Interstate
BRIDGE
Replacement Program

Considering the importance of our natural environment

Geology and Groundwater Technical Report

September 2024

OREGON

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Interstate BRIDGE Replacement Program

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CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
af	Artificial Fill
BRT	bus rapid transit
CPC	City of Portland Code
CRBG	Columbia River Basalt Group
CRC	Columbia River Crossing
CSZ	Cascadia Subduction Zone
CTR	Commute Trip Reduction
C-TRAN	Clark County Public Transit Benefit Area Authority
CU1	Confining Unit 1
CU2	Confining Unit 2
DSL	Oregon Department of State Lands
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
FSCR	Flood Safe Columbia River
ft/day	feet per day
gpd/ft	gallons per day per foot
gpm	gallons per minute
GPTIA	Groundwater Pump and Treat Interim Action
HiA	Hillsboro silt loam, 0 to 3 percent slopes
HoB	Hillsboro silt loam, 3 to 8 percent slopes
I-5	Interstate 5
IBR	Interstate Bridge Replacement

Acronym/Abbreviation	Definition
LgB	Lauren gravelly loam, 0 to 8 percent slopes
LgD	Lauren gravelly loam, 8 to 20 percent slopes
LPA	Locally Preferred Alternative
LRT	light-rail transit
LRV	light-rail vehicle
MAX	Metropolitan Area Express
mgd	million gallons per day
msl	mean sea level
M_W	moment magnitude
NAVD 88	North American Vertical Datum of 1988
NEPA	National Environmental Policy Act
NRCS	Natural Resources Conservation Service
ºC	Celsius
ODOT	Oregon Department of Transportation
ºF	Fahrenheit
OTC	Oregon Transportation Commission
PGIS	pollution generating impervious surfaces
PMLS	Portland Metro Levee System
PNCD	Preliminary Navigation Clearance Determination
POV	Port of Vancouver
Qa	Alluvium
Qal	Quaternary Alluvium
Qf/Qfc	Missoula flood deposits
ROD	Record of Decision
SGA	Sand and Gravel Aquifer
SmA	Sauvie silt loam, 0 to 3 percent slopes

Acronym/Abbreviation	Definition
SOV	single-occupancy vehicle
SR	State Route
TGA	Troutdale Gravel Aquifer
TriMet	Tri-County Metropolitan Transportation District
TSA	Troutdale Sandstone Aquifer
TSSA	Troutdale Sole Source Aquifer
Tt	Troutdale formation
UFSWQD	Urban Flood Safety and Water Quality District
USA	Unconsolidated Sedimentary Aquifer
USACE	U.S. Army Corps of Engineers
USC	United States Code
USCG	U.S. Coast Guard
VMC	Vancouver Municipal Code
VOC	volatile organic compounds
WnB	Wind River sandy loam, 0 to 8 percent slopes
WnD	Wind River sandy loam, 8 to 20 percent slopes
WnG	Wind River sandy loam, 30 to 65 percent slopes
WrB	Wind River gravelly loam, 0 to 8 percent slopes
WrF	Wind River gravelly loam, 12 to 50 percent slopes
WS	Water Station
WSDOT	Washington State Department of Transportation
WSTC	Washington State Transportation Commission

1. PROGRAM OVERVIEW

This technical report identifies, describes, and evaluates temporary and long-term effects from geologic hazards (steep slope areas, landslides, liquefaction, and earthquake-hazard-prone areas) and to geologic resources and groundwater quality related to the proposed Interstate Bridge Replacement (IBR) Program's Modified Locally Preferred Alternative (Modified LPA). Unchecked geologic hazards could have adverse impacts in terms of construction worker and public safety; agency and public relations; quality of natural resources; schedule delay; and cost increase. Identifying and mitigating geologic hazards will help prevent or reduce the effects of these potential impacts.

The purpose of this report is to satisfy applicable portions of the National Environmental Policy Act (NEPA) 42 United States Code (USC) 4321 "to promote efforts which will prevent or eliminate damage to the environment." Information and potential environmental consequences described in this technical report will be used to support the Draft Supplemental Environmental Impact Statement (SEIS) pursuant to 42 USC 4332. The objectives of this report are to:

- Define the study area and the methods of data collection and evaluation (Section 2).
- Describe existing geologic and hydrogeologic conditions (Section 3).
- Discuss and compare potential long-term, temporary, and indirect effects to the Modified LPA and the No-Build Alternative from geologic hazards and the potential impacts to geologic and groundwater resources from the Modified LPA and the No-Build Alternative (Sections 4, 5, and 6).
- Provide proposed mitigation measures to help eliminate, minimize, or mitigate long-term and temporary effects to geologic and groundwater resources from the Modified LPA (Section 7).
- Identify federal, state, and local permits that would be required (Section 8).

The IBR Program is a continuation of the previously suspended Columbia River Crossing (CRC) project with the same purpose to replace the aging Interstate 5 (I-5) Bridge across the Columbia River with a modern, seismically resilient multimodal structure. The proposed infrastructure improvements are located along a 5-mile stretch of the I-5 corridor that extends from approximately Victory Boulevard in Portland to State Route (SR) 500 in Vancouver as shown in Figure 1-1.

The Modified LPA is a modification of the CRC LPA, which completed the National Environmental Policy Act (NEPA) process with a signed Record of Decision (ROD) in 2011 and two re-evaluations that were completed in 2012 and 2013. The CRC project was discontinued in 2014. This Technical Report is evaluating the effects of changes in project design since the CRC ROD and re-evaluations, as well as changes in regulations, policy, and physical conditions.

Figure 1-1. IBR Program Location Overview

1.1 Components of the Modified LPA

The basic components of the Modified LPA include:

- A new pair of Columbia River bridges—one for northbound and one for southbound travel—built west of the existing bridge. The new bridges would each include three through lanes, safety shoulders, and one auxiliary lane (a ramp-to-ramp connection on the highway that improves interchange safety by providing drivers with more space and time to merge, diverge, and weave) in each direction. When all highway, transit, and active transportation would be moved to the new Columbia River bridges, the existing Interstate Bridge (both spans) would be removed.
    a. Three bridge configurations are under consideration: (1) double-deck truss bridges with fixed spans, (2) single-level bridges with fixed spans, and (3) single-level bridges with movable spans over the primary navigation channel. The fixed-span configurations would provide up to 116 feet of vertical navigation clearance, and the movable-span configuration would provide 178 feet of vertical navigation clearance in the open position. The primary navigation channel would be relocated approximately 500 feet south (measured by channel centerline) of its existing location near the Vancouver shoreline.
    b. A two auxiliary lane design option (two ramp-to-ramp lanes connecting interchanges) across the Columbia River is also being evaluated. The second auxiliary lane in each direction of I-5 would be added from approximately Interstate Avenue/Victory Boulevard to SR 500/39th Street.
- A 1.9-mile light-rail transit (LRT) extension of the current Metropolitan Area Express (MAX) Yellow Line from the Expo Center MAX Station in North Portland, where it currently ends, to a terminus near Evergreen Boulevard in Vancouver. Improvements would include new stations at Hayden Island, downtown Vancouver (Waterfront Station), and near Evergreen Boulevard (Evergreen Station), as well as revisions to the existing Expo Center MAX Station. Park and rides to serve LRT riders in Vancouver could be included near the Waterfront Station and Evergreen Station. The Tri-County Metropolitan Transportation District of Oregon (TriMet), which operates the MAX system, would also operate the Yellow Line extension.
    a. Potential site options for park and rides include three sites near the Waterfront Station and two near the Evergreen Station (up to one park and ride could be built for each station location in Vancouver).
- Associated LRT improvements such as traction power substations, overhead catenary system, signal and communications support facilities, an overnight light-rail vehicle (LRV) facility at the Expo Center, 19 new LRVs, and an expanded maintenance facility at TriMet's Ruby Junction.
- Integration of local bus transit service, including bus rapid transit (BRT) and express bus routes, in addition to the proposed new LRT service.
- Wider shoulders on I-5 from Interstate Avenue/Victory Boulevard to SR 500/39th Street to accommodate express bus-on-shoulder service in each direction.

