6. ANALYSIS OF EFFECTS OF THE ACTION

This section analyzes direct, indirect, and cumulative effects to listed species, habitat for listed species, and critical habitat for listed species. This section also analyzes the effects of interrelated and interdependent actions on listed species and critical habitat (USFWS and NMFS 1998). Direct effects include all immediate impacts that are caused by the project (such as construction and demolition) and that are directly related to actions that occur at or very close to the time of the project. Indirect effects are impacts that are caused by the project, but that occur later in time or are farther removed in distance from the project area and are still reasonably certain to occur. Cumulative effects are future state, tribal, local, and private activities that are reasonably certain to occur within the action area and are likely to affect the species considered in this BA. An interrelated action is one that is part of a larger action and depends on the larger action for its justification. An interdependent action is one that has no independent utility apart from the proposed action.

Analysis of the effects due to stormwater runoff appears in Section 6.2.1. Although stormwater impacts may be considered both direct and indirect effects of the action, the analysis appears only in the indirect effects section because most of the effects occur well after project completion and, in some cases, distant from the action. In addition, this format avoids the redundancy of placing the stormwater information in two locations.

Appendix I, the Exposure Matrix, provides a tabular summary of each element of the project that is likely to affect listed species in the action area. It also provides the timing and duration of each project element as well as summarizes the overall effect that each element will have on listed species.

Section 8.0 summarizes the overall effect determination for each listed species and critical habitat that occurs in the action area.

Appendix H provides an assessment of the effects of the project to the killer whale. This information appears in a separate appendix at the request of NMFS liaison Devin Simmons. This format facilitates review by the Office of Protected Resources, a division of NMFS that will review this section separately from the rest of the Biological Assessment.

6.1 DIRECT EFFECTS TO FISH

Direct effects to listed species will only occur during proposed in-water work in the Columbia River and North Portland Harbor. No in-water work will occur in Burnt Bridge Creek or Columbia Slough. Specific elements of the project that may cause direct effects to fish include following:

- In-water pile driving is likely to create elevated noise levels in the Columbia River and North Portland Harbor, potentially causing disturbance, injury, or mortality to listed fish.
- Fish may become entrained in work-area isolation devices in the Columbia River, where they may experience injury or mortality. Additionally, fish salvage operations occurring inside of work-area isolation devices may also pose a risk of injury or mortality.

- Overwater structures in the Columbia River and North Portland Harbor will likely increase shading above ambient levels. This may cause visual disorientation and increased predation pressure on juvenile fish.
- Illumination on overwater structures in the Columbia River and North Portland Harbor may increase light levels at the water surface in the nighttime. Both of these may cause visual disorientation and increased predation pressure on juvenile fish.
- In-water construction may create temporary, localized turbidity above ambient levels, potentially resulting in disturbance to fish.
- In-water and overwater structures may attract avian predators, potentially increasing predation on juvenile fish.

Sections 6.1.1 through 6.1.6 provide more detail on the pathways by which each of these project elements is likely to affect listed species.

6.1.1 Hydroacoustic Impacts

Direct injury, mortality, or behavioral disturbance to fish species may result from sound levels produced by impact pile driving, vibratory pile driving, and other in-water construction techniques used for the installation of temporary and permanent in-water structures in the Columbia River and North Portland Harbor. Impacts associated with impact pile driving may include physical injury (particularly to air-filled spaces such as swim bladders), auditory tissue damage, temporary or permanent hearing loss, behavioral effects, and immediate and delayed mortality. The amount of energy and the resulting sound pressure from impact pile driving depend on the size and type of pile, type of hammer, energy of the hammer, depth of the water column, and substrate. Impacts to individual fish depend on sound pressure levels, fish species, fish size, fish condition, and depth of the water column (Popper et al. 2006). Use of bubble curtains or other noise attenuation devices during impact pile driving may reduce the level of noise impacts to fish (Caltrans 2009).

Sound, measured in dB, is a relative measure and is referenced in the context of underwater sound pressure to 1 micropascal (μPa) ("dB re: 1 μPa"). One pascal is the pressure resulting from a force of 1 newton exerted over an area of 1 square meter. For purposes of this analysis, underwater sound is referenced in units of decibels re: 1 μPa when referring to sound pressure levels (SPLs) or 1 μPa^2-second when referring to SELs, and will be denoted as dB.

Root mean square (RMS) is the quadratic mean sound pressure over the duration of an impulse. This measurement is often used in the context of discussing behavioral effects to fish, in part because behavioral effects, which often result from auditory cues, and effects on hearing may be better expressed through averaged units rather than by peak pressures.

When discussing the effects of explosions on animals, authors often use impulse as the acoustic parameter, as in Yelverton et al. (1973) discussed below. Positive impulse is the integral of pressure over time, from arrival of the leading edge of the pulse until the pressure becomes negative. Impulse is measured in pascal-seconds (Pa-s). As sound propagates away from a source, several factors change its amplitude. These factors include the spreading of the sound over a wider area (spreading loss), losses to friction (absorption), scattering and reflections from objects in the sound's path, and interference with one or more reflections of the sound off the surface of the streambed (in the case of underwater sound).

The sum of all propagation and loss effects on a signal is referred to as the transmission loss. A major component of transmission loss is spreading loss. From a point source in a uniform medium (water or air), sound spreads outward in spherical waves. Sound transmission in shallow water is highly variable and site specific. Refraction can result in either reduced or enhanced sound transmission in shallow water (Richardson et al. 1995). Ambient noise is the background noise. In water, sources of ambient noise include wind, waves, organisms, shipping traffic, and rain.

6.1.1.1 Hydroacoustic Effects to Fish from Impact Pile Driving

Hydroacoustic injury and disturbance thresholds for marine fish species have been identified by NMFS and USFWS for impulse noises, such as impact pile driving (Table 6-1) (Popper et al. 2006; Southall et al. 2007; NMFS 2008f). Some of the thresholds are dependent on whether the fish are greater than or equal to 2 grams (g) in size. Fish potentially occurring in the action area include adult salmonids, adult and subadult green sturgeon, and adult eulachon migrating upriver, steelhead kelts migrating downriver, outmigrating juvenile salmonids, and larval eulachon. All of these species fall into the greater than 2 g size class, except for juvenile chum and larval eulachon, as described in Appendix K.

Table 6-1 lists the injury thresholds and disturbance guidance for noise impacts to fish.

Table 6-1. Hydroacoustic Injury Thresholds and Disturbance Guidance for Fish

Underwater Sound Criteria		
Size Class	**Injury Threshold**	**Disturbance Guidance**
Fish over 2 g	206 dB Peak; 187 SEL_{cum}	150 dB RMS
Fish under 2 g	206 dB Peak; 183 SEL_{cum}	150 dB RMS

Notes: Cumulative SEL (SEL_{cum}) is calculated as: SEL (single strike at ~10 meters from the pile) + 10 log x (number of strikes).

Impact pile driving will occur during installation of temporary in-water work structures in the Columbia River and North Portland Harbor as described in Section 3. As described in Section 3.5, temporary piles used in these structures are expected to fall into two size classes: 18 to 24 inches and 36 to 48 inches in diameter.

Approximately 1,500 temporary steel piles will be installed and removed during the multi-year construction of the Columbia River and North Portland Harbor bridges. The need for piles will be staged over the construction and demolition periods so that between 100 and 400 piles may be in the water at any given time.

Temporary structures that are not load-bearing, such as mooring piles and cofferdams, will be installed with a vibratory driver only. Drilled shaft casings may also be vibrated into position. These vibratory driving activities are proposed to occur year-round and without the use of an attenuation device. Section 6.1.1.2 provides more detail about the effects of vibratory pile driving on listed fish.

Structures requiring load-bearing piles include temporary work bridges, work platforms, tower cranes, and oscillator support platforms. These piles will be installed first with a vibratory driver to refusal and then proofed with an impact hammer.

Each pier complex of the Columbia River bridge will require approximately 132 load-bearing piles for support of work platforms/bridges and an additional eight load-bearing piles for a tower crane several months later (see Table 3-7), for a total of approximately 840 impact driven piles. An average of six temporary, load-bearing piles could be installed per day using one or two impact drivers. The project is anticipating that temporary piles for each of the six work bridges/work platforms will be installed in one 22-day period. Temporary piles for each of the six tower cranes will be installed in one day. Figure 6-14 shows the sequencing of pile-driving activities in the Columbia River based on an impact driving start date of September 2013. Impact pile driving in the Columbia River will occur on approximately 138 days over the approximately 4-year construction period.

Each of the 31 oscillator support platforms in North Portland Harbor will require four load-bearing piles (124 piles). In addition, the nine temporary work bridges will each require approximately 25 load-bearing piles (225 piles) (Table 3-13). There will be a total of approximately 349 impact-driven piles in North Portland Harbor. Only one impact driver will operate at a given time in North Portland Harbor. Figure 6-15 shows the sequencing of pile-driving activities in North Portland Harbor. Impact pile driving in North Portland Harbor will occur on approximately 134 days over the approximately 4-year construction period.

In-water noise attenuation measures will be employed during impact driving activities for the majority of pile strikes. The CRC project assumes that an at-source noise reduction of approximately 10 dB is achievable through use of a noise attenuation device. (Appendix K details the rationale behind this assumption.) Unattenuated pile driving may occur as part of the hydroacoustic monitoring program for this project or incidentally during attenuation equipment failures. In the Columbia River, unattenuated pile driving may occur for up to 7.5 minutes per week. In North Portland Harbor, unattenuated pile driving may occur on average for up to 5 minutes per week.

Based on NMFS models, calculation of distances to injury thresholds and disturbance guidance is related to noise from a single pile strike. For accumulated SEL, the variables include: single-strike dB SEL, the number of pile strikes over a time period, the time period, the distance from pile, and fish movement. Refer to Appendix K for further discussion on attenuation, noise metrics, and impact calculations.

During construction of the Columbia River bridge, up to two impact pile drivers may operate simultaneously in close proximity to one another, although it is not anticipated to produce additional noise levels due to multiple drivers. Pile strikes from both drivers would need to be synchronous (within 0.0 and approximately 0.1 seconds apart) in order to produce higher noise levels than a single pile driver operating alone. Because two pile drivers operating with exactly synchronous pile strikes is highly unlikely, the CRC team assumed for analysis purposes that two pile drivers will not generate noise levels greater than that of a single pile driver.

For construction of the Columbia River bridges, an average of 300 impact blows per pile are estimated to be needed. Project designers estimate that up to 1,800 attenuated pile strikes will occur per day of pile driving. For construction of the North Portland Harbor bridges, a total of 1,800 attenuated pile strikes per day of driving were also assumed. The actual number of pile strikes will vary depending on the type of hammer, the hammer energy and substrate composition. However, these pile strikes will not be spread evenly throughout the work day. It is likely that day-to-day pile driving activities will vary. This hour-to-hour and day-to-day variation, coupled with timing of fish runs and fish speed through the area, creates a complex scenario for analyzing effects.

To accommodate this complex scenario of pile sizes, initial sound levels, pile strike numbers, timing and duration of pile driving, etc., the CRC team developed an analytical tool to determine the extent to which fish are exposed to potentially injurious accumulated sound levels within the project area. The CRC project has called this extent of exposure the “exposure factor.” The exposure factor uses the variables for calculating the accummulated SEL through the moving fish model (size of pile [initial sound levels], daily pile strikes, timing and duration of pile strikes, fish speed, and fish mass) and combines that with variables, such as days of pile driving within a week, to estimate the potential exposure to fish that are within or pass through the project area. Different combinations of any of these elements (such as pile strikes, duration or timing of pile strikes, and initial sound levels) will yield different exposure factors.[1] During construction, the contractor will calculate the weekly, maximum yearly, average yearly, and total project exposure factor to ensure that they do not exceed levels specified in Section 7 of this document.

Exposure factors were calculated for impact pile driving activities in both the Columbia River and North Portland Harbor.

The Services have accepted the use of a revised moving fish model based on this project’s specific conditions, as described in Appendix K, to determine exposure factors and to quantify effects to listed fish. This model uses the mass and the measured or assumed rate of travel for juvenile and adult fish through the project area. Juvenile chum and larval eulachon were assumed to be under 2 g in mass and travel with the current at 0.6 m/s. Other juvenile fish were assumed to be over 2 g in mass and travel a little faster than the current of 0.8 m/s. All adult fish were assumed to be over 2 g in mass and travel at 0.1 m/s through the project area. These assumptions are discussed further in Section 4 of this document and Section 4 of Appendix K.

It is important to correctly assume the rate of travel and mass for the moving fish model. The faster a fish moves through an area, the less time it has to become exposed to accumulated levels of potentially injurious sound energy. The effect of speed on the area of effect is more noticeable at higher fish movement speeds (nearing 1.0 m/s), whereas the area of effect for fish moving 0.1 m/s are substantially the same as the area of effect calculated using the stationary fish model. For example, an attenuated 36- to 48-inch-diameter pile struck 300 times would result in a pile driving time of approximately 7.5 minutes. A fish (over 2 g) moving at a speed of 0.8 m/s would travel approximately 360 m in a 7.5-minute period. If that fish passed within approximately 47 m of the driven pile, it could receive enough sound energy for injury to occur. If the fish were traveling at only 0.6 m/s, then it could experience enough sound energy for injury to occur within approximately 58 m from the pile. If the fish were traveling at 0.1 m/s or was stationary, then it could experience enough sound energy for injury to occur within approximately 83 m from the pile. If the fish passed inside of the threshold distance for its given speed, injury would be more likely.

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[1] As a simple example, a higher number of pile strikes on a small pile with a low initial SPL over a given time period may result in the same exposure factor as a lower number of pile strikes conducted on a large pile that has higher initial sound levels. Section 3 of Appendix K provides detailed information on how typical and maximum exposure factors were calculated, and provides details on how exposure factors can be calculated during construction activities.

In order to analyze potential impacts to listed fish, the CRC project team calculated the proportion of a listed fish run that may be impacted within the Columbia River and North Portland Harbor through potential injury due to increased sound pressure levels from the impact driving of temporary piles. Calculating exposures to fish requires multiplying the proportion of a fish run likely present in the project area in a given week by the weekly exposure factor for that week. The CRC project used 13 full Columbia River Bridge construction scenarios to estimate potential and maximum exposure factors. Details of these analyses, including calculations of estimated impacts for each run, are presented in Appendix K.

Due to the numerous variables in determining exposure factors, the CRC project used representative numbers of pile strikes, such as those in Table 6-2 and Table 6-3, to estimate exposure factors for the project. The numbers in Table 6-2 and Table 6-3 are also used in this section of the BA to illustrate the extent of underwater noise exceeding the injury thresholds and disturbance guidance.

Table 6-2. Pile-Strike Summary for Columbia River Bridge Construction

Pile Size	Strikes per Day	Days per Week[a]	Strike Interval[b]
Without Attenuation Device			
Single pile driver: 18- to 24-inch pile	150	1	1.5
Single pile driver: 36- to 48-inch pile	150	1	1.5
With Attenuation Device			
Single pile driver: 18- to 24-inch pile	400	5	1.5
Single pile driver: 36- to 48-inch pile	800	5	1.5
Two pile drivers: each with 18- to 24-inch pile	200	5	0.75
Two pile drivers: one 18- to 24-inch pile and one 36- to 48-inch pile, or two 36- to 48-inch piles	400	5	0.75

a Days per week during active driving only.
b Measured in seconds between strikes.

Table 6-3. Pile-Strike Summary for North Portland Harbor Bridge Construction

Pile Size	Strikes per Day	Days per Week[a]	Strike Interval[b]
Without Attenuation Device			
Single pile driver: 18- to 24-inch pile	75	1	1.5
Single pile driver: 36- to 48-inch pile	75	1	1.5
With Attenuation Device			
Single pile driver: 18- to 24-inch pile	900	3 to 5	1.5
Single pile driver: 36- to 48-inch pile	900	2	1.5

a Days per week during active driving only.
b Measured in seconds between strikes.

Estimated Extent, Timing, and Duration of Effect

Table 6-4 through Table 6-8 summarize the distances within which noise exceeds the injury thresholds and disturbance guidance in the Columbia River and North Portland Harbor during impact pile driving. These distances are presented for impact pile driving occurring both with and without the use of an attenuation device for comparison. Note that the upstream extent of pile-driving noise may differ from the downstream extent. These values indicate the distance at which noise encounters a landform (such as an island or streambank) that completely blocks the spread of in-water noise. The calculations assume that the noise attenuation device will achieve 10 dB of noise reduction at the source.

Table 6-4, Figure 6-1, and Figure 6-2 show the distances within which noise exceeds peak injury thresholds.

Table 6-4. Distances at Which Underwater Noise Exceeds 206 dB Peak Injury Threshold Levels for Peak Noise in the Columbia River and North Portland Harbor

Pile Size	Distance (m)	
	Without Attenuation Device	With Attenuation Device
18- to 24-inch pile	25	5
36- to 48-inch pile	34	7

Table 6-5 and Figure 6-3 through Figure 6-5 show the distances within which noise is estimated to exceed the 187 dB SEL injury thresholds for fish over 2 g and moving at 0.1 m/s for a single pile driver and for two pile drivers operating simultaneously, as calculated in the moving fish model.

Table 6-5. Distances at Which Underwater Noise Exceeds 187 dB SEL Injury Threshold for Adult Fish Over 2 g at 0.1 m/s in the Columbia River and North Portland Harbor

Pile Size	Distance (m)	
	Without Attenuation Device	With Attenuation Device
18- to 24-inch pile	113	50
36- to 48-inch pile	243	156
Two 18- to 24-inch piles	N/A	59[a]
Two 36- to 48-inch piles OR One 18- to 24-inch and one 36- to 48-inch pile	N/A	130[a]

Note: Includes adult salmon, steelhead, and eulachon.

a Applies to Columbia River only.

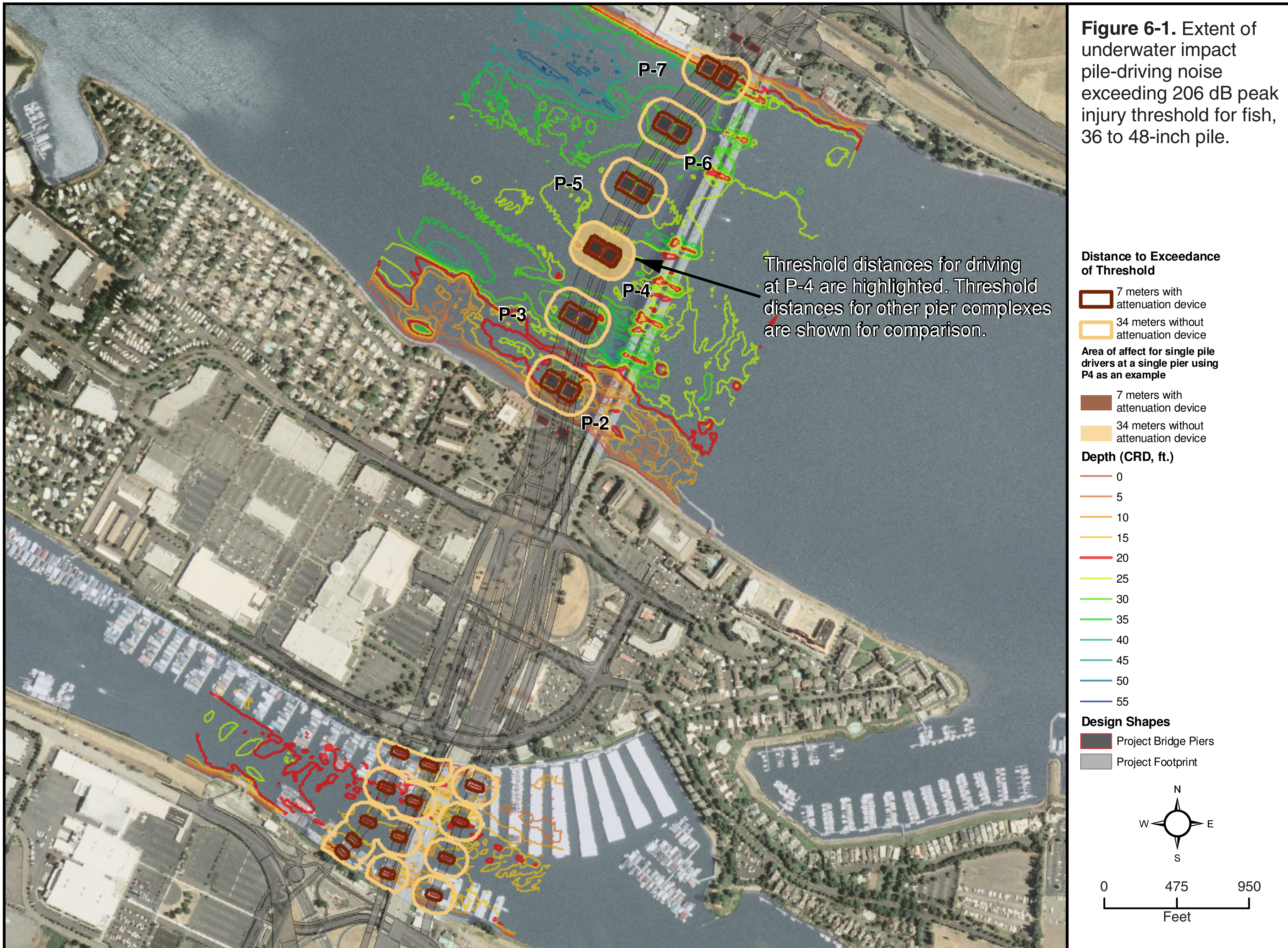

Figure 6-1. Extent of underwater impact pile-driving noise exceeding 206 dB peak injury threshold for fish, 36 to 48-inch pile.

This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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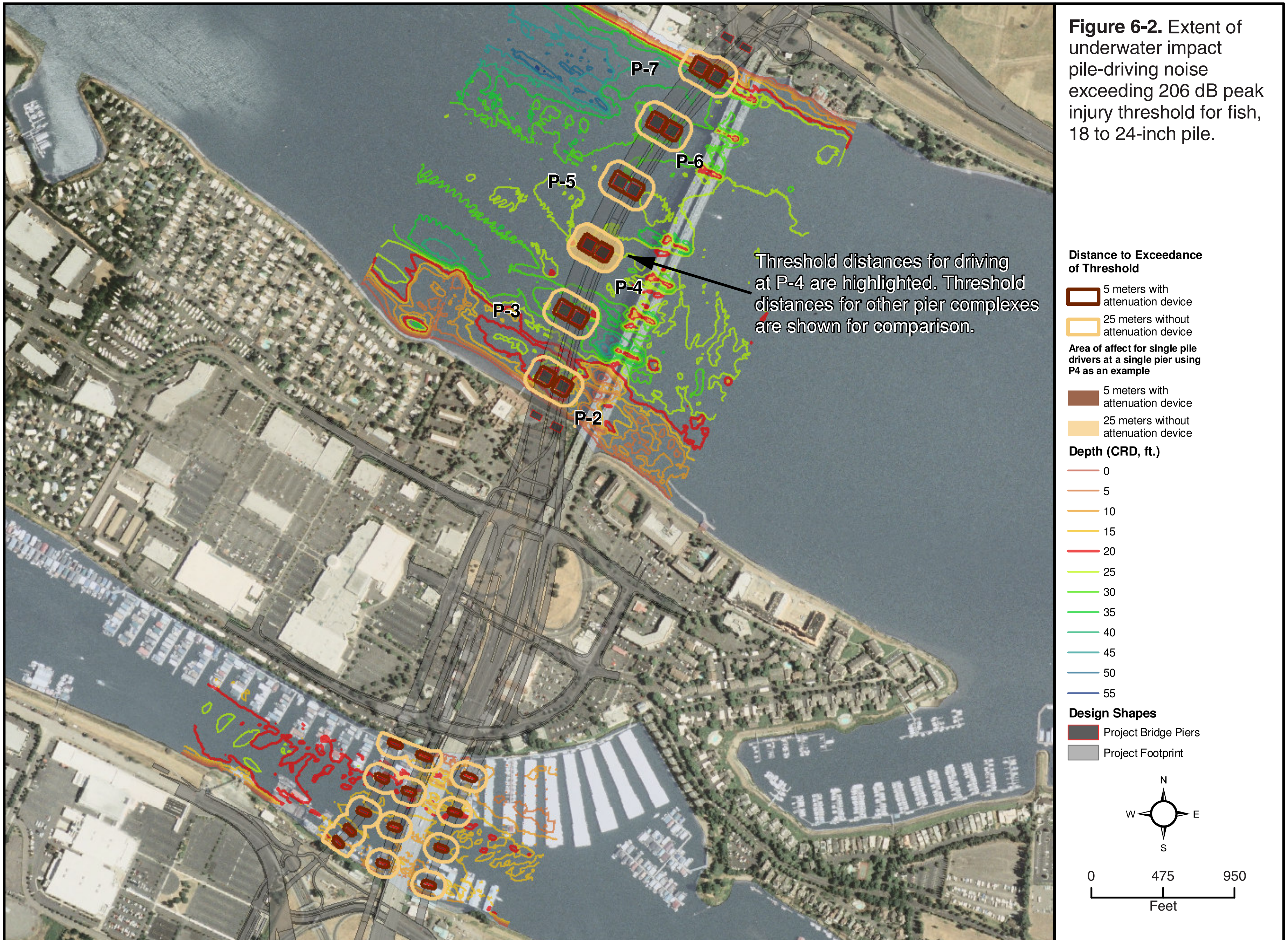
Figure 6-2. Extent of underwater impact pile-driving noise exceeding 206 dB peak injury threshold for fish, 18 to 24-inch pile.



