USACE: Portland District

Dairy Creek Restoration Feasibility Study

Habitat Benefits Model

September 2013

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE), along with local partner West Multnomah Soil & Water Conservation District (WMSWCD), are currently evaluating restoration opportunities for Dairy Creek and Sturgeon Lake in conformance with Section 1135 of the 2000 Water Resources Development Act. The goal of this Dairy Creek Restoration Feasibility Study (Study) is to improve long-term, sustaining, aquatic habitat function and increase aquatic areas and habitat value for fish and wildlife in the Sauvie Island Wildlife Area (SIWA), within the Lower Columbia River estuary. Selection of the preferred restoration alternative is facilitated by an economic analysis, where habitat benefits and cost are compared among the candidate restoration alternatives. This report describes the habitat benefits model and results used for the Study.

Habitat benefits were modeled with a Habitat Evaluation Procedure (HEP), where the Study area is weighted by its suitability for target species, for each restoration measure. For each target species, habitat suitability was assessed with published Habitat Suitability Indices (HSIs), and modified based on specific project conditions. During the subsequent economic analysis, restoration measures are combined in pre-determined ways to form candidate restoration alternatives, with associated habitat benefits and cost.

The Study area is important for multiple wildlife uses, but was represented by waterfowl overwintering and juvenile salmonid rearing. These specific wildlife uses were selected because of resource significance, study relevance, and HSI model availability. The northern pintail, lesser scaup, coho salmon, and Chinook salmon were selected to represent these specific wildlife and fish uses. Habitat suitability for the northern pintail was determined by the availability of shallow open water, emergent vegetation that provided food resources. Lesser scaup habitat suitability was determined by the presence of pelecypod food resources, and relatively undisturbed, open, and deep water. Coho and Chinook salmon habitat suitability was determined by water temperature, riparian function, and the presence of both winter refugia and rearing habitat. New access between the Columbia River and Sturgeon Lake was used to weight the coho and Chinook habitat area and habitat benefits

Among the five restoration measures considered, the restoration of the Dairy Creek channel (Measure 14b combined with dependent Measure 14a) would provide the most new habitat benefits. This channel would provide high-frequency access between the Columbia River and Sturgeon Lake, new off-channel habitat with riparian function, and would moderate lake water temperatures during the late spring and early summer. Restoration of the old Dairy Creek channel (Measure 6 combined with dependent Measure 14a) would provide an intermediate quantity of increased habitat benefits, by providing fish access to the lake during high river stages. Measure 14a provided a minimal amount of habitat units, because it was meant to be combined with Measure 14a and/ or Measure 6. Pumping water from the southern Sauvie Island drainage to Sturgeon Lake (Measures 17 and 18) did not provide any habitat benefits. Benefits were primarily driven by gains in juvenile salmon accessibility and small changes in lake water temperature and riparian vegetation.

ACRONYMS

BiOp	Biological Opinion
Corps	United States Army Corps of Engineers
DO	Dissolved Oxygen
ERTG	Expert Regional Technical Group
ESU	Evolutionary Significant Unit
HEP	Habitat Evaluation Procedure
HSI	Habitat Suitability Index
HU	Habitat Units
LCRE	Lower Columbia River Estuary
MHHW	Mean Higher High Water
NOAA	National Oceanic and Atmospheric Administration
OCS	Oregon Conservation Strategy
ODFW	Oregon Department of Fish and Wildlife
RCG	Reed Canary Grass
SBU	Survival Benefit Unit
SI	Suitability Index
SIWA	Sauvie Island Wildlife Area
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
WSEL	Water Surface Elevation
WMSWCD	West Multnomah Soil and Water Conservation District

1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE or Corps), along with local partner West Multnomah Soil & Water Conservation District (WMSWCD), are currently evaluating restoration opportunities for Dairy Creek and Sturgeon Lake (Sauvie Island; Figure 1) in conformance with Section 1135 of the 2000 Water Resources Development Act. Sturgeon Lake has limited biological connectivity with adjacent riverine habitat because of the historical elimination of local hydrologic inputs, the historical elimination and simplification of tidal channels connecting the lake with the riverine environment, and from the regulation (reduction) of Columbia River flood frequency and magnitude. In 1989, the existing confluence of Dairy Creek with the Columbia was re-opened, and the existing channel was reconfigured with a new, shortened by-pass channel, passing under Reeder Road. The purpose being to connect Sturgeon Lake with the Columbia River at River Mile (RM) 98, in an attempt to increase flows to Sturgeon Lake, increase fish access, and reduce lake sedimentation. The channel functioned as intended until the early 1990s. By 1996, after a 100-year flood event, the channel filled with silts, sands, and debris, and no longer provided regular flow to Sturgeon Lake.

The goal of the current Dairy Creek Restoration Feasibility Study (Study) is to improve long-term, sustaining, aquatic habitat function, and increase aquatic areas and habitat value for fish and wildlife in the Sauvie Island Wildlife Area (SIWA), within the Lower Columbia River estuary. This goal has the following objectives:

- Increase hydrologic inputs in order to increase the depth and area of Sturgeon Lake
- Increase aquatic habitat area available to juvenile salmon
- Increase access points to juvenile salmon from the Columbia River and Sturgeon Lake, with an emphasis on Columbia River locations/stocks
- Increase natural process and habitat function for fish and wildlife species within the current management guidance of the SIWA
- Minimize long-term operation and maintenance costs

This Study is consistent with the ODFW 2010 SIWA Management Plan goal “to protect, enhance and manage wetland habitats to benefit fish and wildlife species” and the specific objective to improve the biological and hydrological function of the 3,000-acre Sturgeon Lake system (ODFW 2010a). This Study is also consistent with the objectives of the 2008 Biological Opinion of Federal Columbia River Power System Operations (BiOp) obligation to implement estuarine restoration which benefits the survival and productivity of ocean and stream type juvenile salmon (ERTG 2010).

The restoration measures (measures) proposed to meet the Study goals and objectives are described in Section 3. These measures have been combined to yield potential restoration alternatives. This report describes the habitat benefits model used to compare benefits among restoration alternatives and a “no-action” alternative. The habitat benefits model is intended to quantify the restoration outcomes associated with meeting the stated goals and objectives, relative to a “no-action” baseline. This comparison will facilitate a cost/ benefit evaluation between alternatives, and will result in formulation of a preferred alternative.

The habitat benefits model selected for this study is a Habitat Evaluation Procedure (HEP), developed by U.S. Fish and Wildlife Service in 1980. The HEP is a calculation of species-specific habitat suitability in a given area that is relevant to the Study. Species are included in the model that represent the desired aquatic habitat function in the Study area, pursuant to the Study goals and objectives. Habitat suitability of a given species is defined in terms of a Habitat Suitability Index (HSI). An HSI is an index that scales the overall suitability of an area for one or more life stages of a species. In general terms, the HSI for each representative species is multiplied by an applicable area that is subject to change as a result of the restoration measures proposed in the Study. Since an objective of this Study is to improve habitat function for a variety of fish and wildlife species, an approach was developed that considers a wide array of species habitat needs in the HEP model, but narrows the number of species-specific scores to the minimum number that represents desired aquatic habitat function in the Study area.

In the methods section of this report, criteria for selection of indicator species are presented, along with the resultant identification of indicator species. Next, the existing HSI models for the recommended indicator species are discussed. Criteria for inclusion of habitat suitability variables are presented, along with the resultant identification of the selected variables for use in this Study. Next, a description of the areas for each species is provided. The HEP output is a function of the HSI and applicable area for each species, respectively. This HEP output is defined as Habitat Units (HUs). Since multiple species contribute their respective HUs to a total HU estimate for each alternative, a discussion of how the individual HUs are aggregated for each restoration measure is provided.

The proposed restoration measures are described in the results section of this report (Section 4). Based on the proposed measures, the data used to populate the HSIs and area functions are presented. The existing and predicted metric values for each restoration measure are applied to its SI curves to return a SI values. From these SI values, the HSIs and HUs for each measure are calculated. These HUs are the input data for the economic analysis.

Figure 1. Site Vicinity and Project Area.

1.1 Wildlife Use in the Study Area

The proposed restoration measures considered in this Study may affect the following wildlife uses that occur in the Study area.

1.1.1 Waterfowl

Although the Study area provides habitat for breeding and other waterfowl life history stages, the primary use of Sturgeon Lake for waterfowl is for overwintering. Waterfowl can have different wintering periods, with a broad range of October- April. The SIWA Management Plan (ODFW 1010a) defines the winter period as December through February. Table 1 shows the winter presence of waterfowl species in the project area on a common, uncommon, and occasional basis (ODFW 1010a). Although this winter season is narrowly defined in Table 1, relative to the wintering periods of some waterfowl species in the Study area, this December through February period is representative (i.e., within the specific species wintering period), and therefore inclusive of most species' wintering periods.

Table 1. Overwintering Occurrence of Waterfowl Species in Project Area.

Species	Winter Occurrence	Behavior	Breeding Occurrence	HSI
Tundra swan (*Cygnus columbianus*)	Common	Dabbler	No	No
Canada goose (*Branta canadensis*)	Common	Dabbler	No	No
Cackling goose (*Branta hutchinsii*)	Common	Dabbler	No	No
Mallard (*Anas platyrhynchos*)	Common	Dabbler	Yes	Overwintering (Lower Mississippi Valley)
Green-winged teal (*Anas crecca*)	Common	Dabbler	No	No
American wigeon (*Anas americana*)	Common	Dabbler	No	No
Northern pintail (*Anas acuta*)	Common	Dabbler	Yes	Overwintering (Gulf Coast)
Northern shoveler (*Anas clypeata*),	Common	Dabbler	Yes	No
Ring-necked duck (*Aythya collaris*)	Common	Diver	No	No
Lesser scaup (*Aythya affinis*)	Common	Diver	Yes	Overwintering (Gulf of Mexico; southern Atlantic Coast); Breeding (Conterminous U.S.)
Snow goose (*Anser Caerulescens*)	Uncommon	Dabbler*	No	Overwintering (Gulf of Mexico, and inland marshes)
Wood duck (*Aix sponsa*)	Uncommon	Dabbler	Yes	Overwintering (West Coast, Southeast)
Gadwall (*Anas strepera*)	Uncommon	Dabbler	Yes	Breeding (Prairies in U.S. and Canada)
Common goldeneye (Bucephala clangula)	Uncommon	Diver	No	No
Common merganser (*Mergus merganser*)	Uncommon	Diver	No	No
Ruddy duck (Oxyura jamaicensis)	Uncommon	Diver	No	No
Bufflehead (*Bucephala albeola*)	Uncommon	Diver	No	No
Greater white-fronted goose (*Anser albifrons*)	Occasional	Dabbler*	No	Overwintering (SE Louisiana and Texas)
Eurasian wigeon (*Anas Penelope*)	Occasional		No	No
Cinnamon teal (*Anas cyanaptera*)	Occasional	Dabbler	Yes	No
Canvasback (Aythya *valisineria*)	Occasional	Diver	No	Breeding (Eastern Montana, S. Dakota, N. Dakota)
Redhead (*Aythya americana*)	Occasional	Dabbler	No	Overwintering (Gulf of Mexico coastal wetlands)
Greater scaup (*Aythya marila*)	Occasional	Diver	No	No
Hooded merganser (*Lophodytes cucullatus*)	Occasional	Diver	Yes	No

*Geese species that require shallow-water habitats like the dabbling ducks

Overwintering waterfowl tend to seek open areas for foraging, but use windbreaks to get out of foul weather. Waterfowl can be broadly classified into the dabbling duck and diving duck guilds, based on their foraging requirements. Dabbling ducks are dependent on the presence of shallow water because they do not dive in order to feed. The wetlands they use for foraging are mostly open emergent wetlands and aquatic habitats with submerged aquatic or floating-leaved aquatic plants (e.g. duck weed). The presence of vegetation is very important for grazing opportunities and invertebrate production. Fluctuating water levels may favor dabbling ducks in instances where the fluctuations provide more water depth diversity and opportunities to feed. Diving ducks prefer deeper water that may only be present in Sturgeon Lake on a seasonal and intermittent basis.

The wetlands and associated riparian areas are important habitats meeting most of the life history needs of many of the waterfowl species. Several of these waterfowl species breed in Sturgeon Lake. Breeding occurs in the spring and summer. They nest in tall grass in the uplands. When the birds molt in the summer, they are unable to fly well and need cover, especially at this time. They tend to use woody plants and thickets to hide during the molt. In late July through October, daily tidal influences and receding river levels provide new foraging habitat as fresh mudflats. This occurs primarily in Sturgeon and Cunningham Lakes. These mudflats are vital for roosting sandhill cranes during their spring and fall migrations. Sandhill crane loafing and roosting areas have been identified in the ODFW Management Plan as particularly susceptible to human disturbance. Seven subspecies of Canada geese (*Branta canadensis*) and several thousand tundra swans (*Cygnus columbianus*) spend part of the winter roosting on area lakes and foraging in surrounding agricultural fields and wetlands.

1.1.2 Amphibians

Amphibians present include the northwestern salamander (*Ambystoma macrodactylum*), long-toed salamander (*Ambystoma macrodactylum*), Pacific treefrog (*Hyla regilla*), non-native bullfrog (*Rana catesbeiana*), roughskin newt (*Taricha granulosa*), and significant populations of three federal Species of Concern and Oregon Conservation Strategy Sensitive Species: the northwestern pond turtle (*Clemmys marmorata marmorata*), western painted turtle (*Chrysemys picta bellii*), and northern red-legged frog (*Rana aurora aurora*). To address turtle habitat needs, the ODFW management plan specifies an intent to develop specific sites in newly restored wetlands to enhance turtle nesting, and to place wood to serve as turtle basking structures (ODFW 1010a).

1.1.3 Fishes

Aquatic habitat for native fish species in Sturgeon Lake is probably different than historical conditions. The current fish assemblage is likely a combination of historical native species and non-native species use. Non-native species, including piscivores, have been introduced to the lake. Non-piscivores, such as carp, can affect the distribution of aquatic vegetation and water quality. Levee construction and other habitat modifications have reduced riverine connectivity and lake circulation. These changes have likely increased peak summer water temperatures,

favoring some non-native fishes over native salmonids. Decreased connectivity with riverine habitat has likely reduced native salmonid use.

Salmonid Distribution near the Project Area

StreamNet (2010) indicates that Sturgeon Lake is used by the following salmonid juveniles for rearing during their downstream migration to the Pacific Ocean:

- Fall Chinook salmon (*Oncorhynchus tshawytscha*)
    - Rearing and migration in Sturgeon Lake (StreamNet, 2010)
- Coho salmon (*Oncorhynchus kisutch*)
    - Rearing and migration in Sturgeon Lake (StreamNet, 2010)
- Winter steelhead (*Oncorhynchus mykiss*)
    - Rearing and migration in Sturgeon Lake (StreamNet, 2010)

Sturgeon Lake and the Gilbert River are currently listed as critical habitat for the Lower Columbia River Fall Chinook and Coho (proposed). Fish monitoring was conducted in 1986 and 1987 and in 1992, before and after the initial Dairy Creek straightening project in 1989 (Ward and Rein, 1992). In 1986 and 1987, 16 and 17 juvenile salmonids were found at the north end of the lake, respectively. At this time, the Gilbert River was the only way that fish could enter Sturgeon Lake during average river levels. Salmonids were not found at the entrance of Dairy Creek in the southern end of the lake. In 1992, after the bypass channel was completed, juvenile salmonids were found in the northern end of the lake (35) and the southern end of the lake (14) near the Dairy Creek bypass channel. Most of these salmonids (98%) were juvenile Chinook; the remainder (2%) were juvenile coho. This Study captured both coho and steelhead in the Columbia River and Multnomah Channel, adjacent to the entrances of Sturgeon Lake. These species are not as likely to rear in shallow near-shore areas as Chinook (Ward and Rein, 1992).

Recent fish monitoring has been conducted in proximity to Sauvie Island and the Study area. The National Marine Fisheries Service (NMFS) has collected qualitative observations of juvenile salmonid presence in the upper Multnomah Channel (i.e., McCarthy Creek and Bonneville Bottoms wetlands), and in the lower Multnomah Channel (e.g., Cunningham Slough, Ruby Channel). Chinook salmon sub-yearling juveniles were present in the lower and upper Multnomah sites during both April and July 2011. Yearling coho were found in the upper Multnomah area in April 2011.

Johnson et al. (2011) reported on juvenile salmonid monitoring upstream and downstream of the current Study area. This Study found juvenile salmonids of multiple stocks and rearing types in shallow freshwater habitats year-round. The highest Chinook densities and the smallest average lengths were observed in spring. The second highest densities for Chinook were noted in winter, when there was a bimodal size distribution of Chinook salmon indicating temporal overlap of

salmon life stages in tidal fresh water. Unmarked Chinook salmon far out-numbered catches of marked (presumably hatchery) Chinook salmon, with approximately 88% unmarked and 12% marked, indicating unmarked fish use shallow tidal freshwater to a greater extent than marked fish (Table 2). Unmarked fish were present year-round, whereas marked fish mostly appeared as a peak in spring. Although some unmarked fish (perhaps approximately 22%) originated in hatcheries, the size distribution and genetics data generally were indicative of naturally produced fish. Therefore, the data support restoration of shallow tidal freshwater habitats to aid recovery of wild fish populations.

The relationship between juvenile salmonid density and habitat features within the shallow tidal freshwater stratum was not apparent in Johnson et al. (2011). Other studies in large river floodplains have been able to associate floodplain wetland and backwater habitats with juvenile salmonid densities. Jeffres et al. (2008) found vegetated ephemeral floodplain habitats provided more favorable rearing conditions for juvenile Chinook salmon than river-channel habitats. In the Sacramento River, juvenile Chinook salmon, associated with off-channel habitats, yielded larger daily otolith increment widths, compared with fish from main-channel habitats (Limm and Marchetti 2009). Recent beach seines in off-channel, wetland channel, and main channel habitat strata near Cottonwood Island, RM 71 (Appendix B in Diefenderfer et al. 2011) reported approximately 99% of captured salmonids being Chinook, with less than 1% consisting of chum, coho, cutthroat, and steelhead juveniles. Juvenile salmonid densities were highest in the off-channel habitat stratum, followed by wetland channel and main channel habitat strata.

Table 2. Percent Composition of Fish Species Collected in Shallow Freshwater Tidal Habitat

	% Composition (all fish species)		%Composition (just salmonids)	
Species	SRD	LRR	SRD	LRR
Chinook (unmarked)	1.22	4.46	79.22	75.21
Chinook (marked)	0.16	0.65	10.58	11.01
Chum Salmon	0.00	0.13	0.00	2.11
Coho (unmarked)	0.08	0.20	5.19	3.31
Coho (marked)	0.07	0.47	4.42	7.88
Steelhead	0.01	0.01	0.39	0.08
Steelhead (marked)	0.00	0.02	0.19	0.39
Total	1.54	5.93	100.00	99.98
Chinook + Chum	**1.38**	**5.24**	**89.81**	**88.33**
Coho + Steelhead	**0.16**	**0.69**	**10.19**	**11.65**

SRD= Sandy River Delta, RM 188- 202, LRR= Lower River Reaches, RM 110-141
Source: Johnson et al. 2011

Salmonid Distribution in the Lower Columbia River Estuary

In the larger Lower Columbia River Estuary (LCRE), varying peaks of use are driven by species, life-history strategy, water conditions, and other factors. Depending on the salmonid evolutionarily significant unit (ESU), the emigration peaks for both juvenile and adults vary between species, as well as for years (Figure 2; Table 3 and Table 4). In general, emigrating juvenile coho have a peak that can occur between March and June (Fisher 2011), or approximately between mid-April and mid-July (Carter et al. 2009, FERC 2009, Bonneville unpublished data). Chinook emigrating juveniles have a peak approximately between March and July/August (Carter et al. 2009, FERC 2009, Bonneville unpublished data). In the LCRE, shallow floodplain lakes and associated wetlands warm up and become relatively unsuitable in the late summer and early fall; approximately June-September (Fisher 2011). Juvenile salmon are vulnerable to predation, entrapment, and poor water quality conditions (Fisher 2011).

Table 3. Regional Fish Presence

Fish presence in lower mainstem Columbia River below Sauvie Island (CRM 87) (Columbia River-Baker Bay HUC #170800060501; Columbia River-Cathlemet Channel HUC #170800030701)

Sources: Bradwood LNG Project BA, June 2009
Eulachon Status Review Update (2010)
Good et al. 2005
WDFW (Brad James, Olaf Langness, and Steve West), ODFW (Tom Rien)

Internal Input: NWFSC (Curtis Roegner)
PRD (Marc Romano)

=present; = relatively abundant; = peak occurrence

Species	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eulachon													
Southern DPS	Adult migration & holding[1, 2]												
	Adult spawning[2]												
	Egg incubation[3]												
	Larvae emigration												
Sturgeon: Green													
Southern DPS	Juvenile rearing[2]												
Salmon: Chinook													
Lower Columbia River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Upper Columbia River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Upper Willamette River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Snake River - Spring/Summer	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Snake River - Fall	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Salmon: Chum													
Columbia River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration[4]												
Salmon: Coho													
Lower Columbia River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Salmon: Sockeye													
Snake River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Steelhead													
Lower Columbia River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Middle Columbia River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Upper Columbia River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Upper Willamette River	Adult migration and holding												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												
Snake River	Adult migration and holding[5]												
	Adult spawning												
	Eggs & pre-emergence												
	Juvenile rearing												
	Juvenile emigration												

[1] Eulachon Status Review Update, 20 January 2010. Available at: http://www.nwr.noaa.gov/Other-Marine-Species/upload/eulachon-review-update.pdf

[2] Personal communication. Conversation between WDFW (Brad James, Olaf Langness, and Steve West), ODFW (Tom Rien), and NMFS (Rob Markle, Bridgette Lohrman) regarding green sturgeon and eulachon presence in the Columbia River. June 23, 2009.

[3] Eulachon egg incubation estimated relative to spawning timing and 20 to 40 day incubation period.

[4] Carter et al. 2009 (Seasonal juvenile salmonid presence and migratory behavior in the lower Columbia River).

[5] Good et al. 2005 (Updated status of federally listed ESUs of West Coast salmon and steelhead

Citations:

Carter, J.A., G.A. McMichael, I.D. Welch, R.A. Harnish, and B.J. Bellgraph. **2009**. Seasonal juvenile salmonid presence and migratory behavior in the Lower Columbia River. PNNL-18246, Pacific Northwest National Laboratory, Richland, Washington. Available at: www.pnl.gov/main/publications/external/technical_reports/PNNL-18246.pdf.

FERC (Federal Energy Regulatory Commission). **2009**. Bradwood Landing Project biological assessment and Essential Fish Habitat assessment (Table 7.3.1-1). Available at: www.ferc.gov under accession #20090624-4002). Division of Gas-Environment and Engineering.

Table 4. Fish Passage past Bonneville Dam

Passage Past Bonneville Dam	Jan		Feb		March		April		May		June		July		Aug		Sept		Oct		Nov		Dec	
Juv Fish Timing LCR																								
chum				j	j	j	j	peak	peak	peak	j	j	j	j										
coho							j	j	j	j	j	j												
Chinook - stream type							j	j	j	j	j													
Chinook - ocean	j	j	j	j	j (ChF H)	peak	peak	peak	peak	peak	peak	peak	j	j	j	j	j	j	j	peak	peak	peak	j	j
Sockeye									peak	peak														
Cutthroat					j	j	j	j	j	j														
Steelhead										peak	peak	peak												
Adult Fish Timing LCR																								
Chum																		a	a	a	peak	peak	a	
coho	LCR coho mainstem spawning RM 113 to 143															a	peak	peak	peak	a	a	a	a	
Chinook LCR (spring)						a	a	a	a	a														
Chinook LCR (fall)																a	peak	peak	a					
Chinook SRB (spr and sum)					a	a	spring peak	spring peak	spring peak	spring peak	summer peak	summer peak	summer peak	a										
Chinook SRB (fall)															a	a	a	a	a	a	a			
Sockeye											a	peak	peak	a	a									
Cutthroat																								
Steelhead LCR (summer)									a	a	A-run	A-run	A-run	A-run	A-run	A-run	B-run	B-run	B-run	B-run				
Steelhead LCR (winte	a	a	a	a	a																a	a	a	a
Steelhead MCR	a	a						a	a	a	a	a	peak	peak	peak	peak	peak	peak	a	a	a	a	a	a
Steelhead UCR										a	a	a												
Steelhead SRB										a	a	a												

Source: Post Office Lake Habitat Benefits Model (USACE 2012)

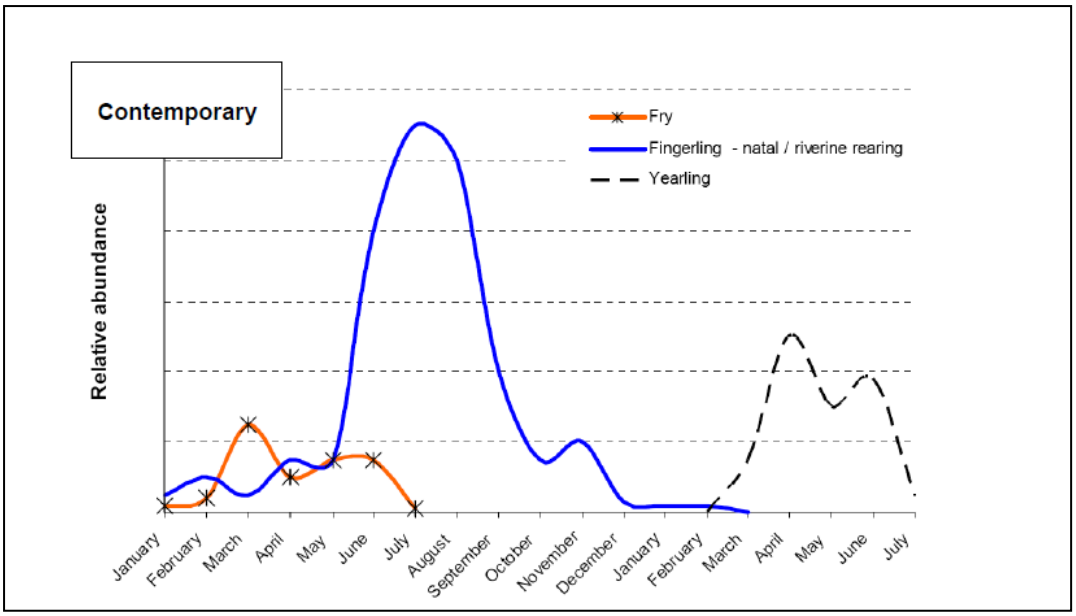

Figure 2. Early Life History of Chinook Salmon in Columbia River Estuary

Source: Fresh et al. 2005

Non-Salmonids

White sturgeon are known to feed in the Gilbert River and Sturgeon Lake (ODFW 2011), although there is no published documentation of this use. Juvenile and sub-adult white sturgeon are known to use both main and off channel habitats in the lower Columbia River, in a variety of depth regimes (ODFW 2010b).

Pacific Lamprey distribution and habitat use data is lacking in the project area. The aquatic habitat present in the project area is suitable for larval (ammocoete) rearing. Distribution of larval lampreys is widespread in the mainstem Columbia and Willamette Rivers, and is not necessarily associated with proximity to spawning tributaries (USFWS 2007). However, USFWS monitoring in the Multnomah Channel has not yielded any juvenile lamprey (USFWS 2011).

A warm-water fish community currently exists in Sturgeon Lake, and potentially in Dairy Creek. Warm-water fish species include bullhead (*Ictaluridae*), largescale sucker (*Catostomus macrocheilus*), three-spine stickleback (*Gasterosteus aculeatus*), goldfish (*Carassius auratus*), white crappie (*Pomoxis annularis*), black crappie (*Pomoxis nigromaculatus*), northern pikeminnow (*Ptychocheilus oregonensis*), largemouth bass (*Micropterus salmoides*), and walleye (*Sander vitreus*) (Ward and Rein 1992). There is limited information about non-native and/ or warm water piscivory on salmonid juveniles. The ODFW (Ward and Rein 1992) collected predator gut contents in Sturgeon Lake, and found no juvenile salmonids in gut contents of potential predators. However, this study was under conditions of very low salmonid densities in the lake. Recent fish use information is lacking in Sturgeon Lake.

2.0 METHODS

2.1 Indicator Species Selection:

To represent habitat benefits from Corps ecosystem restoration project actions, representative species were screened and selected based on the following criteria:

- Resource Significance: The resource (i.e. indicator species) must be significant from an institutional, public, and/ or technical standpoint (ER 1105-2-100). Institutional recognition of a resource means its importance is recognized and acknowledged in the laws, plans, and policies of government and private groups. Technical recognition of a resource or an effect is based upon scientific or other technical criteria that establish its significance. Public recognition means some segment of the general public considers the resource or effect to be important.
- Study Relevance: The habitat of the indicator species is relevant to the current habitat types and anticipated Corps-induced future changes in those habitats.
- HSI Model Availability: The indicator species must have a USACE-certified HSI model available to be considered for benefit modeling. USACE-certified HSI models have been published as peer reviewed technical documents. In addition, the HSI models need to be regionally applicable. A model is regionally applicable if it was developed and calibrated for a region that includes the Study area, or if the model variables, scoring criteria, and structure are transferrable to the Study area. The HSI models also need to be locally applicable, in terms of the life stage evaluated by the HSI. For example, an HSI for salmonid spawning would not be appropriate for a project area that is only used by salmonids for rearing. HSI models that cover multiple life stages can be paired down to the variables that are relevant and appropriate for that life stage.

2.1.1 Resource Significance

The Study objectives are associated with the SIWA Management Plan (ODWF 1010a) objective 1.1, to "Conduct research on methods and then implement these methods to improve the biological and hydrological function of the 3,000 acre Sturgeon Lake system." The SIWA Management Plan (ODFW 1010a) integrates institutional, public, and technical significance considerations by including applicable federal laws, Oregon statutes, ODFW mission and authority, Oregon Administrative Rules, and Oregon Statewide Angling Regulations into its overall goals, objectives, and management strategies. According to the SIWA Management Plan, objective 1.1 is intended to benefit the following biological resources:

- Waterfowl
- Listed anadromous fish
- Pacific lamprey

Therefore, in order for this Study's habitat benefits model to represent significant resources from an institutional, public, and/ or technical standpoint (ER 1105-2-100), as defined by the SIWA Management Plan, the indicator species should be representative of these groups.

2.1.2 Study Relevance

Although Sturgeon Lake provides habitat for multiple life stages of waterfowl and (to a lesser extent) anadromous fish, the lake is primarily used for the following life history stages of waterfowl, anadromous fish, and (presumably) Pacific lamprey:

- Waterfowl - overwintering
- Listed anadromous fish - juvenile rearing
- Pacific lamprey - ammocoete rearing (assumed)

The habitat benefits model for this Study will evaluate restoration measures that will attempt to maintain lake morphology and connectivity with the Columbia River, thereby preserving these existing functions and habitat uses. The restoration measures may also increase the spatial extent and function of the existing habitat.

2.1.3 HSI Availability

The species associated with the ODFW management plan objective 1.1, and their relevant life stages, were compared against the available USACE certified HSI models. Certified HSI models were available for some of the waterfowl species that overwinter on Sturgeon Lake (Table 1).

Out of the dabbling ducks and geese present on Sturgeon Lake (as defined by common, uncommon, or occasional occurrence), the mallard, northern pintail, snow goose, wood duck, greater white-fronted goose, and redhead have certified HSI models for overwintering. The only species with regional applicability of the overwintering component is the wood duck. However, the wood duck overwintering habitat requirements are somewhat unique among the dabbling ducks. Wood ducks require wooded wetlands instead of open water (Sousa and Farmer 1983). Since most overwintering waterfowl rely on open water for overwintering, the wood duck is not representative of this guild. The mallard overwintering model is specific to food resources and habitat types present in the lower Mississippi Valley (Allen 1982). The redhead HSI model is specific to Gulf of Mexico coastal wetlands, with variables specific to shoalgrass and widgeongrass, two species that do not occur in the project area (Howard and Kantrud 1986). The northern pintail, snow goose, and greater white-fronted goose overwintering models were developed for other regions of the United States (Table 1). However, in these three models, the variables are applicable to the Study area (Howard and Kantrud 1986; Kaminski 1986; Leslie and Cordes 1985). Out of these three species, the northern pintail is more common in Sturgeon Lake during the overwintering season (Table 1) than either of the geese. Therefore, the northern pintail will represent the dabbling ducks and geese in the Study HEP model.

Out of the diving ducks that commonly overwinter in Sturgeon Lake, the lesser scaup is the only species that had an overwintering HSI. Lesser scaup generally prefers deeper water, and is only seen in Sturgeon Lake when the water level is above 10 feet (ODFW 2011), but is generally common in the SIWA (Table 1). The overwintering model was developed for the Gulf of Mexico and south Atlantic Coast; however, the model variables are reasonably applicable to the Study area. Therefore, the lesser scaup will represent the diving ducks in the Study HEP model.

The Pacific salmon and winter steelhead all have USACE approved HSI models (Table 5). The juvenile rearing components are the relevant components of the models. The ocean-type Chinook and chum salmon have overlapping requirements, in that they are sub-yearlings as they outmigrate and rear in LCRE wetlands. Chinook juveniles are present in the LCRE year-round (Table 3 and Table 4; Figure 2), and account for nearly 85 to 90% of juvenile salmon abundance (Table 2), and are composed of multiple stocks from throughout the Columbia Basin (Johnson et al. 2011) The juvenile rearing component of the Chinook salmon HSI considers water quality, channel morphology, and substrate characteristics. Many of these variables are applicable to streams and not tidal wetlands. However, a subset of these variables is applicable to the Study area, as discussed in section 2.2. Chum salmon juveniles typically spend less time in the freshwater tidal estuaries and do not have as much seasonal variation as Chinook. The juvenile component of the Chum salmon HSI focuses on outmigration to the brackish estuary and only considers temperature and dissolved oxygen for rearing habitat suitability (Hale et al. 1985). However, chum juveniles utilize freshwater tidal wetlands, but typically in much lower densities than Chinook. Chum juveniles accounted for approximately 2% of the overall juvenile salmonid abundance in a study nearby and downstream of Sauvie Island (Johnson et al. 2011). Given the overlap in juvenile habitat suitability requirements, and the paucity of modeling variables for chum salmon, the Chinook salmon HSI will represent ocean-type salmonid rearing in the Study HEP model.

The stream-type coho and winter steelhead have overlapping requirements, in that they typically rear for at least one year in their natal streams before outmigrating to the LCRE. Winter steelhead juveniles can rear for one to three years in their natal streams. Coho and winter steelhead are found in LCRE wetlands, though in much lower relative abundance than Chinook (Table 2). Juvenile coho occur near the Study area in the fall, winter, and spring, and in regional studies, coho have accounted for approximately 10% of the juvenile salmonids captured (Johnson et al. 2011). Winter steelhead juveniles accounted for less than 0.6% of the juvenile salmonids captured (Johnson et al. 2011). Coho and winter steelhead juvenile rearing variables both include similar water quality, food, and cover variables. Given the extremely low use of winter steelhead in freshwater tidal wetlands, and the similarity in the HSI juvenile rearing variables, the coho HSI will represent stream-type salmonid rearing in the Study HEP model.

Pacific lamprey are not included in the Study HEP Model for three reasons. First, lamprey ammocoetes have never been collected in Sturgeon Lake, and collection attempts in the Multnomah Channel did not yield any ammocoetes (USFWS 2011). Second, a USACE-certified HSI model does not exist for the Pacific lamprey. Third, the habitat requirements for lamprey ammocoetes are similar to the requirements for subyearling Chinook and Chum rearing. Therefore, Pacific Lamprey are represented by the Chinook/ Chum model component.

Table 5. Juvenile Salmonids Expected to Occur in the Study Area and Applicability of USACE Certified HSIs

Species	Type	Local Abundance*	Local Life Stage	HSI Applicable Life Stage
Chinook Salmon (*Oncorhynchus tshawytscha*)	Ocean	High	Juvenile rearing	All
Chinook Salmon (*Oncorhynchus tshawytscha*)	Stream	Medium	Outmigration	All
Chum Salmon (*Oncorhynchus keta*)	Ocean	Low	Outmigration (to brackish estuary)	All
Coho (*Oncorhynchus kisutch*)	Stream	Medium	Outmigration	All
Winter Steelhead (*Oncorhynchus mykiss*)	Stream	Low	Outmigration	All

*Expected and relative local abundance based on Johnson et al. (2011) and Carter et al. (2009)

2.2 Northern Pintail Suitability Index Variables

Northern Pintail

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Photographer: Dick Cannings

Dabbling ducks utilize emergent, shallow, tidal and/or non-tidal wetlands. The northern pintail winters in a wide variety of shallow inland freshwater and intertidal habitats. The northern pintail's breeding habitat is open, unwooded wetlands, such as wet grassland, lakesides or tundra. It is highly gregarious outside the breeding season and forms very large mixed flocks with other ducks. The pintail feeds by dabbling and upending in shallow water for plant food mainly in the evening or at night, and therefore spends much of the day resting. Its long neck enables it to take food items from the bottom of water bodies up to 30 centimeters (1 foot) deep, which are beyond the reach of other dabbling ducks like the mallard. They feed on grain, seeds, weeds, aquatic insects, crustaceans, and snails from the ground surface or from filter-feeding at the surface of water. The winter diet is mainly plant material including the seeds and rhizomes of aquatic plants, but pintail sometimes feed on roots, grain, and other seeds in fields, though less frequently than other *Anas* ducks. During the nesting season the birds mainly eat invertebrates, including aquatic insects, mollusks, and crustaceans.

This species was selected to represent overwintering waterfowl that utilize shallow wetlands with emergent vegetation as food sources. Restoration measures may change the distribution and availability of shallow-water habitat, over the course of a tidal cycle. Increased inundation of lake-fringe wetlands may increase the coverage of native emergent wetland vegetation by displacing reed canary grass (RCG).

2.2.1 Original and Complete Model Version

According to Howard and Kantrud, (1986) the complete HSI overwintering model has the following characteristics:

1. ${}^{NP}V_1$ = Percentage of open water (<10% canopy coverage of emergent vegetation) that is less than 0.5 m deep
2. ${}^{NP}V_2$ = Percentage of area that is covered by persistent emergent vegetation (>10% canopy cover).
3. ${}^{NP}V_3$ = Percentage of emergent vegetation that exceeds 30 cm in height above the water surface and had greater than 40% canopy cover (Note: this variable can be included in the model only if some emergent vegetation is present).
4. ${}^{NP}V_4$ = Percentage of study area dominated by (>50% canopy coverage) submerged or emergent food plants.
5. ${}^{NP}V_5$ = Mean salinity during the growing season.

The following equations are suggested for determining values of the cover and food component indices for a potential wintering area of northern pintail and for determining the overall HSI value for the site.

$$\text{Cover} = [{}^{NP}V_1 * (({}^{NP}V_2 + {}^{NP}V_3)/2)]^{1/2}$$

$$\text{Food (salinity >5 ppt)} = ({}^{NP}V_1 * {}^{NP}V_4 * {}^{NP}V_5)^{1/3}$$

$$\text{Food (salinity <5 ppt)} = ({}^{NP}V_1 * {}^{NP}V_4)^{1/2}$$

$$\mathbf{HSI_{northern\ pintail} = least\ of:}\ \boldsymbol{Food\ and\ Cover}$$

The regional applicability of this model is for the Gulf Coast. However, the suitability index (SI) variables are representative of local conditions in the Study area.

