



## Fish Passage Solutions A Perspective from the Northwestern U.S.

Peter Christensen, P.E.

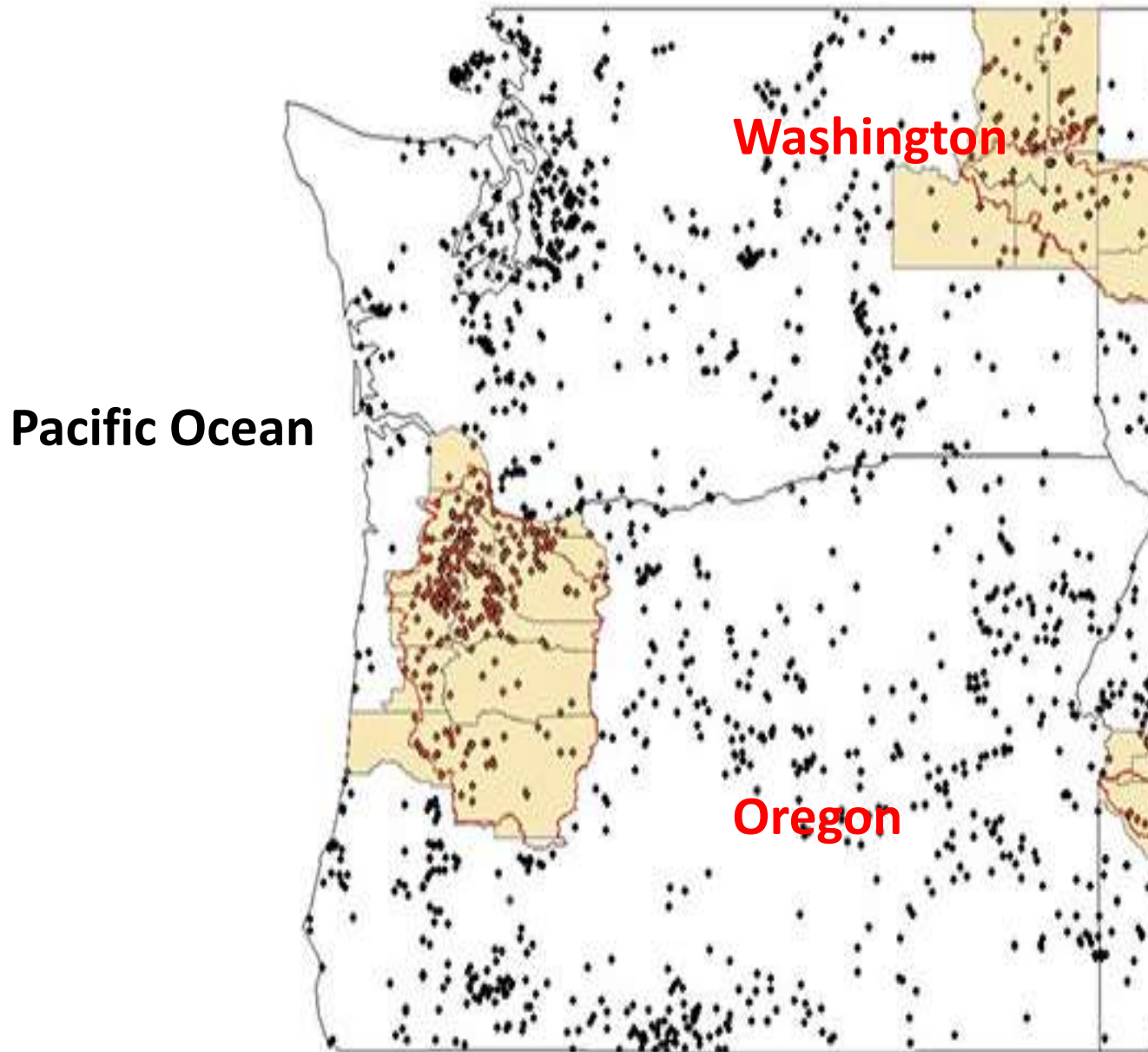
 R2 Resource  
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# Northwestern United States





# Existing Dams in Washington & Oregon States



# There is No Single 'Correct' Fish Passage Solution

## Every Dam Environment is Different

- Dam Height
- Flow Rate
- Reservoir Size
- Current Patterns
- Operations



## Every River Basin is Different

- Number of Dams
- Available Habitat
- Fish Species
- Restoration Goals



# Best Designs Incorporate Project Features



Unique Project  
Features Can Provide  
Both Complications  
and Opportunities

Fish Behave  
Differently at Different  
Projects –

Incorporate Local  
Behavior into Design



# Major Anadromous Species of the Pacific Northwest



Chinook Salmon  
Coho Salmon  
Sockeye Salmon  
Chum Salmon  
Pink Salmon  
Steelhead Trout  
Pacific Lamprey



Major Resident  
Freshwater Species  
of the Pacific  
Northwest

Bull Trout  
Rainbow Trout  
Cutthroat Trout  
Mountain Whitefish  
Kokanee





# Passage Strategies

## Volitional Passage

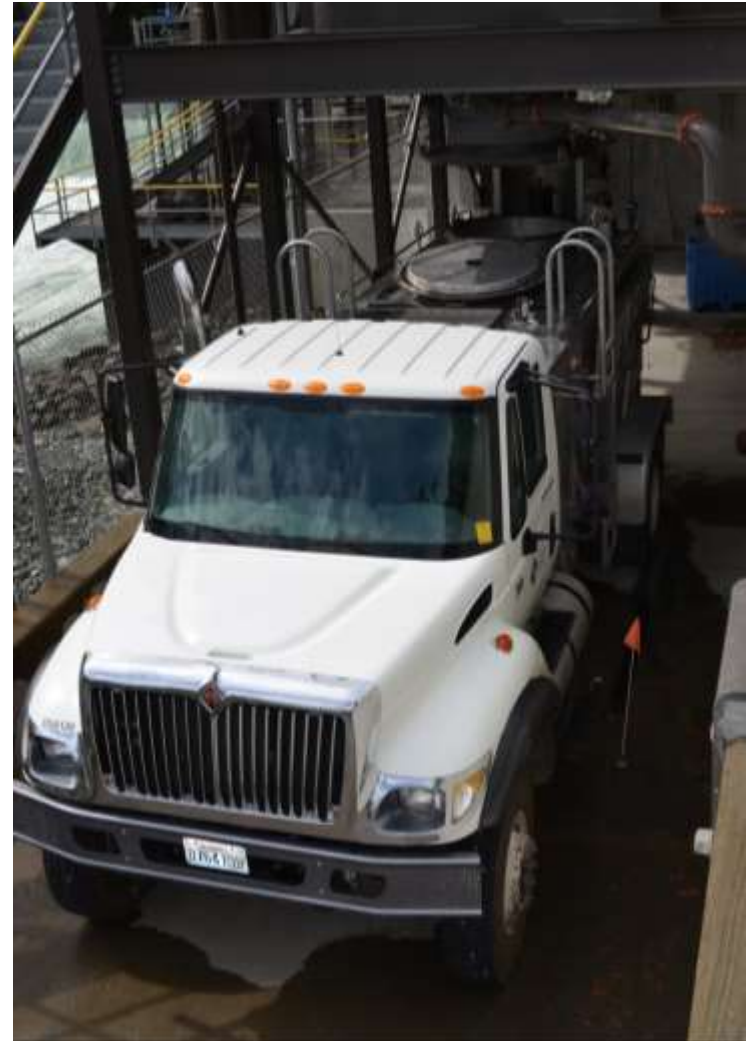


Upstream  
Fish Ladder



Downstream Bypass Discharge

## Trap & Haul



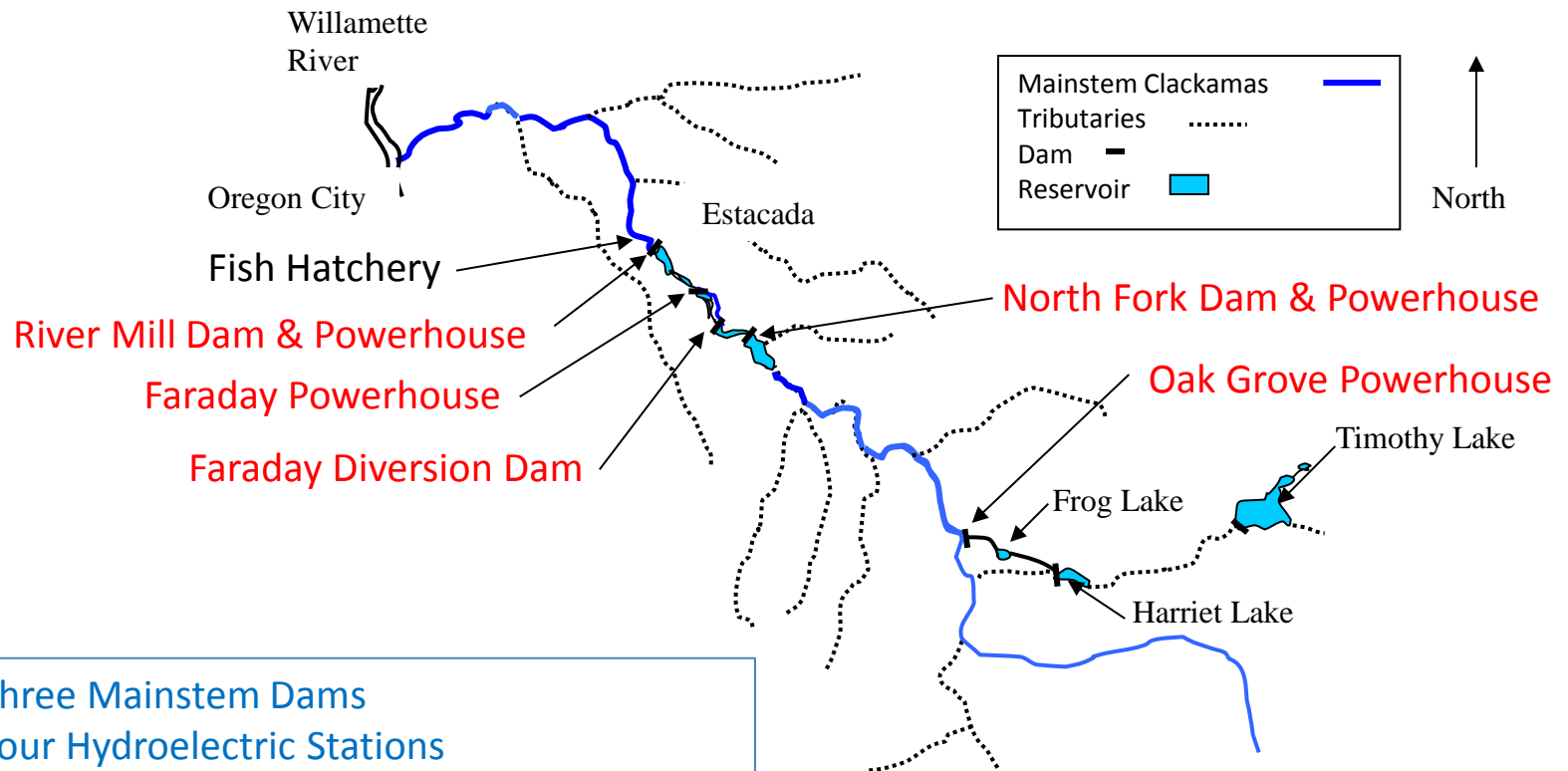
Fish Transport Truck



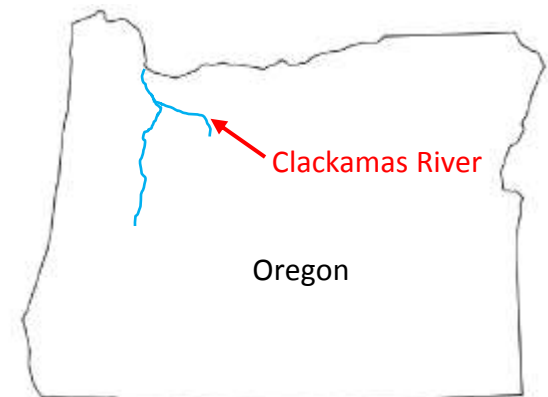
# Will Provide Three River-Basin Passage Examples



# Clackamas River Hydroelectric Project

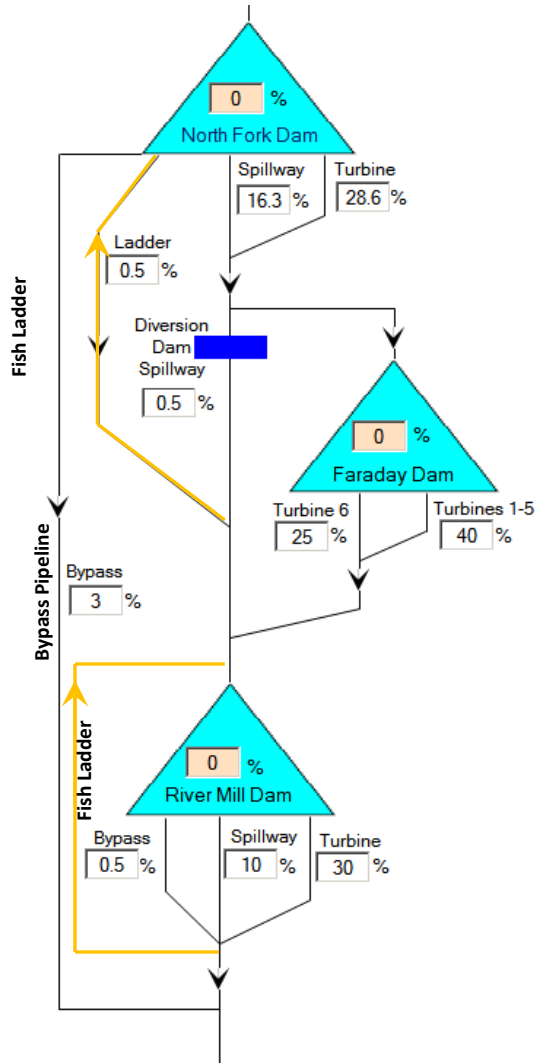


- Three Mainstem Dams
- Four Hydroelectric Stations
- 173 MW Total Capacity
- Target Passage Species
  - Chinook Salmon
  - Coho Salmon
  - Steelhead Trout
  - Pacific Lamprey
- Recreational Fishing below North Fork
- ESA Protected Watershed above North Fork





# Clackamas River Fish Passage Routes



## Upstream Passage

- Fish Ladder Around River Mill Dam
- Single Fish Ladder Around Faraday Dam and North Fork Dam (2.7 km)