This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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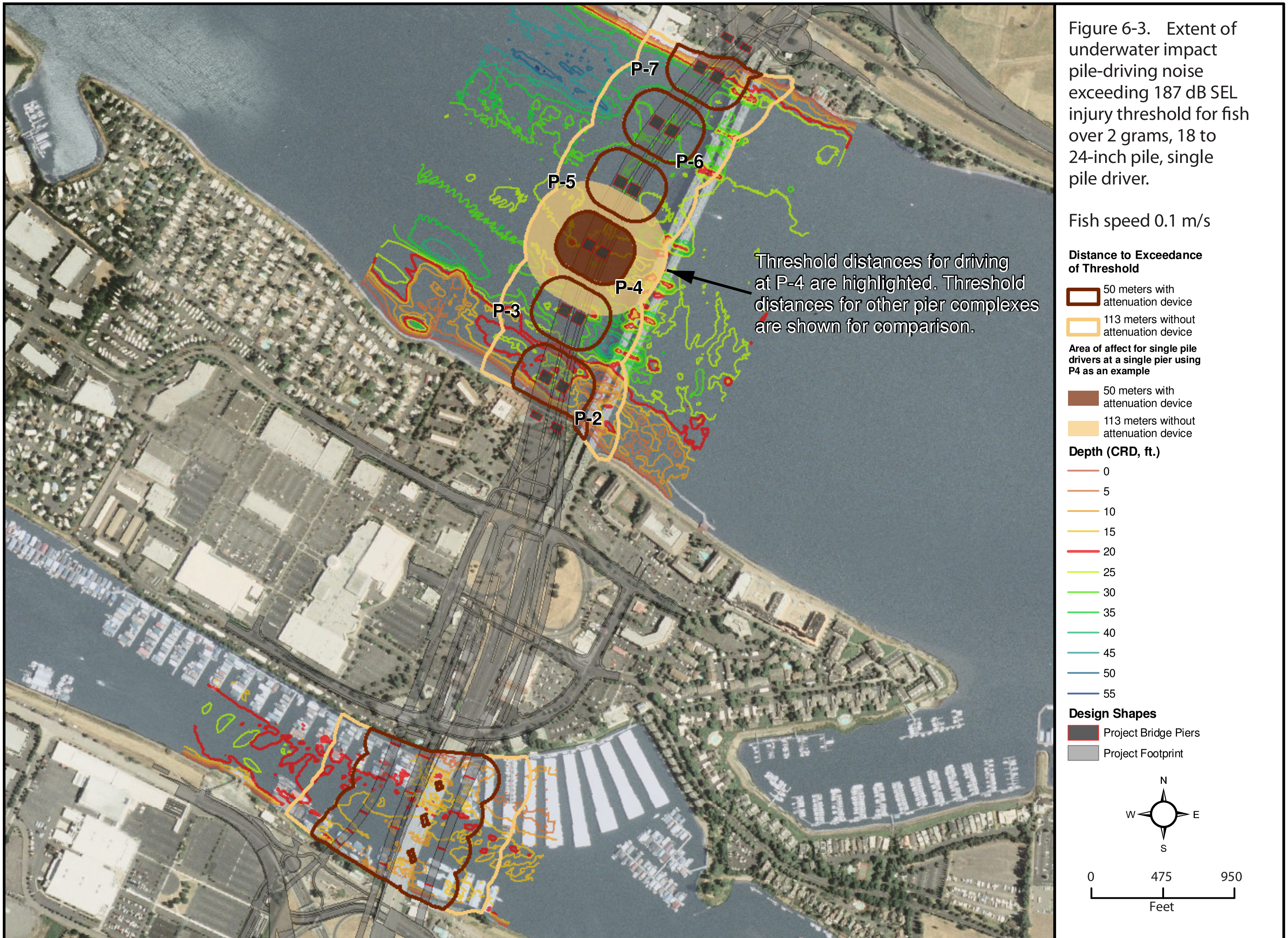

Figure 6-3. Extent of underwater impact pile-driving noise exceeding 187 dB SEL injury threshold for fish over 2 grams, 18 to 24-inch pile, single pile driver.

Fish speed 0.1 m/s

This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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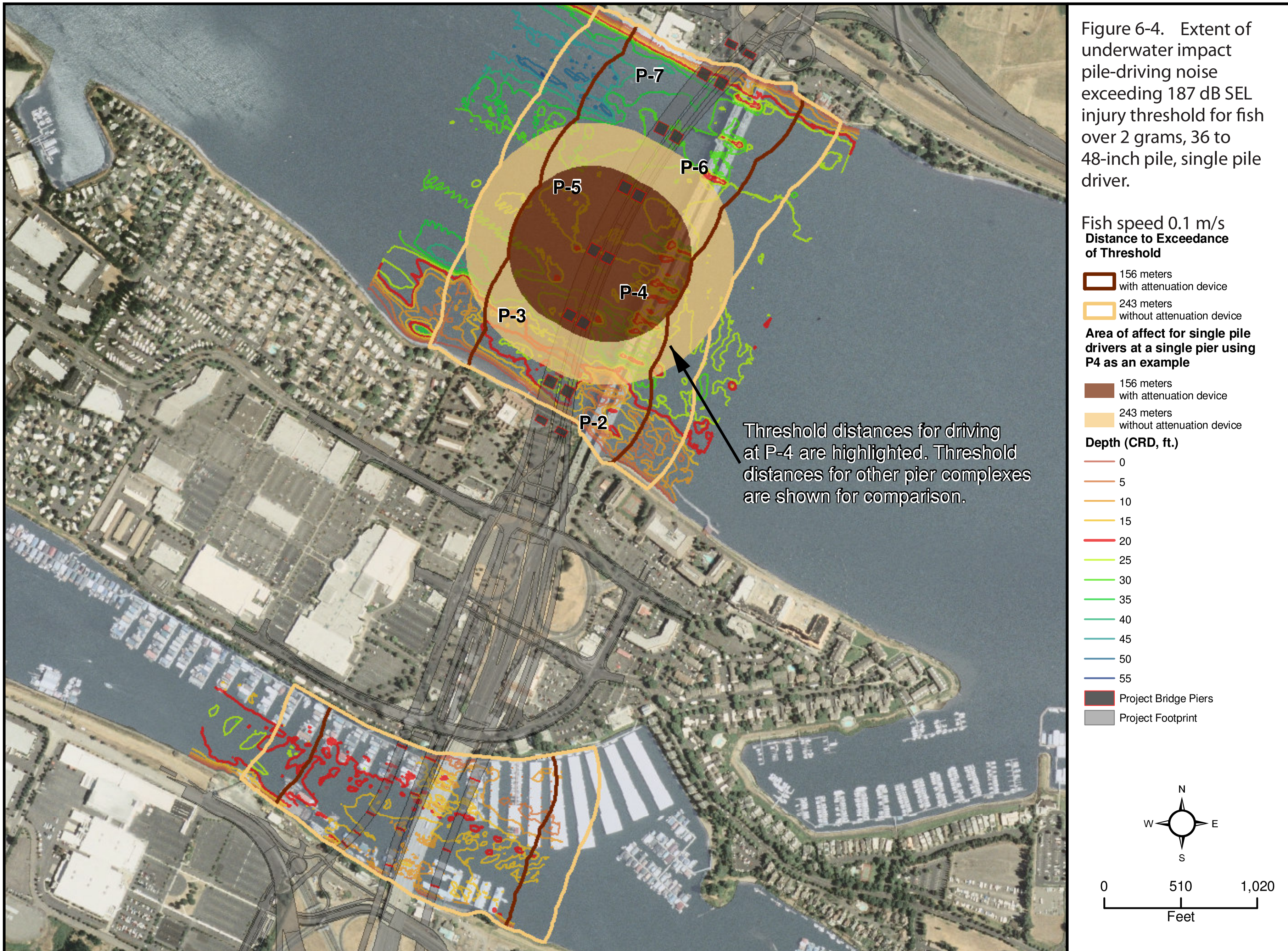

Figure 6-4. Extent of underwater impact pile-driving noise exceeding 187 dB SEL injury threshold for fish over 2 grams, 36 to 48-inch pile, single pile driver.

This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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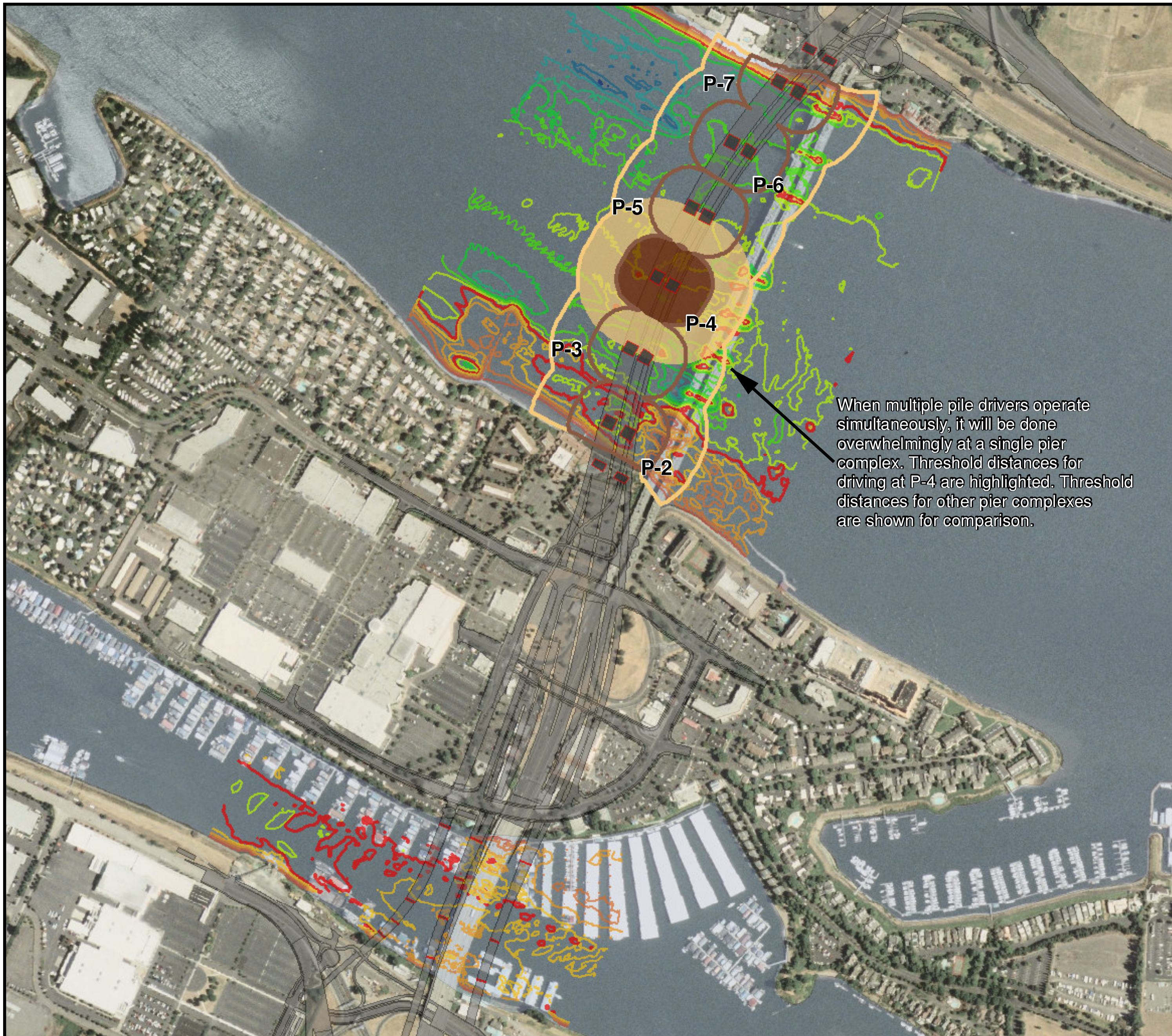
Figure 6-5. Extent of underwater impact pile-driving noise exceeding 187 dB SEL injury threshold for fish over 2 grams, multiple pile drivers.

Fish speed 0.1 m/s



This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Multiple pile drivers will operate simultaneously at a single pier complex for a large majority of impact pile driving. Only rarely (about one day out of every 142 in-water work days) will multiple pile drivers operate at seperate pier complexes.

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Table 6-6 and Figure 6-6 through Figure 6-8 present the results of calculations showing distances within which noise is estimated to exceed the 183 dB SEL injury thresholds for fish under 2 g and moving at 0.6 m/s for a single pile driver and for two pile drivers operating simultaneously.

Table 6-6. Distances at Which Underwater Noise Exceeds 183 dB SEL Injury Threshold for Moving Fish Under 2 g at 0.6 m/s in the Columbia River and North Portland Harbor

Pile Size	Distance (m)	
	Without Attenuation Device	With Attenuation Device
18- to 24-inch pile	200	50
36- to 48-inch pile	446	235
Two 18- to 24-inch piles	N/A	79[a]
Two 36- to 48-inch piles OR One 18- to 24-inch and one 36- to 48-inch pile	N/A	209[a]

Note: Includes juvenile chum and larval eulachon.

a Applies to Columbia River only.

Table 6-7 and Figure 6-9 through Figure 6-11 show the distances within which noise is estimated to exceed the 187 dB SEL injury thresholds for fish over 2 g and moving 0.8 m/s for a single pile driver and for two pile drivers operating simultaneously.

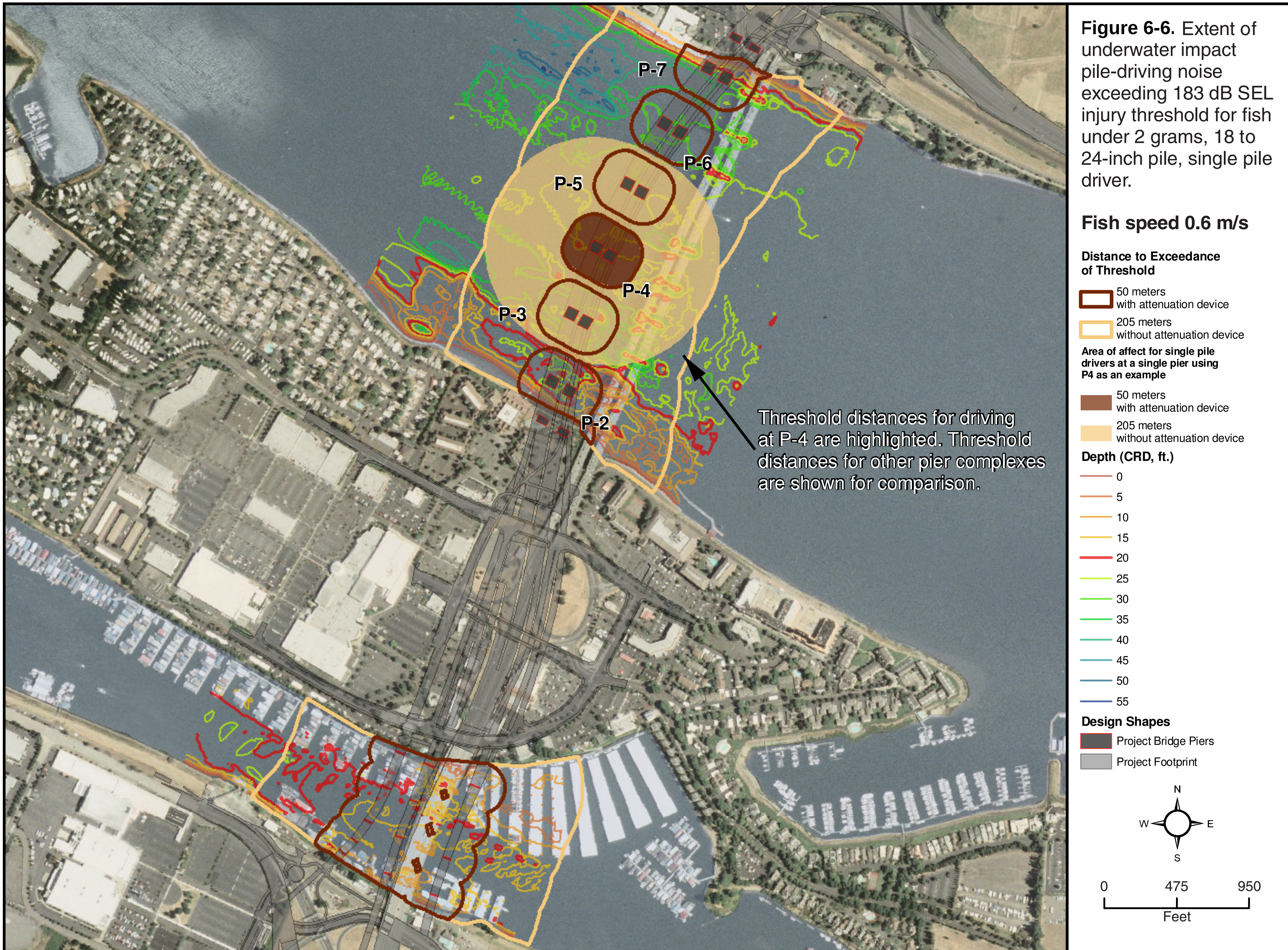
Table 6-7. Distances at Which Underwater Noise Exceeds 187 dB SEL Injury Threshold for Fish Over 2 g at 0.8 m/s in the Columbia River and North Portland Harbor

Pile Size	Distance (m)	
	Without Attenuation Device	With Attenuation Device
18- to 24-inch pile	102	9
36- to 48-inch pile	237	67
Two 18- to 24-inch piles	N/A	48[a]
Two 36- to 48-inch piles OR One 18- to 24-inch and one 36- to 48-inch pile	N/A	111[a]

Note: Includes juvenile salmonids except for chum.

a Applies to Columbia River only.

Figure 6-6. Extent of underwater impact pile-driving noise exceeding 183 dB SEL injury threshold for fish under 2 grams, 18 to 24-inch pile, single pile driver.



This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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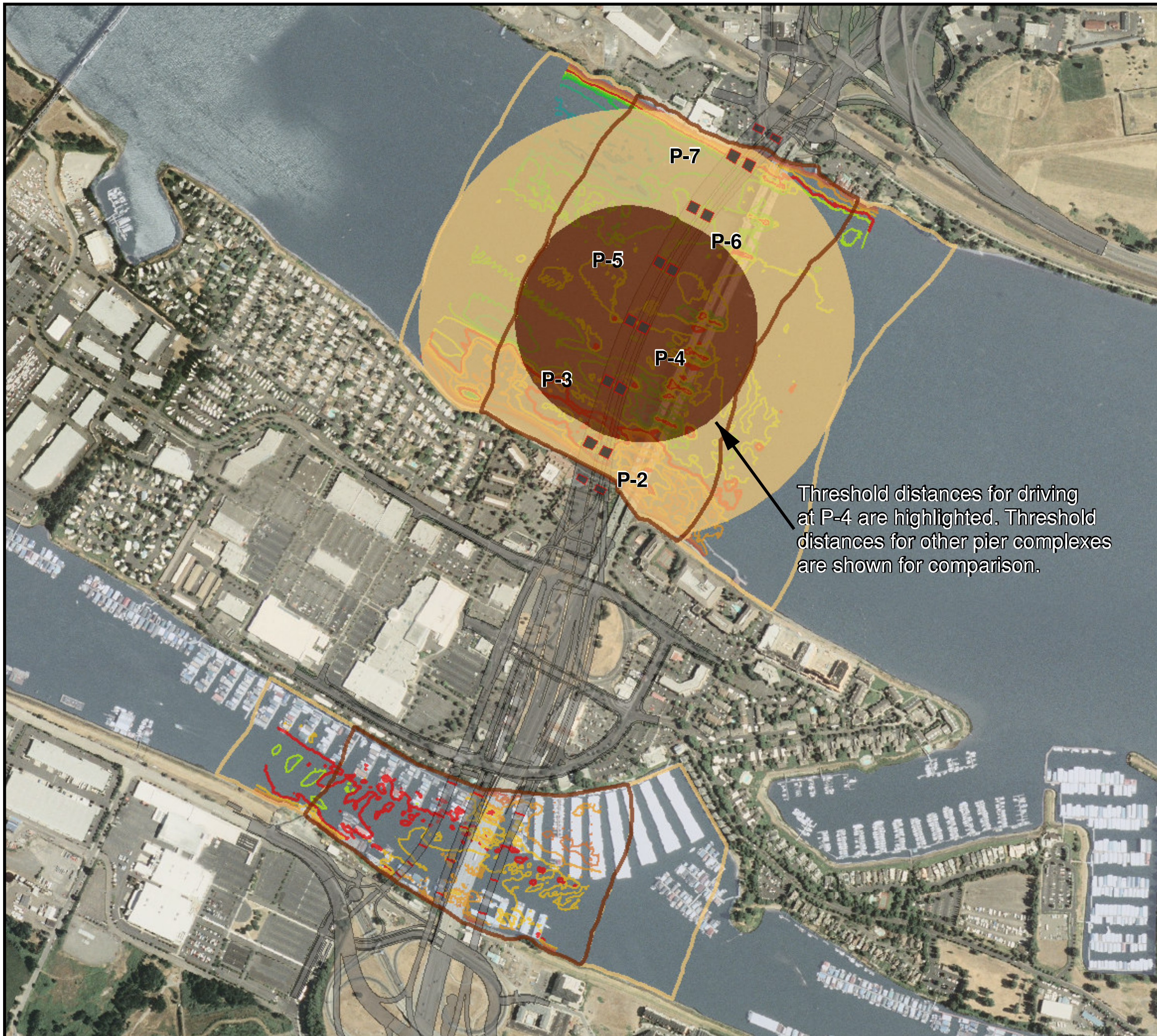

Figure 6-7. Extent of underwater impact pile-driving noise exceeding 183 dB SEL injury threshold for fish under 2 grams, 36 to 48-inch pile, single pile driver.

Fish speed 0.6 m/s

Distance to Exceedance of Threshold

- 235 meters with attenuation device
- 446 meters without attenuation

Area of affect for single pile drivers at a single pier using P4 as an example

- 235 meters with attenuation device
- 446 meters without attenuation device

Depth (CRD, ft.)

0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55

- Project Bridge Piers
- Project Footprint

N W E S

0 600 1,200
Feet

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This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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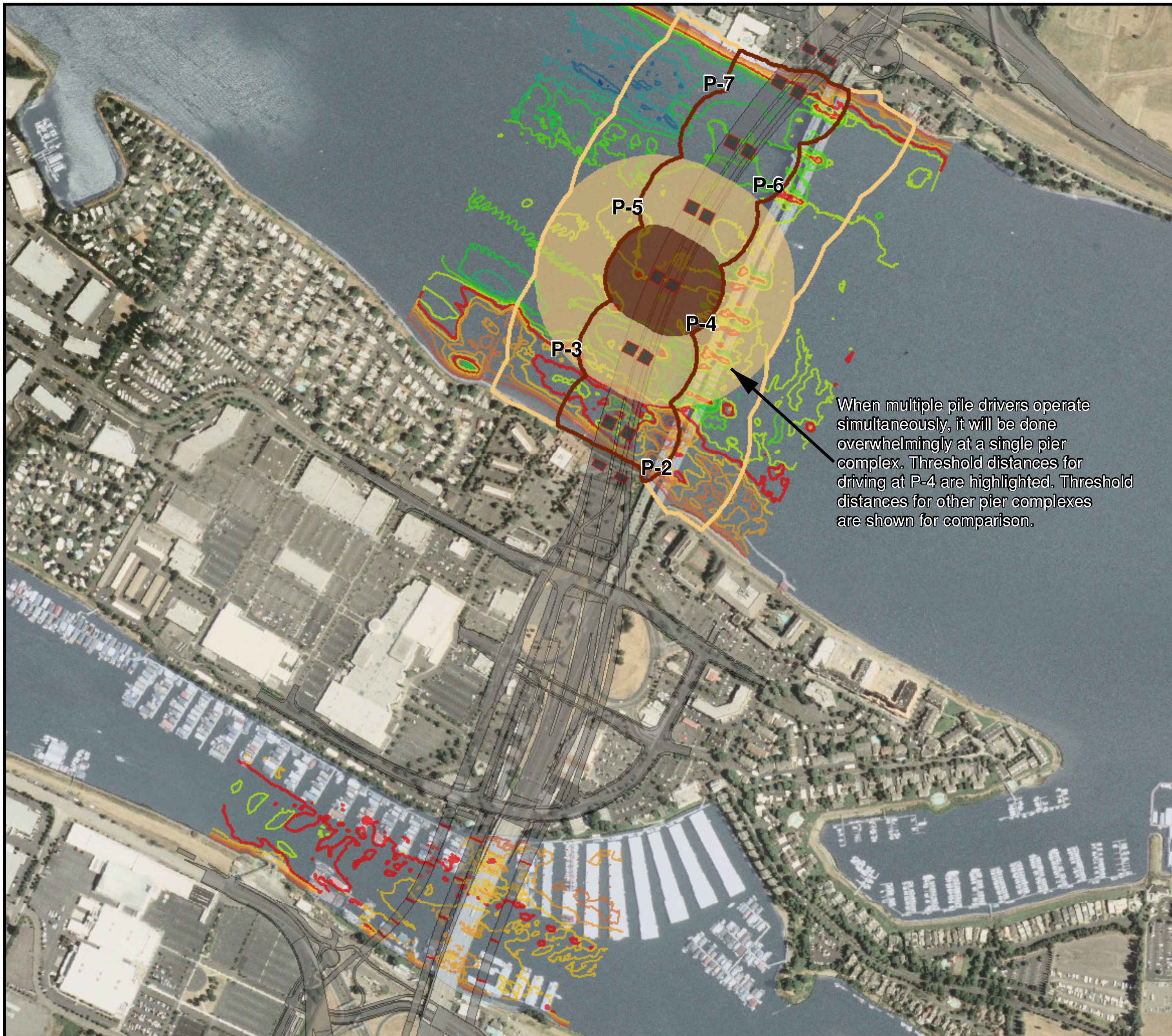

Figure 6-8. Extent of underwater impact pile-driving noise exceeding 183 dB SEL injury threshold for fish under 2 grams, multiple drivers.

