flows (6 kcfs) may be not be realistic.
    - Not sure what the ecological goals are.
    - Movement of gravel in gravel starved reaches are not good.
  - Monitoring needs to have realistic goals.
- And for the Middle Fork Willamette:
  - At 12 kcfs, there is gravel movement occurs based on boat trips by Greg T (popping sounds below boat when floating the river during high flows).
- It was explained that this was an outgrowth of the need to quantify the e-flow events achieved from a certain operational concept as well as determination that lower flow rate but greater duration was a benefit from wintertime floods and spring bankfull flows.
- A paper describing the workshops to MFR process is requested by the group that outlines the sequential progression and outlines the specific reasons for the changes, e.g. Willamette BiOp minimum releases being higher than workshop targets, issues with Fall releases and reasoning behind refinement of durations and flow ranges in the MFR during subsequent reservoir modeling. This was already started and would be added too and included in the adaptive management plan write-up.

<u>WORKSHOP AGENDA:</u>

3) Analysis of e-flows 2008-2015 – 60 Minutes Total
   a. Presentation – 30 minutes – Zach
   b. Questions to prompt discussion and feedback – 30 minutes
      1. Frequently these sustained flow targets were not met. Why? Should they be changed?
      2. Are we measuring flows at the correct locations?
      3. Do the duration and frequency criteria make sense ecologically and operationally?

E-flow Comparisons

- From the hydrograph presentation it was seen there were differences between the MFR flow targets being met versus workshop targets. This was primarily due to different event durations being used.
- This was leading us to believe that there is a need to further refine what durations are really beneficial (1 3 or 4 days, or 1, 2, 3 day etc.).
- MFR e-flow target flow locations were developed for the regulators use, but specific monitoring sites to show benefit will likely be more comprehensive.
- For example Salem+Albany flow hydrographs was thought useful to the group.
- Also it was stated that there was a need to identify stable and unstable channel reaches. Some channel profiles are steepening and losing gravels and sediment due to altered hydrologic

regimes (flows). If undesirable, it was stated there may be a need to determine flow based solutions or other ways to stabilize identified channels. For example, sediment augmentation, grade control etc.

- Overall, it was identified that a need exists for study and information that specifically tie the e-flow targets with specific and quantifiable geomorphic and biological beneficial effects.
- A need was identified to have good correlation between e-flow releases and likely inundation for quantifying e-flow benefits.
- There was a stated need for prioritization of basins and reaches based on monitoring metrics.

<u>WORKSHOP AGENDA:</u>

4) Monitoring Plans and Adaptive Management Plan – 80 minutes Total
  - *a) Summary of Ecological Priorities – 10 minutes - Keith*
  - *b) Summary of Monitoring– 15 minutes - USGS*
  - *c) Drafting an Adaptive Management Plan – 10 minutes – Keith*
  - *d) Questions to prompt discussion and feedback – 45 minutes*
    1.What does future monitoring look like?
    2. How will adaptive management be applied going forward?
    3. Resource constraints? Other constraints?

Monitoring

- Monitoring update
  - o There's a need to link flows with intended benefits.
  - o It was found that longer duration creates more change.
  - o USGS showed a newly created oxbow on McKenzie after 1996 flood, and where chub ended up.
- The monitoring presentation helped identify at need for:
  - o Inundation/stage studies (some has been done by the RDG for TNC and by the Corps on the McKenzie).
  - o Verification of various beneficial bankfull rates on the McKenzie and the Middle Fork.
  - o Do we want transects related information? It was brought up that there may be some information from PHABSim runs and ODWFW spawning monitoring, etc.
  - o There seemed to be a stated need to identify which reaches were dynamic and whether stabilization was needed in some reaches or should be disturbed in others. Again for the need for specific tie from proposed actions to effects and success criteria was made clear.
- Pertinent to the big picture of the SRP e-flow program:
  - o Purpose to protect what we have or to improve in ecological function in areas that are currently degraded but show promise for improvements?
  - o What types of current scale, connectivity, geomorphic types and conditions, habitat diversity and succession and overlap with critical species, factor into setting e-flow prioritizations?
  - o Is basic index monitoring insufficient for tying e-flows to ecological benefits?
- Do we want transects related information? It was brought up that there may be some information from PHABSim runs and ODWFW spawning monitoring, etc.