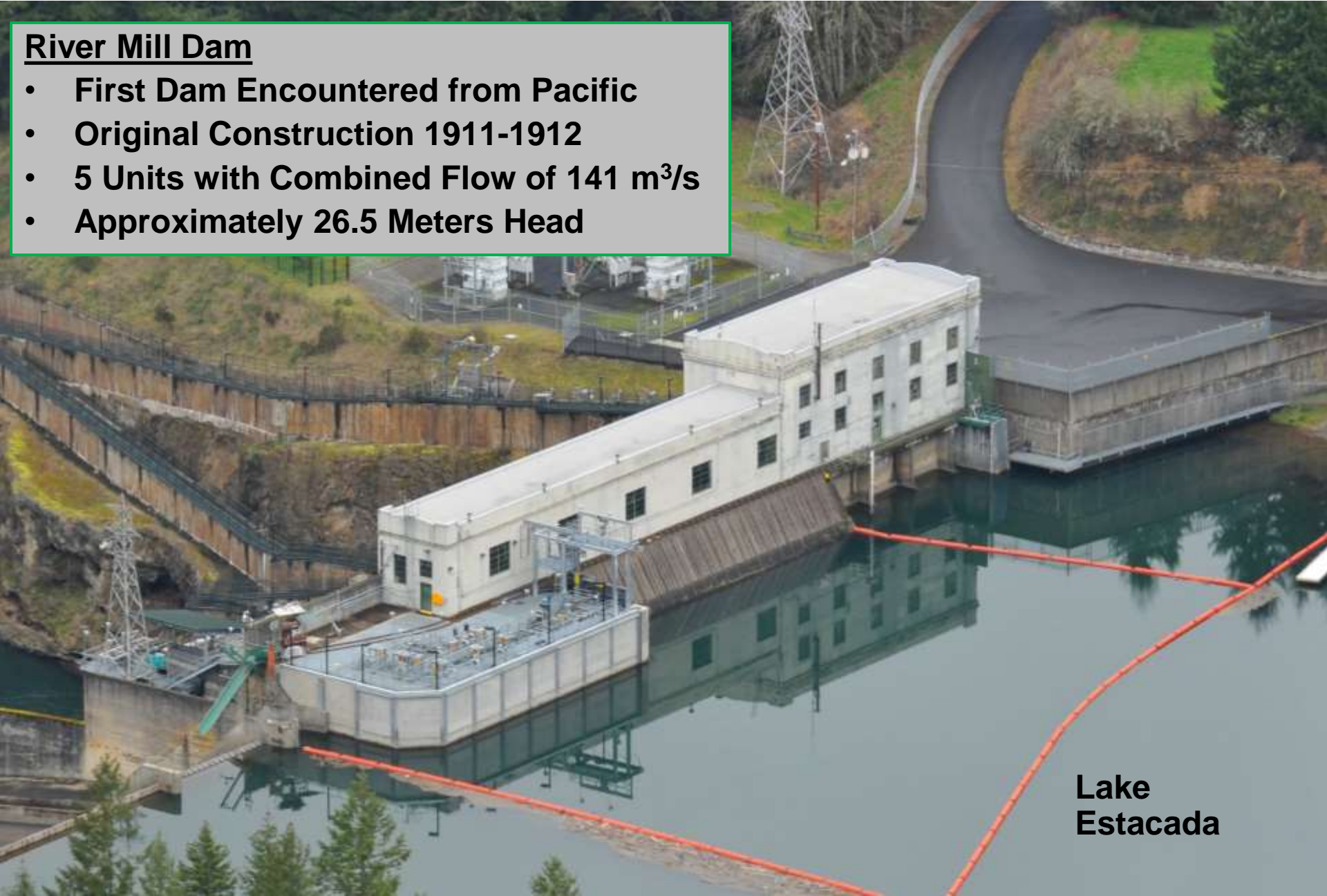
## Downstream Passage

- 2 Collectors at North Fork Dam with 11 km Bypass Pipeline to below River Mill
- Collector & Bypass at River Mill Dam
- Other Routes include Spillways, Turbines, and Fish Ladders (small usage)

# Upstream Passage on Clackamas River

## River Mill Dam

- First Dam Encountered from Pacific
- Original Construction 1911-1912
- 5 Units with Combined Flow of 141 m<sup>3</sup>/s
- Approximately 26.5 Meters Head



Lake  
Estacada



# Original 1912 River Mill Fish Ladder



Low Flow Rate ( $0.17 \text{ m}^3/\text{s}$ ) – Steep Slope (1:6) – Aging Concrete (1912-2005)



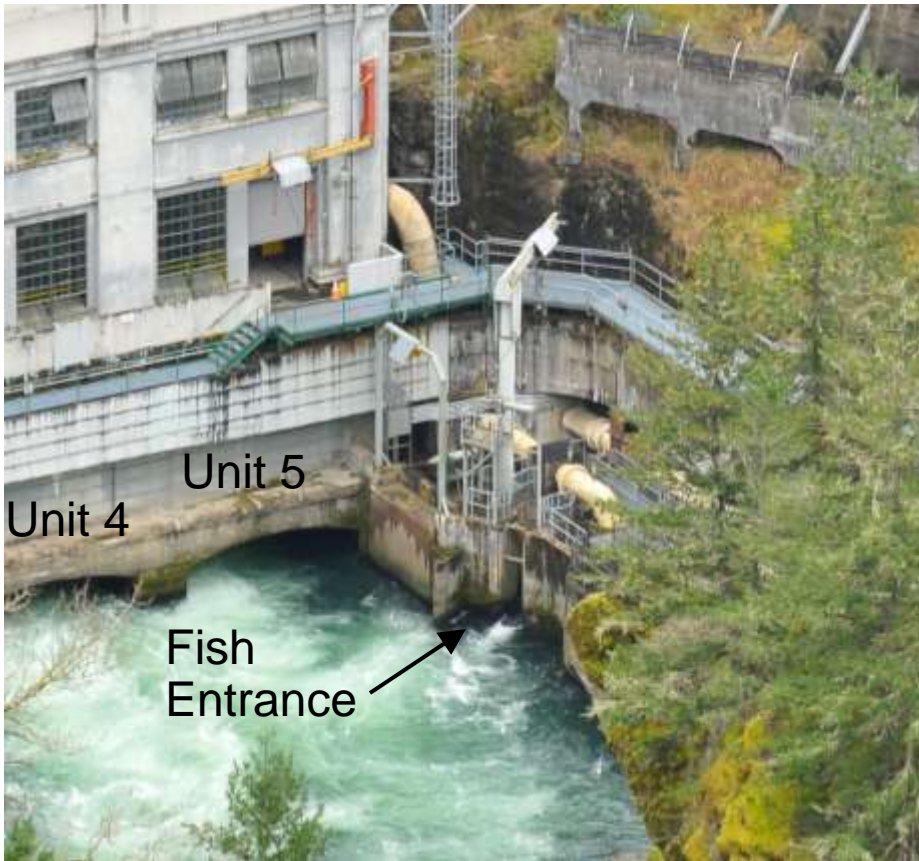
# New River Mill Fish Ladder Completed 2006



Increased Flow Rate ( $0.57 \text{ m}^3/\text{s}$ ) – Reduced Slope (1:10) – 305 Meters Long



# Beneficial Use of Existing Features and Operations



## Fish Entrance below Unit 5 Discharge

- Same Location as Original Entrance
- Reuse of Attraction Flow Piping
- Minimizing Attraction Flow Pumping
- Future Use of Unit 5 as First-On/Last-Off
- Reuse of Entrance Channel



## Wing Wall Upstream of Entrance

- Deflects the Unit 5 Draft Tube Discharge away from the Fish Entrance Flow
- Creates a Flow Shear that Attracts Fish
- Increases the Ability for Fish to Find the Attraction Flow

# Ladder Features

## Screening of Pumped Attraction Flow



Cylindrical T-Screens



Three T-Screens being Installed



T-Screens Installed



Air-Burst Cleaning Cycle



# Ladder Features

## 8 Adjustable Baffle Weirs to Track Lake Level Changes



# River Mill Ladder Passage Results

## Observations of Improvement in Passage:

- Population Increases for All Target Species.
- Whitefish Observed above River Mill Dam.
- Rainbow Trout Passage Greatly Increased.
- Hatchery Chinook above Dam.
- Larger Wild Chinook Individuals.
- Pacific Lamprey Passage Greatly Increased.



# Faraday/North Fork Fish Ladder (1957)

Longest (2.7 km) and Tallest (85 m) Fish Ladder in the World



Fish Ladder Entrance  
Adjacent to the Base  
of the Dam

Typically all Flow  
Below the Dam is  
Discharging from the  
Fish Ladder (except  
during High-Flow  
Spill Events)

Faraday Diversion Dam (1907) and Fish  
Ladder to Above North Fork Dam (1957)



Ladder Entrance Channel



Some Pools almost 100 Meters Long

# Faraday/North Fork Fish Ladder

## Upstream End at North Fork



Ladder Exit is Combined with a Downstream Migrant Collector & Bypass System



Ladder Exit in North Fork Reservoir Originally Designed for Reservoir Surface Fluctuations up to 6 Meters  
Current Licensed Operations Limited to 1.5 Meters, and Typically Operated within 1 Meter

### Ladder is Operated as Designed in 1957 With Three Changes:

- Increased Attraction Flow from 5.1 m<sup>3</sup>/s to 7.6 m<sup>3</sup>/s
- A new Adult Trapping & Sorting Facility added to Separate out the Hatchery fish and Truck them back to the Hatchery
- Modifications made at the Faraday Entrance to Enhance the Successful Entry of Pacific Lamprey



# Existing Downstream Passage Improvements

## Extended Bypass Pipe To North Fork Dam



Fish Ladder at North Fork  
Prior to Extension

- Fish Ladder Served as Downstream Migrant Conduit for Initial 2.4 km
- Then Diverted into 8.6 km Pipeline to River Mill Tailrace



Diversion Box and Pipeline  
Mounted above Fish Ladder (2011)

- Downstream Migrants now Diverted Directly into Pipeline from Collector
- Pipeline 11 km to River Mill Tailrace

# Existing Downstream Passage Improvements

## Improvement of North Fork Bypass Discharge



Old Bypass Discharge (1957)

- Located in the River Mill Tailrace
- Flow Separated & Plunged up to 6 Meters
- New Ladder Required Removal of Pipe



New Hinged Adjustable Discharge (2005)

- Flexible Hose Section in Pipeline
- Final Section Raised & Lowered Automatically
- Discharge Remains 0.5 Meters above Tailwater over 7.6 Meter Range



# Existing Downstream Passage Improvements

## Guide Net at Existing Collector Entrance



Guide Net Float Line

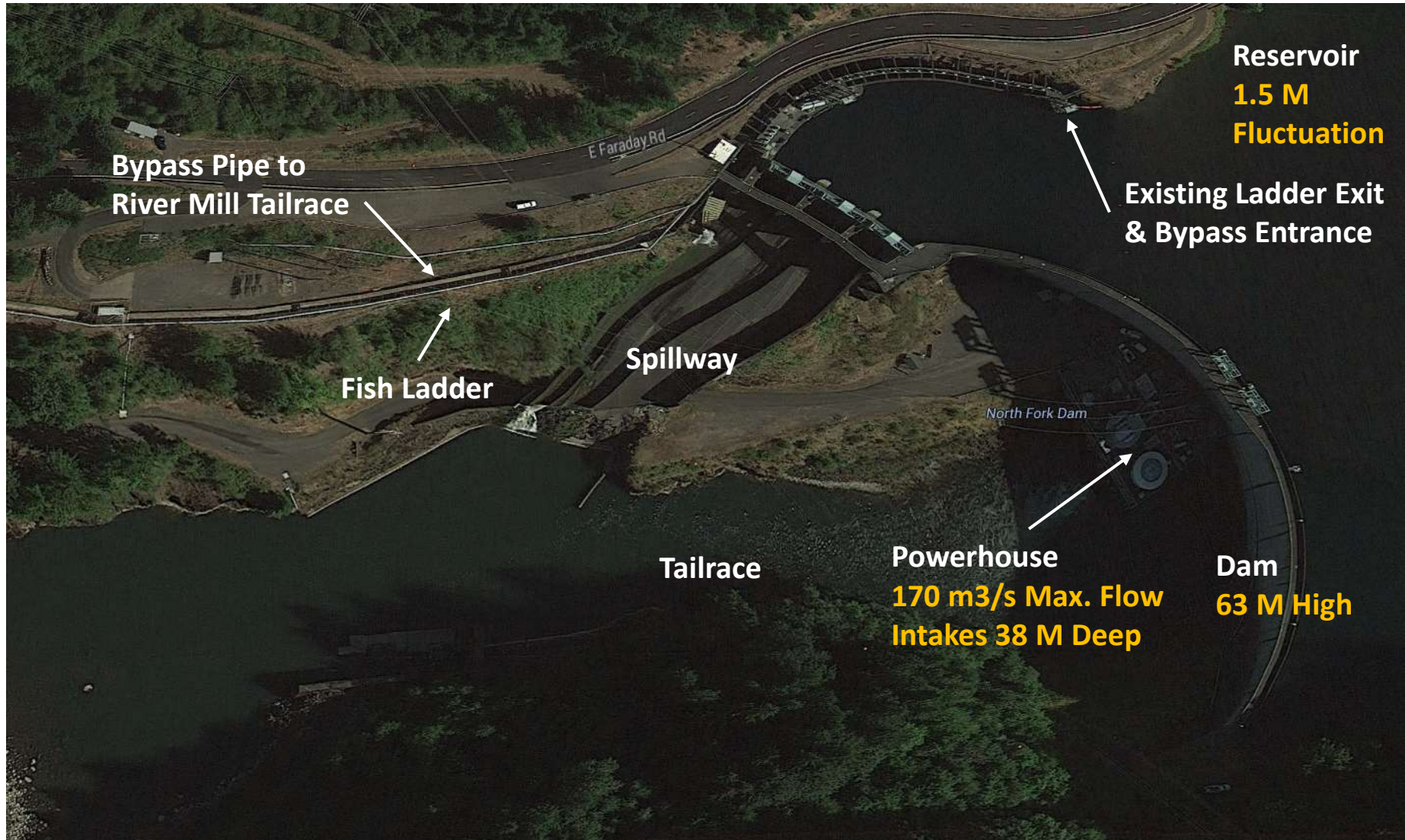


Net Attachment Adjacent to Collector Entrance

- Allows Net to Rise and Lower with Reservoir
- Allows for Sinking of the Net to the Bottom during Periods of large Spill to Protect Net

