Assessment of potential for improving ESA-listed fish habitat associated with operations and maintenance of the U.S. Army Corps of Engineers Willamette Project: an approach to prioritizing revetments for removal or modification to restore natural river function

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Table of Contents **page**

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List of Figures and Tables

List of Acronyms

BiOp	Biological Opinion
BOR	U.S. Bureau of Reclamation
FCA	Flood Control Acts
GIS	Geographic Information System
HTT	Habitat Technical Team
LIDAR	Light Detection And Ranging
NAIP	National Agriculture Imagery Program
NMFS	National Marine Fisheries Service
ODF&W	Oregon Department of Fish and Wildlife
PNW-ERC	Pacific Northwest Ecosystem Research Consortium
RDG	River Design Group
RPA	Reasonable and Prudent Alternative
TNC	The Nature Conservancy
UGB	Urban Growth Boundary
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
UWR	Upper Willamette River
WATER	Willamette Action Team for Ecosystem Restoration
WRBP	Willamette River Basin Bank Protection
WVE	Willamette Valley Ecoregion

Executive Summary

Background

Floodplains and riparian forests are some of the most dynamic zones of any landscape and contain some of the highest levels of biological diversity and habitat complexity. Within the floodplain of the Willamette River and its major tributaries, aquatic habitat conditions have been substantially altered by human activity since EuroAmerican settlement. What had been complex meandering, braided mainstem rivers with extensive floodplain forests on both banks are now greatly simplified, especially in the southern reaches of the Willamette River and lower reaches of its major tributaries, all of which were historically more complex and dynamic. Between 1935 and 1971, the U.S. Army Corps of Engineers (USACE) constructed a series of revetments as part of the Willamette Project, a collection of actions that includes 13 dam and reservoir complexes, approximately 42 miles of revetments for control of floods and preventing bank erosion, as well as four fish hatcheries and related fish collection facilities to mitigate for lost fish production relating to blocked access and alterations to fish habitat. In 2007 the USACE proposed to identify and prioritize those USACE-maintained revetments where removal or modification may be feasible to restore natural river function, particularly as such actions could improve habitat for fish listed under the federal Endangered Species Act.

Project Scope

Beginning in 2011, a team from the University of Oregon, Oregon State University and River Design Group developed and demonstrated a three phase approach to prioritizing the system of USACE-maintained Willamette Project revetments for future consideration for removal or modification to enhance natural river function: *Phase 1)* Working with existing geospatial information and an overarching conceptual framework, a quantitative spatial analysis was performed to produce a revetment prioritization for each of five regions in the study area. With guidance from the Habitat Technical Team, an advisory group of representatives from federal and state agencies, this resulted in a list of 15 high priority revetment zones. These 15 zones were intentionally located throughout the five regions to geographically distribute the ecological benefits of revetment removal or modification; *Phase 2)* Using additional information on revetment damage and cold water refuges available for only a portion of the study area, six of the 15 high priority revetment zones were chosen for field investigation, again insuring the six chosen revetment zones were geographically distributed; *Phase 3)* Information from the field reconnaissance was used to refine priorities based on direct observation of existing revetment condition, existing and potential habitat qualities and land-based improvements currently protected by each revetment. From this group of six, four USACE-maintained revetments are recommended for further, more detailed consideration regarding removal or modification to restore natural river function-- *Cole Island*, *Horseshoe Lake* and two revetments at *Harkens Lake*. The resulting prioritization tool can be actively updated as additional information is obtained to refine the reported priorization of revetment zones or conduct completely new prioritizations.

Project Findings

In the past half-century people have grown accustomed to river controls afforded by Willamette Project revetments. River stabilization and floodplain stability have resulted in significant floodplain encroachments and few revetments can be removed or modified without effecting human activities and property. This means decisions about revetment removal or modifications involve not only ecologic function and physical factors but are inherently connected to social, political, and economic concerns as well. Where restoring natural river function is the goal, a prioritization process that denominates costs and benefits solely in dollars is unlikely to adequately address the biophysical processes that are central concerns in restoring natural river function. While we recommend four USACE-maintained revetments for more detailed consideration, following the field reconnaissance we find that 12 of the 15 USACE-maintained revetments identified as high priority in this study merit further consideration regarding removal or modification. Whichever individual revetments are ultimately chosen, it is clear that moving forward with any revetment's removal or modification requires active participation by affected, willing landowners.

Project Recommendations

Given that much human activity in the Willamette Valley is premised on river controls provided by the Willamette Project, if revetment alterations are to succeed ecologically, socially, economically and politically, these alterations must be a broadly consultative endeavor. In the past half decade, strategic floodplain restoration initiatives have made meaningful progress in the Willamette Valley Ecoregion. They have succeeded through a network of voluntary participation, with river stakeholders working from a common agenda, engaging in complementary restoration activities over many years, and evaluating results according to a shared set of metrics.

We recommend that any USACE efforts to remove or modify Willamette Project revetments directly engage this network, beginning with the four recommended revetments – Cole Island, Horseshoe Lake, and two revetments at Harkens Lake – and in so doing, benefit from the landowner relationships, on-the-ground restoration lessons and larger strategic vision of a restored Willamette system.

To summarize our conclusions and recommendations:

1. We are confident the four top priority revetments are good candidates, but additional good sites likely exist and we recommend they be considered;
2. Development of a 2-year flood inundation zone map for mainstem and tributaries would provide the ability to more holistically assess restoration opportunities;
3. Water temperature and native fish abundance databases supported by sampling are needed in the lower reaches of tributaries to match those available for the mainstem Willamette;
4. Expand this type of assessment to all revetments in the Willamette Basin;
5. Convene a workshop, which includes those from the restoration, regulatory, and engineering communities, to discuss revetment modification and implementation approaches. To continue progress toward revetment modification, the meeting may need to consider formation of a workgroup to meet periodically to share information on techniques and approaches, and otherwise help advance revetment modification activities;
6. NOAA should consider developing a programmatic permitting approach for revetment modifications, to streamline associated regulatory activities;
7. Successful implementation must be pursued with careful and responsive listening to the interests, plans and capacities of those most effected by proposed restoration actions.

I. Introduction

A. Purpose and Context of this Report

Within Oregon's Willamette Valley Ecoregion (WVE), the U.S. Army Corps of Engineers (USACE) is responsible for maintaining approximately 42 miles of revetment, or bank armoring structures, located on the Willamette, Coast Fork Willamette, Middle Fork Willamette, McKenzie, Calapooia, Santiam, Molalla, and Clackamas Rivers (Fig. 1).

The purpose of the revetments is to stabilize the land-water interface while protecting land-based improvements from erosion and flooding. As a result, many natural river functions are repressed, which in turn adversely impacts creatures that depend on complex, dynamic riverine habitats. The 2008 Biological Opinion (BiOp) required by the federal Endangered Species Act, directs the USACE to prioritize revetments for modification or removal to restore natural river functions in the Willamette (NMFS 2008, USFWS 2008). Under section 3.5.4 of the USACE Supplemental Biological Assessment, the USACE proposed an evaluation of the habitat and biological impacts of these revetments, with a key objective being to identify and prioritize those revetments "where removal or modification may be feasible to restore natural river functions", particularly as such actions could improve habitat for fish listed under the federal Endangered Species Act (USACE et al. 2007).

The 2007 NMFS Willamette Project Biological Opinion, Reasonable and Prudent Alternative (RPA) 7.4 directs the USACE to undertake a comprehensive assessment of revetments placed or funded through the Willamette River Bank Protection Program. The intent of this assessment is for the USACE to pursue implementation of the high priority sites for restoration through existing authorities/programs that are described in RPA 7.1.

This report, conducted under a cooperative agreement between the USACE, University of Oregon (UO), Oregon State University (OSU) and River Design Group (RDG), responds to the USACE's objective and the BiOP directive by developing and applying a prioritization approach to answer the question:

Which USACE-maintained Willamette Project revetments are high priorities for modification or removal to restore natural river functions?

The systematic prioritization approach consisted of three phases: Phase 1) Working with existing geospatial information and an overarching conceptual framework, a quantitative spatial analysis was performed to produce a revetment prioritization for each of five regions in the study area. With guidance from the Habitat Technical Team, a group of technical and management representatives from federal and state agencies, this resulted in a list of 15 high priority revetment zones. These 15 zones were intentionally located throughout the five regions to geographically distribute the ecological benefits of revetment removal or modification; Phase 2) Using additional information on revetment damage and cold water refuges available for a portion of the study area, six of the 15 high priority revetment zones were chosen for a field reconnaissance, again insuring that the six chosen revetment zones were geographically distributed; Phase 3) Information from the field reconnaissance was used to refine priorities based on direct observation of existing revetment condition, existing and potential habitat qualities and land-based improvements currently protected by each revetment. This resulted in a final short list of 12 high priority zones, with four individual revetments recommended for more detailed consideration for removal or modification to restore natural river function.

B. The Willamette River Basin Bank Protection Project revetments

Revetment is a general term for a bank protection structure. They are composed of large stone, wood pilings, asphalt or concrete that is placed along the channel banks and terrace walls as riprap, levees, or within the channel bed as wing deflectors. These structures inhibit sediment erosion, prevent the river from naturally meandering and restrain the river's ability to form complex off-channel habitats.

The USACE Portland District has the responsibility of administering the Willamette River Basin Bank Protection (WRBP) Program. The program consists of 223 federally constructed projects that were authorized to clear, slope and revet river banks, construct pile and timber bulkheads and drift barriers, minor channel improvements and maintenance of existing works constructed under the 1936 and 1938 Flood Control Acts (FCAs) for control of floods and preventing erosion at various locations along the Willamette River and tributaries. Projects were constructed along the Willamette River and its major tributaries (Clackamas, Molalla, Santiam, McKenzie, Coast Fork, Calapooia, Middle Fork and Mary's Rivers) through authorizations of the FCAs of 22 June 1936, 28 June 1938 and 17 May 1950. Thirty-seven additional bank protection or river training projects were also constructed under various other authorizations such as the River and Harbors Act and Mitigation and Emergency Bank Protection authorities for navigation or emergency bank protection purposes.

The WRBP program's stated intention was "to prevent bank erosion which destroys productive farmlands, roads, bridges, and other improvements" (USACE 1989). These improvements include agricultural, residential, commercial and industrial property, power and gas lines, telephone cables, irrigation system water intakes, railroads, levees, roads, bridges, as well as other existing revetments (USACE 1989). The Willamette River Basin Bank Protection Program authorized revetments to decrease flood risk, further enabling agricultural and urban land to develop alongside rivers.

Revetments authorized under this program have been built along the most dynamic places in the river as a means to simplify and control channels, such as at tributary confluences, junctures with side channels and alcoves, and in meander bends. More than 25% of the Willamette River has revetments on one or both banks (Gregory et al. 2002a), although not all these are USACE-maintained revetments. Most revetments are located on the outer bank of the river at bends in the channel, primarily in places dominated by highly erodible soils. In some cases, property protected by revetments will still experience inundation during floods, but the possibility of channel migration is reduced by the revetment's presence.

As control structures, revetments have greatly contributed to the simplification of the Willamette River and its major tributaries by diminishing floodplain access and restraining the river's ability to change course in high flow events. During the period from 1850 to 1995, the total area of mainstem Willamette River channels and islands decreased from 41,000 acres to less than 23,000 acres and the total length of all mainstem channels decreased from 355 miles to 264 miles (Gregory et al. 2002b, 2007). There are in excess of 94 miles of revetments at 230 locations along the mainstem Willamette River and its tributaries that were constructed by the USACE and are now in private and public ownership (USACE 2012). A 2002 survey that counted all revetments on the Willamette River, including those not constructed by the USACE, totaled in excess of 96 miles of revetment along the mainstem Willamette alone (Gregory et al. 2002b). This report addresses approximately 42 miles of USACE-constructed and maintained revetments at over 100 locations, some of which are in tributary rivers to the Willamette (Fig. 1). All such revetments were constructed prior to 1953 (USACE et al. 2007).

C. The Biological Opinion, revetments, and Reasonable and Prudent Alternative 7.4

The National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers, Bonneville Power Administration (BPA) and U.S. Bureau of Reclamation (BOR) consulted to produce a Biological Opinion on the effects and recommended management actions related to federal flood control projects in the Willamette River basin (USFWS 2008, NMFS 2008). They identified impairment of habitat formation, flow alteration and warming of water temperatures as major impacts. Revetments contribute directly and indirectly to these impacts:

> "Indirect effects of the (Willamette Project and its revetments) include the alteration of habitat-forming processes. Reduction in the magnitude and frequency of floods alters the natural processes which create backwater, slough and side channel habitats for Oregon chub. The change in flow regime also eliminates the natural mechanism for dispersal of Oregon chub to new sites within the Willamette Basin. Revetments eliminate habitat complexity within the channel that may have provided backwaters for Oregon chub. Reductions in riparian habitats and large wood in stream channels eliminate major sources of slow water habitats for Oregon chub" (USFWS 2008).
>
> "Degraded riparian conditions that are partly a consequence of flood control efforts have tended to warm the mainstem during spring and summer, and channel simplification by the USACE has likely reduced thermal heterogeneity and the availability of cool thermal refugia important to salmonids when mainstem temperatures are warm" (NMFS 2008).
>
> "The installation of revetments, reduced magnitude and frequency of floods, direct channel modifications, development, reduced floodplain forest, reduced amounts of large wood, and gravel mining have significantly diminished both the quantity and quality of anadromous salmonid habitat in the mainstem Willamette River. Resultant decreases in channel complexity may have reduced thermal heterogeneity important to any remaining adult Chinook migrating up the river after water temperatures have risen to sub-optimal levels during late spring or summer. Reduced complexity has also affected the abundance and quality of mainstem summer rearing and/or over-wintering habitat for juvenile Chinook spawned in the river's tributaries. Such habitat includes woody debris jams, side channels, alcoves, areas of lowered velocity along channel margins, summer-time thermal refugia, and quiescent winter refugia on floodplains and in the lower-most reaches of valley floor tributaries" (NMFS 2008).

The Biological Opinion was strongly underpinned by contemporary ecological theory and research. This body of prior work asserts that natural ecological processes and functions lead to cycles of growth, disruption and renewal. These cycles have periods and amplitudes that are defined by rates of change of a small number of key variables, including flow, water temperature and sediment transport in river-dominated ecosystems. The resilience of these cycles is maintained by pulses of natural disturbance. Together, it is the interactions of these cycles, the rates of controlling variables and the natural disturbance regime that allows ecosystems to absorb, buffer and accommodate change while sustaining the species that comprise them (Holling 2001) (Palmer et al. 2005).

This body of theory sees people's efforts to manage ecosystems as a series of weak experiments testing a general notion of stability and resilience. Managers seek to reduce the variability of a target variable (in the case of the Willamette River, floods) by applying external controls. On a time scale of decades, short run success leads to qualitatively different ecosystem trajectories as a result of this management. Institutions co-evolve, with a tendency to improve operational efficiency in achieving control of the target variable. As a result, the coupled natural-human environment becomes less resilient and more dependent on vigilant, error-free management of an increasing number of variables, and ecosystems simplify in response to human-induced reduction of ecological variability (Gregory et al. 1991) (Holling and Gunderson 2002) (Lestelle et al. 2005) (McConnaha et al. 2006) (Bernhardt et al. 2007).

With this body of theory as an underpinning and following a comprehensive analysis of the status and prospects of native fish in the Willamette River basin, the BiOp found: "Revetments simplify habitat and diminish its suitability and capacity to support larger and more productive populations [of listed fish species]" (NMFS 2008). The Reasonable and Prudent Alternative (RPA) 7.4 section of the BiOp requires the relevant federal agencies to complete a comprehensive assessment and prioritization of revetments placed or funded by the Willamette River Bank Protection Program to identify sites with the potential for modification or removal with the goal of restoring natural river functions (NMFS 2008, USFWS 2008).

Research on river restoration conducted since the BiOp was completed identifies four concerns critical for restoration success: 1) the immediate spatial context of the restoration effort matters; 2) proximity to colonists matters as it provides a population source to re-colonize following restoration; 3) minimizing earth-moving and vegetation disturbance during restoration improves likelihood that desired ecosystem qualities will be restored; and 4) problems created at the catchment-scale will not be resolved by reach-scale restoration alone (Colvin et al. 2009) (FEMA 2009) (Tullos et al. 2009) (Whiteway et al. 2010) (Bernhardt and Palmer 2011) (ODFW 2011) (Ja¨ hnig et al. 2011) (Palmer 2012).

With an eye to the directive of RPA 7.4 and recent research on river restoration, this report presents a three phase system-wide prioritization of USACE-maintained Willamette Project revetments, and provides recommendations regarding which subset of these revetments are the highest priorities for removal or modification to restore natural river function. Section II describes the methods used to conduct the prioritization.

II. Methods used to prioritize USACE-maintained revetments

A. Prioritization Phase 1: Quantitative spatial analysis

A GIS-based quantitative spatial analysis was used in this study to identify a tractable short list of revetments most likely to be suitable candidates for modification or removal. Fifteen revetments were identified in Phase 1 as highest priorities. These 15 were distributed among 5 river-defined geographic regions described in Section II A.4. For six of these 15 highest priority revetments, the Phase 1 analysis was followed with a field reconnaissance.

The spatial analysis component of the procedure started with digital maps of the locations of revetments on the mainstem Willamette River and its principal tributaries. From the location of each of the revetments, an area was outlined whose hydrology during a frequent (2-year recurrence interval) flood would likely be influenced as a consequence of revetment modification. A standard set of characteristics relevant to the prioritization was mapped and quantified within each of these 72 areas, which we termed *Zones of Influence*, or simply Zones. These standard characteristics, called *Factors*, were combined to permit classification and prioritization of revetments using a technique developed for work in the Willamette River Basin (Gregory and Hulse 2002). Because there are locations in which multiple revetments have been constructed to protect the same area, Phase 1 prioritized Zones rather than individual revetments. Phases 2 and 3, the qualitative field reconnaissance and final recommendation, addressed individual revetments.

A.1 Four-Box Conceptual Framework and Process Overview

Where resources for ecosystem restoration are limited, prioritization is required to guide choices. The method of prioritization used here characterizes each Zone along two dimensions, sociocultural constraint and biophysical opportunity. The conceptual framework is a simple one: places having both potential for ecological benefit from restorative acts and low sociocultural constraints to doing so are the logical place to begin. These places, and others that don't have both these qualities, are arrayed conceptually in a simple four-box diagram (Fig. 2). With all territory in a study area located within this conceptual space, choices of where to restore can be more clearly compared and contrasted for their relative advantages. In this way, patterns of critical riverine ecosystem qualities and major land use investments create a spatial context for locating restoration efforts (Hulse and Gregory 2001, 2004). A set of mapped factors, characterizing biophysical opportunity and sociocultural constraint, determine where in the four box diagram a given Zone falls. The lower right quadrant is where opportunities are greatest and constraints least.

Sociocultural constraints are factors within a Zone that inhibit a revetment's removal or modification. They are quantified by phenomena such as density of human population, property value, transportation infrastructure and prime agricultural soils. In short, constraints to revetment removal or modification are often the very things revetments were built to protect. Biophysical opportunities, by comparison, are factors within a Zone conducive to the restoration of natural river function and increased habitat for native fish, and are quantified by phenomena such as the presence of frequently inundated floodplain forest, complex river channels and proximity to lands managed primarily for conservation. Section A.3 below provides the complete list of sociocultural constraint and biophysical opportunity factors.