2.2.2 HSI Model Modifications

Since the Study area is in the freshwater tidal zone of the LCRE, salinity (${}^{NP}V_5$) will not be used in the northern pintail model. Also, the percentage of emergent vegetation >30 cm above the water surface (${}^{NP}V_3$) will not be used, because in this region of the country, emergent vegetation is in a senesced state during the overwintering period. Therefore, the following equations will be used to calculate the northern pintail HSI:

$$\text{Cover} = ({}^{NP}V_1 * {}^{NP}V_2)^{1/2}$$

$$\text{Food (salinity <5 ppt)} = ({}^{NP}V_1 * {}^{NP}V_4)^{1/2}$$

$$\mathbf{HSI_{northern\ pintail} = least\ of:}\ \boldsymbol{Food\ and\ Cover}$$

Table 6 describes how the northern pintail variable metrics will be measured and calculated. In general, the variables will consider environmental conditions during the northern pintail overwintering period (December- February). Water depth will be based on a mean water surface elevation, as estimated from recent October- February water level data, and a bathymetric map. The emergent vegetation zone will be calculated based on interpretation of aerial photographs and ground surveys. Borde et al. (2011) provides marsh elevations and percent inundation times for emergent wetland vegetation at local reference sites. This information will be used to develop biological expectations with predicted emergent wetland distribution for the proposed restoration measures. A constant sediment aggradation rate in the lake of 0.1 inches per year is assumed to occur in both the no-action and restoration measure scenarios. This sediment aggradation rate was estimated in a sediment flux study associated with this restoration study (Waterways Consulting 2013).

Table 6. Selected Northern Pintail SI Variables

Northern Pintail (Howard and Kantrud 1986)				
SI Variable	Metric	Metric Value	SI	Measurement Technique
$^{NP}V_1$	Percent of open water (<10% canopy coverage of emergent vegetation) that is less than 0.5 m deep	0	0.1	Without Project: Delineate area inundated at the average Dec- Feb WSEL. Based on field reconnaissance, Exclude the RCG area (all other emergent veg is senesced during the winter period); Delineate 0- 0.5 m deep area with bathymetric bed elevations; Calculate metric for Year 0. Recalculate for future years 1-50, given a 0.1 inch increase in lake-bed elevation per year, and associated changes to lake area, emergent vegetation zone, and bathymetry. Measures: Same as "Without Project" methodology. The average Dec- Feb WSEL will be re-calculated based on any predicted change in state-duration. The existing emergent vegetation zone will be plotted on the existing conditions stage-duration curve. The relationship between % inundation time and the existing emergent vegetation zone will be used to predict if the emergent vegetation zone will change (i.e. if the stage-duration curve changes, it will be used to predict changes to emergent vegetation zone changes).
		10	0.3	
		20	0.45	
		30	0.6	
		40	0.8	
		>50	1.0	
$^{NP}V_2$	Percentage of area that is covered by persistent emergent vegetation (>10% canopy cover)	<30	1.0	Without Project: Delineate area inundated at the average Dec-Feb WSEL. Delineate area with emergent vegetation (based on aerial photography and field verification); Calculate metric for Year 0. Recalculate for future years 1-50, given a 0.1 inch increase in lake-bed elevation per year, and associated changes to lake area and emergent vegetation zone. Measures: Same as "Without Project" methodology. The average Dec- Feb WSEL will be re-calculated based on any predicted change in state-duration. The existing emergent vegetation zone will be plotted on the existing conditions stage-duration curve. The relationship between % inundation time and the existing emergent vegetation zone will be used to predict if the emergent vegetation zone will change (i.e. if the stage-duration curve changes, it will be used to predict changes to emergent vegetation zone changes).
		40	0.9	
		60	0.6	
		80	0.3	
		100	0	
$^{NP}V_4$	Percentage of study area dominated by (>50% canopy coverage) submerged or emergent food plants.	0	0.0	Without Project: Delineate area of emergent vegetation categories (RCG, Eliochris, Sagittaria), based on aerial photography and field verification; Classify food value of each category, based on the literature. Calculate metric for Year 0. Recalculate for future years 1-50, given a 0.1 inch increase in lake-bed elevation per year, and associated changes to the distribution of emergent vegetation. Measures: Same as "Without Project" methodology. The average Dec- Feb WSEL will be re-calculated based on any predicted change in state-duration. The existing emergent vegetation zone will be plotted on the existing conditions stage-duration curve. The relationship between % inundation time and the existing emergent vegetation zone will be used to predict if the emergent vegetation zone will change (i.e. if the stage-duration curve changes, it will be used to predict changes to emergent vegetation zone changes).
		10	0.2	
		20	0.4	
		30	0.6	
		40	0.8	
		>50	1.0	

2.3 Lesser Scaup Suitability Index Variables

Lesser Scaup

© Dick Cannings
Photographer: Dick Cannings
Image ID#: 10655; Location: Lost Lagoon, Vancouver, BC, Canada; Date: November
Gender: male

Lesser scaup was selected to represent the guild of diving ducks, which require deeper, permanently submerged wetland habitat and open water lacustrine environments. The lacustrine, open water of Sturgeon Lake provides such habitat. The wintering lesser scaup provides the only Corps-certified HSI models for diving ducks common in Sturgeon Lake. Therefore, the lesser scaup will reflect project benefits and impacts to deeper, open-water, permanent tidal and non-tidal wetlands in the project area.

Deeper tidal wetlands provide both aquatic and terrestrial benefits. Besides providing loafing areas and important, high-quality food sources for waterfowl, tidal wetlands also provide important rearing nurseries for juvenile fish, including salmonids. Tidally or floodplain connected wetlands afford flood refuge, as well as abundant foraging opportunities and inputs to the aquatic food web.

The lesser scaup is a widely distributed, long-distance migrant, moving south in October to November; Oregon and Washington likely host non-breeding wintering residents (NatureServe 2010, and Ridgley 2003). In the southern winter range, scaup prefer ponds, lakes, or sloughs with fairly clear water one meter or deeper, and they can also be found in large tidal lakes, bays, marshes, and offshore (NatureServe 2010 and Mulholland 1985). In Oregon, their conservation status is considered "vulnerable," though in Washington they are listed as "apparently secure" (NatureServe 2010, and Ridgely 2003). Scaup feed on seeds of pondweeds, widgeongrass, wild rice, sedges, bulrushes, crustaceans, and aquatic insects and possibly small fish, usually at depths between three and eight meters (NatureServe 2010 and Mulholland 1985). Lesser scaup remain in their overwintering range through April. However, the general ODFW SIWA overwintering period is from December through February.

2.3.1 Original and Complete Model Version

Mulholland (1985) further describes the model as follows. The associated HSI model parameters include the following four habitat variables and their *optimal* ranges:

1. ${}^{LS}V_1$ = ***percentage of study area supporting pelecypods (bivalve mollusks)*** (optimum = 50% or greater)
    a. Random sampling method is recommended in model
2. ${}^{LS}V_2$ = ***percentage of area supporting emergent vegetation*** (optimum = less than 5%)
    a. Done with aerial photographs
    b. Done during mean low tide if applicable
3. ${}^{LS}V_3$ = ***water depth at mean sea level or average winter (high) water condition*** (optimum = 1-3 meters, or 3.3-9.8 feet). For this evaluation, winter = December-February

4. ${}^{LS}V_4$ = ***human disturbance***
    a. (optimum = none to light)

According to Mulholland (1985), the coverage of pelecypods is considered the most critical and governing variable in the model. If the index for the value representing pelecypods is less than the geometric mean of the rest of the variables, then the HSI would equal the pelecypod coverage. Additionally, it is recommended in the HSI model that future predictions of the pelecypod coverage be assumed to remain the same, unless there are drastic changes in water quality or substrate (Mulholland 1985). According to the model, the appropriate recommended equation is:

$$\textbf{If } {}^{LS}V_1 < ({}^{LS}V_2 * {}^{LS}V_3 * {}^{LS}V_4)^{1/3}\textbf{; then } HSI_{lesser\ scaup} = {}^{LS}V_1$$

Otherwise:

$$HSI_{lesser\ scaup} = (({}^{LS}V_1)^2) * {}^{LS}V_2 * {}^{LS}V_3 * {}^{LS}V_4)^{1/5}$$

Model documentation indicates that regional applicability may be limited to Gulf of Mexico and Southern Atlantic States, though the species is widely distributed and would seem to have similar wintering needs in the Northwest. For this HEP/HSI, it is assumed that the species needs and habitat parameters are fairly general and would remain representative of current and potential species' habitat needs in the Study area.

2.3.2 HSI Model Modifications

All SI variables were retained for lesser scaup overwintering (Table 7). Field data on pelecypod presence will not be available to this Study. Per direction from the model, assumptions, rather than field measurements, will be made for the variable describing predicted pelecypod coverage in the future. Following this guidance, the future value will be held constant at pre-project conditions. In addition, there are few definitive habitat attributes that can be used to infer pelecypod presence. Since a somewhat subjective constant may be used for the pelecypod variable, and because the other variables are the most representative of dabbling duck overwintering habitat potentially affected by the project, this value should not govern the overall HSI score. Therefore, the pelecypod variable will not be treated as a limiting factor.

The relationship between the percentage of area supporting emergent vegetation (LSV2) and habitat suitability was modified, because of the scale of the project area. Mulholland (1985) indicates that lesser scaup prefer areas with little to no emergent vegetation (i.e. 10% of emergent vegetation in project area results in zero habitat suitability; Figure 3). During the overwintering period, Sturgeon Lake has persistent emergent vegetation (i.e. RCG) along the periphery of the lake, accounting for a large portion of the inundated area of the lake. However, because of the large spatial scale of Sturgeon Lake, large open water zones exist in the middle of the north and south lake basins. The peripheral emergent vegetation does not preclude lesser scaup from using these large open water zones. Their common presence in the project area (ODFW 1010a) supports the modification of the restrictive SI curve proposed by Mulholland (1985). The SI curve was modified to be inversely and linearly proportional to the percent of

emergent vegetation (Table 1; Figure 3). A linear relationship was selected because changes in emergent vegetation would likely occur along the shoreline. The open water area in the middle of the lake would likely be preserved, but would increase or decrease in size, as a linear function of RCG expansion or reduction.

$$\mathbf{HSI_{lesser\ scaup} = ((SI_{v1})^2) \times SI_{v2} \times SI_{v3} \times SI_{v4})^{1/5}}$$

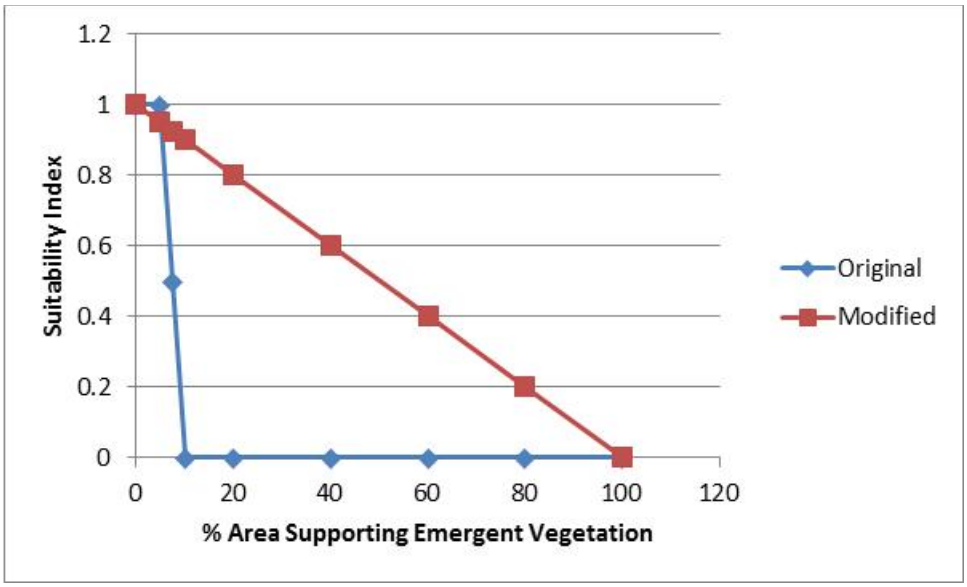

Figure 3. Original and Modified relationship between Lesser Scaup Habitat suitability and the percentage of emergent vegetation during the overwintering period

Table 7. Selected Lesser Scaup SI Variables

Lesser Scaup- Wintering (Mulholland 1985)				
SI Variable	Metric	Metric Value	SI	Measurement Technique
$^{LS}V_1$	% Area Supporting Pelecypods	0	0	Assume constant of 0.5 based on anecdotal evidence (presence on pump station screens).
		20	0.4	
		40	0.8	
		>60	1.0	
$^{LS}V_2$	% Area Supporting Emergent Vegetation	0	1	Without Project: Delineate area inundated at a Dec-Feb Mean WSEL. Delineate area with emergent vegetation (based on aerial photography and field verification); Calculate metric for Year 0. Recalculate for future years 1-50, given a 0.1 inch increase in lake-bed elevation per year, and associated changes to lake area and emergent vegetation zone. Measures: Same as "Without Project" methodology. The Dec- Feb elevation will be re-calculated based on any predicted change in state-duration. The existing emergent vegetation zone will be plotted on the existing conditions stage-duration curve. The relationship between % inundation time and the existing emergent vegetation zone will be used to predict if the emergent vegetation zone will change (i.e. if the stage-duration curve changes, it will be used to predict changes to emergent vegetation zone changes).
		20	0.8	
		40	0.6	
		60	0.4	
		80	0.2	
		100	0	
$^{LS}V_3$	Depth (m), Avg Winter Water Condition	0	0	Without Project: Delineate area inundated at the average Dec- Feb Mean WSEL. Overlay bathymetry contours and calculate the average depth, based on the average Dec- Feb WSEL. Calculate metric for Year 0. Recalculate for future years 1-50, given a 0.1 inch increase in lake-bed elevation per year, and associated changes to lake area, emergent vegetation zone, and bathymetry. Measures: Same as "Without Project" methodology. The WSEL will be re-calculated based on any predicted change in stage-duration. The bathymetry will be recalculated for future years 1-50, based on any predicted change in bathymetry.
		0.5	0.6	
		1-3	1	
		5	0.7	
		7	0.4	
		10	0	
$^{LS}V_4$	Level of Human Disturbance	none-light	1	Without Project: Score will be based on the activity allowed in the ODFW SIWA Management Plan (ODFW 1010a). This management scheme is assumed to persist throughout the 0- 50 year time horizon. Measures: The level of human disturbance is assumed to remain unchanged.
		moderate	0.7	
		heavy	0.3	
		limiting	0	

2.4 Coho Salmon Suitability Index Variables

Coho Salmon

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Most coho juveniles rear in their natal streams. However juveniles will redistribute themselves downstream and utilize off-channel and wetland habitats for rearing and overwintering. As such, Sturgeon Lake and the Gilbert River are proposed as critical habitat for the Lower Columbia River coho. The coho HSI model emphasizes stream systems, as opposed to large river, off-channel and lacustrine wetlands habitats present in the Study area. The coho HSI model contains habitat suitability variables for adult migration, spawning, egg incubation, alevin, parr, and smolts. The model includes water quality, sediment, riparian, and channel morphology variables. The adult migration phase emphasizes water quality variables that are likely applicable in the estuary and in the natal stream. The spawning, egg incubation, and parr rearing variables are specific to a smaller stream setting with fast moving waters and spawning gravels. The parr rearing variables include some habitat variables that could also be applicable to large river and lacustrine wetlands situations. The smolt stage is focused on water quality variables during seaward outmigration.

2.4.1 Original and Complete Model Version

Potential habitat variables from which a suitability index for the ***juvenile parr*** stages of coho salmonids could include (McMahon 1983):

1. **$^{CO}V_1$ = *Maximum temperature during rearing***
2. **$^{CO}V_2$ = *Minimum D.O. during rearing***
3. **$^{CO}V_3$ = *Percent canopy over rearing stream***
4. **$^{CO}V_4$ = *Vegetation composition of riparian zone(* index of riparian zone during summer)**
    a. $^{SI}V_4$ = 2(% canopy of deciduous trees and shrubs) + % canopy cover of grasses and forbs + % canopy cover of conifers
5. **$^{CO}V_5$ = *Percent pools during summer low flow (pool to riffle ratio)***
6. **$^{CO}V_6$ = *Substrate composition in riffle/run areas***
    a. $^{SI}V_6$ = (A+B)/2;
        i. A = % gravel and rubble present
        ii. B = % fines or embeddedness, whichever is lower
7. **$^{CO}V_7$ = *Proportion of pools during summer low flow that are 10 – 80 m^3, or 50-250m^2 in size WITH sufficient riparian canopy to provide shade***
8. **$^{CO}V_8$ = *Percent in-stream and bank cover during summer low flow***
9. **$^{CO}V_9$ = *Winter Cover, % of total area consisting of quiet backwaters and deep (>= 45 cm) pools WITH dense cover of roots, logs, debris jams, flooded brush, or deeply undercut banks***

There is also a set of two smolt life history variables that may be relevant as parr prepare to leave the rearing areas. These variables include:

10. **$^{CO}V_{10}$ = *Maximum Temperature During:***
    a. A = winter (Nov-Mar) in rearing streams
    b. B = spring-early summer (Apr-Jul) in streams where seaward migration of smolt occurs
11. **$^{CO}V_{11}$ = *Minimum DO concentration during April-July in streams where seaward migration of smolt occurs***

According to McMahon (1983), while the model includes several variables that affect the well-being of coho throughout each of the four life stages (with parr further delineated by water quality, food productivity, and cover), the final HSI is also based on the limiting factor theory. Therefore, the lowest SI score among the variables defines the overall HSI.

$$\mathbf{HSI_{coho}=lowest\ {}^{CO}V_i\ of\ {}^{CO}V_1 - {}^{CO}V_9\ (or,\ {}^{CO}V_1 - {}^{CO}V_{11}\ if\ including\ smolts)}$$

2.4.2 HSI Model Modifications

The coho HSI model includes variables that cover the adult, spawner/embryo, parr, and smolt life stage. Out of these life history stages, the parr stage is most representative of coho that would be using riverine wetlands and the shallow lacustrine wetlands for rearing. The project area does not provide habitat value for coho spawning. Furthermore, coho typically rear in their natal stream for a year before entering the estuary. Coho yearlings are abundant in the LCRE between April and June, but most are found in deeper waters, as opposed to the shoreline and floodplain wetlands. However, there are a certain proportion of juvenile coho that utilize shallow water habitats (Johnson et al. 2011). Out of these variables for parr suitability, only the water quality, riparian, and cover variables are applicable to the project area habitat type and potential effects of the proposed restoration measures.

Water temperature ($^{CO}V_1$) and dissolved oxygen concentrations ($^{CO}V_2$) are applicable, regardless of the specific habitat type utilized during the parr stage. Water quality in backwater sloughs can vary greatly depending on depth, canopy cover, flow regimes, and hyporheic connectivity. Water quality is also likely to improve, based on the anticipated measures for improved hydrologic flows into Sturgeon Lake. However, dissolved oxygen data from Sturgeon Lake are incomplete and from the 1980's. Since land use and pollutant sources may have changed in the past 20+ years, these data may not accurately represent current conditions. Collecting new dissolved oxygen data was not possible within the scope and schedule of this project, therefore, the dissolved oxygen variable was excluded from this analysis. Maximum temperature ($^{CO}V_1$) was retained, but modified to a maximum temperature through the month of June (Table 8). Late summer and early fall water temperature was excluded from the analysis, because high water temperatures during this period do not exclude juvenile salmon rearing during the spring (through June), when rearing densities are highest (Johnson et al. 2011). Riparian zone percent canopy cover ($^{CO}V_3$) and riparian vegetative composition ($^{CO}V_4$) are applicable to the deeper channel habitat types that juvenile coho are most likely to inhabit. These habitat types are

represented by the Gilbert River and Dairy Creek channels in the Study area. Benefits from riparian zones to aquatic species like salmonids include: shade, allochthonous inputs to the food web, water quality buffers, bank stability, wood recruitment, and structural habitat diversity. For these reasons, riparian components of the HSI were retained. The percentage of winter cover ($^{CO}V_9$) could be applicable to both the riverine wetlands and lacustrine wetlands. Lacustrine wetlands are particularly relevant during flood situations, where flooded brush in the floodplain is a key refugium for coho parr. The shallow lacustrine wetland habitat provides refugia from piscivores, and provides cover, in terms of emergent vegetation and overhanging riparian vegetation. This variable will measure the flooded fringe that is inundated during the winter months, during coho overwintering. As a result, the variables in Table 8 are recommended for calculating the coho HSI.

An arithmetic average is recommended to combine the SI scores into an HSI index. A minimum SI value, as recommended in McMahon (1983), was not used, because of the variable conditions throughout the year, and the year-round presence of coho juveniles. For example, marginal water temperature suitability during late June does not preclude use of the habitat in the late fall through early summer, when water quality conditions are more suitable. The coho and Chinook juvenile suitability scores will be combined, as discussed in the Chinook section. The combined coho and Chinook HSI equation will be presented in the Chinook section of this report.

Table 8. Selected Coho Salmon SI Variables

Coho Salmon- Juvenile Rearing (McMahon 1983)				
SI Variable	Metric	Metric Value	SI	Suggested Measurement Technique
$^{CO}V_1$	Maximum temperature during presence/ occupation (Deg C)	4	0	Without Project: Estimate max temperature based on WMSWCD (2011) Measures: When measures are predicted to cause an increase in riverine flow to the lake, maximum temperatures will be estimated with a simple mass-balance approach. Existing data for January- June for Sturgeon Lake and the Columbia River will be partitioned. The daily inflow and lake volume each of during that time period will be paired with corresponding daily Columbia River and Sturgeon Lake water surface temperatures for the mass balance calculations.
		6	0.5	
		8-13	1	
		16	0.5	
		20	0.2	
		24	0	
$^{CO}V_3$	Percent canopy cover, rearing stream	0	0.2	Without Project: Estimate riparian condition in stream habitats (Gilbert River and Dairy Creek) with aerial photo interpretation and field work verification Measures: Measures affecting riparian composition will incorporate riparian clearing and/ or planting plans into the overall estimate of canopy cover. New plantings are assumed to incrementally achieve full function over the 0- 50 year time horizon. Full function for canopy cover will be estimated by measuring existing channels with mature riparian condition.
		25	0.5	
		40	0.85	
		50- 75	1	
		90	0.65	
		100	0.4	
$^{CO}V_4$	Vegetation composition of riparian zone (index of riparian zone during summer)	0	0	Without Project: Estimate riparian condition in stream habitats (Gilbert River and Dairy Creek) with aerial photo interpretation and field work verification Measures: Measures affecting riparian composition will incorporate riparian clearing and/ or planting plans into the overall estimate of composition..
		50	0.2	
		100	0.5	
		150	0.95	
		162.5	1	
$^{CO}V_9$	Winter Cover, % of total area consisting of quiet backwaters and deep (>= 45 cm) pools WITH dense cover of roots, logs, debris jams, flooded brush, or deeply undercut banks	0	0.2	Without Project: Based on the winter period (Mean water surface elevation Dec- Feb), Estimate the area of deep (>45 cm) pools with dense cover of root, logs, debris jams, flooded brush (floodplain, emergent vegetation, and forested wetlands), deeply undercut banks (along the Gilbert and Dairy Creek channels) Measures: Measures affecting conveyance capacity from the Columbia River and the tidal prism will require re-calculating this metric, taking into account a new mean water surface elevation.
		10	0.35	
		20	0.6	
		30	0.95	
		>=32	1	

2.5 Chinook Salmon Suitability Index Variables

Juvenile Chinook salmon in Lake Quinault at the mouth of Falls Creek.

Photographer: Roger Tabor, USFWS

Juvenile Chinook salmon have a high potential for rearing in the Study area. As such, Sturgeon Lake and the Gilbert River are currently listed as critical habitat for the Lower Columbia River Fall Chinook. These fish are mostly subyearlings, and therefore prefer shallow aquatic habitat to avoid predation of larger fishes. These fish also benefit from prey productivity in emergent wetlands. These "ocean-type" rearing requirements are shared with chum salmon juveniles. Chum juveniles are expected to spend less time in the freshwater tidal portion of the estuary, but are still a significant part of the juvenile salmon presence in these shallow habitats. For these reasons, the HSIs for Chinook provide a useful representation of anadromous fish use in tidally connected wetlands, and may reflect benefits gained by restoring increased connectivity with the Columbia River. Specifically, juvenile salmonids could benefit from increased floodplain inundation, and access to backwater refuge via increased connectivity.

The Chinook salmon HSI model contains habitat suitability variables for adult migration and holding, spawning/ egg incubation, and juvenile rearing. The model includes water quality, sediment, riparian, stream flow, and channel morphology variables. The model emphasizes stream systems, as opposed to lacustrine and large river systems. The adult migration phase emphasizes water quality variables that are likely applicable in the estuary, and in the natal stream. The spawning/ egg incubation variables are specific to spawning habitat, with fast moving waters and spawning gravels. Juvenile rearing variables include some habitat variables that could also be applicable to large river and lacustrine wetlands situations. The smolt stage is focused on water quality variables during seaward outmigration.

2.5.1 Original and Complete Model Version

According to Raleigh (1986), potential habitat variables for the juvenile stages of Chinook salmonids include the following list. This list precludes adult, fry, and smolt life-history stages, as they would not use this habitat type.

1. $^{CH}V_1$ = ***Annual minimum and maximum pH***
    a. Measured during the summer to fall season
2. $^{CH}V_2$ = ***Maximum temperature***
    a. During warmest period when species are present
    b. Taken at areas that are problematic for high temperatures
    c. *(coho temperature is the same range but more restrictive for optimal (9-12 vs. 12-18 for CHS)*
3. $^{CH}V_3$ = ***Minimum D.O. during periods of occupation***
    a. CHS Temperature Range is divided into 3 categories with separate SIs :

i. ≤ 5 C◦
ii. 5- 10 C◦
iii. >10C◦

4. ${}^{CH}V_4$ = ***Percent pools during low water, late growing season***
   a. *(Virtually the same between salmon, though more curve-like and more restrictive optimal range for coho)*
5. ${}^{CH}V_5$ = ***Pool class rating during low water, late growing season***
   a. One of three classes, A-C, defined in the model
6. ${}^{CH}V_6$ = ***Average annual base flow***
   a. During late summer to winter low-flow as percentage of annual daily flow
7. ${}^{CH}V_7$ = ***Average annual peak flow***
   a. As multiple of average annual daily flow
8. ${}^{CH}V_8$ = ***Predominant substrate class in riffle run areas for food production indicator***
9. ${}^{CH}V_9$ = ***Average % riffle fines in riffle run areas***
10. ${}^{CH}V_{10}$ = ***Nitrate-nitrogen levels in late summer after spawner die-off***
11. ${}^{CH}V_{11}$ = ***Percent escape cover***
    a. During late summer early fall
    b. Average low flow period
    b. Bottom velocities ≤ 40 cm/s***;*** During late summer early fall
    c. Depths ≥ 15 cm
       i. *(this differs from coho since it is shallower cover)*
12. ${}^{CH}V_{12}$ = ***Percent stream areas with 10-40 cm average sized boulders***
    a. Measure at the same time and areas as escape cover

According to Raleigh (1986), two methods can be used to determine the final Chinook HSI. The first (and recommended) approach is based on the limiting factor theory. Therefore, the lowest SI score among the variables defines the overall HSI.

$$\mathbf{HSI_{Chinook} = lowest\ {}^{CH}V_i\ of:\ {}^{CH}V_1 - {}^{CH}V_{13}}$$

The second method applies a compensatory limiting factor approach. This assumes low scores of dependent variables can be partially compensated by high scores for other dependent variables, with the exception of SI's less than or equal to 0.3 (Raleigh 1986). Examples of dependent variables include: percent pool and percent pool class; gravel size, average water column velocity, and percent fines (which are more applicable to adult life history and spawner needs) (Raleigh 1986). Because assumptions and associations describing the dependency of variables to each other is not well defined, this approach may be slightly more arbitrary and of less value than the former limiting factor approach.

2.5.2 HSI Model Modifications

Existing and future conditions of Sturgeon Lake are and will be tidal wetlands associated with the mainstem estuary. Therefore, juvenile Chinook SI variables that are for stream habitat were not considered. These variables included those dealing with pool class; pool/riffle/run distribution; riffle/ run substrate; flow variables related to egg/ alevin/ fry development; and

nitrogen-related water quality variables. Although adults may use the backwater habitat as refugia during migration, variables, indicating juvenile life history requirements, were considered most applicable to habitats potentially affected under the possible action alternatives. In addition, pH and dissolved oxygen data from Sturgeon Lake are incomplete and from the 1980s. Since land use and pollutant sources may have changed in the past 20 plus years, these data may not accurately represent current conditions. Collecting new pH and dissolved oxygen data was not possible within the scope and schedule of this project. Therefore pH and dissolved oxygen variables were excluded from this analysis. Annual maximum water temperature ($^{CH}V_2$) was not retained, because it was redundant with the coho water temperature metric. The coho SI curve is more conservative, in terms of habitat suitability, and therefore, will represent minimum temperature suitability for both species. Existing conditions have been documented, and the effect of measures can be estimated at a coarse level (Table 9).

Percent escape cover ($^{CH}V_{11}$) was retained but modified. The variable is generally applicable to the Study area, but since juvenile Chinook are known to rear in LCRE freshwater tidal wetlands all year (Johnson et al. 2011; Diefenderfer et al. 2011), the seasonality of the metric was modified from the late summer to all year. Water depths were calculated based on an average annual water surface elevation and existing bathymetric data. Finally, the "depth ≥15 cm" was changed to a zero to one meter depth range, because the bathymetry in the lake and the water level estimates in the lake will not differentiate between zero and 15 cm depths. Furthermore, depths up to one meter deep have been identified as having the highest densities of subyearling Chinook (Healey 1980; Tabor et al. 2006). Given these changes, the variable name was changed to "Rearing Habitat." Table 7 represents these recommended HSI model modifications.

Table 9. Selected Chinook Salmon SI Variables.

Chinook Salmon- Juvenile Rearing (Raleigh et al. 1986)				
SI Variable	Metric	Metric Value	SI	Measurement Technique
${}^{CH}V_{11}$	Percent Rearing Habitat a. All seasons b. Mean water surface elevation, c. bottom velocities ≤ 40 cm/s) d 0- 1 m depth	0	0	Without Project: Estimate 0-1 m depth zone, based on mean annual lake water level, existing bathymetry, and velocity vectors from the existing conditions hydraulic model. Recalculate for future years 1-50, given a 0.1 inch increase in lake-bed elevation per year, and associated changes to lake area and bathymetry. Measures: Same as the "Without Project" methods; The sedimentation rate from proposed measures will be estimated by the sediment flux model and will be used to predict changes in the 0-1 m depth zone over time. Changes to the tidal prism (and therefore the Mean water surface elevation), will be estimated using the hydraulic model.
		5	0.25	
		10	0.5	
		15	0.75	
		>20	1	

Ultimately, it was most useful to combine the SIs of both salmonid species. Then the arithmetic average outcome of the combined, most sensitive SIs of the two, provided a final, less species-specific salmonid HSI. Again, the averaging approach in this case reduced the possibility that a single variable governed the overall HSI value, particularly when one or more may be arbitrarily removed due to lack of data or applicability.

$$\mathbf{HSI_{salmon} = ({}^{SI}V_{1CO} + {}^{SI}V_{3CO} + {}^{SI}V_{4CO} + {}^{SI}V_{9CO} + {}^{SI}V_{11CH})/6}$$

This approach averages the most sensitive SIs common between the two species, and addresses habitat requirements directly related to the juvenile life history stage. Depending on both availability of data to fill in these variables and model sensitivity during alternatives scoring, some of these variables may be filtered further from the final HSI_{salmon}. This filtering also depends upon further discussion and evaluation of effects that are expected or, conversely, no longer anticipated to occur under each alternative scenario, as further project and measures development and finalization occurs.

2.6 Determination of Study Boundaries and Calculation of Habitat Units

This intent of this Study is to address the problem of altered lake hydrology and associated loss of habitat capacity (quality) and opportunity (available area). Waterfowl overwintering and juvenile salmonid rearing are presumably both affected by available habitat area, but in differing ways. Waterfowl will use suitable aquatic habitat, regardless of its physical connectivity to the riverine landscape, because they can fly. Changes to aquatic habitat area from altered hydrology (i.e. altered water levels) and sediment dynamics (i.e. conversion to uplands from shoaling) could lead to changes in habitat area over the project time horizon. Juvenile salmonids will only be able to use suitable aquatic habitat if it is physically connected to the riverine landscape (i.e. by channels, sloughs, etc.). Also, because the water levels in the project are dynamic, and a function of tidal and riverine hydrology, the magnitude of this connectivity must be weighted by its frequency and duration. Depending on water surface elevations, fish may not have full access during the entire year, and different measures may provide a different frequency of accessibility for longer or shorter periods of time. In order to calculate the final benefit units that allow comparison of a without-project and project alternatives, the HSI for years 1-50, respectively, must be multiplied by an area function, so that a comparable habitat unit (HU) is obtained. The following sections describe the rational behind assigning areas for calculation of HUs.

2.6.1 Northern Pintail and Lesser Scaup

The habitat overwintering suitability variables for the northern pintail and lesser scaup are focused on wetland characteristics during the overwintering period. Therefore, the acreage associated with the average overwintering water level is used to determine habitat suitability (i.e. HSI). Since both species use the adjacent riparian areas and uplands throughout their life

history, the 50% exceedance flood elevation was used to delineate the overall project area that will be considered in HU calculation.

Areas not expected to be impacted by the Corps project will be excluded from the HU area function. Any non-Corps actions will be assumed to be held constant among the without-project and with-project alternatives. This assumption is reasonable, because the implementation other ODFW Management Plan objectives is not dependent on whether or not this Corps project is built. Given these considerations, the following general calculations are recommended for determination of northern pintail and lesser scaup HUs.

$$\mathbf{HU_{northern\ pintail} = HSI_{northern\ pintail} * Area_{2\text{-}year}\ (acres)}$$

$$\mathbf{HU_{lesser\ scau} = HSI_{lesser\ scaup} * Area_{2\text{-}year}\ (acres)}$$

2.6.2 Chinook and Coho Salmon

The Study area is subject to water level variability as a function of Willamette River discharge, Columbia River discharge, and tidal fluctuations. These three hydrologic factors vary by hour, day, season, and year. These complexities require a specific definition of what constitutes an aquatic area for the Chinook and coho habitat units. The Expert Regional Technical Group (ERTG) guidance for scoring SBUs (survival benefit unit) (ERTG 2010) recommends using the greater elevation of a 50% exceedance flood (Figure 4) or the extreme higher high water (EHHW) tidal event. While the HEP for the cost/ benefit economic analysis does not need to use methods developed by the ERTG, the rationale is based on the understanding that high river events, particularly during spring runoff, inundate floodplain wetlands, and are extremely important for juvenile salmonid survival and productivity. During the spring runoff, the effect of tidal fluctuation on water levels is muted. Elevated water levels can occur for a prolonged period of time. Since riverine flooding is the dominant hydrologic factor during this critical time for juvenile salmonid rearing, the 50% exceedance flood will be used for determination of area boundaries in the Study area. Most of the flooding events in the Lower Columbia are likely associated with the spring runoff. However, all runoff events from throughout the year should be used in the discharge and water level calculations, because both Chinook and coho utilize LCRE tidal freshwater wetlands year-round (Carter et al. 2009).

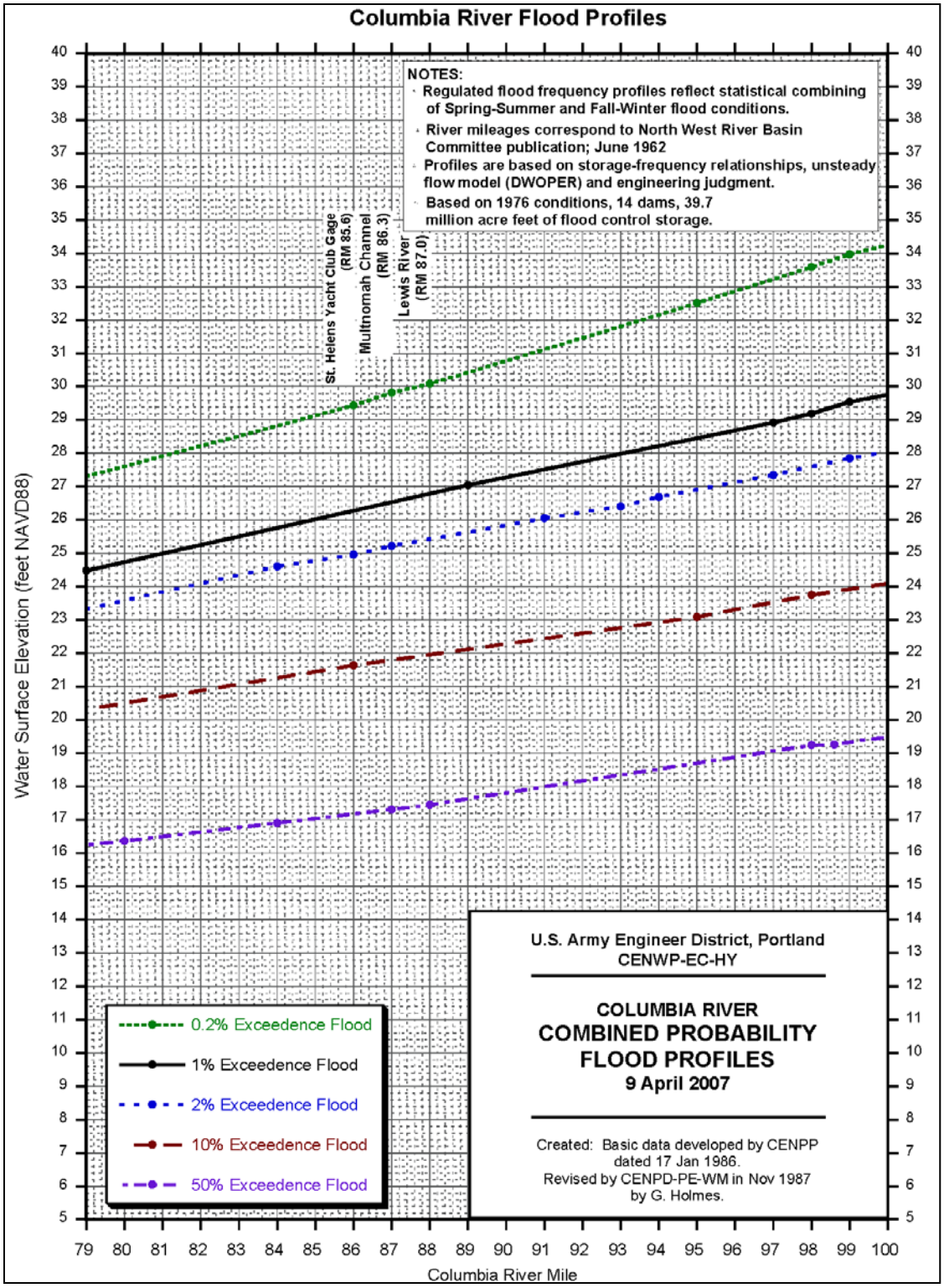

Figure 4. Columbia River Flood Profiles

The entire area inundated by a 50% exceedance flood will be used to calculate habitat units. Although shallow areas along the shoreline are likely to have the highest juvenile salmon use, feeding and rearing opportunities occur in a variety of habitat types in Dairy Creek and Sturgeon Lake. The tidal channels will have overhanging riparian vegetation and an emergent fringe that will contribute fish cover and foraging opportunities. The Dairy Creek channel enters Sturgeon Lake in a shallow meandering channel, surrounded by high-quality forested wetlands that are largely inundated during the spring freshets. This area will provide a large area with cover and invertebrate forage base. The Dairy Creek channel and forested wetlands give way to the open water. The lake littoral zone has large areas of emergent vegetation, providing an invertebrate forage base for rearing salmonids. The open water basins in the lake are generally uniform in depth, with mud bottoms and patches of emergent vegetation. The floodplain around the lake perimeter is vegetated and is managed as a wildlife area by the ODFW. Therefore, during flood events, the inundated floodplain is expected to provide additional feeding and rearing habitat. Dendritic channels exist along the lake fringe, particularly where Dairy Creek enters Sturgeon Lake. These channels will provide natural egress from the floodplain during receding water levels. An increased tidal prism is expected to increase formation of these channels.