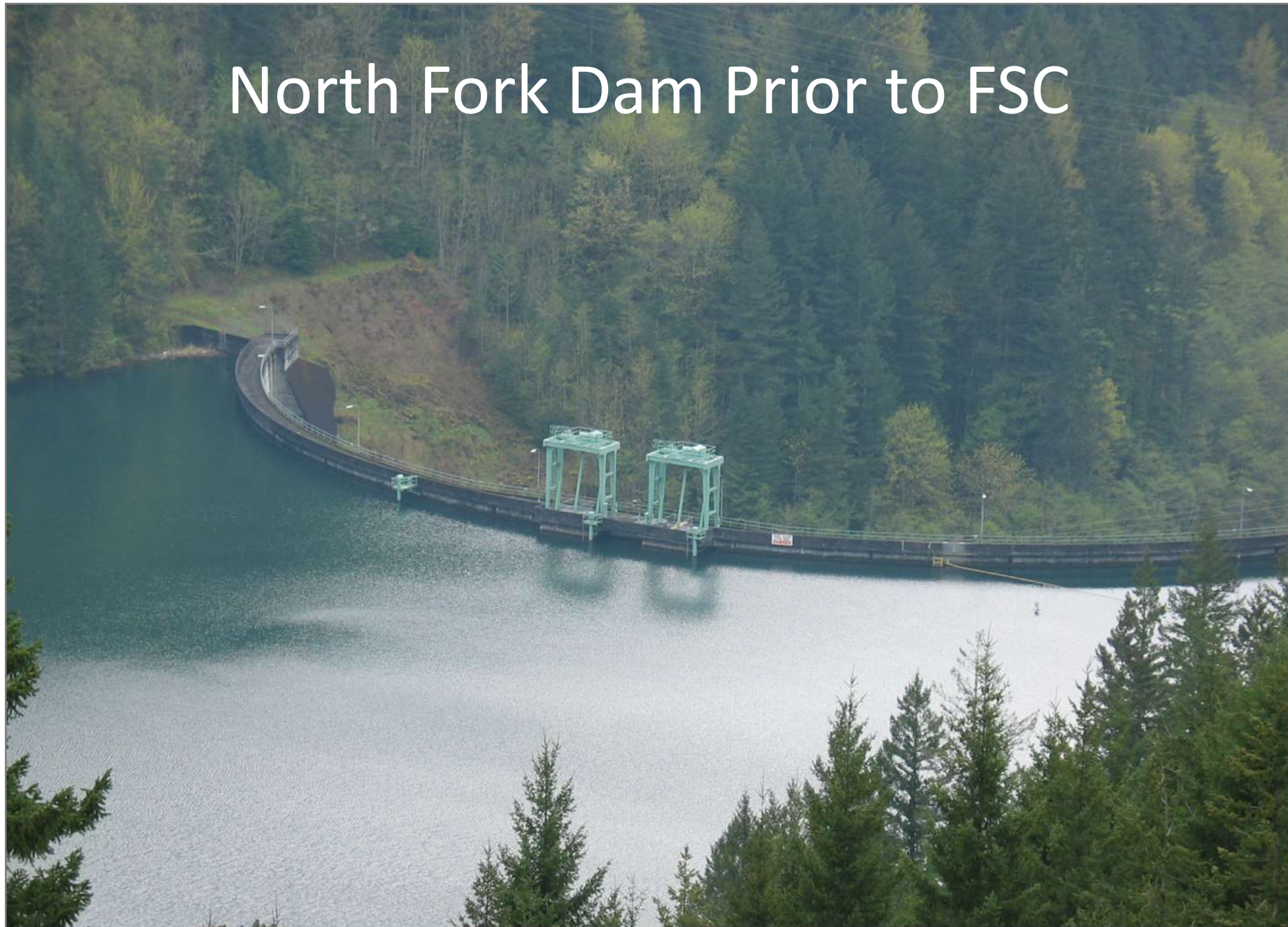
# North Fork Floating Surface Collector - FSC