The amount of each factor present in each Zone was quantified through digital mapping techniques using data available at the time of this project. Once the raw quantities were established, they were normalized so that total amounts of biophysical opportunity and sociocultural constraint could be compared within the four-box diagram framework. Using values provided by an advisory technical group (described in Section II A.4 below), a weight specifying relative importance was assigned to each factor. The normalized factors were then multiplied by the assigned weights. For each Zone all of the weighted opportunity and constraint factors were summed and renormalized. This produced each Zone's overall sociocultural constraint score and its overall biophysical opportunity score, each ranging from zero to one. These two scores, in combination, located each Zone within the conceptual space of the four box diagram (Fig. 2).

The quadrants in the 4 box diagram were defined by the median values for sociocultural constraint and biophysical opportunity. Sociocultural constraint scores greater than the median value were located in the top portion of the four box diagram. Similarly, biophysical opportunity scores above the median value were located in the right portion of the four box diagram. Zones having low sociocultural constraint and high biophysical opportunity (i.e,. in the lower right quadrant) were classified as highest priorities for revetment removal or modification. As a group, the revetments associated with these Zones in the lower right quadrant were assigned highest priority for further evaluation, and a subset of them was selected for on-site examination during the field reconnaissance.

A.2 Delineating Zones of Influence

Revetments have been constructed for multiple reasons–to prevent erosion of banks, to prevent inundation of low lying areas during times of high water flow, to protect industrial facilities, transportation systems and utilities from shifting river channels, to make land available for agriculture throughout the year, and to protect urban areas from flooding. The determination of the area that would experience effects from the alteration of revetments therefore depends on assumptions of the water level involved as well as site specific factors such as topography, adjacent structures such as road and rail embankments, adjacent geology and potential hydrologic interactions resulting from alterations of nearby revetments.

To delineate Zones of Influence, a LIDAR- based (Light Detection and Ranging) map of locations likely to be inundated at a two year frequency produced by River Design Group (RDG 2012) was used to define the reference water level for Zones in the floodplain of the Willamette River mainstem. Imagery of the 1996 flood, vegetation patterns, and topography were used to establish the reference water level for the tributary Zones.

A GIS-derived map produced from one meter LIDAR surface topography data sets (Terrapoint 2004) (Watershed Sciences 2007, 2009) of locations immediately downslope and upslope of each revetment provided a preliminary characterization of the area affected by potential alterations of each revetment. This map, together with maps of topography, floodplain forest, and the revetments were displayed along with 2009 National Agriculture Imagery Program (NAIP) aerial photographs in a GIS to guide delineation of Zones. Initial drafts of the delineations were peer-reviewed, and revised according to recommendations. Two such review and revision cycles were implemented in addition to a review of the zone delineation method by the Habitat Technical Team to produce the final 72 Zones of Influence (Fig. 3, Table 1).

The guidelines used in the delineation were:

- Inclusion of the revetments with a 10-meter buffer
- Floodplain terraces evident in topography (LIDAR)
- Exclusion of areas of elevation higher than those inundated during a 2 year flood (mainstem) and the 1996 flood (tributaries)
- Potential for head-cutting upstream when channel length is shortened due to revetment alteration
- Localized geologic features such as bedrock outcrops

A.3 Factors

In this project "restoration" refers to restoring natural river function as it most directly effects habitat for listed fish species. We represented habitat quality by channel complexity and frequently flooded floodplain forests. For lands in proximity to the Willamette River and its major tributaries that have been developed during the past 150 years, restoration of these qualities may involve reconsidering commitments made during past decades to protect things of economic value. Said differently, an increase in ecological value (i.e., restoration of natural river function) achieved by revetment alteration may result in a loss of other important values (Seedang et al. 2008). Thus, it is necessary to estimate both the quantity of potential biophysical gain and the quantity of potential sociocultural constraint at each Zone to inform revetment alteration choices that are plausible and prudent.

To quantify these considerations, we identified a set of sociocultural constraint factors and a set of biophysical opportunity factors based on previous work in the Willamette Basin (Hulse et al. 2002) as well as on research and practice in the restoration of riverine ecological function through increased fluvial dynamism (Beechie et al. 2008). We selected the most significant elements of sociocultural constraint and biophysical opportunity for which data were available for all of the study area. We summarize these factors below (Table 2).

- Sociocultural Constraint Factors

The use by EuroAmerican settlers of rivers as transportation routes, the presence of fertile soils in floodplains, the availability of water for agricultural, industrial, and domestic uses, and the attractive conditions for human settlement created by river confluences, have combined to make locations near rivers among the most intensively used in the Basin. It is this history of land use that constrains restoration activities that would increase channel complexity and floodplain forests (Benner & Sedell 1997, Gregory et al. 2002b). We include as constraints only those factors physically present in each Zone. We include the following constraint factors in the database (Table 2):

1. *Transportation infrastructure*: The construction of roads and bridges is both a significant cause of modification of stream channels (Payne et al. 2002) (Wohl 2005) and a reason to build revetments to protect them. We used the total length of roads by type and the presence or absence of bridges to express the quantity of transportation system investment in each Zone.

2. *Property value*: Real market value is an indicator of land value and past investment in land improvements. Additionally, acquisition of use rights or outright land purchase may be required for restoration of natural river functions (Loomis et al. 2000) (Hulse & Gregory 2004). We used the sum of ca. 2010 real market land and improvement values from county assessor records to quantify land value in each Zone.

3. *Human population density*: In making additional land available for use and development, revetments in the Willamette River Basin have been constructed to protect people and structures from floods. The more that modification to revetments may increase risk to people, the greater the constraint on such actions. Zones with higher population density were assumed to have higher sociocultural constraint. Here, we used human population density from the 2010 U.S. census (US Dept. of Commerce 2011).

4. *Non-USACE revetments*: In addition to the 103 USACE-maintained revetments that are the subject of this study, there are 166 identified revetments in the study area that are not maintained by the USACE (USACE 1989, 2012). Modification of revetments maintained by the USACE may alter flow regimes in ways that damage the non-USACE revetments and the assets they were constructed to protect. We used the total length of non-USACE revetments in each Zone to quantify this constraint.

5. *Prime agricultural soil*: More revetment length in the study area lies in agricultural than in urban areas, and the vast majority of these agriculturally related revetments occur in areas where soil is susceptible to erosion. Maximizing agricultural production by constricting active floodplains is a principal reason for the construction and maintenance of revetments (Larsen 2008), and is a constraint on their modification. We used the total area of prime agricultural soils (USDA 2012) in each Zone to quantify this constraint.

- Biophysical Opportunity Factors

Assessments of the outcomes of river restoration efforts implemented over the last two decades support a growing consensus that increasing fluvial dynamism is more effective in improving ecological function than is the construction of new, statically maintained channel structures (Kondolf 2006). Benefits include greater hyporheic cooling, greater spawning and rearing habitat, and reestablishment of disturbance dependent floodplain vegetative communities (Whol et al. 2005) (Bernhardt et al. 2005, Bernhardt and Palmer 2011). Additionally, floodplain lands already managed for conservation purposes are locations in which existing ecological function may be greater and restoration may have greater long-term likelihood of success. We quantified existing biophysical opportunity using the following factors (Table 2):

1. *Erodible gravels*: To the degree that they are free of fine sediments, gravels provide cooling and cleaning of water and spawning and rearing habitat for native fish species (Naiman et al. 1995) (Soulsby et al. 2009). The principal data source in the Willamette Valley Ecoregion of accessible, unconsolidated gravels is the Holocene alluvium geological map unit (O'Connor et al. 2001) (Wallick et al. 2006). We used the total area of Holocene alluvium in each Zone to quantify this opportunity factor.

2. *Channel complexity*: Zones with greater channel length may provide more salmonid habitat and potentially more opportunity for the development of additional channel structure (Landers et al. 2002) (Ebersole et al. 2003). We quantified this factor by summing the total length of river channel in each Zone.

3. *Frequently flooded floodplain forest*: The establishment and maintenance of this vegetative community is dependent on frequent fluvial disturbance (Ward 1998). Its presence is, therefore, an indicator of channel dynamism. Shading provided by the forest and wood deposited from it into the river and on stream banks are associated with increased salmonid species abundance (Hawkins et al. 1983) (Gregory et al. 2002c). We quantified this factor by reporting in each Zone the total area of floodplain forest that, in the Willamette mainstem floodplain, is subject to inundation at a two-year frequency, and for Zones in tributary floodplains, that were inundated in the 1996 flood.

4. *Lands managed for conservation*: This factor is both an indicator of reduced sociocultural constraint on new restoration activities, and an indicator of potentially greater ecological function due to past and future management of these lands. Using information compiled from The Nature Conservancy, the PNW-ERC (Hulse et al. 2002) and recent conservation easements, we used the total area of lands in conservation ownership to quantify this factor in each Zone.

A separate digital map was created for each of the factors identified above. Each factor map was separately combined with the digital map of Zones via a GIS overlay operation to yield the quantity of the factor present in each Zone. Once completed for all factors, the quantities were used to calculate the sociocultural constraint and biophysical opportunity scores for each Zone. Taken together, the two scores for each Zone are the coordinates specifying its location in the four-box diagram.

The role of quantitative spatial analysis in this project is to inform priorities. After the GIS-based portion of the spatial prioritization work was complete, the resulting relevant attribute information for each Zone was exported to a spreadsheet where the data were normalized and weighted in preparation for the prioritization. These weights convey relative importance of each factor and are expressed as numbers ranging in value from zero to one. We looked to a group with recognized expertise to determine these weights, described below.

A.4 HTT weights

The Habitat Technical Team (HTT) was established by a federal and state inter-agency coordinating body called the Willamette Action Team for Ecosystem Restoration (WATER). Among other charges, the HTT has responsibility to: a) Develop and implement actions to ensure compliance with the Willamette BiOp and RPA requirements; b) Incorporate research, monitoring, and evaluation components into their work and use this information in future actions; and c) Recommend actions within their area of expertise and identify actions that need to be elevated to the WATER Steering Team for approval or resolution (HTT Charter 2009).

The HTT first reviewed and modified the proposed factors to be used in the Phase 1 prioritization of Zones in December 2011. Once a preliminary prioritization had been produced, the HTT then, in May 2012, reviewed and revised the weights assigned to the factors. A modified Delphi approach was used to query the HTT regarding appropriate weights to be assigned to each factor (Linstone and Turoff 2011). The sixteen members of the HTT were given a brief presentation on the status of the project, its goal and methods. They were then asked, in two rounds, to assign a weight to each factor indicating its relative importance. After the first round, the averaged weights were presented to the entire group and members of the HTT were also shown which Zones were the priorities under those weighting assumptions. In round one, highest biophysical weight was given to channel complexity (0.28) followed by conservation ownership (0.27), frequently inundated floodplain forest (0.26), and finally erodible gravels (0.19). Greatest sociocultural constraint weight was given to population density (0.21), followed by bridges and property value (both 0.17), then prime agricultural soil (0.16), non-USACE revetments (0.15), and finally roads (0.14). The priorities that resulted from these weights were then mapped, graphed and displayed to the HTT, and then discussed.

This allowed them to understand the range of responses from their peers and the implications of different weights on resulting revetment priorities. The individual HTT members were given an opportunity to modify their first round factor weights during the second round of the workshop, and these second round weights were used as the final weights for the Phase 1 prioritization. Applied to the constraint and opportunity factors, the final HTT weights are shown in Table 3.

To avoid a result in which the spatial distribution of the highest priority Zones was clustered into a small geographic area, and thus would not distribute the benefits of revetment removal or modification over the spatial extent that native fish actually use in the Basin, the HTT suggested a regional approach to characterizing high priority revetments. To address this, the study area was subdivided into five regions (Fig. 4) defined by rivers and their associated USACE-maintained revetments, and the Zones were then separately prioritized for each region, always using the HTT weights. This resulted in 15 high priority Zones (Fig. 5, Table 4), distributed among the five regions. From this set of 15, six were selected for site visits using additional information described below. These six Zones were chosen such that at least one selected Zone was present in each of the five regions.

B. Prioritization Phase 2: Getting from 15 to 6 Zones

All 15 Zones shown in Figure 5 have a combination of comparatively low sociocultural constraint and comparatively high biophysical opportunity that makes them, according to this prioritization approach, high-ranking candidates for revetment removal or modification and thus worthy of a closer look. To choose a subset of Zones to visit in the field from the 15 identified in Phase 1, we used two additional sources of information described below.

B. 1 CH2MHill revetment damage assessment

In 2010 USACE retained CH2MHill to conduct an assessment of 18 Willamette Project USACE-maintained revetments identified as damaged during annual USACE maintenance inspections performed since 2001. The purpose of the CH2MHill assessment was to develop maintenance or repair proposals for the damaged revetment sites (CH2MHill 2011). The assessment identified four categories of damage observed among the 18 revetments and specified a suite of eight repair actions that were appropriate for the observed types of damage. Recommended actions were created using a qualitative risk assessment approach that combined a three category ranking of *likelihood* of revetment failure with a three category ranking of severity of *consequence* of complete failure. The arithmetic products of these rankings were then grouped into three tiers of priority, expressing urgency of action required: Tier 1-Increased damage likely, begin repair activities; Tier 2-Repair required to minimize additional costs – plan for repair activity; Tier 3-Damage appears stable – heightened vigilance and inspection warranted.

For our purposes, six of the 15 Zones prioritized in our Phase 1 analysis overlapped in territory with CH2MHill's 18 damaged revetments. By virtue of being damaged, these revetments may require actions that, if taken with the intention to simultaneously enhance natural river function *and* repair damage, may meet multiple objectives and gain access to sources of funding that would be unavailable if pursuing either objective alone. These revetment damage data, available only for the 18 revetments studied by CH2MHill, were consulted in the selection of the subset of Zones to visit from among the 15 high prority candidates.

B. 2 Willamette River mainstem cold water refuges

Alterations of channel structure, flow regimes, and riparian vegetation have created thermal gaps in the Willamette River in which distances between water with temperatures cold enough to meet the biological requirements of salmonid species is, during warm water times of the year, greater than the fish can travel (Hulse et al. 2008). These cold water refuges are also preferentially used by native cold water species during warm water times of year (Gregory, pers. comm. 2012). Revetment modifications that allow greater river dynamism may produce new cold water refuges in these gaps and, thus, deserve consideration. Cold water refuges were not addressed in Phase 1 because the data were available only for the mainstem Willamette River.

Temperature sampling conducted in the mainstem Willamette River since 2005 has found that cold water refuges, defined as areas with water temperatures 2 deg C or more below the average contemporaneous 7 day maximum temperature of water in the adjacent mainstem river, are most likely to be found in side channels and alcoves (Fernald et al. 2006). For the present study, summer water temperature data gathered in side channels and alcoves in 2010 were used to map the distribution of cold water refuges using a 100 meter slice spatial reporting structure developed for the Willamette floodplain (http://ise.uoregon.edu/slices/Main.html) (Fig. 6). If any portion of a Zone was more than 1 kilometer distant from a known cold water refuge, we classified that Zone as being in a cold water gap. These data, available only for the mainstem Willamette River and mouths of major tributaries, were also consulted in the selection of the subset of Zones to visit from among the 15 high priority candidates.

In reducing the short list from 15 to 6 Zones, additional attention was given to Zones associated with revetments that were considered in CH2MHill's damage assessment and/or were in a salmonid cold water gap.

C. Prioritization Phase 3: Field Reconnaissance

In late July and early August 2012, the six Zones were visited by boat and on land by the project team. The team qualitatively assessed each revetment for the following:

- Features protected by the revetment
- Evidence of distress or failure of the revetment
- The geomorphic position of the revetment
- Dominant overstory and extent of vegetation present
- Presence/absence of gravels
- Potential for frequent flooding to inundate existing floodplain forest in the immediate vicinity subsequent to revetment modification
- Potential to increase channel complexity during frequent floods in the immediate vicinity subsequent to revetment modification.

III. Resulting Revetment Priorities

A. Revetment priorities from Phase 1

The 15 high priority zones (Table 5) were those within each of the five regions of the study area with a sociocultural constraint score below the median value and a biophysical opportunity score above the median value based on standardized quantitative analysis, that is, they were in the lower right quadrant of the four box diagram (Table 4). The lone exception to this was Zone 50 Cole Island, which had the highest biophysical opportunity score possible, but had a sociocultural constraint score slightly above the median. The five regions (Fig. 4) and their included Phase 1 high priority zones (Fig. 5) are:

Region 1: Coast Fork and Middle Fork of the Willamette River and the McKenzie River: Zone 4 Pisgah, Zone 9 Clearwater Park 2, and Zone 10 Clearwater Park 1.
Region 2: Calapooia and Santiam Rivers: Zone 46 Folsom Pond, Zone 47 Jefferson, and Zone 50 Cole Island.
Region 3: Molalla and Clackamas Rivers: Zone 65 Kraxberger and Zone 72 Tranquility Lane.
Region 4: Willamette River Mainstem Eugene to Albany: Zone 23 Hentze Produce, Zone 26 Morgan Bend, Zone 29 Harkens Lake, and Zone 36 Truax Island.
Region 5: Willamette River Mainstem Albany to Newburg: Zone 54 Hayden, Brown and Minto Islands, Zone 61 Carlton Plant Nursery, and Zone 62 Horseshoe Lake.

Following review of the CH2MHill and cold water refuge data, six Zones were chosen from the 15 Phase 1 high priority Zones to visit during the field reconnaissance: Zones 9, 29, 47, 50, 62 and 72 (Table 5).

B. Summary description by region of 15 highest priority zones and their associated revetments

In the description that follows, for each of the 15 high priority Zones we list the region, Zone number and place name, along with the USACE revetment name in parentheses, followed by a description of the Zone by relevant factor as well as key characteristics of neighboring lands. Of these 15 Zones, six were chosen for field reconnaissance based on review of additional information from the CH2MHill assessment of revetment damage and cold water refuge data from field measurements taken in summer 2010. Neither of these two additional data sets were available for the entire study area. Table 5 shows the availability of the CH2MHill and cold water data for each of the 15 Zones.

As with the 15 Zones, the six chosen for field reconnaissance were chosen so that at least one Zone was present in each of the five regions, with emphasis on Zones associated with revetments that were also considered in CH2MHill's damage assessment and/or were in a salmonid cold water gap. The six Zones chosen for field reconnaissance are indicated by an asterisk (*) and for those Zones visited in the field, descriptions include findings and photographs from the field reconnassaince.

1. *Region 1, Zone 4 Pisgah* (McCully Left and McCully Right Banks). This 50-acre Zone two miles south of Springfield lies on the Coast Fork of the Willamette River with the 3600-ft McCully Left revetment on the West bank and the 1230 ft-McCully Right revetment on the East bank. On its east the Zone borders publicly owned lands with active restoration underway. Nine hundred and forty-five feet of road are present in the Zone. Erodible gravels are present throughout and twenty percent of the Zone contains prime agricultural soils. Ten acres of the western bank of the Coast Fork are designated as conservation lands. The revetments were not included in the CH2MHill assessment.