Fish speed 0.6 m/s

Distance to Exceedance of Threshold

- 79 meters, two 18 to 24-inch piles
- 209 meters, two 36 to 48-inch piles or one 18- to 24-inch plus one 26- to 48-inch pile

Area of affect for multiple pile drivers at a single pier using P4 as an example

- 79 meters, two 18 to 24-inch piles
- 209 meters, two 36 to 48-inch piles or one 18- to 24-inch plus one 26- to 48-inch pile

Depth (CRD, ft.)

- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50
- 55
- Project Bridge Piers
- Project Footprint

N E S W

0 510 1,020
Feet

Columbia River CROSSING

This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Multiple pile drivers will operate simultaneously at a single pier complex for a large majority of impact pile driving. Only rarely (about one day out of every 142 in-water work days) will multiple pile drivers operate at seperate pier complexes.

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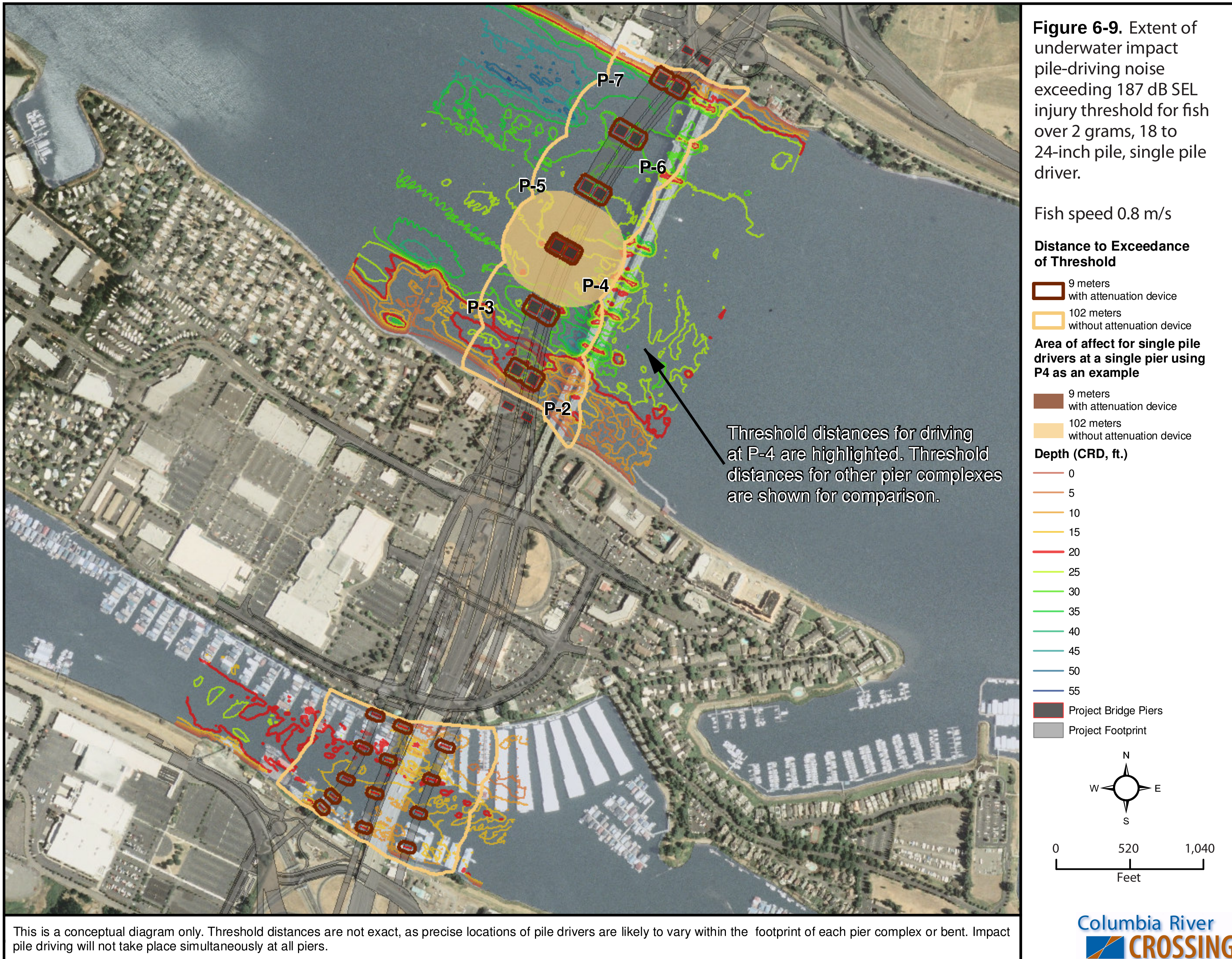

Figure 6-9. Extent of underwater impact pile-driving noise exceeding 187 dB SEL injury threshold for fish over 2 grams, 18 to 24-inch pile, single pile driver.

Fish speed 0.8 m/s

This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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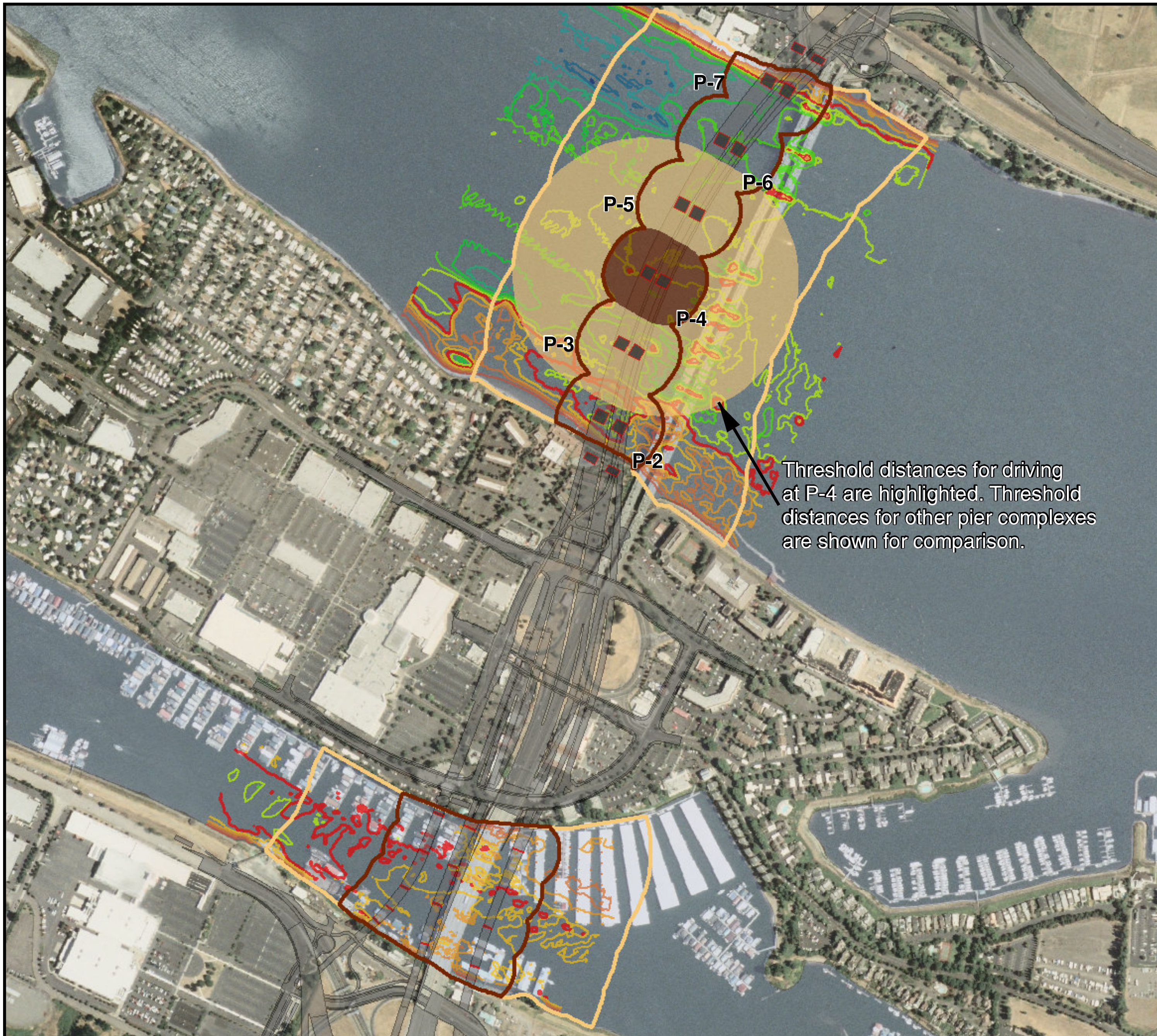

Figure 6-10. Extent of underwater impact pile-driving noise exceeding 187 dB SEL injury threshold for fish over 2 grams, 36 to 48-inch pile, single pile driver.

Fish speed 0.8 m/s

Distance to Exceedance of Threshold

- 67 meters, with attenuation device
- 237 meters, without attenuation device

Area of affect for single pile drivers at a single pier using P4 as an example

- 67 meters, with attenuation device
- 237 meters, without attenuation device

Depth (CRD, ft.)

0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55

- Project Bridge Piers
- Project Footprint

N E S W

0 510 1,020 Feet

Columbia River CROSSING

This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Impact pile driving will not take place simultaneously at all piers.

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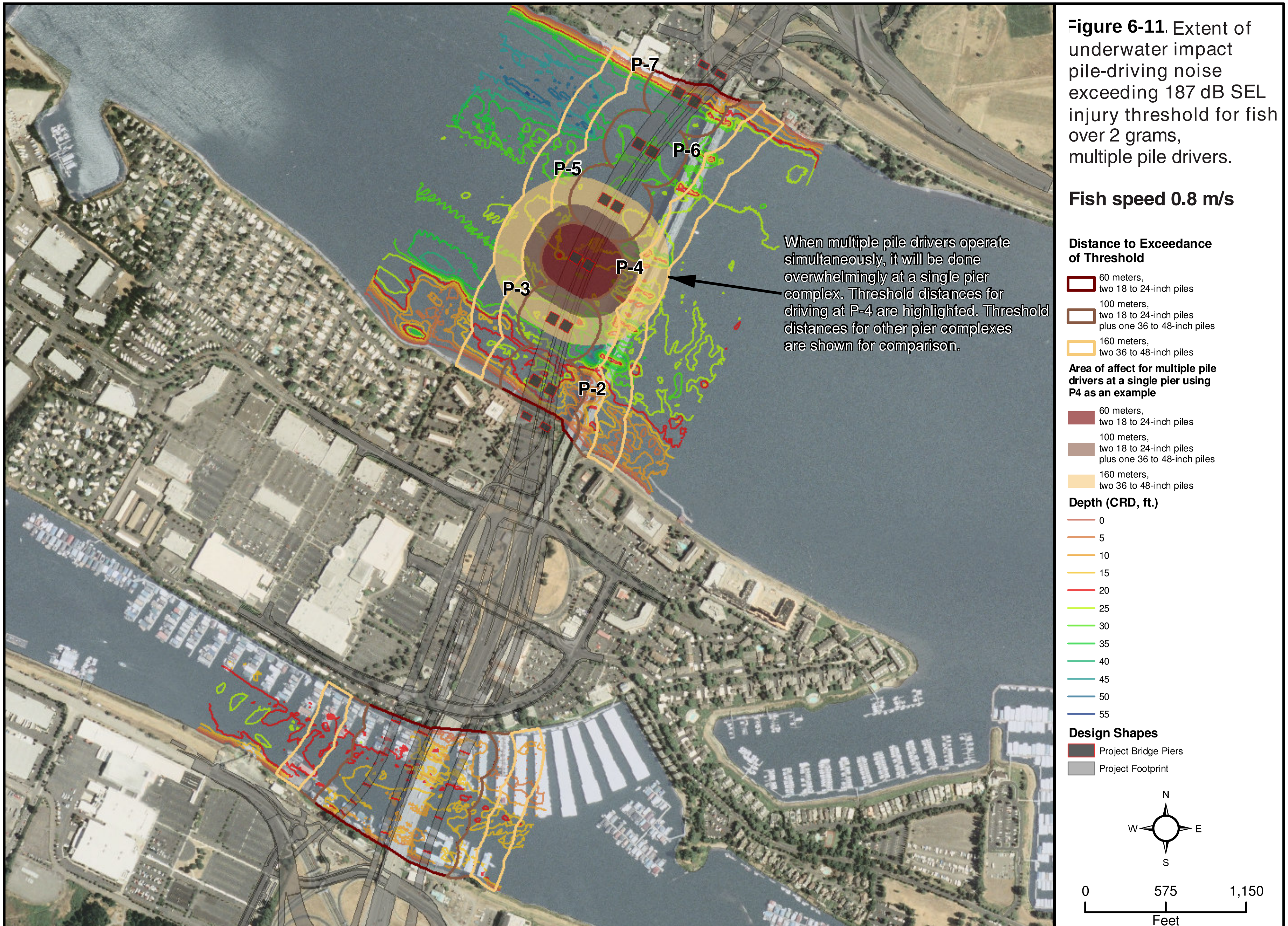
Figure 6-11. Extent of underwater impact pile-driving noise exceeding 187 dB SEL injury threshold for fish over 2 grams, multiple pile drivers.

Fish speed 0.8 m/s



This is a conceptual diagram only. Threshold distances are not exact, as precise locations of pile drivers are likely to vary within the footprint of each pier complex or bent. Multiple pile drivers will operate simultaneously at a single pier complex for a large majority of impact pile driving. Only rarely (about one day out of every 142 in-water work days) will multiple pile drivers operate at separate pier complexes.

Columbia River CROSSING

Analysis by J. Koloszar; Analysis Date: Feb. 25, 2010: File Name: HydroSound_MG246_MultipleDrivers.mxd

Table 6-8, Figure 6-12, and Figure 6-13 show the distances within which noise is estimated to exceed the 150 dB RMS disturbance guidance.

Table 6-8. Distances at Which Underwater Noise Exceeds 150 dB RMS Disturbance Guidance in the Columbia River and North Portland Harbor

	Columbia River		North Portland Harbor	
Impact Pile Driving	**Distance Upstream (m)**	**Distance Downstream (m)**	**Distance Upstream (m)**	**Distance Downstream (m)**
Without Attenuation Device				
18- to 24-inch pile	3,981	3,981	3,058	3,981
36- to 48-inch pile	20,166	8,851	3,058	5,632
With Attenuation Device				
18- to 24-inch pile	858	858	858	858
36- to 48-inch pile	5,412	5,412	3,058	5,412

Figure 6-12. Extent of underwater impact pile-driving noise exceeding 150 dB RMS disturbance guidance for fish, 36 to 48-inch pile.

Distance to Exceedance of Guidance

- 5,412 meters with attenuation device
- 20,166 meters without attenuation device

Design Shapes

- Project Bridge Piers
- Project Footprint

N W E S

0 6,600 13,200
Feet

Columbia River CROSSING

Analysis by J. Koloszar; Analysis Date: Feb. 11, 2010: File Name: HydroSound_MG246_2.mxd

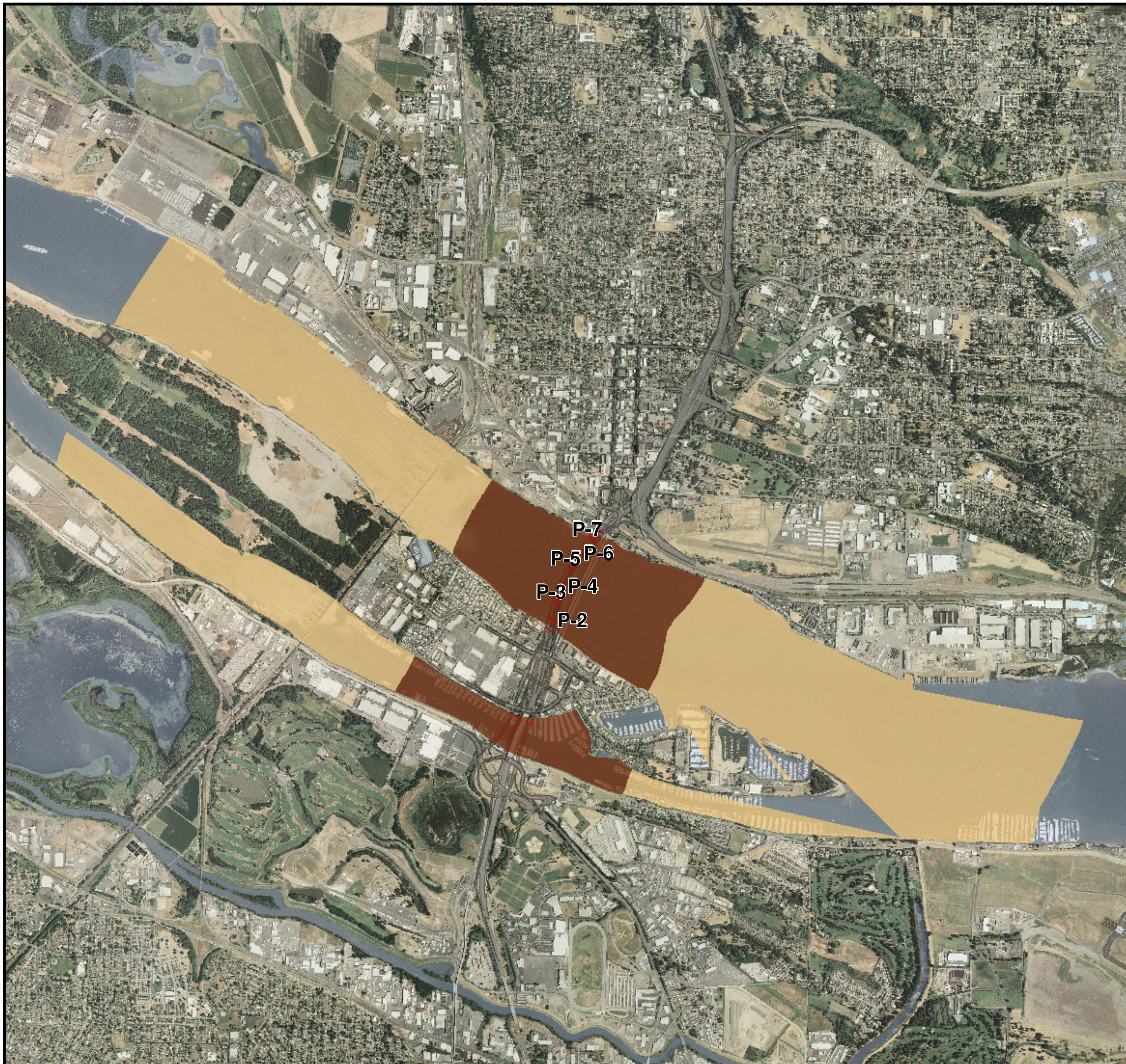
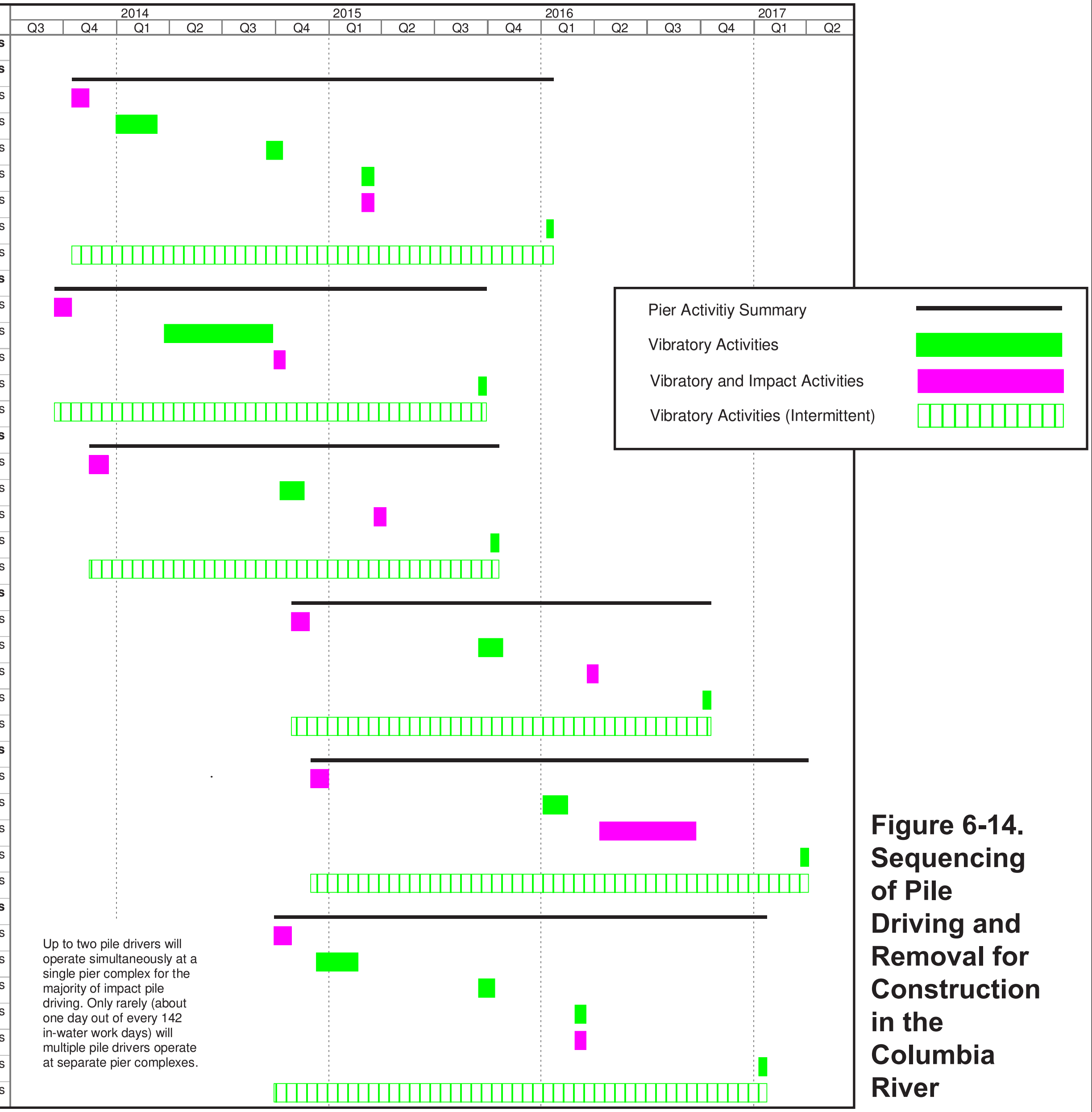


Figure 6-13. Extent of underwater impact pile-driving noise exceeding 150 dB RMS disturbance guidance for fish, 18 to 24-inch pile.

Analysis by J. Koloszar; Analysis Date: Feb. 11, 2010: File Name: HydroSound_MG246_2.mxd

Task Name	Start	Finish	Duration
Bridge Construction Scenario 2/5/13	**9/16/13**	**4/5/17**	**928 days**
Pier 2	**10/16/13**	**1/22/16**	**593 days**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	10/16/13	11/14/13	22 days
Install Cofferdam (Vibratory Installation)	12/31/13	3/11/14	51 days
Remove Work Bridge & Piles (Vibratory Removal)	9/16/14	10/13/14	20 days
Remove Cofferdam (Vibratory Removal)	2/27/15	3/19/15	15 days
Erect Tower Crane (Vibratory & Impact Pile Driving)	2/27/15	3/19/15	15 days
Remove Tower Crane (Vibratory Removal)	1/11/16	1/22/16	10 days
Barge Moorings (Vibratory Installation & Removal)	10/16/13	1/22/16	593 days
Pier 3	**9/16/13**	**9/29/15**	**532 days**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	9/16/13	10/15/13	22 days
Remove Work Platform & Piles (Vibratory Removal)	3/24/14	9/26/14	135 days
Erect Tower Crane (Vibratory & Impact Pile Driving)	9/29/14	10/17/14	15 days
Remove Tower Crane (Vibratory Removal)	9/16/15	9/29/15	10 days
Barge Moorings (Vibratory Installation & Removal)	9/16/13	9/29/15	532 days
Pier 4	**11/15/13**	**10/20/15**	**503 days**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	11/15/13	12/17/13	23 days
Remove Work Platform & Piles (Vibratory Removal)	10/9/14	11/19/14	30 days
Erect Tower Crane (Vibratory & Impact Pile Driving)	3/20/15	4/9/15	15 days
Remove Tower Crane (Vibratory Removal)	10/7/15	10/20/15	10 days
Barge Moorings (Vibratory Installation & Removal)	11/15/13	10/20/15	503 days
Pier 5	**10/29/14**	**10/19/16**	**516 days**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	10/29/14	11/28/14	23 days
Remove Work Platform & Piles (Vibratory Removal)	9/16/15	10/27/15	30 days
Erect Tower Crane (Vibratory & Impact Pile Driving)	3/21/16	4/8/16	15 days
Remove Tower Crane (Vibratory Removal)	10/6/16	10/19/16	10 days
Barge Moorings (Vibratory Installation & Removal)	10/29/14	10/19/16	516 days
Pier 6	**12/1/14**	**4/5/17**	**613 days**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	12/1/14	12/31/14	23 days
Remove Work Platform & Piles (Vibratory Removal)	1/5/16	2/15/16	30 days
Erect Tower Crane (Vibratory & Impact Pile Driving)	4/11/16	9/23/16	120 days
Remove Tower Crane (Vibratory Removal)	3/23/17	4/5/17	10 days
Barge Moorings (Vibratory Installation & Removal)	12/1/14	4/5/17	613 days
Pier 7	**9/29/14**	**1/23/17**	**606 days**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	9/29/14	10/28/14	22 days
Install Cofferdam (Vibratory Installation)	12/11/14	2/20/15	52 days
Remove Work Bridge & Piles (Vibratory Removal)	9/16/15	10/13/15	20 days
Remove Cofferdam (Vibratory Removal)	2/29/16	3/18/16	15 days
Erect Tower Crane (Vibratory & Impact Pile Driving)	2/29/16	3/18/16	15 days
Remove Tower Crane (Vibratory Removal)	1/10/17	1/23/17	10 days
Barge Moorings (Vibratory Installation & Removal)	9/29/14	1/23/17	606 days



Conceptual Schedule Only, April 2010

Note: This is a proposed schedule, so activity dates are likely to change.