## Aerial View of North Fork Dam (Prior to FSC)





# North Fork Dam Prior to FSC



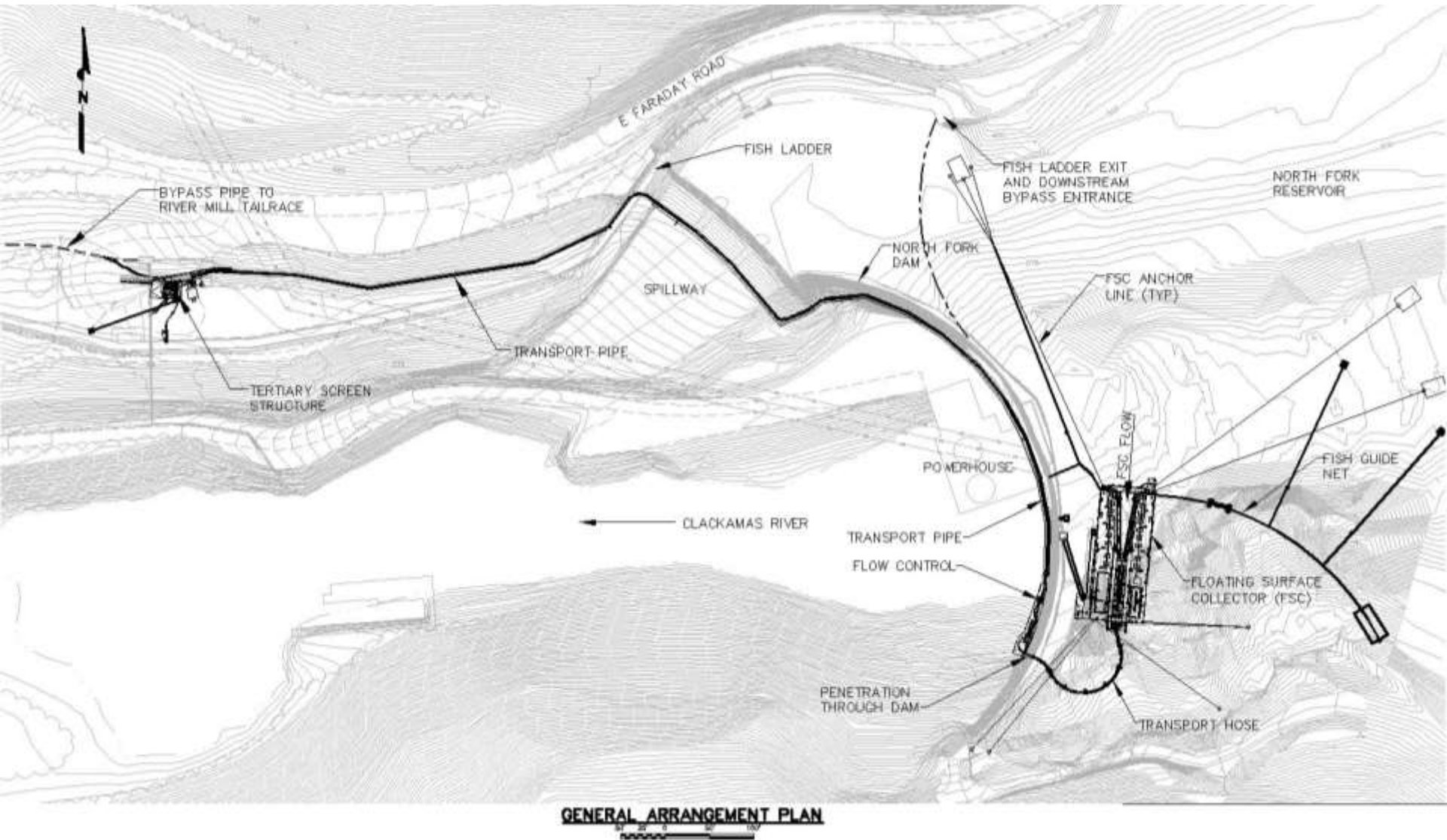


# North Fork Dam with FSC

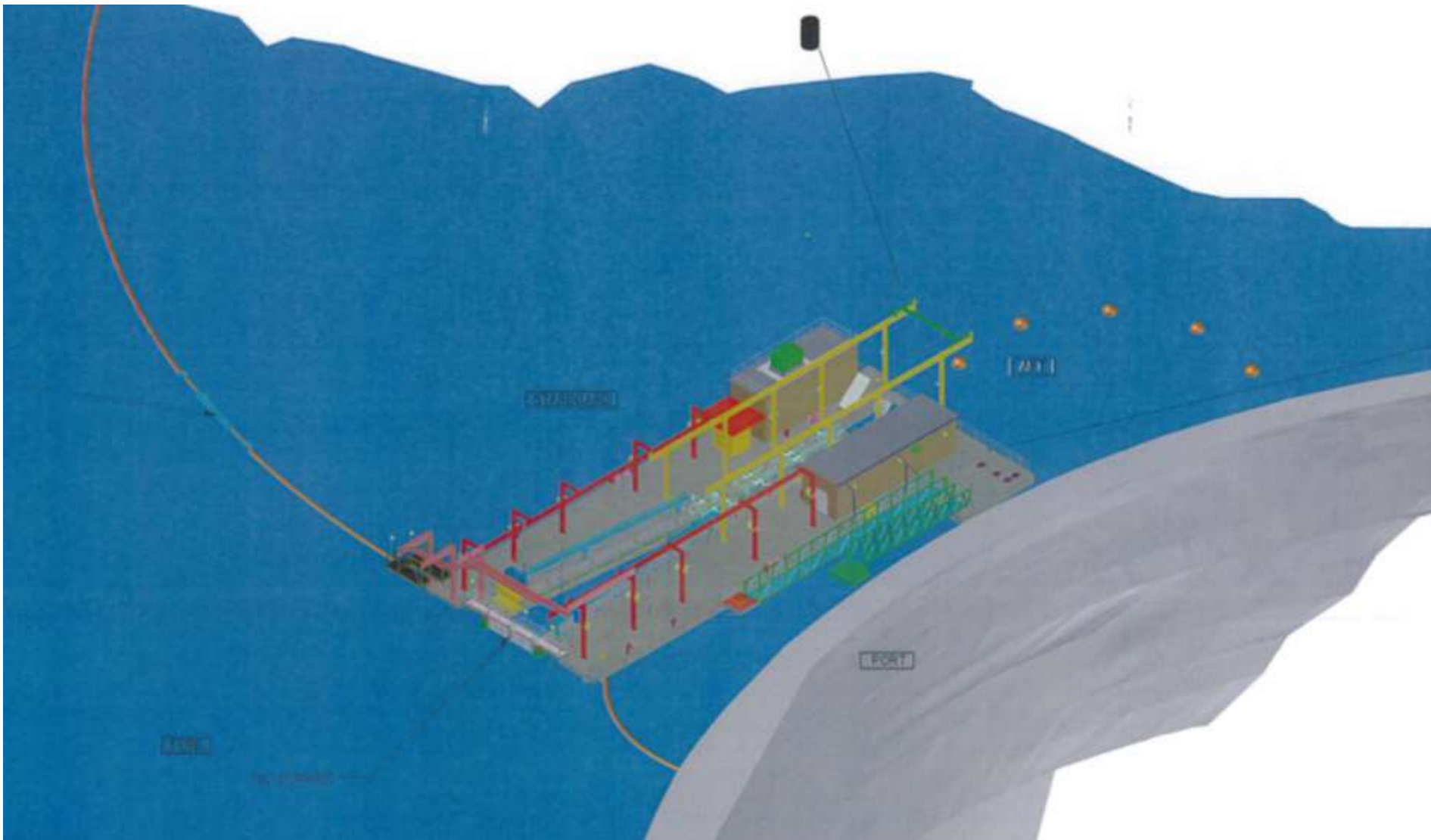




# Overall Plan View of North Fork FSC Project



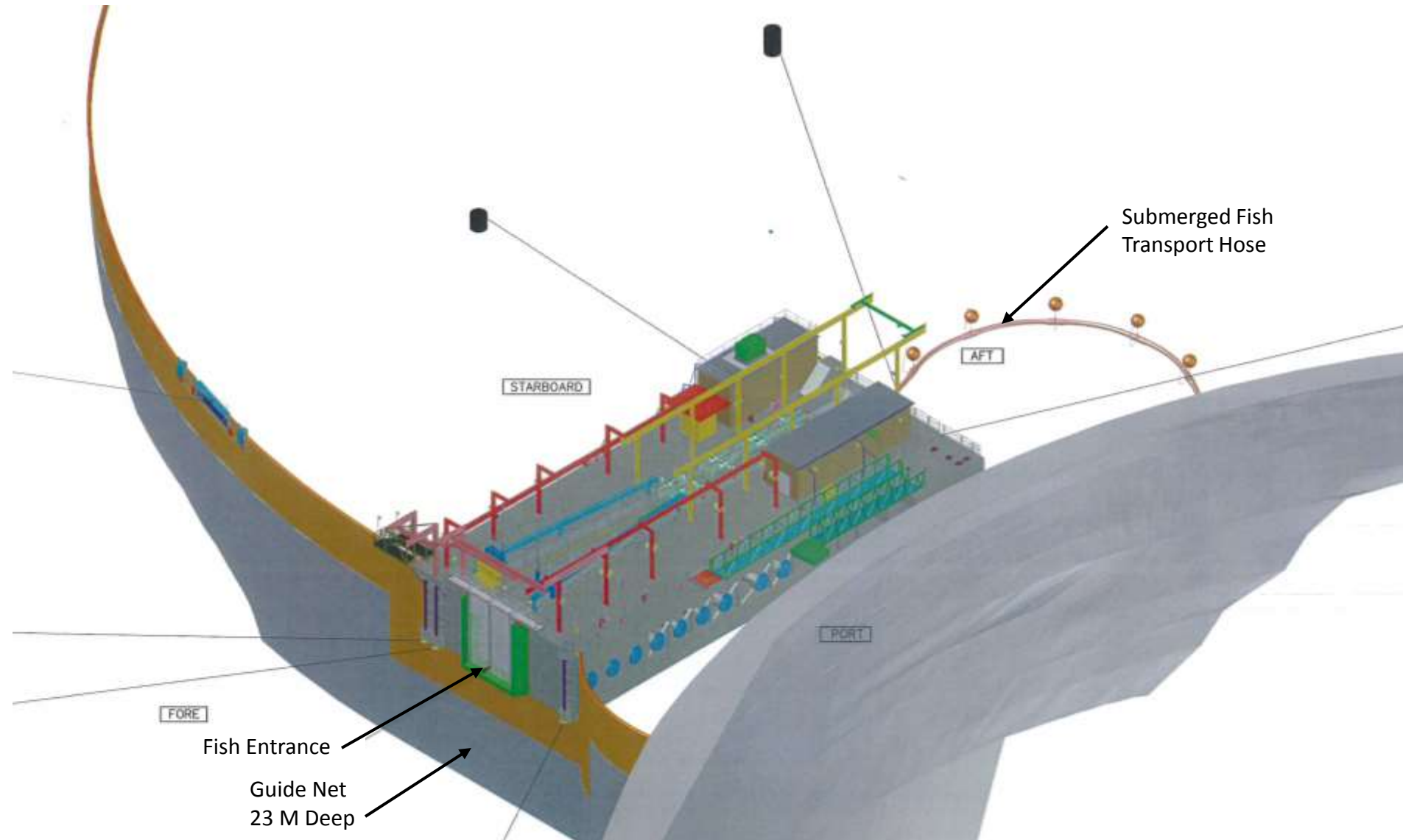
# Isometric Drawing of FSC Installed



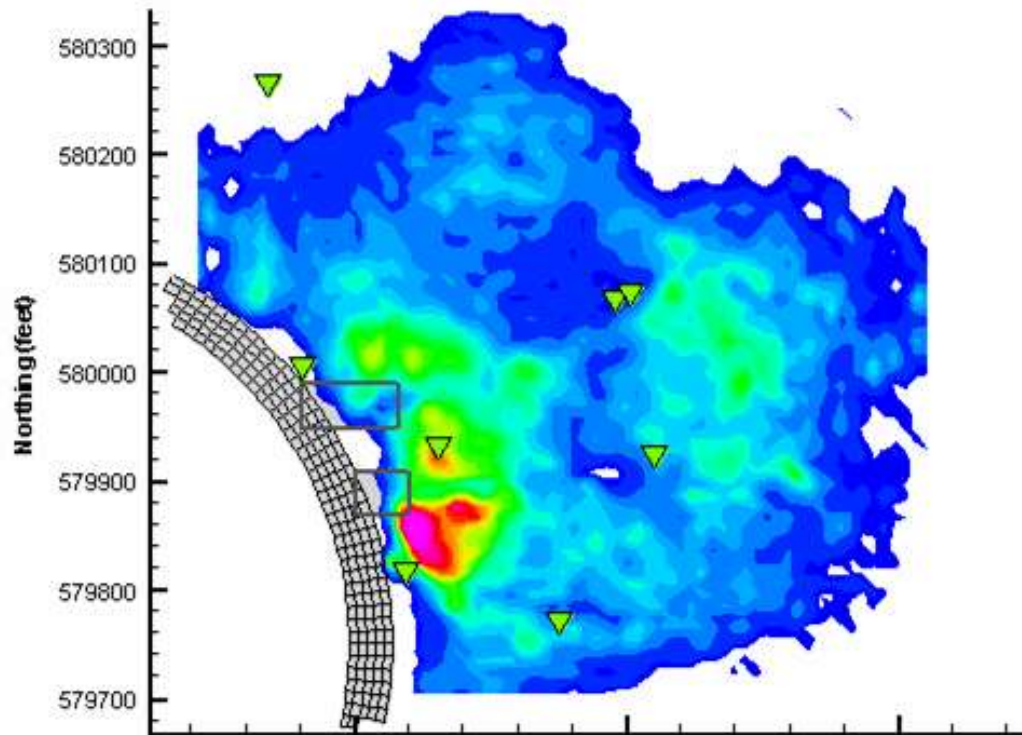


# Isometric Drawing of FSC

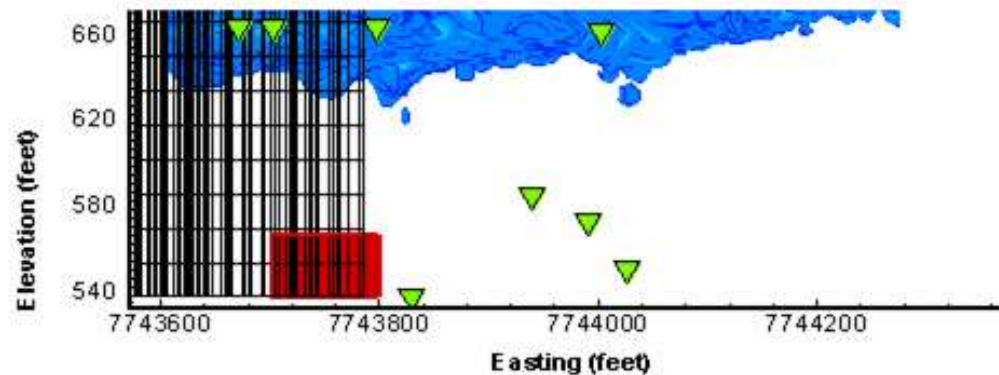
(with view of below water components)