2. **Region 1, Zone 9, Clearwater Park 1* (A.C. Clearwater). The 1978 foot A. C. Clearwater revetment lies on the north side of this 15.6-acre Zone on the Middle Fork of the Willamette River (Fig. 7a). There are no streets, roads, or bridges in the Zone and no non-USACE revetments. One fourth of the zone, about 4 acres, is in conservation lands and is immediately upstream and across the river from The Nature Conservancy's "Confluence Project", a major floodplain and upland restoration effort. Forty percent of the Zone contains prime soils and erodible gravels are present throughout. The revetment was not included in the CH2MHill assessment.

   Notes from field reconnaissance: Much of the A.C. Clearwater revetment (the eastern two-thirds) lines the face of a natural terrace wall separating the active floodplain of the Middle Fork Willamette River from the higher ground to the north. The western-most section of this revetment has sustained significant damage

(Fig. 7b) and, if modified, would give the river access to floodplain forest immediately downstream of the revetment (Fig. 7c). Lands recently acquired by The Nature Conservancy (“The Confluence Project”) are immediately across the Middle Fork to the south and downstream of this revetment. Planning is now underway to restore the former (shallow, 12ft – 20 ft depth) gravel ponds on the inside, south bank of this reach (Fig. 7a) of the Middle Fork to a more fluvial form, allowing the force of the river’s flood flows to be dissipated on the south bank in a way that has been prevented for the past 40+ years by levees built by former gravel extractors on the south bank to prevent pit capture. Additionally, a new boat ramp (Fig. 7d) and recreational access parking area are being added on the north bank immediately downstream of the USACE revetment (Fig. 7e). These improvements include significant bank hardening both upstream and downstream of the boat ramp. In this context, modification of the downstream end of the Clearwater Park 1 revetment is an option. While this would increase the river’s access to a 5-acre patch of floodplain forest immediately downstream of the revetment on the north bank with minimal risk to downstream improvements, the fish habitat benefit would be small because of the small area and limited length of river margin habitat improved by the modification. Additionally, this zone is proximate to an existing population of Oregon chub and ODF&W raised concerns regarding short-term risks to this population due to channel avulsion and habitat change following revetment modification (Garner and Bangs, pers. comm. 2013). For these reasons, Zone 9 merits future consideration, but is not one of the top four recommended revetments.

3. *Region 2, Zone 10 Clearwater Park 2* (Booth-Kelly). Contiguous with Zone 9, Zone 10 is 47 acres in area with the 2569-ft Booth-Kelly revetment on the north bank of the Middle Fork. There are no streets, roads, or bridges in the Zone. Almost all of the area is in conservation lands. Prime soils are not significant and erodible gravels are present throughout. The revetment was classed as Tier 2 (Repair required to minimize additional costs – plan for repair activity) in the CH2MHill assessment. USACE has recently conducted revetment work on Booth-Kelly.

4. *Region 2, Zone 46 Folsom Pond* (Tripp). Located on the South Santiam river 2.5 miles east of its confluence with the North Santiam River, this 101-acre zone contains the 3327-ft Tripp revetment on the north bank of Crabtree Creek. No non-USACE revetments are present; there are 4100 feet of roads in the Zone. Prime soils are present in half of the Zone and erodible gravels are present in ninety percent. Floodplain forest is present in the land between the Creek and the River. A pond and riparian vegetation are present in the north end of the Zone, north of Thomas Creek. The revetment was not included in the CH2MHill assessment.

5. **Region 2, Zone 47 Jefferson* (Wickham). Located on the Santiam River downstream of the town of Jefferson, Zone 47 is 220 acres in area (Fig. 8a). It includes the 4649-ft Wickam revetment at its southeast end and 656 feet of the non-USACE Millar revetment at the northernmost extent of the Zone. Road length totals 6234 feet. More than three fourths of the Zone is in agricultural production (Fig. 8b), one third contains prime soils, and erodible gravels are present throughout. In the CH2MHill assessment, the Wickham revetment was assigned to Tier 3 (Damage appears stable – heightened vigilance and inspection is warranted).

   Notes from field reconnaissance: There is an 8 ft – 10 ft tall earthen levee higher in elevation and northeast of the Wickham revetment, which is continuous for >5000 ft and protects an adjacent 200+ acre agricultural field to the north and east as well as the City of Jefferson's new wastewater treatment facility (Fig. 8c). A 15 acre patch of frequently flooded floodplain forest is immediately downstream of the revetment, and is bisected by a powerline (Fig. 8d). Also, as with Zone 9, ODF&W raised concerns regarding risk to nearby populations of Oregon chub (Garner and Bangs, pers. comm. 2013). Even though there is some minor damage to the revetment, the combination of large acreage of protected agricultural land, a new wastewater treatment plant with extant levee above and adjacent chub populations make this revetment a poor candidate for removal or modification (Fig. 8e).

6. *Region 2, *Zone 50 Cole Island* (Wilfert, SR location 2, SR location 3, Turnidge). Encompassing the confluence of the Santiam and Willamette Rivers, the Zone is 1250 acres in area and includes four USACE revetments, described here from most upstream to most downstream: Wilfert (2700 ft), SR Location 3 (2316 ft) SR Location 2 (3248 ft), and Turnidge (1250 ft). In addition, the non-USACE revetments SR Location 4 (466 ft) and Krebs Property (472 ft) are present in the Zone. Three fifths of the zone is prime soil, nearly all of which is in agricultural use. Floodplain forest occupies two fifths of its area. Erodible gravels are present throughout the Zone. Approximately 15,750 feet of roads are present. The Wilfert, SR Locations Nos 2 and 3, and the Turnidge revetments were assigned to Tier 3 in the CH2MHill assessment (Damage appears stable – heightened vigilance and inspection is warranted). The Zone is in a salmonid cold water gap.

   Notes from field reconnaissance: The location of the four USACE-maintained revetments in Zone 50 relative to areas of intact, frequently flooded floodplain forest directed our attention to the Wilfert revetment, the most upstream of the four (Fig. 9a). As CH2MHill noted, the northern-most extent of the Wilfert revetment is significantly damaged (Fig. 9b). CH2MHill classified this revetment as Tier 3 (Damage appears stable – heightened vigilance and inspection is warranted). More than 500 acres of floodplain forest, including an intact 20 acre patch of river willow and the complex tributary junction of the Santiam and Willamette Rivers are immediately downstream of Wilfert (Fig. 9c). Records from the mid 19th century show that, historically, the confluence of the Santiam and Willamette was the largest contiguous area of floodplain forest along the entire Willamette River (Gregory et al. 2002c). The Wilfert revetment is in an area of wide river channel showing signs of recent sediment deposition (Fig. 9d) and gravel bar formation with accumulation of gravels adjacent to the revetment (Fig. 9e) (Risley et al. 2012). In addition to the qualities listed in the paragraph above, the combination of current revetment damage, being in a cold water refuge gap, the presence of intact adjacent floodplain forest and gravel accumulation in the active channel make this, in our recommendations, one of the top four revetments to be considered for removal or modification to restore natural river function.

7. *Region 3, Zone 65 Kraxberger* (MO Locations 6, 7, and 8). Located 2 miles southeast of Canby on the southern bank of the Mollala River, the three revetments included in this 59-acre Zone are: MO 6 (1089 ft), MO 7 (712 ft), and MO 8 (1916 ft). There are no roads or bridges present, 60% of the Zone contains prime agricultural soils, and erodible gravels are present in 90% of the Zone. Ten percent of the Zone is in agricultural production. MO Location 8 was assigned the Tier 2 rating in the CH2MHill assessment (Repair required to minimize additional costs – plan for repair activity).

8. **Region 3, Zone 72 Tranquility Lane* (Clackamas River Locations 12a, 13), Zone 72 lies 13 miles east of Clackamas on the south bank of the Clackamas River, upstream of its confluence with Foster Creek (Fig. 10a). Two revetments totaling 1762 feet in length are included in the USACE data base for this 148-acre Zone. There are 594 feet of road present, providing access to a cluster of residences and other buildings in and adjacent to the western end of Zone. Prime agricultural soils are present in two-thirds of the zone, erodible gravels are present throughout, ten percent is in pasture, and less than ten percent is in conservation lands. The revetments were not included in the CH2MHill assessment.

   Notes from field reconnaissance: This revetment has been destroyed. We found no evidence of a past revetment at this location. There was no angular rock to be seen above or below, upstream or downstream of the area indicated. The face of the south bank of the Clackamas River, where maps indicate the revetment once existed, was exposed, with a well developed network of large plant roots growing deep into the exposed bank (Fig. 10b and 10c), above a complex set of active gravel bars in the mainstem river (Fig. 10d). Along this same reach of the Clackamas River, restoration work was completed in the mid-2000s by Pacific Gas and Electric and Portland METRO to increase flow into a small side channel (at right in Fig. 10d) on the south side of the mainstem Clackamas via an underground drain field, along with anchored large wood and side channel grade controls.

9. *Region 4 Zone 23 Hentze Produce* (Location 9). Located on the mainstem Willamette 2 miles east of Junction City, this 628-acre Zone contains USACE revetments Location 9 and Location 9 upstream extension totaling 4446 feet in length. Four non-USACE revetments are present: Harper Bend upstream

extension (2287 ft), Junction City (459 ft), Koons (1316 ft), and Koon upstream extension (997 ft). The Zone includes 1818 feet of road, prime soils occupy 40 percent of the Zone, and erodible soils are present in more than 90 percent of the zone. Floodplain forest subject to inundation on a two year interval occupies seventeen
percent of the Zone. One fourth of the Zone is in conservation lands, and the Zone is in a salmonid cold water gap. The revetments were not included in the CH2MHill assessment.

10. *Region 4 Zone 26 Morgan Bend* (Morgan Bend). Located on the Willamette mainstem 3-1/2 miles northwest of Harrisburg, Zone 26 includes one 525-foot revetment and 138 acres of area encompassing 11,800 feet of Perkins Slough 4900 feet west of the Willamette River. Twenty-five acres are in agricultural production, and 6500 feet of road and one bridge are present. The Zone contains thirty-seven acres of prime agricultural soils, 133 acres of erodible gravels, and 86 acres are in floodplain forest inundated on a two year interval. The revetment was not assessed by CH2MHill and the Zone is not in a salmonid cold water gap.

11. **Region 4 Zone 29 Harkens Lake* (Irish Bend and Lower Bend). Located on the Willamette River upstream of Corvallis, Zone 29 is 833 acres in area (Fig. 11a). The Irish Bend revetment at the upstream end is 2530 feet in length (Fig. 11b) and the Lower Bend revetment is 3438 feet in length (Fig. 11c). Harkens Lake, center left of Figure 11a, is a former main channel of the Willamette River now blocked by the revetments, but containing water most of the year. Sixty-five hundred feet of road are present in this Zone. Prime agricultural soils occupy fifteen percent of the Zone and erodible soils are present in 20 percent. Inundatable floodplain forest covers twenty percent of the Zone. Slightly more than half of the Zone is in conservation lands. The Lower Bend revetment is in the downstream component of the Zone and connects to the 1982-foot non-USACE Lower Bend Downstream Extension revetment. In the downstream portion of the Zone, no roads are present. Prime soils occupy three-fourths of the lower component, and erodible gravels are present in ninety-five percent. Inundatable floodplain forest is present in thirteen percent of the Zone. The Zone is in a salmonid cold water gap. The revetments were not included in the CH2MHill assessment.

    Notes from field reconnaissance: Both USACE-maintained revetments in Zone 29 are in good condition. A landowner-operated water control structure, used to cause water to pond to improve waterfowl hunting, sits immediately above and west of the Lower Bend revetment and controls the elevation which ponded water must attain prior to exiting the Harkens Lake side channel complex and flowing into the mainstem Willamette (Fig. 11d). In concert with the upper Irish Bend revetment, these two revetments limit the flux of water through the Harkens Lake side channel complex, with the Irish Bend revetment limiting inflows from the Willamette and the water control structure/Lower Bend revetment influencing return flows to the Willamette. This lack of flushing flows, either from draining flood waters after inundation from the downstream end or flow into the side channel from the upstream end, have resulted in accumulation of sediments in Harkens Lake and the connected side channel and extensive growths of aquatic macrophytes. Both sedimentation and macrophyte growth are associated with increased abundance of non-native fish in floodplain habitats along the Willamette. We sampled Harkens Lake and associated habitats in summer of 2012. Almost no native fish were collected in the isolated lake filled with macrophytes. The slough connected to the river contained more native fish than non-native fish and included juvenile Chinook salmon in April 2012. Interactions among effected landowners (farmers, duck club), a land trust and restoration design consultants are underway as this is written (RDG 2013). There is a consensus among the authors of this report that altering the Lower Bend revetment alone would be insufficient to increase water flux into and out of the oxbow lake (Harkens Lake) west of mainstem, although possibilities exist to culvert or lower the top elevation at the Irish Bend revetment to increase flows into the oxbow lake. A recent conservation easement between farm families and a local land trust are the first step in a series of floodplain restoration efforts now being planned within this Zone (Fig. 11e). The combination of a recent conservation easement, landowner interest and recognized potential for increased channel complexity and frequently flooded floodplain forest area make the revetments at Harkens Lake two of the top four priorities.

12. *Region 4 Zone 36 Truax Island* (Upper Half Moon Bend). Located five miles northeast of Corvallis on the east side of the mainstem Willamette, Zone 36 encompasses 731 ac and includes the 5250-foot Upper Half Moon Bend USACE maintained revetment. There are no non-USACE revetments within the Zone, however, the 5542-foot Half Moon Bend non-USACE revetment stands on the west side of the mainstem opposite the downstream and widest portion of the Zone. There are 8000 feet of roads in the Zone. Sixty percent of the Zone contains prime agricultural soils and erodible gravels are present in half of the Zone. The north end of the Zone contains an orphaned oxbow “horseshoe lake” recently acquired for conservation management, and an additional 66 ac of conservation lands are present. The Zone lies in a salmonid cold water gap. The Upper Half Moon Bend revetment was not included in the CH2MHill assessment.

13. *Region 5 Zone 54 Hayden, Brown and Minto Islands* (Budd’s Chute, Eola Bend, Gray Eagle Bar, and Eyerly). Lying just south of West Salem on the Willamette River, the 2703-acre Zone includes four USACE revetments: Budd’s Chute (2067 ft) and Eola Bend (2913 ft) on the west side of the mainstem and Eyerly (2224 ft) and Grey Eagle Bar (4311 ft) on the east side. The Minto-Brown non-USACE revetment is present at the down stream end of the Zone. Thirty-six thousand feet of roads are present in the Zone. Prime soils occupy two-thirds of the Zone and erodible gravels are present in over ninety percent. The zone includes gravel pit ponds and a portion of a golf course. Twenty percent of the Zone is occupied by

frequently flooded floodplain forest and twelve percent of the Zone is designated as conservation lands. The Zone is in a salmonid cold water gap. The Eola Bend revetment was assigned to Tier 3 in the CH2MHill assessment.

14. *Region 5 Zone 61 Carlton Plant Nursery* (Stoutenburg and Lambert Slough). Lying ten miles south of Newberg on the west side of the mainstem Willamette, this 1391-acre Zone includes the Stoutenburg (3911 ft) revetment on the mainstem and the Lambert Slough (381 ft) revetment on the Slough. There are no non-USACE revetments in the Zone, but the 568-foot Stoutenburg upstream extension is contiguous with the Stoutenburg revetment. There are 9840 feet of road in the Zone.   Almost all of the Zone is in agricultural production. Prime soils occupy eighty-five percent of the Zone, and erodible gravels occupy ninety percent. Fifteen percent of the Zone is occupied by floodplain forest subject to two-year inundation. The Zone is in a salmonid cold water gap. The revetments were not included in the CH2MHill asssessment.

15. **Region 5 Zone 62 Horseshoe Lake* (Weston Bend). Two and one-half miles north of Zone 61 on the Willamette River, the 1347 acre Horseshoe Lake Zone includes the 5492-foot Weston Bend revetment (Fig. 12a). There are no non-USACE revetments in the Zone. Twenty-three thousand feet of roads lie within the Zone. Prime soils occupy three fourths of the Zone and erodible gravels are present in ninety-five percent.   Inundatable floodplain forest occupies twenty percent of the Zone. The Zone is in a salmonid cold water gap. The Weston Bend revetment was assigned to Tier 3 in the CH2MHill assessment (Damage appears stable – heightened vigilance and inspection is warranted).

    Notes from field reconnaissance: This 5000-ft+ revetment shows minor signs of damage (Fig. 12b). It protects >600 acres of high value crops, and in the process prevents the river from changing course onto a low-lying terrace to the north and northwest of the revetment where the agriculture occurs (Fig. 12c). A group of homes and agricultural processing buildings sits on a second terrace above Horseshoe Lake (Fig. 12d).

    As hypothetical illustrations of possible restoration options, Figure 12e shows current conditions (at left) and two future possibilities (center and right) for increasing natural river function at Weston Bend, with each future possibility affecting existing agricultural operations differently. Given the emphasis on improving habitat for federally-listed fish species, the habitat improvements shown focus on restoring channel complexity and frequently-inundated floodplain forest. The two possibilities shown would both involve a partial removal of the downstream portion of the Weston Bend revetment, using the removed rock to create a new revetment, either on the southern portion of the first terrace as shown in the center image of Figure 12e, or on the face of the second terrace on which the homes and agricultural buildings sit, as shown in the right image of Figure 12e.

> We emphasize that such options would only be worth considering if the agricultural land owners were willing participants and were to be adequately compensated for lost agricultural production. Similar arrangements compensating landowners for restoration uses of current agricultural lands are now in place in several locations in the southern Willamette Valley in the mainstem Willamette River floodplain. They require significant coordination among land owners, funders and potentially land trusts if conservation easements are the means chosen to achieve the change in land management. While such an approach would require willing participation by many individuals and sustained effort over many years, the potential for restored natural river function at Horseshoe Lake is large, especially since this reach of the river lacks cold water refuges during the warm water time of year. For this reason, we recommend the Weston Bend revetment at Horsehoe Lake as one of the top four revetments for further consideration but note that it will require substantial consultation and negotiation with adjacent land owners.

As a result of the field reconnaissance, three of the six field-visited 15 Phase 1 high priority Zones (Table 5) were eliminated from further consideration:

> Zone 10 Clearwater Park 2 (Booth-Kelly) due to recent USACE investments and repairs;
>
> Zone 47 Jefferson (Wickham) due to the societal importance of protected improvements; and
>
> Zone 72 Tranquility Lane (Clackamas Location 13) due to the revetment having been destroyed.

Further, another 3 of the 15 high priority Zones, and their associated four revetments (Table 6), were recommended for further consideration:

> Zone 29 Harkens Lake (Irish Bend and Lower Bend);
>
> Zone 50 Cole Island (Wilfert); and
>
> Zone 62 Horseshoe Lake (Weston Bend).

IV. Conclusion

At the conclusion of the 3 Phases of analysis, we recommend three Zones and their associated four revetments for more detailed consideration for removal or modification: Cole Island – Wilfert; Horseshoe Lake – Weston Bend; Harkens Lake – Irish Bend and Lower Bend. To determine the four recommended revetments, we employed the four box prioritization framework and associated factor data, made reference to the 2011 CH2MHill report and 2010 cold water gap data, and synthesized findings from the field reconnaissance of the six Zones visited. However, it must be noted that CH2MHill assessments and cold water data were not available for all of the 15 short-listed revetments and there may be other revetments, particularly those associated with the 12 Zones remaining from the 15 Zones originally identified in Phase 1, that may merit additional consideration (Table 6). In addition, other zones beyond these 12 may have biophysical opportunity or sociocultural constraint scores that located them slightly outside the lower right quadrant (Table 4), but because of various circumstances these Zones may still be appropriate for revetment modification or removal. This is especially true for those Zones located in the upper right quadrant, where high levels of current sociocultural constraints prevent the Zone from being located in the lower right quadrant. By modifying these constraints, through policy or on-the-ground change, the overall priority of a Zone can be improved.