The Gilbert River is a major feature in the lake and provides deep channels with adjacent riparian cover. The Gilbert River channel has produced a natural levee through lateral deposition of sediments over time. This has created a large, deep, channel that meanders to the southern end of the lake, near where Dairy Creek enters. The natural levees create edge habitat with overhanging vegetation, which provides fish cover and invertebrate forage base. Finally, the floodplain around the lake is largely unmodified and vegetated. Flood events activate these floodplain habitats for salmonid feeding and rearing. In summary, these variable features in Sturgeon Lake will provide feeding and rearing opportunities all year for any number of combinations of juvenile salmonid species, populations, and age classes. Given these multiple habitat types, and the fluctuating water levels throughout the year, the entire lake and channel area below the 50% exceedance flood elevation will be used for HU calculations.

When river discharge is low, tidal hydrology is the dominant factor driving lake water levels, fish access, and habitat forming processes. This important aspect of habitat access and opportunity and will be accounted for in terms of access channel inundation frequencies. The salmon area function will be weighted by the percentage of time that an access channel from the Columbia River to Sturgeon Lake is inundated (i.e. the percent of time that juvenile salmon can access Sturgeon Lake from the Columbia River). As described in Section 1.1, both rearing coho and Chinook juveniles are present in the Columbia River and could be present within and adjacent to the project area on a year-round basis. Although shallow floodplain lakes and associated wetlands in the LCRE warm up and become relatively unsuitable in the late summer and early fall, project measures will attempt to reduce these risks (just as current SIWA water management activities do), by providing natural egress into the cooler riverine environment during this time period.

Although a large area of suitable rearing habitat currently exists in Sturgeon Lake for most of the year, access for Columbia River juvenile salmon is severely limited. When Columbia River

water levels are below 10 ft, juvenile salmon from the Columbia River and tributaries must travel up the Multnomah Channel and down the Gilbert River to access the lake. When river elevations are above 15 ft, fish can move past the sediment/ debris plug at the mouth of Dairy Creek, but then encounter additional barriers at the primary channel (i.e. Reeder Road culverts) and historical Dairy Creek channels (i.e. two perched culverts). Since one of the objectives of this project includes providing access to Sturgeon Lake for Columbia River juvenile salmon, the percentage of time that fish can access the lake is a key consideration in weighting the relative value of available habitat for each alternative.

Given these considerations the following general calculations are recommended for determination of Chinook and coho salmon HUs.

$$\mathbf{HU_{Salmon} = HSI_{Salmon} * [(\sum_{i=1}^{n} Passage_i * Rearing\ Area_i) + Riparian\ Area]}$$

Where….

There are i…n channels or access points from the Columbia River to Sturgeon Lake

Passage= the percentage of time throughout the year that the maximum elevation of the channel is inundated

Rearing Area= The lake and channel area inundated at a 2-yr flood elevation

Riparian Area= The area of functional riparian habitat within 200 feet of the channel bank

The summation function that adds a weighted rearing area for each new access point is not a quantitative function of increased habitat opportunity. Habitat units are not meant to estimate specific quantities of habitat opportunity or capacity. The habitat units proposed here are simply meant to provide a logical ranking methodology that is scientifically defensible, transparent in its assumptions, and replicable by others using this approach.

2.7 Application of the Habitat Evaluation Procedure (HEP)

2.7.1 Recommended Species HU Weighting for HEP

The four indicator species represent overwintering for two waterfowl guilds and juvenile salmon rearing. As discussed in Chapter 1.0, the waterfowl and fish uses are both recognized and valued on an institutional, public, and scientific basis. Therefore waterfowl and salmonid “groups” will have equivalent weighting for the HEP model.

Within the waterfowl category, the northern pintail and lesser scaup are intended to represent the two main waterfowl guilds (dabbling and diving ducks) present during the overwintering period. Assuming that these two guilds are equally valued and represented during overwintering in the Study area, these two species will not be weighted relative to each other.

Within the salmonid category, juveniles Chinook and coho are intended to represent the types of salmonid rearing strategies that are used by Columbia basin salmon and winter steelhead (ocean-type and stream-type). Although the Chinook and coho HUs are combined, the salmon HU will not be weighted relative to the waterfowl components. The additive nature the area function in calculation of salmon HUs for each new access point to the lake is a more meaningful weighting for salmon HUs.

2.7.2 Incorporating Average Annual Benefits

The following principles were applied to the calculation of average annual benefits:

- Temperature effects from increased water circulation is assumed to be 100% realized after project construction.
- Increased inundation will be 100% realized after project construction. However, emergent wetland formation may be realized over time.
- Changes to existing wetland vegetation may change over time after project construction.
- Changes to lake bathymetry after project construction may change over time, and will be governed by the hydraulics, assumptions on channel formation, and sediment flux over time.
- Riparian ecological function will increase over time, with an asymptotic relationship towards the end of the 50-year project life.

2.7.3 Formula for Combining Species and Determining Final Habitat Units for HEP

Based on the relative species weighting described in section 2.7.1, and the iterative summation and averaging of annual benefit units, the following equation will be used to determine HUs for the "without project" and proposed measures:

$$\mathbf{HU_{measure} = \sum_{i=1}^{50} \left({}^{i}HU_{Pintail} + {}^{i}HU_{scaup} + {}^{i}HU_{Salmon} \right)]*1/50}$$

3.0 PROPOSED RESTORATION MEASURES

The development and screening of restoration measures are described in Chapter 3 of the Dairy Creek Restoration Feasibility Study (HDR 2013). From the original 19 measures proposed by the project team, five were retained after screening. These five measures are summarized, below. Figures showing measure locations and extent are in Appendix D of the Dairy Creek Restoration Feasibility Study.

3.1 Measure 6

Connect the historic Dairy Creek channel to Sturgeon Lake close to the terminus of current north Gilbert River. This concept requires deepening approximately 8,000 to 10,000 linear feet of the existing "historic" Dairy Creek channel. This concept requires excavating the thalweg of the old Dairy Creek channel and replacing culverts in order to allow for fish passage. This concept assumes that selective increased riverine hydrologic exchange at more locations, possibly in

combination with other measures, will increase water volume in Sturgeon Lake during high flow events, improve juvenile salmonid access into the lake, and improve natural habitat forming processes for fish and wildlife.

3.2 Measure 14a

Improve Existing Dairy Creek Channel from Mouth to Reeder Road. Redesigning the Dairy Creek by-pass channel with a low flow and high flow geometry would allow for higher water velocities at low river flows, and also allow for high conveyance capacity at high flows. Higher velocities at lower flows would keep sediment flushed out of the channel, thereby reducing maintenance. A jetty, groin, or dike structure(s) may be necessary to control local hydraulics, thereby reducing sediment shoaling at the mouth of the conveyance channel(s). A sedimentation pond or floodplain configurations will be evaluated to capture sand that may enter the channel. This will increase the sustainability new conveyance channel(s) to Sturgeon Lake and minimize sand shoaling.

3.3 Measure 14b

Improve Existing Dairy Creek Channel from Reeder Road to Sturgeon Lake. Construct a larger opening at Reeder Road crossing to allow for increased conveyance, debris movement, and channel scour. Higher velocities at lower flows would keep sediment flushed out of the channel, thereby reducing maintenance.

3.4 Measure 17

Alter management of Federal levee area to increase conveyance to Sturgeon Lake with additional flows. Use passive tide gate or pump to re-direct flows from Multnomah Channel into Steelman or Sturgeon Lake. This measure would also look to improve the SIDIC intake on the Multnomah Channel and withdraw the maximum water right to provide additional volume of water to the Lake. Flows increased above current levels entering the south Gilbert River (inside the Federal levee) would flow north and enter Sturgeon Lake through a pump house or passive tide gate through the levee. This concept requires allowing the drainage from within the Federal levee to pass into Sturgeon Lake, rather than to the Multnomah Channel. Increased flow contribution to the southern portion of the lake alters the hydraulics of the lake, maximizing open water area.

3.5 Measure 18

Alter management of Federal levee area to increase conveyance to Sturgeon Lake (no additional flows). Use passive tide gate or pump to re-direct flows from Multnomah Channel into Steelman or Sturgeon Lake. Flows increased above current levels entering the south Gilbert River (inside the Federal levee) would flow north and enter Sturgeon Lake through a pump house or passive tide gate through the levee. This concept requires allowing the drainage from within the Federal levee to pass into Sturgeon Lake, rather than to the Multnomah Channel. Increased flow contribution to the southern portion of the lake alters the hydraulics of the lake, maximizing open water area.

3.6 Final Array of Alternatives

Measures were combined into alternatives based on whether or not they were mutually exclusive, combinable, or dependent on other measures. Measures can be combined in the following ways:

- No Action Alternative cannot be not combined with other measures.
- Measure 6 is dependent on Measure 14a, and can be combined with Measures 14b, 17, and 18.
- Measure 14a is dependent on either Measure 6 or 14b. Measure 14a in combination with Measure 6 or 14b (or both) can be combined with Measures 17 or 18.
- Measure 14b is dependent on Measure 14a. Measures 14b+14a can be combined with Measures 6, 17, and 18.
- Measure 17 can stand alone or is combinable with Measures 14a+14b, 14a+6, or 14a+14b+6, but mutually exclusive with Measure 18.
- Measure 18 can stand alone or is combinable with Measures 14a+14b, 14a+6, or 14a+14b+6, but mutually exclusive with Measure 17.

Based on these interrelationships, 12 design alternative combinations, including the "No Action" Alternative, were advanced to the economic analysis. Table 10 defines these alternatives.

Table 10. Composition of Alternative Plans

Plan Number	No Action	6 Historic Dairy Creek Channel	14a Dairy Creek from Mouth to Reeder Rd	14b Dairy Creek Reeder Rd to Sturgeon Lake	17 SIDIC Pump and Intake	18 SIDIC Pump only
1	✓					
2		✓	✓			
3			✓	✓		
4		✓	✓	✓		
5					✓	
6		✓	✓		✓	
7			✓	✓	✓	
8		✓	✓	✓	✓	
9						✓
10		✓	✓			✓
11			✓	✓		✓
12		✓	✓	✓		✓

4.0 RESULTS

4.1 General Supporting Results

4.1.1 Stage-Duration

Several habitat suitability metrics used in this analysis are potentially affected by modeled changes to the stage-duration relationships, from restoration measures in Sturgeon Lake. The northern pintail and lesser scaup are potentially affected by changes in water levels during the December- February overwintering period, but also by changes to emergent vegetation distribution. The emergent vegetation distribution is assumed to be affected by changes to percent inundation time, as reflected in the modeled annual stage-duration curves.

Changes to the winter (December- February) and annuals stage-duration curves were very small (Figure 5 and Figure 6). Minor changes to the average surface water elevation during the winter and annual periods also occurred, with all measures within 0.1 ft of existing conditions for each respective metric (Table 11).

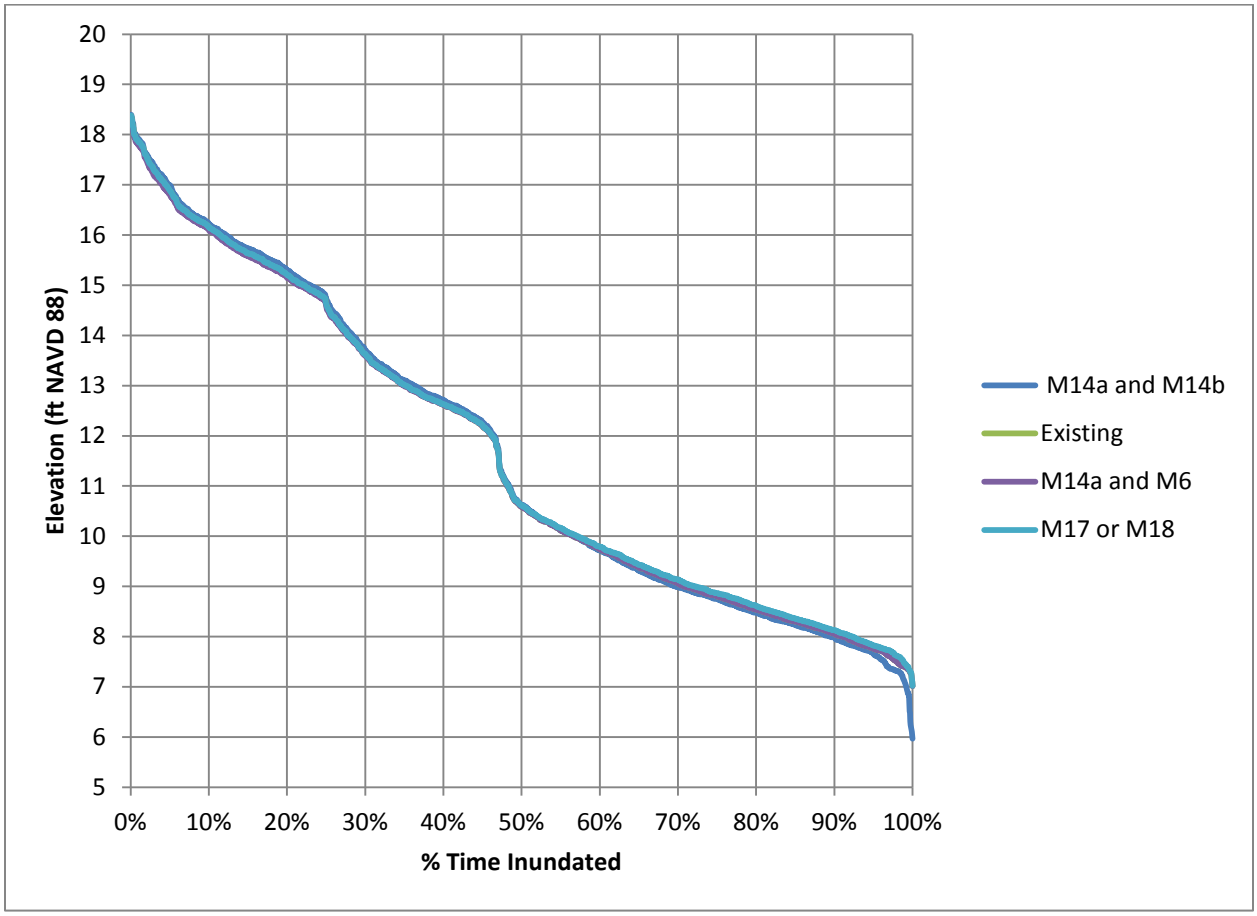

Figure 5. December 2011- February 2012 Stage-Duration Curves for Existing Conditions and Each Respective Measure

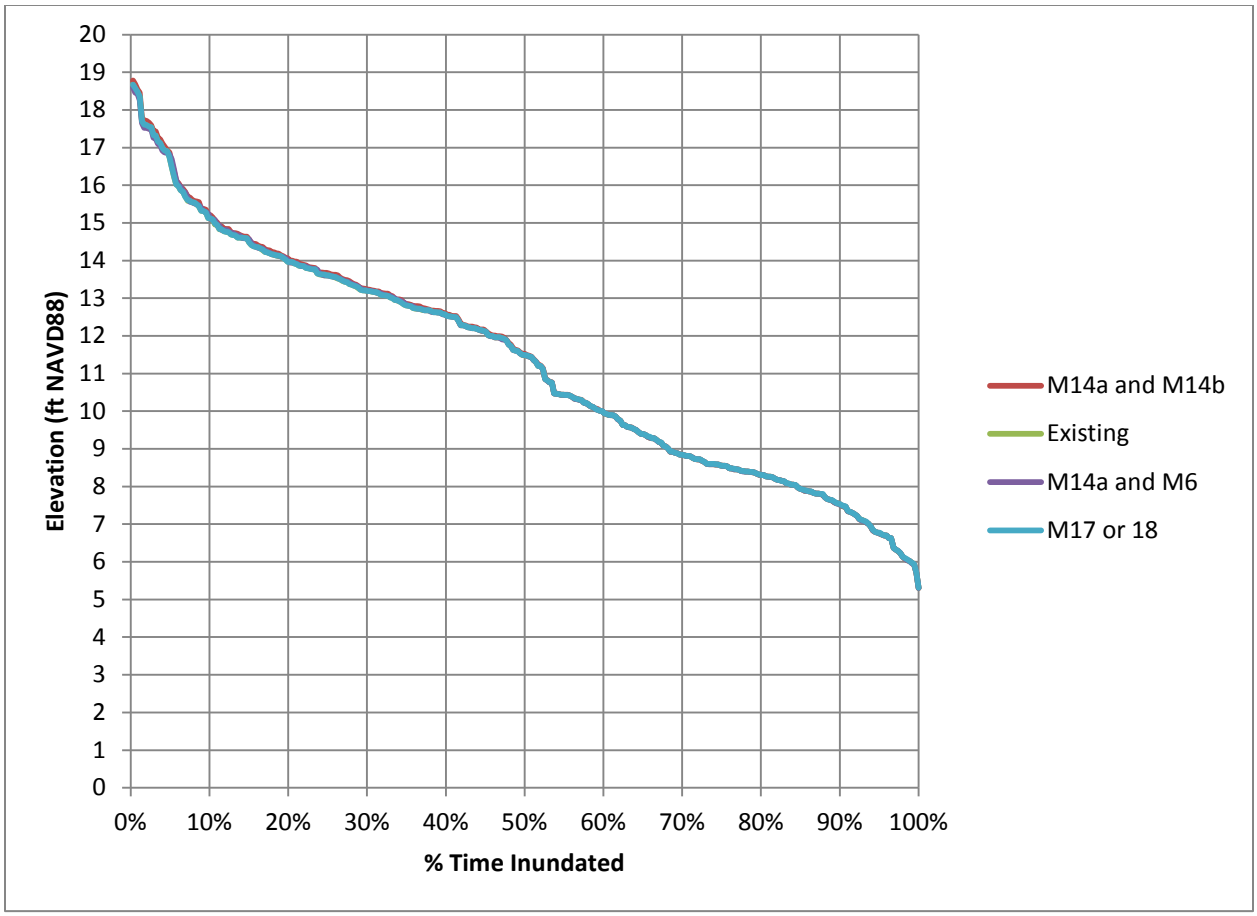

Figure 6. 2012 Stage-Duration Curves for Existing Conditions and Each Respective Measure

Table 11. Central Tendency of Overwintering Period (December- February) Lake Elevation and Area

Measure	December- February		Annual	
	Average WSEL (ft)	Average Lake Area (acres)	Average WSEL (ft)	Average Lake Area (acres)
Alt 1-No Action	11.64	2,518	11.27	2,415
Measure 6	11.62	2,513	11.27	2,415
Measure 14a	11.64	2,518	11.27	2,415
Measure 14b	11.65	2,521	11.27	2,415
Measure 17/18	11.67	2,518	11.27	2,415

4.1.2 Emergent Vegetation

The lower and upper elevation bounds for *Eliocharis palustris*, and the lower bound of Reed Canary Grass (RCG) were surveyed during August of 2012. The upper bound of RCG was not

surveyed. Although spot elevations of *Sagittaria latifolia* (Wapato) were surveyed, no definitive upper or lower bound was determined in Sturgeon Lake. The spot elevations were generally within the *Eliocharis palustris* range. Therefore, Wapato was not used in the habitat suitability index calculations that involved emergent vegetation. RCG was considered "persistent", because the dense stands are still present in the overwintering period, whereas the *Eliocharis palustris* generally senesces. The existing zonation of both RCG and *Eliocharis palustris* were consistent with regional reference sites in vegetation zone 4 (Borde et al. 2012), with *Eliocharis palustris* ranging from 7.1 to 9.5 ft NAVD88 and the lower bound of RCG at 8.5 ft (Table 12). A mixed stand of *Eliocharis palustris* and RCG occurs on the Sturgeon Lake shoreline, between 8.5 and 9.5 ft. The vertical distribution of these emergent plants is generally governed by the percentage of time that they are inundated (Borde et al. 2011). These percentages were determined by plotting their upper and lower elevation bounds on the existing conditions stage-duration curve. Emergent vegetation bounds for the proposed restoration measures were assumed to shift in vertical distribution, if the annual stage-duration curve for each respective restoration measure was different than existing conditions. While sustained flood levels during the spring freshet also influence vegetation distribution, the restoration measures will not change this aspect of lake hydrology. For each restoration measure with a modified stage-duration curve, the upper and lower elevation bounds for each species was determined by plotting the same percent inundation times on the their respective stage-duration curves. However, since none of the proposed restoration measures made a substantive change in the stage-duration curve, no changes to emergent vegetation zonation were predicted to occur (Table 12).

Table 12. Predicted Emergent Vegetation Ranges.

Vegetation Distribution	Vegetation Zone 4 Reference Elevation (ft)	No Action			Elevation (ft)		
		Elevation (ft)	Inundation (% of time)	M6	M14a	M14b	M17/18
RCG low	8.6	8.5	76.8	8.5	8.5	8.5	8.5
Eliocharis high	9.9	9.5	65.6	9.5	9.5	9.5	9.5
Eliocharis low	7.0	7.1	93.2	7.1	7.1	7.1	7.1

4.1.3 Estimating Inundated Lake Areas and Sediment Aggradation in Sturgeon Lake

Inundated lake areas and specific zones within the lake were calculated with an elevation-area curve (Figure 7 and Figure 8). For example, inundation areas for the overwintering and average annual WSELs were compared to areas with open water ($^{NP}V_1$), persistent emergent vegetation ($^{NP}V_2$, $^{LS}V_2$, $^{CO}V_9$), and emergent food plants ($^{NP}V_4$). These elevation-area curves were constructed with limited bathymetric data. The shoreline contours were constructed with LiDAR data (USACE 2011), and the deeper areas of the lake were constructed with a qualitative bathymetric survey from 1982 (Klingeman 1982). The precision of the lake bathymetry is estimated at +/- 1 to 2 feet. Elevation-Area equations were developed in order to calculate lake area for any given stage (Figure 7). Separate equations were developed for portions of the curve with different slopes.

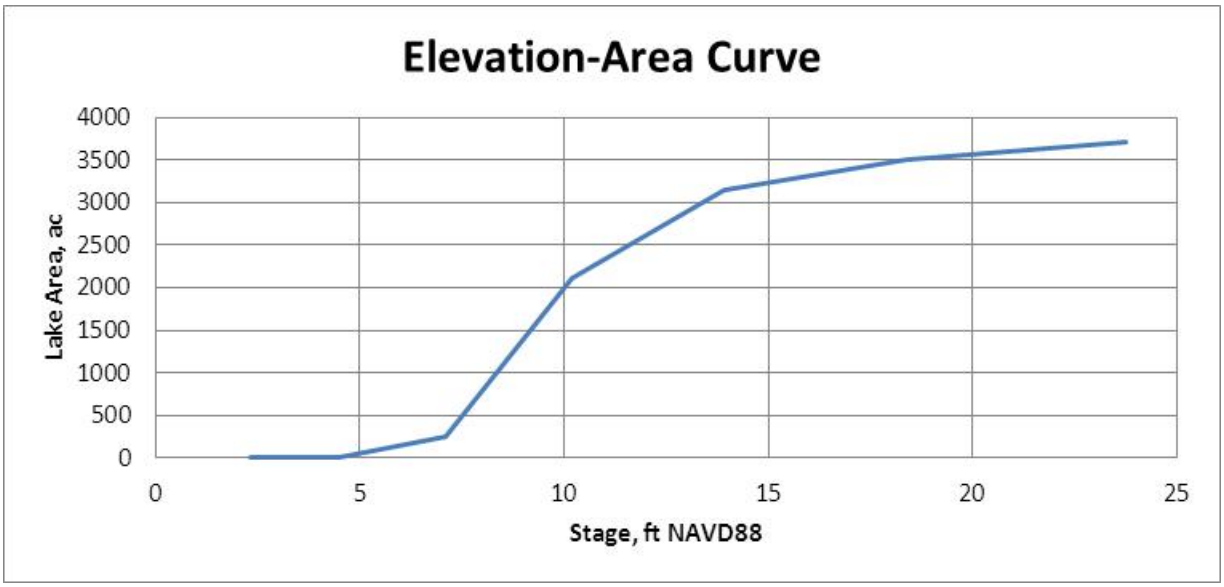

Figure 7. Elevation-Area Curve for Sturgeon Lake

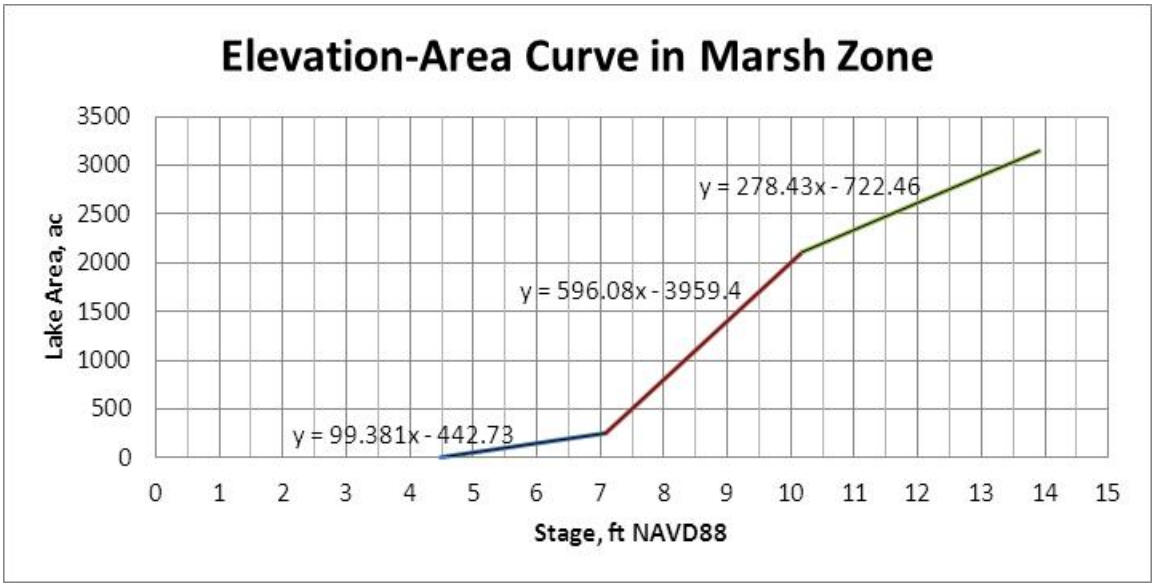

Figure 8. Elevation-Area Curve for Sturgeon Lake in the Emergent Vegetation Zone

The Sturgeon Lake sediment flux study (Waterways 2013) estimated a sediment aggradation rate of 0.1 inches per year. This rate was a worst-case scenario with no sediment export. The study assumed uniform deposition throughout the lake. Although this modeled amount of sediment aggradation only amounted to 0.5 feet of aggradation over the 50 year time horizon of this study, the changes in lake depth were accounted for in the habitat suitability metrics. These gross changes to the lake morphology were accounted for in the habitat suitability metrics by subtracting the aggradation depth from the lake WSEL and emergent vegetation elevations at any given time horizon.

$$ELEV_{Y(x)} = ELEV_{Y0} + AGGRADE_{Y(x)}$$

ELEV is any given bathymetric lake bed elevation at x number of years after project, implementation Y(x). AGGRADE is the depth of sediment aggradation at x number of years after project implementation, Y(x).

Although the proposed restoration measures could potentially change sediment flux into and out of the lake, this potential change in lake sedimentation could not be predicted with a level of precision comparable to the existing rate of 0.1 inches of sediment per year. Furthermore, over the 50 year time horizon, the existing rate of sedimentation is much smaller than the error associated with bathymetric elevation contours. Because the feasibility study had a limited 1-D model, the internal dynamics of the lake (i.e. shoaling) were not predicted. Measures 14b (with 14a), and 17 are expected to affect local change in sediment movement, because of locally

increased water velocities. Predictions of net sediment import or export into the lake from these measures were not possible because of data limitations. Paired total suspended solids data between the Columbia River (for Measures 14a/ 14b) and the leveed A-1 Canal forebay (Measure 17/18) were not available. If suspended solids in the lake are higher than in the A-1 Canal and Columbia River, then a reduction in sediment aggradation or a net export of sediment from the lake could occur.

4.2 Northern Pintail

4.2.1 $^{NP}V_1$: Percent of Open Water that is less than 0.5 m deep

Sturgeon Lake has an abundance of shallow, open water, as reflected in the high degree of suitability in variable NPV1 (Table 13). The proposed restoration measures did not change average water levels and emergent vegetation zonation (Table 12), and therefore did not change this metric. Lake bed aggradation over the 50-year time horizon did not have a significant effect on shallow open water (Table 13).

Table 13. Northern Pintail Habitat Metrics, Suitability Index Scores, and Habitat Suitability Index Scores

	NPV1: Shallow Open Water		NPV2: Emergent Vegetation		NPV4: Emergent Food Plants		HSI (cover)	HSI (food)
	Metric	SI	Metric	SI	Metric	SI		
Alt 1-No Action								
Target Year 0 - 5 (x5)	78	1.00	57	0.64	>50	1.00	0.80	1.00
Target Year 6 - 15 (x10)	78	1.00	59	0.61	>50	1.00	0.78	1.00
Target Year 16 - 25 (x10)	78	1.00	61	0.58	>50	1.00	0.76	1.00
Target Year 26 - 50 (x 25)	77	1.00	66	0.51	>50	1.00	0.71	1.00
Measure 6								
Target Year 0 - 5 (x5)	78	1.00	57	0.64	>50	1.00	0.80	1.00
Target Year 6 - 15 (x10)	78	1.00	59	0.61	>50	1.00	0.78	1.00
Target Year 16 - 25 (x10)	78	1.00	61	0.58	>50	1.00	0.76	1.00
Target Year 26 - 50 (x 25)	77	1.00	66	0.51	>50	1.00	0.71	1.00
Measure 14a								
Target Year 0 - 5 (x5)	78	1.00	57	0.64	>50	1.00	0.80	1.00
Target Year 6 - 15 (x10)	78	1.00	59	0.61	>50	1.00	0.78	1.00
Target Year 16 - 25 (x10)	78	1.00	61	0.58	>50	1.00	0.76	1.00
Target Year 26 - 50 (x 25)	77	1.00	66	0.51	>50	1.00	0.71	1.00
Measure 14b								
Target Year 0 - 5 (x5)	78	1.00	57	0.64	>50	1.00	0.80	1.00
Target Year 6 - 15 (x10)	78	1.00	59	0.61	>50	1.00	0.78	1.00
Target Year 16 - 25 (x10)	78	1.00	61	0.58	>50	1.00	0.76	1.00
Target Year 26 - 50 (x 25)	77	1.00	66	0.51	>50	1.00	0.71	1.00
Measure 17 and 18								
Target Year 0 - 5 (x5)	78	1.00	57	0.64	>50	1.00	0.80	1.00
Target Year 6 - 15 (x10)	78	1.00	59	0.61	>50	1.00	0.78	1.00
Target Year 16 - 25 (x10)	78	1.00	61	0.58	>50	1.00	0.76	1.00
Target Year 26 - 50 (x 25)	77	1.00	66	0.51	>50	1.00	0.71	1.00

4.2.2 ${}^{NP}V_2$: Percentage of area that is covered by persistent emergent vegetation (>10% canopy cover)

RCG is the primary form of persistent emergent vegetation type that occurs along the Sturgeon Lake shoreline. At the average winter WSEL, this RCG zone is inundated, accounting for

around half of the total inundated area (Table 13). The proposed restoration measures did not change average water levels and emergent vegetation zonation (Table 12), and therefore did not change this metric. Lake bed aggradation over the 50-year time horizon had the effect of increasing the RCG zone and lowering habitat suitability over time.

4.2.3 $^{NP}V_4$: Percentage of study area dominated by (>50% canopy coverage) submerged or emergent food plants

RCG, *Eliocharis palustris, and* Wapato are all emergent food plants that occur along the Sturgeon Lake shoreline. *Eliocharis palustris* is the only plant where the lower and upper bound have been surveyed in the project area. The cluster of seeds in the spike provides food for various species of ducks and geese (Guard 1995). During the overwintering period, this species is senesced, but likely provides a natural forage base along the shallow open-water zone. This zone accounts for over half of the inundated overwintering area, and results in 100% suitability for the northern pintail (Table 13). The proposed restoration measures did not change average water levels and emergent vegetation zonation (Table 12), and therefore did not change this metric. Lake bed aggradation over the 50-year time horizon had the effect of decreasing the *Eliocharis palustris* zone for all measures, but this did not affect habitat suitability (Table 13). The RCG and Wapato areas were not counted for this metric, because their distribution bounds were not surveyed. Adding their areas to *Eliocharis palustris* would have the effect of increasing the overall food area; however, this would have resulted in the same suitability scores (100% suitability).

4.2.4 HSI and HU Calculation

Habitat suitability for the northern pintail is calculated in terms of both cover and food indices. The lesser of the two indices are used to calculate habitat units. In Sturgeon Lake, the Cover HSI scores were lower that the Food HSI scores, owing to the large RCG zone that is inundated during the overwintering period (Table 13). These Cover HSI scores were multiplied by the two-year flood area to yield habitat units (Table 14). Since no changes are anticipated to occur to stage-duration or emergent vegetation, none of the measures changed habitat suitability, relative to the No-Action alternative.

Table 14. Northern Pintail Habitat Areas and Habitat Unit Calculations.

Habitat Unit Calculations					
Overwintering Area (acres)[1]	**Alt 1-No Action**	**Measure 6**	**Measure 14a**	**Measure 14b**	**Measure 17/18**
Target Year 0 - 5 (x5)	4,116	4,116	4,116	4,116	4,116
Target Year 6 - 15 (x10)	4,116	4,116	4,116	4,116	4,116
Target Year 16 - 25 (x10)	4,116	4,116	4,116	4,116	4,116
Target Year 26 - 50 (x 25)	4,116	4,116	4,116	4,116	4,116
Habitat Units[2]					
Target Year 0 - 5 (x5)	3,293	3,293	3,293	3,293	3,293
Target Year 6 - 15 (x10)	3,215	3,215	3,215	3,215	3,215
Target Year 16 - 25 (x10)	3,135	3,135	3,135	3,135	3,135
Target Year 26 - 50 (x 25)	2,939	2,939	2,939	2,939	2,939
Total	153,443	153,443	153,443	153,443	153,443
AA Benefits	3,069	3,069	3,069	3,069	3,069
Change in Habitat Units					
Target Year 0 - 5 (x5)	0	0	0	0	0
Target Year 6 - 15 (x10)	0	0	0	0	0
Target Year 16 - 25 (x10)	0	0	0	0	0
Target Year 26 - 50 (x 25)	0	0	0	0	0
Change Total	0	0	0	0	0
Change AA Benefits	0	0	0	0	0

[1]Overwintering Area= Sturgeon Lake Area inundated at a 50% exceedance flood elevation (i.e. a 2-year flood recurrence interval)
[2]Habitat Units= $HU_{northern\ pintail} = HSI_{northern\ pintail} * Area_{2\text{-}year}$ (acres)

4.3 Lesser Scaup

4.3.1 SLSV1: % area supporting pelecypods

Sampling for pelecypod bivalves was beyond the scope of this study, so an area distribution of pelecypod presence was not determined. However, the presence of bivalve shells along the shoreline and on ODFW pump screens indicates overall presence. Therefore, a constant SI of 0.5 was applied to all restoration measures, across all years (Table 15).

4.3.2 LSV2: % Area supporting emergent vegetation

During the overwintering period, RCG is the primary persistent emergent vegetation type along the Sturgeon Lake shoreline. Approximately half of the inundated area, during the overwintering period, is occupied by RCG for all measures (Table 15). Although lesser scaup prefer areas with little to no emergent vegetation (Mulholland 1985), large unvegetated areas exist in the middle of the north and south lake basins. These large areas are suitable for lesser scaup use and result in intermediate SI scores. The proposed restoration measures did not change average water levels and emergent vegetation zonation (Table 12), and therefore did not change this metric. Lake bed aggradation over the 50-year time horizon had the effect of increasing the RCG zone and lowering habitat suitability over time (Table 15).

Table 15. Lesser scaup habitat metrics, suitability index scores, and habitat suitability index scores.

	LSV1: Pelecypods (% Area)		LSV2: Emergent vegetation (% Area)		LSV3: Winter Water Depth (m)		LSV4: Human Disturbance		
	Metric	SI	Metric	SI	Metric	SI	Metric	SI	HSI
Alt 1-No Action									
Target Year 0 - 5 (x5)	25	0.50	57	0.43	1.07	1.00	Moderate	0.70	0.60
Target Year 6 - 15 (x10)	25	0.50	59	0.41	1.04	1.00	Moderate	0.70	0.59
Target Year 16 - 25 (x10)	25	0.50	61	0.39	1.01	1.00	Moderate	0.70	0.58
Target Year 26 - 50 (x 25)	25	0.50	66	0.34	0.94	0.95	Moderate	0.70	0.56
Measure 6									
Target Year 0 - 5 (x5)	25	0.50	57	0.43	1.07	1.00	Moderate	0.70	0.60
Target Year 6 - 15 (x10)	25	0.50	59	0.41	1.04	1.00	Moderate	0.70	0.59
Target Year 16 - 25 (x10)	25	0.50	61	0.39	1.01	1.00	Moderate	0.70	0.58
Target Year 26 - 50 (x 25)	25	0.50	66	0.34	0.94	0.95	Moderate	0.70	0.56
Measure 14a									
Target Year 0 - 5 (x5)	25	0.50	57	0.43	1.07	1.00	Moderate	0.70	0.60
Target Year 6 - 15 (x10)	25	0.50	59	0.41	1.04	1.00	Moderate	0.70	0.59
Target Year 16 - 25 (x10)	25	0.50	61	0.39	1.01	1.00	Moderate	0.70	0.58
Target Year 26 - 50 (x 25)	25	0.50	66	0.34	0.94	0.95	Moderate	0.70	0.56
Measure 14b									
Target Year 0 - 5 (x5)	25	0.50	57	0.43	1.08	1.00	Moderate	0.70	0.60
Target Year 6 - 15 (x10)	25	0.50	59	0.41	1.05	1.00	Moderate	0.70	0.59
Target Year 16 - 25 (x10)	25	0.50	61	0.39	1.02	1.00	Moderate	0.70	0.58
Target Year 26 - 50 (x 25)	25	0.50	66	0.34	0.95	0.95	Moderate	0.70	0.56
Measure 17/18									
Target Year 0 - 5 (x5)	25	0.50	57	0.43	1.07	1.00	Moderate	0.70	0.60
Target Year 6 - 15 (x10)	25	0.50	59	0.41	1.04	1.00	Moderate	0.70	0.59
Target Year 16 - 25 (x10)	25	0.50	61	0.39	1.01	1.00	Moderate	0.70	0.58
Target Year 26 - 50 (x 25)	25	0.50	66	0.34	0.94	0.95	Moderate	0.70	0.56

4.3.3 LSV3: Winter Water Depth

During the overwintering period, the average water depth was around a meter deep for all measures (Table 15). This average depth is suitable for the lesser scaup. Sediment aggradation on the lake bed lowers the average depth, but still within the suitable range for the lesser scaup.