Figure 6-14. Sequencing of Pile Driving and Removal for Construction in the Columbia River

Columbia River CROSSING

Task Name	Duration	Start	Finish
Widening of Existing Bridge	**111 days**	**9/15/13**	**1/30/14**
Bent 4	**20 days**	**9/15/13**	**10/8/13**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	9/15/13	9/22/13
Remove Work Bridge and Piles (Vibratory Removal)	1 day	10/8/13	10/8/13
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	9/23/13	9/24/13
Remove Oscillator Support Piles (Vibratory Removal)	1 day	10/8/13	10/8/13
Bent 5	**10 days**	**10/11/13**	**10/24/13**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	10/11/13	10/14/13
Remove Oscillator Support Piles (Vibratory Removal)	1 day	10/24/13	10/24/13
Bent 6	**10 days**	**10/27/13**	**11/7/13**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	10/27/13	10/28/13
Remove Oscillator Support Piles (Vibratory Removal)	1 day	11/7/13	11/7/13
Bent 7	**10 days**	**11/10/13**	**11/21/13**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	11/10/13	11/11/13
Remove Oscillator Support Piles (Vibratory Removal)	1 day	11/21/13	11/21/13
Bent 8	**22 days**	**11/24/13**	**12/19/13**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	11/24/13	11/25/13
Remove Oscillator Support Piles (Vibratory Removal)	1 day	12/19/13	12/19/13
Bent 9	**42 days**	**12/12/13**	**1/30/14**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	12/12/13	12/19/13
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	1/1/14	1/8/14
Remove Work Bridge and Piles (Vibratory Removal)	1 day	1/30/14	1/30/14
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	12/22/13	12/23/13
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	1/9/14	1/10/14
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	1/18/14	1/20/14
Remove Oscillator Support Piles (Vibratory Removal)	1 day	1/30/14	1/30/14
Barge Moorings - All Bents (Vibratory Installation & Removal)	111 days	9/15/13	1/30/14
Light Rail Transit/Multi-Use Plan Bridge	**142 days**	**9/15/14**	**3/12/15**
Bent 2	**30 days**	**9/15/14**	**10/22/14**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	9/15/14	9/22/14
Remove Work Bridge and Piles (Vibratory Removal)	1 day	10/22/14	10/22/14
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	9/22/14	9/23/14
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	10/2/14	10/3/14
Remove Oscillator Support Piles (Vibratory Removal)	1 day	10/22/14	10/22/14
Bent 3	**21 days**	**10/25/14**	**11/20/14**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	10/25/14	10/26/14
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	11/4/14	11/5/14
Remove Oscillator Support Piles (Vibratory Removal)	1 day	11/20/14	11/20/14
Bent 4	**20 days**	**11/23/14**	**12/18/14**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	11/23/14	11/24/14
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	12/3/14	12/4/14
Remove Oscillator Support Piles (Vibratory Removal)	1 day	12/18/14	12/18/14
Bent 5	**34 days**	**12/21/14**	**1/29/15**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	12/21/14	12/22/14
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	12/31/14	1/1/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	7 days	1/10/15	1/17/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	1/29/15	1/29/15
Bent 6	**41 days**	**1/22/15**	**3/12/15**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	1/22/15	1/29/15
Remove Work Bridge and Piles (Vibratory Removal)	1 day	3/12/15	3/12/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	2/1/15	2/2/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	2/11/15	2/12/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	2/21/15	2/22/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	3/12/15	3/12/15
Barge Moorings - All Bents (Vibratory Installation & Removal)	142 days	9/15/14	3/12/15

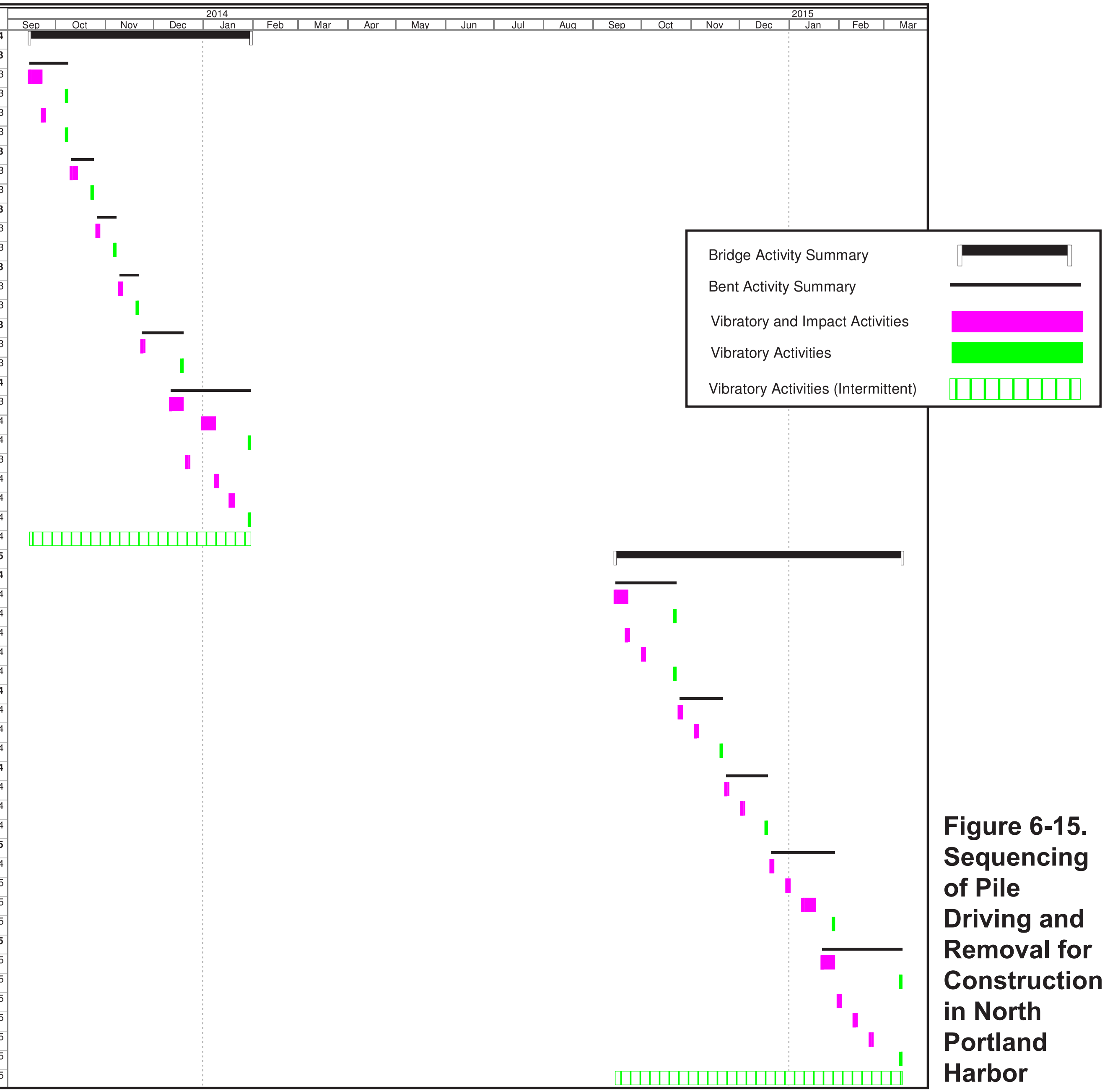
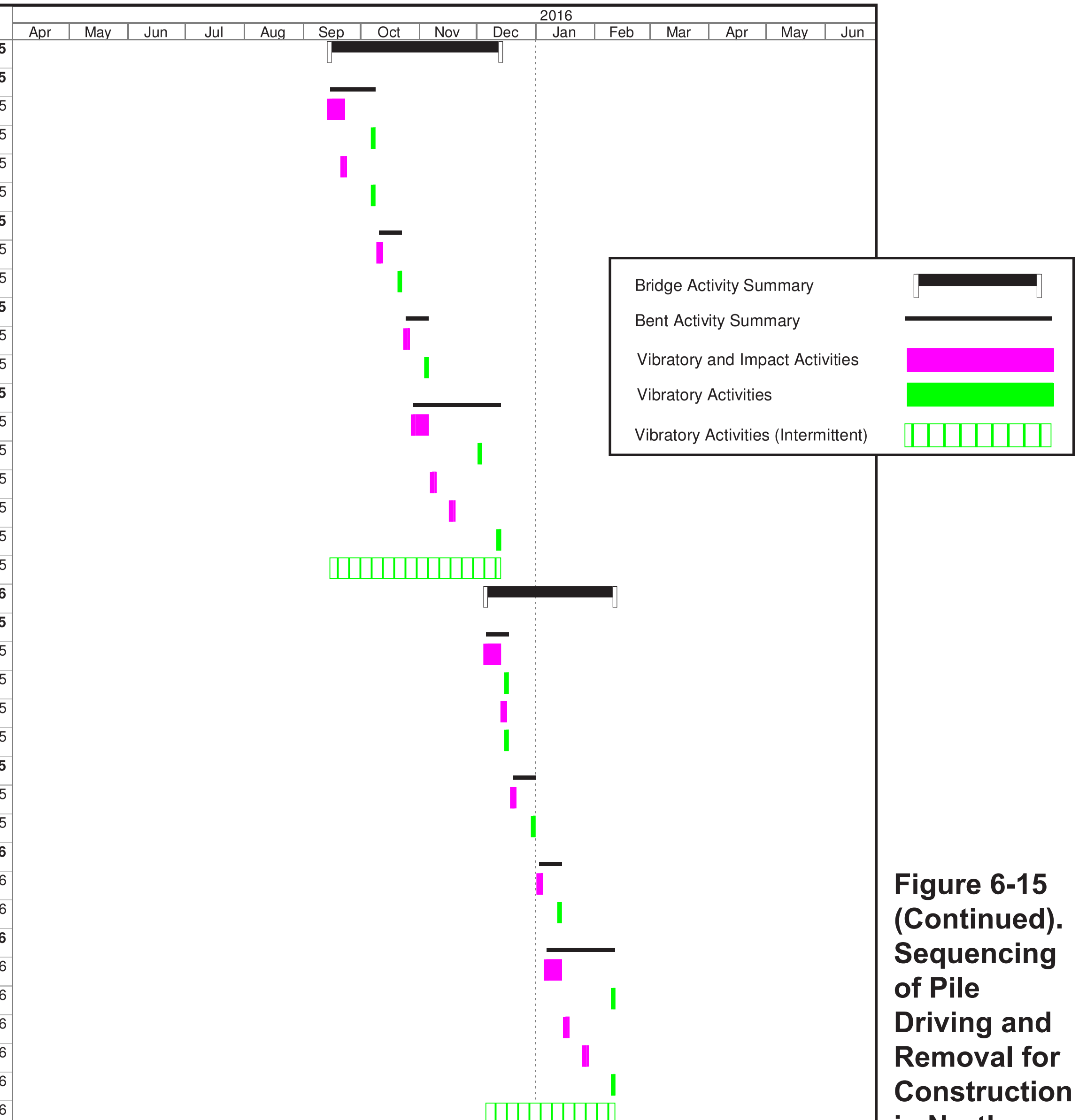


Figure 6-15. Sequencing of Pile Driving and Removal for Construction in North Portland Harbor

Conceptual Schedule Only, April 2010
Note: This is a proposed schedule, so activity dates are likely to change.

Columbia River CROSSING

Task Name	Duration	Start	Finish
Northbound Collector Distributor Ramp	**74 days**	**9/15/15**	**12/13/15**
Bent 6	**20 days**	**9/15/15**	**10/8/15**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	9/15/15	9/22/15
Remove Work Bridge and Piles (Vibratory Removal)	1 day	10/8/15	10/8/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	9/22/15	9/23/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	10/8/15	10/8/15
Bent 7	**10 days**	**10/11/15**	**10/22/15**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	10/11/15	10/12/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	10/22/15	10/22/15
Bent 8	**12 days**	**10/25/15**	**11/5/15**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	10/25/15	10/26/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	11/5/15	11/5/15
Bent 9	**38 days**	**10/29/15**	**12/13/15**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	10/29/15	11/5/15
Remove Work Bridge and Piles (Vibratory Removal)	1 day	12/3/15	12/3/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	11/8/15	11/9/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	11/18/15	11/19/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	12/13/15	12/13/15
Barge Moorings - All Bents (Vibratory Installation & Removal)	74 days	9/15/15	12/13/15
Southbound Collector Distributor Ramp	**57 days**	**12/6/15**	**2/11/16**
Bent 2	**12 days**	**12/6/15**	**12/17/15**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	12/6/15	12/13/15
Remove Work Bridge and Piles (Vibratory Removal)	1 day	12/17/15	12/17/15
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	12/15/15	12/16/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	12/17/15	12/17/15
Bent 3	**10 days**	**12/20/15**	**12/31/15**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	12/20/15	12/21/15
Remove Oscillator Support Piles (Vibratory Removal)	1 day	12/31/15	12/31/15
Bent 4	**12 days**	**1/3/16**	**1/14/16**
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	1/3/16	1/4/16
Remove Oscillator Support Piles (Vibratory Removal)	1 day	1/14/16	1/14/16
Bent 5	**29 days**	**1/7/16**	**2/11/16**
Install Work Bridge Piles (Vibratory & Impact Pile Driving)	8 days	1/7/16	1/14/16
Remove Work Bridge and Piles (Vibratory Removal)	1 day	2/11/16	2/11/16
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	1/17/16	1/18/16
Install Oscillator Support Piles (Vibratory & Impact Pile Driving)	2 days	1/27/16	1/28/16
Remove Oscillator Support Piles (Vibratory Removal)	1 day	2/11/16	2/11/16
Barge Moorings - All Bents (Vibratory Installation & Removal)	57 days	12/6/15	2/11/16

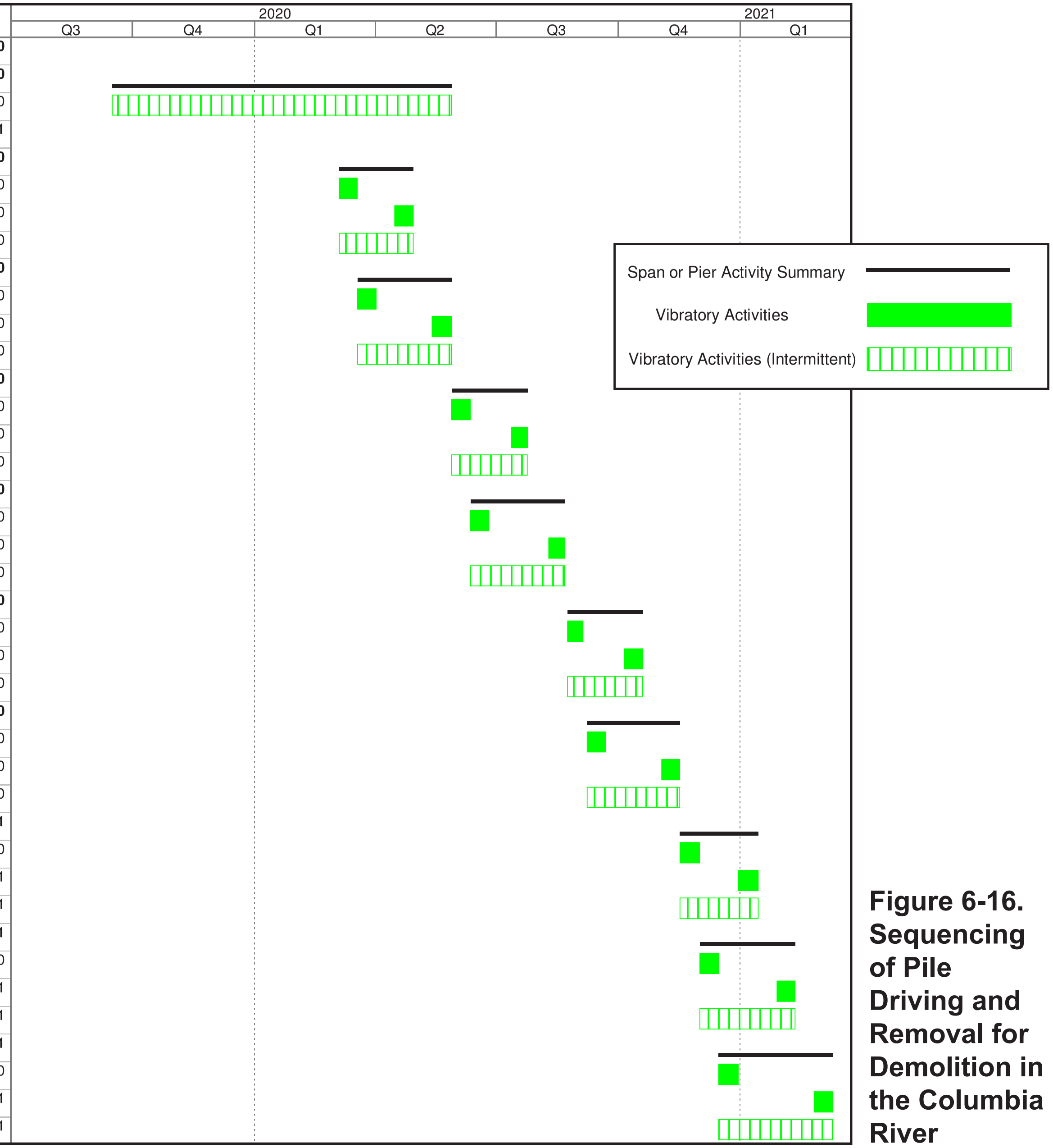


Conceptual Schedule Only, April 2010
Note: This is a proposed schedule, so activity dates are likely to change.

Figure 6-15 (Continued). Sequencing of Pile Driving and Removal for Construction in North Portland Harbor

Columbia River CROSSING

Task Name	Duration	Start	Finish
Superstructure Demolition	**184 days**	**9/16/19**	**5/28/20**
Spans 1-10	**184 days**	**9/16/19**	**5/28/20**
Install and Remove Barge Moorings (Vibratory)	184 days	9/16/19	5/28/20
Substructure Demolition	**266 days**	**3/5/20**	**3/11/21**
Pier 2	**40 days**	**3/5/20**	**4/29/20**
Install Cofferdam (Vibratory Installation)	10 days	3/5/20	3/18/20
Remove Cofferdam (Vibratory Removal)	10 days	4/16/20	4/29/20
Install and Remove Barge Moorings (Vibratory)	40 days	3/5/20	4/29/20
Pier 3	**51 days**	**3/19/20**	**5/28/20**
Install Cofferdam (Vibratory Installation)	10 days	3/19/20	4/1/20
Remove Cofferdam (Vibratory Removal)	11 days	5/14/20	5/28/20
Install and Remove Barge Moorings (Vibratory)	51 days	3/19/20	5/28/20
Pier 4	**41 days**	**5/29/20**	**7/24/20**
Install Cofferdam (Vibratory Installation)	10 days	5/29/20	6/11/20
Remove Cofferdam (Vibratory Removal)	10 days	7/13/20	7/24/20
Install and Remove Barge Moorings (Vibratory)	41 days	5/29/20	7/24/20
Pier 6	**51 days**	**6/12/20**	**8/21/20**
Install Cofferdam (Vibratory Installation)	10 days	6/12/20	6/25/20
Remove Cofferdam (Vibratory Removal)	10 days	8/10/20	8/21/20
Install and Remove Barge Moorings (Vibratory)	51 days	6/12/20	8/21/20
Pier 7	**41 days**	**8/24/20**	**10/19/20**
Install Cofferdam (Vibratory Installation)	10 days	8/24/20	9/4/20
Remove Cofferdam (Vibratory Removal)	10 days	10/6/20	10/19/20
Install and Remove Barge Moorings (Vibratory)	41 days	8/24/20	10/19/20
Pier 8	**50 days**	**9/8/20**	**11/16/20**
Install Cofferdam (Vibratory Installation)	10 days	9/8/20	9/21/20
Remove Cofferdam (Vibratory Removal)	10 days	11/3/20	11/16/20
Install and Remove Barge Moorings (Vibratory)	50 days	9/8/20	11/16/20
Pier 9	**43 days**	**11/17/20**	**1/14/21**
Install Cofferdam (Vibratory Installation)	11 days	11/17/20	12/1/20
Remove Cofferdam (Vibratory Removal)	11 days	12/31/20	1/14/21
Install and Remove Barge Moorings (Vibratory)	43 days	11/17/20	1/14/21
Pier 10	**52 days**	**12/2/20**	**2/11/21**
Install Cofferdam (Vibratory Installation)	10 days	12/2/20	12/15/20
Remove Cofferdam (Vibratory Removal)	10 days	1/29/21	2/11/21
Install and Remove Barge Moorings (Vibratory)	52 days	12/2/20	2/11/21
Pier 11	**62 days**	**12/16/20**	**3/11/21**
Install Cofferdam (Vibratory Installation)	11 days	12/16/20	12/30/20
Remove Cofferdam (Vibratory Removal)	10 days	2/26/21	3/11/21
Install and Remove Barge Moorings (Vibratory)	62 days	12/16/20	3/11/21



Conceptual Schedule Only, April 2010

Note: This is a proposed schedule, so activity dates are likely to change.

Figure 6-16. Sequencing of Pile Driving and Removal for Demolition in the Columbia River

Columbia River CROSSING

Note that in most instances, use of an attenuation device decreases the area of effect appreciably. For example, when comparing scenarios in which a single pile driver is operating:

- The radius of the 206 dB Peak injury zone decreases by about 80 percent.
- In the Columbia River, the radius of the disturbance zone decreases by about 80 percent for smaller piles and by 40 to 70 percent for larger piles, depending on the direction (upstream or downstream).
- In North Portland Harbor, radius of the disturbance zone decreases for smaller piles by about 75 percent. For the larger piles, use of a noise attenuation device does not shrink the disturbance zone because noise encounters landforms at fairly short distances from the source (3,058 m upstream and 5,412 m downstream).
- Similar reductions in distances to accumulated SEL threshold levels will occur with attenuation devices, but details are not presented here due to the numerous variables associated with calculating accumulated SEL in the moving fish model.

Table 6-9 and Table 6-10 summarize these results, showing the extent and duration of noise levels exceeding the injury thresholds and disturbance guidance.

Figure 6-14 and Figure 6-15 further describe the timing and duration of these effects, showing the sequencing of all pile-driving activities.

Table 6-9. Exposure of Fish to Threshold/Guidance Levels of Underwater Noise in the Columbia River

		Without Attenuation Device[a]			With Attenuation Device (assumes 10 dB of attenuation)		
Size Class	**Threshold or Guidance**	**Distance (m)**	**Duration**	**Number of Days**	**Distance (m)**	**Duration**	**Number of Days**
≥ 2 grams	Injury: 206 dB Peak	25 - 34	7.5 min/ week	38	5 - 7	0.66 hr / day	138
	Injury:[b] 187 SEL_{cum}						
	0.1 m/sec	113 - 243			50 - 156		
	0.8 m/sec	102 - 237			9 - 111		
	Disturbance:[c] 150 dB RMS						
	Upstream	3,981-20,166			858-5,412		
	Downstream	3,981-8,851			858-5,412		
< 2 grams	Injury: 206 dB Peak	25 - 34	7.5 min/ week	38	5 - 7	0.66 hr / day	138
	Injury:[b] 183 SEL_{cum}	205 - 446			50 - 235		
	Disturbance:[c] 150 dB RMS						
	Upstream	3,981-20,166			858-5,412		
	Downstream	3,981-8,851			858-5,412		

a As part of the hydroacoustic monitoring program and to account for equipment failure, up to 7.5 minutes one day per week of pile driving is assumed to occur for purposes of estimating impacts

b Accumulated SEL (injury) threshold distances are calculated based on the construction scenario presented in Table 6-2.

c. Distances show extent of calculated values or where noise stops at landforms.