The recommendations and method of analysis developed in this report provide an additional tool for the USACE as they prepare to implement more detailed studies of ecosystem restoration and enhancement projects in the Willamette basin. The USACE intends to use this approach to prioritize funding of the more detailed analyses and implementation efforts on the priority sites. In addition, the USACE intends to use this approach, over time and as resources are available, to reevaluate the other bank protection projects; and expand the evaluation to other projects not maintained by the USACE. The Willamette basin stakeholders may also employ this methodology to analyze both federal or non-federal revetment projects for their planning purposes.

The analysis tools and priorities established in this report will further assist the USACE in the development of justifications and requests for Congressional appropriations for more in-depth studies. The USACE currently has several authorities that could apply to modification of authorized projects for the purpose of ecosystem enhancement and restoration. Typically, these authorities require the USACE to identify and partner with non-Federal sponsors and require that the sponsors share in the study and construction costs.

To summarize our conclusions and recommendations:

1. We are confident the four top priority revetments are good candidates, but additional good sites likely exist and we recommend they be considered;
2. Development of a 2-year flood inundation zone map for mainstem *and* tributaries would provide the ability to more holistically assess restoration opportunities;

3. Water temperature and native fish abundance databases supported by sampling are needed in the lower reaches of tributaries to match those available for the mainstem Willamette;
4. Expand this type of assessment to all revetments in the Willamette Basin;
5. Convene a workshop, which includes those from the restoration, regulatory, and engineering communities, to discuss revetment modification and implementation approaches. To continue progress toward revetment modification, the meeting may need to consider formation of a workgroup to meet periodically to share information on techniques and approaches, and otherwise help advance revetment modification activities;
6. NOAA should consider developing a programmatic permitting approach for revetment modifications, to streamline associated regulatory activities;
7. Successful revetment removal/modification must be pursued with careful and responsive listening to the interests, plans and capacities of those most effected by proposed restoration actions.

V. Limitations of the approach

The rankings of revetments reported in this document are an outgrowth of the overall prioritization framework and the relative weights assigned to the Factors by the Habitat Technical Team. A change in the conceptual framework or these weights has the potential to cause changes in the Zone priorities. The approach is amenable to revising the weights assigned to the Factors and re-tabulating the resultant Zone priorities.

The prioritization presented here addressed only a portion of all revetments on the Willamette River and its major tributaries. As a result, there may be revetments not considered here that, by virtue of their sociocultural constraints and biophysical opportunities, would be ranked as high or higher than those recommended.

The stepwise nature of the three phases of the prioritization approach, and the fact that important data sets were not available for the full study area, means that a reasonable case can be made for revetments other than the four we most highly recommend. This is especially true for the other Zones on Table 6 that were not among our top 4. The findings of Phases 1 and 2, combined with finite time for field reconnaissance and the absence of either cold water refuge or CH2MHill damage assessments for some Zones, directed us to the four revetments we recommend. We are confident of these recommendations, but acknowledge that other good candidates for revetment removal or modification remain beyond these four revetments.

VI. Future Research And Data Needs

The absence of certain key data sets constrained the information that could be brought to bear in this prioritization. A consistent representation of area inundated by a 2-year regulated flood is currently available for the floodplain of the mainstem Willamette River, but has not been assembled for all the major westward-flowing tributaries. We recommend a consistent 2-year flood inundation data set be created for the tributaries, up to the first federal dam, and joined with the same information for the mainstem Willamette. If available funds require this be done in sequence, we recommend beginning with the Santiam and McKenzie Rivers. A conservation and restoration-oriented prioritization, change-tracking and data reporting framework is now in place for the Willamette River floodplain (http://ise.uoregon.edu/slices/Main.html). We recommend it be extended up the major westward-flowing tributaries to the first federal dam. A systematic database developed under consistent sampling and reporting protocol is also needed for water temperature (cold water refuges) and native fish abundance in the lower reaches of the Clackamas, North, South and mainstem Santiam, McKenzie, Middle Fork and Coast Fork Rivers to match that currently available for the Willamette River (Schroeder et al. 2011, Hulse et al. 2013). If available funds require this be done in sequence, we recommend beginning with the Santiam and McKenzie Rivers.

We acknowledge that the prioritization described in this document was focused solely on the USACE-maintained revetments, which are a subset of all revetments currently effecting the Willamette and its major tributaries. We recommend the approach described here or a suitable alternative be applied to the complete set of Willamette River Basin revetments, thus producing a set of revetment-related recommendations to restore natural river function independent of who owns, operates or maintains the revetment.

Future management of the USACE revetments along the Willamette River and its tributaries will require effective conversations with the public and potentially affected private landowners. Discussions with the public will be enhanced by improved information on potential future hydrologic regimes, status and effectiveness of existing revetments, complex effects of revetments on upstream and downstream reaches that cause additional river change, alternatives to revetments, and possible modifications that maintain some degree of channel control while providing flood dissipation and increased winter habitat for native fish. The technical abilities of the USACE make it well prepared for design and implementation of revetment modifications, but social innovations and increased capacity to share information with the public may hold even greater promise for future revetment management (NRC 2012).

Finally, we end with a recommendation that grows from our deepened appreciation of how intertwined people's lives in the floodplain have become with the river controls afforded by USACE Willamette Project dams and revetments. While prioritizations to restore natural river function can and should be based on quantitative measures of relative cost and benefit, the half-century long accommodation that has occurred to a changed river cannot be quickly undone without disruption to long-standing investments, patterns of land use and ways of life. The successes of floodplain restoration that have occurred in the Willamette in the past decade have avoided such disruptions by *combining* lessons of systematic spatial prioritization *together* with careful and responsive listening to the interests, plans and capacities of those most effected by restoration-driven change on the ground (OWEB 2010). We recommend a similar approach be taken as the next step in revetment alteration to restore natural river function.

VII. References

Beechie, T., G.Pess, and P. Roni. 2008. Setting River Restoration Priorities: a Review of Approaches and a General Protocol for Identifying and Prioritizing Actions. North American Journal of Fisheries Management 28:891-905.

Benner P., and J.R. Sedell, 1997. "Upper Willamette River: A Historic Perspective", Pages 23-47 in Dunnette, D.A., River Quality: Dynamics and Restoration. CRC Press, Boca Raton, Florida, USA.

Bernhardt, E.S., M.A. Palmer, J.D.Allan, G. Alexander, K. Barnas, S. Brooks, J. Carr, S. Clayton, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G.M. Kondolf, P.S. Lake, R. Lave, J.L. Meyer, T.K. O'Donnell, L. Pagano, B. Powell, E. Sudduth. 2005. Synthesizing U.S. River Restoration Efforts. Science. 29 April 2005. Vol. 308.

Bernhardt, E.S., M. Palmer. 2011. River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation. Ecological Applications. 21 (6) 1926-1931.

Bernhardt, E. S., E. B. Sudduth, M. A. Palmer, J. D. Allan, J. L. Meyer, G. Alexander, J. Follastad-Shah, B. Hassett, R. Jenkinson, R. Lave, J. Rumps, and L. Pagano. 2007. Restoring rivers one reach at a time: results from a survey of US river restoration practitioners. Restoration Ecology 15:482–493.

CH2MHill. 2011. Willamette River Basin, Oregon Bank Protection and Channel Improvement Damage Assessment and Maintenance Repair Reconnaissance Report. Prepared for the U.S. Army Corps of Engineers Portland District. WBG110410222457PDX, USACE Portland District, 333 SW 1st Ave # 200 Portland, OR 97204.

Colvin, R., G.R. Giannico, J. Li, K. Boyer, W.J. Gerth. 2009. Fish use of intermittent watercourses draining agricultural lands in the Upper Willamette River Valley, Oregon. Transactions of the American Fisheries Society. 138:6, 1302-1313.

Ebersole, J.L., W.J. Liss, and C.A.Frissell. 2003. Thermal heterogeneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. Can. J. Fish. Aquat. Sci. 60: 1266–1280.

Federal Emergency Management Agency (FEMA). 2009. Engineering with nature: alternative techniques to riprap bank stabilization. Accessed online May 16, 2013. http://www.fema.gov/pdf/about/regions/regionx/Engineering_With_Nature_Web.pdf

Fernald, A. G., D. H. Landers, and J. P.J. Wigington. 2006. Water quality changes in hyporheic flow paths between a large gravel bed river and off-channel alcoves in Oregon, USA. River Research and Applications 22:1111-1124.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. Bioscience 41:540-551.

Gregory, S. and D. Hulse. 2002. Conceptual and Spatial Framework for River Restoration. Pages 132-133 in D. Hulse, S. Gregory, and J. Baker, editors. Willamette River Basin planning atlas: trajectories of environmental and ecological change. Oregon State University Press, Corvallis, Oregon, USA.

Gregory, S., L. Ashkenas, D. Oetter, R. Wildman, P. Minear, S. Jett and K. Wildman. 2002a. Revetments. Pages 32–33 in D. Hulse, S. Gregory, and J. Baker, editors. Willamette River Basin planning atlas: trajectories of environmental and ecological change. Oregon State University Press, Corvallis, Oregon, USA.

Gregory, S., L. Ashkenas, D. Oetter, P. Minear and K. Wildman. 2002b. Historical Willamette River Channel Change. Pages 18–25 in D. Hulse, S. Gregory, and J. Baker, editors. Willamette River Basin planning atlas: trajectories of environmental and ecological change. Oregon State University Press, Corvallis, Oregon, USA.

Gregory, S., L. Ashkenas, D. Oetter, P. Minear and K. Wildman. 2002c. Longitudinal Patterns – Floodplain Vegetation. Pages 136–137 in D. Hulse, S. Gregory, and J. Baker, editors. Willamette River Basin planning atlas: trajectories of environmental and ecological change. Oregon State University Press, Corvallis, Oregon, USA.

Gregory, S.V., L.R. Ashkenas, and C. Nygaard. 2007. Summary Report: Environmental Flows Workshop for the Middle Fork and Coast Fork of the Willamette River, Oregon. Report of the Institute for Water and Watersheds, Oregon State University, Michael Campana, Director.

Habitat Technical Team (HTT) Charter. 2009. Accessed online November 1, 2011.

Hawkins, C.P., M.L. Murphy, N.H. Anderson, and M.A. Wilzbach. 1983. Density of Fish and Salamanders in Relation to Riparian Canopy and Physical Habitat in Streams of the Northwestern United States. Canadian Journal of Fisheries and Aquatic Sciences. 40(8):1173.

Holling, C.S. 2001 Understanding the complexity of economic, ecological and social systems. Ecosystems. 4: 390-405.

Holling, C.S. and L. Gunderson. 2002. Resilience and Adaptive Cycles, ch. 2 in Panarchy: understanding transformations in human and natural systems. Island Press. ISBN: 1-55963-857-5.

Hulse, D. And S.V. Gregory. 2001. Alternative Futures as an integrative framework for riparian restoration of large rivers, chapter 9 in Applying Ecological Principles to Land Management, V.H. Dale and R. Haeuber (eds.). Springer-Verlag, New York. Pp. 194-212. ISBN 0-387-95099-0.

Hulse, D. and S. Gregory. 2004. Integrating resilience into floodplain restoration. Journal of Urban Ecology. Special Issue on Large-Scale Ecosystem Studies: Emerging trends in urban and regional ecology, vol. 7, pp. 295-314.

Hulse, D., S. Gregory, J. Baker. (Eds). 2002. Willamette River Basin Planning Atlas: Trajectories of environmental and ecological change. (2nd edition), Oregon State University Press, Corvallis, Oregon 97333. 180 p. http://www.fsl.orst.edu/pnwerc/wrb/Atlas_web_compressed/PDFtoc.html

Hulse, D., S. Gregory, A. Branscomb, C. Enright, R. Wildman. 2008. Linking cold water refuges into a biologically effective network in the southern Willamette River floodplain: outlining key locations and knowledge gaps. http://www.willamettepartnership.org/publications

Hulse, D.W., S.V. Gregory, A. Branscomb, C. Enright and C. Brehm. 2013. Slices: An information framework for a biologically effective Willamette River floodplain. Spatial and tabular data regarding mainstem cold water refuges ca. 2010. Accessed April 30, 2013. [machine readable data files]. http://ise.uoregon.edu/slices/Main.html

Ja¨ hnig, S. C., A. W. Lorenz, D. Hering, C. Antons, A. Sundermann, E. Jedicke, and P. Haase. 2011. River restoration success: a question of perception. Ecological Applications 21:2007–2015.

Kondolf, G.M., 2006. River Restoration and Meanders. Ecology and Society 11(2):42.

Landers, D., A. Fernald, C. Andrus. 2002. Off-channel Habitats. Pages 26–27 in D. Hulse, S. Gregory, and J. Baker, editors. Willamette River Basin planning atlas: trajectories of environmental and ecological change. Oregon State University Press, Corvallis, Oregon, USA.

Larsen, E.W. 2008. Modeling Revetment Removal and Implications for Meander Migration of Selected Bends River Miles 222 to 179 of the Sacramento River. Final Technical Report for Ducks Unlimited. 31 pp.

Lestelle, L., W. E. McConnaha, G. Blair, and B. Watson. 2005. Chinook salmon use of floodplain, secondary channel and non-natal tributary habitats in river of Western North America: Application to the Willamette River (Oregon) and Formulation of Species-Habitat Rules for EDT Analysis. Prepared by Mobrand-Jones & Stokes for Mid-Willamette Council of Governments U.S. Army Corps of Engineers.

Linstone, H.A. and Turoff, M. 2011. Delphi: A brief look backward and forward. Technological Forecasting and Social Change, vol. 78, pp 1712-1719.

Loomis, J., P. Kent, L. Strange. K. Fausch, and A. Covich. 2000. Measuring the Total Economic Value of Restoring Ecosystem Services in an Impaired River Basin: Results from a Contingent Valuation Survey. Ecological Economics. 33, pp. 103-117.

McConnaha, W.E., B. Torell, B. Dykaar. 2006. Analysis of the potential benefits of floodplain habitats in the Middle Fork Willamette River using geomorphic splice analysis. Prepared by Mobrand-Jones & Stokes and Ecohydrology West for Mid-Willamette Council of Governments, U.S. Army Corps of Engineers and Oregon Dept. of Fish and Wildlife. 31 pp.

Naiman, R.J., J.J. Magnuson, D.M. Knight, J.A. Stanford. (eds). 1995. The freshwater imperative: a research agenda. Island Press, Wash. D.C.

National Marine Fisheries Service. (NMFS) 2008. Endangered Species Act Section 7(a)(2) Consultation. Biological Opinion & Magnuson-Stevens, Fishery Conservation & Management Act, Essential Fish Habitat Consultation. Consultation on the "Willamette River Basin Flood Control Project". NOAA Fisheries Log Number: FINWRl2000/02117. July 11, 2008.

National Research Council (NRC). 2012. Corps of Engineers Water Resources Infrastructure: Deterioration, Investment, or Divestment?. Committee on U.S. Army Corps of Engineers Water Resources Science, Engineering, and Planning. Water Science and Technology Board, Division on Earth and Life Sciences. The National Academies Press. Wash. D.C. online at http:www.nap.edu/openbook.php?record_id=13508&page=R1.

O'Connor JE, Sarna-Wojcicki A, Wozniak KC, Polette DJ and RJ Fleck. 2001. Origin, extent, and thickness of Quaternary geologic units in: Willamette Valley, Oregon. Professional Paper 1620, U.S. Geological Survey, Reston, Virginia.

Oregon Department of Fish and Wildlife (ODFW). 2011. Upper Willamette River conservation and recovery plan for Chinook salmon and steelhead. Executive Summary. Accessed April 2012 from: http://www.dfw.state.or.us/fish/CRP/upper_willamette_river_plan.asp

Oregon Watershed Enhancement Board (OWEB). 2010. Willamette River Habitat Protection and Restoration Program 2010-2015: a proposal of the Habitat Technical Team.
Available online at: www.nwcouncil.org/fw/projectselection/BiOp/200901200.pdf

Palmer, M.A., E.S. Bernhardt, J.D. Allan, P.S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C. N. Dahm, J. Follstad Shah, D.L. Galat, G. Loss, P. Goodwin, D.D. Hart, B. Hassett, R. Jenkinson, G. M. Kondolf, R. Lave, J. L. Meyer, T.K. O'Donnell, L. Pagano, E. Sudduth. 2005. Standards for ecologically successful river restoration. J. of Applied Ecology. 42:208-217.

Palmer, M. 2012. Socioenvironmental sustainability and actionable science. Bioscience. 62 (12) 5-6.

Payne, S., J. Goicochea Duclos. 2002. Road Density. Pages 70–71 in D. Hulse, S. Gregory, and J. Baker, editors. Willamette River Basin planning atlas: trajectories of environmental and ecological change. Oregon State University Press, Corvallis, Oregon, USA.

PNW-ERC (Pacific Northwest Ecosystem Research Consortium) 2002. Digital Spatial Data available online at: http://www.fsl.orst.edu/pnwerc/wrb/access.html [machine readable data files].

Risley, J.C., R. Wallick, J. Mangano, K. Jones. 2012. An environmental streamflow assessment for the Santiam River Basin, Oregon. U.S. Geological Survey Open-File Report 2012-1133, 60 p. plus appendices.

River Design Group (RDG). 2012. Willamette River Floodplain Inundation Mapping: Eugene to Oregon City, Oregon. 311 SW Jefferson Avenue, Corvallis, OR 97333.

River Design Group (RDG). 2013. Harkens Lake Inundation Investigation and Restoration Alternatives Analysis: Draft Report 2. 311 SW Jefferson Avenue, Corvallis, OR 97333. Submitted to Greenbelt Land Trust March 1, 2013.

Schroeder, K. B. Cannon, L. Whitman. 2011. Willamette Spring Chinook: Life in the river. Internal publication. Oregon Department of Fish and Wildlife. 28655 Highway 34, Corvallis, OR. 97333. 6 pp.

Seedang, S, A.G. Fernald, R.M. Adams, and D.H. Landers. 2008. Economic Analysis of Water Temperature Reduction Practices in a Large River Floodplain: An Exploratory Study of the Willamette River, Oregon. River. Res. Applic. 24: 941–959.

Soulsby, C., I.A. Malcom, D. Tetzlaff, and A.G. Youngson. 2009. Seasonal and Inter-annual Variability in Hyporheic Water Quality Revealed by Continuous Monitoring in a Salmon Spawning Stream. River. Res. Applic. 25: 1304-1319.

TerraPoint. 2004. LIDAR data and metadata provided by Puget Sound LIDAR Consortium.

Tullos, D. D., D. L. Penrose, G. D. Jennings, and W. G. Cope. 2009. Analysis of functional traits in reconfigured channels: implications for the bioassessment and disturbance of river restoration. Journal of the North American Benthological Society 28:80–92.