# 2001 Acoustic Tag Study Results

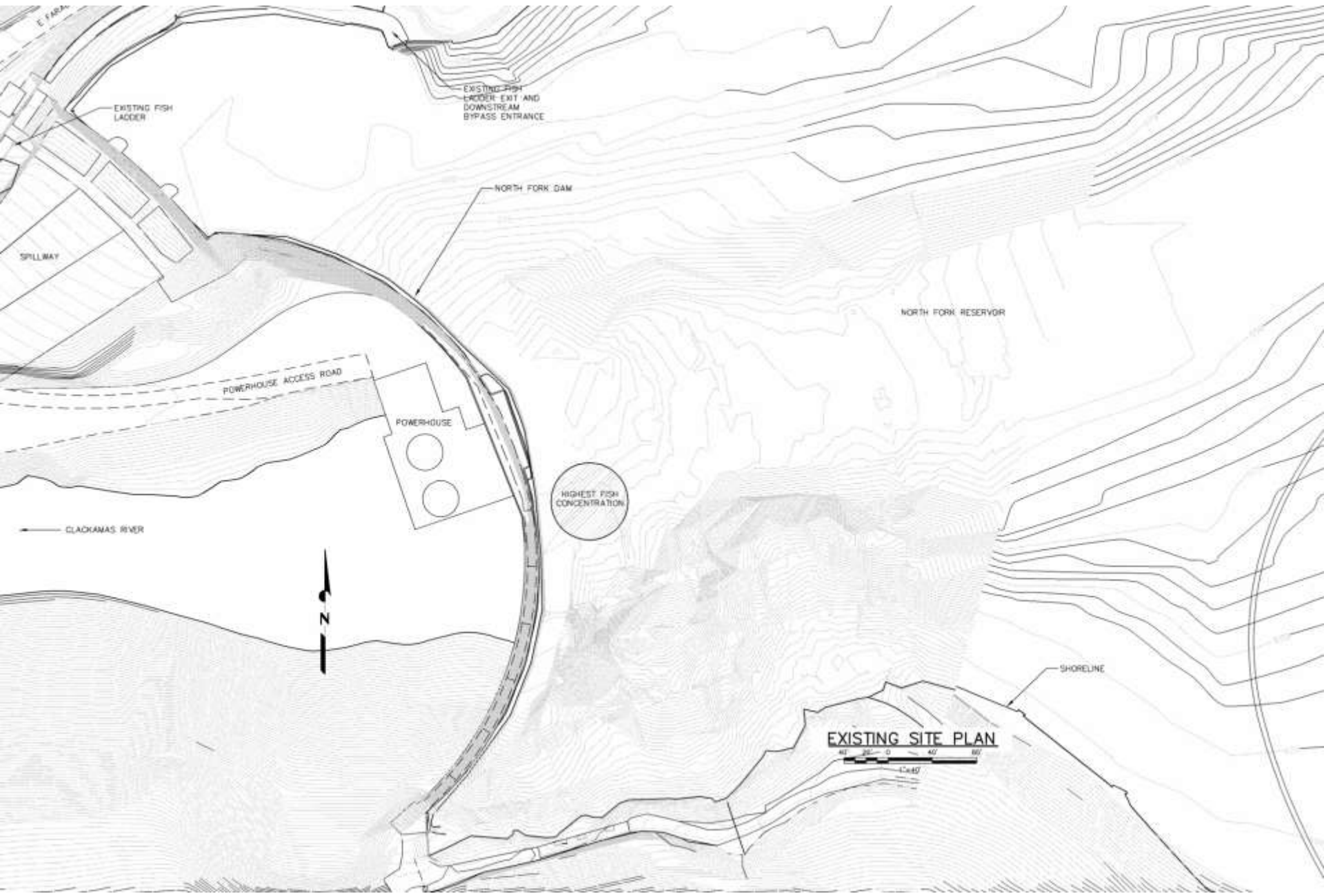


Red Areas Represent the  
Highest Concentration of  
Detections

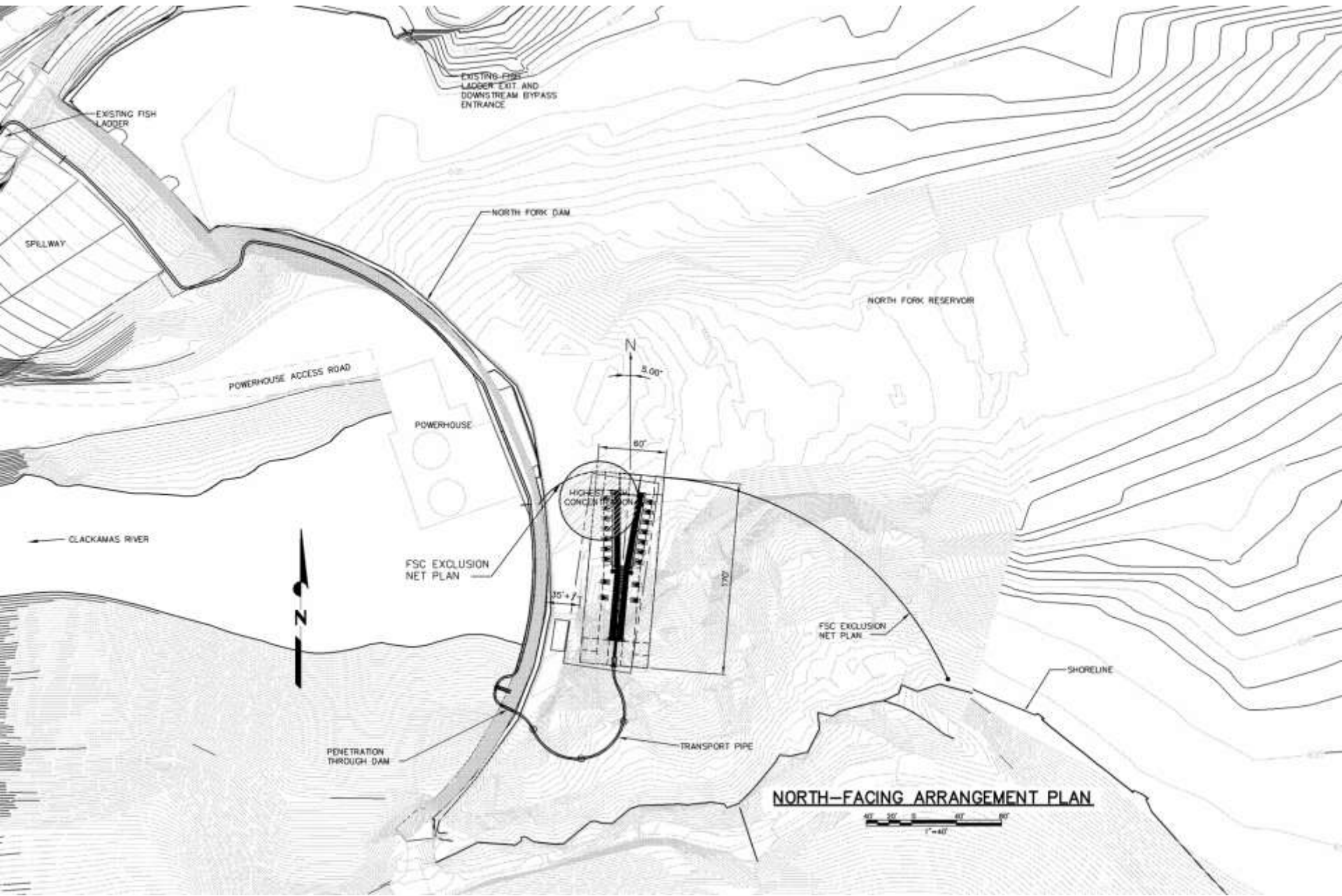




# Forebay Plan (with Fish Concentration Highlighted)

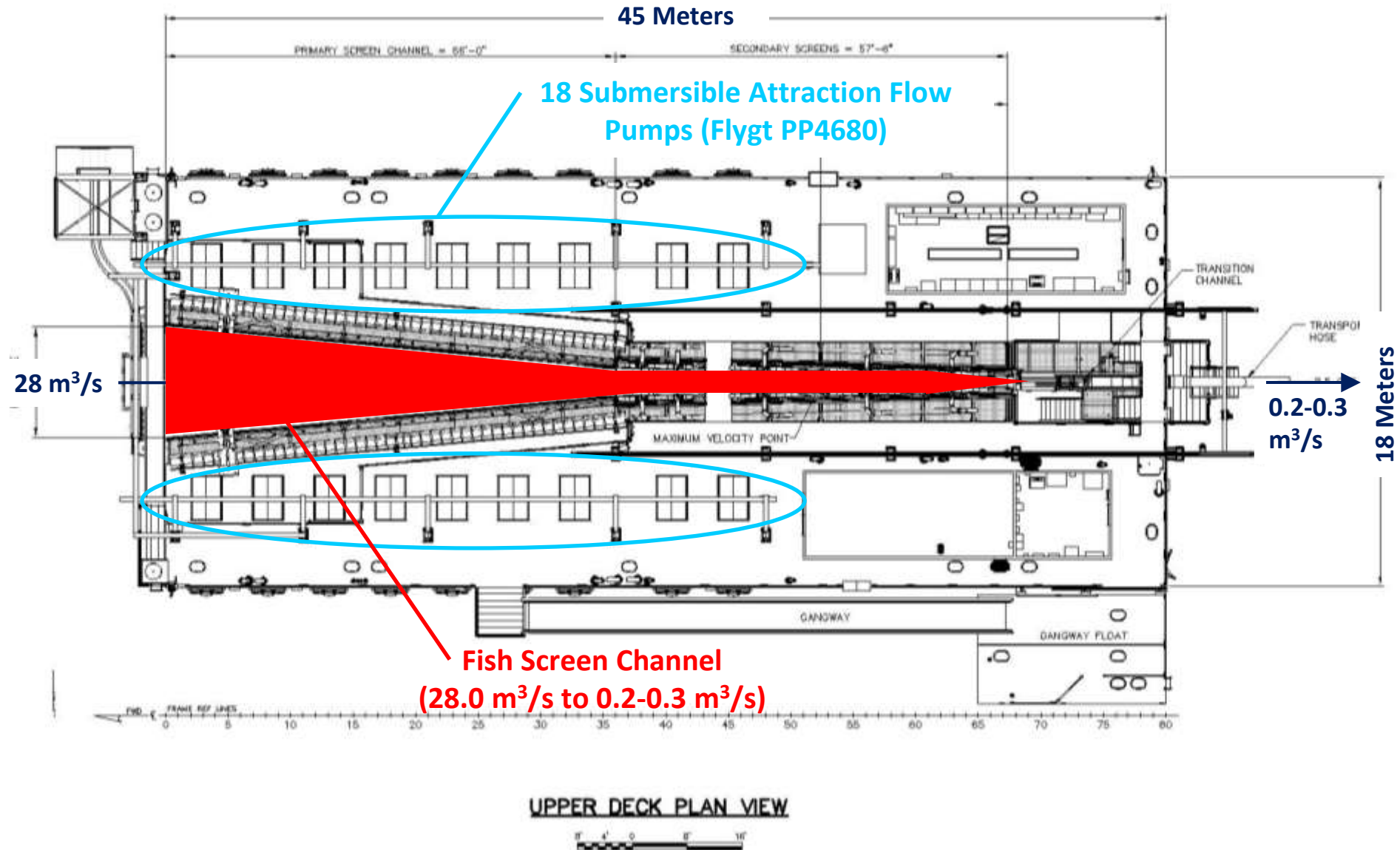


# FSC Entrance Located at Natural Fish Concentration

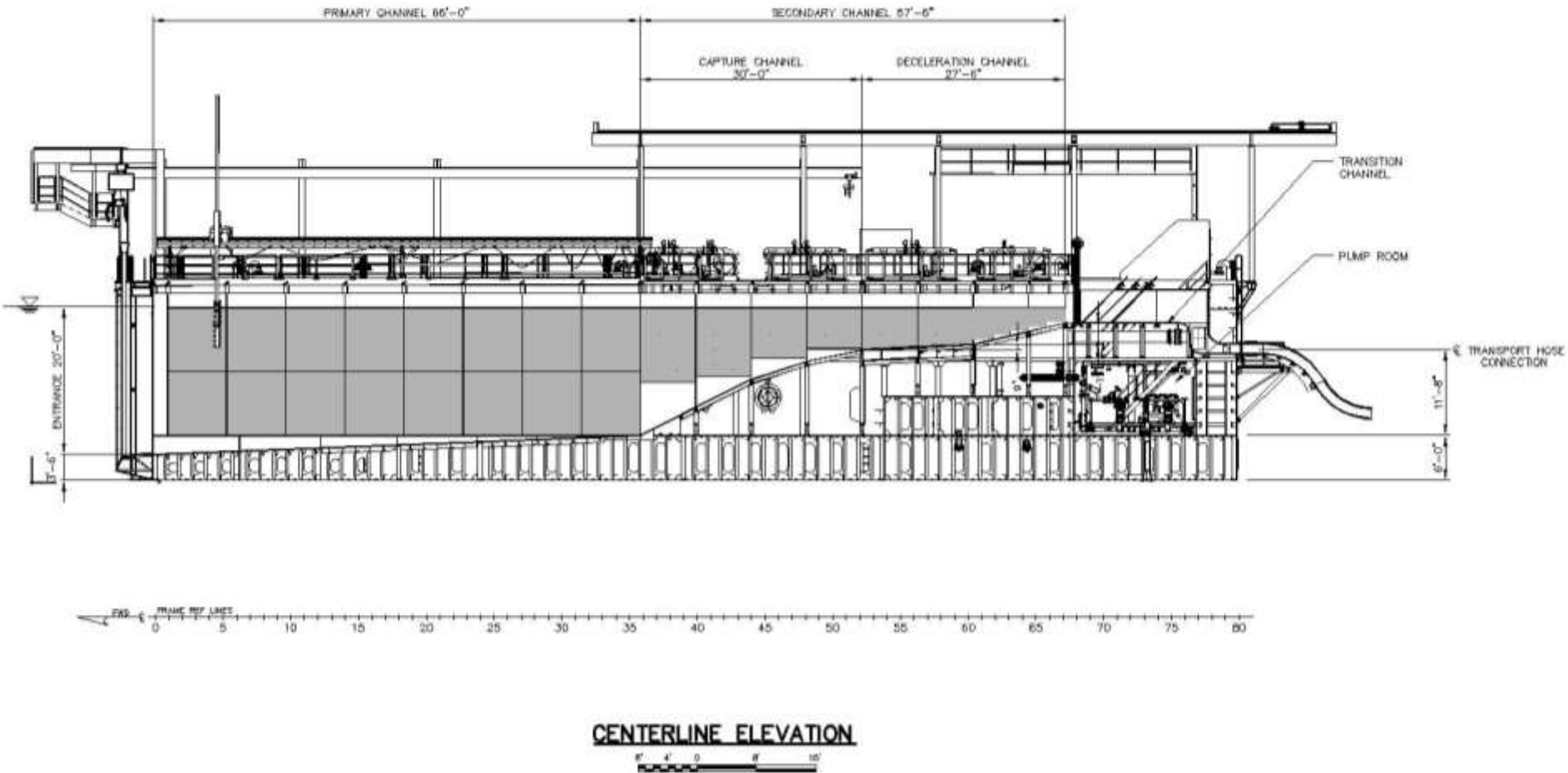




# Plan View of the FSC Upper Deck



# Centerline Profile of the FSC Fish Screen Channel





# Fish Screen Channel



# Transition Channel

**Positioned at Downstream  
End of FSC between the End  
of the Screen Channel and the  
Fish Discharge to the  
Transport Hose**

**Includes Three Half Racks to  
Remove Debris from the Fish  
Flow**





# FSC Dry Construction and Launching



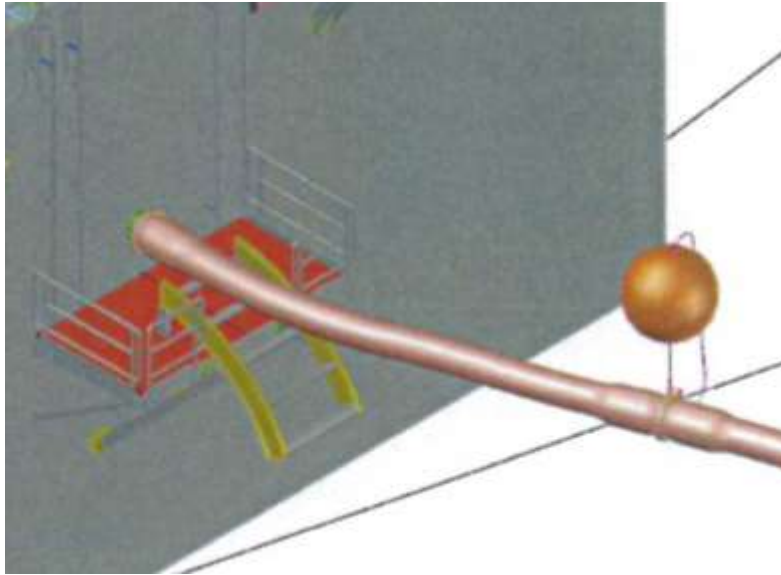


# FSC and Submerged Transport Hose Floats

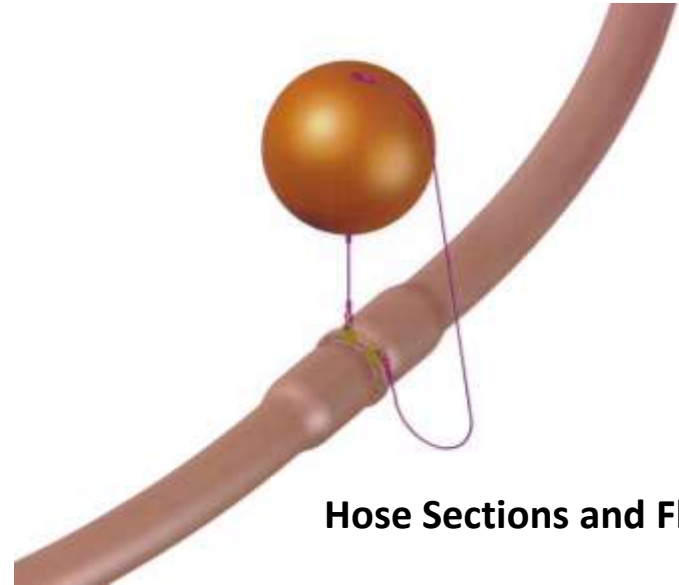




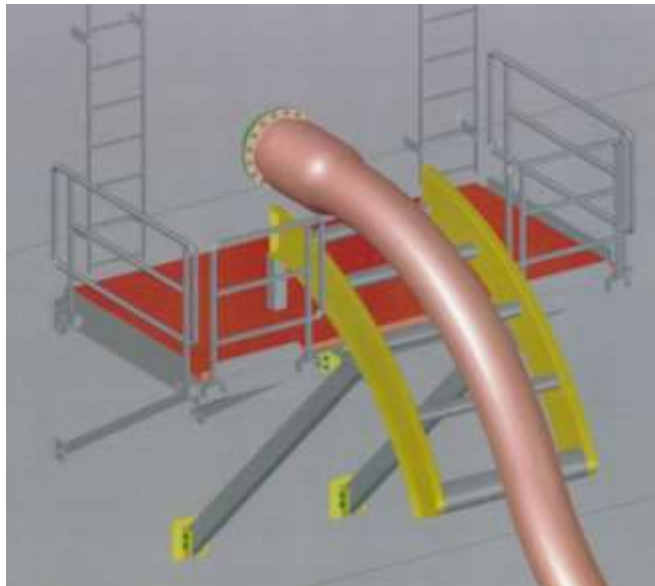
# Design Features of Submerged Transport Hose



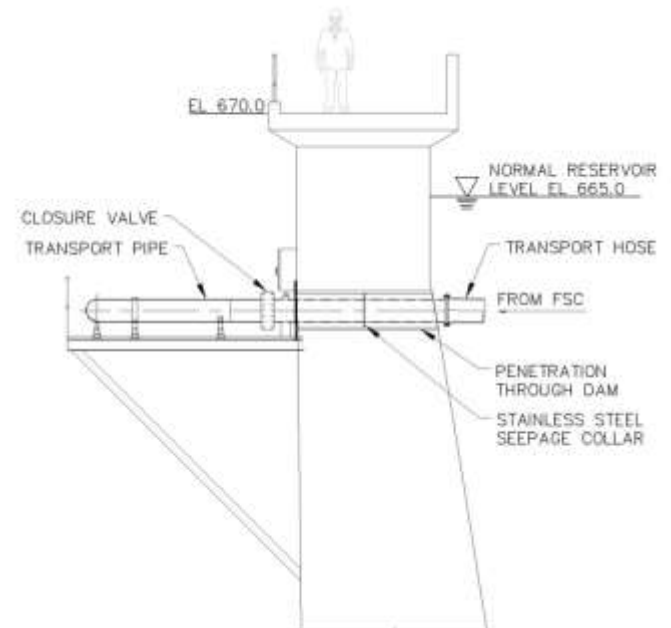
**Hose Connection in Operating Position**



**Hose Sections and Floats**



**Hose Connection in Raised FSC Position**



**Dam Penetration**

# Fish Transport Pipe



**Transport Pipe Along Dam Face**



**Transport Flow Control**



# Fish Transport Pipes Along North Bank



Tertiary Dewatering  
Structure (TSS)

Transport Pipe from  
North Bank Collector

Transport Pipe  
from FSC

# Tertiary Screen Structure During Construction

## Right Bank Collector Flow Operating





# Tertiary Screen Structure (detail photos)



**Fish Discharge from Transport Pipes**



**Traveling Screens and Trashrack**



**Debris Trough Discharge**



# Preliminary Test Results

FSC Completed in September 2015 (ahead of schedule).

Formal Testing of Fish Passage Effectiveness in Spring 2016.

Results are Preliminary (2015) and Initial Formal (2016) Tests.

	Release Groups		Passage	Guidance Rate			% Thru FSC
Species	# Groups <sup>1</sup>	# Released	# Detected	Min	Mean	Max	Mean
Coho <sup>2</sup>	4	401	379	93%	95%	96%	69%
Steelhead	6	515	492	93%	96%	99%	56%
Chinook <sup>3</sup>	1	55	48	NA	87%	NA	92%

1. Pooled head-of-reservoir and forebay release groups. Guidance rates from two locations were not statistically different.