- Associated bus transit service improvements would include three additional bus bays for eight new electric double-decker buses at the Clark County Public Transit Benefit Area Authority (C-TRAN) operations and maintenance facility (see Section 1.1.7, Transit Operating Characteristics, for more information about this service).
- Improvements to seven I-5 interchanges and I-5 mainline improvements between Interstate Avenue/ Victory Boulevard in Portland and SR 500/39th Street in Vancouver. Some adjacent local streets would be reconfigured to complement the new interchange designs, and improve local east-west connections.
    a. An option that shifts the I-5 mainline up to 40 feet westward in downtown Vancouver between the SR 14 interchange and Mill Plain Boulevard interchange is being evaluated.
    b. An option that eliminates the existing C Street ramps in downtown Vancouver is being evaluated.
- Six new adjacent bridges across North Portland Harbor: one on the east side of the existing I-5 North Portland Harbor bridge and five on the west side or overlapping with the existing bridge (which would be removed). The bridges would carry (from west to east) LRT tracks, southbound I-5 off-ramp to Marine Drive, southbound I-5 mainline, northbound I-5 mainline, northbound I-5 on-ramp from Marine Drive, and an arterial bridge for local traffic with a shared-use path for pedestrians and bicyclists.
- A variety of improvements for people who walk, bike, and roll throughout the study area, including a system of shared-use paths, bicycle lanes, sidewalks, enhanced wayfinding, and facility improvements to comply with the Americans with Disabilities Act. These are referred to in this document as *active transportation* improvements.
- Variable-rate tolling for motorists using the river crossing as a demand-management and financing tool.

The transportation improvements proposed for the Modified LPA and the design options are shown in Figure 1-2. The Modified LPA includes all of the components listed above. If there are differences in environmental effects or benefits between the design options, those are identified in the sections below.

Figure 1-2. Modified LPA Components

Section 1.1.1, Interstate 5 Mainline, describes the overall configuration of the I-5 mainline through the study area, and Sections 1.1.2, Portland Mainland and Hayden Island (Subarea A), through Section 1.1.5, Upper Vancouver (Subarea D), provide additional detail on four geographic subareas (A through D), which are shown on Figure 1-3. In each subarea, improvements to I-5, its interchanges, and the local roadways are described first, followed by transit and active transportation improvements. Design options are described under separate headings in the subareas in which they would be located.

Table 1-1 shows the different combinations of design options analyzed in this Technical Report. However, **any combination of design options is compatible**. In other words, any of the bridge configurations could be combined with one or two auxiliary lanes, with or without the C Street ramps, a centered or westward shift of I-5 in downtown Vancouver, and any of the park-and-ride location options. Figures in each section show both the anticipated limit of ground disturbance, which includes disturbance from temporary construction activities, and the location of permanent infrastructure elements.

Figure 1-3. Modified LPA – Geographic Subareas

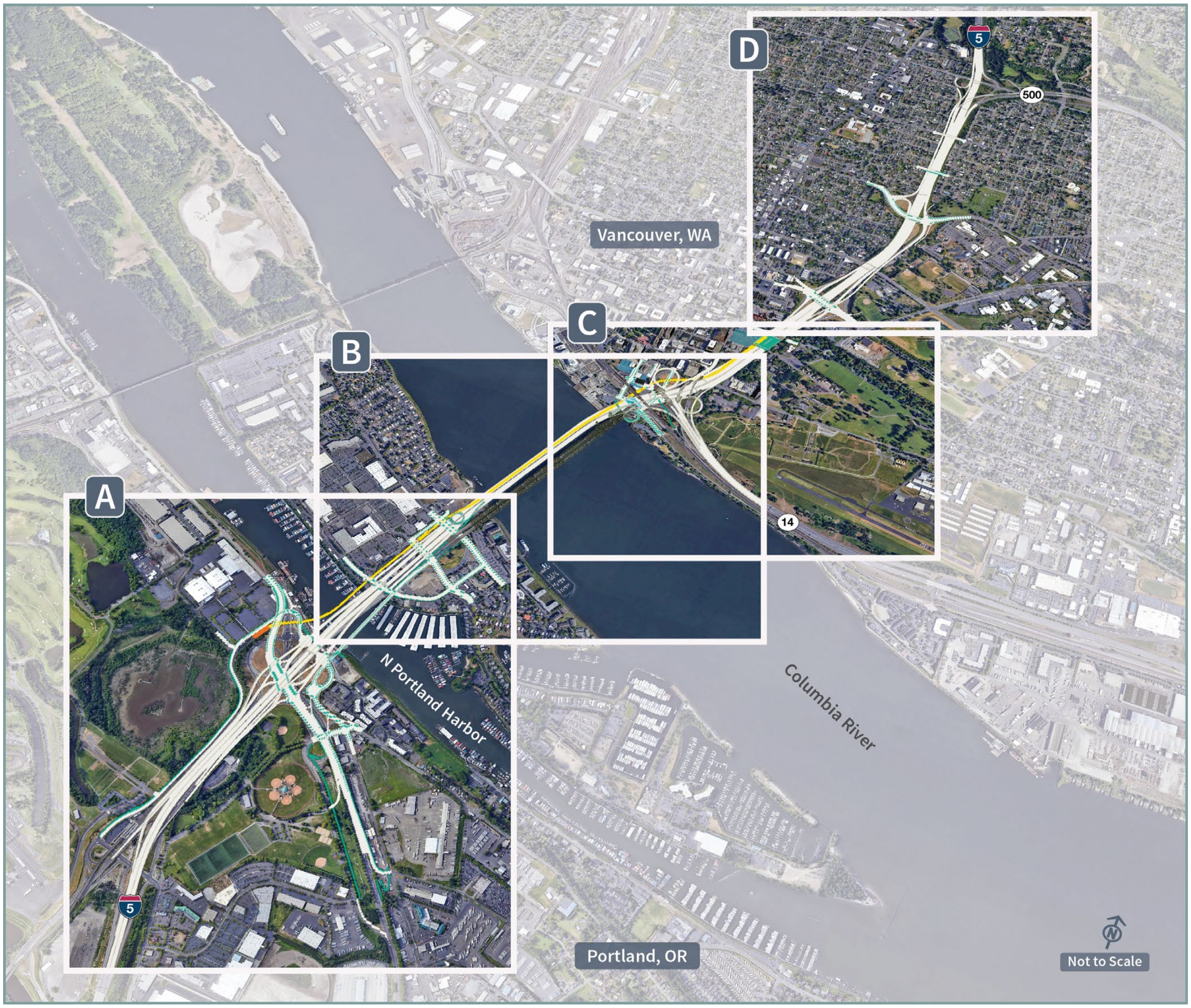


Table 1-1. Modified LPA and Design Options

Design Options	Modified LPA	Modified LPA with Two Auxiliary Lanes	Modified LPA Without C Street Ramps	Modified LPA with I-5 Shifted West	Modified LPA with a Single-Level Fixed-Span Configuration	Modified LPA with a Single-Level Movable-Span Configuration
Bridge Configuration	**Double-deck fixed-span***	Double-deck fixed-span	Double-deck fixed-span	Double-deck fixed-span	**Single-level fixed-span***	**Single-level movable-span***
Auxiliary Lanes	**One***	**Two***	One	One	One	One
C Street Ramps	**With C Street ramps***	With C Street ramps	**Without C Street Ramps***	With C Street ramps	With C Street ramps	With C Street ramps
I-5 Alignment	**Centered***	Centered	Centered	**Shifted West***	Centered	Centered
Park-and-Ride Options	**Waterfront**:* 1. Columbia Way (below I-5); 2. Columbia Street/SR 14; 3. Columbia Street/Phil Arnold Way **Evergreen**:* 1. Library Square; 2. Columbia Credit Union					

Bold text with an asterisk (*) indicates which design option is different in each configuration.