U.S. Army Corps of Engineers (USACE). 1989. Willamette River Bank Protection Programs Summary. Portland District. Electronic document obtained from USACE, Portland District Office, January 2012. 58 pgs.

U.S. Army Corps of Engineers (USACE), Bonneville Power Administration and U.S. Bureau of Reclamation. 2007. Supplemental Biological Assessment of the effects of the Willamette River Basin Flood Control Project on species listed under the Endangered Species Act. USACE, Portland District, 333 SW 1st Ave # 200 Portland, OR 97204.

U.S. Army Corps of Engineers (USACE). 2012. Revetment database. Digital geodatabase of all known revetments within the Willamette Basin. Includes USACE and non-USACE revetments. Obtained from Jerry Otto, USACE Portland District Office, May 2012. [machine readable data files].

U.S. Department of Agriculture (USDA). 2012. Natural Resources Conservation Service. National soil survey handbook, title 430-VI. Farmland Classification (622.03) Available online at http://soils.usda.gov/technical/handbook/contents/part622.html Accessed [02/16/2012].

U.S. Department of Commerce. 2011. 2010 Census Summary File 1 [Oregon]/prepared by the U.S. Census Bureau. [machine readable data files].

U.S. Fish and Wildlife Service (USFWS). 2008. Biological Opinion On the Continued Operation and

Maintenance of the Willamette River Basin Project and Effects to Oregon Chub, Bull Trout, and Bull Trout Critical Habitat Designated Under the Endangered Species Act. As Proposed by: U.S. Army Corps of Engineers (Department of Army) Bonneville Power Administration (Department of Energy) and Bureau of Reclamation (Department of Interior).

Wallick, J.R., S.T. Lancaster, and J.P. Bolte, 2006. Determination of bank erodibility for natural and anthropogenic bank materials using a model of lateral migration & observed erosion along the Willamette River, Oregon, USA, River Research and Applications, 22(6), 631-649

Ward, J.V., 1998. Riverine Landscapes: Biodiversity Patterns, Disturbance Regimes, and Aquatic Conservation. Biological Conservation 83(3): 269-278.

Watershed Sciences, Inc. 2007. LIDAR Remote Sensing Data Collection: Department of Geology and Mineral Industries and Oregon Department of Forestry. 42 page report and LIDAR data. Provided by Puget Sound LIDAR Consortium.

Watershed Sciences, Inc. 2009. LIDAR Remote Sensing Data Collection: Department of Geology and Mineral Industries LIDAR. Willamette Valley Phase 1, Oregon. 43 page report and LIDAR data. Provided by Department of Geology and Mineral Industries.

Whiteway, S. L., P. M. Biron, A. Zimmermann, O. Venter, and J. W. A. Grant. 2010. Do in-stream restoration structures enhance salmonid abundance? A meta-analysis. Canadian Journal of Fisheries and Aquatic Sciences 67:831–841.

Whol, E., 2005. Compromised Rivers: Understanding Historical Human Impacts on Rivers in the Context of Restoration. Restoration. Ecology and Society 10(2): 2.

Whol, E., P.L. Angermeier, B. Bledsoe, G. M. Kondolf, L. MacDonnell, D.M. Merritt, M.A. Palmer, N.L. Poff, and David Tarboton. 2005. River Restoration. Water Resources Research 41: W1031.

Figure 1. Context map of USACE-maintained revetments in the Willamette Basin

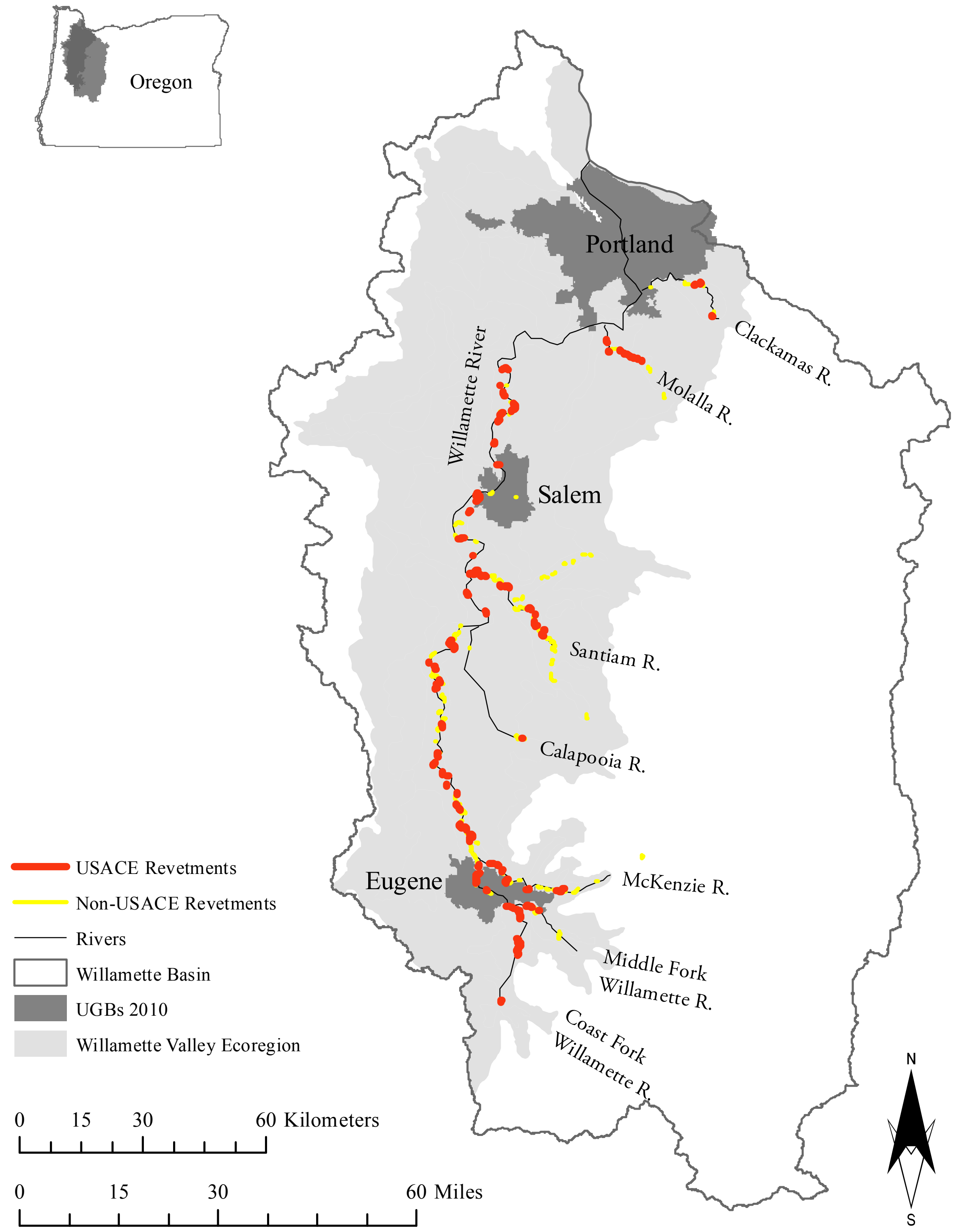

Figure 2. 4-box conceptual diagram: Each revetment Zone of Influence is placed within one of the four quadrants of the 4-box diagram. Note the lower right quadrant is where opportunities are greatest and constraints least.

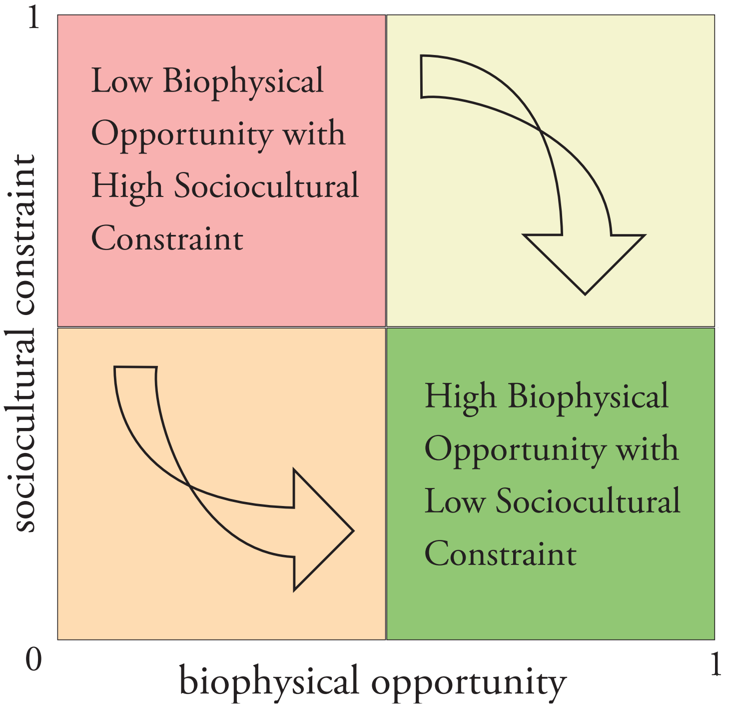

Figure 3. Map of 72 Zones of Influence: Note that Zones of Influence tend to be larger in the mainstem Willamette River than in the tributaries.

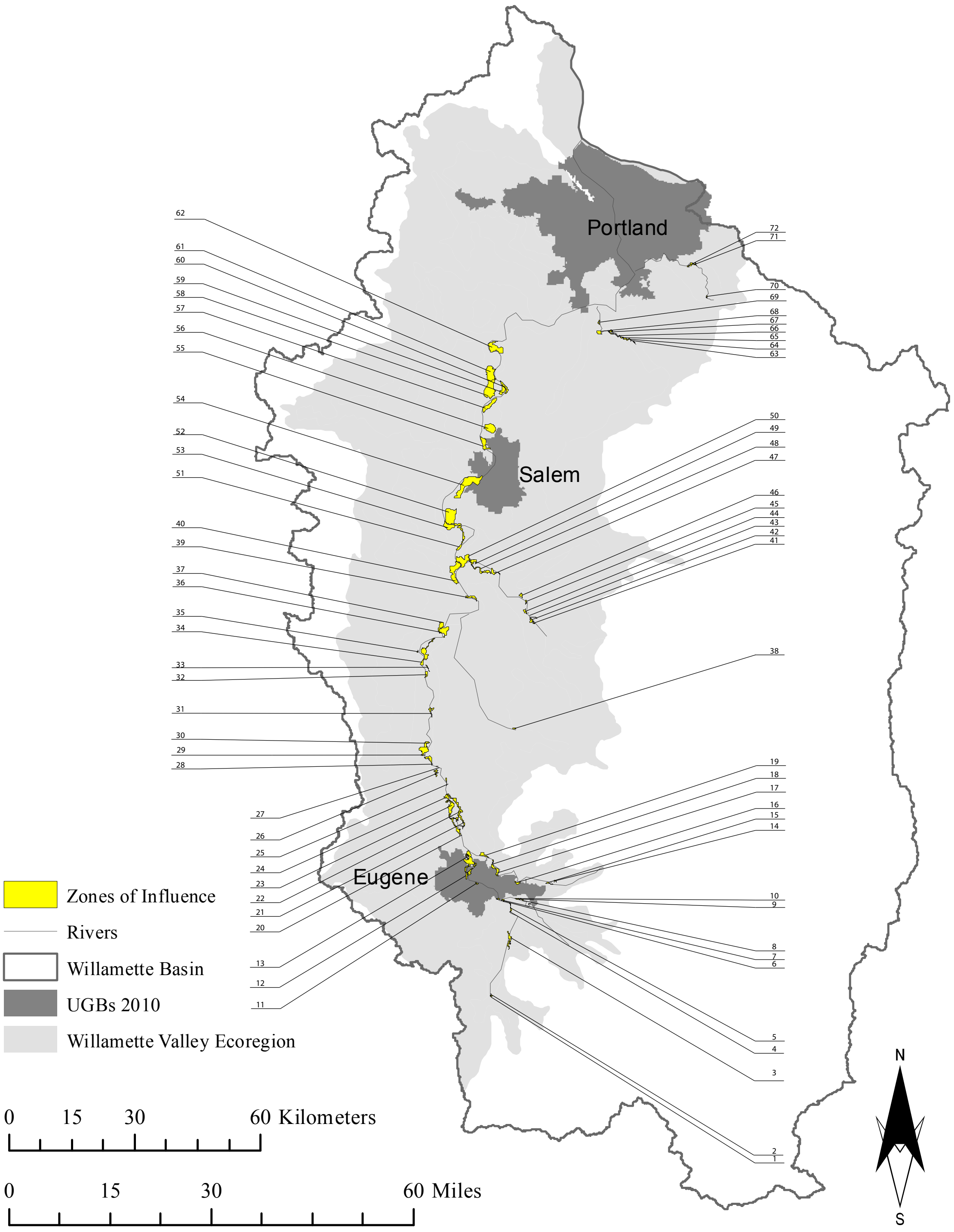

Figure 4. Map of 5 Regions: The Zones were prioritized separately for each of 5 regions, so that habitat improvement benefits of revetment removal or modification would be geographically distributed.

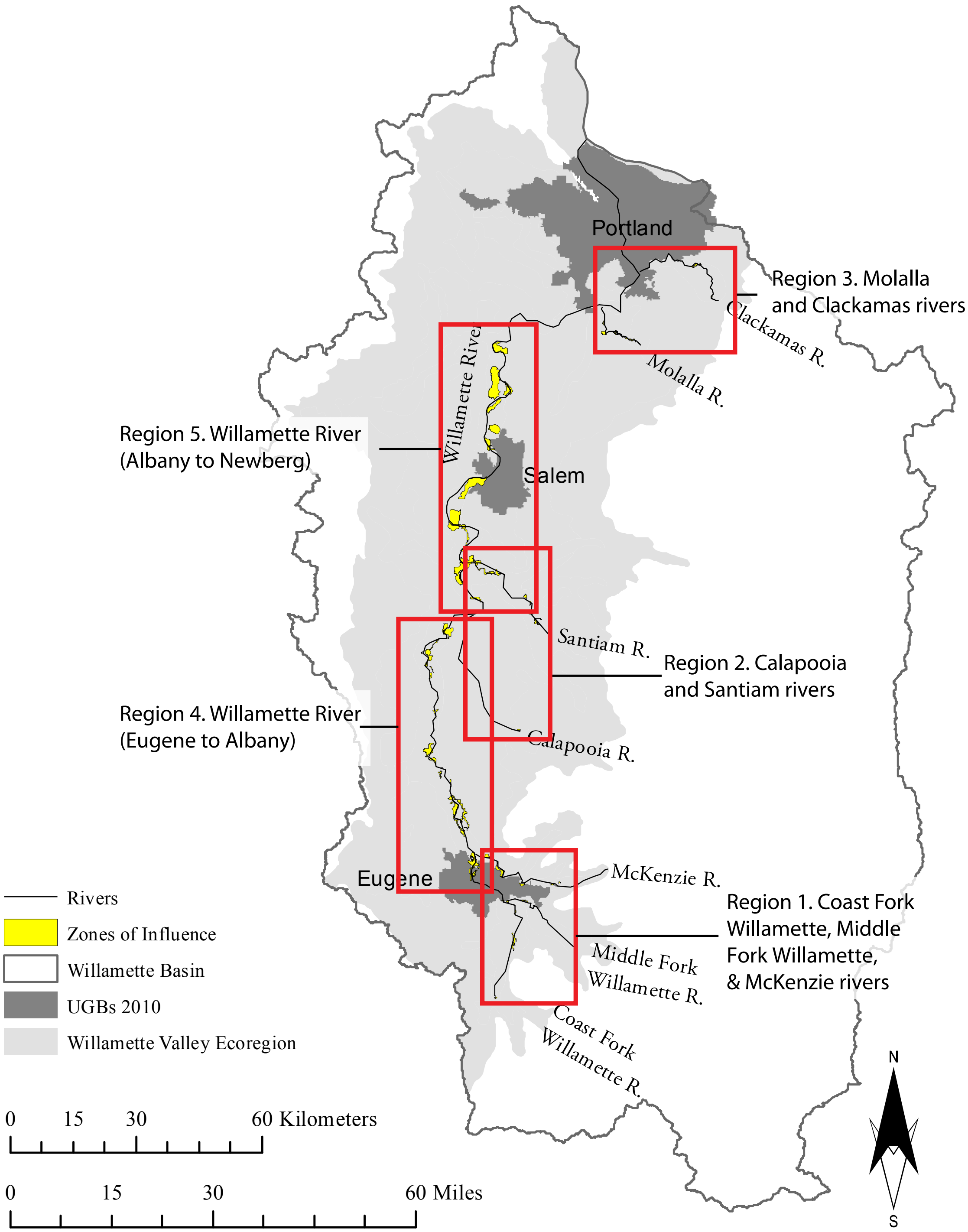

Figure 5. Map of 15 high priority Zones of Influence resulting from Phase 1 prioritization: At least two Zones are present in each of the 5 regions shown in Figure 4.

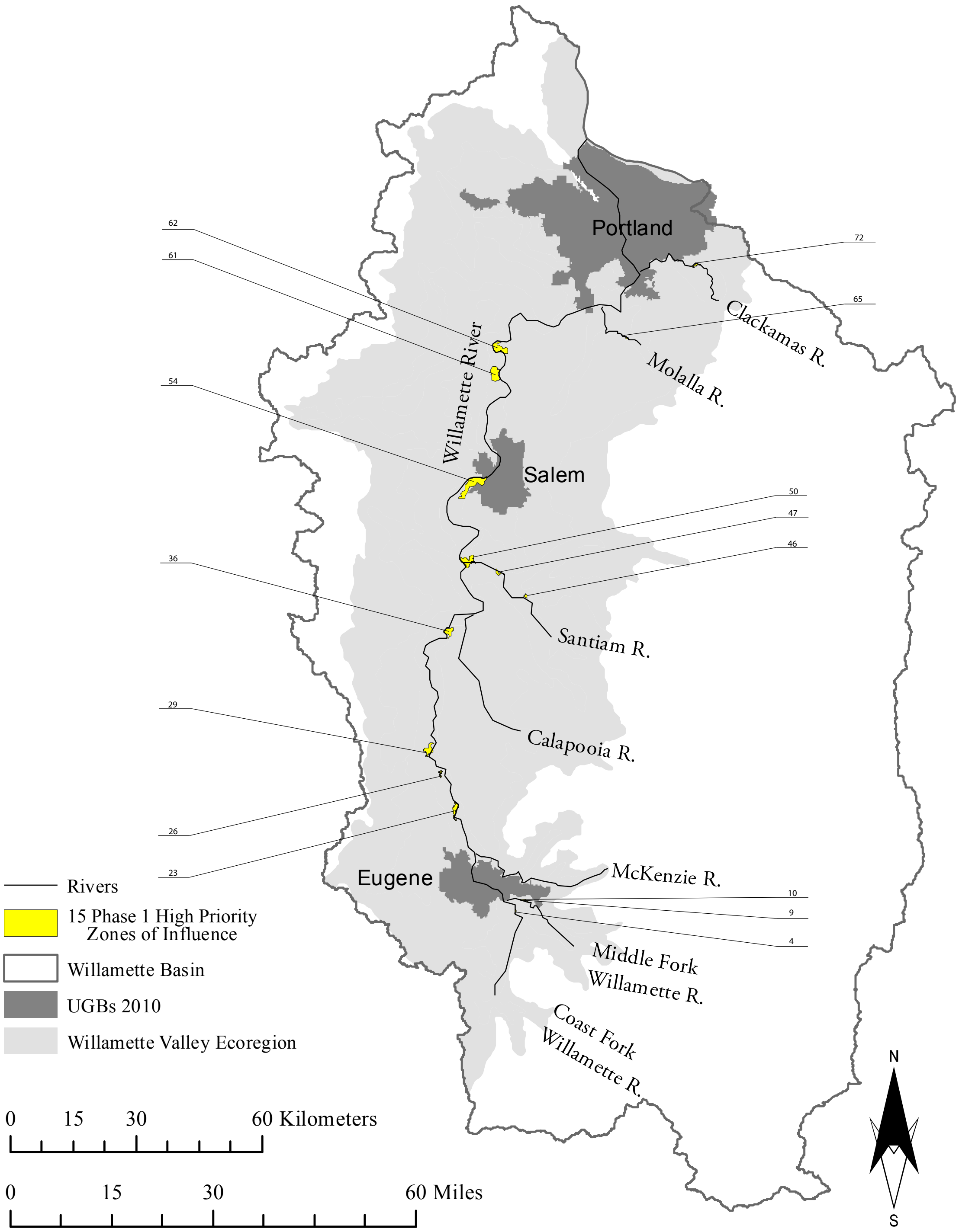

Figure 6. Map of cold water refuges in the mainstem Willamette River ca. 2010 with 15 Phase 1 high priority Zones of Influence: If any portion of a Zone was > 1 km from a cold water refuge, it was considered to be in a cold water gap (Tables 5 & 6). See http://ise.uoregon.edu/slices/main.html for additional detail.