Table 6-10. Exposure of Fish to Threshold/Guidance Levels of Underwater Noise in North Portland Harbor

		Without Attenuation Device[a]			With Attenuation Device (assumes 10 dB of attenuation)		
Size Class	**Threshold/Guidance**	**Distance (m)**	**Duration**	**Number of Days**	**Distance (m)**	**Duration**	**Number of Days**
≥ 2 grams	Injury: 206 dB Peak	25 -34	2–5 min/ week	18 - 31	5 - 7	0.66 hr / day	134
	Injury:[b] 187 SEL_{cum}						
	0.1 m/sec	113 - 243			50 - 156		
	0.8 m/sec	102 - 237			9 - 111		
	Disturbance:[c] 150 dB RMS						
	Upstream	3,058			858-3,058		
	Downstream	3,981-5,632			858-5,412		
< 2 grams	Injury: 206 dB Peak	25 - 34	2–5 min/ week	18 - 31	5 - 7	0.66 hr / day	134
	Injury:[b] 183 SEL_{cum}	205 - 446			50 - 235		
	Disturbance:[c] 150 dB RMS						
	Upstream	3,058			858-3,058		
	Downstream	3,981-5,632			858-5,412		

a As part of the hydroacoustic monitoring program and to account for equipment failure, up to 3.75 minutes one day per week of pile driving is assumed to occur for purposes of estimating impacts

b Accumulated SEL (injury) threshold distances are calculated based on the construction scenario presented in Table 6-3.

c. Distances show extent of calculated values or where noise stops at landforms.

Exposure factors were calculated using the information presented in the above tables for the 13 different construction scenarios for the Columbia River and the one scenario for North Portland Harbor. Table 6-11 shows representative weekly exposure factors for adult fish (over 2 g, speed of 0.1 m/s) calculated from the in-water impact pile-driving scenario based on a construction contract awarded on February 5, 2013. Weekly exposure factors are presented for both Columbia River and North Portland, in addition to the total weekly exposure factor. When no pile driving is anticipated to occur, the weekly exposure factor is zero. While this representative table shows the weekly exposure factors for adult fish in one scenario, they were also calculated for juvenile fish (over 2 g, moving at 0.8 m/s, and under 2g, moving at 0.6 m/s) and those for the other scenarios 12 scenarios.

Table 6-11. Pile-Strike Summary for Construction in North Portland Harbor

Pile Size	Estimated Piles Installed per Day	Estimated Strikes per Pile	Estimated Maximum Strikes per Day	Hours of Pile Driving/12-hr Daily Pile Driving Work Period
Temporary Work Bridge				
18“– 24”	3	300	900	0.165
Oscillator Support Platforms				
36” – 48”	3	300	900	0.165

For purposes of estimating impacts and performance measure thresholds, exposure factors were calculated for all construction scenarios using the moving fish model, based on a fish of over 2 grams with a movement rate of 0.1 m/s. The following exposure factor results were found during these calculations:

- The maximum weekly exposure factor (based on one calendar week) for all scenarios was 0.18649 (the minimum was zero, when no impact pile driving was scheduled to occur).
- The maximum yearly total exposure factor (the sum of all weekly exposure factors in one calendar year) was 0.20218.
- The average maximum yearly exposure factor (the mean value of all yearly total exposure factors) was 0.12009 per calendar year of construction.
- The maximum total exposure factor (the sum of all weekly exposure factors throughout the project) was 0.48036.

Effects of Impact Pile Driving on Listed Fish

Impact pile driving will result in effects to fish that may range from behavioral disturbance to immediate death, depending on size of the fish, duration of exposure to sound pressure, proximity to the strike site, size of the pile, and number of strikes in a given time frame (e.g., per 12-hour period).

Actual exposure to noise above the injury thresholds and disturbance guidance will be fairly limited, restricted to the periods when impact pile driving is occurring: 138 days in the Columbia River and 134 days in North Portland Harbor interspersed over the entire four-year in-water construction period from roughly mid-September through mid-April of each year (Figure 6-14 and Figure 6-15). Within this time period, exposure will be further restricted to no more than approximately 40 minutes per 12-hour work day.

Project-generated noise above the injury threshold may cause a range of lethal and sublethal injuries to fish, as outlined in Appendix K. Effects may include damage to non-auditory tissues, including rupture of air-filled organs, such as the swim bladder. Damage to the swim bladder may lead to loss of control over vertical movement or may result in mortality. Loud noise may cause damage to the skin, nerves, and eyes of fish. Elevated sound levels may also result in the formation of gas bubbles in tissue, causing inflammation, cellular damage, and blockage or rupture of blood vessels. These injuires may lead to immediate or delayed mortality.

Intense sound may lead to hearing loss in fish. Such hearing loss may be temporary and reversible, known as temporary threshold shift (TTS). TTS and represents fatigue of the hair cells in the inner ear and is not considered tissue damage (Carlson et al. 2007). Intense sound may also reach levels that cause permanent threshold shift (PTS): permanent hearing loss resulting from the irreversible death of sensory hair cells in the inner ear. Such auditory damage may result in a general decrease in fitness, foraging success, ability to avoid predators, and ability to communicate. Thus, even if intense noises do not directly result in death, auditory damage could result in delayed mortality to fish.

Project-generated noise above the disturbance guidance may cause behavioral effects to fish (as described in more detail in Appendix K). Literature related to the effect of pile driving on fish behavior is extremely limited and somewhat conflicting. Effects could be relatively minor, limited to startling, disruption in feeding, or avoidance of the action area (WSDOT 2008). Other effects could be more significant, with consequences for survival and reproduction. For example, while exposure to noise levels above 150 dB RMS is not likely to directly cause mortality or injury, it could result in an impaired ability to avoid predators, indirectly resulting in death (WSDOT 2008). Additionally, avoidance of the action area could presumably cause delays in migration. Migration delays, in turn, may present a variety of risks for fish including: depletion of energy reserves; delayed or reduced spawning; increased exposure to predation, disease, and thermal stress; disruption of arrival timing to the estuary (which may desynchronize arrival with prey availability); and an increase in residualism in some steelhead and Chinook (NMFS 2008a).

Overall, this element of the project is likely to adversely affect individuals of all listed salmon, steelhead, and eulachon present in the areas exposed to noise above the injury threshold and disturbance guidance during impact pile driving activities. Table 6-12 summarizes the species and life stages of listed fish likely to be exposed to this effect. Section 5 of Appendix K presents detailed results of modeling exposure factors and run timing on impacts to these fish at the ESU/DPS and life stage scale.

Due to the extremely limited numbers of green sturgeon and bull trout present in the action area, risk of exposure is discountable. Thus, this element of the project is not likely to adversely affect green sturgeon and bull trout.

Table 6-12. Species and Life Stages Expected to be Present in the Action Area During Pile Driving

	Life Stage				
Species	**Spawning**	**Incubation**	**Rearing**	**Outmigrating Juveniles**	**Migrating/ Holding Adults**
Chinook					
LCR ESU			X	X	X
UCR Spring-Run ESU			X	X	X
UWR ESU			X	X	X
SR Fall-Run ESU				X	X
SR Spring/Summer-Run ESU				X	X
Steelhead					
LCR DPS			X	X	X
MCR DPS				X	X
UWR DPS				X	X
UCR DPS				X	X
SR DPS				X	X
Sockeye					
SR ESU				X	X
Coho					
LCR ESU			X	X	X
Chum					
CR ESU	X	X	X	X	X

	Life Stage				
Species	**Spawning**	**Incubation**	**Rearing**	**Outmigrating Juveniles**	**Migrating/ Holding Adults**
Bull Trout					
CR DPS					X[a]
Green Sturgeon					
Southern DPS					X[a]
Eulachon					X
Southern DPS	X	X		X	X

a Includes subadults.

6.1.1.2 Hydroacoustic Impacts to Fish from Vibratory Pile Driving and Removal

Vibratory pile driving will be used to install cofferdams and temporary piles throughout the in-water project area in the Columbia River and North Portland Harbor. Load-bearing piles (used for temporary work platforms, work bridges, tower cranes, and oscillator platforms) will be vibrated into place before being proofed with an impact hammer. Piles that are not load bearing (mooring piles) will be installed using vibration only.

Vibratory pile driving produces lower peak noise levels than impact pile driving of the same sized pile, and this generally results in fewer injuries to fish (USFWS 2009), as described in greater detail in Appendix K. Rise time is also much slower during vibratory pile driving, decreasing the potential for injury (Carlson et al. 2004, Nedwell and Edwards 2002, as cited in USFWS 2009). USFWS states that there are no documented kills attributed to the use of a vibratory hammer (USFWS 2004a, as cited in WSF 2009).

Currently there are no established thresholds for noise levels generated by vibratory pile driving that are likely to cause injury or behavioral disturbance to fish. Additionally, there are no established threshold distances at which vibratory noise is likely to harm fish. However, NMFS offers the guidance that vibratory pile driving noise at 150 dB RMS may cause behavioral disturbance to fish.

Vibratory pile driving on the CRC project is likely to create noise above 150 dB RMS. Table 6-13 outlines a range of typical noise levels produced by vibratory pile driving as measured by Caltrans during hydroacoustic monitoring of several construction projects (Caltrans 2009). The monitoring showed that vibratory driving of pipe pile (up to 72-inches in diameter) generated initial sound levels of up to 180 dB RMS, and vibratory driving of sheet pile generated initial sound levels of 160 to 165 dB RMS.

Table 6-13. Summary of Unattenuated Underwater Sound Pressures for Vibratory Pile Driving

Pile Type and Approximate Size	Water Depth (meters)	SPLs (dB RMS)[a]
0.30-meter (12-inch) steel H-type	<5	150
0.30-meter (12-inch) steel pipe pile	<5	155
0.6-meter (24-inch) AZ steel sheet – typical	~15	160
0.6-meter (24-inch) AZ steel sheet – loudest	~15	165
1.0-meter (36-inch) steel pipe pile – typical	~5	170
1.0-meter (36-inch) steel pipe pile – loudest	~5	175
1.8-meter (72-inch) steel pipe pile – typical	~5	170
1.8-meter (72-inch) steel pipe pile – loudest	~5	180

Source: Caltrans 2009, Appendix I.

a Impulse level (35 millisecond average).

On the CRC project, vibratory pile driving is likely to occur frequently during installation of temporary structures throughout the four-year in-water construction period and the 18-month in-water demolition period. Figure 6-14, Figure 6-15, and Figure 6-16 show the locations and duration of vibratory pile driving for temporary structures in the project area. Vibratory pile driving for installation of temporary structures will likely take place up to approximately 5 hours per day during the in-water construction period and may occur during any hour of day.

Vibration may also be used to install the 10-foot-diameter steel casings for the drilled shafts of the permanent structures in the Columbia River and North Portland Harbor. No data were available regarding the initial SPLs generated by steel casings of this size. Therefore, it is currently not possible to calculate the extent of noise generated from vibratory installation of 10-foot-diameter casings. However, the assumption is that vibration of the 10-foot steel casings will produce at least as many initial SPLs as 72-inch steel pipe pile (180 dB RMS at 5 m), and therefore, noise from 10-foot-diameter casings will extend at least as far as that from 72-inch-diameter steel pipe pile. The design team estimates that vibratory installation of the drilled shaft casings will take approximately 90 days in the Columbia River and 31 days in North Portland Harbor. Vibratory installation is not restricted to the in-water work window and therefore may take place any time during the four-year in-water construction period.

All of the species and life stages of salmon, steelhead, and eulachon shown in Table 6-12 could be exposed to this effect when they are present in this portion of the action area (Figure 4-1 and Figure 4-2). However, because fish kills attributed to the use of a vibratory hammer have never been documented, this activity is unlikely to injure fish and is not expected to significantly interfere with behaviors such as migration, rearing, or foraging. Thus, vibratory pile driving is not likely to adversely affect any of these species.

Due to the extremely limited numbers of green sturgeon and bull trout present in this portion of the action area, risk of exposure is discountable. Thus, this element of the project is not likely to adversely affect green sturgeon or bull trout.

6.1.1.3 Noise Impacts to Fish from Excavating Drilled Shaft Casings

After the casings are installed, the project will excavate the material from inside of the permanent shafts. Hydroacoustic impacts from drilling and excavating inside of casings have not been well documented but will be far less than impacts from impact pile driving. Drilling shafts will likely elevate in-water noise levels, causing disturbance to fish, but the extent of this disturbance cannot be calculated. Lethal effects from drilling of shafts have not been documented on other projects and are not likely to occur. Shafts will be excavated year-round during the in-water construction period (roughly, January 2014 to August 2017 in the Columbia River and September 2013 to February 2016 in North Portland Harbor). Effects to listed fish are expected to be insignificant.

6.1.2 Work-Area Isolation and Fish Salvage

The project will use cofferdams to isolate the in-water work area from active flow during construction in the Columbia River. Cofferdams will be used during demolition of the existing bridge in the Columbia River if a wire saw is not used to cut the existing piers into pieces. The purpose of the cofferdams is to avoid contaminating the Columbia River with work materials or wastes, to contain re-suspended sediments, and to minimize disturbance and injury to fish. Cofferdams will be installed in a manner that minimizes fish entrapment. Sheet piles will be installed from upstream to downstream and lowered slowly until contact with the substrate.

Tables 3-5, 3-6, 3-19, and 3-20 provide a summary of the size of the cofferdams and their timing and duration in the Columbia River. Up to 11 cofferdams are anticipated. The two cofferdams used during construction of Piers 2 and 7 in the Columbia River will cover a combined area of approximately 15,750 sq. ft. The nine cofferdams used during demolition of the existing in-water Columbia River bridge piers 2 through 10 will each encompass an area of 7,500 sq. ft. (for a total area of 67,500 sq. ft.). Cofferdams will likely be installed and removed at any time of year, pending approval from USFWS and NMFS. ODFW and WDFW have both agreed that performing this activity outside of the standard work window will not cause significant harm to fish. Installation will use low-impact methods such as vibrating or pressing into place.

Cofferdams used for construction will each require 10 days to install, be in place for approximately 330 to 470 calendar days apiece, and will require 15 days for removal. Figure 6-14 shows the timing and duration of cofferdam installation and removal during construction in the Columbia River.

Each cofferdam used for demolition will require 10 days to install, be in place for approximately 20 additional work days apiece, and require approximately 10 work days to remove. Figure 6-16 shows the timing and duration of cofferdam installation and removal during demolition in the Columbia River.

Installation of the cofferdams is likely to generate low-level noise and visual disturbance. For this reason, fish are likely to actively avoid the work area during the construction of cofferdams. Nevertheless, due to the large size of the cofferdams, it is impossible to guarantee that no fish will become trapped inside. To minimize impacts to fish, the project will perform measures to remove fish from the work area during and after the installation of the cofferdams. Fish salvage will be conducted by qualified biologists in compliance with protocols outlined in Section 7 and Appendix E. Methods may include seining, electrofishing, trapping, and encouraging volitional movement of fish away from the work area. Captured fish will be released outside of the work area. To avoid entrainment of fish, pump intakes will be screened according to ODFW and WDFW standards and ODOT and WSDOT protocols outlined in Section 7.

The salvage operation involves capture, direct handling, and transporting of fish; therefore, there is a reasonable risk that the operation may harass, injure, or kill fish. If fish remain trapped in a cofferdam during construction, mortality is likely.

Because the fish salvage operations may take place at any time of year, individuals from any of the fish species using the project area in the Columbia River and North Portland Harbor may be exposed to this effect. Table 6-14 shows the species and life stages of fish that may potentially be present during work-area isolation.

Table 6-14. Species and Life Stages of Fish Expected to be Present in the Action Area During Work-Area Isolation

Species	Life Stage				
	Spawning	Incubation	Rearing	Outmigrating Juveniles	Migrating/ Holding Adults
Chinook					
LCR ESU			X	X	X
UCR Spring-Run ESU			X	X	X
SR Fall-Run ESU				X	X
SR Spring/Summer-Run ESU				X	X
Steelhead					
LCR DPS			X	X	X
MCR DPS				X	X
UCR DPS				X	X
SR DPS				X	X
Sockeye					
SR ESU				X	X
Coho					
LCR ESU			X	X	X
Chum					
CR ESU			X	X	X
Bull Trout					
CR DPS					X[a]
Green Sturgeon					
Southern DPS					X[a]
Eulachon					
Southern DPS	X	X		X	X

a Includes subadults.

The species of salmon, steelhead, and eulachon shown in Table 6-14 are likely to be present in the action area at the time of the fish salvage and work area isolation. Thus, these species are likely to be adversely affected by this element of the project.

Due to the extremely limited numbers of green sturgeon and bull trout present in the action area, these species are not likely to be present while this activity is taking place. The risk of exposure is therefore discountable. Thus, this element of the project is not likely to adversely affect green sturgeon or bull trout.

6.1.3 Shading

The project will create several temporary and permanent sources of new overwater coverage in the Columbia River and North Portland Harbor and will increase the overall shade footprint in the action area. Temporary overwater structures include work platforms, work bridges, tower cranes, oscillator support platforms, and barges. Permanent overwater structures include the shaft caps of the new Columbia River bridges and the new spans of the Columbia River and North Portland Harbor bridges (Table 6-15).

Studies have shown that fish communities under overwater structures differ from those in adjacent areas, in part due to the effect of shading (Southard et al. 2006). In general, shade may affect listed fish by increasing habitat for predators, causing visual disorientation, and decreasing primary productivity.

6.1.3.1 General Effects of Shading on Fish

Overwater coverage increases the amount of shade in the water column. Fish rely on visual cues when performing life functions such as foraging, schooling, avoiding predators, and migration. The literature shows that changes in light conditions can alter fish behavior (Simenstad et al. 1999; Nightingale and Simenstad 2001). Overwater structures that alter the existing light regime may limit the ability of fish to perform essential life functions (Southard et al. 2006). Shade may also affect the productivity of underwater plants, the basis of the food web for many juvenile fish (Nightingale and Simenstad 1999). Finally, shade may affect fish by providing cover for predators (Carrasquero 2001).

Predation

Shade attracts and provides cover for many species of predatory fish, including northern pikeminnow, smallmouth bass, and largemouth bass (Pribyl et al. 2004; Celedonia et al. 2008). The literature does not draw a clear, consistent relationship between an increase in predation and an increase in shade; predation rates have been shown to both increase and decrease with increasing light (Carrasquero 2001). In a review of the available literature, researchers concluded that the effect of shading on predation is “inconclusive” (WSF 2009). However, a literature review conducted by Carrasquero (2001) shows that largemouth and smallmouth bass have a strong affinity for piers and overwater structures, potentially using the cover of darkness to ambush fish. In a study in the Columbia River, Beamesderfer and Riemen (1991, as cited in Celedonia et al. 2008) noted that northern pikeminnow selected low-velocity microhabitats created by in-water structures, where juvenile salmonids were congregating. In a study conducted in the lower Columbia River, Zimmerman (1999) found that smallmouth bass consumed salmonids averaging 119 mm in length, and pikeminnow consumed salmonids averaging 167 mm in length. Relatively few salmonids consumed by pikeminnow were greater than 250 mm in length (Zimmerman 1999). This indicates that predation risks are greater for juvenile salmonids.

Migration and Orientation

The literature provides empirical evidence that juvenile salmonids may become disoriented beneath overwater structures or other shaded areas with sharp contrast between light and dark. Heiser and Finn (1970), Weitkamp (1982), and Pentec (1997) reported that fish were reluctant to enter shadow zones under docks and or other sources of intense shade. Pentec (1997), Taylor and Willey (1997), Simenstad et al. (1999), Williams et al. (2003), and Toft et al. (2004) reported observing fish movement along the shadow zone boundary without penetration into the shadow. Shreffler and Moursund (1999) found that juvenile Chinook ceased directional movement at the shadow line rather than immediately continuing under an overwater structure. Juvenile salmon consistently swam from the shadow line into the light, then immediately darted down and back into the light-dark transition area again.

Other literature suggests that a sharp light/dark interface caused by overwater structures may interfere with migration in juvenile salmonids. Response of fish to overwater structures is complex, as some fish will readily pass under structures, and others will not. Schools may either disband upon encountering an overwater structure, or they may pause and proceed as a group (Southard et al. 2006). A study conducted by Pacific Northwest National Laboratory (PNNL) (Williams et al. 2003) concluded that overwater structures are likely to be impediments to juvenile migration, depending on numerous factors such as light levels, angle of the sun, cloud cover, current velocity and direction, and tidal stage. For example, the study indicated that effects of shading were reduced during low tide when more light can dissipate beneath overwater structures. The same study also observed that juvenile chum would not cross into shade when the decrease in light level was 85 percent over a horizontal distance of approximately 5 m. Acoustic tagging at Port Townsend revealed that juvenile Chinook and coho passed under overwater structures more quickly in the evening when the light-dark interface is indistinct (Southard et al. 2006). On the other hand, Weitkamp (1982) found that juvenile salmonids will readily swim under overwater structures. Williams et al. (2003) found that salmon fry were not inhibited by the 33-foot-wide shadow cast by an overwater structure at the Mukilteo Ferry Terminal, even though light levels under the structure were 97 percent lower than ambient levels.

Thus, although the literature is not in agreement regarding the effects of a shade on orientation, there appears to be some evidence that a shadow line under overwater structures could interfere with the migration of salmonid juveniles during some daylight hours. Studies have suggested that this may prompt fish to enter deeper water, where they could presumably be exposed to predation from birds, mammals, and other fish (WSF 2009). Additionally, juveniles may congregate at the edge of the shadow line, making them more vulnerable to predation (Southard et al. 2006).

Primary Productivity

Shading may result in decreased productivity of underwater vegetation. Macrophytes, benthic algae, and phytoplankton contribute to aquatic habitat complexity and form the basis of the food web for many species of fish. Carrasquero (2001) notes that lowered light levels may reduce or eliminate macrophyte beds, algae, and other aquatic vegetation beneath overwater structures. This may, in turn limit the amount of prey available to fish (Simenstad and Nightingale 2001). Epibenthic crustaceans are of most concern because they are typically associated with nearshore plants (Simenstad et al. 1999). Loss of underwater vegetation may also reduce cover for juvenile fish, potentially increasing exposure to predation (Carrasquero 2001). Furthermore, shading underneath overwater structures may reduce primary production in phytoplankton. However, this relationship is complex and poorly understood (Carrasquero 2001). For example, there is evidence that primary productivity of phytoplankton may be greater at the edge of overwater structures than in areas outside of the structure (White 1975, as cited in Carrasquero 2001). On the other hand, Mulvihill et al. (1980, as cited in Carrasquero 2001) report that pilings and piers beneath overwater structures may provide substrate for algal growth where bottom depths are below the photic zone or where bottom substrates are unstable. The increase in algal growth may potentially compensate for loss of phytoplankton primary productivity.

6.1.3.2 Sources of Shade on the CRC Project

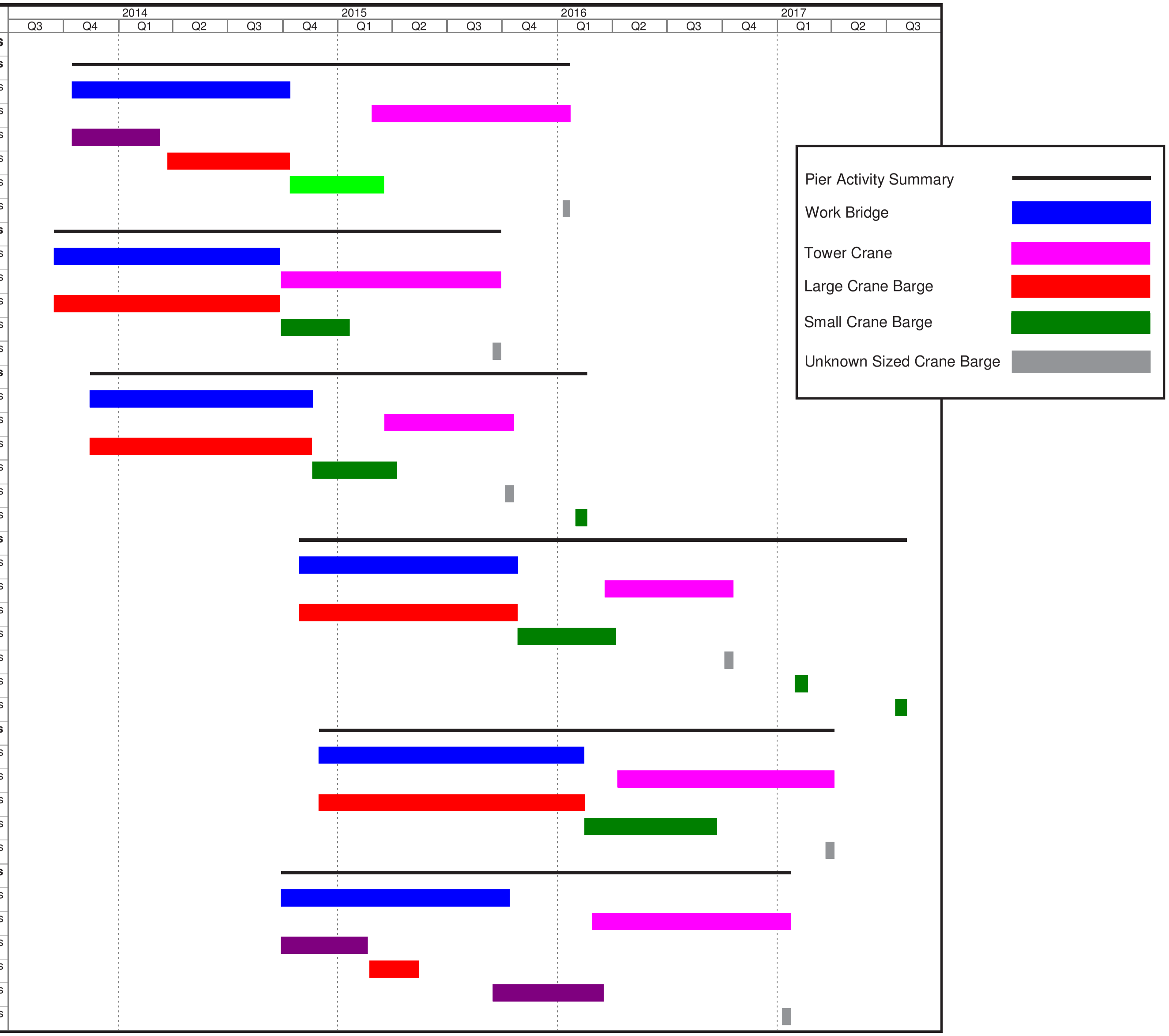
The CRC project will create several temporary sources of in-water shade: barges, in-water work platforms, work bridges, tower cranes, and oscillator support platforms. The project will also introduce permanent new shade by creating the new bridges over the Columbia River and North Portland Harbor. Finally, the project will remove some existing sources of shade, namely, the existing Columbia River bridge, and an overwater structure located on the north shore of the Columbia River at the Red Lion at the Quay hotel. Table 6-15 summarizes the sources of shade produced by this project. There will be a net increase in both permanent and temporary shade.