2. Two groups excluded due to anomalously low guidance performance (53 - 75%). Inclusion in final estimates TBD.

3. Chinook test performed in the fall on 2015, prior to the start of formal biological testing.



# Original River Mill Project Layout (2005)



# Experimental Test Channel (2007)





# Integrated Collector & Bypass (2013)



Screened Downstream Migrant Collector  
Incorporating Unit 5

Unit 4

Unit 3

Unit 2

Unit 1

14.1 cms

# Forebay Fish Collector Entrance

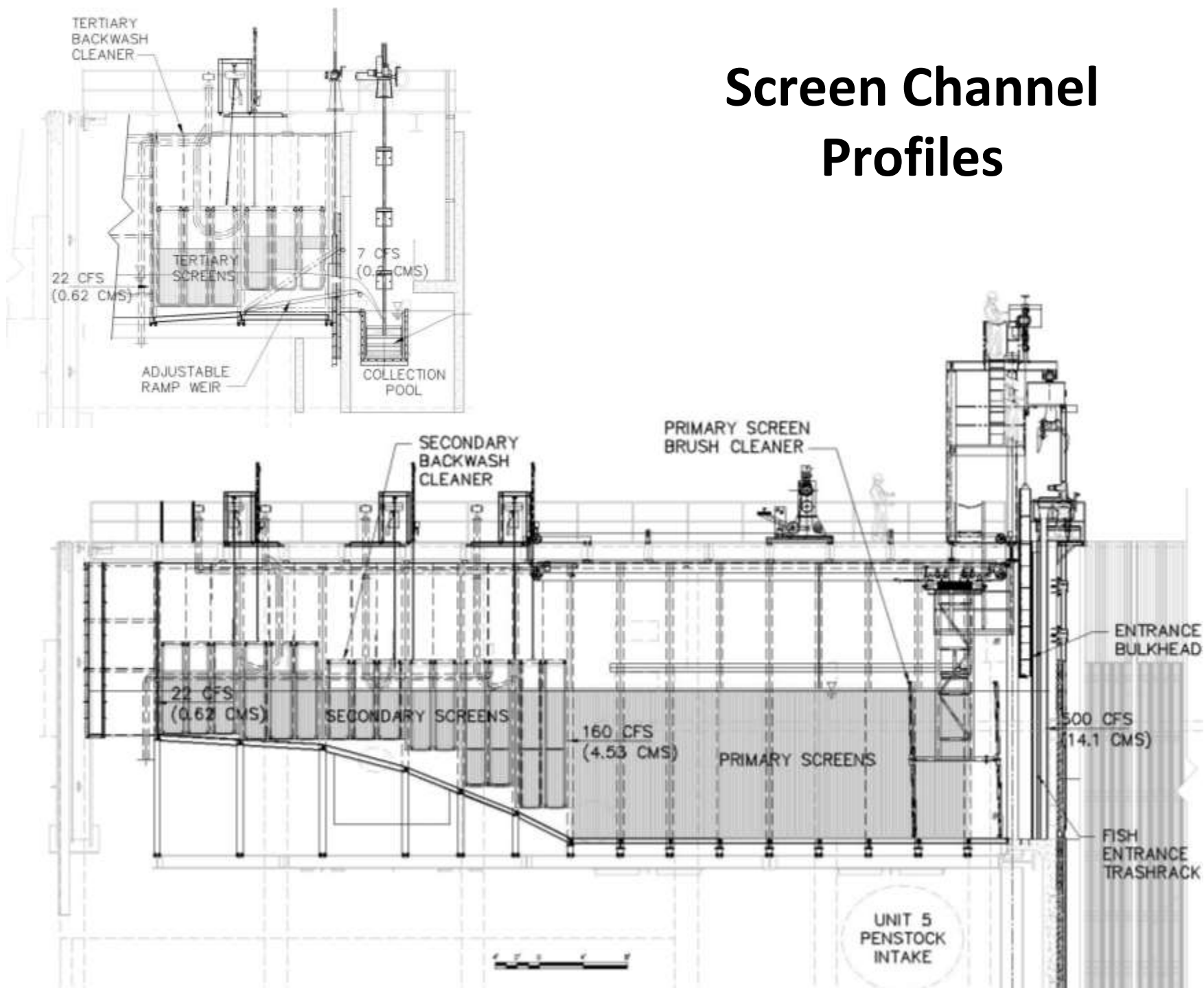




# Forebay Fish Collector Aerial View

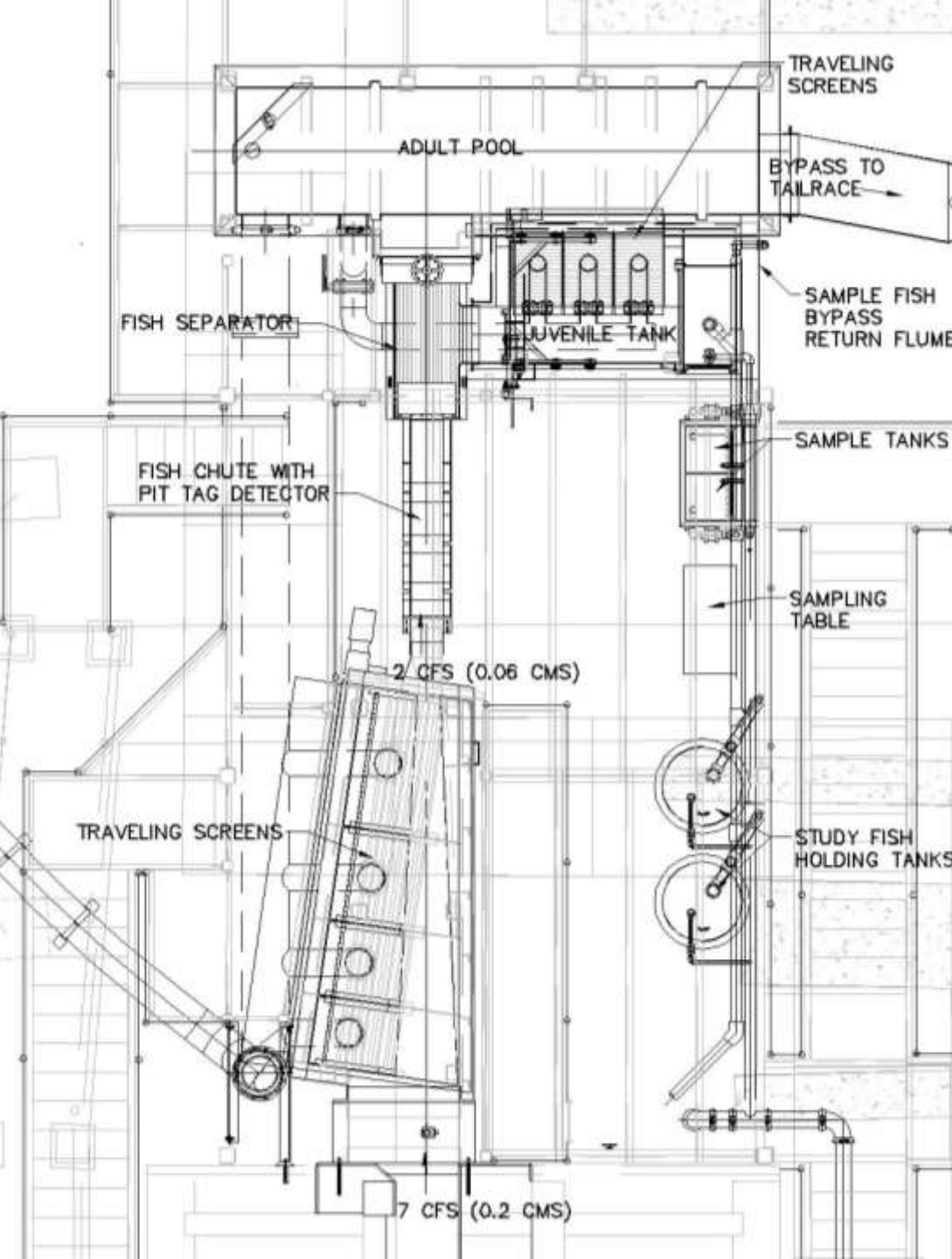


# Screen Channel Profiles





# Fish Sampling Station Plan



- Fish flow is dewatered from 0.2 to 0.06 m<sup>3</sup>/s
- Smaller juvenile fish are separated from larger adult fish.
- Juvenile fish are held for sampling.
- Adult fish pass into adult pool and then directly into the downstream bypass pipe.

# Fish Sampling Station on Downstream Side of Dam





# Bypass Pipe across Powerhouse Roof



# Biological Monitoring Results

Based on PIT Tag Studies in 2013 and 2014

## Collector Fish Guidance Efficiency

Chinook Salmon	98%
Coho Salmon	99%
Steelhead	96%

## Lake Survival

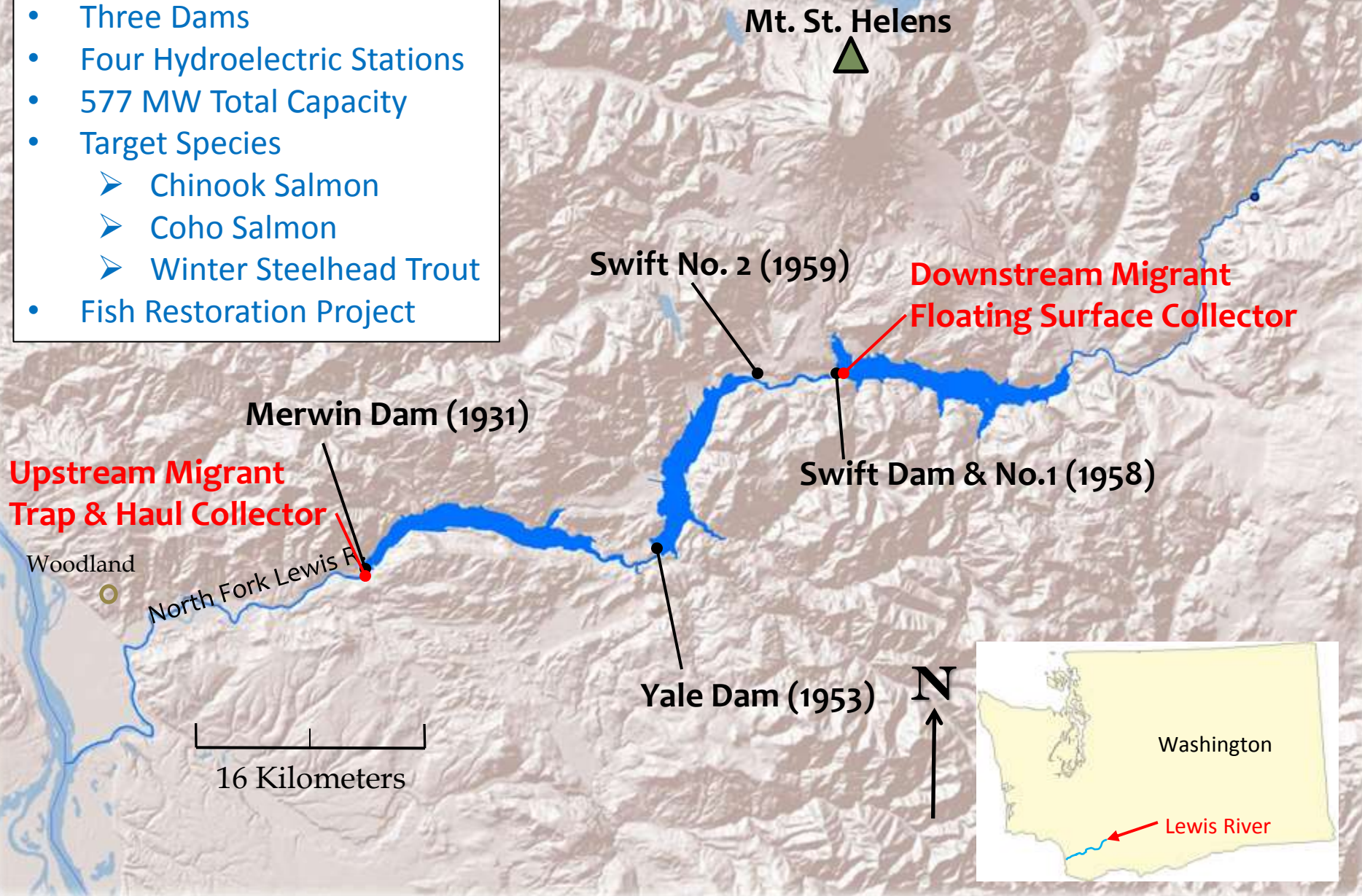
Chinook Salmon	99%
Coho Salmon	96%
Steelhead	96%

Injury Rates were consistently below 2%



# Lewis River Hydroelectric Project

- Three Dams
- Four Hydroelectric Stations
- 577 MW Total Capacity
- Target Species
  - Chinook Salmon
  - Coho Salmon
  - Winter Steelhead Trout
- Fish Restoration Project



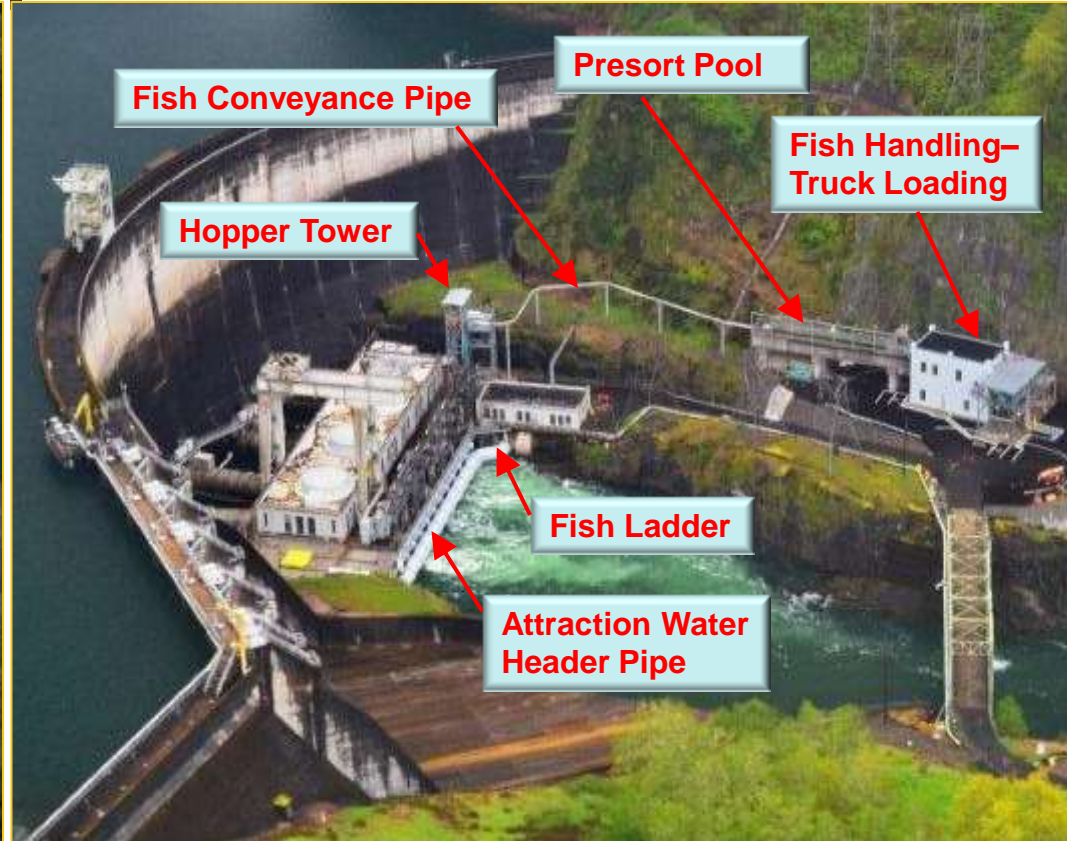


# Upstream Passage on Lewis River

Merwin Dam (Pre-Project)



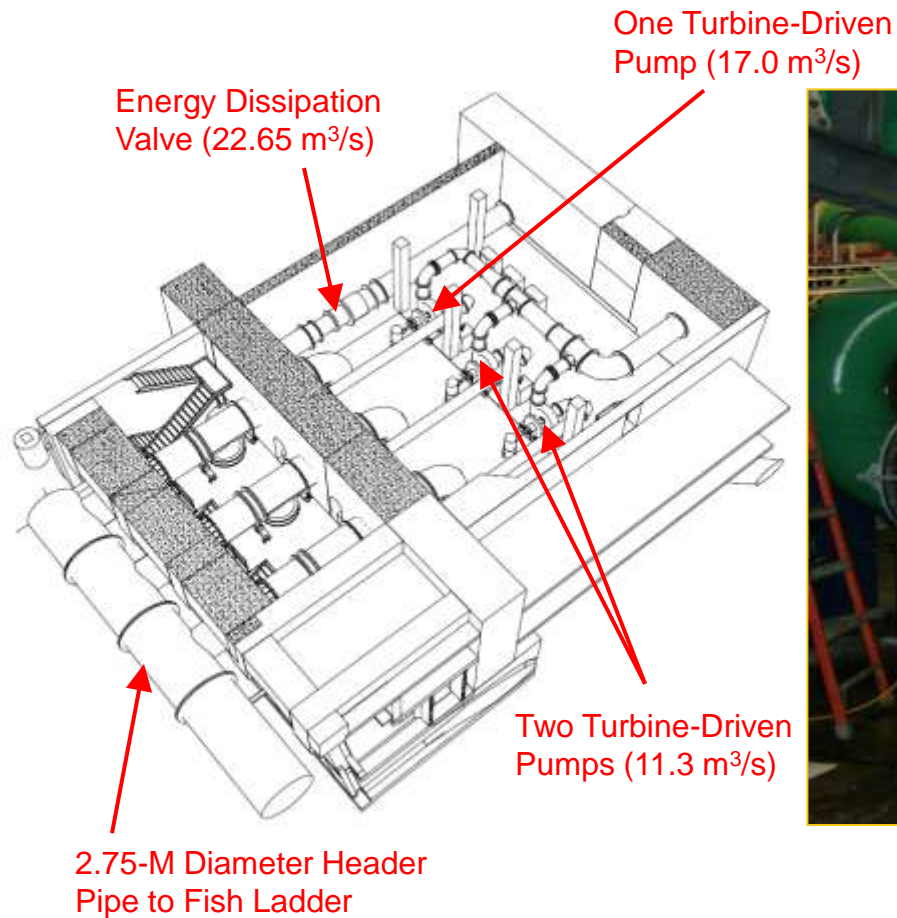
With New Trap & Haul Facility (2014)