4.3.4 LSV4: Human Disturbance

Human disturbance is assumed to be constant in the project area, because it is managed as a state wildlife area. Land use in this wildlife area is expected to remain a public natural area. In addition, access to the lake is restricted during the overwintering period (ODFW 1010a). A conservative score of 0.7 was applied to all measures over all time periods (Table 15), corresponding to a "moderate" amount of human disturbance (Mulholland 1985).

4.3.5 HSI and HU Calculation

Because of the apparent presence of pelecypods, average winter depth, low level of human disturbance, and large open water area in Sturgeon Lake, the project area is moderately suitable for lesser scaup (Table 15). These HSI scores were multiplied by the two year flood area to yield habitat units (Table 16). Since no changes are anticipated to occur to stage-duration or emergent vegetation, none of the measures changed habitat suitability, relative to the No-Action alternative.

Table 16. Lesser Scaup Habitat Areas and Habitat Unit Calculations.

Habitat Unit Calculations					
Overwintering Area (acres)[1]	**Alt 1-No Action (without project)**	**Measure 6**	**Measure 14a**	**Measure 14b**	**Measure 17/18**
Target Year 0 - 5 (x5)	4,116	4,116	4,116	4,116	4,116
Target Year 6 - 15 (x10)	4,116	4,116	4,116	4,116	4,116
Target Year 16 - 25 (x10)	4,116	4,116	4,116	4,116	4,116
Target Year 26 - 50 (x 25)	4,116	4,116	4,116	4,116	4,116
Habitat Units[2]					
Target Year 0 - 5 (x5)	2,453	2,453	2,453	2,453	2,453
Target Year 6 - 15 (x10)	2,430	2,430	2,430	2,430	2,430
Target Year 16 - 25 (x10)	2,406	2,406	2,406	2,406	2,406
Target Year 26 - 50 (x 25)	2,317	2,317	2,317	2,317	2,317
Total	118,554	118,554	118,554	118,554	118,554
AA Benefits	2,371	2,371	2,371	2,371	2,371
Change in Habitat Units					
Target Year 0 - 5 (x5)	0	0	0	0	0
Target Year 6 - 15 (x10)	0	0	0	0	0
Target Year 16 - 25 (x10)	0	0	0	0	0
Target Year 26 - 50 (x 25)	0	0	0	0	0
Change Total	0	0	0	0	0
Change AA Benefits	0	0	0	0	0

[1]Overwintering Area= Sturgeon Lake Area inundated at a 50% exceedance flood elevation (i.e. a 2-year flood recurrence interval)
[2]Habitat Units= $HU_{lesser\ scaup}$= $HSI_{lesser\ scaup}$* $Area_{2\text{-}year}$ (acres)

4.4 Chinook and Coho

4.4.1 COV1: Maximum Temperature

Sturgeon Lake water temperature exceeds suitable conditions for juvenile salmonid rearing during the late summer. However, these late summer conditions do not preclude rearing during the periods of highest juvenile salmonid presence in the LCRE, in the spring and early summer. In addition, juvenile salmon have the ability to egress from the lake as conditions become unsuitable for rearing. Therefore, maximum water temperatures were calculated from January-June in order to quantify habitat suitability. Measure 14b (with 14a) is the only measure that had large modeled flow inputs into the lake from the Columbia River during this time period. Measure 6 contributes a minimal amount of Columbia River flow to the lake, because the invert channel elevation is at 12 ft NAVD88. Measure 14b (with 14a) would have an invert elevation of 8 ft NAVD88 (four feet lower than the Measure 6 channel). These elevations allow for much more flow exchange from the Columbia River to the lake. Measure 17 does not include pumping water to the lake during the late spring and early summer, because the water quality from within the SIDIC levee is poor.

Changes to Sturgeon Lake water temperature in measure 14b was calculated with a simple stepwise mass-balance approach. For each calendar day, the Columbia River flow input volumes were compared to the corresponding lake volume. Each day, a new lake temperature was calculated based on the temperature differential and an assumption of full mixing. Sturgeon Lake water temperatures, with no restoration measures, had a maximum seasonal temperature of 19.8 degrees Celsius (Figure 9; Table 17). This corresponded to an SI score of 0.2. Measure 14b had a reduction in 1.2 degrees C, resulting in a SI score of 0.31. These scores are assumed to be representative of conditions over the 50-year project horizon.

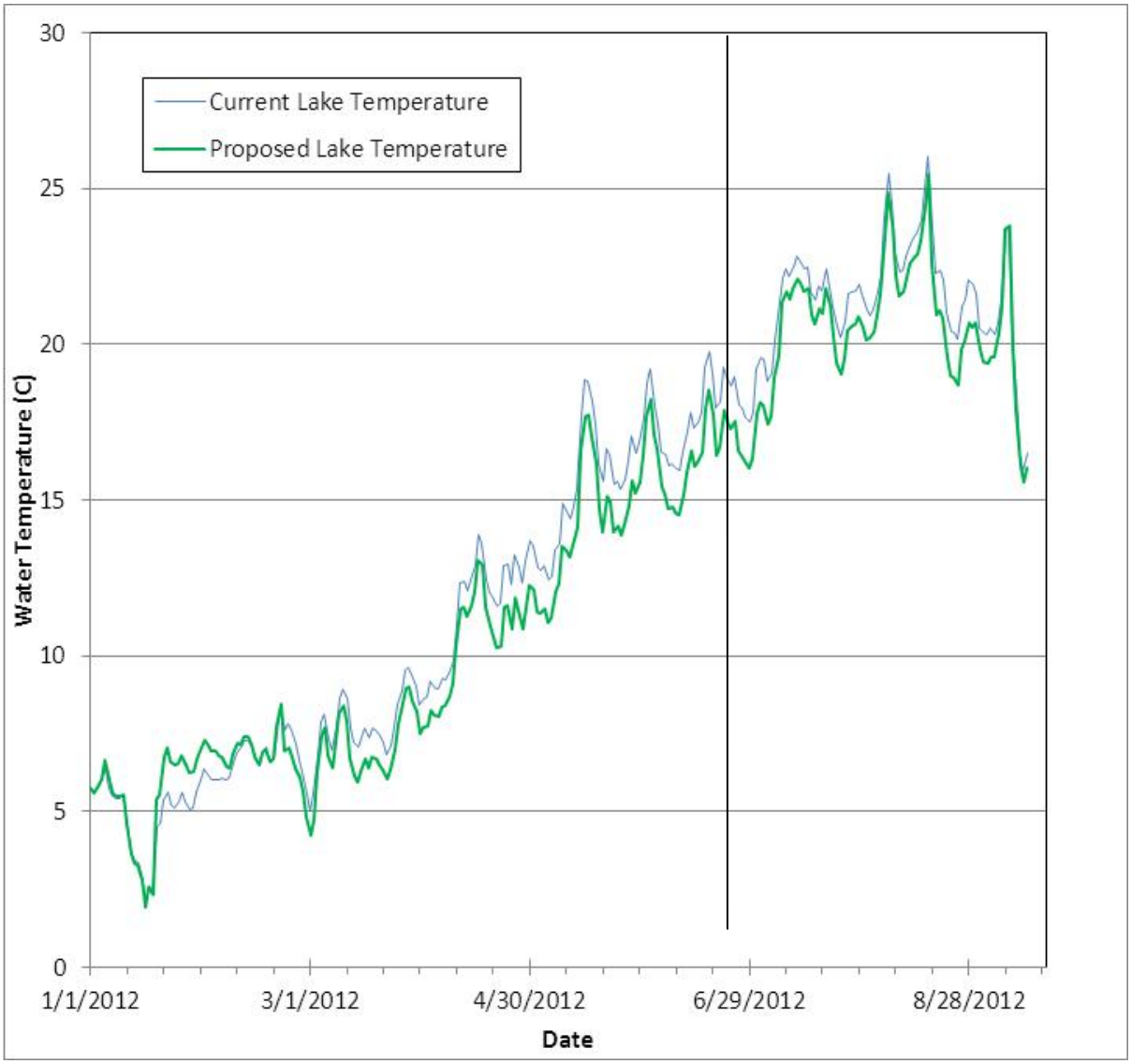

Figure 9. Current and Proposed Measure 14b Sturgeon Lake Water Temperatures Given Modeled Daily Columbia River Flow Inputs.

Table 17. Salmonid Habitat Metrics, Suitability Index Scores, and Habitat Suitability Index Scores. Compare to A4 and COV3

	COV1: Max Temp		COV3: % Canopy Cover		COV4: Vegetation Composition		COV9: % Winter Cover		CHV11: % Rearing Habitat		
	Metric	SI	Metric	SI	Metric	SI	Metric	SI	Metric	SI	HSI
Alt 1-No Action											
Target Year 0 - 5 (x5)	19.8	0.20	22	0.46	43	0.17	57	1.00	69	1.00	0.57
Target Year 6 - 15 (x10)	19.8	0.20	22	0.46	43	0.17	59	1.00	71	1.00	0.57
Target Year 16 - 25 (x10)	19.8	0.20	22	0.46	43	0.17	61	1.00	73	1.00	0.57
Target Year 26 - 50 (x 25)	19.8	0.20	22	0.46	43	0.17	66	1.00	78	1.00	0.57
Measure 6											
Target Year 0 - 5 (x5)	19.8	0.20	23	0.48	45	0.18	57	1.00	69	1.00	0.57
Target Year 6 - 15 (x10)	19.8	0.20	24	0.49	47	0.19	59	1.00	71	1.00	0.58
Target Year 16 - 25 (x10)	19.8	0.20	25	0.50	50	0.20	61	1.00	73	1.00	0.58
Target Year 26 - 50 (x 25)	19.8	0.20	26	0.52	52	0.21	66	1.00	78	1.00	0.59
Measure 14a											
Target Year 0 - 5 (x5)	19.8	0.20	22	0.46	43	0.17	57	1.00	69	1.00	0.57
Target Year 6 - 15 (x10)	19.8	0.20	22	0.46	43	0.17	59	1.00	71	1.00	0.57
Target Year 16 - 25 (x10)	19.8	0.20	22	0.46	43	0.17	61	1.00	73	1.00	0.57
Target Year 26 - 50 (x 25)	19.8	0.20	22	0.46	43	0.17	66	1.00	78	1.00	0.57
Measure 14b											
Target Year 0 - 5 (x5)	18.6	0.31	24	0.49	48	0.19	57	1.00	69	1.00	0.60
Target Year 6 - 15 (x10)	18.6	0.31	25	0.50	50	0.20	59	1.00	71	1.00	0.60
Target Year 16 - 25 (x10)	18.6	0.31	26	0.52	52	0.21	61	1.00	73	1.00	0.61
Target Year 26 - 50 (x 25)	18.6	0.31	29	0.59	57	0.24	66	1.00	78	1.00	0.63
Measure 17/18											
Target Year 0 - 5 (x5)	19.8	0.20	22	0.46	43	0.17	57	1.00	69	1.00	0.57
Target Year 6 - 15 (x10)	19.8	0.20	22	0.46	43	0.17	59	1.00	71	1.00	0.57
Target Year 16 - 25 (x10)	19.8	0.20	22	0.46	43	0.17	61	1.00	73	1.00	0.57
Target Year 26 - 50 (x 25)	19.8	0.20	22	0.46	43	0.17	66	1.00	78	1.00	0.57

4.4.2 COV3: % Canopy Cover

Canopy cover in channel rearing habitat provides cover from predators and produces invertebrate prey items. The primary areas of this channel habitat include the North Gilbert River, the main Dairy Creek Channel (focus of Measures 14a and 14b), and the historical Dairy Creek Channel (focus of Measure 6). Direct canopy cover measurements were not possible because this analysis occurred during the winter, when the deciduous trees did not have leaves. Instead, canopy cover was estimated by delineating the average annual inundated areas with summer aerial imagery and measuring the proportion of those areas that were covered with tree canopy. Sample plots were selected in the channel habitat on a systematic basis, spaced approximately 0.25 miles apart (Figure 10).

Existing conditions had an average canopy cover of 22%, corresponding to an SI value of 0.46 (Table 17). These values were used for the No Action alternative and Year 0 conditions for each restoration measure. Riparian plantings are part of Measures 14a, and 14b. Conceptual riparian restoration areas are provided in the Dairy Creek Feasibility Study (HDR 2013). Canopy cover over the 50 year project horizon was assumed to reach 70%. This was the average canopy cover in existing channel areas that had mature riparian vegetation. Linear increases in canopy cover in planting areas were assumed between Year 0 and Year 50. Average riparian canopy cover for measures 14a, and 14b increased between four and seven percent (Table 17). Average canopy cover increases were small, because plantings are only occurring over a small proportion of the total channel habitat in the project area.

Figure 10. Existing Conditions Canopy Cover Survey Locations.

4.4.3 COV4: Vegetation composition

The vegetation composition of riparian zones in rearing channel habitat is almost exclusively deciduous. ${}^{CO}V_4$ is an index that is calculated by doubling the percent canopy cover from deciduous trees and adding an un-weighted canopy cover from coniferous trees. Therefore, the index results are proportional to ${}^{CO}V_3$. Measures 14a and 14b had modest increases in index scores and corresponding SI values (Table 17).

4.4.4 COV9: % Winter Cover

Backwater areas with cover provide refugia to juvenile salmon when high flows in the main channel are unsuitable for rearing and holding their position in the channel. This variable is most applicable to yearling coho and Chinook that would otherwise be in deeper mainstem channel habitat. In the project area, this "winter cover" includes the inundated emergent vegetation zone and floodplain. Deep pools in the lake were excluded from the analysis, because recent pool survey data were not available, and the total pool area is likely very small compared to the flooded emergent vegetation zone and floodplain. The average winter WSEL inundates a large percentage of emergent and floodplain habitat, and is optimal for winter rearing (Table 17). The small changes to average winter WSEL and emergent vegetation zones are still in the optimal ranges. Sediment aggradation in the project area slightly increases this percentage of winter cover habitat, and is still in the optimal range.

4.4.5 CHV11: % Rearing Habitat

Shallow areas with low velocity are important for sub-yearling juvenile salmonids to safely feed and rear, while avoiding predation from larger fish. This variable is most applicable to sub-yearling Chinook that are vulnerable to predation. In the project area, this rearing area includes the inundated emergent vegetation zone and other shallow, quiet areas. A large percentage of Sturgeon Lake match these habitat requirements during average annual WSEL conditions, making it optimal for rearing (Table 17). Since no changes are anticipated to occur to stage-duration or emergent vegetation, none of the measures changed habitat suitability, relative to the No-Action alternative (Table 17). Sediment aggradation in the project area increases this percentage of rearing habitat, and is still in the optimal range (Table 17).

4.4.6 HSI and HU Calculation

Habitat suitability for juvenile salmonid rearing is generally good in the project area, even though the temperature and riparian habitat suitability is marginal. Juvenile salmon will likely rear in multiple habitat types, depending on the species and year class. Sub-yearling Chinook salmon will benefit from the shallow emergent marsh zones and floodplain during the spring freshets, when water temperatures are near optimal. Restoration measures 6 and 14b slightly increase the combined HSI scores (Table 17). However, the main benefit to juvenile salmon from the proposed restoration measures is increased connectivity and access from the Columbia River to the interior lake rearing habitat throughout the year. The salmon habitat area is multiplied by the HSI in order to yield habitat units. The habitat area is weighted by the increased frequency of access that is afforded to juvenile salmon to the lake. Measure 14b

creates a channel that provides fish access to the lake 84% of the time (Table 18). Most of the 16% of the time that access is not provided is during the late summer and early fall, when temperatures are not suitable for rearing in the lake. Measure 6 is a higher elevation channel that only provides access to the lake when water levels are above 12 ft (45% of the time). Measure 14a does not provide new access as a stand-alone measure, and measure 17 does not provide new fish access. As a result, Measure 14b provides the largest amount of new salmon habitat units, with measure 6 providing an intermediate amount of habitat units (Table 19).

Table 18. Frequency of Access to Sturgeon Lake from the Columbia River.

Measure	Channel Invert Elevation (ft)	Frequency of Access Throughout the Year (%)
Alt 1-No Action	14	20
Measure 6	12	45
Measure 14a	14	20
Measure 14b	8	84
Measure 17	14	20

Table 19. Salmon Habitat Areas and Habitat Unit Calculations

Habitat Unit Calculations	No Action Alt 1 (without project)	Measure 6	Measure 14a	Measure 14b	Measure 17/18
Extent of Functioning Riparian Area (Acres)					
Target Year 0 - 5 (x5)	18.25	49	25	21.65	18.25
Target Year 6 - 15 (x10)	18.25	49	25	21.65	18.25
Target Year 16 - 25 (x10)	18.25	49	25	21.65	18.25
Target Year 26 - 50 (x 25)	18.25	49	25	21.65	18.25
Rearing Area Weighted by Fish Passage (Acres)[1]					
Target Year 0 - 5 (x5)	823	1852	823	3457	823
Target Year 6 - 15 (x10)	823	1852	823	3457	823
Target Year 16 - 25 (x10)	823	1852	823	3457	823
Target Year 26 - 50 (x 25)	823	1852	823	3457	823
Habitat Units[2]					
Target Year 0 - 5 (x5)	476	1087	480	2080	476
Target Year 6 - 15 (x10)	476	1095	480	2094	476
Target Year 16 - 25 (x10)	476	1103	480	2117	476
Target Year 26 - 50 (x 25)	476	1115	480	2188	476
Total	23,813	55,295	23,994	107,212	23,813
AA Benefits	476	1106	480	2144	476
Change in Habitat Units					
Target Year 0 - 5 (x5)	0	611	4	1604	0
Target Year 6 - 15 (x10)	0	619	4	1618	0
Target Year 16 - 25 (x10)	0	626	4	1641	0
Target Year 26 - 50 (x 25)	0	639	4	1711	0
Change Total	0	31482	181	83399	0
Change AA Benefits	0	630	4	1668	0

[1] Sturgeon Lake Area inundated at a 50% exceedance flood elevation, multiplied by the proportion of time fish passage is available (Table 18)
[2]See HU calculation in section 2.6.2

4.5 HU Aggregation

Overall habitat benefits were determined by summing the northern pintail, lesser scaup, and salmon habitat benefits. Measure 14b had the largest increase in total and average annual habitat units, followed by measure 6 (Table 20; Figure 11). Measure 14a yielded a very small amount of habitat units because it is intended to be combined with measure 14b or 6 during formation of alternatives, and provides very little habitat as a stand-alone measure. Measures 17 and 18 did not yield any habitat units, because they did not substantively change lake hydrology, lake vegetation, or provide fish access. Since none of the measures substantively affected lake hydrology or the distribution of emergent vegetation, habitat suitability for the northern pintail and lesser scaup was unchanged from the no action alternative. Therefore, the overall benefits were determined by changes in salmon habitat units.

Table 20. Overall Habitat Units from Combined Northern Pintail, Lesser Scaup, and Salmon Analyses

	Species Benefits as Average Annual Habitat Units					
Species	**AAHU**	**No Action Alt 1**	**Measure 6**	**Measure 14a**	**Measure 14b**	**Measure 17/18**
Northern Pintail	Total	3,069	3,069	3,069	3,069	3,069
	Net	0	0	0	0	0
Lesser Scaup	Total	2,371	2,371	2,371	2,371	2,371
	Net	0	0	0	0	0
Salmon	Total	476	1,106	480	2,144	476
	Net	0	630	4	1,668	0
Overall	**Total**	**5,916**	**6,546**	**5,920**	**7,584**	**5,916**
	Net	**0**	**630**	**4**	**1,668**	**0**

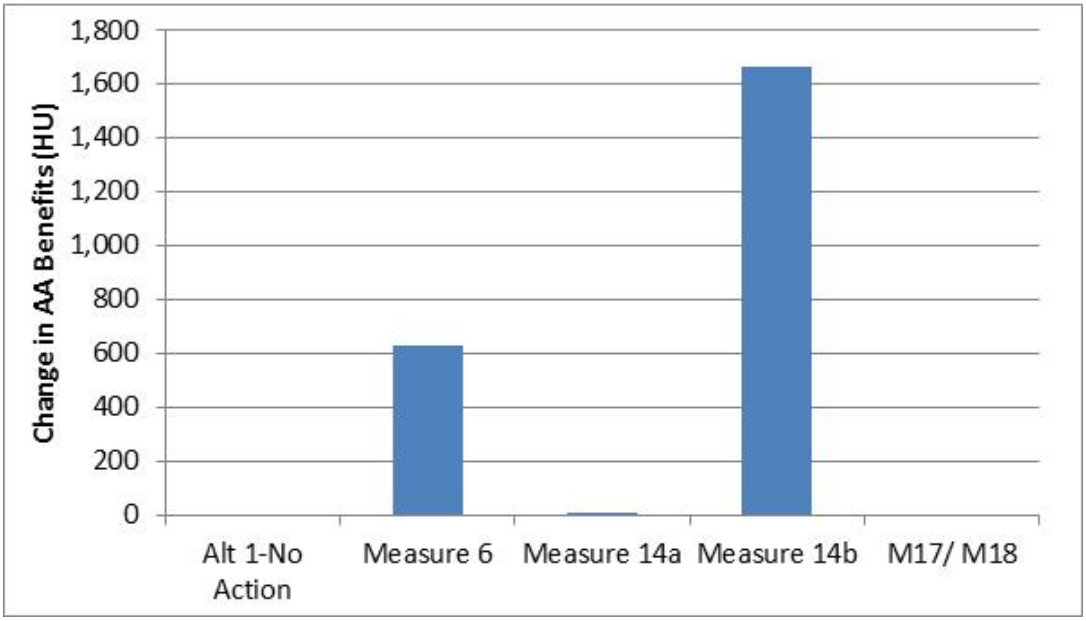

Figure 11. Change in Overall Average Annual Benefits, Expressed in Terms of Habitat Units

4.6 Alternative Approaches

4.6.1 Summary

The plan formulation process used AAHUs which were generated for each measure and then added. This approach was selected because the habitat benefits associated with each component measure are independent of each other. However, additional analysis was completed to determine if a different approach would yield different results related to plan selection. This analysis calculated AAHUs two different ways.

First, AAHUs were calculated for restoration Plans 2, 3, and 4 as a single plan HSI and Area Function. Plans 2, 3, and 4 are combinations of Measures 14a, 14b, and 6 (Table 21). These measures were selected because they had the greatest potential for area and HSI overlap.

Second, these same plans were calculated using the standard analysis, but with smaller, non-overlapping habitat areas in the lake. That is, the AAHUs for Measures 14a and 6 were assumed to affect 400 acres of lake habitat around their respective confluences with Sturgeon Lake, as opposed to using the entire area of the Lake. Since the spatial extent of both fish use and water temperature effects are unknown, this area was arbitrarily selected for this sensitivity analysis.

Table 21. Composition of Plans 2, 3, and 4.

Measures	Plan 2	Plan 3	Plan 4
Measure 14a (Mouth to Reeder Road)	X	X	X
Measure 14b (Reeder Road to Lake)		X	X
Measure 6 (Historic Dairy Creek Channel)	X		X

The analysis found that calculating AAHUs by plan, with one HSI and area, yielded different results for Plan 4 (Table 22), because measures in a given plan assume a combined effect on habitat for a certain area. This alternative approach in effect double counted the effects of some of the benefits. Whereas calculating by measure enabled a more refined tailoring of affected area that was more biologically accurate.

When AAHUs were calculated by measure with a non-overlapping lake area of 400 acres, the results were all less than the approach of using the entire lake, but roughly proportional.

Table 22. Comparison of Net AAHU, calculated by plan versus measure.

Net AA Benefits	Plan 2	Plan 3	Plan 4
Calculated by Measure, then Summed into Plans	633	1,672	2,301
Calculated by Plan	633	1,672	2,832
Calculated by Measure, with Non-overlapping Lake Areas, then Summed into Plans	81	168	246

The modified AAHU's were then evaluated in IWR-PLAN to evaluate if the increase of AAHU's changed the NER Plan selection. IWR-PLAN showed that when AAHUs were calculated by plan, Plan 3 was no longer the NER Plan, but this plan remained a best buy. However, estimating AAHUs by plan is not recommended, because the habitat benefits from Measures 14b and 6 are independent from each other, and therefore calculation of a composite HSI and area function for both measures together is not reflective of expected conditions.

When AAHUs were calculated by measure with the non-overlapping 400-acre benefit areas, Plan 3 remained the NER plan. Calculating AAHUs by measure with overlapping and non-overlapping areas produce proportional AAHUs, similar IWR-Plan results, and the same

recommended plan (Plan 3). The spatial extent of fish use and water quality effects from the channels is unknown. However, this sensitivity analysis shows that regardless of whether the entire lake area is used (overlapping areas), or smaller non-overlapping areas are used, the same NER Plan is selected. Additional detail on the analysis is provided below.

4.6.2 Calculating AAHUs by Plan

The methods used to calculate the AAHUs used for the study are presented in Section 2.0. The section below summarizes the methods used to calculate the AAHU by plan.

Calculating AAHU's by plan, with one HSI and area, implies that all of the measures in a given plan have a combined effect on habitat for a certain area. This methodology for calculating juvenile salmonid Plan AAHU's is summarized by the following steps:

1. Calculate HSI value for plan by calculating arithmetic average of variable SI scores, considering all component measures together.
    a. COV1- maximum temperature
    b. COV3- riparian canopy cover
    c. COV4- riparian vegetation composition
    d. COV9- percent winter cover
    e. CHV11- percent rearing habitat
2. Calculate area for plan, considering all component measures together, according to the area function in the Dairy Creek Restoration Feasibility Study Habitat Benefits Model
3. Calculate total HU and AAHU for each plan
4. Re-run IWR-PLAN using revised AAHU's

4.6.3 AAHU by Plan Results

When calculated by plan the following results were found:

- Metric and SI scores for Plan 2 were identical to scores for Measure 6 (Table 23 through Table 25).
- Metric and SI scores for Plans 3 and 4 were identical to scores for Measure 14b.
- The percentage of overwintering habitat (COV9) and year-round rearing habitat (COV11) are 100% suitable when calculated by individual measure or by combined plans. HSI scores for Plan 2 were identical to scores for Measure 6 (Table 26).
- HSI scores for Plans 3 and 4 were identical to scores for Measure 14b. Areas and AAHUs for Plan 2 were identical to areas for Measure 6 (Table 27).
- Areas and AAHUs for Plan 3 were identical to areas for Measure 14b.
- Areas and AAHUs for Plan 4 were larger than any single measure, because it incorporates areas for Measures 14a, 14b, and 6. When compared as plan AAHUs, plans

2 and 3 were the same, regardless of whether or not they were calculated, measure and summed, or calculated directly by plan (Table 22).

- Plan 4 AAHU was larger when calculated directly by plan, because the all components of the habitat area were multiplied by the larger HSI value that they otherwise would have had as individual measures. Specifically, the measure 6 habitat area was multiplied by a larger HSI, because the inclusion of Measure 14 B effects.

Table 23. COV1 Metric and SI Results, Calculated by Plan.

	Max Temp (Jan- June)	SI
Alt 1-No Action	19.8	0.20
Plan 2	19.8	0.20
Plan 3	18.6	0.31
Plan 4	18.6	0.31

Table 24. COV3 Metric and SI Results, Calculated by Plan.

	% Canopy Cover Year 0	SI	% Canopy Cover Year 5	SI	% Canopy Cover Year 15	SI	% Canopy Cover Year 25	SI	% Canopy Cover Year 50	SI
Alt 1-No Action	22	0.46	22	0.46	22	0.46	22	0.46	22	0.46
Plan 2	22	0.46	23	0.48	24	0.49	25	0.50	26	0.52
Plan 3	22	0.46	24	0.49	25	0.50	26	0.52	29	0.59
Plan 4	22	0.46	24	0.49	25	0.50	26	0.52	29	0.59

Table 25. COV4 Metric and SI results, calculated by plan.

	Veg Comp Year 0	SI	Veg Comp Year 5	SI	Veg Comp Year 15	SI	Veg Comp Year 25	SI	Veg Comp Year 50	SI
Alt 1-No Action	43	0.17	43	0.17	43	0.17	43	0.17	43	0.17
Plan 2	43	0.17	45	0.18	47	0.19	50	0.20	52	0.21
Plan 3	43	0.17	48	0.19	50	0.20	52	0.21	57	0.24
Plan 4	43	0.17	48	0.19	50	0.20	52	0.21	57	0.24

Table 26. Suitability Index Summary and Habitat Suitability Index Results, calculated by plan.

Suitability Index - Variable	Suitability Index			
	W/out Project			
	Alt 1-No Action	Plan 2	Plan 4	Plan 3
COV1: Max Temp				
Target Year 0 - 5 (x5)	0.20	0.20	0.31	0.31
Target Year 6 - 15 (x10)	0.20	0.20	0.31	0.31
Target Year 16 - 25 (x10)	0.20	0.20	0.31	0.31
Target Year 26 - 50 (x 25)	0.20	0.20	0.31	0.31
COV3: % Canopy Cover				
Target Year 0 - 5 (x5)	0.46	0.48	0.49	0.49
Target Year 6 - 15 (x10)	0.46	0.49	0.50	0.50
Target Year 16 - 25 (x10)	0.46	0.50	0.52	0.52
Target Year 26 - 50 (x 25)	0.46	0.52	0.59	0.59
COV4: Vegetation composition				
Target Year 0 - 5 (x5)	0.17	0.18	0.19	0.19
Target Year 6 - 15 (x10)	0.17	0.19	0.20	0.20
Target Year 16 - 25 (x10)	0.17	0.20	0.21	0.21
Target Year 26 - 50 (x 25)	0.17	0.21	0.24	0.24
COV9: % Winter Cover				
Target Year 0 - 5 (x5)	1.00	1.00	1.00	1.00
Target Year 6 - 15 (x10)	1.00	1.00	1.00	1.00
Target Year 16 - 25 (x10)	1.00	1.00	1.00	1.00
Target Year 26 - 50 (x 25)	1.00	1.00	1.00	1.00
CHV11: % Rearing Habitat				
Target Year 0 - 5 (x5)	1.00	1.00	1.00	1.00
Target Year 6 - 15 (x10)	1.00	1.00	1.00	1.00
Target Year 16 - 25 (x10)	1.00	1.00	1.00	1.00
Target Year 26 - 50 (x 25)	1.00	1.00	1.00	1.00
HSI Suitability Index				
Target Year 0 - 5 (x5)	0.57	0.57	0.60	0.60
Target Year 6 - 15 (x10)	0.57	0.58	0.60	0.60
Target Year 16 - 25 (x10)	0.57	0.58	0.61	0.61
Target Year 26 - 50 (x 25)	0.57	0.59	0.63	0.63

Table 27. Area summary and habitat units, calculated by plan.

Habitat Unit Calculations	W/out Project No Action Alt 1	Plan 2	Plan 4	Plan 3
Extent of Functioning Riparian Area (Acres)				
Target Year 0 - 5 (x5)	18.25	55	59	28.05
Target Year 6 - 15 (x10)	18.25	55	59	28.05
Target Year 16 - 25 (x10)	18.25	55	59	28.05
Target Year 26 - 50 (x 25)	18.25	55	59	28.05
Habitat Access Weighted by % Inundation Time (Acres)				
Target Year 0 - 5 (x5)	823	1852	5310	3457
Target Year 6 - 15 (x10)	823	1852	5310	3457
Target Year 16 - 25 (x10)	823	1852	5310	3457
Target Year 26 - 50 (x 25)	823	1852	5310	3457
Habitat Units				
Target Year 0 - 5 (x5)	476	1091	3210	2084
Target Year 6 - 15 (x10)	476	1099	3232	2098
Target Year 16 - 25 (x10)	476	1106	3267	2121
Target Year 26 - 50 (x 25)	476	1119	3376	2192
Total	23813	55481	165432	107409
AA Benefits	476	1110	3309	2148
Change in Habitat Units				
Target Year 0 - 5 (x5)	0	615	2734	1608
Target Year 6 - 15 (x10)	0	622	2756	1622
Target Year 16 - 25 (x10)	0	630	2791	1645
Target Year 26 - 50 (x 25)	0	643	2899	1715
Change Total	0	31668	141619	83596
Change AAHU	0	633	2832	1672

4.6.4 Calculating AAHUs by Measure, with Non-Overlapping Lake Areas

The methods used to calculate the AAHUs by measure with non-overlapping areas are identical to the standard methods presented in Section 2.0, except the lake area that each measure affected was assumed to be independent 400-acre areas instead of sharing the entire lake as an area of common benefit. The 400-acre areas were still weighted by the percentage of time that the measure would provide fish access between the Columbia River and Sturgeon Lake. The resulting AAHUs were much smaller values, but roughly proportional to the standard analysis. Since the results were roughly proportional, the plan selection was similar, with Plan 3 (Measures 14a and 14b) being the NER Plan.

Table 28. Area Summary and Habitat Units, Calculated by Measure, with Non-overlapping Lake Areas.

Habitat Unit Calculations	W/out Project			
	No Action Alt 1	Measure 6	Measure 14a	Measure 14b
Extent of Functioning Riparian Area (Acres)				
Target Year 0 - 5 (x5)	18.25	49	25	21.65
Target Year 6 - 15 (x10)	18.25	49	25	21.65
Target Year 16 - 25 (x10)	18.25	49	25	21.65
Target Year 26 - 50 (x 25)	18.25	49	25	21.65
Habitat Access Weighted by % Inundation Time (Acres)				
Target Year 0 - 5 (x5)	80	180	80	336
Target Year 6 - 15 (x10)	80	180	80	336
Target Year 16 - 25 (x10)	80	180	80	336
Target Year 26 - 50 (x 25)	80	180	80	336
Habitat Units				
Target Year 0 - 5 (x5)	56	131	59	214
Target Year 6 - 15 (x10)	56	132	59	215
Target Year 16 - 25 (x10)	56	133	59	218
Target Year 26 - 50 (x 25)	56	134	59	225
Total	2780	6659	2962	11021
AA Benefits	56	133	59	220

Habitat Unit Calculations	W/out Project			
	No Action Alt 1	Measure 6	Measure 14a	Measure 14b
Change in Habitat Units				
Target Year 0 - 5 (x5)	0	75	4	158
Target Year 6 - 15 (x10)	0	76	4	160
Target Year 16 - 25 (x10)	0	77	4	162
Target Year 26 - 50 (x 25)	0	79	4	169
Change Total	0	3879	181	8241
Change AA Benefits	0	78	4	165

4.6.5 Discussion

Calculating AAHU's by plan was considered to be a less biologically representative approach as it has the potential to overestimate benefits for acreages associated with some of its component measure areas. The habitat benefits for the Measure 6 component are largely independent of the Measure 14b effects on the lake. When calculating AAHUs by plan, the Plan 4 AAHU's were inflated because of the inclusion of Measure 14b habitat benefits applied to the Measure 6. Therefore, it is more appropriate to calculate the AAHU's by measure, and then add them up for plan AAHUs.

Calculating AAHUs by measure with non-overlapping lake areas explicitly acknowledges that Measures 14b and 6 do not provide mutual habitat suitability for fish using the new access to the lake. For example, the cooling effect of water temperature from Measure 14b would not benefit fish entering Sturgeon Lake through the Measure 6 channel. The spatial extent of fish use and water temperature effects throughout the lake from the proposed measures are unknown, but assumed to be largely independent of each other. This analysis demonstrates that when calculating AAHUs by measure, and applying the entire lake area or a small patch of the lake near channel confluences, the results are proportional to the original analysis, and does not change plan selection.

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Technical Memorandum

To:	Alison Burcham, Technical Lead U.S. Army Corps of Engineers 333 S.W. First Avenue Portland, OR 97204-3495	Date:	July 2013
		Project:	147808
From:	Amy Dammarell, Project Manager		
Project:	USACE #W9127N-08-D-0006, Task Order 29 - Dairy Creek Tidal Restoration Feasibility Study		
Re:	**Hydrology and Hydraulic (H&H) Analysis (Model Setup)**		

1.0 Introduction

1.1 Project Background

The U.S. Army Corps of Engineers (USACE), along with local partner West Multnomah Soil and Water Conservation District (WMSWCD), are currently evaluating restoration opportunities for Sturgeon Lake (on Sauvie Island) in conformance with Section 1135 of the 2000 Water Resources Development Act. Before construction of the levee surrounding the southern half of Sauvie Island, the Gilbert River flowed north through Sturgeon Lake into the Multnomah Channel. Since the truncation of the watershed, the Gilbert River no longer flows through the lake, resulting in altered lake hydrology. The intent of the Dairy Creek Restoration Feasibility Study (Study) is to identify and evaluate alternatives to enhance Sturgeon Lake and preserve and/or restore its aquatic habitat value.

Sturgeon Lake is located approximately 12 miles northwest of Portland, Oregon on Sauvie Island (Figure 1). It is a large waterbody connected to the Columbia River at river mile (RM) 98.5 through the highly modified Dairy Creek Channel and to the Multnomah Channel, a Columbia River tributary, through the Gilbert River. For the purpose of this memorandum, the Study area is defined as Sturgeon Lake and the surrounding area between the Multnomah Channel and Columbia River and between the Sauvie Island Federal levee and the mouth of the Gilbert River. The Study area boundary may change as the planning process progresses to include potential alternatives.

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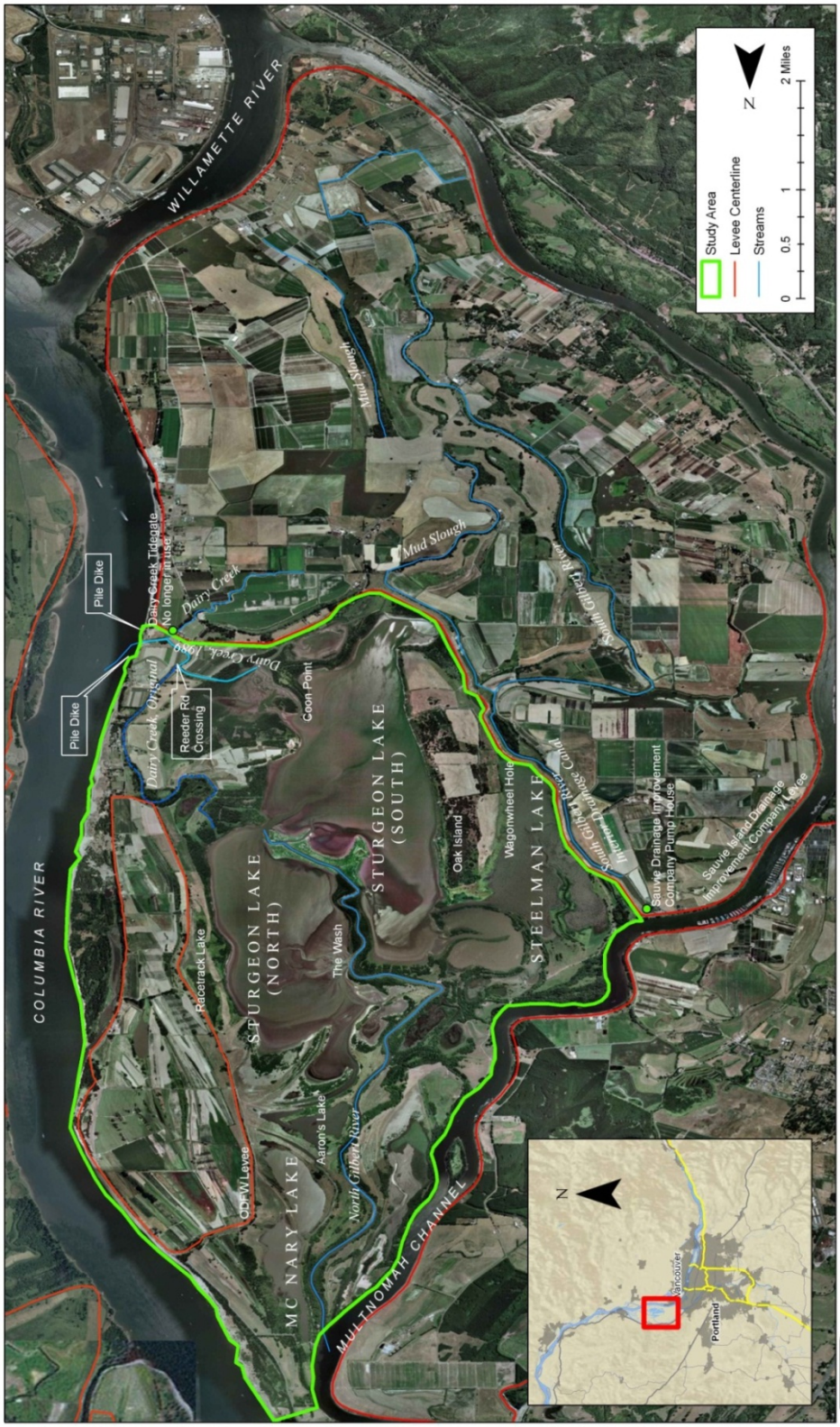

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The HE provide
a baseline for estimating the potential function and success of restoration alternatives. Evaluated parameters include estimates of flow, water surface elevations, and velocity. The HEC-RAS

output is used in the Habitat Evaluation Procedure (HEP) to estimate habitat characteristics that are scored in the HEP benefit model.