1.1.1 Interstate 5 Mainline

Today, within the 5-mile corridor, I-5 has three 12-foot-wide through lanes in each direction, an approximately 6- to 11-foot-wide inside shoulder, and an approximately 10- to 12-foot-wide outside shoulder with the exception of the Interstate Bridge, which has approximately 2- to 3-foot-wide inside and outside shoulders. There are currently intermittent auxiliary lanes between the Victory Boulevard and Hayden Island interchanges in Oregon and between SR 14 and SR 500 in Washington.

The Modified LPA would include three 12-foot through lanes from Interstate Avenue/Victory Boulevard to SR 500/39th Street and a 12-foot auxiliary lane from the Marine Drive interchange to the Mill Plain Boulevard interchange in each direction. Many of the existing auxiliary lanes on I-5 between the SR 14 and Main Street interchanges in Vancouver would remain, although they would be reconfigured. The existing auxiliary lanes between the Victory Boulevard and Hayden Island interchanges would be replaced with changes to on- and off-ramps and interchange reconfigurations. The Modified LPA would also include wider shoulders (12-foot inside shoulders and 10- to 12-foot outside shoulders) to be consistent with ODOT and WSDOT design standards. The wider inside shoulder would be used by express bus service to bypass mainline congestion, known as “bus on shoulder” (refer to Section 1.1.7, Transit Operating Characteristics). The shoulder would be available for express bus service when general-purpose speeds are below 35 miles per hour (mph).

Figure 1-4 shows a cross section of the collector-distributor (C-D)[1] roadways, Figure 1-5 shows the location of the C-D roadways, and Figure 1-6 shows the proposed auxiliary lane layout. The existing Interstate Bridge over the Columbia River does not have an auxiliary lane; the Modified LPA would add one auxiliary lane in each direction across the new Columbia River bridges.

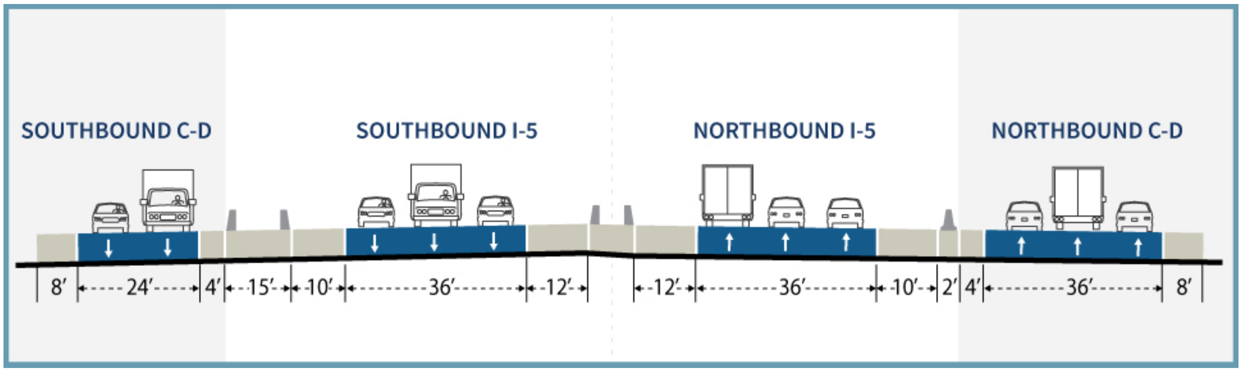
On I-5 northbound, the auxiliary lane that would begin at the on-ramp from Marine Drive would continue across the Columbia River bridge and end at the off-ramp to the C-D roadway, north of SR 14 (see Figure 1-5). The on-ramp from SR 14 westbound would join the off-ramp to the C-D roadway, forming the northbound C-D roadway between SR 14 and Fourth Plain Boulevard. The C-D roadway would provide access from I-5 northbound to the off-ramps at Mill Plain Boulevard and Fourth Plain Boulevard. The C-D roadway would also provide access from SR 14 westbound to the off-ramps at Mill Plain Boulevard and Fourth Plain Boulevard, and to the on-ramp to I-5 northbound.

On I-5 northbound, the Modified LPA would also add one auxiliary lane beginning at the on-ramp from the C-D roadway and ending at the on-ramp from 39th Street, connecting to an existing auxiliary lane from 39th Street to the off-ramp at Main Street. Another existing auxiliary lane would remain between the on-ramp from Mill Plain Boulevard to the off-ramp to SR 500.

On I-5 southbound, the off-ramp to the C-D roadway would join the on-ramp from Mill Plain Boulevard to form a C-D roadway. The C-D roadway would provide access from I-5 southbound to the off-ramp to SR 14 eastbound and from Mill Plain Boulevard to the off-ramp to SR 14 eastbound and the on-ramp to I-5 southbound.

On I-5 southbound, an auxiliary lane would begin at the on-ramp from the C-D roadway and would continue across the southbound Columbia River bridge and end at the off-ramp to Marine Drive. The combined on-ramp from SR 14 westbound and C Street would merge into this auxiliary lane.

Figure 1-4. Cross Section of the Collector-Distributor Roadways



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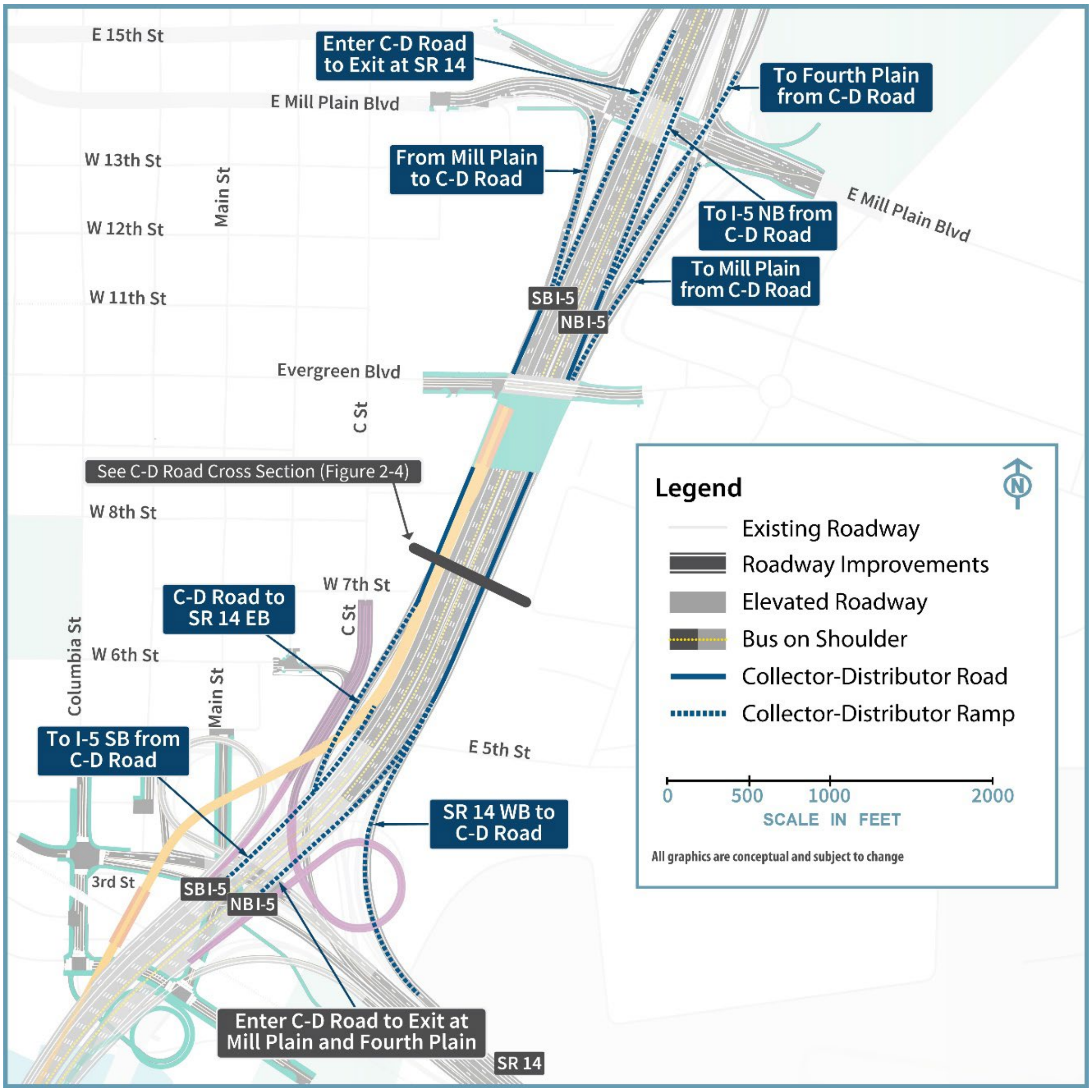
[1] A collector-distributer roadway parallels and connects the main travel lanes of a highway and frontage roads or entrance ramps.