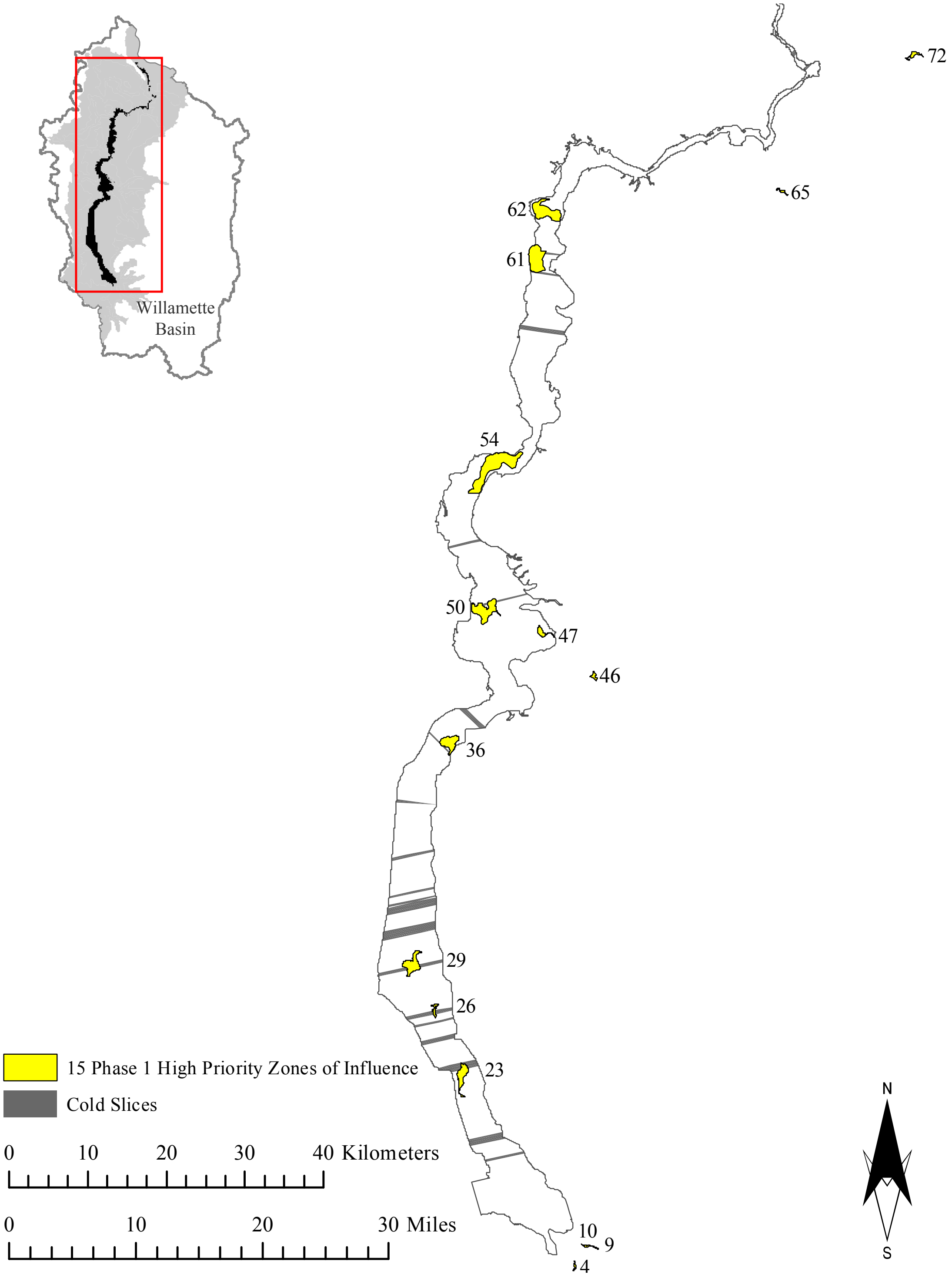

Figure 7a. Aerial photograph of Zone 9 Clearwater Park 1 (A.C. Clearwater) on Middle Fork Willamette River with key to ground-level photographs: Note shallow, former gravel pits on south bank that are part of The Nature Conservancy's Confluence Project restoration effort, now being planned.

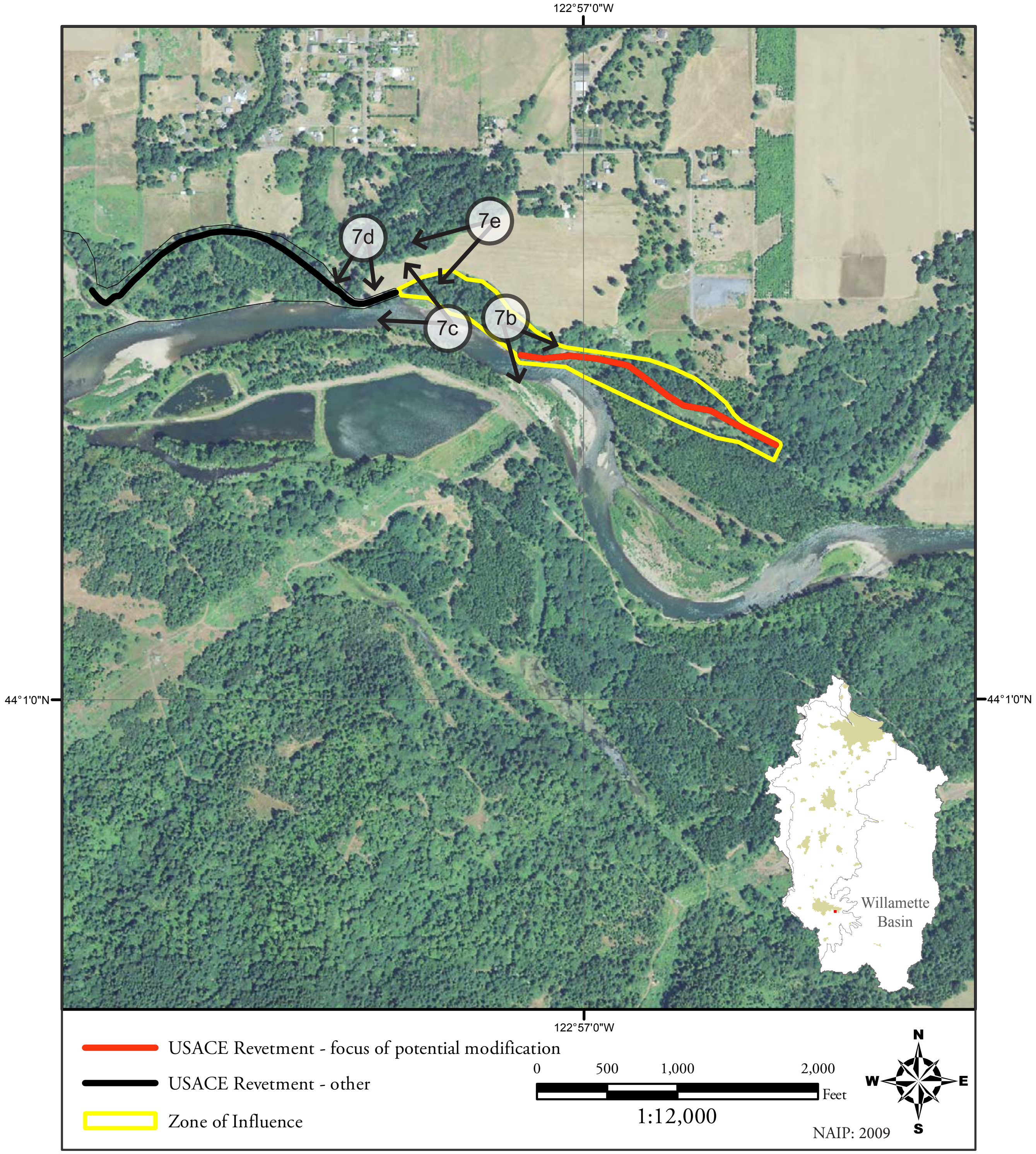

Figure 7b

Figure 7c

Figure 7d

Figure 7e

Figure 7b: view of damage to A.C. Clearwater revetment.

Figure 7c: floodplain forest on right bank, immediately downstream of A.C. Clearwater revetment.

Figure 7d: boat ramp under construction with bank hardening on both sides.

Figure 7e: aerial view of boat ramp and recreational access parking under construction.

Figure 8a. Aerial photograph of Zone 47 Jefferson (Wickham) on mainstem Santiam River with key to ground-level photographs.

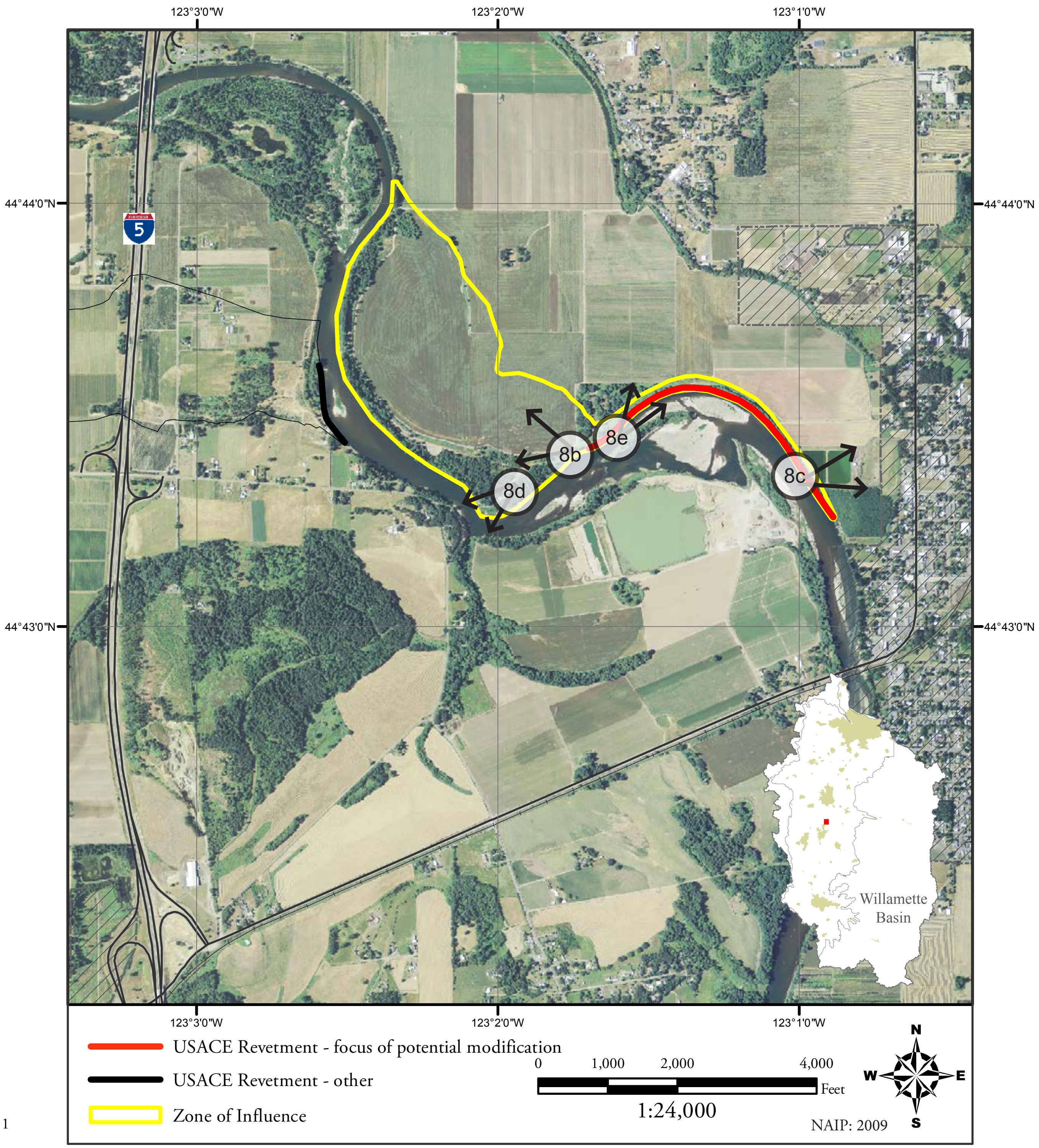

Figure 8b

Figure 8c

Figure 8d

Figure 8e

Figure 8b: The majority of Zone 47 is in active agricultural use.

Figure 8c: The City of Jefferson's wastewater facility is protected by the Wickham revetment.

Figure 8d: A 15 acre patch of frequently inundated floodplain forest is immediately downstream of the revetment.

Figure 8e: Damage to the downstream end of the Wickham revetment.

Figure 9a. Aerial photograph of Zone 50 Cole Island (Wilfert) on mainstem Santiam River with key to ground-level photographs.

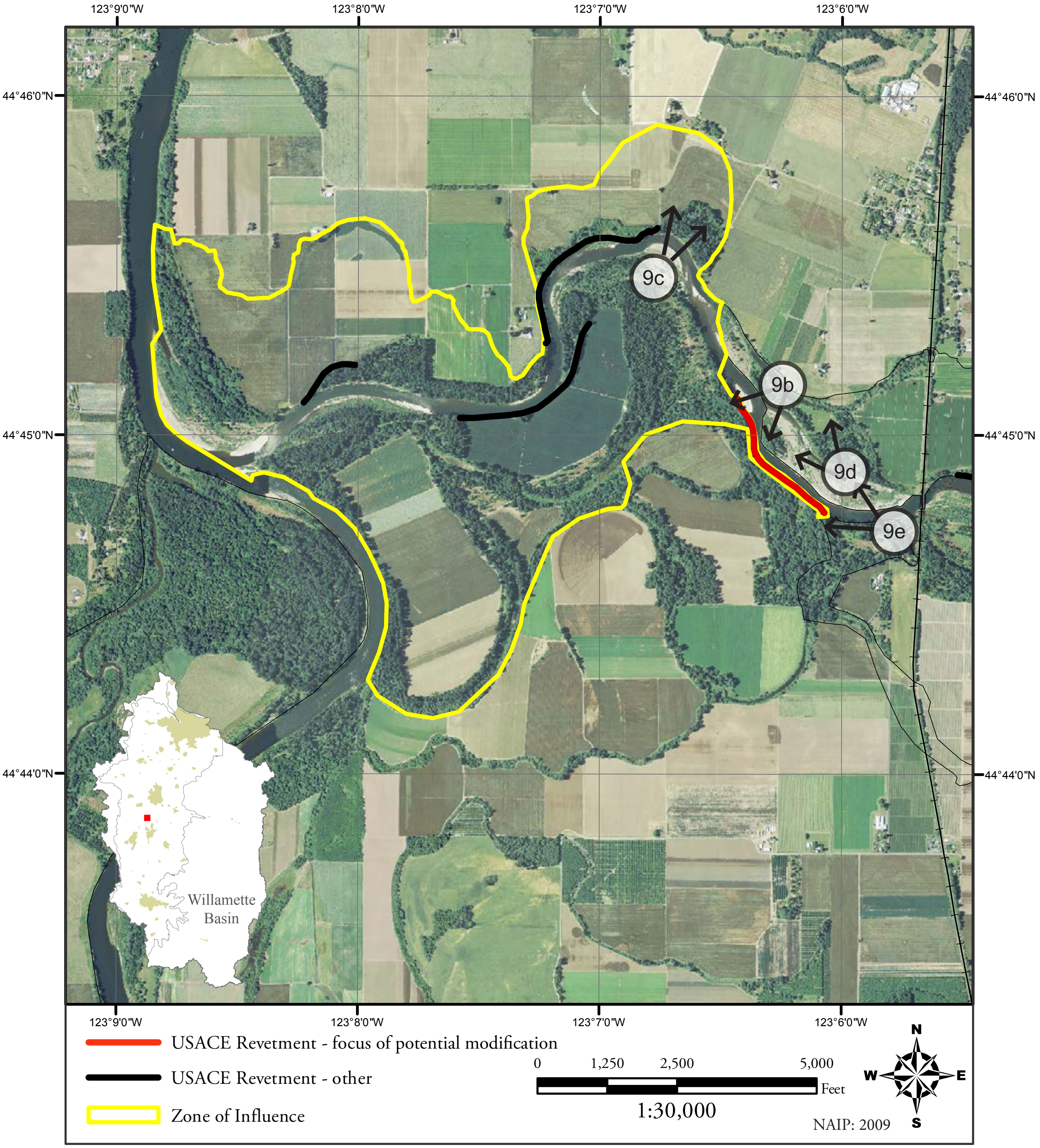

Figure 9b

Figure 9c

Figure 9d

Figure 9e

Figure 9b: Damage to the Wilfert revetment at its northern extent.

Figure 9c: A mature stand of river willow on the north bank of the Santiam River.

Figure 9d: Recent gravel deposition opposite the Wilfert revetment.

Figure 9e: The Wilfert revetment on the left bank.

Figure 10a. Aerial photograph of Zone 72 Tranquility Ln. (Location 13) on mainstem Clackamas River with key to ground-level photographs.