This hydraulic model is not validated, is intended to be used as a planning tool, and is very useful for evaluating alternatives against the baseline condition. At the design phase, specific flows can be added to the model and used to validate field measurements for determining sizing and placement of restoration features.

3.0 Terrain Development

The Study model geometry was developed using geographic information system (GIS) capabilities and USACE HEC-GeoRAS extensions. The foundation for the model geometry used in this process is a digital terrain model, or Triangular Irregular Network (TIN). This terrain model uses a dense network of elevation points and breakline data which is then triangulated to generate a three-dimensional surface representing the ground elevation for the Study area.

Data used to create Study area topography came from three sources:

1. Current USACE acquired Light Detection and Ranging (LiDAR) surveys, flown in support of the upcoming Columbia River Treaty (CRT) renegotiation (Figure 3);
2. 1982 data from Klingeman's multivolume investigation of Sturgeon Lake and Dairy Creek (Figure 5; Klingeman, 1982); and
3. Transects surveyed by West Multnomah Soil Water Conservation District (WMSWCD) in 2011 and ready for use in January 2012 (data incorporation pending).

The two data sets were merged (Figure 4) to create the existing condition. A raster is a two-dimensional plane of cells where each cell is assigned a value. For this Study, the cells are assigned an elevation value and each cell is 3.28 feet square (1 meter by 1 meter).

LiDAR data from the USACE was processed to:

- Re-project the data from Universal Transverse Mercator (UTM; metric) to State Plane (feet), and
- Adjust the data vertically from meters to feet.

This data represents the best available above-water information combined with recent bathymetric surveys of the Columbia River, Willamette River, and Multnomah Channel. No current bathymetric data is available for Sturgeon Lake. The data was processed, merged, and provided to USACE by a local surveying contractor.

The best available bathymetry data for Sturgeon Lake was acquired in 1982 during the original study of Dairy Creek by Dr. Peter Klingeman at Oregon State University (Figure 5). As most LiDAR surveys cannot penetrate water, the 1982 bathymetric contours are the best available below-water information for the Study area at the time. The bathymetric map was developed

from several transects of the lake and prepared in the same datum as the U.S. Geological Survey quadrangle maps (National Geodetic Vertical Datum of 1929 [NGVD29]).

The 1982 bathymetric data for the lake was digitized using the following steps:

- The scanned map was added graphically via "rubbersheeting," matching the map features to several prominent above-water features in the USACE LiDAR data.
- The contour lines were carefully digitized, distance between vertices is generally 200 feet or less.
- The contour elevations were updated to North American Vertical Datum of 1988 (NAVD88) using Vertcon conversion (add 3.2 feet).

For the Gilbert River, three depth profiles were surveyed in 1982 (left, right, and center) and graphed in the Sturgeon Lake reports (Klingeman, 1982). The data was digitized using the following steps:

- Scaled the river profile graphs within GIS.
- Digitized the profiles, smoothed the lines by adding vertices (densify polyline) to place a vertex every 10 feet, and exported the (X,Y) data.
- Converted (X,Y) data to (X,Y,Z) using linear interpolation to solve for Z values in Excel.
- Updated Z values to NAVD88 using Vertcon conversion (add 3.2 feet) in Excel.
- Converted the polyline vertices to points in GIS.
- Added Z values from the Excel calculation to the (X,Y) points in GIS to create three-dimensional points.

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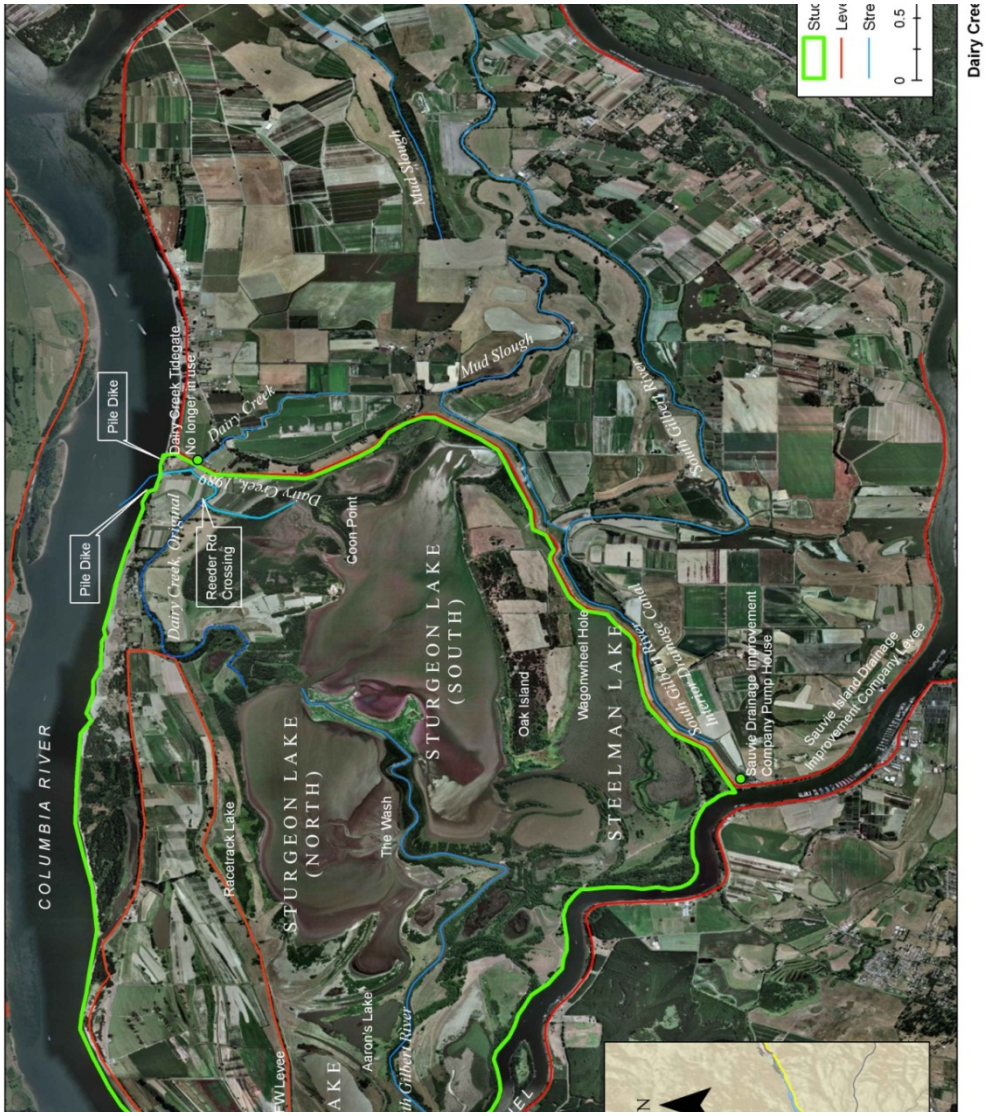

Figure 2. Vicinity Map.

Two breaklines were added manually to better represent the existing conditions shown on recent aerial images. The breaklines provided missing data at two points where Gilbert River spills into Sturgeon Lake (one on the west side of the river and one at the very southern end).

Using the lake and channel bathymetry listed above and the breaklines, a TIN was built in GIS to represent the 1982 Sturgeon Lake condition. The TIN was then converted to a raster for the following operation.

Using the raster calculator tool in GIS, the 1982 data was added to the USACE CRT LiDAR information. The 1982 data superseded the LiDAR information, completing the LiDAR dataset with information below the water surface within Sturgeon Lake.

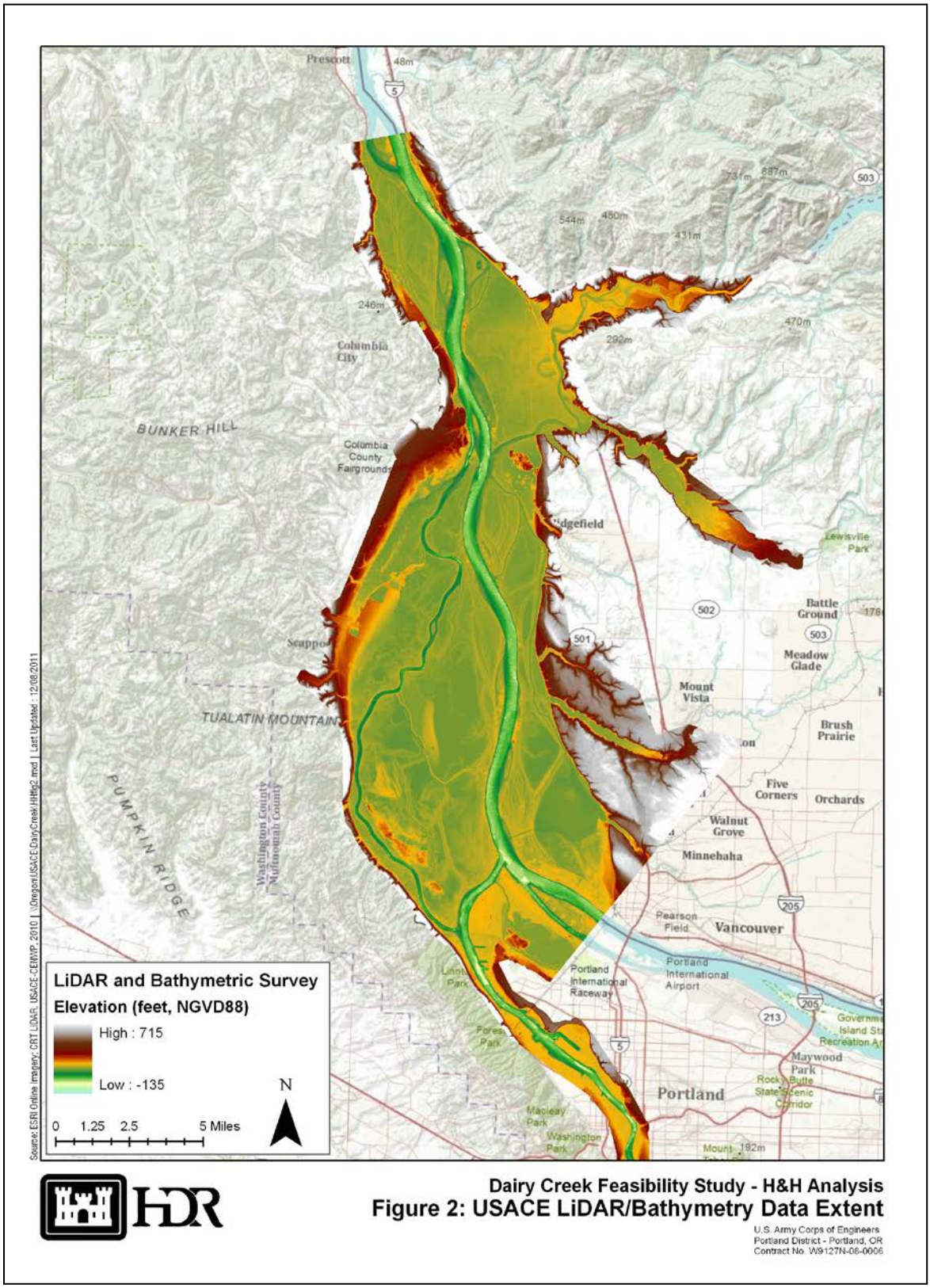

Figure 3. USACE LiDAR/Bathymetry Data Extent

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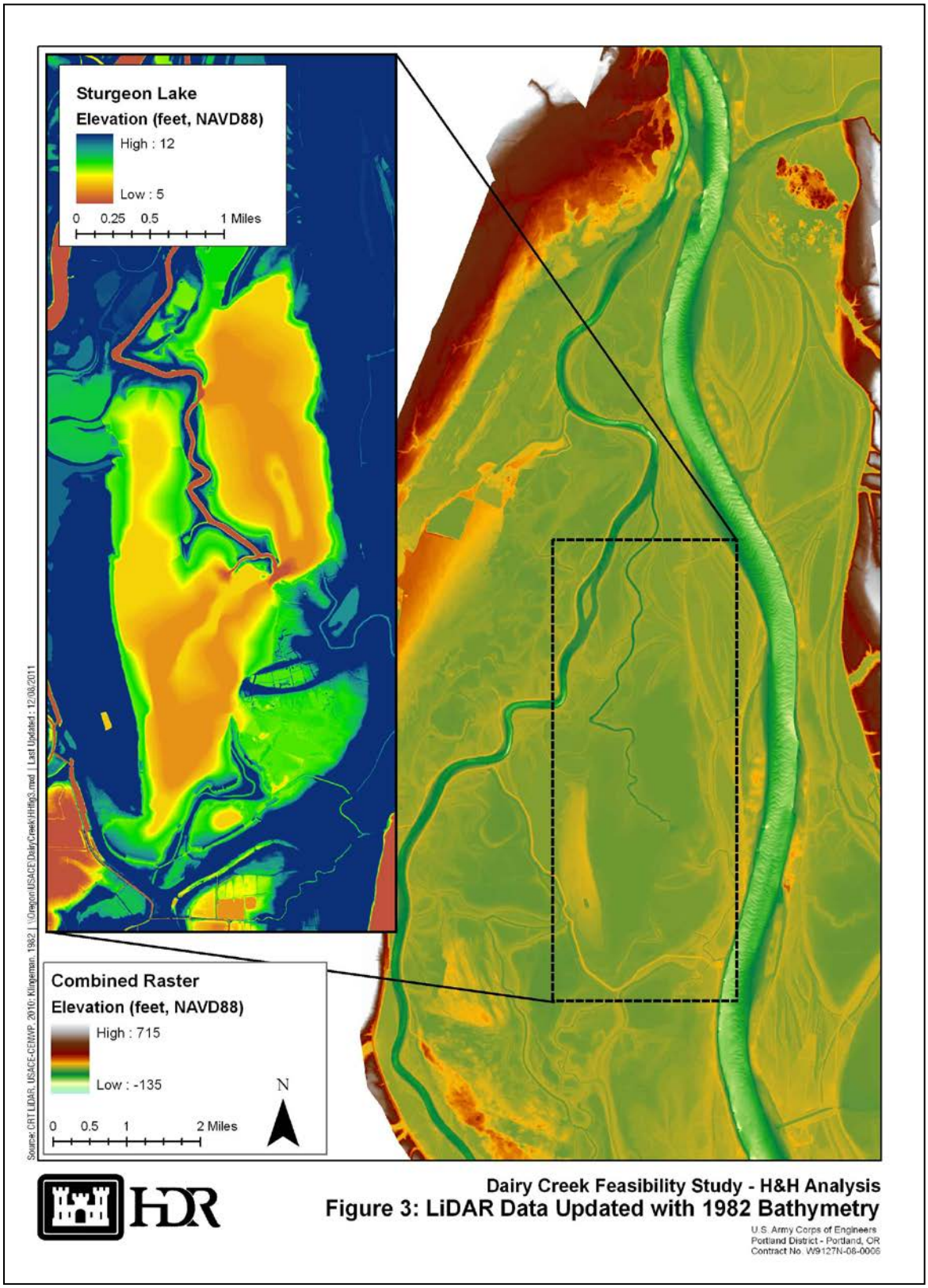

Figure 4. LiDAR Data Updated with 1982 Bathymetry

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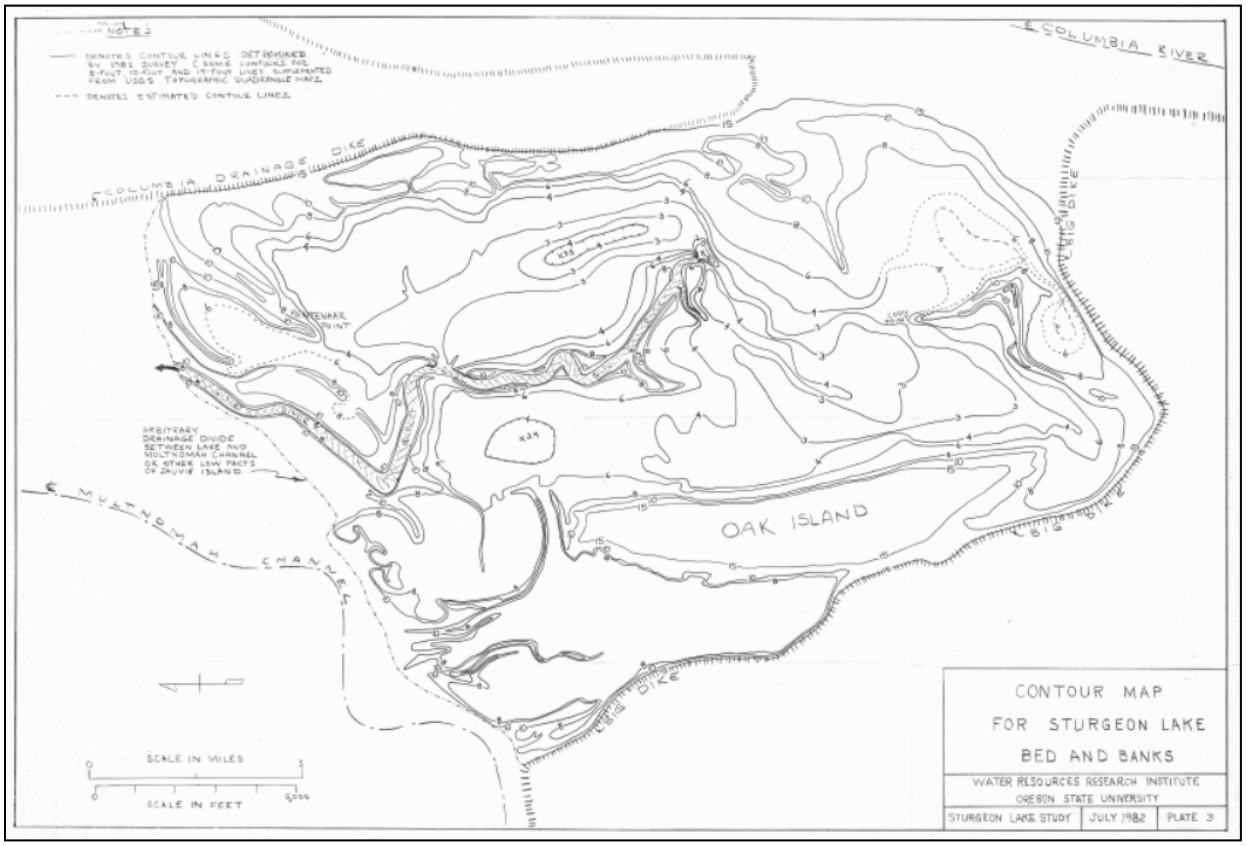

Figure 5. Sturgeon Lake Bathymetry as Surveyed in 1982

4.0 Hydraulic Model Development

4.1 Geometry Development

Upon completion of the digital terrain model (DTM), HDR used GIS to develop model geometry for export into the HEC-RAS model. Geometric information used for the hydraulic modeling was derived using the USACE HEC-GeoRAS v4.2.93 program in combination with ArcMap v9.3. The stream centerlines, cross-sections, bank lines, and flow paths were digitized using aerial photograph imagery and the DTM. Cross-sections were drawn in accordance with guidelines in the HEC-GeoRAS Users Manual (USACE, 2011).

These features were then processed using HEC-GeoRAS with the raster to produce a geometry file for import into HEC-RAS. Storage area connections were built within HEC-RAS with data from GIS. Additional geometry files were developed to model the alternatives proposed in the planning process.

4.2 HEC-RAS Model Development

The GIS data were imported into HEC-RAS v4.1 and used to develop the existing conditions model of the study reach. Specific model parameters used are discussed below.

Manning's n: Base Manning's n values for channel and overbank regions were estimated from aerial imagery and observation during site visits (OSU, 2012). The Manning's n values ranged from 0.02ins to 0.045 for channels and overbanks, respectively. Table 4-1 summarizes the values selected.

Table 4-1. Manning's n Values for Channel and Overbank Regions

River	Manning's n Value:		Comments
	Channel	Floodplain	
Columbia River	0.025	0.04	Wide, smooth, straight channel; floodplain is generally agricultural, some wooded and industrial areas
Gilbert River	0.03	0.04	Smaller, smooth channel with more complex bed; vegetated overbank
Multnomah Channel	0.025	0.04	Smooth, straight channel; floodplain is generally agricultural, some wooded and industrial areas
Willamette River	0.025	0.04	Wide, smooth, straight channel; floodplain is generally agricultural, some wooded and industrial areas

Manning's n values from Chow via Oregon State University (OSU, 2012)

Ineffective Flow Areas: Ineffective flow areas were not used in this model as the levees on the floodplain perform the same function.

Levees: The levees on the floodplain were included in the model. The levee data originated from the USACE CRT study. A bright pink dot marks where the levees intersect the cross-section in Figure 5.

Bridges: Contraction and expansion coefficients were not used in this analysis because the model runs in unsteady state (flows can change with time) to account for the tides. The only bridge in the model is the Sauvie Island Bridge at Multnomah Channel cross-section 11550.

Bank Stations: Banks were digitized in GIS and incorporated into the cross-section data using HEC-GeoRAS. The bank stations define the overbank versus channel areas and appear as red dots in Figure 5.

Storage Area: The Sturgeon Lake storage area was developed in HEC-GeoRAS. Using a digitized lake boundary, GeoRAS developed a storage-elevation table that defines the available storage in the lake. The outline of the lake shown in Figure 5 is simply a graphic, not an outline of the actual lake area. The lake was connected to the river through the Gilbert River, which has its upstream end connected to the lake and downstream end at the Multnomah Channel; and with a lateral weir placed at the Dairy Creek entrance (Columbia River cross-section #87766.42). The lateral weir elevation was developed using the LiDAR data and includes the height of the sand plug at the mouth as that control flows into the creek from the Columbia River.

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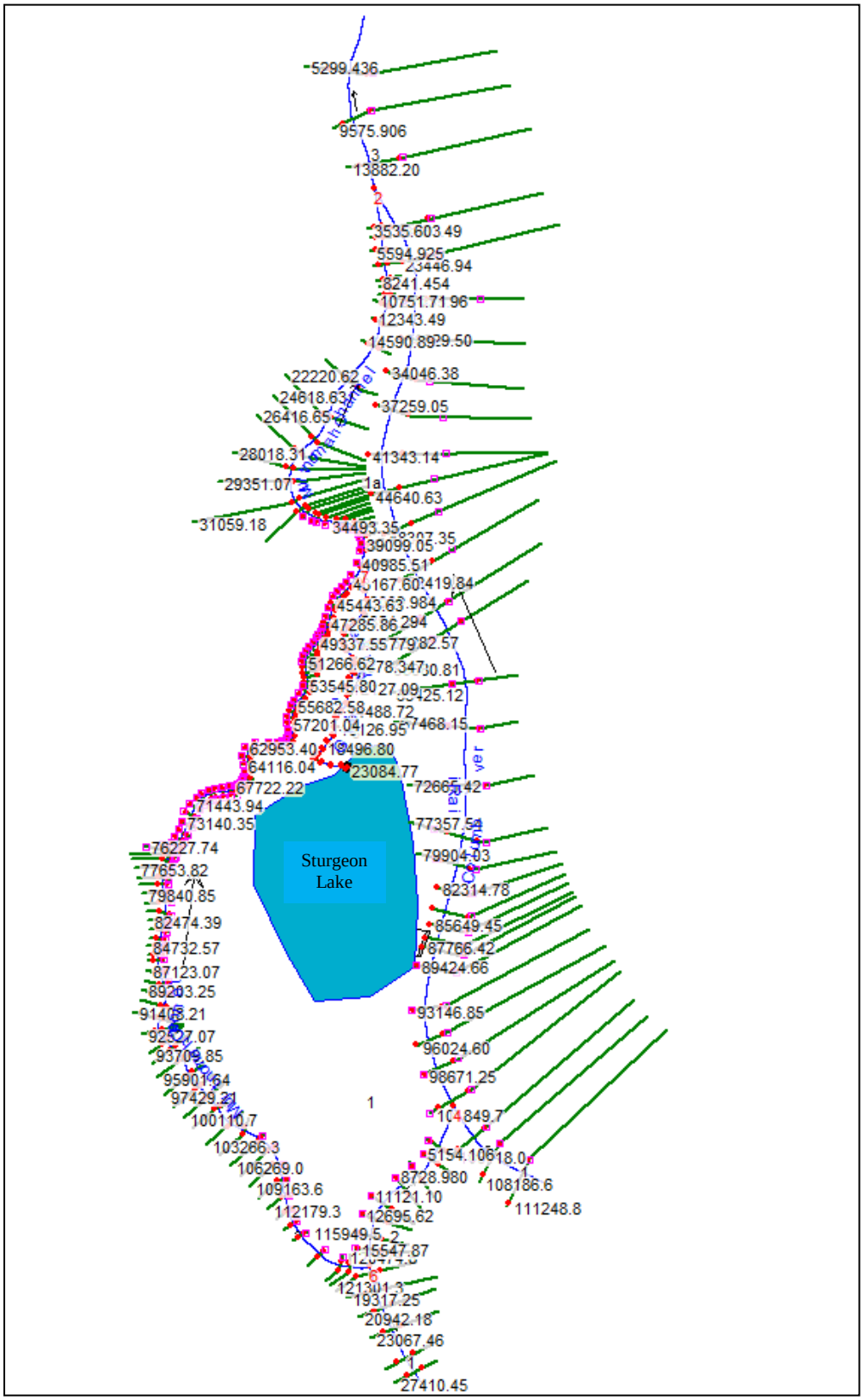

Figure 6. Dairy Creek Model Setup (HEC-RAS).

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Modeling parameters were entered into the model and appropriate flows and boundary conditions, as described below, were used to complete the existing conditions model.

4.3 Flow Inputs and Boundary Conditions

The model is run in unsteady state to capture the effect of the incoming tides river and lake stages. The upstream and downstream boundary conditions are defined in the following sections.

4.3.1 Upstream Boundary Conditions

Upstream boundary conditions are required for the Willamette and Columbia Rivers in this unsteady state analysis. The model uses available USACE data for the Columbia River at The Dalles Dam and the Willamette River at Portland acquired and linked to the model through the USACE Hydrologic Engineering Centers Data Storage System Visual Utility Engine (HEC-DSSVue). For The Dalles Dam, the data is daily. The data for the Willamette River is hourly or daily depending upon the year. Each provides a long period of record.

Although The Dalles Dam is upstream of the site, considering the scale of the Columbia Basin, the error is small. Hydrologic studies estimate that 97 percent of the Columbia River flows pass through The Dalles Dam gage (Lower Columbia River Estuary Partnership [LCREP], 2005). The remaining 3 percent includes the Willamette, included in this model, and smaller basins such as the Sandy and Washougal, upstream of the Study area, and the Kalama, Lewis, and Cowlitz which enter the Columbia downstream of the Study area.

4.3.2 Downstream Boundary Conditions

The downstream boundary condition for the model provides the tidal signal. This boundary condition is defined by the stage records at the St. Helens National Oceanic and Atmospheric Administration (NOAA) tide gage providing a “known water surface” elevation. This gage has a more limited period of record than the upstream gages and limits the time periods that can be run in the model. The data was acquired through USACE Dataquery (gage: SHNO) and NOAA’s website (Station #9439201). Datums were corrected to NAVD88 and some records were updated from reporting tenths of a foot to whole feet. Missing records were estimated using linear regression or if longer than 8 hours, by copying the previous day’s stages over the same time period. To date, this hourly data has been prepared for 1991, 1992, 2006, and 2012.

4.4 Model Limitations

The model geometry and flow conditions developed for the Dairy Creek Study area represent the best estimate based on information available at the start of the project. Given the lack of recent bathymetric lake information, the lake bed information and storage-elevation curve are out of date. Transect data was recently made available and the TIN will be updated with this data in the next model iteration.

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The limited period of record for the St. Helens tidal gage, the downstream boundary condition also presents a restriction on model runs. This information is necessary to cycle the tidal signal through the system; however the record at this gage is much shorter than The Dalles Dam or Willamette River gages. A synthetic record could be developed to estimate data outside the existing record if necessary.

4.4.1 Model Calibration and Validation

The model is not calibrated with water surface elevations from field measurements or gage data at this time. The model has been validated and input variables adjusted to compare the modeled water surface elevations (Figure 7) to minor gages on the Multnomah Channel (Figure 8) and Columbia River (Figure 9). The following graphs display the model results on the Multnomah Channel plotted with a local NOAA gage at Rocky Pointe Marina. The model appears to estimate lower flows better than higher flows. The high flow period was a significant flood on the Willamette and Columbia Rivers. The Columbia River peaked at 14.95 feet on January 13, 2006 (action stage is 15 feet, flood stage 16 feet) and the Willamette River peaked at 15.09 feet on the same day (action and flood stage is 18 feet, this was not the annual peak; NOAA, 2012).

Figure 7 displays the stage on the Columbia River for the 2006 calendar year.

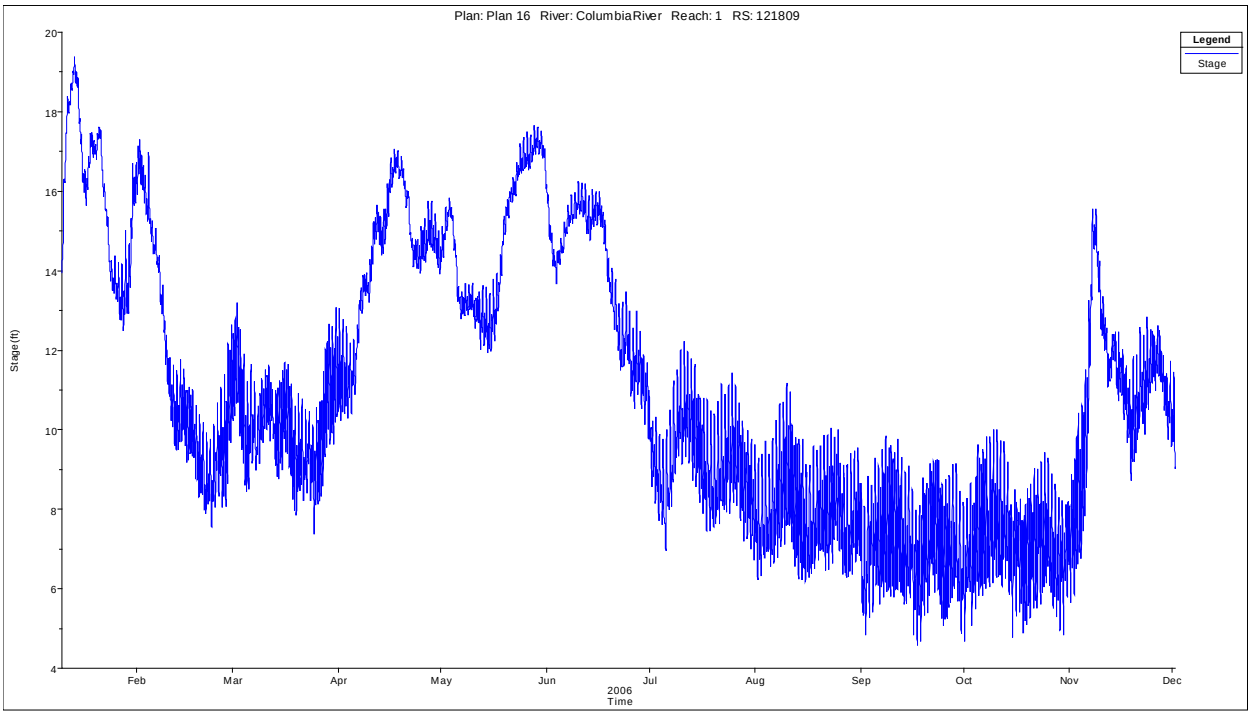

Figure 7. Columbia River Modeled Water Surface Elevations for the 2006 Period of Record.

Figure 8 and Figure 9 display the relationship between the modeled and observed data at tidally dominated flows in October. There is much better correlation on the Multnomah Channel than the Columbia River. The Columbia River modeled elevations tend to have a greater amplitude than the observed data and the peak is slightly ahead of the observed data on most tidal cycles.

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Figure 8 is in synch and Figure 9 is slightly out of phase on 6 October 2006, the low flow period of the Columbia River when tides dominate.

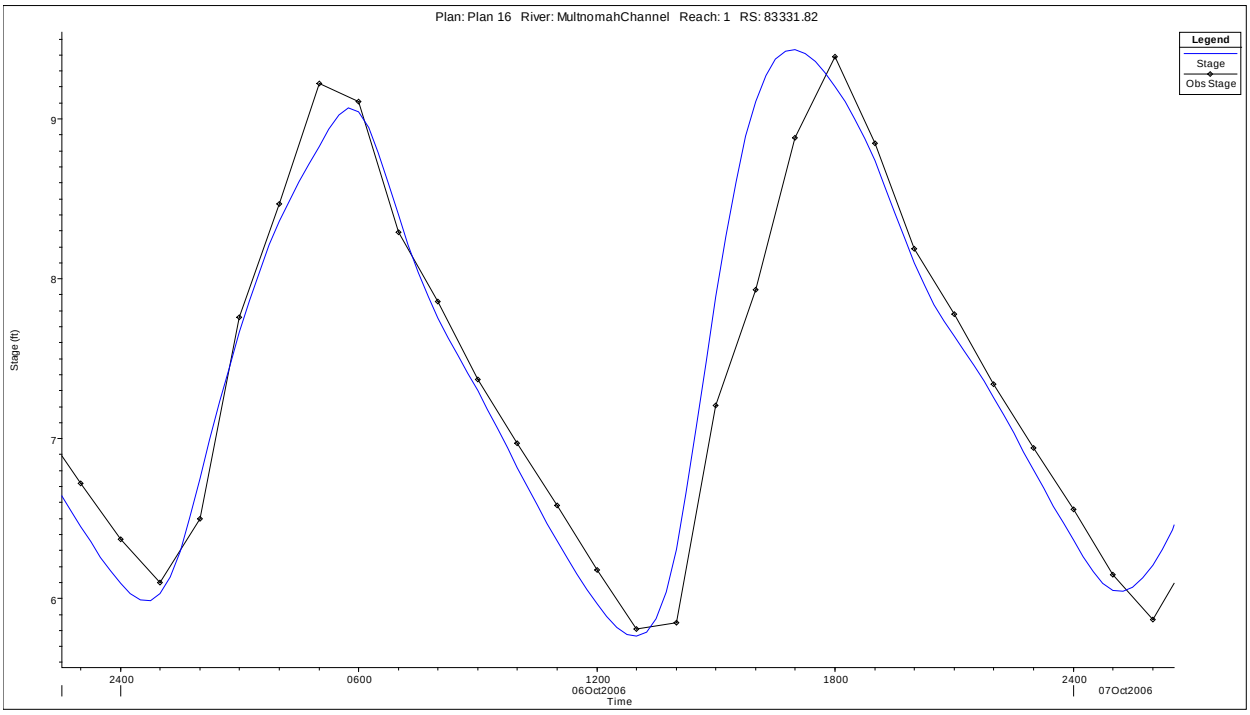

Figure 8. Multnomah Channel Modeled Water Surface Elevation (blue) and Observed Elevations (black) on 06 October 2006.

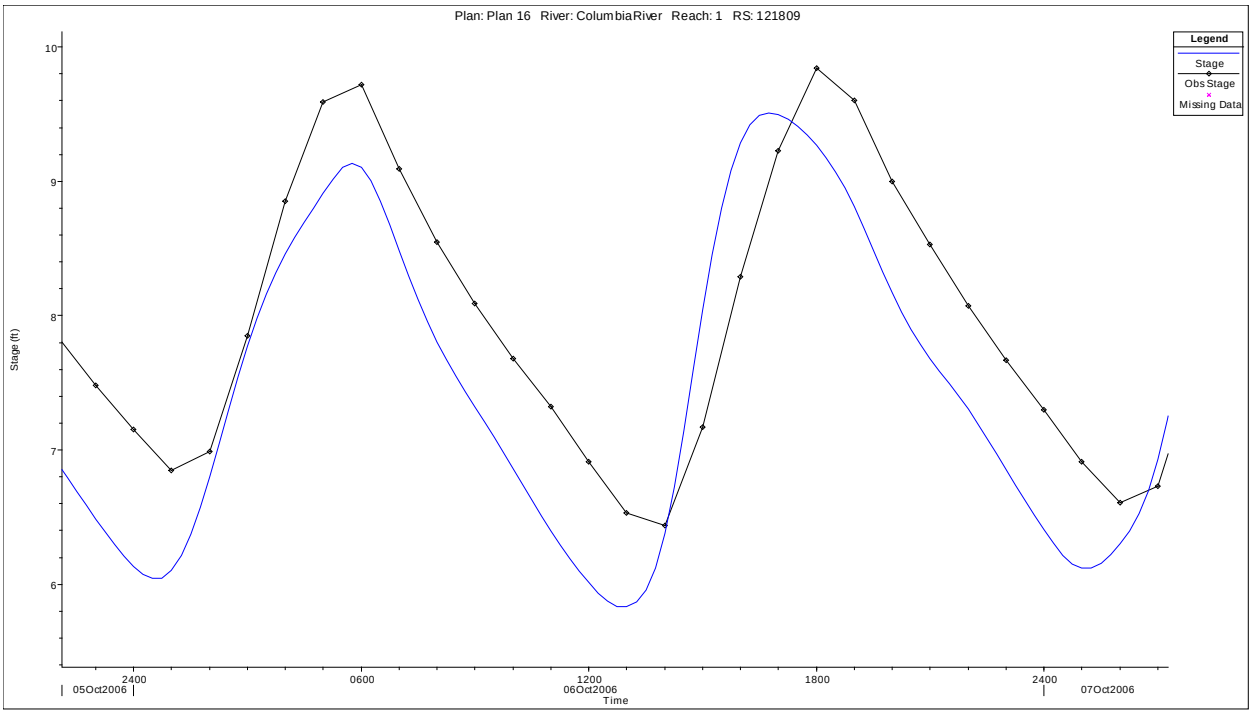

Figure 9. Columbia River Modeled Water Surface Elevation (blue) and Observed Elevations (black) on 06 October 2006.

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Figure 10 and Figure 11 illustrate that the model tends to underestimate the river stages on the Columbia River during high flow events, but is much closer on the Multnomah Channel. Since most of the modeling would occur during the normal, tidally-dominated flows, this is not a concern.