Figure 1-5. Collector-Distributor Roadways



C-D = collector-distributor; EB = eastbound; NB = northbound; SB = southbound; WB = westbound

1.1.1.1 Two Auxiliary Lane Design Option

This design option would add a second 12-foot-wide auxiliary lane in each direction of I-5 with the intent to further optimize travel flow in the corridor. This second auxiliary lane is proposed from the Interstate Avenue/Victory Boulevard interchange to the SR 500/39th Street interchange.

On I-5 northbound, one auxiliary lane would begin at the combined on-ramp from Interstate Avenue and Victory Boulevard, and a second auxiliary lane would begin at the on-ramp from Marine Drive. Both auxiliary lanes would continue across the northbound Columbia River bridge, and the on-ramp from Hayden Island would merge into the second auxiliary lane on the northbound Columbia River bridge. At the off-ramp to the C-D roadway, the second auxiliary lane would end but the first auxiliary lane would continue. A second auxiliary lane would begin again at the on-ramp from Mill Plain Boulevard. The second auxiliary lane would end at the off-ramp to SR 500, and the first auxiliary lane would connect to an existing auxiliary lane at 39th Street to the off-ramp at Main Street.

On I-5 southbound, two auxiliary lanes would begin at the on-ramp from SR 500. Between the on-ramp from Fourth Plain Boulevard and the off-ramp to Mill Plain Boulevard, one auxiliary lane would be added to the existing two auxiliary lanes. The second auxiliary lane would end at the off-ramp to the C-D roadway, but the first auxiliary lane would continue. A second auxiliary lane would begin again at the southbound I-5 on-ramp from the C-D roadway. Both auxiliary lanes would continue across the southbound Columbia River bridge, and the combined on-ramp from SR 14 westbound and C Street would merge into the second auxiliary lane on the southbound Columbia River bridge. The second auxiliary lane would end at the off-ramp to Marine Drive, and the first auxiliary lane would end at the combined off-ramp to Interstate Avenue and Victory Boulevard.

Figure 1-6 shows a comparison of the one auxiliary lane configuration and the two auxiliary lane configuration design option. Figure 1-7 shows a comparison of the footprints (i.e., the limit of permanent improvements) of the one auxiliary lane and two auxiliary lane configurations on a double-deck fixed-span bridge. For all Modified LPA bridge configurations (described in Section 1.1.3, Columbia River Bridges (Subarea B)), the footprints of the two auxiliary lane configurations differ only over the Columbia River and in downtown Vancouver. The rest of the corridor would have the same footprint. For all bridge configurations analyzed in this document, the two auxiliary lane option would add 16 feet (8 feet in each direction) in total roadway width compared to the one auxiliary lane option due to the increased shoulder widths for the one auxiliary lane option.[2] The traffic operations analysis incorporating both the one and two auxiliary lane design options applies equally to all bridge configurations in this Technical Report.

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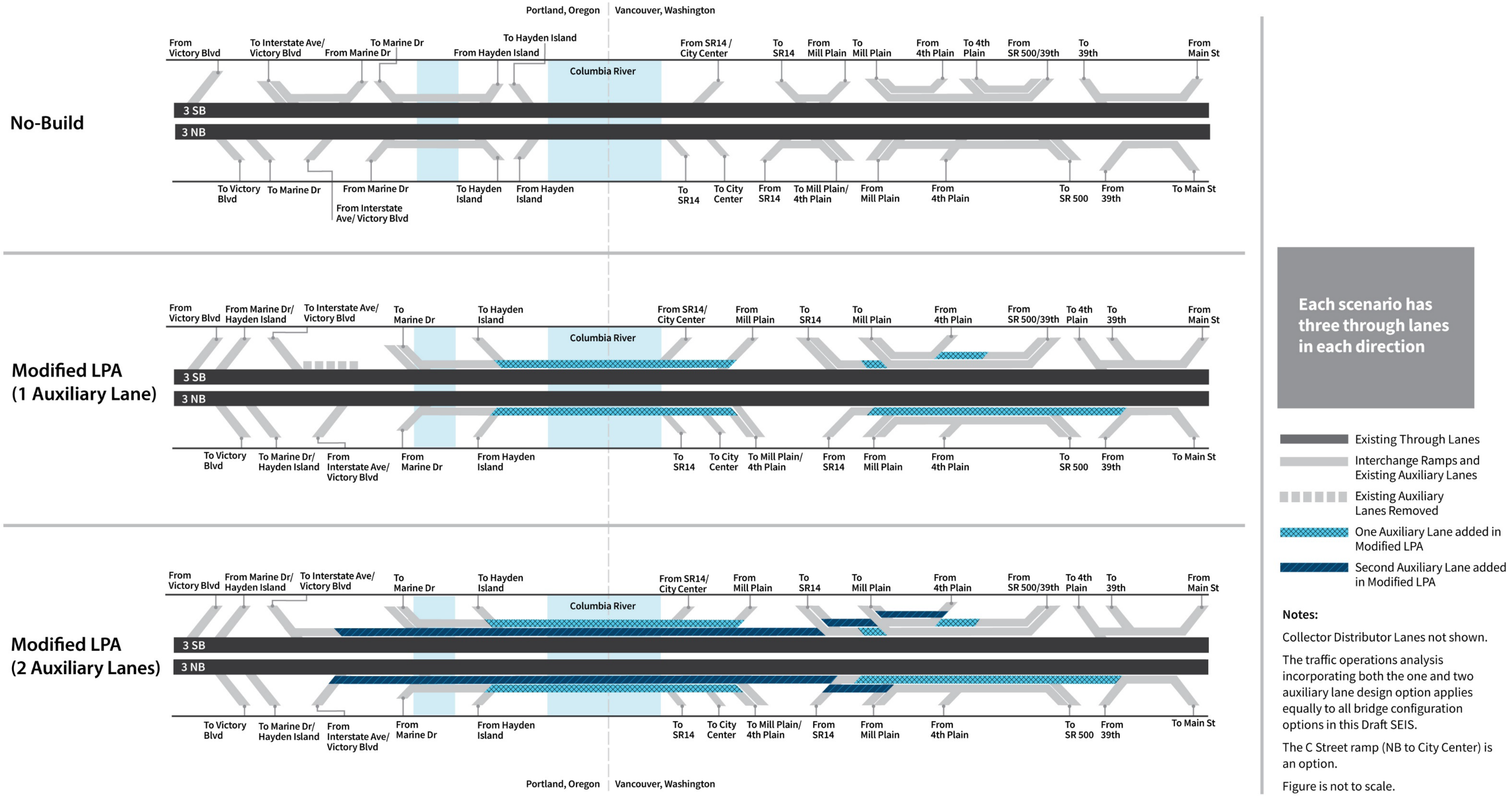
[2] Under the one auxiliary lane option, the width of each shoulder would be approximately 14 feet to accommodate maintenance of traffic during construction. Under the two auxiliary lane option, maintenance of traffic could be accommodated with 12-foot shoulders because the additional 12-foot auxiliary lane provides adequate roadway width. The total difference in roadway width in each direction between the one auxiliary lane option and the two auxiliary lane option would be 8 feet (12-foot auxiliary lane – 2 feet from the inside shoulder – 2 feet from the outside shoulder = 8 feet).