- Each reservoir pool level needs to be included in the objectives and implementation priorities.

- Relating e-flow options to pool elevation / regulation options should assist regulators/operators making decisions about flows AND pool elevations.

Adaptive Management

- Adaptive Management plan is being written with input received at this meeting.
- Start with statement that we are managing adaptively because dams are regulated and responses to dynamic systems.
- Some existing studies that can be tapped for additional information useful for adaptive management. Especially since future monitoring and adaptive management will not have a sustained funding sources? They were identified as.
  - Need biology input from Rich.
  - ODFW funded to study spawning surveys.
  - Rearing habitat needs transects, transects, North Santiam.
  - ODFW studies chub in all channel habitats.
  - Stranding? Not sure if study is available.
  - Chub and Salmon abundance are tracked regularly.
  - Recruitment surveys with flow and temperature studies.
- Additional questions for the Adaptive Management Plan
  - Which flows can we implement?
  - Are durations in e-flow targets correct or need redefinition?
  - What are the responses associated with those flows?
  - What is the frequency asscoatiated with monitoring those flows?
  - What is the priority of monitoring responses important to this group?
  - What tributary would we want to prioritize (start with)?

Prioritization

- Funding for RM&E in the Willamette is significant. Funding for e-flows is minimal. How can SRP monitoring better align with RM&E monitoring to better take advantage of the work being done?

- What are the specific goals of e-flows?
  - Maintain River reaches that are already good.
  - Monitor where we expect changes.
  - McKenzie reach from Ellinger to Armitage is "good".
  - Leverage existing stakeholder resources and studies like EWEB on the McKenzie.
  - N Santiam has chum and WSH and SCH studies.
  - Leaburg to mouth – all alluvial.
  - Cougar better than Detroit due to socio economics.
- The Basin Review was identified as an integral driver for the prioritization in the Valley.
  - Study through summer.
  - Will look at in-stream flows related to ecological benefits.
  - "Water to play with" in the McKenzie (Cougar)

        - Have Blue River and Cougar to supply water?
        - Blue River was not in the MFR.
    - Need to define what "success" is, what is the effect?
        - Action team?
- Some main prioritization questions were:
    - Where do e-flows do most benefit?
    - Where do we have the most data?
        - McKenzie – channel complexity exists.
        - N. Fork – One of the sweet spots.
- Understanding the channel dynamics, side channels and veg. was key to prioritizing too.
- Some additional preliminary feedback on basin prioritization was that:
    - McKenzie shows the most promise then the North Santiam and finally the Middle Fork.
        - McKenzie reaches of most opportunity are: Leaburg to the confluence
- N Santiam reaches of most opportunity are: Stayton to confluence.
- McKenzie: Ellinger boat ramp to Armitage/Green Island was also seen as dynamic with further opportunity from e-flow operations.
- The downside with the McKenzie was that e-flows are only released from Cougar and that using Blue River flows to supplement may be problematic from an authorization and legal standpoint.
- Flows in the North Santiam are more constrained and scrutinized by stakeholders and river users.
- The Middle Fork has limited opportunities relative to the other two basins.

<u>WORKSHOP AGENDA:</u>

5) *Possible Future Training for Operators and Regulators – 15 minutes Total – Group Discussion*
    1. *Is the training needed?*
    2. *What would it look like?*
    3. *What are the goals of training?*
    4. *What do operators need to perform and document e-flows?*
    5. *How can regulators promote e-flows to operators?*

- Training is beneficial to the regulators but not necessarily to the operators.
- It should provide background and explanation why e-flows are what they are.
- There was a stated need to further refine the communication and the decision tree whether or not to perform an e-flow operation. So far, only Mary Karen has "done" e-flows in actual real time.