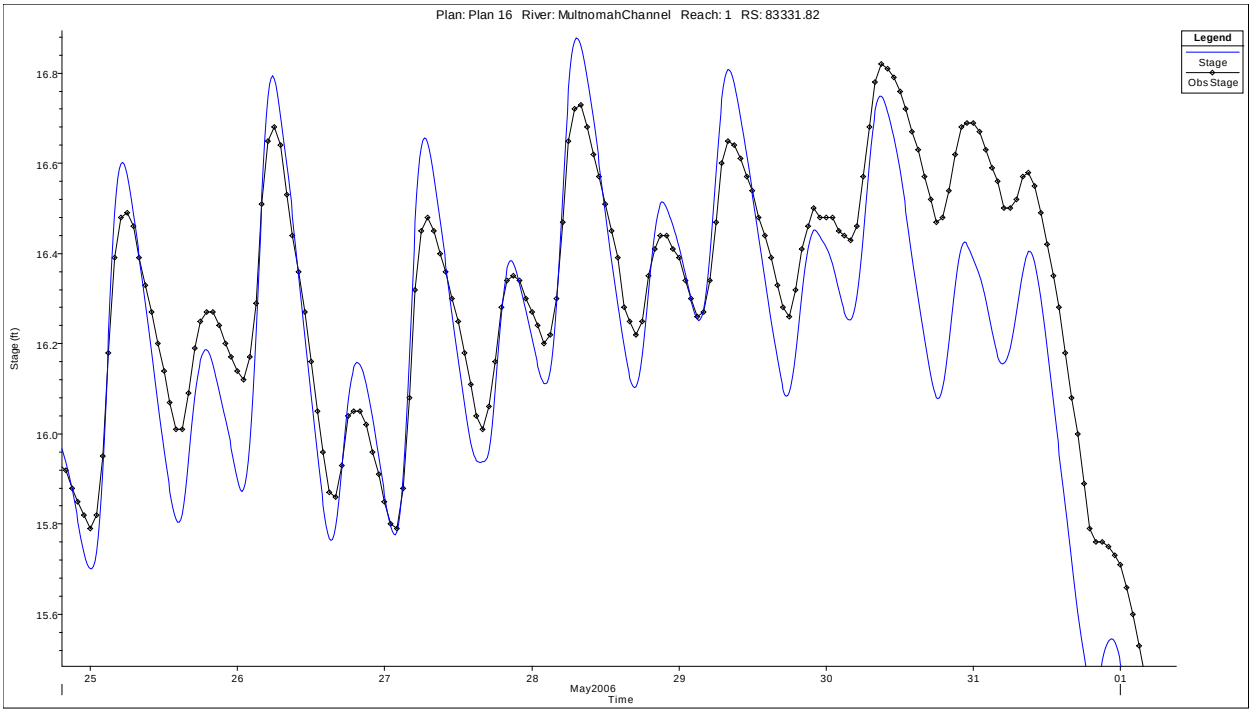

Figure 10. Multnomah Channel Modeled Water Surface Elevation (blue) and Observed Elevations (black) 25 May through 1 June 2006 (spring freshet).

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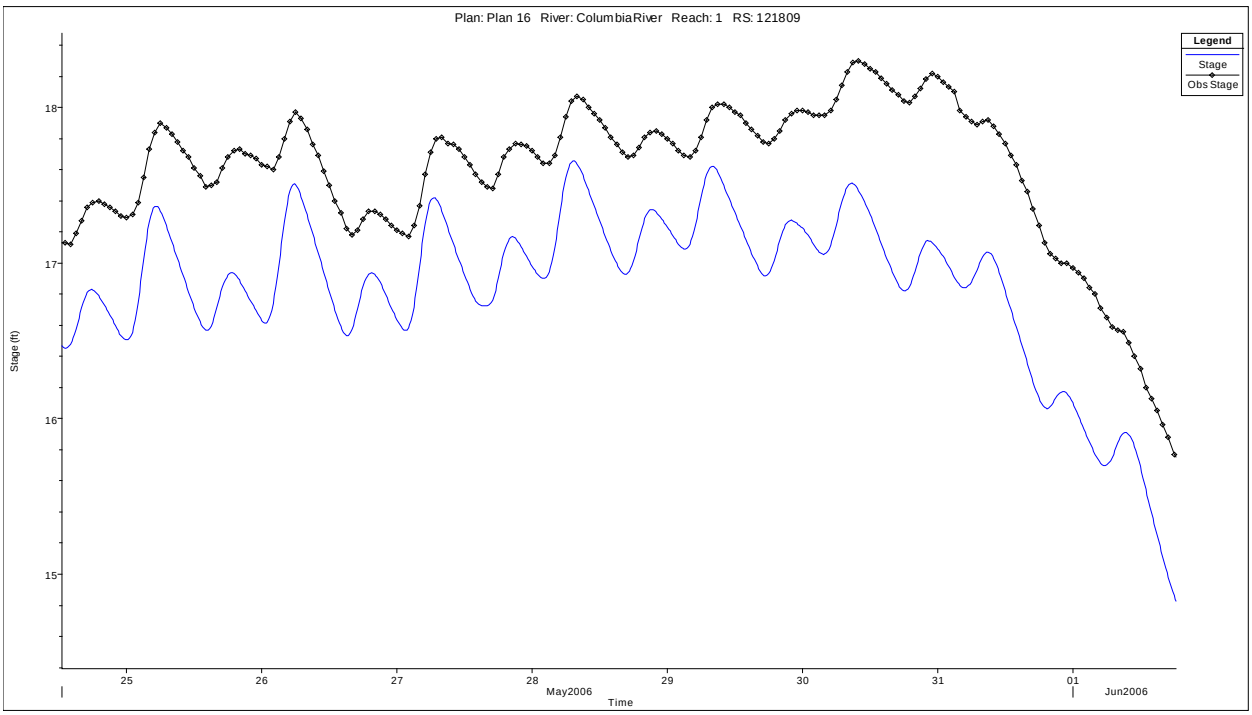

Figure 11. Columbia River Modeled Water Surface Elevation (blue) and Observed Elevations (black) 25 May through 1 June 2006 (spring freshet).

4.5 HEC-RAS Model of Dairy Creek

A model of Dairy Creek was created to estimate water surface elevations and velocities reflecting existing and proposed conditions. Model geometry was developed from the same LiDAR data used to create the larger unsteady model; the channel model has 16 cross-sections including the culverts as shown in Figure 12. Bank stations are set low in the channel to the limits of the proposed low flow channel, allowing channel velocitiesy to be compared between existing and proposed conditions. Levee markers are included on the banks to prevent erroneous inundation of low areas behind the channel bank. The flows investigated do not overtop the channel banks. The top of bank at the Columbia River is approximately 25 feet (ft) NAVD88 which is just above the 10-year (0.10 Annual Exceedance Probability [AEP]) flood water surface elevation according to LCR-99-120 (USACE, 2007). The 100-year (0.01 AEP) flood water surface elevation is approximately 29 ft NAVD88.

Figure 12. Channel Model Geometry

The existing condition model includes the existing culverts with their characteristics estimated from field observations and original design drawings. The proposed alternative of two, 42-foot concrete arch culverts was modeled using characteristics from the project data sheets provided by the vendor. Other culvert configurations were tested as part of the investigation in Appendix G (HDR, 2013).

4.5.1 Upstream and Downstream Boundary Conditions

Boundary conditions are set by the results of the unsteady model. For the downstream boundary condition, the lake elevations were selected from the stage duration curves developed from the unsteady model. Example durations investigated include the 5-, 50-, and 95-percent exceedance stages. Stages for the same durations were acquired from the Columbia River stage-duration curves near the Dairy Creek mouth. The stages were used to set the “known water surface” elevation.

With the downstream boundary condition (lake water surface elevation) set, the model was run with differing flow rates to estimate what discharge in the channel results in the water surface elevation from the Columbia River stage-duration curve (Table 4-2). This discharge estimate was run in a geometry with no culverts limiting the flow through the channel.

Table 4-2. Upstream and Downstream Boundary Conditions

Percent Exceedance (November – July)	Columbia River at Dairy Creek (ft NAVD88)	Sturgeon Lake (ft NAVD88)	Estimated Dairy Creek Discharge (cfs)
5%	18.12	17.12	1,300
95%	8.14	8.12	0

The 95-percent exceedance flow represents low stages in the river and Lake and is lower than the invert of the proposed low flow channel; therefore those boundary conditions are associated with no active flow in the channel.

This model is simplistic and used only for estimating appropriate culvert sizes. Additional channel and culvert modeling (with survey to supplement the LiDAR) should be performed during the Design and Implementation phase to finalize the culvert size and the size and placement of other channel features.

5.0 Modeling Results

The HEC-RAS models have been used to develop stage estimates in the lake for the sediment flux analysis and to support the HEP in estimating habitat differences between the existing condition and proposed alternatives. The models have also informed the discussions on fish passage and culvert sizing. The following sections provide additional information on the modeling results and their uses.

5.1 Stage-Duration Curves by Season

Utilizing the output of the system-wide hydrographs from HEC-RAS, a series of seasonal stage-duration curves were developed to study the changes in lake water surface elevation due to the alternatives investigated. The data from HEC-RAS was processed in Excel to create a dataset of average water surface elevation for each day of record. The data was arranged from high to low stages and ranked to create the percentile rankings. The stage-duration curves illustrated that the improved conveyance between the Columbia River and Sturgeon Lake would not affect Lake water surface elevations to a measurable degree. The curves, Figure 13 and Figure 14, are labeled with the proposed measures (HDR, 2013).

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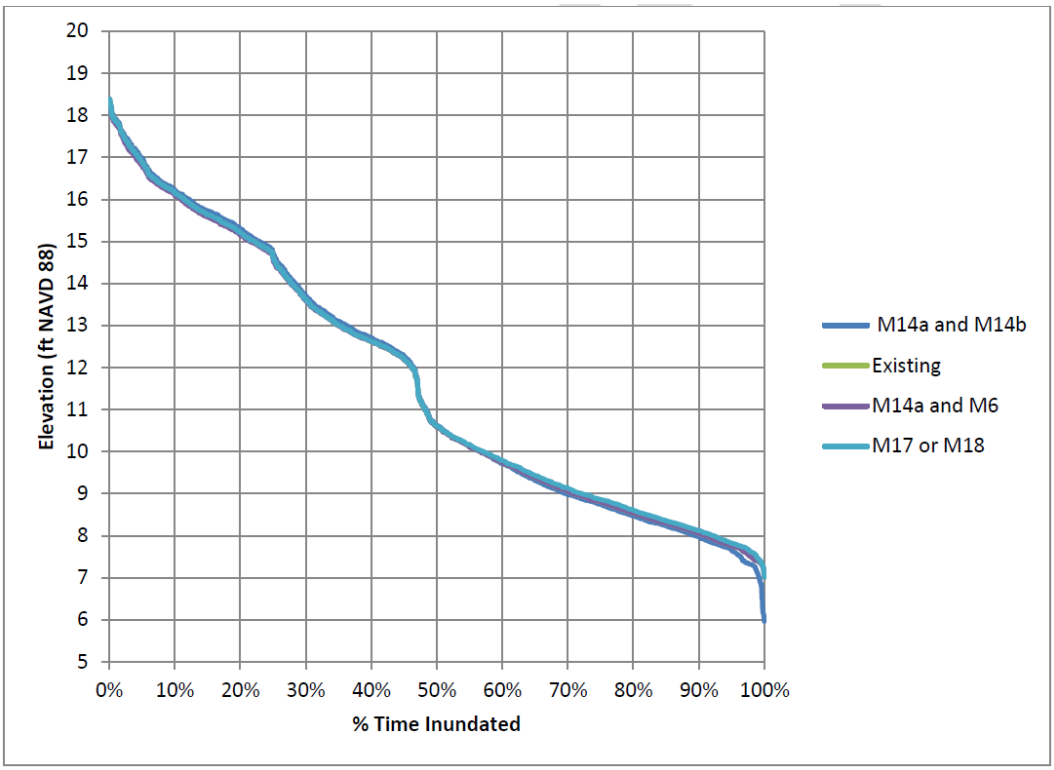

Figure 13. December 2011 to February 2012 Stage-Duration Curves for Existing Conditions and Measures

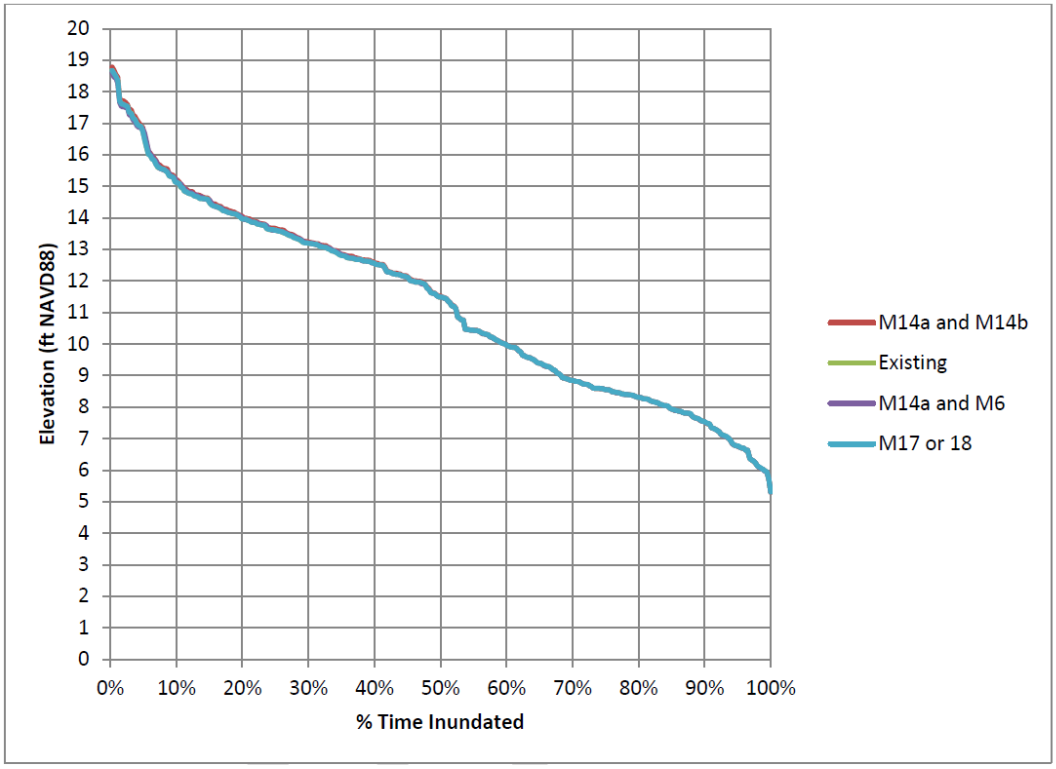

Figure 14. 2012 Stage-Duration Curves for Existing Conditions and Each Measure

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5.2 Dairy Creek Model Results

Using the modeling discussed previously, the estimated discharge in Dairy Creek was run in the existing and proposed channel conditions.

The existing condition, as shown in Figure 15, includes the debris jam at the mouth of the channel which creates a high bed profile at the Columbia River. It also includes the culverts which create a constriction, increasing the water surface elevation on the Columbia River side of the channel.

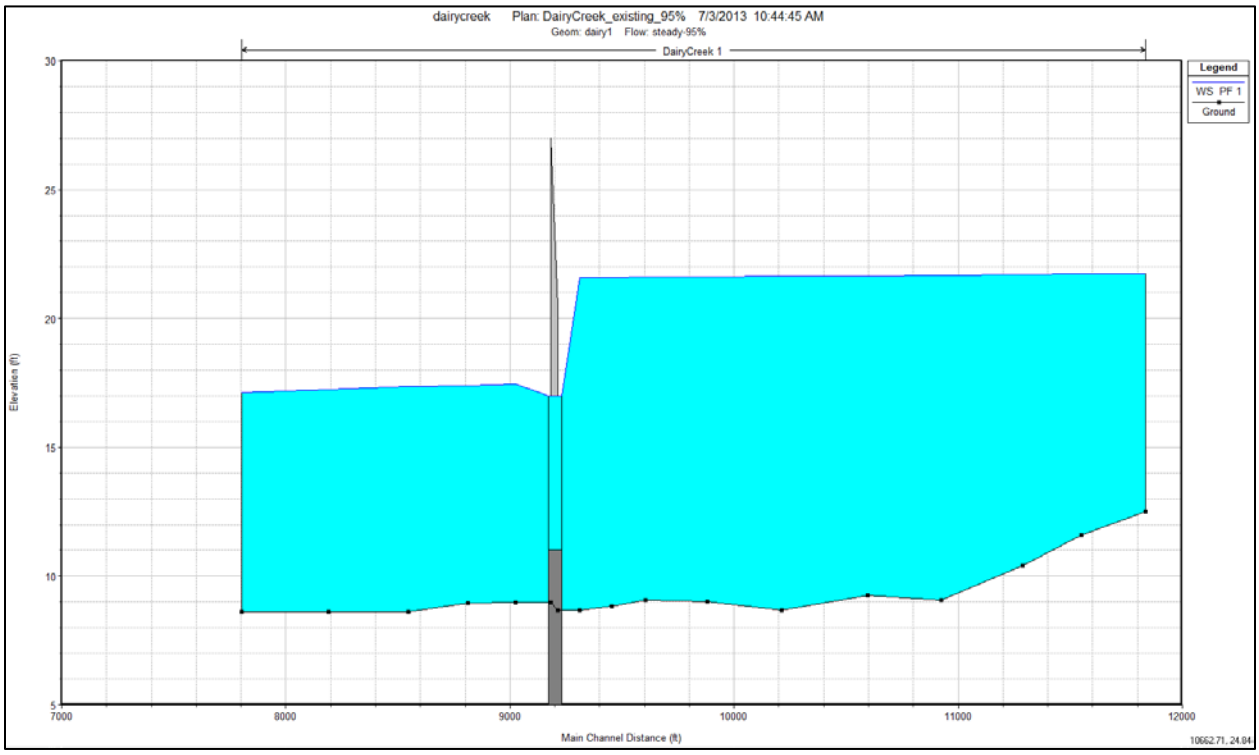

Figure 15. Existing Conditions

In the proposed condition, the issues identified in the existing condition have been remediated. The two, 42-foot by 15-foot arch culverts would alleviate the constriction at the Reeder Road crossing and channel regrading would create a low flow channel with an invert of 8 ft NAVD88. Culverts would manage the velocities in the channel to allow fish passage at the 5-percent exceedance flow. This is further discussed in the Appendix G (HDR, 2013). In Figure 16, the water surface profile under the proposed conditions would be reduced on the Columbia River side of the channel, creating a more fish friendly environment and passage to the lake.

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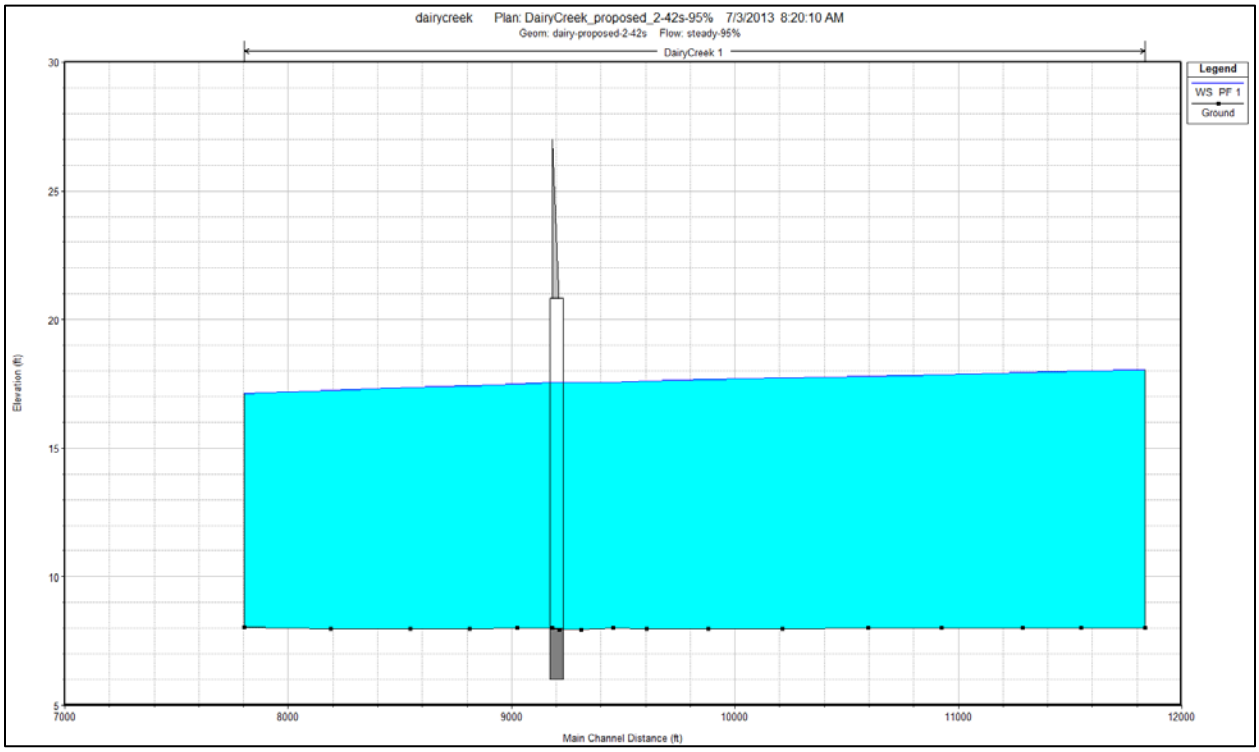

Figure 16. Proposed Conditions

5.3 Conclusion

The HEC-RAS model was used to evaluate alternatives in the planning process by estimating the effect of each alternative on the hydraulic components of the HEP. The modifications proposed for the Dairy Creek channel would not change the hydrology of the lake to a level observable on the stage-duration curves. However, the improved connection would create a disturbance within the southern lobe of the lake, and thus improve lake aquatic habitat in this area. The Dairy Creek HEC-RAS model was used to evaluate the performance of larger culverts and to investigate low-flow channel velocities. Both models would benefit from additional survey data, although acquiring it for the channel is a higher priority and survey would be incorporated into the Design and Implementation phase of the Project. Additional next steps would include incorporating the survey data into a two-dimensional model of the channel for additional sizing and velocity studies.

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TECHNICAL MEMORANDUM

To: Amy Dammarell, HDR Engineering, Inc.

From: John Dvorsky, Waterways Consulting, Inc.

Date: June 11, 2013

Re: Sediment Flux Analysis for Sturgeon Lake

Introduction

In 2010 the U.S. Army Corps of Engineers (USACE) initiated an effort to evaluate the feasibility of potential restoration actions at Sturgeon Lake (Lake) to improve ecosystem function and accessibility to the Lake by Columbia River salmon populations. Understanding the hydrologic and sediment dynamics of the Lake is one element of evaluating the feasibility of restoring the Lake as prime rearing habitat for juvenile salmonids. Such a study would answer the following questions and allow for the development of project objectives that can be monitored and evaluated for their effectiveness:

- What is the flux of water into and out of Sturgeon Lake?
- What is the current rate of aggradation in the Lake?

To answer these questions a one dimensional hydraulic model was developed to evaluate flux into and storage within Sturgeon Lake through the existing Gilbert River and Dairy Creek channels (HDR, 2012) (Figure 1). The output from the hydraulic model was used, along with existing data for the region, to develop a sediment budget for the Lake. This technical memorandum describes the work associated with the sediment budget analysis and the implications of the results on the objectives for the restoration of Sturgeon Lake.

Project Background

Hydrodynamics

Three primary hydrologic regimes affect sediment flux in and out of Sturgeon Lake. They include the diurnal tidal cycle, flow from the Willamette River, and flow from the Columbia River. Although these hydrologic regimes interact in very complicated ways, water and sediment flux into and out of the Lake is generally controlled by the following processes:

- Late Spring/Early Summer: Annual snowmelt driven high flows on the Columbia River results in high water surface elevations for an extended period with a muted tidal signal,
- Late Fall/Winter: Episodic, short duration, rainfall or rain-on-snow driven high flow events occur on the Willamette River,
- Early Spring: Snowmelt driven high flows on the Willamette River results in high water surfaces elevations for an extended period, and
- Summer/Fall: Diurnal tidal cycle results in frequent filling and flushing of the Lake.

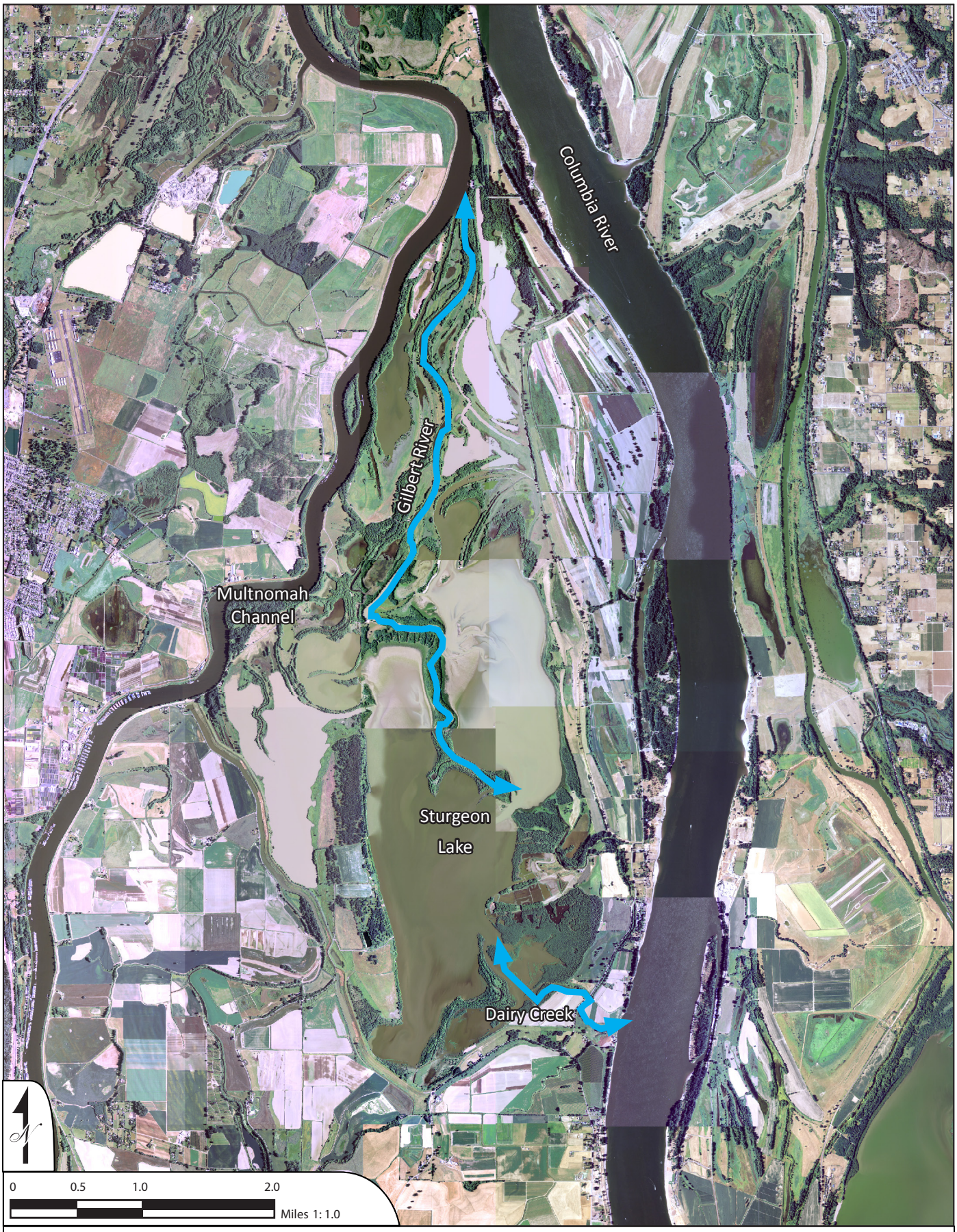

FIGURE 1

Sturgeon Lake with flowlines of Gilbert River and Dairy Creek shown. The Multnomah Channel separates from the Willamette River at the South end of the island.

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Historically, water and sediment would enter the Lake through a network of sloughs and channels that connected the Lake to the Willamette and Columbia Rivers (Dvorsky, 2011). Sediment flux most likely mirrored suspended sediment concentrations of the contributing bodies of water with the highest concentrations delivered from the Willamette River and the lowest delivered from the Columbia River. Consequently, large fluxes of sediment into and out of the Lake were most likely in response to large flood events on the Willamette River. Conversely, the total flux of water into and out of the Lake is dominated by the tidal exchange, which occurs twice a day, every day.

In 1941 a system of levees called the 'Big Dike' was completed on Sauvie Island, limiting connectivity of the Lake from the Willamette and Columbia Rivers through one or two outlets, depending on the stage (i.e. – Gilbert River and Dairy Creek). This changed the hydrodynamics of the Lake from a flow-through system to a backwater system and altered tidal dynamics, circulation patterns within the Lake, and deposition and resuspension patterns. In addition to changes resulting from construction of the Big Dike, current conditions have been impacted by other factors such as:

- Flow regulation on the Columbia River
- Compartmentalizing of lakes and other water bodies
- Possible dredge spoil disposal
- Changes in land use and local sediment supply on Sauvie Island

The Columbia River has been substantially altered over time with 17% less water now flowing at The Dalles as compared to historic conditions when the Columbia River was unregulated. The timing and peak discharge of flood events have also changed, with a 50% decrease in peak discharge of snowmelt driven floods since 1969, and a 35% increase in discharge during summer baseflow conditions. Compartmentalizing of lakes and conversion of land to farming has also led to a 45% reduction in the extent of water bodies and wetlands on Sauvie Island since 1944.

Sediment Dynamics

Anecdotal evidence and work completed in the 1980's by researchers at Oregon State University (Klingeman, 1982a; Klingeman, 1982b) suggested that land use changes, modifications to regional hydrodynamics, and levee construction had altered the Lake in such a way that the Lake had shifted towards a slow, but steady, process of lakebed aggradation. It was estimated that the rate of aggradation was on the order of 1 inch per year and would ultimately result in a slow but continuous conversion of the Lake from a shallow, open waterbody, to a wetland prairie system interspersed with riparian forest.

In response to these concerns of Lake aggradation, USACE, in conjunction with its partners at the West Multnomah Soil and Water Conservation District (formerly SCS), designed and constructed the Dairy Creek Project in 1989. The Dairy Creek Project created a new connection from the Columbia River to the Lake by widening the channel at the Columbia River and excavating a new, more direct channel and adding new culverts at Reeder Road. The goal of the Dairy Creek Project was to provide a more efficient pathway for Columbia River water to enter the Lake, thereby improving Lake circulation and reversing the observed trend of long-term aggradation. Because the suspended sediment concentration of Columbia River water is typically lower compared to water entering the Lake from the Gilbert River via the Multnomah Channel, it was postulated that a net increase in sediment transport out of the Lake would result.

Following construction of the Dairy Creek Project, preliminary evaluations suggested that modifications to the channel to increase conveyance of water to the Lake from the Columbia River were indeed improving overall circulation within the Lake (Klingeman, 1992; Cronin, 1992). Although much of the observed benefits of the Dairy Creek Project were anecdotal or qualitative, discharge estimates in Dairy Creek and water surface elevation monitoring in the Lake verified the increase in flow conveyance from the Columbia River to the Lake (Cronin, 1992).

Unfortunately the level of benefit provided by the Dairy Creek Project diminished over time due to deposition of sand where Dairy Creek meets the Columbia River. A study conducted in 1993 by Oregon State University identified a layer of sand at the mouth of Dairy Creek that was approximately 2 feet deep and extended 1,800 feet up Dairy Creek towards Reeder Road (Hendron, 1994). The total volume of sand estimated to have deposited at the mouth of Dairy Creek was 8,500 cubic yards. By 2010 approximately 17,240 cubic yards of sediment was estimated to have accumulated at the mouth of Dairy Creek along with hundreds of pieces of large wood, effectively blocking access to Sturgeon Lake.

Sediment Budget

Framework

The objective of the sediment budget analysis is to create quantitative estimates of sediment flux into and out of Sturgeon Lake, provide an estimate of the natural variability of sediment accumulation on the lakebed, evaluate the assumptions of past assessments (which were more qualitative in nature) and provide a model framework to evaluate potential restoration scenarios.

A simple, yet useful approach to sediment flux modeling in a lake is to conceptualize the lake as a bucket (Figure 2). Sediment laden water[1] can be added or removed from the bucket with the net difference being expressed as either the lakebed filling with sediment (aggradation) or the lakebed lowering (degradation). The net flux of sediment in the lake can be determined for a given time period as the difference between the total input of sediment minus the total output of sediment. In the Sturgeon Lake system, sediment enters and exits through the Gilbert River and Dairy Creek.

This approach simplifies our physical understand of movement and deposition of sediment into and out of a lake because it ignores processes such as resuspension, flocculation, and the uneven distribution of deposited sediments. With that said this approach provides a first order estimate of sedimentation rates within the Lake and establishes a framework to build upon if more resolution is required through more detailed modeling techniques.

With this framework in mind, annual sediment budget estimates were prepared for Sturgeon Lake for 1991, 1992, and 1996, by utilizing the HEC-RAS model output generated by HDR (HDR, 2012). In

[1] The sediment flux modeling approach assumed that the primary source of sediment into and out of the Lake is suspended rather than bedload. Although in some cases, the bedload portion could total up to 10% of the total load, bedload into and out of Sturgeon Lake is most likely much less than that. Since this exercise is meant to be a first order approximation of sediment flux, the load associated with bedload has not been accounted for.

addition sediment flux estimates were developed, with limited success, for 2001-2010 by correlating the HEC-RAS model output to the longer term gage record for the Willamette River.

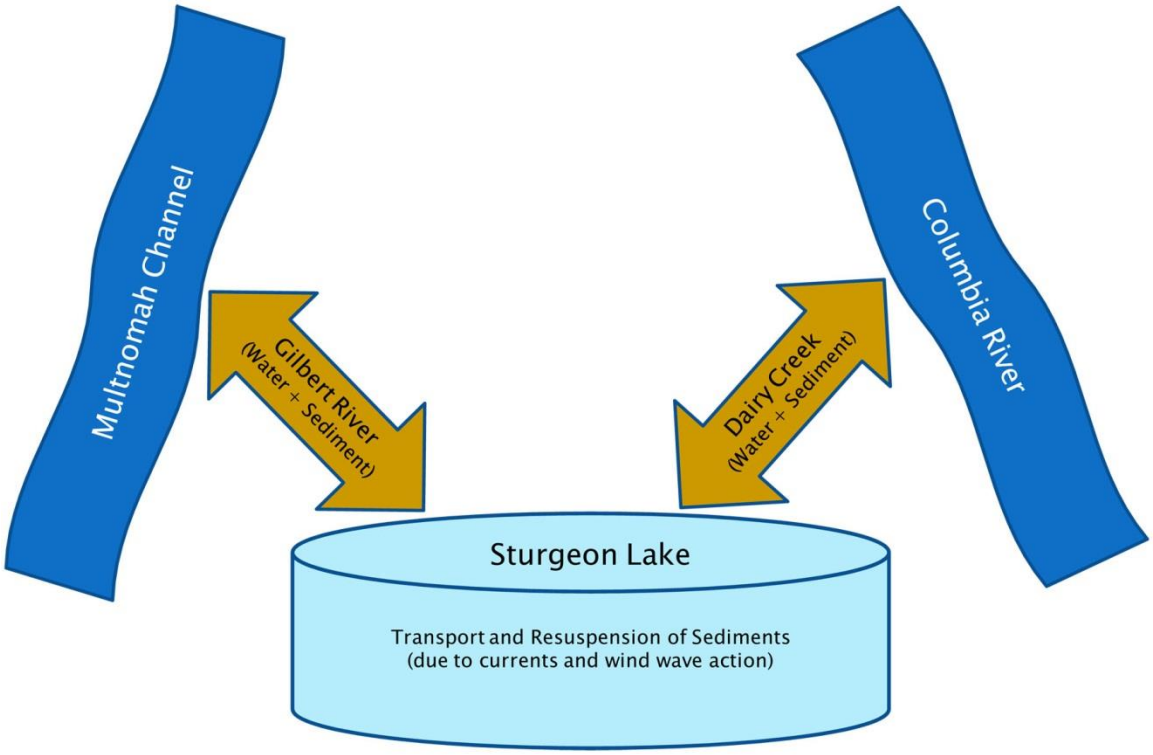


Figure 2: Conceptual sediment budget model for Sturgeon Lake.

Suspended Sediment Data

Developing a long-term sediment budget for Sturgeon Lake is complicated by the lack of hydrologic data for the channels entering and exiting the Lake, limited stage data within the Lake to calibrate a hydrologic model, and limited suspended sediment measurements within the Lake to develop relationships between discharge and sediment movement. To understand what existing data are available and how that ultimately affects the quality and precision of the sediment flux model, a significant amount of effort was invested in collecting, compiling, and exploring the existing data. A summary of the existing data sources are presented in Table 1, along with an overview of their value to the modeling effort.

To effectively estimate sediment flux into and out of Sturgeon Lake over the course of a year, or multiple years, Suspended Sediment Concentration (SSC) data that represents the range of hydrologic conditions and variations in Lake stage are needed. Because the sediment budget model focuses on calculating sediment movement through the Gilbert River, SSC measurements within the Gilbert River under a broad range of hydrologic conditions would provide the most robust dataset.

Table 1: Summary of existing Suspended Sediment Concentration (SSC) data for Sturgeon Lake and the surrounding region for use in the sediment budget modeling.

Waterbody	Site	Period of Record	# of Samples	Notes
Willamette River	USGS Station #14211720, Morrison Bridge	1974 - 2011	409	Comprehensive SSC dataset for a waterbody contributing to Sturgeon Lake. Encompasses the range of flow conditions
Gilbert River	Mouth	1980, 1981, 1986, 1987, 1990-1993	21	Two sample sets taken by Portland State University and Oregon DEQ. Sampling location and time not correlated to a particular water surface, flow, or depth.
	Wash	1981 - 1982	5	Data taken by Portland State University. Sampling location and time correlated with inflow and outflow conditions but not Sturgeon Lake stage.
Multnomah Channel	Gilbert River	1980, 1981, 1986, 1987, 1990-1993	19	Two sample sets taken by Portland State University and Oregon DEQ. Sampling location and time not correlated to a particular water surface, flow, or depth.
Sturgeon Lake	South Embayment	1980, 1981, 1986, 1987, 1990-1993	24	Two sample sets taken by Portland State University and Oregon DEQ. Sampling location and time not correlated to a particular water surface, flow, or depth.
	North Embayment	1980, 1981, 1986, 1987, 1990-1993	23	Two sample sets taken by Portland State University and Oregon DEQ. Sampling location and time not correlated to a particular water surface, flow, or depth.
Columbia River	USGS Station #14144700, at Vancouver	1965 - 1969	2990	Comprehensive SSC dataset for the Columbia River. Limited by its location in Vancouver and age of record. The existing conditions sediment flux model rarely utilizes the SSC curve for the Columbia because of limited flows through Dairy Creek during the modeled years.

As Table 1 suggests, 21 SSC measurements in the Gilbert River spread out over eight years with little to no supporting information to define hydrologic conditions at the time the samples were taken limits the applicability of this information. Based on the information that was provided when SSC samples were collected on the Gilbert River, it appears that most were collected under baseflow conditions on the Willamette and Columbia Rivers when tidal processes dominated. Although it is important to understand sediment dynamics under conditions where tidal processes dominate, it is equally important to understand the dynamics under winter and spring flood conditions when suspended sediment concentration are high on the Willamette or Columbia Rivers.