Figure 1-6. Comparison of Auxiliary Lane Configurations



Notes:

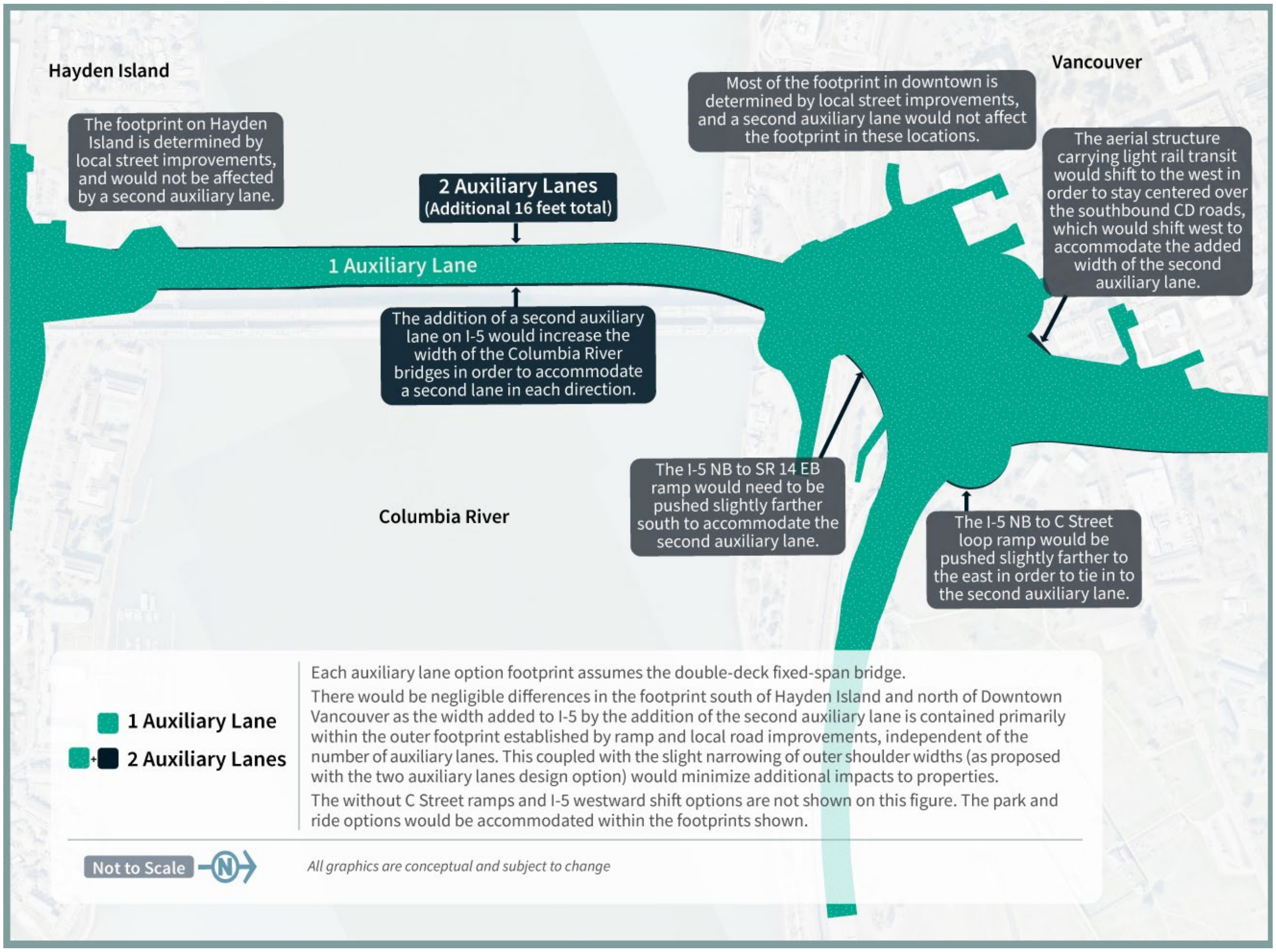
Collector Distributor Lanes not shown.

The traffic operations analysis incorporating both the one and two auxiliary lane design option applies equally to all bridge configuration options in this Draft SEIS.

The C Street ramp (NB to City Center) is an option.

Figure is not to scale.

Figure 1-7. Auxiliary Lane Configuration Footprint Differences



The footprint on Hayden Island is determined by local street improvements, and would not be affected by a second auxiliary lane.

Most of the footprint in downtown is determined by local street improvements, and a second auxiliary lane would not affect the footprint in these locations.

The aerial structure carrying light rail transit would shift to the west in order to stay centered over the southbound CD roads, which would shift west to accommodate the added width of the second auxiliary lane.

The addition of a second auxiliary lane on I-5 would increase the width of the Columbia River bridges in order to accommodate a second lane in each direction.

The I-5 NB to SR 14 EB ramp would need to be pushed slightly farther south to accommodate the second auxiliary lane.

The I-5 NB to C Street loop ramp would be pushed slightly farther to the east in order to tie in to the second auxiliary lane.

Each auxiliary lane option footprint assumes the double-deck fixed-span bridge.

There would be negligible differences in the footprint south of Hayden Island and north of Downtown Vancouver as the width added to I-5 by the addition of the second auxiliary lane is contained primarily within the outer footprint established by ramp and local road improvements, independent of the number of auxiliary lanes. This coupled with the slight narrowing of outer shoulder widths (as proposed with the two auxiliary lanes design option) would minimize additional impacts to properties.

The without C Street ramps and I-5 westward shift options are not shown on this figure. The park and ride options would be accommodated within the footprints shown.