- First Dam Encountered from Pacific
- Original Construction 1931
- 3 Turbine Units (Constructed with a 4<sup>th</sup> Future Turbine Bay)
- Originally Trapped and Trucked Fish Upstream but Unsuccessful – Abandoned in 1940's
- New Trap & Haul Facility to Restore Upstream Stocking and Wild Fish Restoration



# Fish Attraction Water Supply

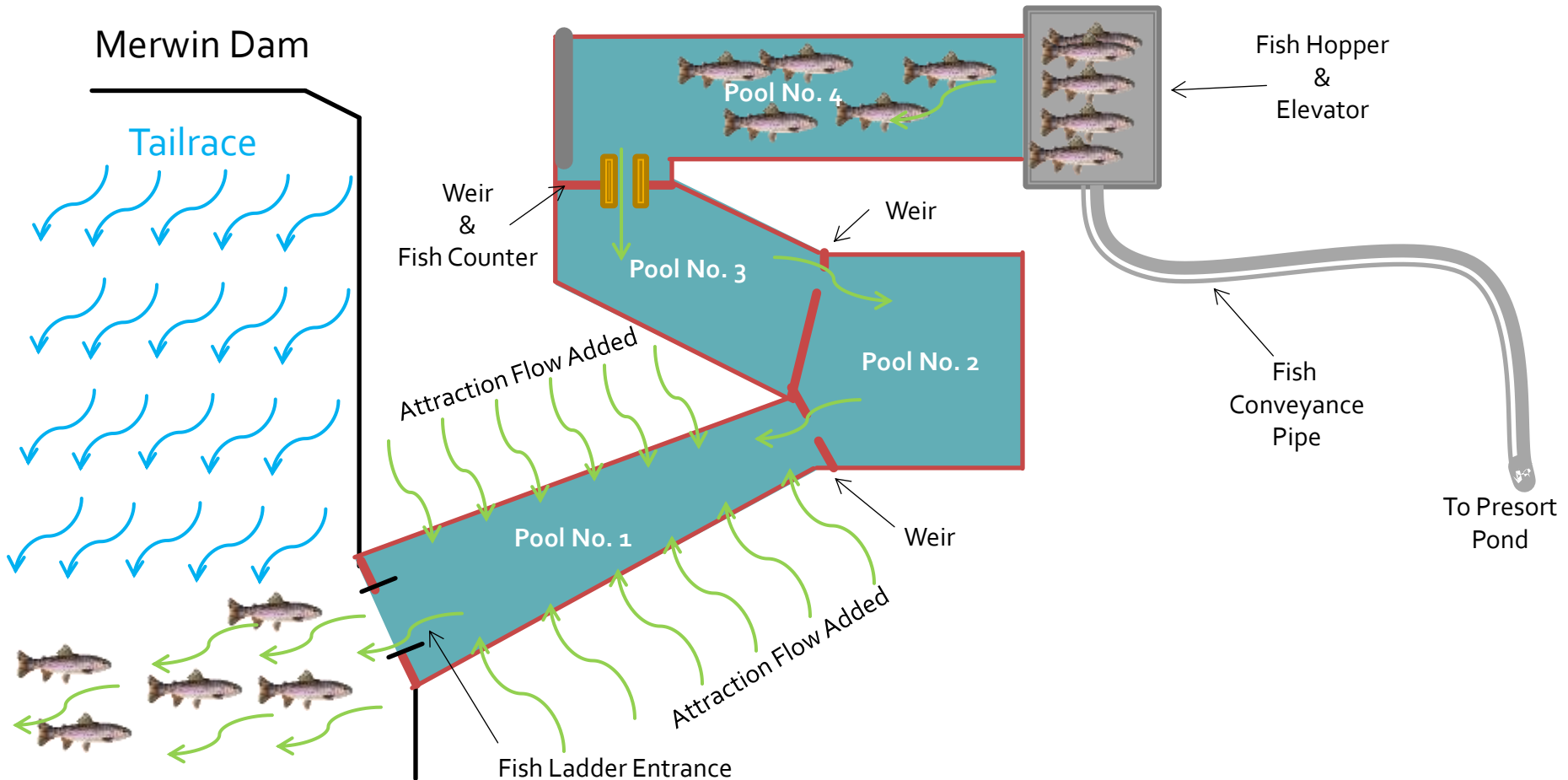


## Two Installed Turbine-Driven Pumps



- Took Advantage of the 4<sup>th</sup> Empty Turbine Bay to House the Turbine-Driven Pumps
- Quantity of Attraction Flow Tested in 3 Phases
  - Phase 1: 11.3 m³/s
  - Phase 2: 17.0 m³/s
  - Phase 3: 22.65 m³/s

# Fish Ladder and Conveyance System





# Fish Lift Hopper



Hopper Lift Tower

Fabricated Fish  
Hopper



Hopper at Top of  
Tower Discharging  
to Conveyance Pipe



# Fish Conveyance Pipe & Presort Pool





# Fish Sorting & Handling Facility



Entry Flume from  
Presort Pool

Fish Sorting &  
Handling Table



# Fish Transfer Tanks & Truck Loading



Fish Holding Tanks for  
Transfer to Transport Trucks

Water-to-Water Transfer of  
Fish to Truck Tank





# **Downstream Passage on Lewis River**

## **Swift Reservoir Floating Surface Collector (FSC) 2012**



### **Swift Reservoir FSC**

- **Dam Height 156 Meters**
- **Reservoir Fluctuation up to 30.5 Meters**
- **FSC Attraction Flow 17.0 m<sup>3</sup>/s**
- **Fish Sorted Onboard into 3 Sizes**