Given the limited SSC data available to evaluate sediment movement into Sturgeon Lake, suspended sediment data from adjacent waterbodies (i.e. - Willamette and Columbia Rivers) were used in place of site specific information for the Gilbert River and Dairy Creek.

Sediment Rating Curves

The most effective approach to understanding sediment flux in a flowing waterbody is to develop a statistical relationship between measured suspended sediment concentration and discharge. To do this requires discharge to be measured at the same time that the suspended sediment sample is being collected. The result is a sediment rating curve that can be used to interpolate SSC for a longer time period if discharge is measured continuously. The predicted SSC values can then be multiplied by the volume of water to estimate the sediment flux, which is the total sediment load passing a particular point of interest.

The rating curve for sediment input to Sturgeon Lake was developed from SSC measurements and discharge data for the Willamette River at Portland (USGS Gage #14211720). The sediment rating curve used for the analysis is presented in Figure 3. A number of best-fit lines were explored to represent the data. An attempt was also made to separate the data into tidal or runoff derived events though ultimately it was decided to create a single rating curve to represent the data. Although a correlation coefficient of 0.6 can be considered low, the relationship is fairly strong, especially at flows less than 50,000 cubic feet per second (cfs). The SSC values at discharges greater than 150,000 cfs are an order of magnitude higher than at 50,000 cfs.

The dominant hydrologic conditions present on the Willamette River in Portland are the tidal process during the summer and early fall months, a combination of rain and rain-on-snow events in the winter and early spring, and a long period snowmelt driven event some time in spring. A hydrograph for the Willamette Daily data from 1974 to 2011 shows the range of flow conditions that occur, both seasonally and from year to year over the past few decades (Figure 4).

With a sediment rating curve developed to define sediment inputs into Sturgeon Lake through the Gilbert River, the next step was to estimate the concentration of sediment in the water that was leaving Sturgeon Lake. This presented a much greater challenge because of the limited amount of data available. The datasets presented in Table 1 were explored in detail in conjunction with the hydrologic data provided by HDR for 1991, 1992, and 2006. Those years were modeled by HDR to potentially improve our understanding of the hydrologic conditions that were present at the time the samples were collected (e.g. – Lake stage, tidal condition, Willamette discharges, etc).

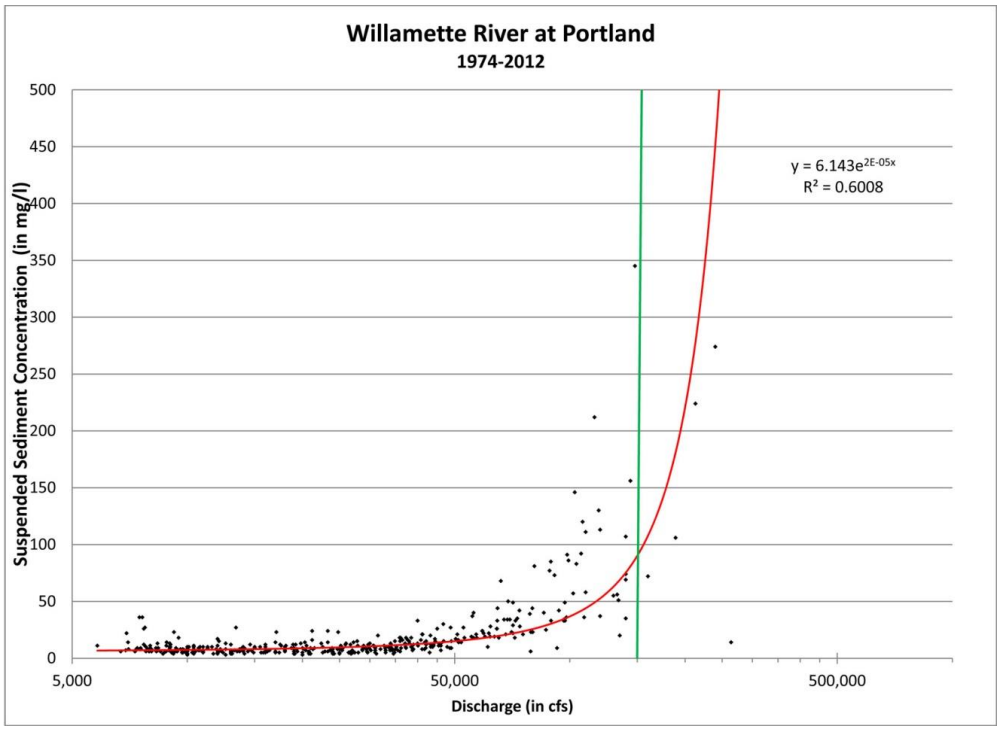


Figure 3: SSC versus discharge as measured at the Morrison Street Bridge from 1974 to present. The equation represents the function with the best correlation of the measured data. The green line is included as a reference to Figure 4 to identify 150,000 cfs.

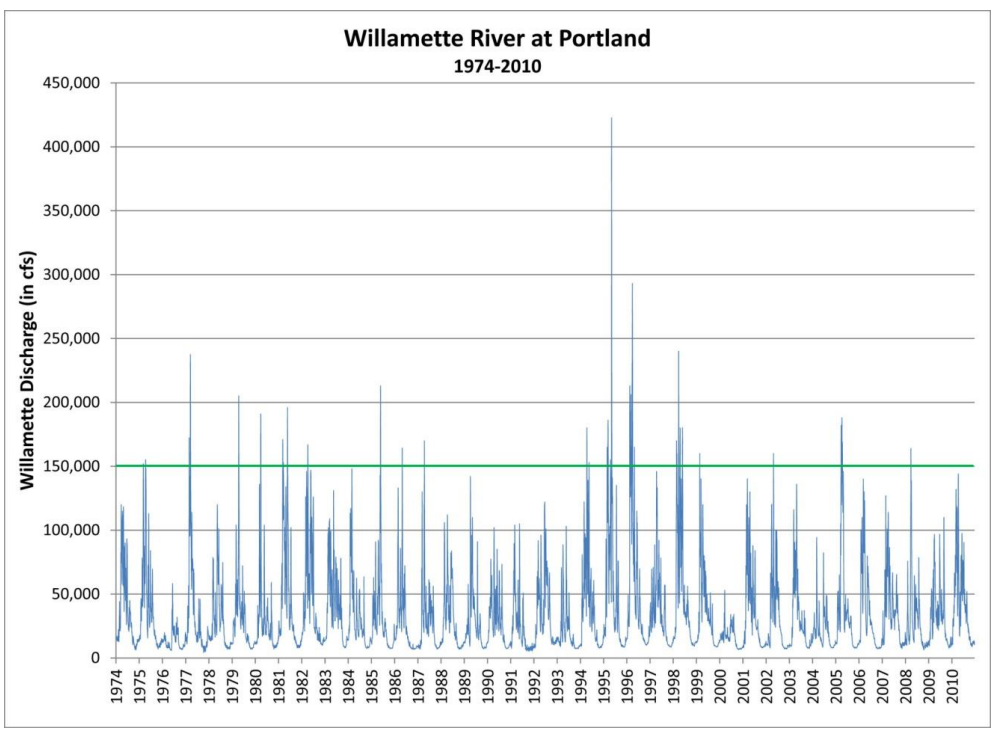


Figure 4: Discharge on the Willamette River as measured at the Morrison Street Bridge from 1974 to present. Note that the tidal process does not influence discharge, just stage, which is not presented in this graphic. The green line is included as a reference to Figure 3 to identify 150,000 cfs.

Utilizing the hydrologic information provided by HDR, along with limited information collected at the time each sample was taken, each dataset from each sampling location presented in Table 1 was run through a rigorous process to identify a statistical relationship that could be used to interpolate what was collected to a larger period of record in support of estimating sediment flux out of Sturgeon Lake through the Gilbert River. For example, the available SSC data from the Gilbert River and Sturgeon Lake were analyzed for relationships to stage/discharge in the Lake, Willamette River conditions, and wind speed, among other factors, but no strong patterns emerged. Unfortunately all of the attempts to correlate any of the known physical parameters to the existing measurements produced results with low correlation coefficients.

Ultimately the effort was simplified by focusing on the data from the Gilbert River mouth, where it meets the Multnomah Channel. Existing SSC data for the Gilbert River mouth, collected between 1980 and 1993, was classified into samples collected when water was flowing into Sturgeon Lake and when water was flowing out of Sturgeon Lake. The average of SSC values during outflow conditions was applied to the modeled Gilbert River flows to calculate output of sediment. The average SSC during times of outflow was 11.9 mg/L (Standard deviation = 6.4 mg/L).

Sediment Flux Results

As mentioned previously, a sediment flux can be determined for a given time period by multiplying the predicted suspended sediment concentration for a given discharge (in this case mg/L) by the volume of water for a given time period. This was achieved by using the sediment rating curves in combination with the modeled discharges provided by the HDR model to arrive at the net flux of sediment for the modeled period. In this case, HDR modeled flow into and out of Sturgeon Lake via the Gilbert River and Dairy Creek. Flow dynamics were modeled for 1991, 1992, and 2006 with a time step of 1 hour. The HDR model also provided modeled flow conditions for each time step for the Willamette River.

To calculate sediment input to the Lake, the sediment rating curve for the Willamette River was used. For each time step, the Willamette River discharge was referenced to determine a suspended sediment concentration, in mg/L. The concentration was then multiplied by the calculated volume of water entering the Lake through the Gilbert River for each one hour time step to produce an estimate of the total load of sediment in milligrams. A similar method was used to estimate sediment flux out of the Lake through the Gilbert River. Because an average value of SSC samples collected at the mouth of the Gilbert River were used, this value was simply multiplied by the volume of water for the one hour time step to estimate the total sediment load. Table 2 and Figure 5 summarize the results of this analysis.

To understand the potential impact that the sediment loads described in the analysis above have on changes in lakebed surface elevation, an estimate was made of the rate of deposition for the modeled years. This required making several assumptions. First, to convert the mass of sediment developed from the flux analysis to a volume, it was assumed that the material being deposited in the Lake was primarily silty-clay and a conversion factor of 1.2 g/cm^3 was used. The resulting volume was then converted to an average rate of deposition by assuming that the net flux of sediment accumulating in the Lake was distributed evenly across the entire bed of the Lake. A surface area of 2400 acres was used which represents Sturgeon Lake at Mean High High Water (MHHW) from the HDR HEC-RAS model. The results are presented in Table 2 and Figure 6. For the HDR model years, 2006 had the highest estimated rate of sediment deposition within the Lake at 2.9 millimeters (mm). The estimate for 1991 was 0.1 mm and 1992 actually produced a net outflow of sediment averaging 0.2 mm over the entire lake (degradation). The net deposition over the three modeled years was 2.8 mm or 0.1 inches.

Table 2: Summary of sediment budget analysis.

		Sediment Flux			Rate of Deposition (with inflow and outflow)		Rate of Deposition (assumming no outflow)	
		Input	Output	Net				
		tons/yr	tons/yr	tons/yr	mm/yr	in/yr	mm/yr	in/yr
Using HEC-RAS Model Output	CY1991	21,675	20,400	1,275	0.11	0.004	1.9	0.075
	CY1992	18,783	21,292	(2,509)	-0.22	-0.009	1.6	0.063
	CY2006	47,612	14,450	33,162	2.85	0.112	4.1	0.162
Using Synthetic Data based on Correlations to HEC-RAS Model Results for 1991, 1992, and 2006	WY2002	7,212	6,184	1,028	0.09	0.004		
	WY2003	7,693	7,304	389	0.03	0.001		
	WY2004	8,038	7,385	654	0.06	0.002		
	WY2005	6,605	7,639	(1,035)	-0.09	-0.004		
	WY2006	7,993	6,156	1,838	0.16	0.006		
	WY2007	7,303	6,366	937	0.08	0.003		
	WY2008	7,863	6,643	1,220	0.1	0.004		
	WY2009	7,510	7,428	82	0.01	0.000		
	WY2010	8,455	7,545	910	0.08	0.003		

Unfortunately, three years of data is a limited sampling period when attempting to understand long-term sedimentation rates in Sturgeon Lake. This is exacerbated by the fact that 2006 was only one of the three years where peak discharges on the Willamette exceeded 150,000 cfs (Figure 2). Both 1991 and 1992 were low to moderate runoff years. The sediment rating curve for the Willamette suggests that discharges in excess of 100,000 cfs to 150,000 cfs are required before high concentrations of suspended sediment occur. Ideally the model would include higher discharge years, such as 1996 to get a sense of the potential upper limit for sediment delivery to Sturgeon Lake.

Due to the fact that limited resources and data were available for HDR to extend their hydraulic model to additional years, an attempt was made to utilize the existing data to expand our understanding of sediment flux into and out of Sturgeon Lake. The approach that was taken involved several steps. Since the Willamette River (at Portland) has a record of mean daily discharge that extends from 1974 to 2011, we contacted USGS to determine if a higher resolution dataset would be available for that time period. USGS was able to provide us with a stage record from 1998 to 2010 with a half hour time step and a discharge record for a similar period. Unfortunately the discharge record was discontinuous for the entire period with large, frequent gaps in the data.

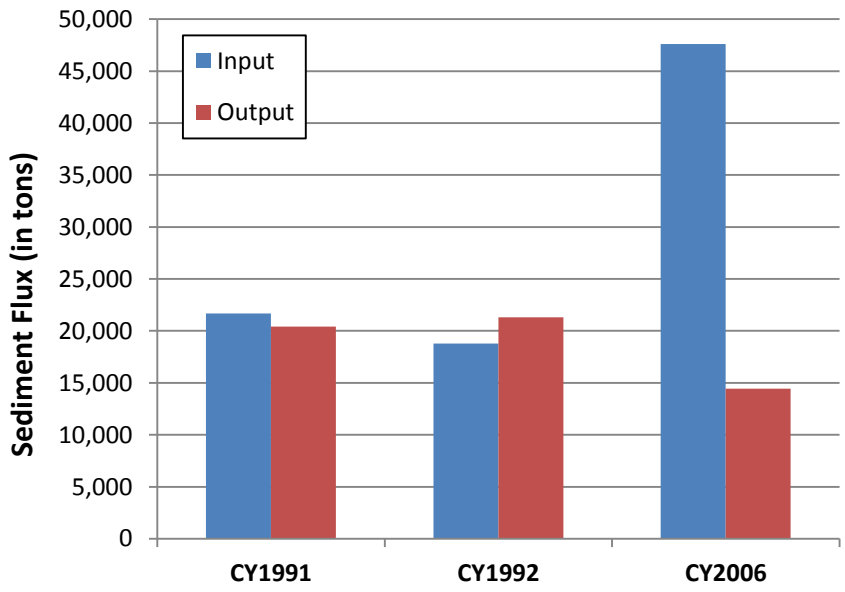


Figure 5: Estimated sediment flux into and out of Sturgeon Lake for the years included in the HDR hydraulic model (CY. See Figure 6 for estimates rates of deposition in Sturgeon Lake.

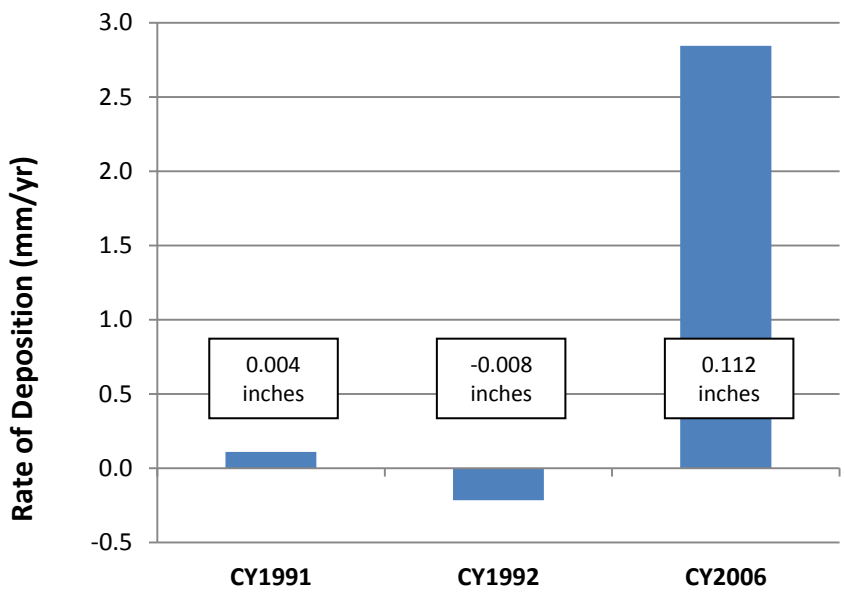


Figure 6: Estimated rate of sediment deposition in Sturgeon Lake for the years included in the HDR hydraulic model (CY). The rate of deposition, in inches, is shown for reference.

The stage data acquired from USGS was used to correlate changes in Willamette River stage to discharge into and out of the Gilbert River, as modeled by HDR for 1991, 1992, and 2006. The correlation used the HDR HEC-RAS output to determine the flow occurring in the Gilbert River to the corresponding change in Willamette stage. A lag time of 2 hours between a trough, or peak, at the Willamette River in Portland and a trough, or peak, in the Gilbert River produced the best correlation (R-squared of 0.68). Similar to the flux analysis, discussed previously using the HDR model years, calculating the sediment flux from 2001 to 2010 required an estimate of discharges on the Willamette at Portland to utilize the Willamette sediment rating curve. Since the 1 hour discharge dataset for the Willamette at Portland was incomplete, a synthetic record was generated by developing a correlation between the Willamette River at Portland and the Willamette River at Newburg. The Willamette at Portland to Willamette at Newburg relation was fit with a linear model having a high R-squared of 0.92. The results of this analysis are presented in Tables 2 and 3 (WY Years). What is clear from the results is that the estimates of sediment flux are dampened by the need to create synthetic records and correlate stage on the Willamette to flow on the Gilbert River. This can clearly be seen by comparing the results from 2006, using this method, to the results for 2006 using the HDR model data.

Discussion

The analysis presented in this technical memorandum represents a simplified approach to provide a first order estimate of potential rates of sediment aggradation in Sturgeon Lake. Despite the limitations of this simplified approach, the results suggest that the rate of aggradation is ultimately limited by the supply of sediment to Sturgeon Lake from the source river systems. Even if it was assumed that suspended sediment delivered to the Lake was deposited without the potential for that material to exit the Lake when flows are reversed, long-term sedimentation of the Lake would be a very slow process, requiring 50 years to aggrade the lakebed 6 inches.

These results conflict with anecdotal observations over the past several decades that suggest Sturgeon Lake is filling relatively rapidly. Anecdotal evidence includes recreational opportunities that were enjoyed in the past that are no longer possible due to shallow water depths. They also include observations of an increase in mud flats and encroachment of woody plant species along the margin of the Lake due to shallower water depths.

Why is there a disconnect between the modeling results and decades of anecdotal evidence on the Lake? One possibility for this discrepancy is that there are other sources of sediment entering the Lake and that modeling the input as primarily suspended sediment derived from the Willamette River misses an important component of the sediment budget. Bed load transport from both the Gilbert River and Dairy Creeks during high flow conditions could be delivering large volumes of sand into Sturgeon Lake. This may be the case in localized areas such as the Wash, in other crevasses along the Gilbert River, and at the mouth of Dairy Creek. It is not likely to be the case throughout the entire lakebed, however, due to low velocity conditions throughout most of Lake making mass transport of sand unlikely.

Another possibility is the delivered sediment is depositing unevenly throughout the lakebed causing rapid aggradation in some areas and no changes in others. This process, referred to as shoaling, would encourage additional sediment accumulation as depths become shallow enough to support woody vegetation. As woody vegetation grows and matures it encourages localized deposition of finer grained suspended sediment by increasing local roughness and encouraging flocculation. This process would set up a positive feedback in some areas thereby accelerating lakebed aggradation.

Another possibility that was explored further as part of this study is the effect that changes in the hydrology of the Columbia River affects water surface elevations in Sturgeon Lake. It has been well-documented that construction of dams throughout the Columbia River Basin has affected the timing and magnitude of flows along the mainstem Columbia River. The primary impact of dam construction has been significant decreases in the peak flow discharge of the annual spring/summer flood (or freshet) that is generated from snowmelt in the upper Columbia Basin. The effect of these changes on water surface elevations within Sturgeon Lake would be to significantly reduce average water depths in the Lake.

To understand the magnitude of the changes that have occurred on the lower Columbia River, we compiled a record of stage data for the lower Columbia River dating back to 1878. Because the gage on the Columbia River does not have published records dating back to 1878, we created a synthetic record by correlating stage data at Vancouver with stage data at The Dalles, which has a much longer period of record. The results are presented in Figure 7 and suggest that even since the 1950's and 1960's, water surface elevations in Sturgeon Lake in June may have declined up to 7 feet due to changes in hydrologic conditions on the Columbia River. Even in July the decline in water surface elevations may be on the order of 3 to 5 feet.

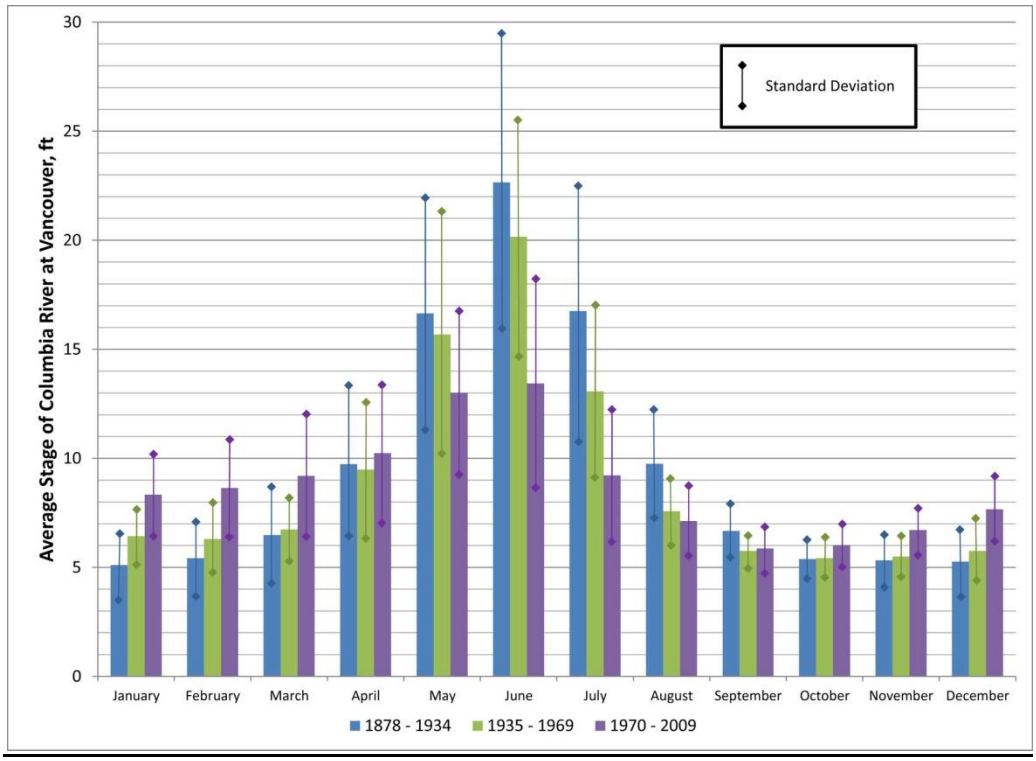
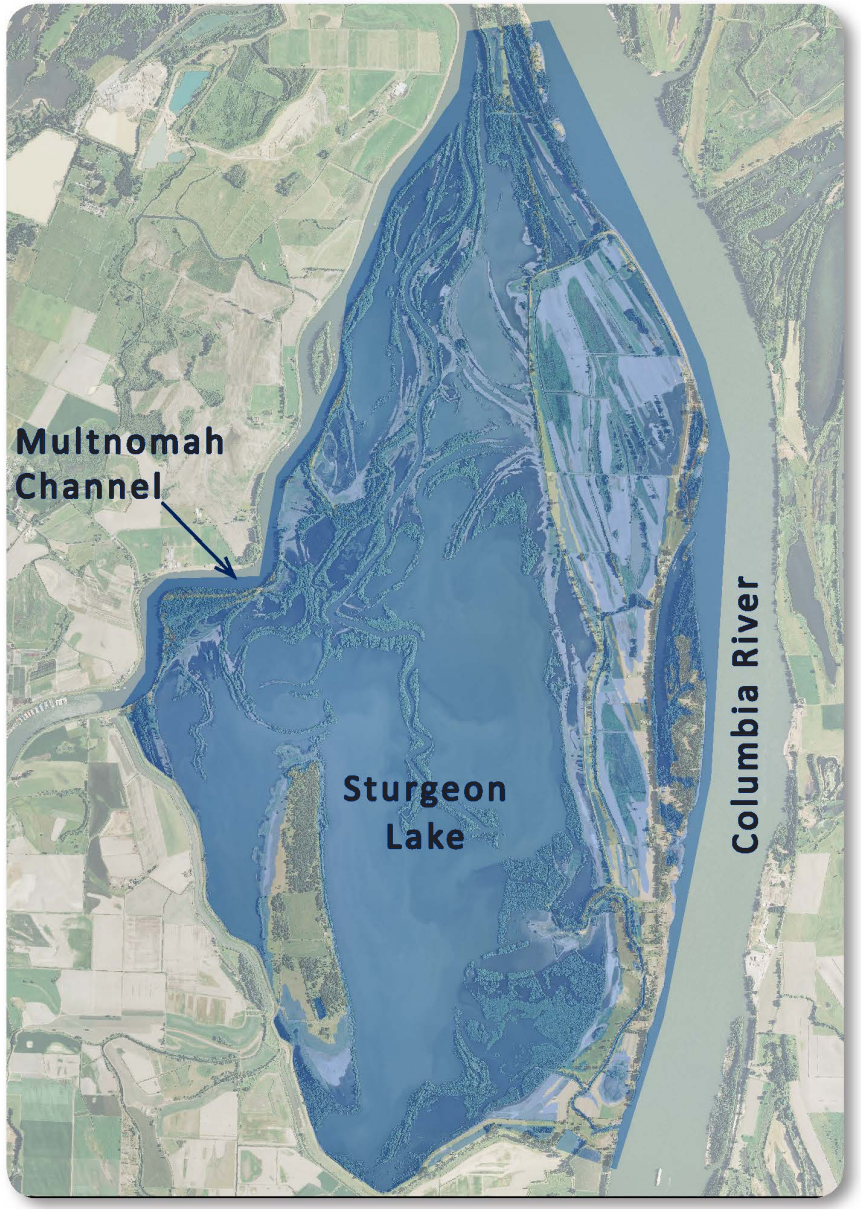


Figure 7: Changes in river stage on the lower Columbia River from 1978 to 2009. The data was generated from data for the Columbia River at Vancouver and The Dalles.

Although the analysis of how changes in water surface elevations on the Columbia River affect Sturgeon Lake will require further refinement and verification using independent datasets, the results suggest that the changes observed in Sturgeon Lake over the past half century or more may in fact be a result of lower average water surface elevations in the Lake rather than the lakebed aggrading. Dramatic declines in water surface elevations in the Lake, especially during the peak growing season, would ultimately encourage the lakeward expansion of woody vegetation and set in motion the positive feedback loop described above. Figure 8 provides a rough analysis of how changes in water surface elevations in June would ultimately affect the extent of inundation in the Lake. Although the changes in surface extent are not overly dramatic, the estimates of changes in average water depth throughout the Lake are.



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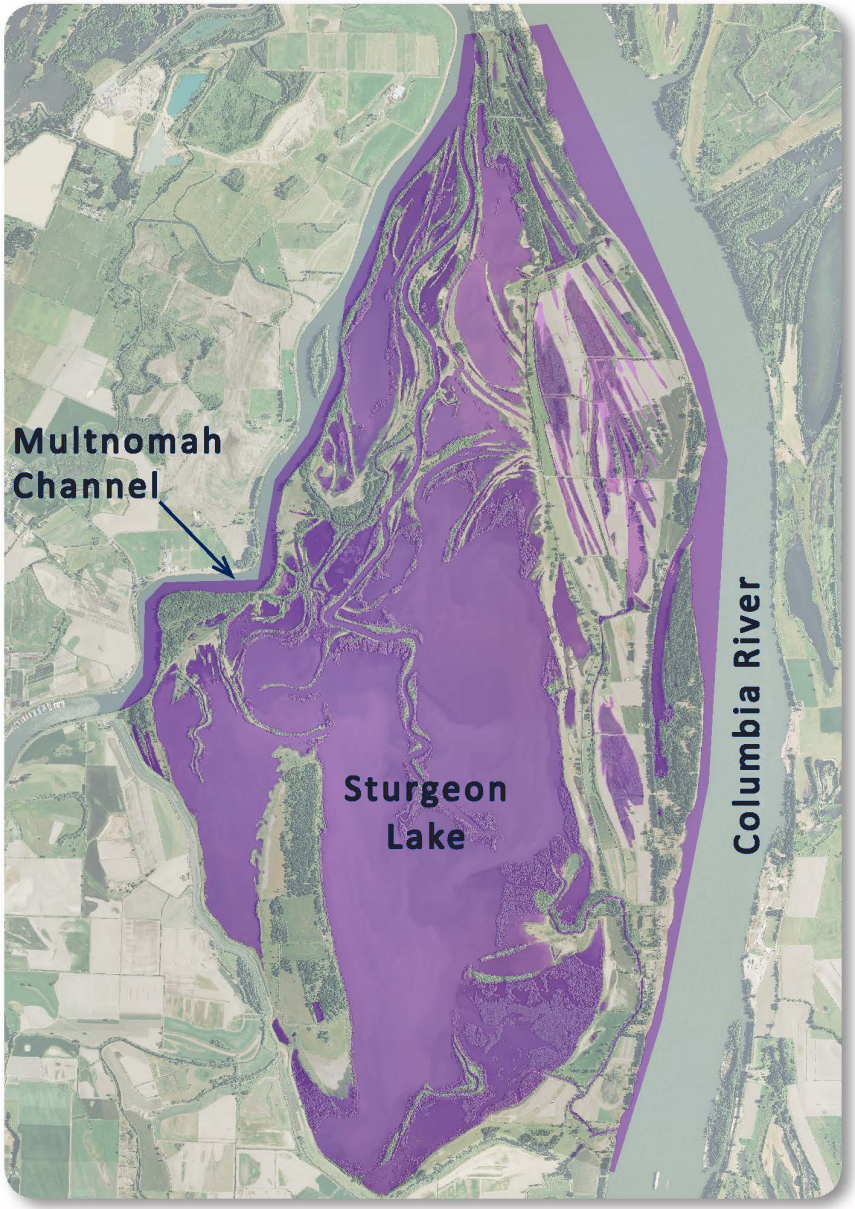

B

FIGURE 8

Comparison of Sturgeon Lake's historic average WSE in June. Note that the assumed average bottom elevation of the lake is 7 feet based on a 1991 survey (Klingeman).
Photo A: 1878- 1934 Average June WSE of 22 feet (Water depth of 15 feet)
Photo B: 1970- 2009 Average June WSE of 14 feet (Water depth of 7 feet)

DAIRY CREEK RESTORATION FEASIBILITY STUDY

SEDIMENT BUDGET MEMORANDUM
JUNE 2013

WATERWAYS CONSULTING, INC.
Santa Cruz, CA | watways.com | Portland, OR

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Appendix D. Concept Summary

To:	Jim Adams, USACE Alison Burcham, USACE		
From:	Amy Dammarell	Project:	USACE TO 29 Dairy Creek
Copy:	File		
Date:	September 2013	Job No:	147808
Re:	Dairy Creek Restoration Feasibility Study		

Introduction

Conceptual measures were formulated during the team workshop conducted on 12 January 2012. Workshop participants consisted of USACE, consultant team, and multiple stakeholders including Oregon Department of Fish and Wildlife (ODFW), Sauvie Island Drainage Improvement Company (SIDIC), West Multnomah Soil Water Conservation District (WMSWCD), and Multnomah County. Measures were identified that could potentially meet the goals and objectives of the project, without regard for project constraints or technical feasibility. Measures were later evaluated and screened based on project criteria. Since the workshop and completion of feasibility evaluation, modifications and changes were made to some measures to account for additional collected technical information, objective refinements, and public and agency input.

This memo provides a brief summary of the measures evaluated during the course of this feasibility studies. Figure 1 shows the approximate locations of each measure described below.

Measure Descriptions

The following measure descriptions describe the specific action, the conceptual basis for that action, and dependencies with other measures. In these measure descriptions, the North Gilbert River refers to the river in Sturgeon Lake and continuing north to the Multnomah Channel. The South Gilbert River refers to the river within the SIDIC to the south and currently disconnected from Sturgeon Lake.

New Channels

1. Connect North Gilbert River to the Columbia River via McNary Lake. This concept requires a new channel approximately 2,500 feet long routed through McNary Lake. This concept will result in a greater Columbia River influence on the North Gilbert River flow; however, due to timing of the high flows, the channel would likely affect hydrology in a small portion of the lake (North Sturgeon). Increased hydrologic exchange with the Columbia River would improve juvenile salmonid access to the lake and natural habitat forming processes for fish and wildlife.
2. Connect McNary Lake to the Columbia River; Connect McNary Lake and Aarons Lake to Sturgeon Lake. This concept requires a new channel approximately 2,000 feet long. This concept requires that McNary Lake be hydrologically connected to Sturgeon Lake by breaching the berm between Aarons Lake (located between McNary Lake and Sturgeon Lake) and Sturgeon Lake. McNary Lake is connected to Aarons Lake, but the two lakes are currently isolated from Sturgeon Lake and other waterbodies. This concept will result in increased Columbia River

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influence to Sturgeon Lake. Selective increased riverine hydrologic exchange at more locations will improve juvenile salmonid access into the lake and improve natural habitat forming processes for fish and wildlife.

3. Connect McNary Lake to the Multnomah Channel; connect McNary and Aarons Lakes to Sturgeon Lake. This concept would require a new excavated channel approximately 400 feet long, north of the Gilbert River confluence with the Multnomah Channel. This concept requires that McNary Lake be hydrologically connected to Sturgeon Lake by breaching the berm between Aarons Lake and Sturgeon Lake. McNary Lake is connected to Aarons Lake, but the two lakes are currently isolated from Sturgeon Lake and other waterbodies. Selective increased riverine hydrologic exchange at more locations, possibly in combination with other measures, will increase water volume in Sturgeon Lake during high flow events, improve juvenile salmonid access into the lake, and improve natural habitat forming processes for fish and wildlife.

4. Connect Steelman Lake to the Multnomah Channel. This concept requires a new channel approximately 400 feet long between the Multnomah Channel and Steelman Lake. This concept requires that Steelman Lake be hydrologically connected to Sturgeon Lake and would involve modifying a weir between Steelman Lake and Sturgeon Lake (if fish access is desired in Steelman Lake). Steelman Lake is currently isolated from Sturgeon Lake and other waterbodies, unless the water level is high. This concept assumes that selective increased riverine hydrologic exchange at more locations, possibly in combination with other measures, will increase water volume in Sturgeon Lake during high flow events, improve juvenile salmonid access into the lake, and improve natural habitat forming processes for fish and wildlife.

5. Connect Sturgeon Lake to the Columbia River with an excavated channel starting at Sauvie Cove. This concept requires excavating one single-thread or multi-thread channel between Sauvie Cove and Sturgeon Lake. This channel would require breaching the Eastern Management Unit Levee, and could include levee setbacks on the north and south sides of the new channel. This concept will increase riverine hydrologic exchange and juvenile salmonid access to the north basin of Sturgeon Lake, and could be completed, in combination with other measures. This concept assumes that selective increased riverine hydrologic exchange at more locations, possibly in combination with other measures, will increase water volume in Sturgeon Lake during high flow events, improve juvenile salmonid access into the lake, and improve natural habitat forming processes for fish and wildlife.

6. Connect the historic Dairy Creek channel to Sturgeon Lake close to the terminus of current North Gilbert River. This concept requires deepening approximately 8,000 to 10,000 linear feet of the existing “historic” Dairy Creek channel. This concept requires excavating the thalweg of the old Dairy Creek channel and replacing culverts in order to allow for fish passage. This concept assumes that selective increased riverine hydrologic exchange at more locations, possibly in combination with other measures, will increase water volume in Sturgeon Lake during high flow events, improve juvenile salmonid access into the lake, and improve natural habitat forming processes for fish and wildlife.

7. Connect South Gilbert River to the Willamette River with an excavated channel and tide gate. This concept requires excavating approximately 2,000 to 3,000 feet of new channel through the Big Levee and uplands inside the Big Levee. Flow entering the South Gilbert River would flow north and enter Sturgeon Lake through a passive tide gate. Tide gate installation assumes that a positive hydraulic head would allow water to flow into Sturgeon Lake. Increased flow contribution to Sturgeon Lake will alter the hydraulics of the lake, increasing water volume in the lake. Increasing hydrologic inputs to the lake will contribute to other project objectives and improve natural habitat forming processes for fish and wildlife.

Sediment Traps

8. Install sediment trap at the mouth of the North Gilbert River. This concept requires an excavated facility or pond to accumulate sediment that was suspended upon entry to the North Gilbert River. The decrease in suspended sediment entering the lake presumably has a corresponding decrease in lake sedimentation. Due to the size of Gilbert River and associated volume, this trap would have to be relatively large (e.g., the size of McNary Lake).

9. Install managed water control structures. This concept requires installation of water control structures at the mouth of all channels entering the lake (e.g. Dairy Creek and the North Gilbert River). Water control structures would allow managers to manipulate water levels and water velocities in the lake in such a way to maximize open water in Sturgeon Lake.

In-lake Work

10. Remove portions of North Gilbert River Peninsula (i.e., breach many locations along Gilbert River levee). Beaching locations along the Gilbert River Peninsula increases the hydraulic complexity of riverine flow entering Sturgeon Lake. It is unlikely that this would ultimately affect the hydrology of the lake.

11. Dredge sediment in Sturgeon Lake in order to improve habitat quality and hydraulics. This concept requires a large amount of dredging lake bed sediments to immediately increase localized lake depth, improve habitat complexity, and to create channels or other bathymetric features to increase flow through the lake. Dredging channels or other features in Sturgeon Lake will increase open water area and depth. It is unlikely that this would ultimately affect the hydrology or water surface of the lake.

Changes to Levees

12. Remove Set Back SIDIC levee. Breaching and/ or setting back this levee could allow for overbank flooding from the Columbia River into Sturgeon Lake. Increased riverine hydrologic exchange reduces the increases sediment flushing during Columbia River high flow events. Increased area susceptible to flooding may increase overall habitat value in the project area.

13. Create a corridor through the Big Levee (SIDIC levee) area by installing new levees along either side of the South Gilbert River and breach locations connecting the South Gilbert River to the Willamette River and Sturgeon Lake. This concept requires reconfiguring the Big Levee into two separate ring levees with a corridor down the middle that connects the southern apex of Sauvie Island with Sturgeon Lake. This corridor would be open and susceptible to flooding increasing water volume into Sturgeon Lake.

Improvements to Existing Dairy Creek Channel

14 a. Improve Existing Dairy Creek Channel from Mouth to Reeder Road. Redesign the Dairy Creek by-pass channel with a low flow and high flow geometry would allow for higher water velocities at low river flows and also allow for high conveyance capacity at high flows. Higher velocities at lower flows would keep sediment flushed out of the channel, thereby reducing maintenance. A jetty, groin, or dike structure(s) may be necessary to control local hydraulics, thereby reducing sediment shoaling at the mouth of the conveyance channel(s). A sedimentation pond or floodplain configurations will be evaluated to capture sand that may enter the channel. This will increase the sustainability new conveyance channel(s) to Sturgeon Lake and minimize sand shoaling.