All graphics are conceptual and subject to change

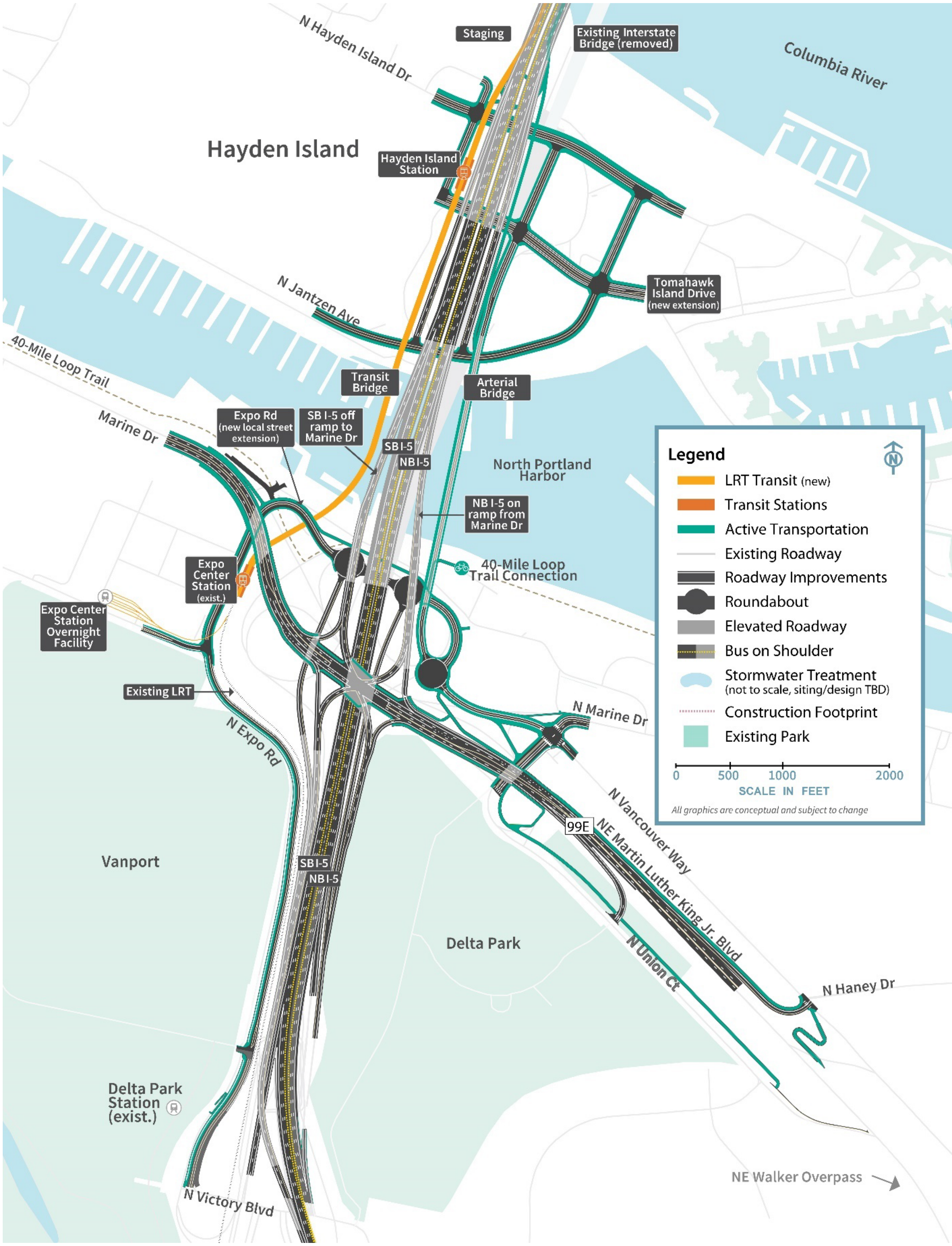
1.1.2 Portland Mainland and Hayden Island (Subarea A)

This section discusses the geographic Subarea A shown in Figure 1-3. See Figure 1-8 for highway and interchange improvements in Subarea A, including the North Portland Harbor bridge. Figure 1-8 illustrates the one auxiliary lane design option; please refer to Figure 1-6 and the accompanying description for how two auxiliary lanes would alter the Modified LPA's proposed design. Refer to Figure 1-3 for an overview of the geographic subareas.

Within Subarea A, the IBR Program has the potential to alter three federally authorized levee systems:

- The Oregon Slough segment of the Peninsula Drainage District Number 1 levee (PEN 1).
- The Oregon Slough segment of the Peninsula Drainage District Number 2 levee (PEN 2).
- The PEN1/PEN2 cross levee segment of the PEN 1 levee (Cross Levee).

Figure 1-8. Portland Mainland and Hayden Island (Subarea A)



LRT = light-rail transit; NB = northbound; SB = southbound; TBD = to be determined

The levee systems are shown on Figure 1-9, and intersections with Modified LPA components are described throughout Section 1.1.2, Portland Mainland and Hayden Island (Subarea A), where appropriate. Within Subarea A, the IBR Program study area intersects with PEN 1 to the west of I-5 and with PEN 2 to the east of I-5. PEN 1 and PEN 2 include a main levee along the south side of North Portland Harbor and are part of a combination of levees and floodwalls. PEN 1 and PEN 2 are separated by the Cross Levee that is intended to isolate the two districts if one of them fails. The Cross Levee is located along the I-5 mainline embankment, except in the Marine Drive interchange area where it is located on the west edge of the existing ramp from Marine Drive to southbound I-5.[3]

There are two concurrent efforts underway that are planning improvements to PEN1, PEN2, and the Cross Levee to reduce flood risk:

- The U.S. Army Corps of Engineers (USACE) Portland Metro Levee System (PMLS) project.
- The Flood Safe Columbia River (FSCR) program (also known as “Levee Ready Columbia”).

The Urban Flood Safety and Water Quality District (UFSWQD)[4] is working with the USACE through the PMLS project, which includes improvements at PEN 1 and PEN 2 (e.g., raising these levees to elevation 38 feet North American Vertical Datum of 1988 [NAVD 88]).[5] Additionally, as part of the FSCR program, UFSWQD is studying raising a low spot in the Cross Levee on the southwest side of the Marine Drive interchange.

The IBR Program is in close coordination with these concurrent efforts to ensure that the IBR Program’s design efforts consider the timing and scope of the PMLS and the FSCR proposed modifications. The intersection of the IBR Program proposed actions to both the existing levee configuration and the anticipated future condition based on the proposed PMLS and FSCR projects are described below, where appropriate.

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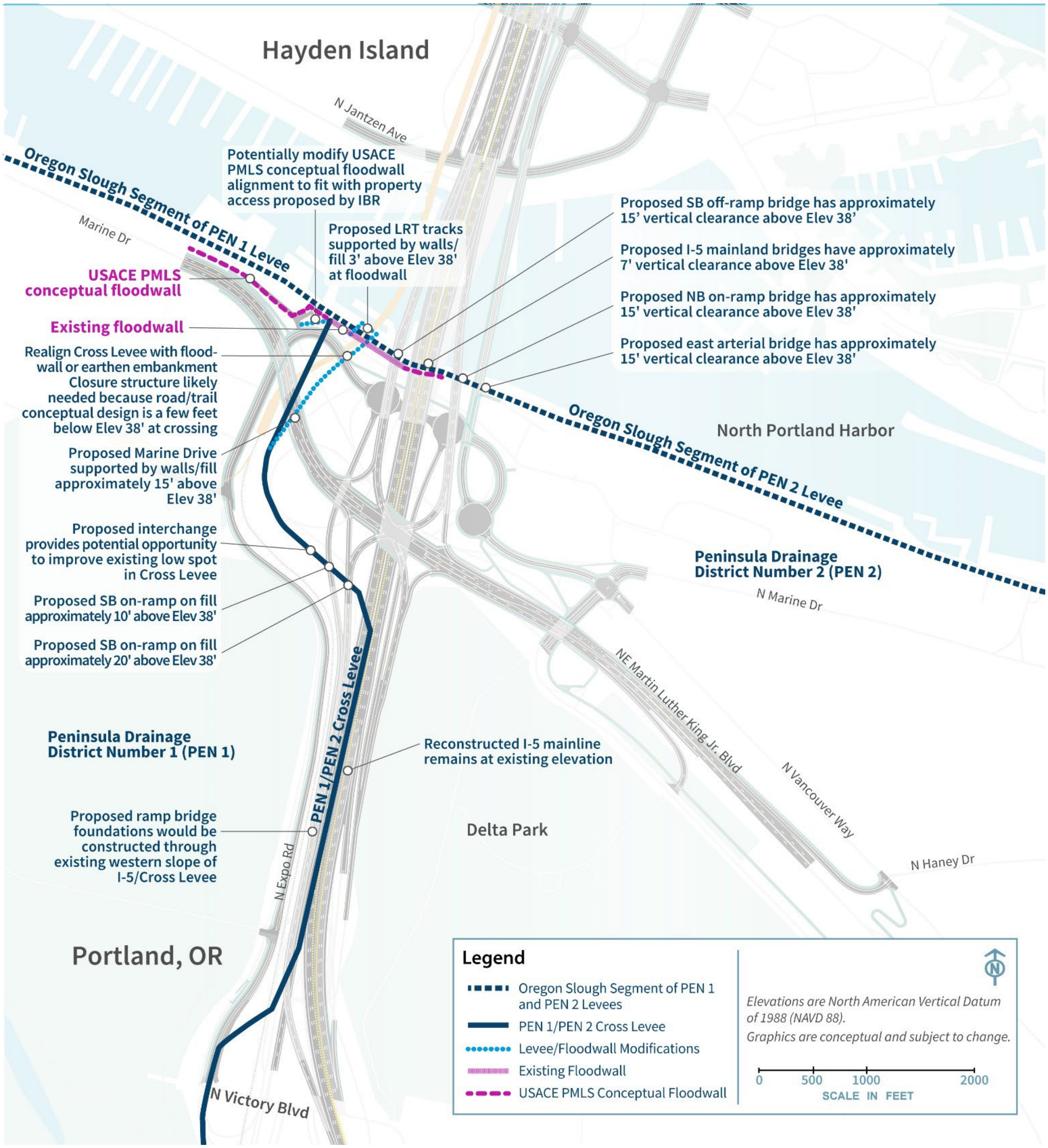
[3] The portion of the original Denver Avenue levee alignment within the Marine Drive interchange area is no longer considered part of the levee system by UFSWQD.