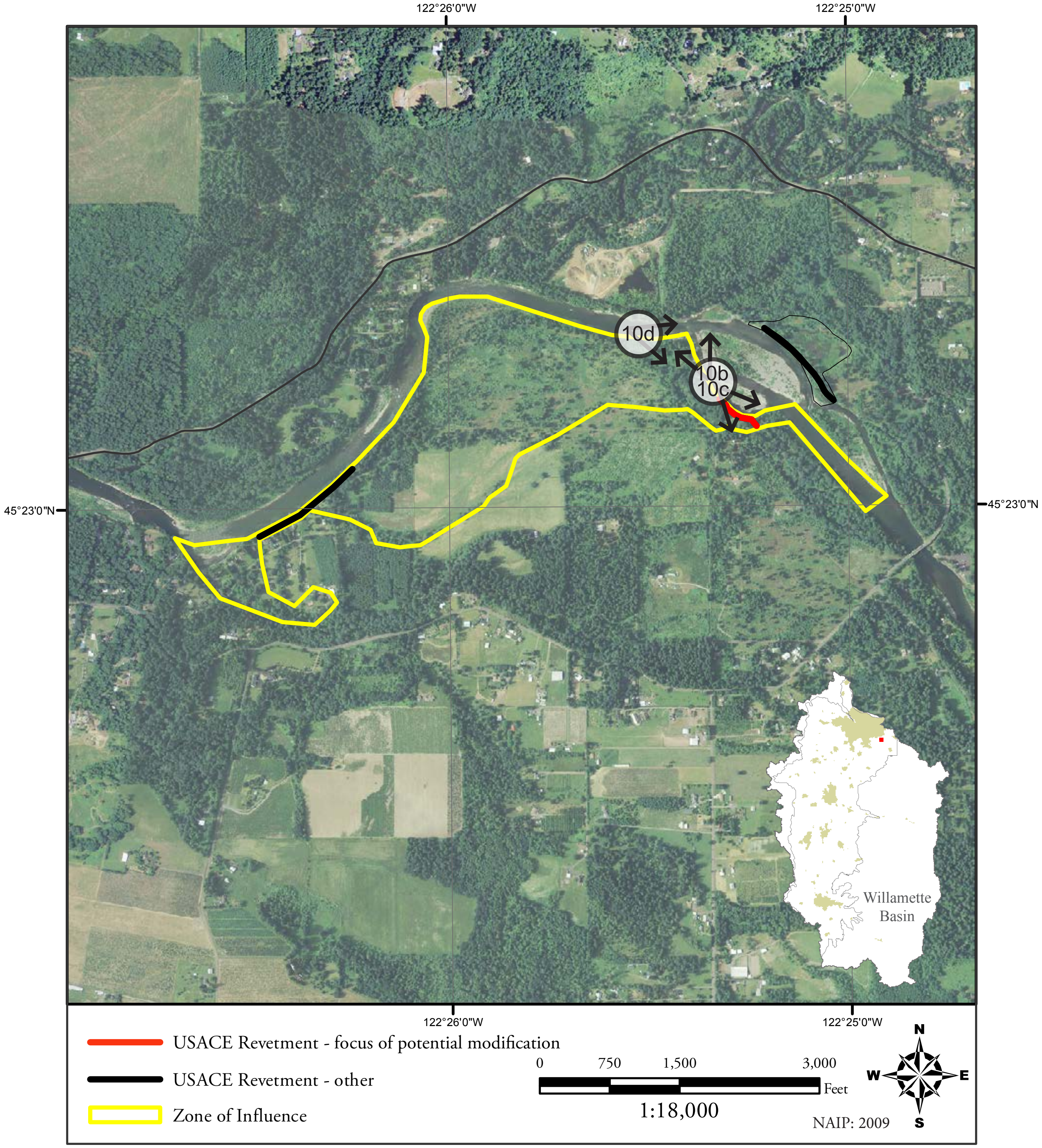

Figure 10b

Figure 10c

Figure 10d

Figure 10b: The former location of Clackamas revetment 13 looking downriver.

Figure 10c: Looking upriver from the former site of Clackamas revetment 13.

Figure 10d: Gravel bar complex in main stem Clackamas River, immediately north of the former revetment 13. A restored side channel enters the Clackamas at the right edge of the photograph.

Figure 11a. Aerial photograph of Zone 29 Harkens Lake (Irish Bend and Lower Bend) on mainstem southern Willamette River with key to ground-level photographs.

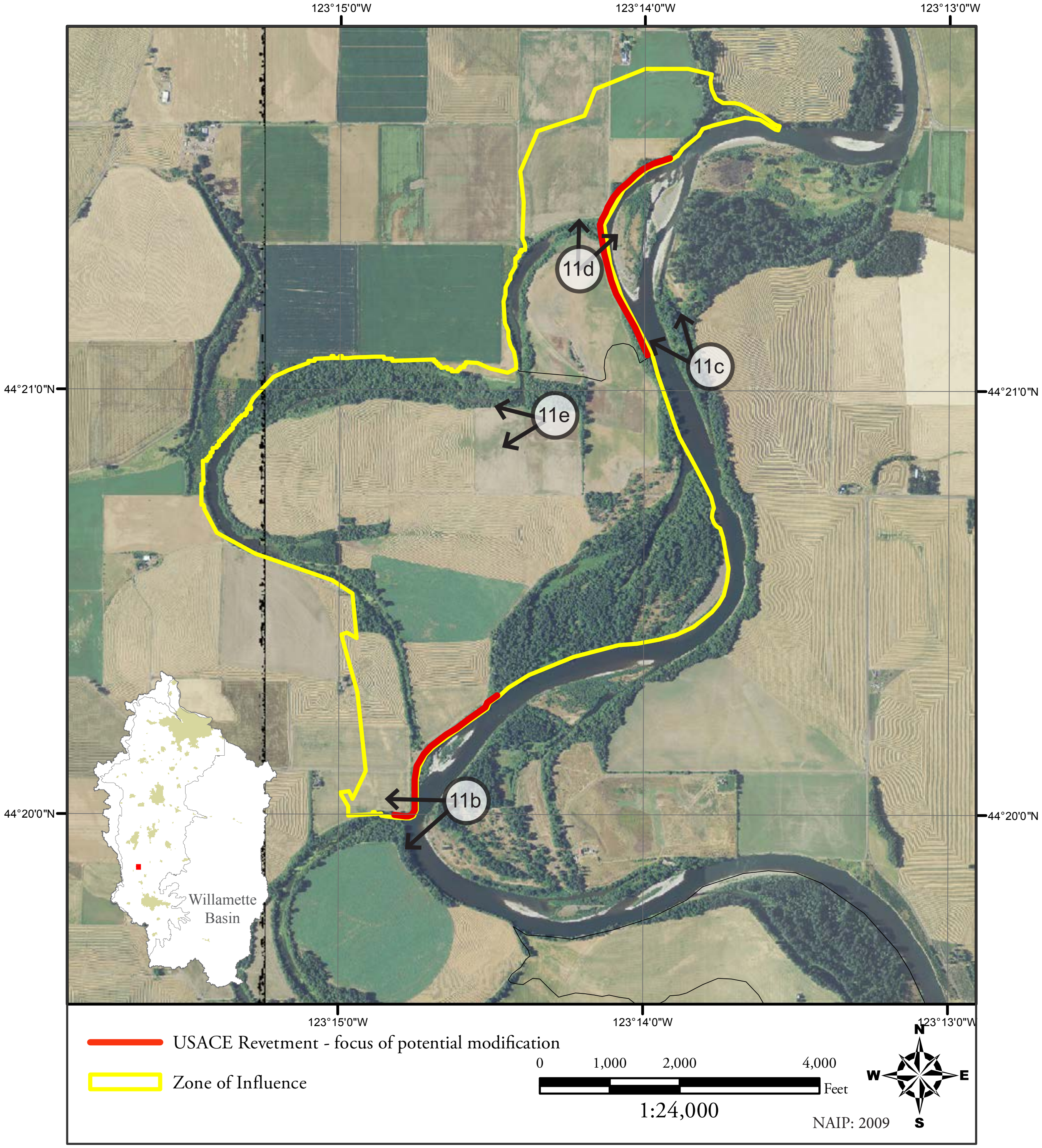

Figure 11b

Figure 11c

Figure 11d

Figure 11e

Figure 11b: The Irish Bend revetment looking upriver.

Figure 11c: The Lower Bend revetment looking downriver.

Figure 11d: A water-control structure which regulates the outflow from Harkens Lake to the Willamette River.

Figure 11e: Agriculture field and floodplain forest in Zone 29.

Figure 12a. Aerial photograph of Zone 62 Horseshoe Lake (Weston Bend) on mainstem northern Willamette River with key to ground-level photographs.

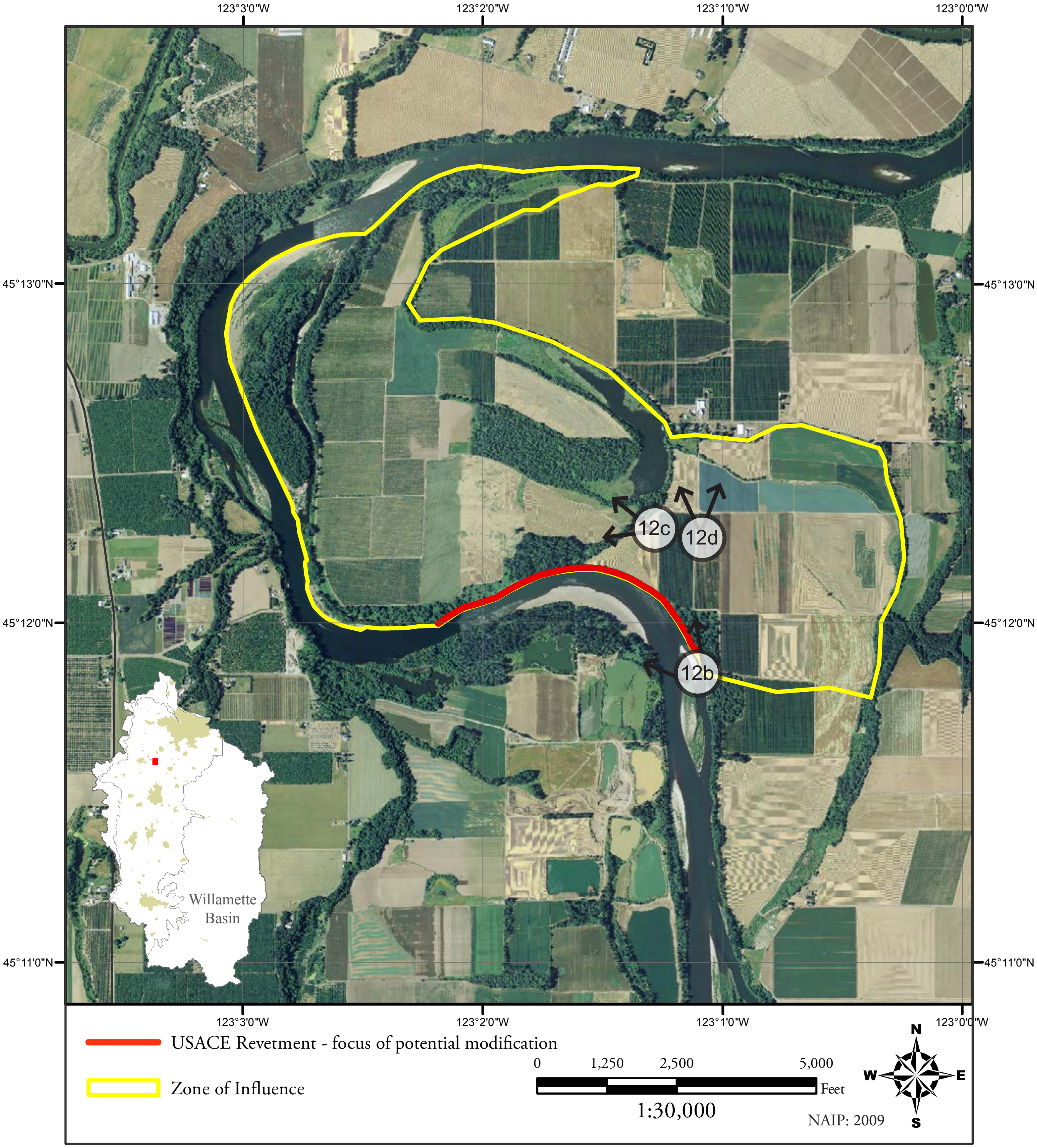

Figure 12b

Figure 12c

Figure 12d

Figure 12e

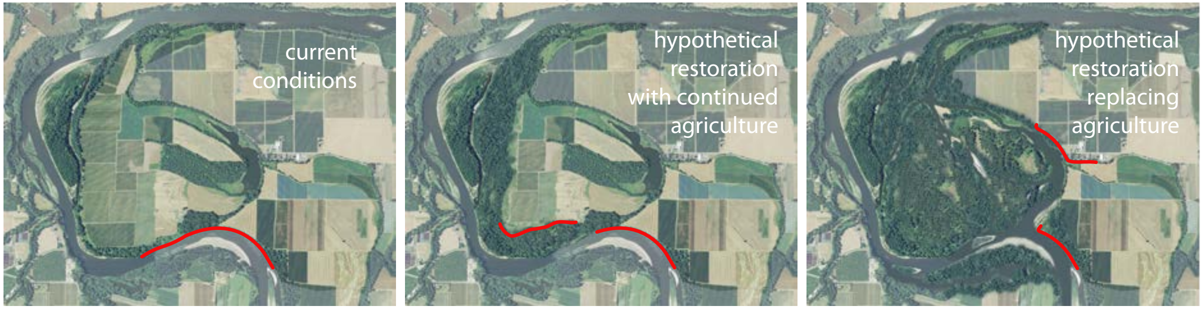

Figure 12b: The Weston Bend revetment with gravel bar on opposite bank.

Figure 12c: Agriculture fields on first terrace.

Figure 12d: Agriculture processing buildings atop second terrace.

Figure 12e: Current and two hypothetical future conditions illustrating a range of restoration options. Any restoration would require the active involvement of willing land owners.

Table 1: 72 Zones of Influence: including corresponding river, place name, and USACE revetment names. For a description of the relevance of Tiers 1, 2 & 3 see Section II, B.1.

Region #	Zone #	River	Place Name	USACE Revetment Names	Biophysical Opportunity Score	Sociocultural Constraint Score
3	72	Clackamas	Tranquility Lane	Location 12a and Location 13	0.67	0.10
3	71	Clackamas	Barton	Location 14	0.02	0.04
3	70	Clackamas	Paradise Park	Paradise Park	0.04	0.22
3	69	Molalla	Canby 2	Location 1	0.22	1.00
3	68	Molalla	Cemex Sand and Gravel	Location 2	0.18	0.05
3	67	Molalla	Canby 1	Location 4	0.55	0.16
3	66	Molalla	Alder Creek	Location 5	0.26	0.98
3	65	Molalla	Kraxberger	Locations 6, 7, (8 Tier 2)	0.36	0.02
3	64	Molalla	Molalla at railroad	Location (10 Tier 3) and (11 Tier 1)	1.00	0.76
3	63	Molalla	Mulino Hamlet	Location No. 12	0.00	0.00
5	62	Willamette - North	Horseshoe Lake	Weston Bend	0.33	0.10
5	61	Willamette - North	Carlton Plant Nursery	Stoutenburg and Lambert Slough	0.29	0.15
5	60	Willamette - North	Eldriedge Slough	Ditmars Bend	0.10	0.00
5	59	Willamette - North	Grand Island	Grand Island	0.07	0.50
5	58	Willamette - North	Lambert Slough	Wheatland Dam A & B, Stoutenburg, and Lambert Slough	0.92	1.00
5	57	Willamette - North	Willamette Mission State Park	Bechtold	0.42	0.52
5	56	Willamette - North	Clear Lake	H. L. Pearcy	0.24	0.57
5	55	Willamette - North	Salem Wastewater Treatment Plant	Keizer Rapids	0.14	0.32
5	54	Willamette - North	Hayden, Browns & Minto Islands	Eola Bend, Gray Eagle Bar, and Eyerly	0.93	0.49
5	53	Willamette - North	Independence 2	Probst	0.20	0.70
5	52	Willamette - North	Independence 1	Murphy's Bar	0.59	0.78
5	51	Willamette - North	Wells Island	Catlin	0.16	0.47
2	50	Santiam	Cole Island	Wilfert (Tier 3), Loc. 2, Loc. 3 (Tier 3) and Turnidge	1.00	0.64
2	49	Santiam	Santiam-Willamette Confluence Railroad	Wintermantel	0.28	0.86
2	48	Santiam	At I-5	Banick Drift Barrier	0.31	1.00
2	47	Santiam	Jefferson	Wickham	0.13	0.34
2	46	Santiam	Folsom Pond	Tripp	0.15	0.27
2	45	Santiam	Noris Farms	COX	0.07	0.30
2	44	Santiam	Folsom Road	COX	0.12	0.42
2	43	Santiam	Crabtree	COX	0.00	0.00
2	42	Santiam	Hwy 226	Pape	0.06	0.85
2	41	Santiam	Tennessee Rd	Ketcham	0.10	0.59
5	40	Willamette - North	Luckiamute State Natural Area	Black Dog Bar	1.00	0.62
5	39	Willamette - North	Spring Hill Country Club	Ufford	0.00	0.03
2	38	Calapooia	Brownsville	Brownsville No. 2	0.02	0.68

Table 1 (continued)

Region #	Zone #	River	Place Name	USACE Revetment Names	Biophysical Opportunity Score	Sociocultural Constraint Score
4	37	Willamette - South	Half Moon Bend	Half Moon Bend	0.15	0.28
4	36	Willamette - South	Truax Island	Upper Half Moon Bend	0.28	0.07
4	35	Willamette - South	Hwy 34 Bridge	City of Corvallis	0.02	0.36
4	34	Willamette - South	Stahlbush Island	Corvallis Location	0.63	0.61
4	33	Willamette - South	Brown Bend	Brown Location	0.02	0.00
4	32	Willamette - South	John Smith & Kiger Islands	John Smith Island and Kiger Bend	0.08	0.02
4	31	Willamette - South	Hoacum Island	Jacobs Bend	0.13	0.08
4	30	Willamette - South	Harkens Lake Lower	Lower Bend	0.14	0.10
4	29	Willamette - South	Harkens Lake Upper	Irish Bend and Lower Bend	0.82	0.15
4	28	Willamette - South	Ingram Island	Ingram Island	0.16	0.34
4	27	Willamette - South	Morgan Island	Alford	0.00	0.02
4	26	Willamette - South	Morgan Bend	Morgan Bend	0.16	0.03
4	25	Willamette - South	City of Harrisburg	City of Harrisburg	0.03	0.21
4	24	Willamette - South	Harrisburg Railroad	Harper Bend and Harrisburg Railroad	0.10	0.39
4	23	Willamette - South	Hentze Produce	Location No. 9	0.46	0.27
4	22	Willamette - South	Junction City 2	Location 8a	0.65	0.50
4	21	Willamette - South	Junction City 1	Location No. 8 (Fertile District)	0.80	0.48
4	20	Willamette - South	Marshall Island	Location 7a	0.32	0.38
1	19	McKenzie	Coburg Rd Bridge	Coburg Bridge and Blankton	0.11	0.70
1	18	McKenzie	Armitage Park	Armitage	0.03	0.06
1	17	McKenzie	Sacred Heart Medical at River Bend	Conley Place	0.52	0.47
1	16	McKenzie	Weyerhaeuser	Myers-Eyler	0.26	1.00
1	15	McKenzie	Thurston	Hart and Thurston	0.05	0.14
1	14	McKenzie	Stockade	Stockade	0.02	0.11
4	13	Willamette - South	Whitely Landing	Maclay Place	0.09	0.17
4	12	Willamette - South	Goodpasture Island	Bauer Ln. (Tier 2), Upper Goodpasture, Lower Goodpasture, Wilbur Bend (Tier 1)	1.00	1.00
4	11	Willamette - South	Ferry Street Bridge	Ferry Street Br	0.05	0.46
1	10	Middle Fork Willamette	Clearwater Park 2	Booth-Kelly	0.14	0.02
1	9	Middle Fork Willamette	Clearwater Park 1	A.C. Clearwater	0.06	0.07
1	8	Middle Fork Willamette	Jasper Road	Natron	0.00	0.04
1	7	Coast Fork Willamette	Dorris Ranch	Dorris-Leonard	0.05	0.19
1	6	Coast Fork Willamette	TNC Confluence Project	Evans	0.09	0.53
1	5	Coast Fork Willamette	Seavey Way Bridge	Dorena Reservoir: Seavey Bridge	0.03	0.65
1	4	Coast Fork Willamette	Pisgah	McCully Left and McCully Right Banks	0.18	0.09
1	3	Coast Fork Willamette	Creswell	Lower Benter and Harrold. Dorena Reservoir: (Rinehart, Benter, Sly-Upper, Sly-Lower, Haskins-Upper, Haskins-Lower, Jenkins, Melton, and Lower Melton)	1.00	0.66
1	2	Coast Fork Willamette	Cottage Grove 2	Dorena Reservoir: Veatch	0.03	0.05
1	1	Coast Fork Willamette	Cottage Grove 1	Dorena Reservoir: Hemenway	0.03	0.00

Table 2: Sociocultural Constraint and Biophysical Opportunity Factors: a list of the mapped factors and the data source date where relevant.