14 b. Improve Existing Dairy Creek Channel from Reeder Road to Sturgeon Lake. Construct a larger opening at Reeder Road crossing to allow for increased conveyance, debris movement, and

channel scour. Higher velocities at lower flows would keep sediment flushed out of the channel, thereby reducing maintenance.

15. Reconfigure Dairy Creek between Reeder Road and Lake. Where Measure 14 remains the existing channel alignment, this Measure would reconfigure Dairy Creek primarily between Reeder Road and the Lake to remove, or lessen the 90 degree bends in the current channel. Redesigning the Dairy Creek channel to be a straight connection between the lake and Columbia River will maximize the water flow between the two water bodies improving conveyance into the lake and minimizing the potential for sediment accumulation in Dairy Creek. A two stage channel and new crossing would be a component of this measure.

16. Create wetlands or re-connect historic drainage in Dairy Creek drainage area (upstream of old tide gate) to create positive discharge at mouth. Conveying the local hydrology with more wetland area and function inside the levee in the vicinity of Dairy Creek would result in more constant base flow that could be conveyed to the mouth of Dairy Creek channel, outside the levee. This concept would require a retrofitting or replacement of the existing tide gate or installation of a pumping station that conveys the water across the Big Levee to Dairy Creek (outside the Big Levee). Creating positive discharge at the mouth of Dairy Creek would presumably help keep sediment from shoaling in the channel.

Tide Gates and Pumps

17. Rebuild SIDIC pump house to discharge south Sauvie Island drainage to Steelman Lake. Modify SIDIC Gilbert River Intake and exercise maximum water right withdrawals to divert additional flows. Alter management of Big Levee area to increase conveyance to Sturgeon Lake with additional flows. Use passive tide gate or pump to re-direct flows from Multnomah Channel into Steelman or Sturgeon Lake. This measure would also look to improve the SIDIC intake on the Multnomah Channel and withdraw the maximum water right to provide additional volume of water to the Lake. Flows increased above current levels entering the South Gilbert River (inside the Big Levee) would flow north and enter Sturgeon Lake through a pump house or passive tide gate through the levee. This concept requires allowing the drainage from within the Big Levee to pass into Sturgeon Lake, rather than to the Multnomah Channel. Increased flow contribution to the southern portion of the lake alters the hydraulics of the lake, maximizing open water area.

18. Rebuild SIDIC pump house to discharge south Sauvie Island drainage to Steelman Lake. Operate pump house “as-is” without intake. Alter management of Big Levee area to increase conveyance to Sturgeon Lake (no additional flows). Use passive tide gate or pump to re-direct flows from Multnomah Channel into Steelman or Sturgeon Lake. Flows increased above current levels entering the South Gilbert River (inside the Big Levee) would flow north and enter Sturgeon Lake through a pump house or passive tide gate through the levee. This concept requires allowing the drainage from within the Big Levee to pass into Sturgeon Lake, rather than to the Multnomah Channel. Increased flow contribution to the southern portion of the lake alters the hydraulics of the lake, maximizing open water area.

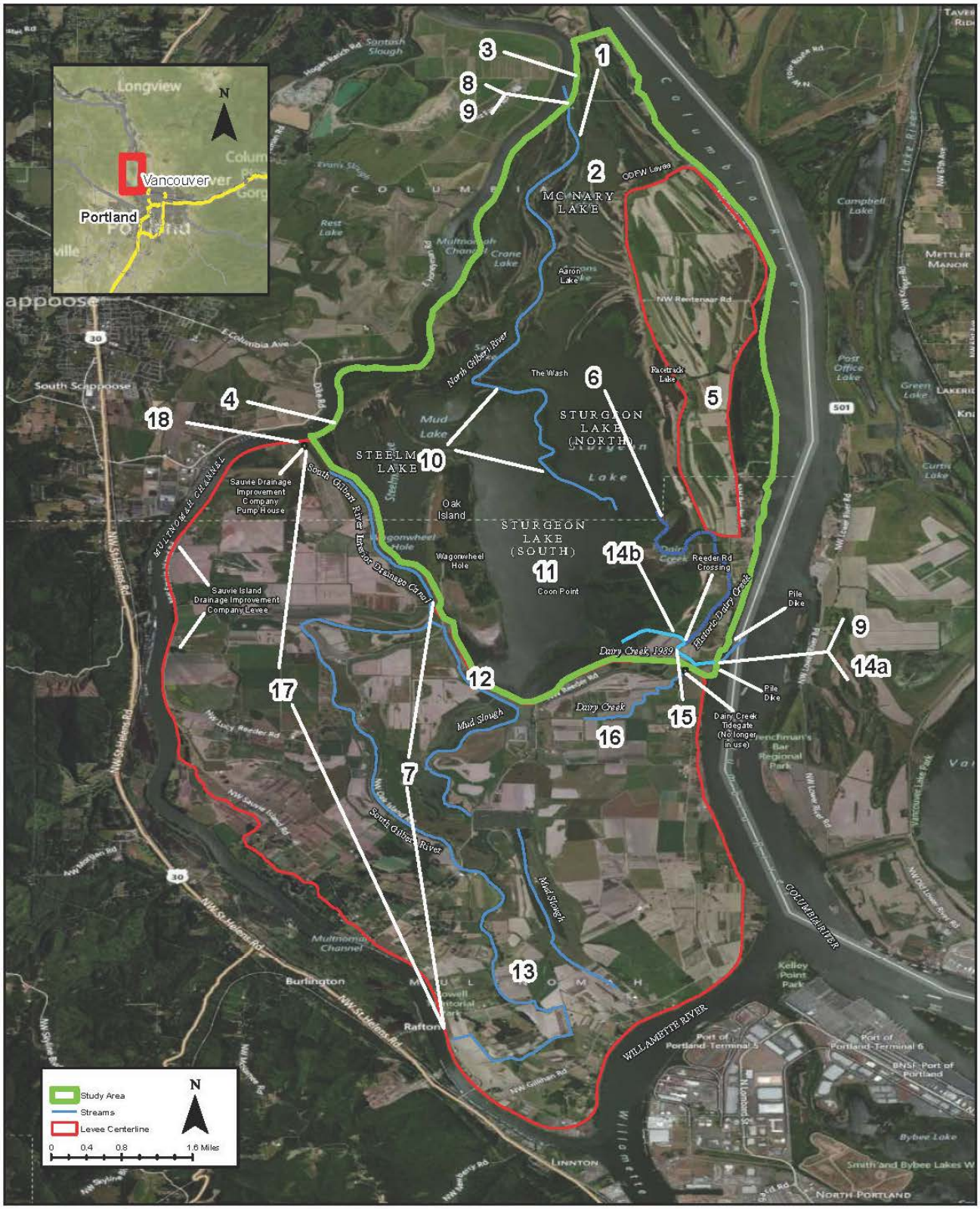

Figure 1: Dairy Creek Restoration Project Proposed Measure Locations

CENWP-EC-HR (Sediment Quality Program) March 1, 2013

Memorandum for: Portland District, Civil and Environmental Design Section (CENWP-EC-DC, A. Burcham)

Subject: Portland District Sediment Quality Program (SQP) sediment suitability determination for the Dairy Creek-Sturgeon Lake (DCSL), Section 1135 planning study, sampled June 14 and 22, 2012.

Review: This technical memorandum documents baseline sediment quality conditions in the DCSL project area. This sediment quality determination was made by the SQP (CENWP-EC-HR) in accordance with the 2009 *Sediment Evaluation Framework for the Pacific Northwest* (USACE et al, 2009).

Applicable Authorities Governing the Project: Section 1135 of the 1986 Water Resources Development Act (WRDA86); Sections 401 and 404 of the Clean Water Act; Section 7 of the Endangered Species Act (ESA); Section 305 of the Magnuson-Stevens Act; et al.

Project Description: The Dairy Creek-Sturgeon Lake (DCSL) project is currently funded under Section 1135 of WRDA86. The US Army Corps of Engineers Portland District (Corps), Bonneville Power Administration, Oregon Department of Fish and Wildlife, and the West Multnomah Soil and Water Conservation District are the action agencies for the project. The feasibility of project restoration measures is currently being evaluated by the interagency team.

The DCSL study area is located at Columbia River Mile (RM) 98.5. The major water features in the study area include Sturgeon Lake, the Gilbert River (tributary to the Columbia River via the Multnomah Channel), and Dairy Creek (tributary to the Columbia River). These water features are part of the Sauvie Island Wildlife Area (Figure 1). Sturgeon Lake is a large, shallow, mud-bottomed lake within Sauvie Island, near the confluence of the Willamette and Columbia Rivers. Most of the lake bottom is 3 to 5 feet below the water surface, depending on tidal fluctuations and seasonal flow variations in the Columbia River. A few deeper drainage channels are present. The lake surface area is approximately 3,200 acres. The mean depth in the Dairy Creek bypass channel is approximately 7 feet. Depth in the Gilbert River is generally greater than 7 feet.

Natural flushing of the lake was historically provided by flood events on the Willamette and Columbia River and several creeks and sloughs that are now cut off from the lake. Construction of dikes and dams on the Columbia and Willamette Rivers has significantly reduced the flushing regime for Sturgeon Lake. Currently, water exchange between Sturgeon Lake and the Multnomah Channel via the Gilbert River, and between Sturgeon Lake and the Columbia River via the Dairy Creek bypass channel, only occurs when the Columbia River is at its highest stages.

The DCSL restoration project would restore flows into DCSL from the Columbia River. Measures would be implemented to permanently open up the stream channel in Dairy Creek to improve water conveyance to and from, and circulation within, the 3,200-acre Sturgeon Lake. Restoration actions would be designed to reduce the sedimentation in both the lake and creek.

Major types of restoration actions that could benefit fish and wildlife species, and that are recommended for evaluation in the feasibility study include:

- Removal of sediment and debris from Dairy Creek beginning at its confluence with the Columbia River and extending inland approximately 1,800 feet.
- Construction of one or two rock jetties to minimize sedimentation of the Dairy Creek inlet during all tidal cycles.
- Removal of a sand shoal at the confluence of Dairy Creek with the Columbia River.
- Placement of a debris boom to prevent accumulations of large woody debris in the channel.
- Riparian plantings along Dairy Creek.

Data Quality Objectives: The Corps' data quality objectives for sediment characterization included:

- Reconnaissance-level characterization of sediments in areas where excavation is most likely; characterize Sturgeon Lake bed sediments to determine if chemicals of concern are present at concentrations that could adversely affect species that would use the habitat. Additional sediment characterization would be necessary if the project scope expands.
- Characterize soils/sediments in accordance with the regional dredge material testing manual protocols:
    - The 2009 SEF (USACE et al, 2009)
    - *The Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual* (EPA/USACE, 1998)
- Collect, handle and analyze representative sediment from the DCSL study area in accordance with protocols and Quality Assurance/Quality Control (QA/QC) requirements identified in the SEF.

Management Area Ranking: Low Moderate. Available information indicates a "low" rank may be warranted, but data are not sufficient to validate the low ranking. The majority of the study area is primarily undeveloped land due to the extent of wetlands and open water throughout the wildlife area. ODFW operates the Sauvie Island Wildlife Area, and permitted activities in the wildlife area include hunting, recreational canoeing/kayaking, nature watching, and hiking. Potential sources of contamination have been reported on the periphery of the study area, but these areas are removed from locations where habitat improvements would likely be implemented (Corps, 2012).

Sampling and Analysis Description: The Gilbert River and Sturgeon Lake portions of the study area were sampled by boat on June 14, 2012; the Dairy Creek was sampled using hip waders on June 22, 2012. The Corps adhered to the January 2012 sediment sampling and analysis plan (SAP) for the project (Corps, 2012). Sediment sampling locations were selected to characterize key habitat areas (Sturgeon Lake) and areas where excavation would likely occur (Dairy Creek and Gilbert River) as shown in Figures 2 and 3. Subsamples were composited into a single sample in each area for a total of 3 samples. Coordinates of subsample locations appear in Table 1.

The sampling team used both a Ponar grab sampler and soil auger to obtain samples from the DCSL study area. The sampling device selection was adjusted in the field based on water depth and substrate characteristics. Subsamples taken on the Gilbert River and Sturgeon Lake were collected with the Ponar grab sampler; a soil auger was used to sample clayey substrate in the Sturgeon Lake and in the Dairy Creek. The subsample alphanumeric IDs indicate if the sample was collected with a Ponar grab sampler (PG) or a soil auger (AU).

The Corps followed QA/QC procedures as outlined in the SAP. The three composite samples were shipped to the contract laboratory and received in good condition. Chain of custody forms appear in Attachment A. The contract laboratory analyzed three composite samples for the following physical and chemical parameters:

- Conventional parameters:
    - Grain size by method ASTM D422
    - ASTM dredge analyses
    - Total volatile solids
- Total organic carbon by method 9060
- Metals (Ag, As, Cd, Cr, Cu, Ni, Pb, Sb, Zn & Hg) by method 6020 & 7471 series
- Semi-volatile organic compounds by 8270C SIM method or other low level detection method:
    - Polynuclear aromatic hydrocarbons (PAHs)
    - Phenols
    - Phthalates
    - Chlorinated organic compounds
    - Misc. extractables
- Pesticides by method 8081
- Polychlorinated biphenyls (PCBs) by method 8082
- Total petroleum hydrocarbons (TPH) by Northwest-TPH method

Deviations from the SAP: Due to time constraints, one subsample station was dropped from the Dairy Creek area (subsample DCSL-AU-03C); two subsamples were collected to form the composite sample (three subsamples were planned).

Evaluation: Samples were compared to the 2006 Interim Final SEF freshwater benthic toxicity screening levels (SLs).

Results: Physical and chemical results are summarized in Tables 2 and 3, respectively.

Physical: The Gilbert River bed substrate was generally coarse grained; the Dairy Creek bed substrate was silty; and the Sturgeon Lake substrate was fine-grained. Other physical sediment characteristics are reported in Table 2.

Sediment Chemistry: All chemical concentrations were below the SEF SLs. Sediment chemistry is summarized in Table 3. In all samples:

- SEF metals were detected.
- PAHs were present at low concentrations.

- Other SVOCs (phenols, phthalates, miscellaneous extractable compounds, and chlorinated hydrocarbons) were either not detected, or the laboratory estimated the concentration ([J-qualified data] between the method detection limit and the method reporting limit).
- Pesticides were either not detected, or the laboratory estimated the concentration (J-qualified data).
- PCBs (Aroclors) were not detected.
- Petroleum hydrocarbons were not detected.

Suitability Determination: This sediment suitability determination only applies to the Gilbert River, Dairy Creek, and Sturgeon Lake areas of Sauvie Island, Oregon. In accordance with the SEF guidance, sediment in DCSL study area does not contain contaminants at levels that would be harmful to aquatic life. Also, sediment within the study area can be used to construct aquatic habitat features as appropriate.

If the project scope expands beyond the identified study area, additional sediment characterization may be necessary.

Contact: This memorandum was prepared by James McMillan (Lead, Portland Sediment Evaluation Team); questions should be directed to him at (503) 808-4376 or e-mail to: james.m.mcmillan@usace.army.mil.

References:

Environmental Protection Agency/U.S. Army Corps of Engineers. 1998. Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. Inland Testing Manual. EPA823-B-98-004.

U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, Washington Department of Ecology, Washington Department of Natural Resources, Oregon Department of Environmental Quality, Idaho Department of Environmental Quality, National Marine Fisheries Service, and U.S. Fish and Wildlife Service. 2006. *Interim Final Sediment Evaluation Framework for the Pacific Northwest*. Published September 30, 2006, by the U.S. Army Corps of Engineers, Northwestern Division, 194 pp + Appendices.

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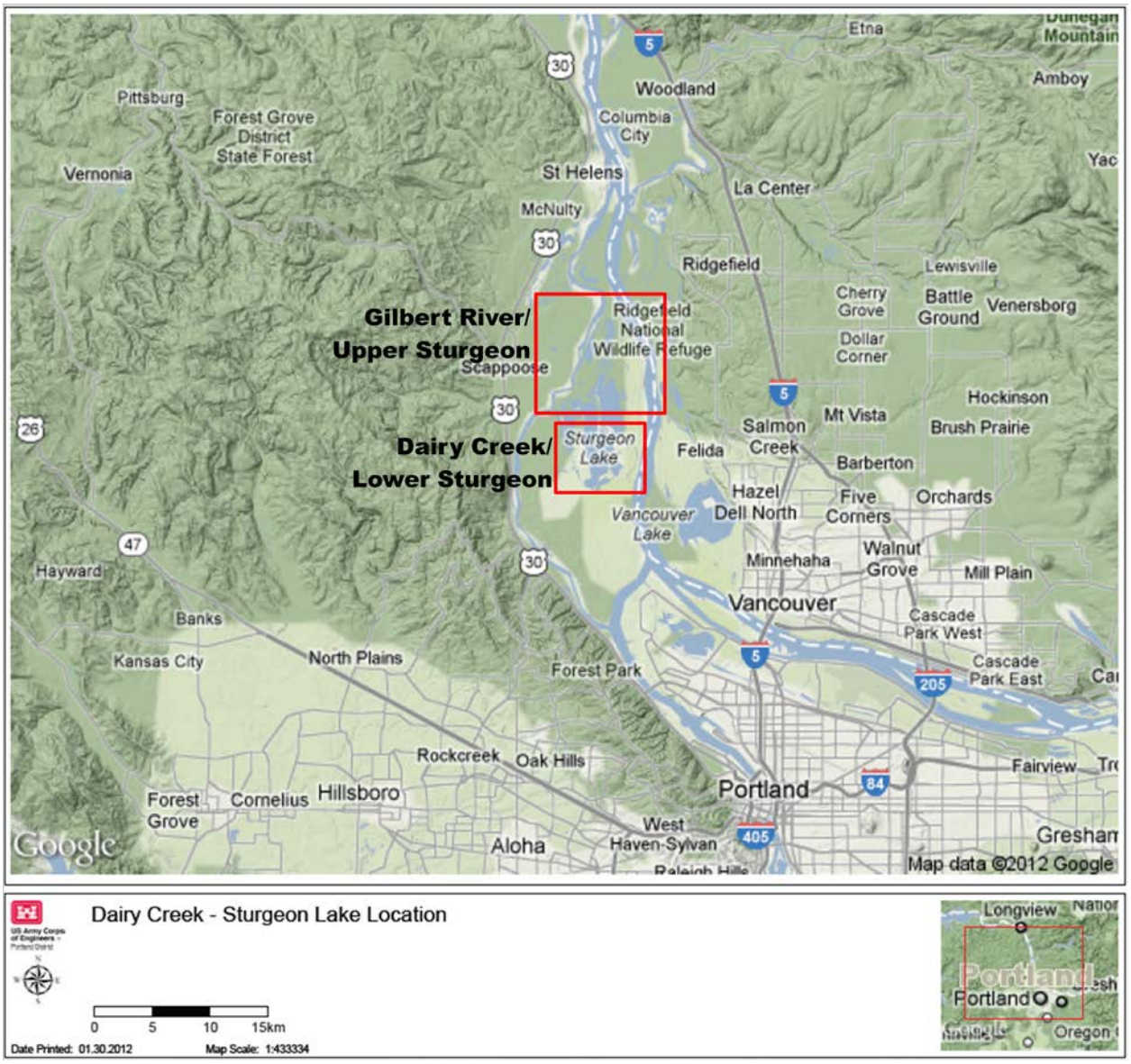

Figure 1. Dairy Creek-Sturgeon Lake Study Area Location Map.

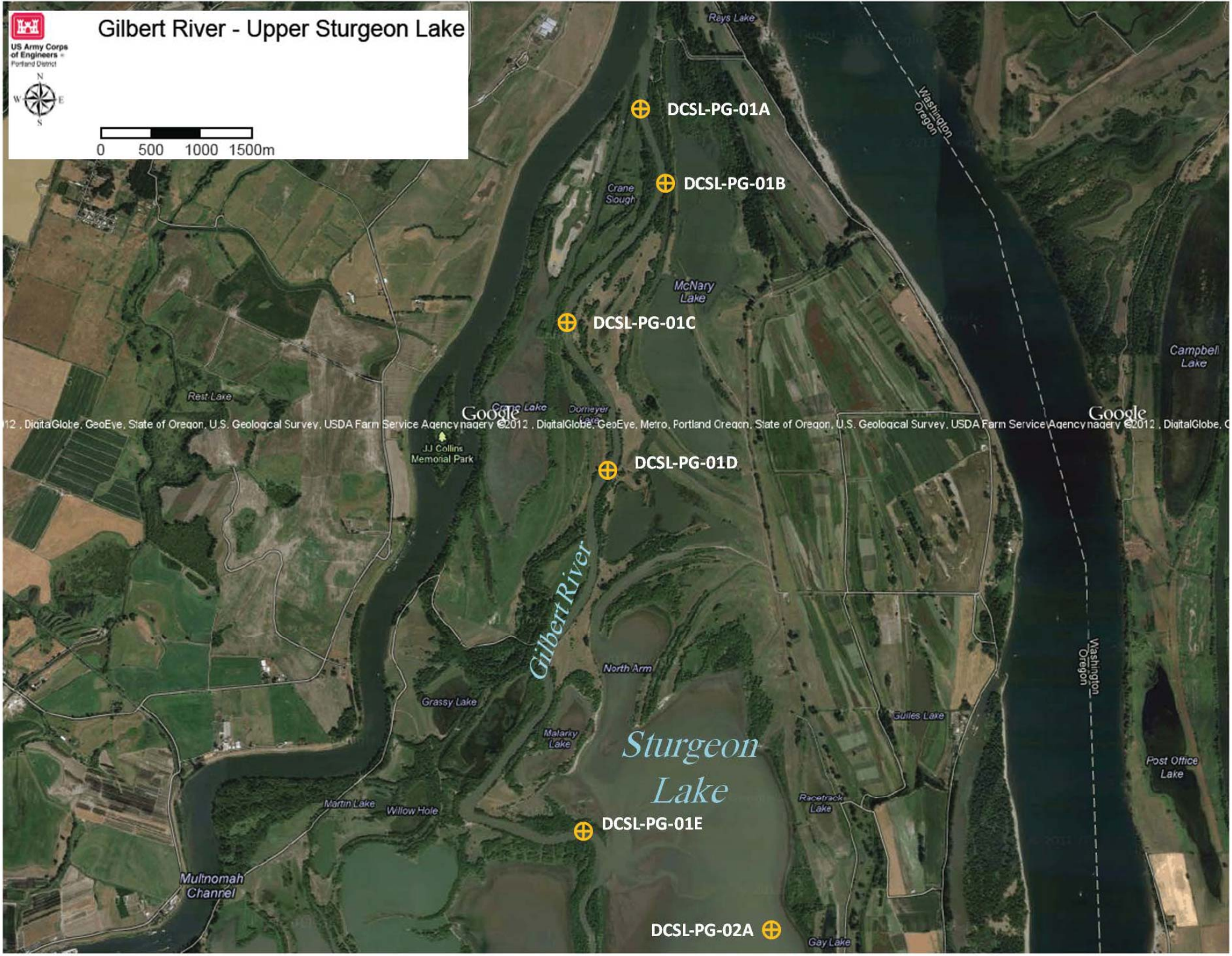

Figure 2: Subsample Locations, Gilbert River-Upper Sturgeon Lake.

Figure 3: Subsample Locations, Dairy Creek-Lower Sturgeon Lake.

Table 1. Subsample Locations, Dairy Creek-Sturgeon Lake.			
Composite Sample ID	**Subsample ID**	**Latitude**	**Longitude**
DC01 COMP (06142012) ***Gilbert River***	DCSL-PG-01A	45.787445 N	122.800232 W
	DCSL-PG-01B	45.782444 N	122.798653 W
	DCSL-PG-01C	45.774033 N	122.806915 W
	DCSL-PG-01D	45.765087 N	122.803215 W
	DCSL-PG-01E	45.742596 N	122.806671 W
DC02 COMP (06142012) ***Sturgeon Lake***	DCSL-PG-02A	45.736507 N	122.788773 W
	DCSL-PG-02B	45.722221 N	122.792816 W
	DCSL-AU-02C	45.721092 N	122.813454 W
DC03 COMP (06222012) ***Dairy Creek***	DCSL-AU-03A	45.702644 N	122.783722 W
	DCSL-AU-03B	45.702942 N	122.785210 W

Table 2. Summary of Physical Results, Dairy Creek-Sturgeon Lake.			
	DC01 COMP	**DC02 COMP**	**DC03 COMP**
Parameter	***Gilbert River***	***Sturgeon Lake***	***Dairy Creek***
Total Gravel	**26.3**	**0.8**	**0.8**
>5"	0.1	0.1	0.1
5-2.5"	0.1	0.1	0.1
2.5-1.25"	0.1	0.1	0.1
1.25-0.625"	18.3	0.1	0.1
0.625-0.3125"	6.6	0.1	0.1
0.3125"-4 mm	1	0.1	0.2
4-2 mm	0.1	0.2	0.1
Total Sand	**58.1**	**21.6**	**37.6**
2-1 mm	0.4	0.2	0.2
1-0.5 mm	2	0.3	0.3
0.5-0.25 mm	10.7	0.6	1.3
0.25-0.125 mm	31.8	6.1	13.6
0.125-0.063 mm	13.2	14.4	22.2
Total Fines	**16**	**78.2**	**62.1**
63-32 um	3.7	18.3	20.4
32-22 um	2.9	11	10.8
22-13 um	1.2	12.6	4.6
13-9 um	1.2	7.9	3.9
9-7 um	1.2	7.9	2.3
7-3.2 um	2.9	7.9	6.2
<3.2 um	2.9	12.6	13.9
ASTM Dredge Analyses			
D15 (um)	60	190	19000
D50 (um)	4.4	23	84
D85 (um)	3.8	40	130
United Soil Classification System	SM (silty sand w/ gravel; non-plastic)	CH (fat clay w/ sand; high plasticity)	ML (sandy silt; low plasticity)
Plasticity Index	not applicable	32.5	10.1
Liquid Limit	not applicable	64.4	35.3
Plastic Limit	not applicable	31.9	25.2
Dry Density (lb/ft^3)	68.4	47.3	73.4
Wet Density (lb/ft^3)	107.2	92.6	109.2
Specific Gravity (std. units)	2.7	2.6	2.6
Total Solids (%)	63.82	51.09	67.21
Porosity (fraction)	59	71	55

Table 3. Summary of Chemical Results, Dairy Creek-Sturgeon Lake.

Bold value = concentration detected above the method reporting limit (MRL); Underlined value = chemical summation

J = estimated concentration between the method detection limit (MDL)and the MRL; NA = not analyzed

P = The gas chromatography or high-performance liquid chromatography confirmation criteria was exceeded. The relative percent difference is greater than 40% between the two analytical results.

U = not detected above the MDL; MRL is reported

Ui = not detected above the MDL; MDL elevated due to matrix interference

Chemical Group Chemical	**DC-COMP1** *Gilbert River*	**DC-COMP2** *Sturgeon Lake*	**DC-COMP3** *Dairy Creek*	**SEF Freshwater SL**
Total Solids (%)	**57.3**	**49.7**	**65.1**	--
Ammonia (NH3) as Nitrogen(N) (mg/kg)	**19.3**	**14.7**	NA	--
Sulfide (mg/kg)	**1.7 U**	**2.9**	NA	--
Total Organic Carbon (%)	**0.742**	**0.886**	**0.425**	--
Metals (mg/kg)				
Antimony	0.359 J	0.162 J	0.075 J	--
Arsenic	**4.29**	**3.72**	4.4 J	20
Cadmium	**0.172**	**0.418**	0.98 U	1.1
Chromium	**19.1**	**19.5**	**21.7**	95
Copper	**18.1**	**23.9**	**42.2**	80
Lead	**8.43**	**15**	9.5 J	340
Mercury	**0.028**	**0.063**	**0.04**	0.28
Nickel	**21.3**	**17**	**19.5**	60
Silver	**0.072**	**0.106**	**0.089**	2
Zinc	**72.8**	**85.4**	**80.7**	130
PAHs (ug/kg)				
Total LPAHs	40.5 (J)	30.4 (J)	7.7 U	6,600
Naphthalene	3.8 J	**7**	7.7 U	500
Acenaphthylene	**7.1**	3.8 J	7.7 U	470
Acenaphthene	2 J	1 J	7.7 U	1,100
Fluorene	2.6 J	1.5 J	7.7 U	1,000
Phenanthrene	**15**	**12**	7.7 U	6,100
Anthracene	**10**	**5.1**	7.7 U	1,200
Total HPAHs	254 (J)	**459.8**	17.7 (J)	31,000
Fluoranthene	**31**	**52**	4.8 J	11,000
Pyrene	**39**	**71**	5.5 J	8,800
Benzo(a)anthracene	**17**	**27**	7.7 U	4,300
Chrysene	**26**	**37**	7.7 U	5,900
Benzo(b)fluoranthene	**30**	**53**	3.7 J	600 (b+k)
Benzo(k)fluoranthene	**13**	**22**	7.7 U	
Benzo(a)pyrene	**32**	**59**	3.7 J	3,300
Indeno(1,2,3-cd)pyrene	**30**	**63**	7.7 U	4,100
Dibenzo(a,h)anthracene	4 J	**6.8**	7.7 U	800
Benzo(ghi)perylene	**32**	**69**	7.7 U	4,000
Chlorinated Hydrocarbons (ug/kg)				
1,4-Dichlorobenzene	10 U	10 U	7.7 U	--
1,2-Dichlorobenzene	10 U	10 U	7.7 U	--
1,2,4-Trichlorobenzene	10 U	10 U	7.7 U	--
Hexachlorobenzene	10 U	10 U	7.7 U	--
Phthalates (ug/kg)				
Dimethylphthalate	10 U	10 U	7.7 U	46
Diethylphthalate	10 U	10 U	7.7 U	--
Di-N-Butylphthalate	20 U	20 U	16 U	--
Butylbenzylphthalate	10 U	10 U	4.5 J	260
Bis(2-Ethylhexyl) Phthalate	16 J	100 U	28 J	220
Di-N-Octyl Phthalate	10 U	10 U	7.7 U	26

Table 3. Summary of Chemical Results, Dairy Creek-Sturgeon Lake.

Bold value = concentration detected above the method reporting limit (MRL); Underlined value = chemical summation

J = estimated concentration between the method detection limit (MDL)and the MRL; NA = not analyzed

P = The gas chromatography or high-performance liquid chromatography confirmation criteria was exceeded. The relative percent difference is greater than 40% between the two analytical results.

U = not detected above the MDL; MRL is reported

Ui = not detected above the MDL; MDL elevated due to matrix interference

Chemical Group Chemical	**DC-COMP1** *Gilbert River*	**DC-COMP2** *Sturgeon Lake*	**DC-COMP3** *Dairy Creek*	**SEF Freshwater SL**
Phenols (ug/kg)				
Phenol	6.3 J	4.5 J	3.7 J	--
2-Methylphenol	10 U	10 U	7.7 U	--
4-Methylphenol	10 U	10 U	7.7 U	--
2,4-Dimethylphenol	50 U	50 U	39 U	--
Pentachlorophenol	100 U	100 U	77 U	--
Miscellaneous Extractable Compounds (ug/kg)				
Benzyl Alcohol	20 U	20 U	16 U	--
Benzoic Acid	97 J	600 U	460 U	--
Dibenzofuran	10 U	10 U	7.7 U	400
Hexachlorobutadiene	10 U	10 U	7.7 U	--
N-Nitrosodiphenylamine	10 U	10 U	7.7 U	--
Pesticides (ug/kg)				
4,4'-DDE	0.22 J	0.32 J	1 U	9
4,4'-DDD	0.31 J	0.54 J	1 U	16
4,4'-DDT	0.87 U	0.88 J	1 U	12
Aldrin	0.87 U	1 U	1 Ui	9.5
gamma-Chlordane	0.87 U	0.092 J	1 Ui	--
cis-Chlordane	0.87 U	1 U	1 Ui	--
Oxychlordane	0.87 U	1 U	1 U	--
cis-Nonachlor	0.87 U	0.15 JP	1 U	--
trans-Nonachlor	0.87 U	1 U	0.87 J	--
Total Chlordane	0.87 U	0.24 J	0.87 J	2.8
Dieldrin	0.87 U	1 U	1 U	1.9
Heptachlor	0.87 U	1 U	1 U	1.5
Lindane	0.87 U	1 U	1 U	--
PCBs (ug/kg)				
Total PCBs	18 U	20 U	20 U	60
PCB-aroclor 1016	8.7 U	10 U	10 U	--
PCB-aroclor 1221	18 U	20 U	20 U	--
PCB-aroclor 1232	8.7 U	10 U	10 U	--
PCB-aroclor 1242	8.7 U	10 U	10 U	--
PCB-aroclor 1248	8.7 U	10 U	10 U	--
PCB-aroclor 1254	8.7 U	10 U	10 U	--
PCB-aroclor 1260	8.7 U	10 U	10 U	--
Petroleum Hydrocarbons (mg/kg)				
Gasoline Range Organics	20 U	20 U	20 U	--
Diesel Range Organics	50 U	50 U	50 U	--
Residual Range Organics	100 U	100 U	100 U	--

ATTACHMENT A

CHAIN OF CUSTODY FORMS

DAIRY CREEK-STURGEON LAKE
SECTION 1135 PLANNING STUDY

Sampled June 14 and 22, 2012

Columbia Analytical Services™

800.695.7222
www.caslab.com

Usa Domenighini
ALS Environmental
1317 S. 13th Ave
Kelso, WA 98626
360-577-7222

Client: USACE-Portland Dist. (CENWP-EC-HR)

Project Manager: James McMillan (Wendy Briner [alt.])

james.m.mcmillan@usace.army.mil; wendy.k.briner@usace.army.mil

CHAIN of CUSTODY

Project: Dairy Creek-Sturgeon Lake

Telephone No. McMillan 503.808.4376
Briner: 503.808.4975

Fax No. 503.808.4875

Page _1__ of _1__

Method of Shipment: FEDEX

Special Detection Limit/Reporting: See attached minimum quanititation limits

Sample I.D.	Lab Sample No.	No. of Containers	Matrix: Soil	Matrix: Water	Matrix: Air	Matrix: Other	Prsv.: Yes	Prsv.: No	Sampling Date	Sampling Time	Metals (Ag, As, Cd, Cr, Cu, Ni, Pb, Sb, Zn, & Hg) (method 6010; 7471)	TOC (method 9060)	SVOCs 8270C SIM	Pesticides (method 8081)	PCBs (method 8082) Aroclors	Total Petroleum Hydrocarbons (NWTPH, HCID screen w/ follow-up) DRO & RRO	Grain size (sieve sizes 5, 10, 18, 35, 60, 120, and 230), sans H2O2	>No. 230 sieve fraction hydrometer	TVS	Moisture Content	ASTM Dredge Analysis			Turn Around Time (working days)
DC03 COMP		1	X						06222012	1135	X	X	X	X	X	X								Std
DC03 COMP		2	X						06222012	1154							X	X	X	X	X			Std
DC01 COMP		2	X						06142012	1138							X	X	X	X	X			Std
DC02 COMP		2	X						06142012	1237							X	X	X	X	X			Std

MARKS: *please ship physical samples to ARI

Sample Received Intact: Yes No

Temperature received: Ice No ice

Relinq. by sampler (Sign & Print Name)	Date	Time	Received by (Sign & Print Name)
W.H. Briner W.Briner	25 June 12	920	
Relinquished by	Date	Time	Received by
Relinquished by	Date	Time	Received by: Elaine Wyck /ALS
Relinquished by	Date	Time	Received by laboratory — Date 6/26/12 Time 0915

Lab Work No.: K1206145

Columbia Analytical Services™

CHAIN OF CUSTODY

1317 South 13th Ave, Kelso, WA 98626 | 360.577.7222 | 800.695.7222 | 360.636.1068 (fax)

SR#: K1205904

PAGE 1 OF 1 COC #

PROJECT NAME: DAIRY CREEK – SAUVIE ISLAND
PROJECT NUMBER:
PROJECT MANAGER: James M. McMillan
COMPANY/ADDRESS: USACE-Portland (EC-HR) 333 SW 1st Av
PO Box 2946
CITY/STATE/ZIP: PORTLAND, OR 97208-2946
E-MAIL ADDRESS: james.m.mcmillan@usace.army.mil
PHONE #: 503.808.4376 FAX#: 503.808.4875
SAMPLER'S SIGNATURE:

SAMPLE I.D.	DATE	TIME	LAB I.D.	MATRIX	NUMBER OF CONTAINERS	Semivolatile Organics by GC/MS 625 ☐ 8270C 8270LL ☐	Volatile Organics 624 ☐ 8260 ☐	Hydrocarbons (*see below) Gas ☒ Diesel ☒	BTEX ☐	☒ NW-HCID Screen	Oil & Grease/TRPH 1664 SGT ☐ 1664 HEM ☐	Fuel Fingerprint (FIO)	PCB's Aroclors ☒	Congeners ☐	Pesticides/Herbicides 608 ☐ 8081A ☒ 8141A ☐ 8151A ☐	Chlorophenolics - 8151M Tri ☐ Tetra ☐ PCP ☐	PAHS 8310 ☐ SIM ☒	Metals, Total or Dissolved (See list below)	Cyanide ☐	pH, Cond., Cl, SO4, PO4, F, NO2, NO3, BOD, TSS, TDS (circle)	Hex-Chrom ☐	NH3-N, COD, Total-P, TKN, TOC, DOC (circle) NO2+NO3	TOX 9020 ☐	AOX 1650 ☐ 506 ☐	Total Sulfides (TSEP 1997)			REMARKS
DC01 Comp	6/14/2012	1130		S	1	X		X	X		X	X		X	X			X			X			X				
DC02 Comp	6/14/2012	1237		S	1	X		X	X		X	X		X	X			X			X			X				

REPORT REQUIREMENTS

- ___ I. Routine Report: Method Blank, Surrogate, as required
- ___ II. Report Dup., MS, MSD as required
- X III. Data Validation Report (includes all raw data)
- ___ IV. CLP Deliverable Report
- X V. EDD

INVOICE INFORMATION

P.O. #
Bill To:

TURNAROUND REQUIREMENTS

- ___ 24 hr. ___ 48 hr.
- ___ 5 Day
- X Standard (10-15 working days)
- ___ Provide FAX Results

Requested Report Date

Circle which metals are to be analyzed:

Total Metals: Al (As) (Sb) Ba Be B Ca (Cd) Co (Cr) (Cu) Fe (Pb) Mg Mn Mo (Ni) K (Ag) Na Se Sr Tl Sn V (Zn) (Hg)

Dissolved Metals: Al As Sb Ba Be B Ca Cd Co Cr Cu Fe Pb Mg Mn Mo Ni K Ag Na Se Sr Tl Sn V Zn Hg

*INDICATE STATE HYDROCARBON PROCEDURE: AK CA WI NORTHWEST OTHER: _____ (CIRCLE ONE)

SPECIAL INSTRUCTIONS/COMMENTS:
See attached quantitation limits & prep/analytical methods for clarification

☐ Sample Shipment contains USDA regulated soil samples (check box if applicable)

RELINQUISHED BY:	RECEIVED BY:	RELINQUISHED BY:	RECEIVED BY:
Signature / Date/Time	Ellayna Wick / 6/19/12 0900	Signature / Date/Time	Signature / Date/Time
Printed Name / Firm	Ellayna Wick / ALS	Printed Name / Firm	Printed Name / Firm