Table 6-15. Summary of Shade Sources in the Columbia River and North Portland Harbor

	Columbia River		North Portland Harbor	
Type	Area (sq. ft.)	Duration in Water (days)	Area (sq. ft.)	Duration in Water (days)
Temporary				
Work platforms/bridges for drilling shafts	148,000	120	29,640.	up to 42
Tower cranes	2,400.	600	N/A	N/A
Oscillator support platforms	N/A	N/A	27,900	Up to 33
Barges for construction	106,432	Varies	1,085,000	up to 42
Barges for demolition	42,000.	~1	N/A	N/A
Total Temporary Impact	**256,432**	---	**1,142,540**	---
Permanent				
Shaft caps	58,200	Permanent	N/A	Permanent
New bridge spans	676,000.	Permanent	310,000–416,000	Permanent
Existing spans - to be removed	-284,000	N/A	N/A	N/A
Overwater structure at the Quay - to be removed	-12,647–35,120	N/A	N/A	N/A
Total Permanent Impact	**415,080–437,553**		**310,000–416,000**	

The shade sources shown in Table 6-15 will not all be present in the action area at the same time. Figure 6-17, Figure 6-18, and Figure 6-19 show the anticipated sequencing of the temporary overwater structures in the action area. Appendix A, Figures 1-11 provide preliminary plan sheets for Columbia River construction sequencing.

Task Name	Start	Finish	Duration
Bridge Construction Scenario 2/5/13	**9/16/13**	**8/4/17**	**1015 days**
Pier 2	**10/16/13**	**1/22/16**	**593 days**
Work Bridge (17,500 s.f.)	10/16/13	10/13/14	259 days
Tower Crane (400 s.f.)	2/27/15	1/22/16	236 days
Medium Crane Barge (10,500 s.f.)	10/16/13	3/11/14	104 days
Large Crane Barge (30,000 s.f.)	3/24/14	10/13/14	145 days
Medium and Small Crane Barges (16,500 s.f.)	10/14/14	3/19/15	112 days
Unknown Sized Crane Barge	1/11/16	1/22/16	9 days
Pier 3	**9/16/13**	**9/29/15**	**532 days**
Work Bridge (29,000 s.f.)	9/16/13	9/26/14	270 days
Tower Crane (400 s.f.)	9/29/14	9/29/15	262 days
Large Crane Barge (30,000 s.f.)	9/16/13	9/26/14	269 days
Small Crane Barge (6,000 s.f.)	9/29/14	1/21/15	82 days
Unknown Sized Crane Barge	9/16/15	9/29/15	10 days
Pier 4	**11/15/13**	**2/19/16**	**591 days**
Work Bridge (29,000 s.f.)	11/15/13	11/19/14	264 days
Tower Crane (400 s.f.)	3/20/15	10/20/15	153 days
Large Crane Barge (30,000 s.f.)	11/15/13	11/19/14	263 days
Small Crane Barge (6,000 s.f.)	11/20/14	4/9/15	100 days
Unknown Sized Crane Barge	10/7/15	10/20/15	10 days
Small Crane Barge (6,000 s.f.)	2/1/16	2/19/16	15 days
Pier 5	**10/29/14**	**8/4/17**	**723 days**
Work Bridge (29,000 s.f.)	10/29/14	10/27/15	260 days
Tower Crane (400 s.f.)	3/21/16	10/19/16	153 days
Large Crane Barge (30,000 s.f.)	10/29/14	10/27/15	259 days
Small Crane Barge (6,000 s.f.)	10/28/15	4/8/16	117 days
Unknown Sized Crane Barge	10/6/16	10/19/16	10 days
Small Crane Barge (6,000 s.f.)	1/31/17	2/20/17	15 days
Small Crane Barge (6,000 s.f.)	7/17/17	8/4/17	15 days
Pier 6	**12/1/14**	**4/5/17**	**613 days**
Work Bridge (29,000 s.f.)	12/1/14	2/15/16	315 days
Tower Crane (400 s.f.)	4/11/16	4/5/17	258 days
Large Crane Barge (30,000 s.f.)	12/1/14	2/15/16	316 days
Small Crane Barge (6,000 s.f.)	2/16/16	9/23/16	158 days
Unknown Sized Crane Barge	3/23/17	4/5/17	10 days
Pier 7	**9/29/14**	**1/23/17**	**606 days**
Work Bridge (18,500 s.f.)	9/29/14	10/13/15	272 days
Tower Crane (400 s.f.)	2/29/16	1/23/17	236 days
Medium Crane Barge (10,500 s.f.)	9/29/14	2/20/15	104 days
Large Crane Barge (30,000 s.f.)	2/23/15	5/15/15	60 days
Medium Crane Barge (10,500 s.f.)	9/16/15	3/18/16	132 days
Unknown Sized Crane Barge	1/10/17	1/23/17	10 days

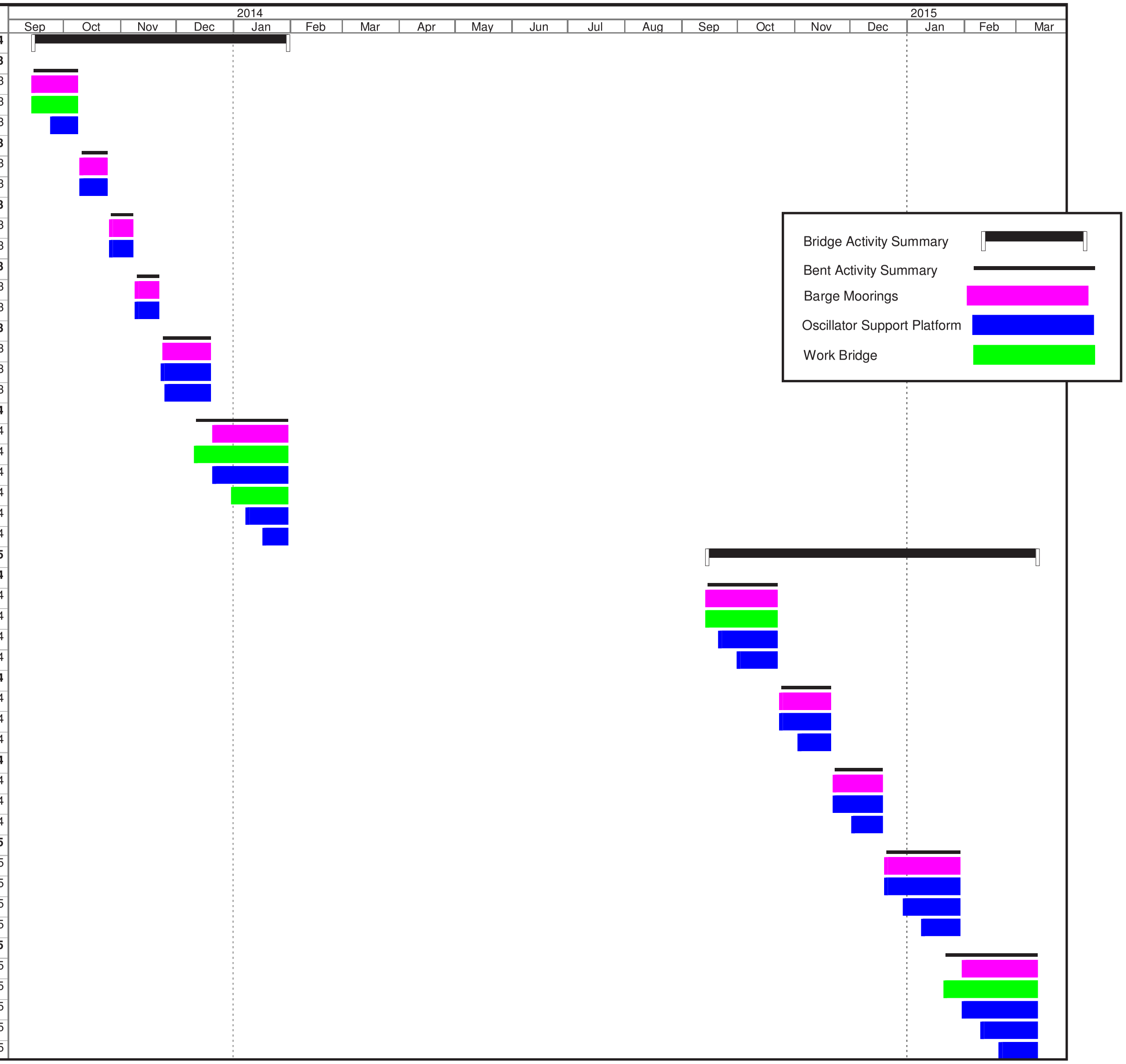


Conceptual Schedule Only, March 2010
Note: This is a proposed schedule, so activity start and finish dates are likely to change.

Figure 6-17. Sequencing of Temporary Over-Water Structures for Construction in the Columbia River

Columbia River CROSSING

Task Name	Duration	Start	Finish
Widening of Existing Bridge	**111 days**	**9/15/13**	**1/30/14**
Bent 4	**20 days**	**9/15/13**	**10/8/13**
Two Medium Crane Barges (35,000 s.f.)	20 days	9/15/13	10/8/13
Work Bridge (3,360 s.f.)	20 days	9/15/13	10/8/13
Oscillator Support Platform (900 s.f.)	10 days	9/25/13	10/8/13
Bent 5	**10 days**	**10/11/13**	**10/24/13**
Two Medium Crane Barges (35,000 s.f.)	10 days	10/11/13	10/24/13
Oscillator Support Platform (900 s.f.)	10 days	10/11/13	10/24/13
Bent 6	**10 days**	**10/27/13**	**11/7/13**
Two Medium Crane Barges (35,000 s.f.)	10 days	10/27/13	11/7/13
Oscillator Support Platform (900 s.f.)	10 days	10/27/13	11/7/13
Bent 7	**10 days**	**11/10/13**	**11/21/13**
Two Medium Crane Barges (35,000 s.f.)	10 days	11/10/13	11/21/13
Oscillator Support Platform (900 s.f.)	10 days	11/10/13	11/21/13
Bent 8	**22 days**	**11/24/13**	**12/19/13**
Four Medium Crane Barges (70,000 s.f.)	22 days	11/24/13	12/19/13
Oscillator Support Platform 1 (900 s.f.)	22 days	11/24/13	12/19/13
Oscillator Support Platform 2 (900 s.f.)	20 days	11/26/13	12/19/13
Bent 9	**42 days**	**12/12/13**	**1/30/14**
Six Medium Crane Barges (105,000 s.f.)	33 days	12/22/13	1/30/14
Work Bridge 1 (2,240 s.f.)	42 days	12/12/13	1/30/14
Oscillator Support Platform 1 (900 s.f.)	33 days	12/22/13	1/30/14
Work Bridge 2 (2,240 s.f.)	25 days	1/1/14	1/30/14
Oscillator Support Platform 2 (900 s.f.)	17 days	1/9/14	1/30/14
Oscillator Support Platform 3 (900 s.f.)	10 days	1/18/14	1/30/14
Light Rail Transit/Multi-Use Plan Bridge	**142 days**	**9/15/14**	**3/12/15**
Bent 2	**30 days**	**9/15/14**	**10/22/14**
Four Medium Crane Barges (70,000 s.f.)	30 days	9/15/14	10/22/14
Work Bridge (2,960 s.f.)	30 days	9/15/14	10/22/14
Oscillator Support Platform 1 (900 s.f.)	23 days	9/22/14	10/22/14
Oscillator Support Platform 2 (900 s.f.)	15 days	10/2/14	10/22/14
Bent 3	**21 days**	**10/25/14**	**11/20/14**
Four Medium Crane Barges (70,000 s.f.)	21 days	10/25/14	11/20/14
Oscillator Support Platform 1 (900 s.f.)	21 days	10/25/14	11/20/14
Oscillator Support Platform 2 (900 s.f.)	13 days	11/4/14	11/20/14
Bent 4	**20 days**	**11/23/14**	**12/18/14**
Four Medium Crane Barges (70,000 s.f.)	20 days	11/23/14	12/18/14
Oscillator Support Platform 1 (900 s.f.)	20 days	11/23/14	12/18/14
Oscillator Support Platform 2 (900 s.f.)	12 days	12/3/14	12/18/14
Bent 5	**34 days**	**12/21/14**	**1/29/15**
Six Medium Crane Barges (105,000 s.f.)	34 days	12/21/14	1/29/15
Oscillator Support Platform 1 (900 s.f.)	34 days	12/21/14	1/29/15
Oscillator Support Platform 2 (900 s.f.)	26 days	12/31/14	1/29/15
Oscillator Support Platform 3 (900 s.f.)	18 days	1/10/15	1/29/15
Bent 6	**41 days**	**1/22/15**	**3/12/15**
Six Medium Crane Barges (105,000 s.f.)	32 days	2/1/15	3/12/15
Work Bridge (1,520 s.f.)	41 days	1/22/15	3/12/15
Oscillator Support Platform 1 (900 s.f.)	32 days	2/1/15	3/12/15
Oscillator Support Platform 2 (900 s.f.)	24 days	2/11/15	3/12/15
Oscillator Support Platform 3 (900 s.f.)	16 days	2/21/15	3/12/15

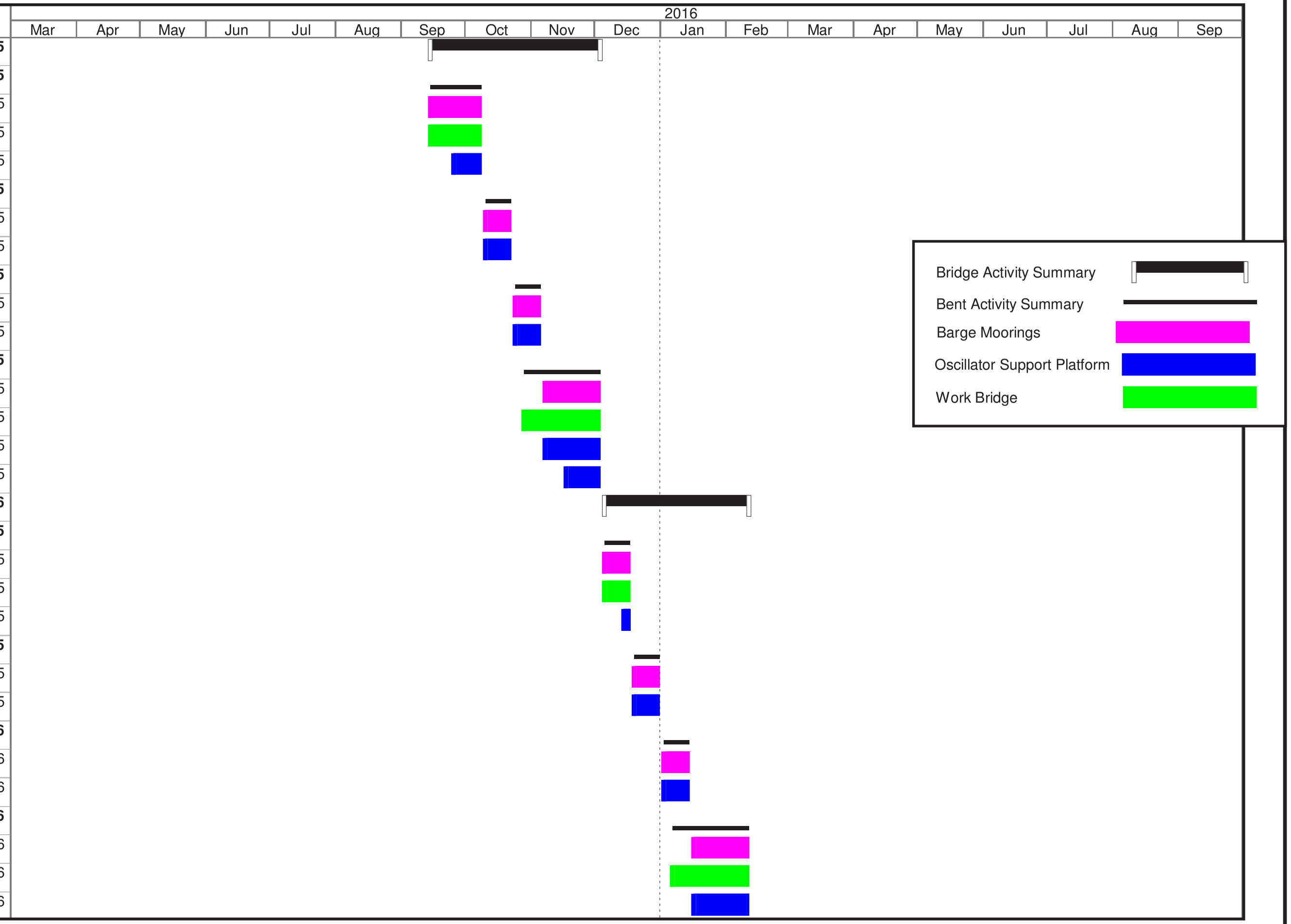


Conceptual Schedule Only, April 2010
Note: This is a proposed schedule, so activity dates are likely to change.

Figure 6-18. Sequencing of Temporary Overwater Structures for Construction in North Portland Harbor

Columbia River CROSSING

Task Name	Duration	Start	Finish
Northbound Collector Distributor Ramp	**66 days**	**9/15/15**	**12/3/15**
Bent 6	**21 days**	**9/15/15**	**10/8/15**
Two Medium Crane Barges (35,000 s.f.)	21 days	9/15/15	10/8/15
Work Bridge (4,080 s.f.)	21 days	9/15/15	10/8/15
Oscillator Support Platform (900 s.f.)	10 days	9/26/15	10/8/15
Bent 7	**10 days**	**10/11/15**	**10/22/15**
Two Medium Crane Barges (35,000 s.f.)	10 days	10/11/15	10/22/15
Oscillator Support Platform (900 s.f.)	10 days	10/11/15	10/22/15
Bent 8	**12 days**	**10/25/15**	**11/5/15**
Two Medium Crane Barges (35,000 s.f.)	12 days	10/25/15	11/5/15
Oscillator Support Platform (900 s.f.)	12 days	10/25/15	11/5/15
Bent 9	**29 days**	**10/29/15**	**12/3/15**
Four Medium Crane Barges (70,000 s.f.)	20 days	11/8/15	12/3/15
Work Bridge 1 (2,240 s.f.)	29 days	10/29/15	12/3/15
Oscillator Support Platform 1 (900 s.f.)	20 days	11/8/15	12/3/15
Oscillator Support Platform 2 (900 s.f.)	12 days	11/18/15	12/3/15
Southbound Collector Distributor Ramp	**57 days**	**12/6/15**	**2/11/16**
Bent 2	**12 days**	**12/6/15**	**12/17/15**
Two Medium Crane Barges (35,000 s.f.)	12 days	12/6/15	12/17/15
Work Bridge (4,880 s.f.)	12 days	12/6/15	12/17/15
Oscillator Support Platform (900 s.f.)	3 days	12/15/15	12/17/15
Bent 3	**10 days**	**12/20/15**	**12/31/15**
Two Medium Crane Barges (35,000 s.f.)	10 days	12/20/15	12/31/15
Oscillator Support Platform (900 s.f.)	10 days	12/20/15	12/31/15
Bent 4	**12 days**	**1/3/16**	**1/14/16**
Two Medium Crane Barges (35,000 s.f.)	12 days	1/3/16	1/14/16
Oscillator Support Platform (900 s.f.)	12 days	1/3/16	1/14/16
Bent 5	**29 days**	**1/7/16**	**2/11/16**
Four Medium Crane Barges (70,000 s.f.)	20 days	1/17/16	2/11/16
Work Bridge (2,280 s.f.)	29 days	1/7/16	2/11/16
Oscillator Support Platform (900 s.f.)	20 days	1/17/16	2/11/16



Conceptual Schedule Only, April 2010

Note: This is a proposed schedule, so activity dates are likely to change.

Figure 6-18 (Continued). Sequencing of Temporary Overwater Structures for Construction in North Portland Harbor

Columbia River CROSSING

Construction Barges

Barges will be anchored in the Columbia River and North Portland Harbor to serve as in-water work platforms during construction of in-water and overwater bridge elements. Stationary barges will be used at each of the in-water piers or bents. The shade footprint of moving barges (such as materials and spoils barges) was not included in this analysis. These barges move more or less constantly and on an unpredictable schedule, so it is impossible to quantify the extent or duration of shade cast by these sources.

Although the project will use numerous barges, there will be a limited number of barges in place at any one time. During construction in the Columbia River, there will likely be one to four stationary barges operating in the Columbia River at one time (Figure 6-17), casting no more than 120,000 sq. ft. of shade at once. In North Portland Harbor, there will likely be no more than six crane barges operating at one time, creating a maximum of approximately 105,000 sq. ft. of shade at one time (Figure 6-18).

In-Water Structures

The project will use temporary in-water work platforms, work bridges, tower cranes, and oscillator support platforms to support the equipment used to drill shafts in the Columbia River and North Portland Harbor.

In the Columbia River, there will be six temporary work platforms/bridges, one at each of the in-water pier complexes. At pier complexes 2 and 7, the work bridges will be L-shaped, approximately 17,500 sq. ft. and 18,500 sq. ft. in size, respectively. At pier complexes 3 through Pier 6, each work platform will cover an area of approximately 29,000 sq. ft. (Table 6-15). Up to four platforms will be in place at one time (Figure 6-17). Once drilled shafts are completed, the platforms will be removed. Six temporary tower cranes will be installed, one for each in-water pier complex. Each will shade an area of approximately 400 sq. ft. (Figure 6-17). Including the work platforms, work bridges, and the tower cranes, roughly 125,000 sq. ft. will be shaded at one time in the Columbia River.

In North Portland Harbor, the project will use nine work bridges of different sizes to build the nine bents nearest the shorelines (Figure 6-18). Only one or two work bridges will be in place at any given time. Additionally, the project will use 31 oscillator support platforms (900 sq. ft.), one for each in-water shaft in North Portland Harbor (Figure 6-18). Only one to three oscillator support platforms will be in place at once. At any one time, in-water structures in North Portland Harbor will shade no more than 7,180 sq. ft altogether.

Demolition in the Columbia River will not require shade-producing in-water structures.

Demolition Barges

Demolition of the existing structures in the Columbia River will require one to three stationary barges at any one time, with a maximum shade footprint of approximately 21,000 sq. ft. at once. Figure 6-19 shows the sequencing of stationary barges for demolition in the Columbia River.

There will be no demolition or demolition barges in North Portland Harbor.

Task Name	Duration	Start	Finish
Superstructure Demolition	**121 days**	**12/12/19**	**5/28/20**
Demolish Lift Span Towers	**20 days**	**12/12/19**	**1/8/20**
Two Medium Crane Barges (21,000 s.f.)	20 days	12/12/19	1/8/20
Remove Spans	**83 days**	**2/4/20**	**5/28/20**
Span 2	**2 days**	**2/4/20**	**2/5/20**
Medium Crane Barge (10,500 s.f.)	2 days	2/4/20	2/5/20
Span 3	**2 days**	**2/18/20**	**2/19/20**
Medium Crane Barge (10,500 s.f.)	2 days	2/18/20	2/19/20
Span 4	**2 days**	**3/3/20**	**3/4/20**
Medium Crane Barge (10,500 s.f.)	2 days	3/3/20	3/4/20
Span 5	**2 days**	**3/17/20**	**3/18/20**
Medium Crane Barge (10,500 s.f.)	2 days	3/17/20	3/18/20
Span 6	**2 days**	**3/31/20**	**4/1/20**
Medium Crane Barge (10,500 s.f.)	2 days	3/31/20	4/1/20
Span 7	**2 days**	**4/14/20**	**4/15/20**
Medium Crane Barge (10,500 s.f.)	2 days	4/14/20	4/15/20
Span 8	**2 days**	**4/28/20**	**4/29/20**
Medium Crane Barge (10,500 s.f.)	2 days	4/28/20	4/29/20
Span 9	**2 days**	**5/12/20**	**5/13/20**
Medium Crane Barge (10,500 s.f.)	2 days	5/12/20	5/13/20
Span 10	**2 days**	**5/27/20**	**5/28/20**
Medium Crane Barge (10,500 s.f.)	2 days	5/27/20	5/28/20
Substructure Demolition	**266 days**	**3/5/20**	**3/11/21**
Pier 2	**40 days**	**3/5/20**	**4/29/20**
Small Crane Barge (6,000 s.f.)	40 days	3/5/20	4/29/20
Pier 3	**51 days**	**3/19/20**	**5/28/20**
Small Crane Barge (6,000 s.f.)	51 days	3/19/20	5/28/20
Pier 4	**41 days**	**5/29/20**	**7/24/20**
Small Crane Barge (6,000 s.f.)	41 days	5/29/20	7/24/20
Pier 6	**51 days**	**6/12/20**	**8/21/20**
Small Crane Barge (6,000 s.f.)	51 days	6/12/20	8/21/20
Pier 7	**41 days**	**8/24/20**	**10/19/20**
Small Crane Barge (6,000 s.f.)	41 days	8/24/20	10/19/20
Pier 8	**50 days**	**9/8/20**	**11/16/20**
Small Crane Barge (6,000 s.f.)	50 days	9/8/20	11/16/20
Pier 9	**43 days**	**11/17/20**	**1/14/21**
Small Crane Barge (6,000 s.f.)	43 days	11/17/20	1/14/21
Pier 10	**52 days**	**12/2/20**	**2/11/21**
Small Crane Barge (6,000 s.f.)	52 days	12/2/20	2/11/21
Pier 11	**62 days**	**12/16/20**	**3/11/21**
Small Crane Barge (6,000 s.f.)	62 days	12/16/20	3/11/21

Conceptual Schedule Only, April 2010
Note: This is a proposed schedule, so activity dates are likely to change.