[4] UFSWQD includes PEN 1 and PEN 2, Urban Flood Safety and Water Quality District No. 1, and the Sandy Drainage Improvement Company.

[5] NAVD 88 is a vertical control datum (reference point) used by federal agencies for surveying.

Figure 1-9. Levee Systems in Subarea A



1.1.2.1 Highways, Interchanges, and Local Roadways

VICTORY BOULEVARD/INTERSTATE AVENUE INTERCHANGE AREA

The southern extent of the Modified LPA would improve two ramps at the Victory Boulevard/Interstate Avenue interchange (see Figure 1-8). The first ramp improvement would be the southbound I-5 off-ramp to Victory Boulevard/ Interstate Avenue; this off-ramp would be braided below (i.e., grade separated or pass below) the Marine Drive to the I-5 southbound on-ramp (see the Marine Drive Interchange Area section below). The other ramp improvement would lengthen the merge distance for northbound traffic entering I-5 from Victory Boulevard and from Interstate Avenue.

The existing I-5 mainline between Victory Boulevard/Interstate Avenue and Marine Drive is part of the Cross Levee (see Figure 1-9). The Modified LPA would require some pavement reconstruction of the mainline in this area; however, the improvements would mostly consist of pavement overlay and the profile and footprint would be similar to existing conditions.

MARINE DRIVE INTERCHANGE AREA

The next interchange north of the Victory Boulevard/Interstate Avenue interchange is at Marine Drive. All movements within this interchange would be reconfigured to reduce congestion for motorists entering and exiting I-5. The new configuration would be a single-point urban interchange. The new interchange would be centered over I-5 versus on the west side under existing conditions. See Figure 1-8 for the Marine Drive interchange's layout and construction footprint.

The Marine Drive to I-5 southbound on-ramp would be braided over I-5 southbound to the Victory Boulevard/Interstate Avenue off-ramp. Martin Luther King Jr. Boulevard would have a new more direct connection to I-5 northbound.

The new interchange configuration would change the westbound Marine Drive and westbound Vancouver Way connections to Martin Luther King Jr. Boulevard. An improved connection farther east of the interchange (near Haney Street) would provide access to westbound Martin Luther King Jr. Boulevard for these two streets. For eastbound travelers on Martin Luther King Jr. Boulevard exiting to Union Court, the existing loop connection would be replaced with a new connection farther east (near the access to the East Delta Park Owens Sports Complex).

Expo Road from Victory Boulevard to the Expo Center would be reconstructed with improved active transportation facilities. North of the Expo Center, Expo Road would be extended under Marine Drive and continue under I-5 to the east, connecting with Marine Drive and Vancouver Way through three new connected roundabouts. The westernmost roundabout would connect the new local street extension to I-5 southbound. The middle roundabout would connect the I-5 northbound off-ramp to the local street extension. The easternmost roundabout would connect the new local street extension to an arterial bridge crossing North Portland Harbor to Hayden Island. This roundabout would also connect the local street extension to Marine Dr and Vancouver Way.

To access Hayden Island using the arterial bridge from the east on Martin Luther King Jr. Boulevard, motorists would exit Martin Luther King Jr. Boulevard at the existing off-ramp to Vancouver Way just west of the Walker Street overpass. Then motorists would travel west on Vancouver Way, through the intersection with Marine Drive and straight through the roundabout to the arterial bridge.

From Hayden Island, motorists traveling south to Portland via Martin Luther King Jr. Boulevard would turn onto the arterial bridge southbound and travel straight through the roundabout onto Vancouver Way. At the intersection of Vancouver Way and Marine Drive, motorists would turn right onto Union Court and follow the existing road southeast to the existing on-ramp onto Martin Luther King Jr. Boulevard.

The conceptual floodwall alignment from the proposed USACE PMLS project is located on the north side of Marine Drive, near two industrial properties, with three proposed closure structures[6] for property access. The Modified LPA would realign Marine Drive to the south and provide access to the two industrial properties via the new local road extension from Expo Road. Therefore, the change in access for the two industrial properties could require small modifications to the floodwall alignment (a potential shift of 5 to 10 feet to the south) and closure structure locations.

Marine Drive and the two southbound on-ramps would travel over the Cross Levee approximately 10 to 20 feet above the proposed elevation of the improved levee, and they would be supported by fill and retaining walls near an existing low spot in the Cross Levee.

The I-5 southbound on-ramp from Marine Drive would continue on a new bridge structure. Although the bridge's foundation locations have not been determined yet, they would be constructed through the western slope of the Cross Levee (between the existing I-5 mainline and the existing light-rail).

NORTH PORTLAND HARBOR BRIDGES

To the north of the Marine Drive interchange is the Hayden Island interchange area, which is shown in Figure 1-8. I-5 crosses over the North Portland Harbor when traveling between these two interchanges. The Modified LPA proposes to replace the existing I-5 bridge spanning North Portland Harbor to improve seismic resiliency.

Six new parallel bridges would be built across the waterway under the Modified LPA: one on the east side of the existing I-5 North Portland Harbor bridge and five on the west side or overlapping the location of the existing bridge (which would be removed). From west to east, these bridges would carry:

- The LRT tracks.
- The southbound I-5 off-ramp to Marine Drive.
- The southbound I-5 mainline.
- The northbound I-5 mainline.
- The northbound I-5 on-ramp from Marine Drive.
- An arterial bridge between the Portland mainland and Hayden Island for local traffic; this bridge would also include a shared-use path for pedestrians and bicyclists.

Each of the six replacement North Portland Harbor bridges would be supported on foundations constructed of 10-foot-diameter drilled shafts. Concrete columns would rise from the drilled shafts and connect to the superstructures of the bridges. All new structures would have at least as much vertical navigation clearance over North Portland Harbor as the existing North Portland Harbor bridge.

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[6] Levee closure structures are put in place at openings along the embankment/floodwall to provide flood protection during high water conditions.

Compared to the existing bridge, the two new I-5 mainline bridges would have a similar vertical clearance of approximately 7 feet above the proposed height of the improved levees (elevation 38 feet NAVD 88). The two ramp bridges and the arterial bridge would have approximately 15 feet of vertical clearance above the proposed height of the levees. The foundation locations for the five roadway bridges have not been determined at this stage of design, but some foundations could be constructed through landward or riverward levee slopes.