Sociocultural Constraint Factors					
roads ca. 2005	bridges ca. 2011	total property value ca. 2010	human population density ca. 2010	non-USACE revetments	prime agricultural soil
Biophysical Opportunity Factors					
erodible gravels	channel complexity ca. 2005	frequently inundated forest ca. 2000	land managed for conservation ca. 2011		

Table 3: Weights assigned by the Habitat Technical Team to the Factors:
The weights shown below were used to indicate relative importance of each factor in determining overall revetment priorities for removal or modification to restore natural river function.

Biophysical Factors	**Weight**
Frequently Inundated Floodplain Forest	0.24
Conservation Ownership	0.31
Channel Complexity	0.28
Geology / Erodibility	0.18
Sociocultural Factors	**Weight**
Roads: Highways	0.06
Roads: All Other	0.05
Roads: Farm & Unimproved	0.03
Bridges	0.18
Non-USACE Revetments	0.16
Prime Agricultural Soil	0.13
Population Density	0.21
Property Value	0.18

Note: due to rounding, totals may not sum to 1.0

Table 4: Scatterplot of 15 high priority Zones

Fourteen zones fell within the lower right quadrant, where opportunity is high and constraint low. These fourteen zones are represented by the green dots. Zone 50 (Cole Island) was added due to having the highest possible opportunity score with a constraint score slightly above the median. Note the size of the lower right quadrant varies as median biophysical opportunity and sociocultural constraint scores change from region to region.

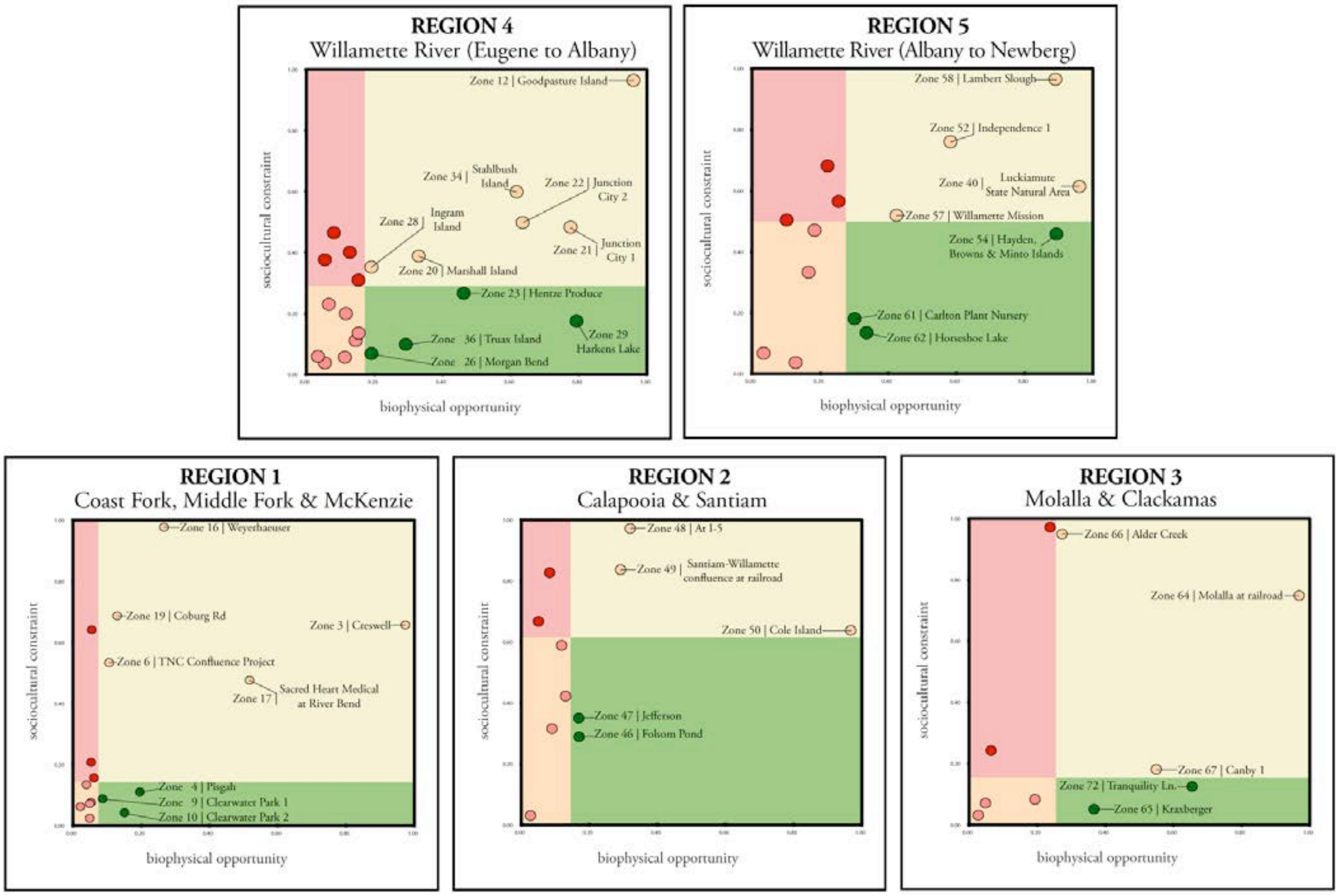

Table 5: 15 High Priority Phase 1 Willamette Project Zones for removal or modification to restore natural river function

Note: the asterisk indicates the 6 Zones chosen for field reconnaissance.

Region #	River Name	Zone #	Place Name	USACE Name	Biophysical Opportunity Score	Sociocultural Constraint Score	CH2MHILL Revetment Damage	In Cold Water Gap?
2	Santiam	*Zone 50	Cole Island	Wilfert	1.00	0.64	Tier 3	Yes
5	Willamette-north	*Zone 62	Horseshoe Lake	Weston Bend	0.33	0.10	Tier 3	Yes
4	Willamette-south	*Zone 29	Harkens Lake	Irish Bend & Lower Bend	0.82	0.15	N.A.	Yes
1	Middle Fork	*Zone 9	Clearwater Park 1	A.C. Clearwater	0.06	0.07	N.A.	N.A.
2	Santiam	*Zone 47	Jefferson	Wickham	0.13	0.34	Tier 3	N.A.
3	Clackamas	*Zone 72	Tranquility Lane	Location 13	0.67	0.10	N.A.	N.A.
3	Mollala	Zone 65	Kraxberger	Location 8	0.36	0.02	Tier 2	N.A.
5	Willamette-north	Zone 54	Hayden/ Brown/ Minto Islands	Budd's Chute, Eola Bend, Gray Eagle Bar, Eyerly	0.93	0.49	Tier 3	Yes
4	Willamette-south	Zone 23	Hentze Produce	Location 9	0.46	0.27	N.A.	Yes
4	Willamette-south	Zone 36	Truax Island	Upper Half Moon Bend	0.28	0.07	N.A.	Yes
2	Santiam	Zone 46	Folsom Pond	Tripp	0.15	0.27	N.A.	N.A.
5	Willamette-north	Zone 61	Carlton Plant Nursery	Stoutenburg and Lambert Slough	0.29	0.15	N.A.	Yes
1	Middle Fork	Zone 10	Clearwater Park 2	Booth-Kelly	0.14	0.02	Tier 2	N.A.
1	Coast Fork	Zone 4	Pisgah	McCully Left and Right Banks	0.18	0.09	N.A.	N.A.
4	Willamette-south	Zone 26	Morgan Bend	Morgan Bend	0.16	0.03	N.A.	No

N.A. = data not available

Note: Biophysical opportunity and sociocultural constraint scores for a given zone reflect the range within that zone's region.

CH2MHill:
Tier 1 = increased damage likely, begin repair activities
Tier 2 = repair required to minimize add'l costs, plan for repair
Tier 3 = damage appears stable, heightened vigilance & inspection

Table 6: 12 High Priority Phase 3 Willamette Project Zones for removal or modification to restore natural river function

recommend for further consideration

Region #	River Name	Zone #	Place Name	USACE Name	Biophysical Opportunity Score	Sociocultural Opportunity Score	CH2MHILL Revetment Damage	In Cold Water Gap?
2	**Santiam**	***Zone 50**	**Cole Island**	**Wilfert**	**1.00**	**0.64**	**Tier 3**	**Yes**
5	**Willamette-north**	***Zone 62**	**Horseshoe Lake**	**Weston Bend**	**0.33**	**0.10**	**Tier 3**	**Yes**
4	**Willamette-south**	***Zone 29**	**Harkens Lake**	**Irish Bend & Lower Bend**	**0.82**	**0.15**	**N.A.**	**Yes**
1	Middle Fork	*Zone 9	Clearwater Park 1	A.C. Clearwater	0.06	0.07	N.A.	N.A.
3	Mollala	Zone 65	Kraxberger	Location 8	0.36	0.02	Tier 2	N.A.
5	Willamette-north	Zone 54	Hayden/ Brown/ Minto Islands	Budd's Chute, Eola Bend, Gray Eagle Bar, Eyerly	0.93	0.49	Tier 3	Yes
4	Willamette-south	Zone 23	Hentze Produce	Location 9	0.46	0.27	N.A.	Yes
4	Willamette-south	Zone 36	Truax Island	Upper Half Moon Bend	0.28	0.07	N.A.	Yes
2	Santiam	Zone 46	Folsom Pond	Tripp	0.15	0.27	N.A.	N.A.
5	Willamette-north	Zone 61	Carlton Plant Nursery	Stoutenburg and Lambert Slough	0.29	0.15	N.A.	Yes
1	Coast Fork	Zone 4	Pisgah	McCully Left and Right Banks	0.18	0.09	N.A.	N.A.
4	Willamette-south	Zone 26	Morgan Bend	Morgan Bend	0.16	0.03	N.A.	No

N.A. = data not available

Note: Biophysical opportunity and sociocultural constraint scores for a given zone reflect the range within that zone's region.

CH2MHill: Tier 1 = increased damage likely, begin repair activities
Tier 2 = repair required to minimize add'l costs, plan for repair
Tier 3 = damage appears stable, heightened vigilance & inspection

BOLD = 4 revetments recommended for further considertaion: note two revetments are contained in Zone 29.

IX. Appendix

1. Factors Database

In general, a digital map source was identified for each factor meeting requirements of source identity, areal coverage completeness, attribute relevance and accuracy, and spatial accuracy.

Depending on whether the source data were in vector or raster form, appropriate GIS map overlay operations were performed to calculate the raw quantity of each factor present in each Zone. The attribute tables produced by the overlay operations were exported to spreadsheets wherein the remainder of factor calculations were performed.

- Constraints
    - *Transportation infrastructure*: Roads, streets, and highways were obtained from the 2005 TeleAtlas "U.S. and Canada Detailed Streets" geodatabase. The Oregon State Department of Transportation "Bridges_2011" shape file was the source for bridge locations. Roads were classified into three categories, major highways, non-farm roads, and farm roads. Total length in meters for each category was recorded for each Zone. Zones were marked as either not containing a bridge, or as having a bridge if one or more were present.
    - *Property value*: Taxlot databases obtained from county agencies provided the ca. 2010 source of real market land and improvement values. For each parcel these quantities were summed and expressed as a value per unit area to avoid reporting artificially high values for fragments of parcels that are created when their polygonal representations are intersected with Zone boundaries in GIS overlay operations. In order to make the resulting large range of property values manageable, the natural logarithmic derivatives of the values were used in calculating this factor.
    - *Human population*: The US 2010 census for Oregon was the source data set for this factor. For this factor, the number of persons reported in the data was converted to a persons/square mile density value.
    - *Non-ACOE revetments*: For this project, the Portland office of the USACE provided two digital maps depicting locations of revetments not managed by USACE, one for revetments on the Willamette River and the other for revetments on tributaries. For each Zone the total length in meters of the revetments derived from these sources is the reported value of this factor.

  - *Soil resources*: The area in square meters of prime soils, derived from the Natural Resources Conservation Service 2006 Soil Survey Geographic (SSURGO) county data sets, is the reported value of this factor.

- Opportunities

  - *Erodible gravels*: A source of salmonid spawning habitat, less consolidated riverbank gravels are principally available from Holocene alluvium. Obtained from the Oregon Geospatial Enterprise Office web site, the 2008-2009 "G_MAP_UNIT" statewide geologic map of Oregon produced by the Oregon Department of Geology and Mineral Industries provided the locations of the Qalc map unit identifying Holocene alluvium. For the Clackamas River Zones, map units Qt1-Qt9 were used. Total area of alluvium in square meters is reported.

  - *River channel length*: Total length of streams derived from the National Hydrography Dataset Flow Line feature is summed for each Zone and reported in meters.

  - *Frequently flooded Floodplain forest*: Locations classified as floodplain forest were derived from the ca. 2000 Land Use and Land Cover digital map LULC2000 (PNW-ERC 2002). From this selection, all areas that were not shown to be inundated at a 2 year frequency for the mainstem Zones, and all areas not shown to be inundated by the 1996 flood for Zones lying outside of the mainstem floodplain, were excluded. For each Zone, the remaining total area of frequently flooded floodplain forest is reported in square meters.

  - *Conservation ownership*: Two principal sources were combined to produce this factor. The first source is the PNW-ERC Conservation and Restoration Opportunities 2050 map CRO50 (PNW-ERC 2002). The second is a series of maps provided by The Nature Conservancy identifying lands managed for conservation purposes:

    TNC Willamette Valley Preserves Dec. 2011
    NRCS Permanent Easements
    Areas of critical concern
    West Eugene Wetlands conservation ownership Dec. 2011
    Publands Willamette Basin conserved Dec. 2011
    PDX conservation ownership Dec. 2011

    These sources were combined with digital taxlot data outlining recently established conservation reserves within the study area (as of Jan. 2011) and the total area in square meters in each Zone is the reported value of this factor.

- Preparation of Factors Database

The factors database was constructed to provide the quantitative analytic basis for prioritizing Zones. The spreadsheet database was constructed in three steps. For each dimension (biophysical opportunity and sociocultural constraint), the various factors were made commensurate by a normalization calculation that expressed each factor value for each Zone within a range from zero to one. Then, each normalized factor value was multiplied by a weight assigned to the factor expressing its importance when prioritizing Zones relative to other factors within its dimension. The weights were determined by an advisory committee described in Section II. Finally, the weighted factors were combined within each dimension to express, within a range of zero to one, each Zone's sociocultural constraint and biophysical opportunity. For each Zone, these two values are the coordinates that determine its location within the four-box prioritization diagram.

2. Determination of factor weight for roads in the transportation infrastructure constraint

During its review of factor weights, the Habitat Technical Team questioned whether the use of a single weight for all road types adequately expressed the actual constraint to restoration that roads represent. Wouldn't the difference between freeways, state and local roads, and farm roads matter to the outcome of the prioritization?

We examined this question by conducting a sensitivity analysis to determine whether a multi-tier weighting of roads would alter the prioritization of revetments. Based on the Tele-Atlas road classification system, freeways were assigned a sub-weight of 0.06, state and local roads were assigned 0.05 and farm roads assigned 0.02. These values summed to the 0.13 weight initially assigned to roads overall by the HTT. The sensitivity analysis was conducted separately for each of the five regions used to prioritize revetments.

As Table App. 1 below shows, in general Zones prioritized highest for restoration based on a single value (for all types of roads) remained most highly prioritized when the multi-tiered weighting was used as well. With few exceptions, if a Zone was ranked in the top three on the basis of one weighting method, it remained in the top three when the other method was used. Zones that the different weighting methods moved from low to high or high to low constraint were those that were near the Sociocultural constraint median threshold initially. The sensitivity analysis results were used to inform the selection of the top 15 candidates from the original pool of 72 Zones. Zone numbers at the top of each regional column in Table (App. 1) were those ranked highest when: a) roads were considered as a single "AllRoads" class, and b) when roads were classified into three separate classes "3 Road Classes".

Table (App. 1). The result of a sensitivity analysis testing the sensitivity of overall zone rankings to treating roads as one vs. three classes (see Table 3).

Rank	**Region 1** Coast Fork, Middle Fork, & McKenzie rivers		**Region 2** Calapooia & Santiam rivers		**Region 3** Molalla & Clackamas rivers		**Region 4** Willamette River Eugene to Albany		**Region 5** Willamette River Albany to Newberg	
	Single Class	3 Road Classes	Single Class	3 Road Classes	Single Class	3 Road Classes	Single Class	3 Road Classes	Single Class	3 Road Classes
1st	4	4	46	46	64	64	29	29	62	62
2nd	10	10	47	47	65	65	23	36	61	61
3rd	9	9	50	50	72	72	36	26	40	54
4th	3	3	49	49	67	67	26	23	54	40
5th	17	17	48	48	66	66	21	21	58	58
6th	16	16	43	43	68	68	22	34	57	52
7th	19	19	44	44	71	71	12	22	52	57
8th	6	6	45	45	63	63	34	12	60	60
9th	1	1	41	41	69	69	20	20	55	55
10th	18	18	42	42	70	70	28	28	51	51
11th	2	2	38	38			31	33	59	59
12th	14	14					30	31	39	39
13th	8	8					32	32	56	56
14th	15	15					13	30	53	53
15th	7	7					33	13		
16th	5	5					25	25		
17th							27	27		
18th							37	37		
19th							24	24		
20th							11	11		
21st							35	35		

3. Ability of non-Federal proponents to modify revetments

A method for non-Federal proponents to modify federally authorized revetments also exists. 33 USC §408 (Section 408) titled; Taking Possession of, Use of, or Injury to Harbor or River Improvements, provides the authority to the Secretary of the Army (delegated to the USACE Chief of Engineers) to allow for modification or removal of these projects through an established process that the USACE Portland District administers in the Willamette basin. Under Section 408, the proponent is responsible for providing 100% of all costs and analysis including USACE review of all required engineering, real estate and environmental documentation. The proponent must clearly prove through analysis that the modification will not create adverse effects or increased risk for adjacent landowners, the public, environments and ecosystems.