Figure 6-19. Sequencing of Temporary Barges Used During Demolition in the Columbia River

Columbia River CROSSING

Permanent Shade Sources

The permanent new bridges over the Columbia River and North Portland Harbor will create new sources of shade, as shown in Table 6-15. After the new bridges are completed, the project will demolish the existing Columbia River bridges, removing 284,000 sq. ft. of overwater shade.

The project will also permanently remove at least part of the overwater structure at the Red Lion at the Quay. At the very least, portions of the structure within 50 feet of the bridge will be removed (12,647 sq. ft. over water).

Project wide, there will be a permanent net gain of approximately 725,080 to 853,553 sq. ft. of shade (Table 6-15) in the Columbia River and North Portland Harbor.

The project will also remove floating homes from North Portland Harbor, resulting in the elimination of approximately 155,810 sq. ft. of shade from the project area. Floating homes will likely be moved from their current location to elsewhere in North Portland Harbor, the Willamette River, or the lower Columbia River. It is not possible to predict where each floating home will be placed, but it is likely that many will remain in the Lower Columbia system and move to existing floating home communities. Because it is not known whether the floating homes will be relocated outside of the project area in the long term, it is also unknown whether relocation of the homes will result in a net loss of shade. Section 6.7.5 outlines in greater detail the effects of floating home relocation.

6.1.3.3 Potential Effects of Shading on Fish in the CRC Action Area

Although there is a net gain of overall permanent shade in the project area, not all shade sources are likely to have negative effects on juvenile fish. The new bridge spans will permanently shade the action area, but are not likely to result in shading effects on any of the listed fish that use the project area (Table 6-14). The North Portland Harbor spans will be approximately 35 feet above OHW (similar to the existing spans, which are approximately 30 feet above OHW), and the Columbia River spans will range from 50 to 90 feet above OHW (compared to the existing spans which range from 40 to 80 feet above OHW). At these heights, light can readily dissipate beneath the structures and the spans are not likely to create the type of intense shade that attracts predators or causes visual disorientation to fish.

The bottoms of the shaft caps of the Columbia River structures will be located just below the water line and are likely to create the type of intense light-dark contrast that could potentially attract predators or cause visual disorientation to fish. This effect would be permanent, adding 52,800 sq. ft. of dense shade to the project area. (The current structure does not generate this type of dense shade. Thus, the shaft caps represent a new permanent, dense shade source.) Removal of the overwater structure at the Quay will permanently eliminate approximately 12,647 sq. ft. of dense shade. Compared to the 58,500 sq. ft. of intense shade created by the shaft caps, this represents a net gain of roughly 45,000 sq. ft. of permanent, intense shade. This could potentially degrade habitat for juvenile fish, increasing the probability of predation and interference with migration.

Temporary overwater structures, including the barges, work platforms, work bridges, oscillator support platforms, and tower cranes, are also located at the water line and therefore could create new, high-intensity shade in the Columbia River and North Portland Harbor. This impact will be temporary, limited to the time that these structures are in the water (Figure 6-17, Figure 6-18, and Figure 6-19).

Temporary shading will not be uniform over all of the in-water construction years (Figure 6-17). In the Columbia River, shading will be limited to the first three pier complexes during the first year, expand to all six in the second, and taper off to three or fewer during the last two years. In North Portland Harbor, temporary shade will be distributed more or less evenly over the first two years of the in-water construction periods with more shade-producing activities concentrated in the last in-water construction year (Figure 6-18). Temporary shading will be evenly dispersed over the in-water demolition period (Figure 6-19).

Effects to Predation

The existing Columbia River and North Portland Harbor bridges likely attract predators, such as largemouth bass, smallmouth bass, and northern pikeminnow. The project increases the amount of shade in the action area compared to existing levels, but chiefly on a temporary basis. Permanent increases in dense shade are limited to the net new 23,000 to 45,000 sq. ft. created by the shaft caps in the Columbia River. It is impossible to quantify the extent to which increased shade may affect predation rates on juveniles. However, it is probable that an increase in predator habitat will increase predation pressure on juvenile salmonids and larval eulachon in the action area during daylight hours. Project-related sources of shade likely to attract predators (barges, temporary overwater structures, and shaft caps) are located in juvenile migration routes, creating an opportunity for predators to forage on juveniles during migration. Additionally, rearing juvenile salmonids are present in the action area and could experience increased predation pressure as a result of increased shade. Figure 4-2 shows the timing of juvenile fish presence in the Columbia River and North Portland Harbor, indicating the time periods when they could be exposed to this effect. Green sturgeon and bull trout are unlikely to be subjected to increased predation pressure, because only adult and subadults may use the action area and the risk of predation is extremely low for fish of this size (Zimmerman 1999). Likewise, adult salmonids are unlikely to be exposed, for the same reason.

The increase in shade along the nearshore may have particularly adverse effects on certain life stages of juvenile salmonids. In general smaller, rearing and subyearling-migrant salmonids are highly dependent on the nearshore. Overwater structures that create a shadow line completely blocking the nearshore may force these runs into deeper water where they could be subjected to higher levels of predation. (It should be noted that the literature does not show widespread agreement on this effect, and therefore this result is not certain to occur.) This scenario could occur in several locations: at the temporary work bridges at Columbia River pier complexes 2 and 7, the permanent new shaft cap at pier complex 7 in the Columbia River, and at all of the temporary work bridges in the North Portland Harbor. While all runs of juvenile salmonids could be exposed to increased predation, species that rear in this portion of the action area (LCR Chinook, UCR spring-run Chinook, UWR Chinook, LCR coho, and LCR steelhead) and species that migrate as subyearling through this portion of the action area (CR chum and a portion of the LCR Chinook run) are generally more vulnerable to this effect both because they are dependent on the nearshore and because they are of a small size more easily captured by predators. It is not possible to quantify how many of these individuals will be exposed to increased predation in shallow water. However it is possible to estimate the physical extent, timing and duration of the effect. Exposure is presented as the overlap of when structures are present in shallow water (Table 6-33, Table 6-34, Figure 6-32, and Figure 6-33) with the timing of juvenile fish presence in this portion of the action area (Figure 4-2).

Effects to Orientation and Migration

As stated earlier, the literature is not in agreement as to whether the light-dark interface definitively causes visual disorientation or interference with migration in juvenile salmonids. This analysis assumes a worst-case scenario, that is, that all new intense shade sources in the action area may result in visual disorientation during the day time. Assuming this is true, juvenile salmonids could be exposed to this effect during daylight hours when they are present in the Columbia River and North Portland Harbor portions of the action area (Figure 4-2). It is impossible to quantify the magnitude of the effect on fish, but it is possible to estimate the duration and physical extent of the effect. Permanent effects would be limited to the net new 45,000 sq. ft. of intense shade (the shaft caps minus the existing pier at the Quay) (Table 6-15). The timing, duration, and areal extent of the temporary effects are illustrated in Figure 6-17, Figure 6-18, and Figure 6-19. These values represent the size of the shadow when the sun is directly overhead. At other times of day, the shadow will likely be larger.

For juvenile salmonids, visual disorientation could presumably lead to delayed migration and increased vulnerability to predation. The literature indicates that these effects are not certain to occur, and in any case, it is impossible to quantify the magnitude of these effects. The project will not create a swath of dense shade that completely spans either the Columbia River or North Portland Harbor stream channel. Therefore, even if the light-dark interface does prompt avoidance of the shadow zone, it is not likely to completely block migration. Nighttime migration would be unaffected.

Eulachon larvae do not have volitional movement (Langness personal communication 2009) and are therefore not subject to disorientation.

Green sturgeon are bottom feeders (NMFS 2008c) that inhabit portions of the stream channel with low light levels. Shade effects (particularly, a sharp light-dark interface) are not likely to extend to the depths that green sturgeon inhabit. In addition, their presence in the action area is extremely limited. Therefore, green sturgeon are not likely to experience visual disorientation as a result of increased shade in the action area.

Because bull trout abundance is extremely low in the action area and because the proportion of the action area likely to be exposed to increased shade is very limited, the risk of exposure to this effect is discountable. Additionally, only adult and subadult bull trout could potentially occur in this portion of the action area, and these age classes are not subject to visual disorientation from shade.

The increase of shade in shallow-water habitat may have particularly adverse effects to species that are highly dependent on the nearshore for migration: CR chum and the portion of the LCR run that migrates as subyearlings. Shade may completely overlap shallow-water habitat at the temporary work bridges at Columbia River pier complexes 2 and 7, at the permanent new shaft cap at pier complex 7 in the Columbia River, and at all of the temporary work bridges in the North Portland Harbor, potentially prompting these salmonids to swim into deeper water to circumvent the shadow line. It is not possible to quantify how many individuals may experience delayed migration due to the presence of shade in the nearshore. However it is possible to estimate the physical extent, timing, and duration of the effect. Exposure is presented as the overlap of when structures are present in shallow water (Table 6-33, Table 6-34, Figure 6-32, and Figure 6-33) with the timing of juvenile fish presence in this portion of the action area (see Figure 4-2).

Effects to Primary Productivity

The project is not expected to cause significant impacts to primary productivity or the food web for any of the fish species using the action area. The project may reduce the productivity of plants, algae, and phytoplankton occurring both within the photic zone and beneath overwater structures. However, shade will be limited to localized, discrete areas, measuring no more than several hundred to several thousand square feet. Permanent effects to primary production will be limited to shaded areas adjacent to the shaft caps in the Columbia River, estimated at 58,500 sq. ft. Other sources of shade, (barges, work platforms, tower cranes, and oscillator support platforms) will be temporary. The extent and duration of this effect are shown in Figure 6-17, Figure 6-18, and Figure 6-19.

Although the project may result in loss of primary production in the shadow zone, this loss is not likely to significantly impact the food web. The project area does not contain habitats that are known to support high primary and secondary productivity for fish. In northwest estuaries, such habitats include areas that produce and retain high levels of detritus: floodplains, vegetated riparian areas with overhanging vegetation, shallow marshes, tidal creeks, dendritic channel networks, low intertidal and subtidal eelgrass beds, emergent vegetation in tidal wetlands, and macroalgal beds (such as mudflats and sandflats). In the Columbia River estuary, detritus is concentrated in low-velocity peripheral bay habitats (Bottom et al. 2005). These habitats are completely lacking in the project area, which is dominated by high-velocity open water that is severed from the historical floodplain and lacks emergent vegetation, structural complexity, and riparian areas with overhanging vegetation. In areas of the upper estuary that lack these habitat features, there has been a shift from detritus-based primary production to production dominated by phytoplankton. This has led to widespread loss of food webs supporting epibenthic feeders such as juvenile salmonids (Bottom et al. 2005). This type of food web also favors production of a microdetrital food web dominated by simple-celled plants and organic particles (NMFS 2005c), as well as calanoid copepods and other organisms that are not consumed by juvenile salmon (Bottom et al. 2005). Because of the shift in the food web, the suspension/deposit feeder *Corophium salmonisis* is now the most abundant prey item of juvenile salmonids in the estuary. This species is a poor food source because it is low in protein and high in chitin (NMFS 2005c). Because the project area lacks detritus-rich habitat types and harbors a microdetrital food web, it provides only limited, low-quality foraging habitat and food web support for salmonids.

In shallow-water areas of the lower Columbia River, the large majority of primary productivity is driven by benthic algae, with some contribution from filamentous algae and flowering grasses. Within the water column, primary productivity is driven by phytoplankton (NMFS 2005c). Because shallow-water habitat is limited in the project area, the majority of primary productivity is likely driven by phytoplankton. Sections 6.3.1 and 6.3.2 discuss this in further detail.

There have been no known surveys of underwater vegetation or periphyton in the project area. However, in the lower Columbia, small diatoms (*Achnanthes*, *Cocconeis*, and some filamentous blue greens) are expected to be present. Other grazing-resistant algae are expected to be present on the riprap along shorelines and on bridge piers, together with filamentous green algae (such as *Cladophora*) and its associated epiphyton (for example, *Rhoicosphenia*, *Cocconeis*, and *Epithemia*). Red algae are also probably very common (Carpenter personal communication 2010).

Typical macrophytes in the lower Columbia River include *Potomogeton crispus*, *Elodea* (*cascadensis*, *nuttallii*, and others), *Ceratophyllum*, and possibly *Hetheranthera dubia*. However, macrophytes are likely not present or are very limited in the project area, as they typically occur in backwater areas (Carpenter personal communication 2010). Because underwater portions of the project area are characterized by high current velocity and an armored streambank, backwater areas are generally lacking, and thus, macrophytes are limited. Additionally, substrate is unstable sand, and the underwater topography slopes off steeply, reducing the size of the photic zone.

Because the project area lacks high-productivity, detritus-based plant communities and is dominated by plankton and periphyton, shading will not impact habitats of particularly high quality. Additionally, outside of the areas potentially influenced by shading, the surrounding area contains dozens of square miles of water available for primary production both upstream and downstream. Shading will only impact a tiny fraction of the remaining area available for primary production, such that there is no measureable reduction in baseline levels of production. All of the listed species that forage in the action area are highly mobile and can readily move to these nearby areas in response to localized impacts to vegetation or the food web. Because the impact is small relative to the amount of habitat present in the surrounding area, this effect will be insignificant.

The new bridge piers in the Columbia River and North Portland Harbor may also provide additional substrate for algae. This is a potential benefit to fish habitat, although the magnitude of this effect is likely very small, and its impact on fish is impossible to quantify.

Beneficial Effects of Shade

Shade may also confer benefits to salmonids using the action area. Salmonids require cool water to perform life history functions. Temperatures of 50 to 57ºF are considered adequate to support spawning, migration, and rearing (Bjornn and Reiser 1991). The 303(d) listings for the Columbia River portion of the project area indicate that temperature exceeds standards for spawning, migrating, and rearing salmonids during summer months in the Columbia River and North Portland Harbor (DEQ 2009), with measured temperatures ranging as high as 72ºF (USGS 2007). Overwater structures may create shade, resulting in localized areas of cooler water. The temporary overwater structures and the permanent shaft caps will create new areas of dense shade that could potentially provide an increase in summertime cool-water refugia compared to the current condition. These increases in shade may confer a benefit to migrating and rearing salmon, although it is impossible to quantify to what extent.

6.1.4 Artificial Lighting over Water

The project will require several new sources of overwater artificial lighting to be used during nighttime construction. The following sections outline the general effects of lighting on fish and provide an analysis of the likely effects on fish in the CRC action area.

6.1.4.1 General Effects of Artificial Lighting on Fish

Artificial light sources associated with overwater structures or construction activities may attract fish. Because salmon rely on vision for capturing prey, the artificial lights may improve both prey detection and predator avoidance (Tabor et al. 1998, as cited in Carrasquero 2001). During a study of the Columbia River at Bonneville Pool, Collis et al. (1995) observed that juvenile salmon were attracted to work lights directed at the water surface. In Lake Washington, juvenile Chinook have been observed congregating at night near streetlights on the SR 520 bridge (Celedonia et al. 2008). Tabor et al. (2004) observed sockeye fry in the Cedar River, noting that they were significantly more abundant under city street lights than at nearby sites that were not illuminated. Light levels as low as 0.22 lux (0.020 foot candle) appeared to influence fry behavior. In one location, turning off the streetlights resulted in a significant decrease in the number of sockeye fry present.

Artificial lights can create sharp boundaries between dark and light areas under water. This, in turn, may cause juvenile fish to become disoriented or avoid crossing the light-dark interface, as outlined in detail in Section 6.1.3.1. Williams and Thom (2001) noted that artificial lighting on docks may change nighttime movement patterns in juvenile salmon. Numerous other studies (Fields 1966, Prinslow et al. 1979, Weitkamp 1982, Ratte and Salo 1985, Pentec 1997, Taylor and Willey 1997, and Johnson et al. 1998; as cited in Southard et al. 2007) corroborate these findings, noting behavioral changes in juvenile salmon in response to artificial lighting. McDonald (1960, as cited in Tabor et al. 2004) found that sockeye fry will stop swimming downstream upon encountering artificial lighting, and was able to completely stop nightly migration of sockeye salmon fry with artificial lighting kept on all night at 30 lux (2.8 foot candles). A USFWS (1998) literature review noted that sockeye fry moved through experimental streams more quickly in complete darkness than under bright lights (Tabor et al. 1998). Increased light appeared to inhibit migration of sockeye fry, with significant effects to migration when light levels reached 2.0 lumens/ft^2 (2.0 foot candles). A later study (Tabor et al. 2004) corroborated the finding that fewer sockeye moved through illuminated artificial streams than in darkness, and those that did move, moved more slowly. In this study, light intensity levels from 1.08 to 5.40 lux (0.1 to 0.5 foot candle) appeared to inhibit migration. The same study noted that the delay in outmigration in sockeye fry increased their vulnerability to predation.

Another USFWS study (Tabor and Piaskowski 2001) observed juvenile Chinook in nearshore habitat in Lake Washington, noting that individuals became active when light levels reached 0.08 to 0.21 foot candle and were scarce in the study area when light levels were between 2.2 to 6.5 foot candles. A review of the impact of ferry terminals on juvenile migration in Puget Sound (Simenstad and Nightingale 1999) cites Ali (1958, 1960, and 1962) as stating that light is tremendously important for numerous life functions of chum, coho, sockeye, and pink salmon, noting that feeding, minimum prey capture, and schooling are dependent on light levels lower than 10^{-4} foot candles (similar to a clear, moonless night) and that maximum prey capture for chum and pink fry occurs when the light level is 1.0 foot candle (similar to light levels at dawn and dusk).

Artificial light sources may provide an advantage to predators such as smallmouth bass, largemouth bass, northern pikeminnow, and salmonids. Rainbow trout predation on sockeye fry in artificial streams increased with increased lighting at levels of less than 1.1 lux (Ginetz and Larkin 1976, as cited in Tabor et al. 2004). Northern pikeminnow are attracted to areas where juvenile salmonids congregate, such as hatchery release sites and dams (Collis et al. 1995;

Beamesderfer and Rieman 1991). If light sources attract congregations of juvenile salmonids, this could cause an increase in predation by northern pikeminnow. Celedonia et al. (2008) found that smallmouth bass may feed at night in the vicinity of artificial light or under moonlight. Largemouth bass have been shown to forage efficiently at light levels ranging from low-intensity daylight to full moonlight, with less foraging at light levels equivalent to a starlit, moonless night (McMahon and Holanov 1995).

Tabor et al. (2004) observed the effect of light intensity on cottid predation of sockeye fry in artificial streams, noting that cottids consumed 45 percent of the fry under intense illumination (5.4 lux or 0.50 foot candle), 28 percent under dim light (0.22 lux or 0.020 foot candle), and 5 percent in complete darkness (0 lux or 0 foot candle). The study also observed that fewer fry emigrated in illuminated streams and did so at a faster rate when predators were present than in lighted streams where predators were not present, indicating that the presence of predators may inhibit migration in some individuals. In a field study in the Cedar River, Washington, Tabor et al. (2004) further noted that the number of shoreline fry and rates of predation by cottids increased with an increase in light levels. At one site, shielding the lights to levels of 0.1 to 0.32 lux (0.013 to 0.030 foot candle) substantially reduced predation.

The literature is not in complete agreement about light levels that are likely to impede migration or increase predation on juvenile fish. However, data from Tabor et al. (2004) may present a worst-case scenario. That is, light levels as low as 0.22 lux (0.20 foot candle) may delay migration or increase predation on juvenile salmonids.

6.1.4.2 Effects of Lighting on Fish in the CRC Action Area

The project will install both temporary and permanent lighting.

Temporary Lighting

Temporary overwater lighting sources will include the cofferdams, barges, work platforms/bridges, oscillator platforms, and tower cranes. Figure 6-17, Figure 6-18, and Figure 6-19 show the locations and sequencing of temporary structures requiring artificial lighting in the work area. Temporary lighting will not be uniform over all of the in-water construction years. During the Columbia River in-water construction period, temporary lighting will be limited to the first three pier complexes during the first year, expand to all six in the second, and taper off to three or fewer during the last 2 years (Figure 6-17). In North Portland Harbor, temporary lighting will be distributed more or less evenly over the first 2 years of the in-water construction periods with illumination-producing structures concentrated in the last in-water construction year (Figure 6-18). Temporary lighting will be distributed evenly across the Columbia River in-water demolition period (Figure 6-19).

The barges and temporary in-water structures will cast light at the water surface during construction and demolition in the Columbia River and North Portland Harbor. At this stage in the project design, the intensity of light likely to be cast on the water surface is not known. However, to the extent practicable, the project will implement conservation measures that minimize the effects of lighting on fish. Measures may include using directional lighting with shielded luminaries to control glare and to direct light onto work areas instead of surface waters.

Although it is impossible to quantify how many fish will be exposed to increased lighting, it is possible to estimate the locations, timing, and duration of this effect (Figure 6-17, Figure 6-18, and Figure 6-19). All of the juvenile fish that use the action area could be exposed to this effect when they are rearing in or migrating through the project area (see Figure 4-2). The exposure to this effect is the overlap of: (1) juvenile salmonid presence (see Figure 4-2) with, (2) the timing of temporary lighting in the project area, and (3) the areas exposed to elevated levels of temporary lighting (Figure 6-17, Figure 6-18, and Figure 6-19).

It is possible that the increase in lighting in the action area could cause some interference with juvenile salmonid migration. Overwater structures will be limited to discrete locations measuring from several hundred to several thousand square feet and will only span a fraction of the entire channel. While lighting may prompt juvenile fish to avoid the illuminated area, it will not constitute a complete barrier to migrating juvenile fish.

It is also possible that rearing and migrating juvenile salmonids could congregate under light sources, potentially becoming exposed to an increased risk of predation than they are currently. As with effects to migration, it is impossible to quantify the extent to which predation will increase. However, it seems likely that an increase in the conditions that confer an advantage to visual predators could increase levels of predation. Rearing juveniles (LCR Chinook, coho, and steelhead) are present in the area for a relatively long proportion of the year, and therefore could be especially vulnerable to this effect.

Illumination in shallow water may place subyearling migrants (LCR Chinook and CR chum) at particular risk, as these individuals are highly dependent on nearshore areas. This effect is discussed in greater detail in Section 6.1.3.3.

Permanent Lighting

The permanent lighting on the bridges has not yet been designed. USCG will require bridge lighting to be brighter than the background lighting. While there is likely to be a large amount of illumination on the bridge spans high above the water, permanent lighting at the water surface will likely be minimal, limited to navigation lights, which are typically small, dim, and not cast directly on the water surface. Although it is not known at this point whether permanent lighting on the bridge will represent an increase in overall lighting in the project area, any increases are likely to be small.

The project will implement measures that minimize the effects of lighting on fish. Measures may include using directional lighting with shielded luminaries to control glare and to direct light onto work areas, instead of surface waters. Therefore, permanent lighting is not expected to cause significant adverse effects to listed fish.

6.1.5 Temporary Effects to Water Quality

The project will implement BMPs during in-water and upland construction activities to avoid and minimize impacts to water quality. Without implementation of BMPs, water quality could be impacted in a number of ways. Chemical contamination could potentially occur through the accidental release of construction materials or wastes. Upland excavation could lead to erosion, causing turbidity in adjacent water bodies. In-water work (such as pile driving, demolition, debris removal, barge use, and installation of bridge piers) could generate turbidity directly in waterways. The implementation of BMPs will help ensure that these effects will be localized and temporary, limited to the duration of the project, and will result in minimal impacts to water quality.

This section describes the sources of effects to water quality, outlines the BMPs that will be used to contain them, and analyses the potential effects to listed fish.

6.1.5.1 Chemical Contamination

There are numerous potential sources of chemical contamination associated with in-water work in the Columbia River and North Portland Harbor.