# Varying Reservoir Level



Near Full Pool Elevation



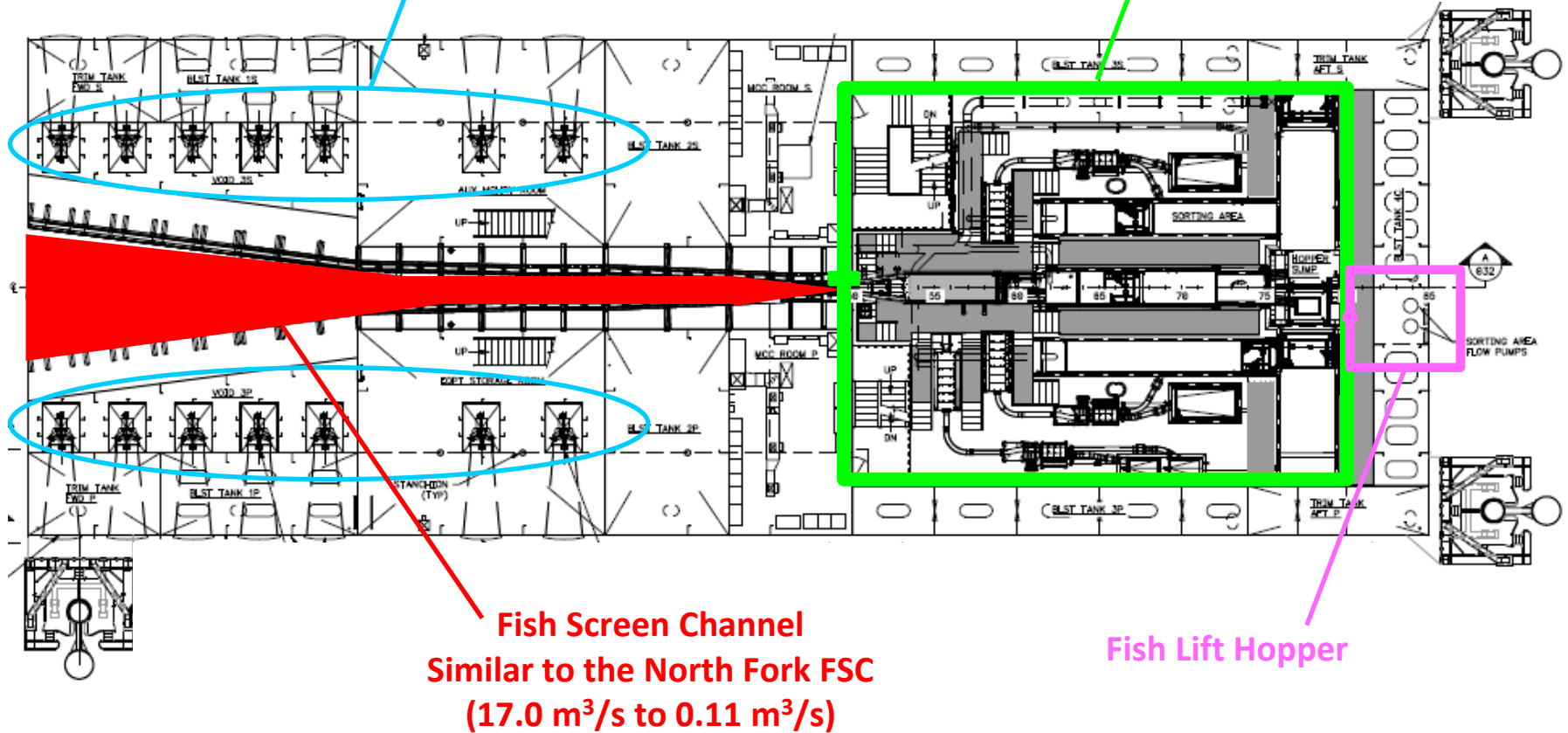
Down Approximately 21 Meters



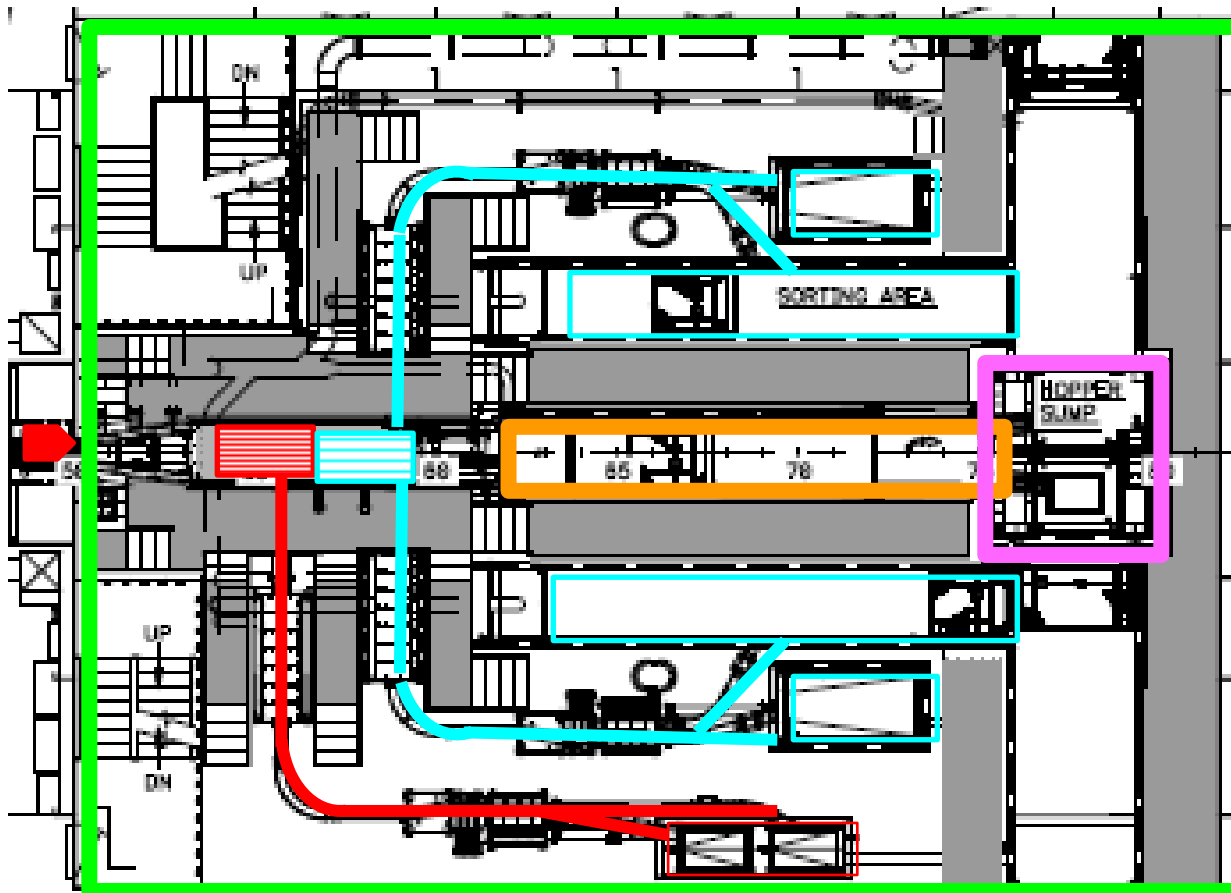
# FSC Plan View Layout of Facilities

## 14 Submersible Attraction Flow Pumps (Flygt PP4680)

## Fish Sorting & Handling Facilities



# Fish Sorting & Holding Facilities



Fry



Smolt



Adult

Birds eye view of separation and holding level



# Sorting & Handling Details



Fry and Smolt Separators



Fry Switch Gate and  
Holding Tank



Smolt Holding &  
Sample Tanks



Smolt Sample Tanks  
Raised to Sampling  
Facilities Above

# Fish Transfer Hopper



Being Raised out of FSC



Being Lifted to Loading Bay

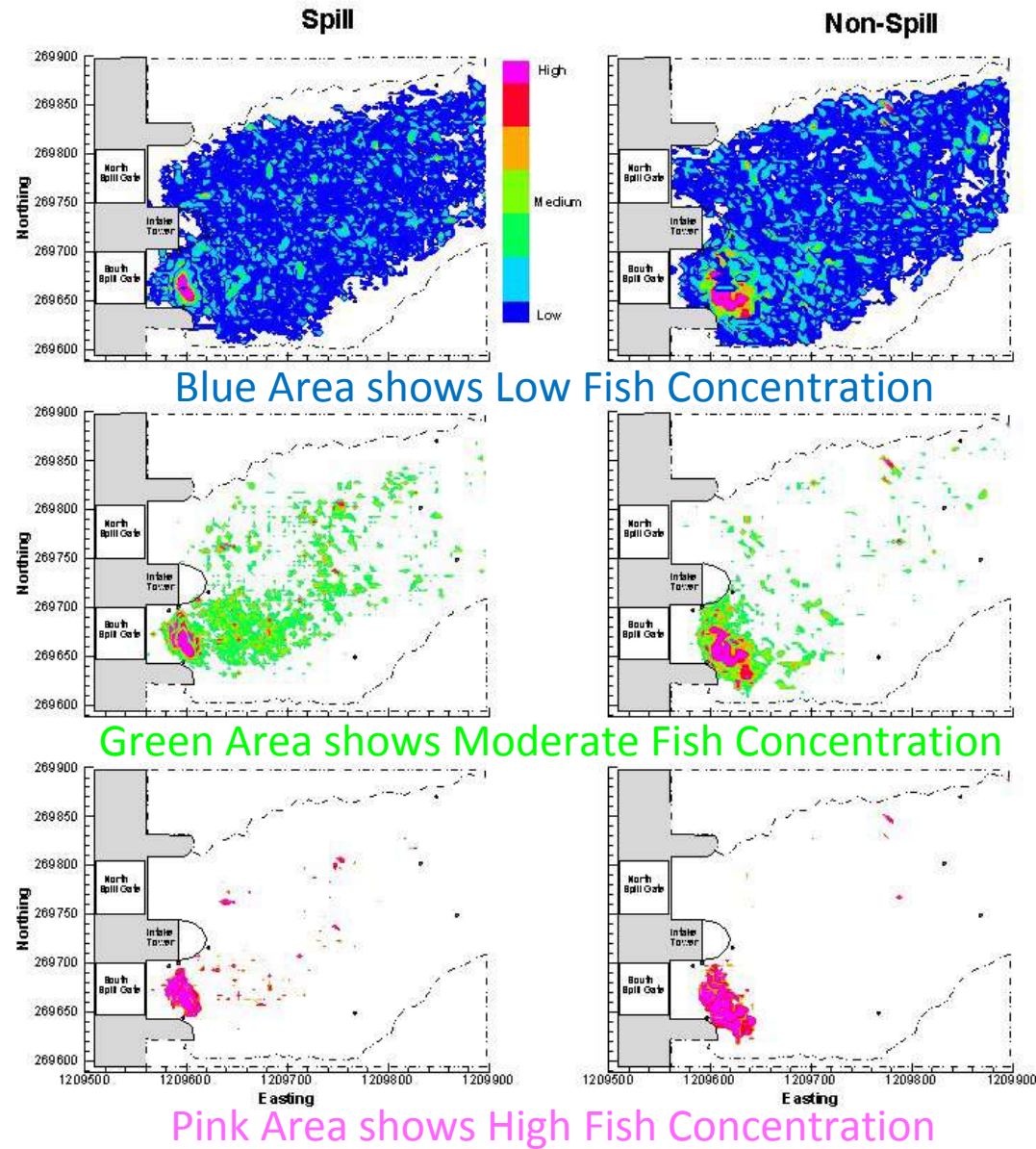
Transfer of  
Fish to Truck



Transport Truck in Loading Bay



# Restricted Choice of Location



Results of 3-D Radio Tagging Smolt Study



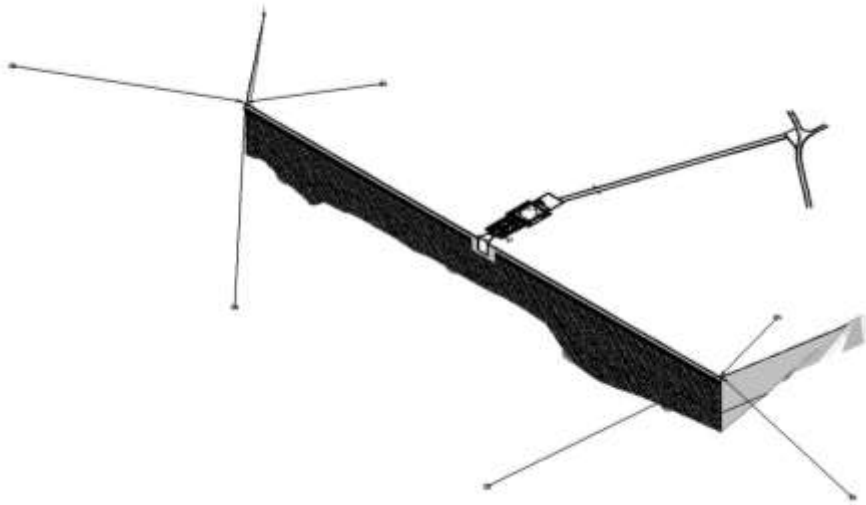
Intake Area during Extreme Low Pool



Location of FSC Mooring Tower

# Exclusion Net

Full Exclusion Netting  
Shore-to-Shore  
Surface-to-Bottom



Poor Collection Efficiency in First  
Few Seasons of Collection



# Lead Net

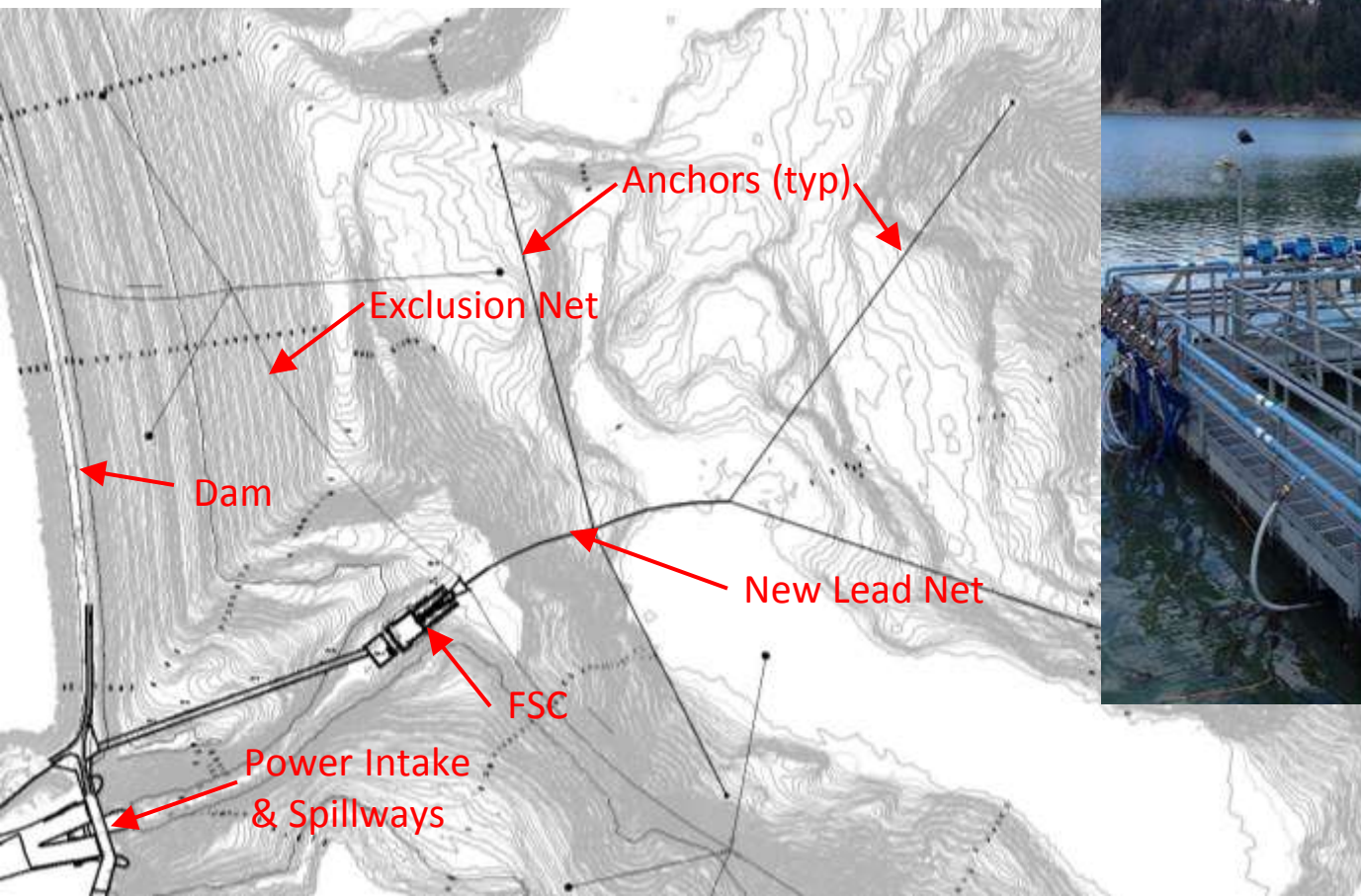
Lead Net Added (2015)

Deflects Fish Wandering Forebay toward FSC

Tested in 2016

More than Doubled the Collection Efficiency

Plan View Layout of Lead Net

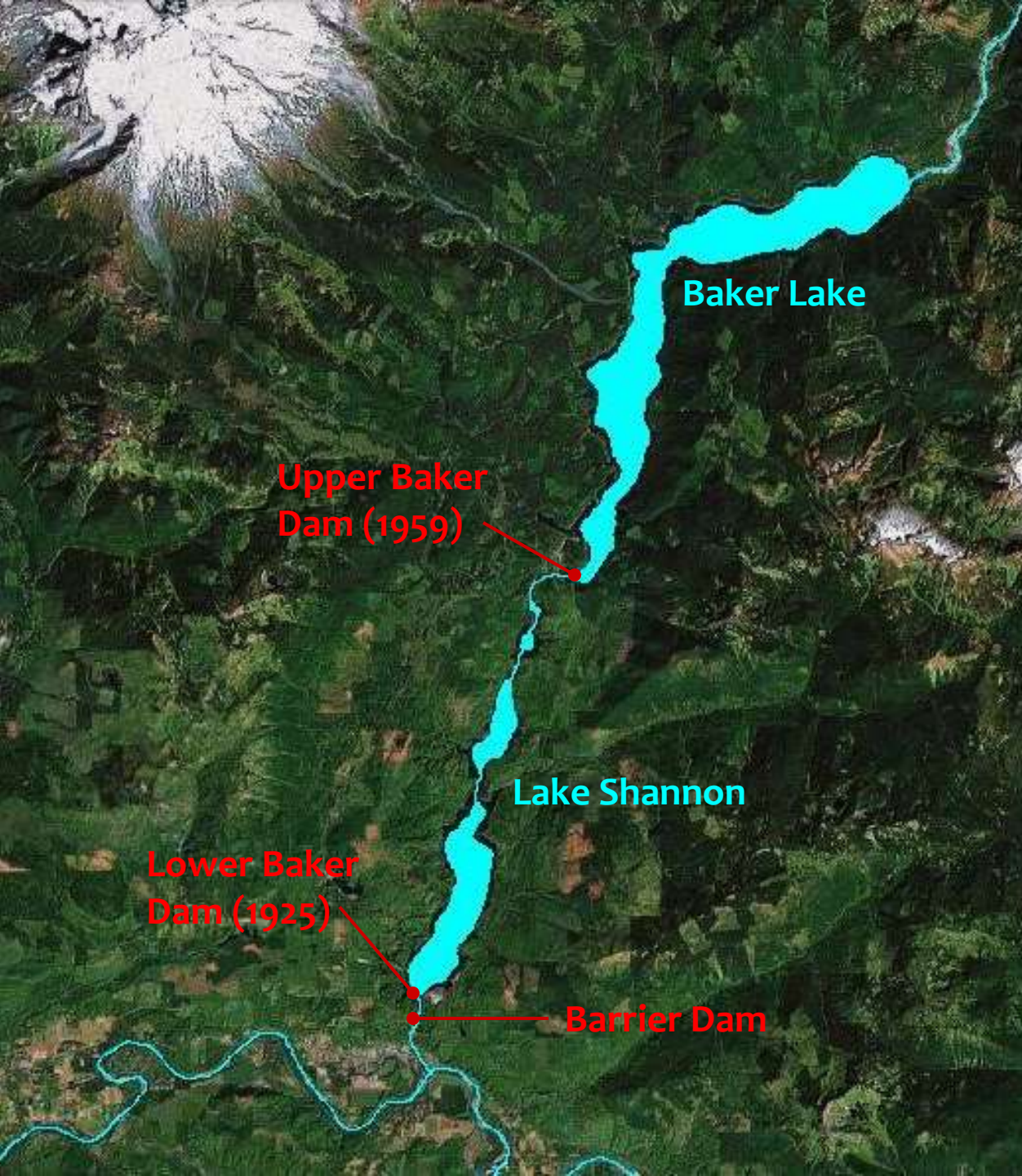


Installed Lead Net



# Baker River Hydroelectric Project

- Three Dams
- Two Hydroelectric Stations
- 170 MW Total Capacity
- Target Passage Species
  - Sockeye Salmon
  - Coho Salmon
  - Bull Trout
- Success of New Passage Projects has Resulted in Recreational Sockeye Fishery in Both Reservoirs





# Barrier Dam



- First Dam Encountered from Pacific
- Constructed with Lower Baker Dam to Trap Fish
- Original Fish Trap Entrance on Right
- 1925 to 1959 Lifted Fish Above Lower Baker with Gondola Baskets
- 1959 to 2010 Trucked Fish Unsorted above Both Dams

# Upstream Passage on Baker River



Old Hopper Lift Facility (1959)

New Fish Lock Facility (2010)





# Entrances to Fish Lock Trap



Flow Nappe over Barrier Dam

Reuses the Existing Entrance with Increased Flow

Fish Jump at Barrier and Get Behind Nappe

Second Entrance Attracts Fish Behind Nappe



New Fish Lock Facility from Downstream

# Visual Species Sort of Fish from Lock



Fish Passed One at a Time from the Lock into a Sorting Flume



# Multiple Holding Tanks



Separate Holding Tanks based on Species and Release Destinations

# Fish Sampling & Tagging Station



Fish are Sampled & Tagged then Placed into Appropriate Holding Tanks



# Transport Truck Loading



Fish Crowded to Loading Tank above for Water-to-Water Truck Loading

# Downstream Passage on Baker River



Lower Baker Dam (87 M High)  
FSC in Distance Upstream



Upper Baker Dam (95 M High)  
FSC Directly above Dam

Screen Channels Similar to Other FSCs Presented

Holding Tanks Onboard the FSCs

Fish Sorting Performed Manually Prior to Transport



# Upper Baker FSC



FSC in Un-Ballasted  
Maintenance Position

FSC in Ballasted  
Operating Position



# Lower Baker FSC



FSC in Un-Ballasted  
Maintenance Position

FSC in Ballasted  
Operating Position





# Fish Sorting & Handling



Fish Sorting Station on FSC

Fish Holding Tanks  
at End of Screen Channel



# Fish Transport



Fish Placed in Transport  
Tanks on FSC



Tanks Barged to Dam for Lifting up to Trucks





# Conclusions

- Consider Local Project Conditions in Design
- Establish Pre-Knowledge of Fish Behavior
- Choose Alternatives to Meet Biological Goals
- Be Prepared to Make Modifications

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