- Equipment located in or over the water (such as barges or equipment operating on barges, temporary work platforms, the existing structures, or the new structures) are potential sources of contamination.
- Uncured concrete will be present in numerous locations, both in and over the water, for the construction of the shaft caps, piers, and superstructure for the new bridges.
- Construction of the superstructure will involve the use of numerous other potential contaminants, including various petroleum products, adhesives, metal solder, concrete and metal dust, asphalt, and others.
- Bridge demolition will occur both in and over the water and may release contaminants such as concrete debris, concrete dust created by saw cutting, and lead paint.
- There are a total of approximately 1,800 timber piles at the nine existing Columbia River bridge piers. It is assumed that these piles have been chemically treated, based on their age and intended purpose. Contaminants from the piles could be mobilized during demolition of the piers.

Although there are several sources of chemical contaminants, there is a low risk that chemicals will actually enter the Columbia River and North Portland Harbor. A SPCC plan will be implemented to completely contain sources of chemical contamination such as equipment leaks, uncured concrete, and other pollutants.

During construction of the drilled shafts, uncured concrete will be poured into water-filled steel casings, creating a mix of concrete and water. As the concrete is poured into the casing, it will displace this highly alkaline mixture. The project will implement BMPs to contain the mixture and ensure that it does not enter any surface water body. Once contained, the water will be treated to meet state water quality standards and either released to a wastewater treatment facility or discharged to a surface water body.

In-water bridge demolition will take place only in the Columbia River. All demolition activities will be completely contained within cofferdams. The contractor is required to prepare a demolition plan according to ODOT and WSDOT standard specifications. The plan will be submitted to ODOT and WSDOT and will not be implemented without being approved and stamped by a registered professional engineer. The demolition plan will specify containment methods to ensure that bridge elements and wastes do not enter the Columbia River. Breaking up the concrete piers with an excavator or saw cutter could potentially introduce concrete dust into the water; however, because of the containment proposed, there is minimal risk that dust or debris will enter the Columbia River during demolition. Any concrete wastes will be allowed to settle in the cofferdams before the cofferdams are disassembled. During removal of the cofferdams, released water will meet state water quality standards.

Removal of the timber piles that are deemed navigational hazards and located beneath the existing Columbia River piers will be contained within cofferdams during the demolition of the rest of the piers. There may be, however, some piles that must be removed and are located outside of the cofferdam footprint. These will likely be cut off at or below the mudline. No containment is proposed for the removal of these pilings. However, given the high flow in the Columbia River, dilution of contamination is likely to be high, and the extent of the contamination is expected to be minimal.

The project will obtain several regulatory permits that include terms and conditions for controlling and containing chemical releases to surface water bodies. These permits include: Ecology's 401 Water Quality Certification, WDFW HPA, DEQ's 401 Water Quality Certification, DSL's Removal/Fill Permit, and USACE's 404 Removal/Fill Permit. The project will adhere to the terms and conditions of all of these permits, further minimizing risks to water quality in the Columbia River and North Portland Harbor.

In general, construction equipment operating on land poses a low risk of releasing chemical contaminants (such as petroleum fuel or other fluids) that could enter surface water bodies by way of stormwater inlets, ditches, or other forms of conveyance. Implementation of a Pollution Control Plan will minimize the risk of landward contaminants entering water, to ensure that the risk of contaminant release is discountable. These measures are outlined in greater detail in Section 7. Overall, this aspect of the project is not likely to adversely affect any listed fish.

6.1.5.2 Temporary Turbidity and Suspended Sediment

The project is likely to generate temporary, localized turbidity during the in-water work in the Columbia River and North Portland Harbor. Table 6-16 lists the activities that could potentially generate turbidity downstream of each activity and summarizes the effect to the environmental baseline in the Columbia River and North Portland Harbor.

Table 6-16. Potential Sources of Turbidity

Activity	Timing[a]	Location[b]	Likely Extent of Downstream Turbidity	Duration of Effect (hr/day)	Number of Workdays
Install temporary piles, impact methods	9/15 – 4/15	Adjacent to P2 – P7 in CR Adjacent to new NPH shafts	~25 feet	0.66	138 in CR 134 in NPH
Install temporary piles and cofferdams, vibratory methods	Year-round	Adjacent to P2 – P7 in CR Adjacent to new NPH shafts	~25 feet	Up to 24	Continually over ~1015 days in CR ~334 in NPH
Remove temporary piles and cofferdams, direct pull or vibratory	Year-round	Adjacent to P2 – P7 in CR Adjacent to new NPH shafts	Minimal	Up to 24	Continually over ~1015 days in CR ~334 days in NPH

Activity	Timing[a]	Location[b]	Likely Extent of Downstream Turbidity	Duration of Effect (hr/day)	Number of Workdays
Install steel casings to drill permanent shafts – vibratory hammer, oscillator, or rotator	Year-round	P2 – P7 in CR New NPH shafts	~25 feet	8 – 10	250 / CR pier <1 / NPH shaft
Drill and excavate permanent shafts	Year-round	P2 – P7 in CR New NPH shafts	Minimal (contained)	n/a	100 / CR pier ≤8 / NPH shaft
Operate stationary and moving barges in shallow water	Year-round	P2 – P7 in CR new NPH shafts	<300 feet	Varies	Continually over ~1015 days (CR) ~640 in NPH
Debris removal (clamshell)	11/1 – 02/28	Potentially at 31 locations in NPH.	~300 feet (or as prescribed by permits)	4-6 hr/day, ≤ 4x/day	Less than 7 days
Demolish existing Columbia River bridge piers (includes installation of cofferdams)	Year-round	Existing Piers 2 - 11 in CR	Minimal	8 – 10	~266

a All activities likely to take place within the 4-year in-water construction period.

b CR = Columbia River; NPH = North Portland Harbor, P = pier complex.

Potential Effects to the Environmental Baseline

The project will employ numerous BMPs to minimize the extent and duration of turbidity. These BMPs may include (but will not be limited to) a Spill Prevention/Pollution Control Plan, an Erosion Control Plan, and others as outlined in Section 7. The exact BMPs have not yet been determined. However, these BMPs will ensure that the amount and extent of turbidity will meet the terms and conditions of the two Section 401 Water Quality Certifications that will be obtained from DEQ and Ecology. The certifications will specify a mixing zone for turbidity: that is, a specified distance beyond which turbidity may not exceed ambient levels downstream of the source. We anticipate that the permits will specify a mixing zone of 300 feet downstream of turbidity-generating activities, as this is typical for water bodies the size of the Columbia River and North Portland Harbor (that is, with flows of 300 cubic feet per second [cfs] or greater). Typically, these permits allow exceedance of ambient levels of turbidity for a period of 4 hours within the mixing zone and 2 hours outside of the mixing zone, after which the applicant must stop work until the turbidity dissipates to ambient levels. The project will implement regular water quality monitoring in accordance with the permits to ensure that the project adheres to the permit conditions, with cessation of work if conditions are not met.

In actuality, many of the activities listed in Table 6-16 are not expected to generate large amounts of turbidity. The following activities are expected to generate turbidity at far shorter distance than the anticipated 300-foot mixing zone: installation of piles and cofferdams using impact or vibratory methods, removal of piles and cofferdams using direct pull or vibratory methods, installation of large diameter steel casings using an oscillator, rotator, or vibratory hammer, and demolition activities contained within a cofferdam. These activities do not involve in-water excavation and disturb relatively small amounts of material; therefore, the potential for generating turbidity is greatly reduced.

EPA advises that turbidity extends no more than 25 feet from the source during impact or vibratory pile installation (WSF 2009). Assuming that this is an average value observed over a range of substrate types and flow levels, we expect this threshold distance to be achievable on the CRC project. The Columbia River and North Portland Harbor are large water bodies, providing very high levels of dilution, and reducing size of the potential mixing zone. Additionally, substrates in these water bodies are coarse sand, which settles in relatively short distances compared to finer sediments. Given these mitigating circumstances, we expect that turbidity levels in the CRC action area will be similar to average conditions in other streams, or at least not exceed them. Therefore, we expect that the turbidity will extend to no more than 25 feet from installation of piles, cofferdams, and the steel casings for drilled shafts.

Few studies document the magnitude or extent of turbidity resulting from pile removal. Roni and Weitkamp (1996) reported that pile removal in Manchester, Washington, generated turbidity at less than 1 Nephelometric Turbidity Unit (NTU) above background levels. Washington State Ferries (WSF) performed water quality monitoring during pile removal at Friday Harbor Ferry Terminal; they reported that turbidity levels did not exceed 1 NTU above background levels and were less than 0.5 NTU above background for most of the samples. WSF also performed water quality monitoring during pile removal at Eagle Harbor Maintenance Facility in 2005, reporting that removal of steel and creosote pile resulted in turbidity levels of no more than 0.2 NTU. These values represent extremely small increases above background turbidity levels. Given that the Columbia River and North Portland Harbor have very high dilution capacity and given that substrate in the project area is coarse sediment that settles readily, it is expected that turbidity generated by removal of piles and cofferdams will dissipate within a minimal distance Specifically, it is assumed that this distance will be less than that for pile installation (25 feet), as pile removal displaces less sediment than pile installation.

Drilling and cleaning the permanent shafts will introduce only minimal amounts of sediment into the water. All of the drilling and excavation will occur within the closed steel casings. To the extent practicable, excavated materials will not be allowed to enter the water, but will be stored in contained areas on the barges or work platforms and transported to a permitted upland disposal site.

Debris removal is the only aspect of in-water work likely to generate significant amounts of turbidity. Debris removal could potentially occur at discrete locations in North Portland Harbor. While debris removal is not certain to occur, this information is presented as a worst-case analysis.

There are anecdotal reports that remnant pieces of the original North Portland Harbor bridge (including riprap used as scour protection), still remain on the stream floor. The exact location of the material is not known, but the design team believes that it occurs in several scattered locations, potentially within the footprint of any of the new North Portland Harbor bridge shafts. If this is the case, the material must be removed before drilled shafts can be installed in these locations. Before debris removal begins, divers will pinpoint the locations of the material. Debris removal will be performed only in the precise locations where the material occurs within the footprint of the new bents, greatly minimizing the areal extent of the activity. As stated previously, the amount of material in this location is not known. Assuming a worst-case scenario, that the area of the material is the same as the footprint of the drilled shafts, the project would remove debris at each of the 31 new bridge shafts (encompassing an area of roughly

2,433 sq. ft., total). The design team estimates that no more than 90 cubic yards of material will be removed.

Due to the large size of the North Portland Harbor, the design team anticipates that it will not be possible to install physical BMPs to contain turbidity during debris removal in these locations. Regardless, the project will comply with the terms of all permits related to in-water turbidity, and turbidity will not exceed the levels, distance, or duration specified by the permits. Depending on the permit specifications, the turbidity plumes are expected to reach no more than 300 feet downstream of the source for a duration of no more than 4 to 6 hours. In all cases, debris removal will be performed using a clamshell and at a slow, controlled pace to minimize turbidity.

Barges operating in shallow water have the potential to produce turbidity at Pier Complexes 2 and 7 in the Columbia River and at all of the new North Portland Harbor bents. Barges will have a draft depth of about 13 feet and will operate in water as shallow as 20 feet deep. Therefore, barge propellers may produce turbulence that causes sediments to become suspended. Additionally, tug boats that position barges may also have propellers that generate suspended sediment. Tug boats will operate only during discrete time periods to (1) position the work barges at each of the shallow-water piers (Pier Complex 7 in the Columbia River and all North Portland Harbor bents) and (2) to remove them when work is completed. These barges will remain stationary for the duration of the work, and therefore have little potential to produce turbidity. Additionally, there will be one or two barges at each of the shallow-water piers used to store and move materials and dredge spoils. These barges will make numerous trips, as needed, operating on a sporadic schedule. Because the schedule is unknown, it is not possible to predict the timing and duration of the turbidity plumes. In any case, the size of the plumes is expected to be much smaller than the typical plume created by dredging (estimated to be no more than 300 feet). Given that sediment in this portion of the action area consists mainly of coarse material with only minor amounts of fines, suspended sediment is expected to settle quickly, further restricting the size of the potential turbidity plume. Additionally, compared with the existing energy generated by high-velocity flow in this portion of the action area, disturbance of sediment by tug and work boat propellers is expected to be minimal. Because little aquatic vegetation is present in this portion of the action area, turbidity generated by barges and tug boats is not expected to have a significant impact on underwater vegetation. In any case, turbidity will not exceed the levels, distance, or duration specified by the permits. Construction barges will not be grounded.

Demolition will involve cutting, breaking, and removing the nine existing Columbia River bridge piers. Exact demolition methods are unknown at this time and will be determined by the contractor at a later date. However, the CRC team anticipates that all demolition work will be performed from barges and will be completely contained inside of enclosed cofferdams. Installation and removal of the cofferdams is the only aspect of bridge demolition likely to cause turbidity. Turbidity is likely to extend only a minimal distance from the source (Table 6-16) and could potentially be present for the duration of the time it takes to install or remove each cofferdam. Installation of the cofferdam, demolition of the pier, and removal of the cofferdam is expected to take 40 days throughout the 18-month in-water demolition period (Figure 6-16). In any case, turbidity will not exceed the levels, distance, or duration specified by the permits.

In general, upland excavation has the potential to cause erosion, which in turn may introduce suspended sediments into water bodies by way of stormwater inlets, ditches, or other forms of conveyance. However, it is not likely that upland construction will cause turbidity in the CRC action area water bodies. To prevent the introduction of sediments into waterways from upland excavation, the project will adhere to an erosion control plan that specifies the type and placement of BMPs, mandates frequent inspections, and outlines contingency plans in the event of failure. Additionally, in many cases, there will likely be numerous other barriers between the potential sources and the action area water bodies. Therefore, there is only a discountable risk that upland excavation will generate turbidity in action area water bodies. Erosion control specifications are outlined in further detail in Section 7.

General Effects of Turbidity on Fish

Turbidity is a naturally occurring phenomenon; however, turbidity above background levels may harm fish. Several factors contribute to turbidity levels in water, including suspended sediments, dissolved particles, finely divided organic and inorganic matter, chemicals, plankton, and other microscopic organisms. Not all of these materials are necessarily harmful, meaning that turbidity levels alone may not accurately indicate the effect on fish. TSS, a direct measure of particles transported in the water column, may be a more useful indicator of the effect to fish. However, due to the ease of taking turbidity measurements, turbidity is in widespread use throughout the literature as an indicator of the effect of suspended sediments on fish (Bash et al. 2001).

The response of fish to turbidity is complex. High levels of turbidity may be fatal to salmonids, but salmonids may also be affected by turbidity at relatively low levels (Lloyd 1987). Juvenile salmonids have been observed in naturally turbid estuaries and highly turbid glacial streams, which indicates that that salmon are able to cope with elevated turbidity during certain life stages (Gregory and Northcote 1993, as cited in Bash et al. 2001). In contrast, salmonids not normally exposed to elevated turbidity levels may be adversely affected at relatively low levels (Gregory 1992, as cited in Bash et al. 2001). The severity of effect depends on a variety of factors, such as the turbidity level, extent of the turbidity plume, the duration and frequency of exposure, the toxicity and angularity of the particles, life stage of the fish, and access to “turbidity refugia” (Bash et al. 2001). Depending on the amount of exposure, turbidity above background levels may prompt the following effects: direct mortality, gill tissue damage, physiological stress, and behavioral effects.

Numerous studies document that direct mortality for juvenile salmonids occurs at a 96-hour median sediment concentration of 6,000 mg/L (Stober et al. 1981 as cited in Bash et al. 2001; Salo et al. 1980; LeGore and DesVoigne 1973 as cited in WSF 2009).

Suspended sediments have been shown to damage gill structure (Noggle 1978). When the filaments of salmonid gills are clogged with sediment, fish attempt to expunge the sediment by opening and closing their gills excessively, in a physiological process known as “coughing.” In response to the irritation, the gills may secrete a protective layer of mucus. Although this may interfere with respiration, it is not a lethal effect (Berg 1982, as cited in Bash et al. 2001). Servizi and Martens (1992) noted a significant increase in coughing in subyearling coho when turbidity measured 30 NTU. Berg (1982, as cited in Bash et al. 1991) observed a significant increase in coughing in juvenile coho at 60 NTU, with a decline or return to pre-exposure levels of coughing at 10 NTU. This indicates that turbidity somewhere between 10 and 30 NTUs may cause onset of coughing. Servizi and Martens (1987) found that gill trauma occurred in subyearling sockeye at suspended sediment concentrations of 3,148 mg/L.

The literature indicates that exposure to suspended sediments may cause stress response in both adult and juvenile salmonids. Physiological stress generally manifests itself as elevated blood sugar, plasma glucose, and plasma cortisol (Bash et al. 2001). Redding et al. (1987) observed physiological stress in subyearling coho after exposure to sediment concentrations of 2,000 mg/L for 7 to 8 days. Servizi and Martens (1987) observed elevated blood glucose levels in adult and juvenile sockeye after contact with fine sediment. In adults, this response occurred at concentrations of 500 to 1,500 mg/L after exposure for 2 to 8 days. At levels of 150 to 200 mg/L, no stress response was observed (Redding et al. 1987; Servizi and Martens 1987). At the individual level, stress may reduce growth, increase the likelihood of disease, inhibit the development from parr to smolt, disrupt osmotic balance, impair migration, and reduce survival (Wedermeyer and McLeay 1981, as cited in Bash et al. 2001). At the population level, stress may reduce spawning success, increase larval mortality, and decrease overall population abundance (Bash et al. 2001).

Turbidity may also prompt behavioral responses in fish, including avoidance, migration delays, and changes in foraging and predation. Numerous studies document salmonids avoiding suspended sediments and migrating to less turbid areas (Berg 1982; Sigler et al. 1984). Lloyd et al. (1987) showed that juvenile salmonids avoid streams that are chronically turbid unless they cannot avoid these areas on their migration path. Cederholm and Salo (1979) showed that the upstream migration of salmonids in the lower Columbia River may be delayed when water clarity is reduced. On the other hand, adult male Chinook experienced no disruption in migration to spawning grounds after exposure to sediment concentrations of 650 mg/L over 7 days.

The literature is not in complete agreement as to whether or not turbidity increases the rate of prey capture in salmonids. Some studies reveal that fish have decreased foraging success in response to increased turbidity (Berg 1982; Berg and Northcote 1985; Redding et al. 1987; Gardner 1981 as cited in Bash et al. 2001; Boehlert and Morgan 1985 as cited in Bash et al. 2001; Vogel and Beauchamp 1999 as cited in Bash et al. 2001). One study showed decreased foraging at levels as low as 20 NTU (Berg 1982). In contrast, other studies show that juvenile coho, steelhead, and Chinook have increased foraging success in “slightly to moderately turbid” water (Sigler at al. 1984; Gregory and Levings 1998). There is also evidence that suspended sediments may offer cover from predators (Gregory 1993; Gregory and Levings 1996; Davies-Colley and Smith 2001), which may both enhance survival and increase foraging success.

Turbidity and concurrent sedimentation may negatively affect survival of eggs and emergence of fry or larvae. After being deposited in spawning areas, high levels of fines may become embedded in the substrate, reducing the permeation of oxygen into eggs, potentially resulting in mortality. Additionally, deposition of sediment may physically block the emergence of fry or larval fish (Cederholm and Salo 1979).

Effects on Fish in the CRC Action Area

There are few water quality monitoring studies that cite turbidity levels encountered during installation and removal of piles, cofferdams, and steel casings. Due to the lack of data, the analysis of the effects of turbidity on fish is based on turbidity levels observed during dredging, for which there are numerous monitoring studies. Havis (1988, as cited in WSF 2009)), Salo et al. (1979, as cited in WSF 2009), and Palermo et al. (1990, as cited in WSF 2009) note that typical samples collected within 150 feet of dredging contain sediment concentrations between 50 and 150 mg/L. LaSalle (1988, as cited in WSF 2009) concluded that maximum sediment concentrations resulting from dredging range between 700 and 1,100 mg/L at a distance of approximately 300 feet from the source, based on monitoring data from seven clamshell dredging operations. These levels would be expected for dredging of fine sediments such as silt or clay. Much lower concentrations, 50 to 150 mg/L, would be expected for dredging in coarser substrates (LaSalle 1988). The CRC in-water project area contains a mixture of coarser sediments and silty sand. Therefore, the amount of turbidity encountered during debris removal is likely to be more than 50 to 150 mg/L but is not expected to exceed 700 to 1,100 mg/L. Turbidity levels for the other activities listed in Table 6-16 (installation and removal of piles and cofferdams, installing large steel casings, barge use, and drilling shafts) are expected to be much lower than levels resulting from dredging.

Turbidity levels on the CRC project are not expected to reach levels that cause mortality in fish. The highest sediment concentrations expected to occur (1,100 mg/L) will be well below levels known to kill fish (6,000 mg/L). Likewise, turbidity levels on the CRC project are not likely to cause gill trauma, as gill trauma occurs at roughly 3,000 mg/L, well above the highest levels of turbidity expected on the project. However, turbidity will likely reach levels that could cause "coughing." Coughing may occur at 30 NTU, a value roughly estimated to be greater than 100 mg/L (Lloyd 1987). Actual exposure to these levels is expected to be minimal, however. Regulatory permits will require restricting the size of the plumes (about 300 feet from the source) and their duration (about 4 to 6 hours). Additionally, because of the large size and the high dilution capacity of the Columbia River and North Portland Harbor, there are abundant turbidity refugia, and listed fish should not become trapped in turbid water. The turbidity will be localized in areas downstream of specific activities (Table 6-16) and will not extend across the entire width of the Columbia River or North Portland Harbor. Therefore, it will not cause a complete barrier to movement. Thus, while turbidity levels are theoretically high enough to prompt coughing in fish, it is unlikely that the duration and extent of exposure will be great enough to cause gill damage.

The project may produce turbidity at levels that could cause physiological stress in fish. Of the studies available, the data indicate that stress may occur at a minimum level of 500 mg/L after several days of exposure. The project may generate a maximum of 1,100 mg/L of sediment concentration, but more typically in the range of 50 to 150 mg/L. On the CRC project, the actual duration of exposure to elevated turbidity is likely to be quite low, as regulatory permits will restrict the size and duration of the turbidity plumes, about 300 feet and to about 4 to 6 hours at a time. Additionally, because of the large size and the high dilution capacity of the Columbia River and North Portland Harbor, listed fish will be able to avoid the turbidity plumes and not become trapped in turbid water. The turbidity will not cause a complete migration barrier. Thus, while turbidity levels are theoretically high enough to prompt stress in fish, it is unlikely that the duration and extent of exposure will be great enough to cause stress.

It is highly likely that turbidity generated by the project will cause both adult and juvenile fish to avoid discrete portions of the work area (Table 6-16), as avoidance has been documented at very low turbidity levels. Figures 4-1 and 4-2 show when listed fish may be present in portions of the action area where they could be exposed to this effect. Turbidity-generating activities will be ongoing for the duration of the 4-year in-water construction period, and, therefore, these activities are likely to intersect up to four migration periods of juvenile salmon and steelhead.

The exception is debris removal, which will likely intersect only about 7 days of one juvenile migrational period. Fish will likely circumvent the turbidity plumes and swim into less turbid areas. Whether this avoidance will result in a biologically significant effect is less clear. Although the literature shows that juvenile salmonids may delay migration in response to high turbidity, this may not necessarily be true in the CRC action area for two reasons. First, due to the large size of the Columbia River and North Portland Harbor, turbidity refugia will be abundant, and juvenile fish will probably circumvent the plumes with no significant delay to migration. Second, larger sediment plumes (anticipated to be no more than 300 feet) will occur in the action area for no more than roughly 4 to 6 hours at a time. Therefore, there is ample time for juveniles to migrate between sediment pulses, and even if there were a delay, it would only be for a matter of hours. Adults have not been shown to delay migration even after many days of exposure to high turbidity. Because the CRC project will cause only low exposure (due to the abundance of turbidity refugia) over a limited spatial extent and over short durations, delays to adult migration are not probable.

Turbidity will likely reach levels that have been shown both to enhance and impede foraging abilities in fish. Therefore, we can expect that turbidity generated by the project will cause listed fish in the action area to increase foraging in some circumstances and decrease foraging in others. There is also evidence that turbidity may provide cover from predators, creating a benefit to juvenile fish. However, due to the uncertainly in the literature, and due to the wide variations in the levels of turbidity shown to cause either of these outcomes, it is impossible to quantify this effect.

Turbidity and resulting sedimentation may affect spawning eulachon in the action area. (Other listed fish will not be exposed to this effect because none spawn in portions of the action area downstream of activities likely to generate turbidity.) High levels of turbidity have the potential to smother eggs and block the emergence of larvae (Langness 2009 personal communication). There are no known eulachon spawning concentrations in portions of the action area likely to be exposed to elevated turbidity and sedimentation (see Section 4). Given the lack of precise spawning locations, it is assumed that spawning could potentially occur anywhere in the portions of the Columbia River and North Portland Harbor with water depths of 8 to 20 feet, and if spawning occurs in this area, it would likely be exposed to elevated turbidity. In other words, exposure could result from turbidity-generating activities at Pier 7 in the Columbia River and throughout North Portland Harbor. Actual exposure is expected to be quite low, as high levels of turbidity will be limited to approximately 300 feet downstream of the discrete areas where debris removal will occur and will be restricted to a much smaller area for other in-water activities (Table 6-16). This represents a minuscule proportion of the channel and an insignificant fraction of the total available spawning habitat immediately surrounding the affected area for many miles upstream and downstream.

Exposure to eulachon eggs or larvae would be limited to the overlap of (1) the incubation and emergence period, approximately from January through June, with (2) the 4-year in-water construction period. Table 6-17 summarizes the effect of turbidity and sedimentation on various life functions of fish.