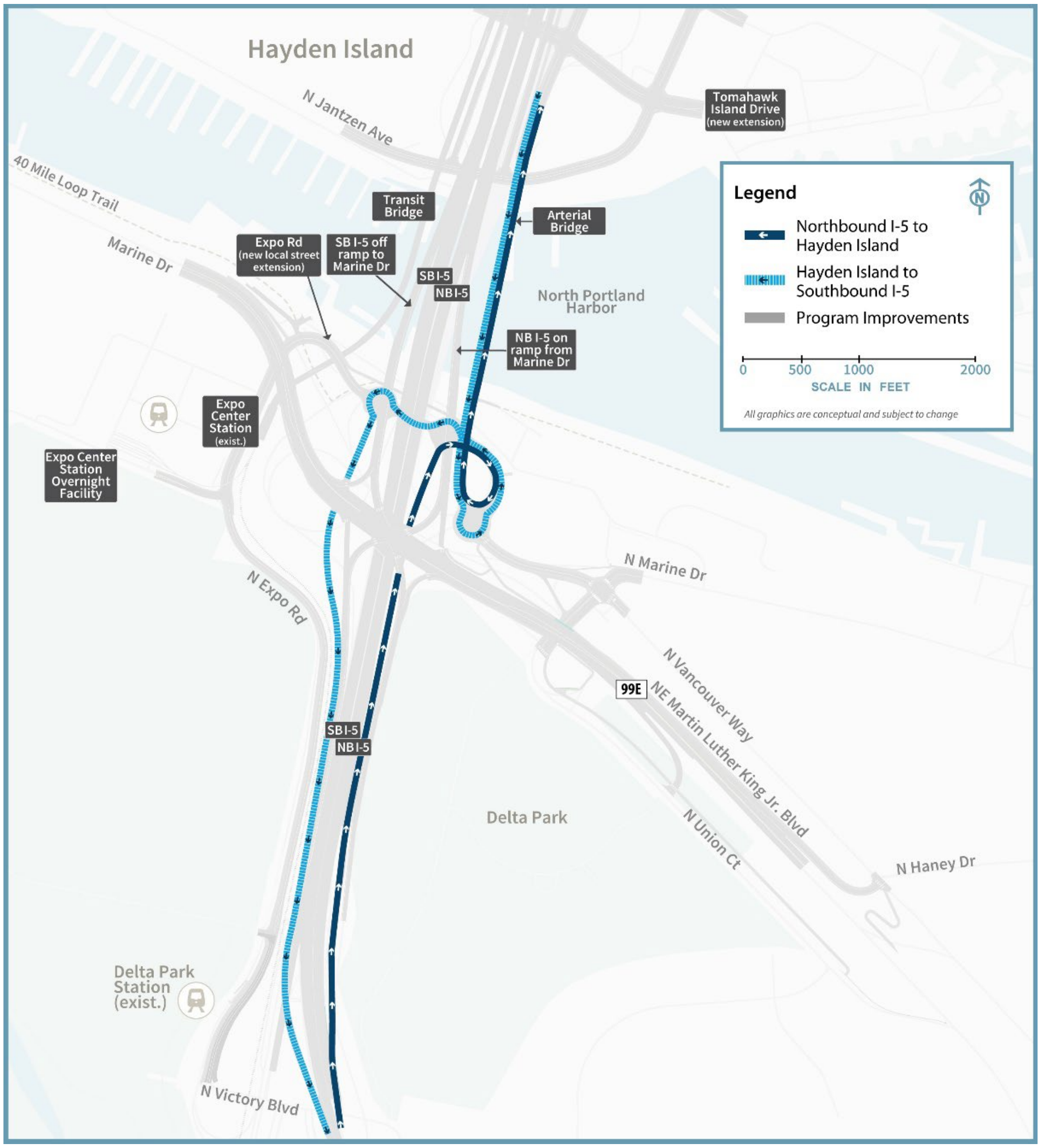
HAYDEN ISLAND INTERCHANGE AREA

All traffic movements for the Hayden Island interchange would be reconfigured. See Figure 1-8 for a layout and construction footprint of the Hayden Island interchange. A half-diamond interchange would be built on Hayden Island with a northbound I-5 on-ramp from Jantzen Drive and a southbound I-5 off-ramp to Jantzen Drive. This would lengthen the ramps and improve merging/diverging speeds compared to the existing substandard ramps that require acceleration and deceleration in a short distance. The I-5 mainline would be partially elevated and partially located on fill across the island.

There would not be a southbound I-5 on-ramp or northbound I-5 off-ramp on Hayden Island. Connections to Hayden Island for those movements would be via the local access (i.e., arterial) bridge connecting North Portland to Hayden Island (Figure 1-10). Vehicles traveling northbound on I-5 wanting to access Hayden Island would exit with traffic going to the Marine Drive interchange, cross under Martin Luther King Jr. Boulevard to the new roundabout at the Expo Road local street extension, travel east through this roundabout to the easternmost roundabout, and use the arterial bridge to cross North Portland Harbor. Vehicles on Hayden Island looking to enter I-5 southbound would use the arterial bridge to cross North Portland Harbor, cross under I-5 using the new Expo Road local street extension to the westernmost roundabout, cross under Marine Drive, merge with the Marine Drive southbound on-ramp, and merge with I-5 southbound south of Victory Boulevard.

Improvements to Jantzen Avenue may include additional left-turn and right-turn lanes at the interchange ramp terminals and active transportation facilities. Improvements to Hayden Island Drive would include new connections to the new arterial bridge over North Portland Harbor. The existing I-5 northbound and southbound access points from Hayden Island Drive would also be removed. A new extension of Tomahawk Island Drive would travel east-west through the middle of Hayden Island and under the I-5 interchange, thus improving connectivity across I-5 on the island.

Figure 1-10. Vehicle Circulation between Hayden Island and the Portland Mainland



NB = northbound; SB = southbound

1.1.2.2 Transit

A new light-rail alignment for northbound and southbound trains would be constructed within Subarea A (see Figure 1-8) to extend from the existing Expo Center MAX Station over North Portland Harbor to a new station at Hayden Island. An overnight LRV facility would be constructed on the southeast corner of the Expo Center property (see Figure 1-8) to provide storage for trains during hours when MAX is not in service. This facility is described in Section 1.1.6, Transit Support Facilities. The existing Expo Center MAX Station would be modified to remove the westernmost track and platform. Other platform modifications, including track realignment and regrading the station, are anticipated to transition to the extension alignment. This may require reconstruction of the operator break facility, signal/communication buildings, and traction power substations. Immediately north of the Expo Center MAX Station, the alignment would curve east toward I-5, pass beneath Marine Drive, cross the proposed Expo Road local street extension and the 40-Mile Loop Trail at grade, then rise over the existing levee onto a light-rail bridge to cross North Portland Harbor. On Hayden Island, proposed transit components include northbound and southbound LRT tracks over Hayden Island; the tracks would be elevated at approximately the height of the new I-5 mainline. An elevated LRT station would also be built on the island immediately west of I-5. The light-rail alignment would extend north on Hayden Island along the western edge of I-5 before transitioning onto the lower level of the new double-deck western bridge over the Columbia River (see Figure 1-8). For the single-level configurations, the light-rail alignment would extend to the outer edge of the western bridge over the Columbia River.

After crossing the new local road extension from Expo Road, the new light-rail track would cross over the main levee (see Figure 1-9). The light-rail profile is anticipated to be approximately 3 feet above the improved levees at the existing floodwall (and improved floodwall), and the tracks would be constructed on fill supported by retaining walls above the floodwall. North of the floodwall, the light-rail tracks would continue onto the new light-rail bridge over North Portland Harbor (as described above).

The Modified LPA's light-rail extension would be close to or would cross the north end of the Cross Levee. The IBR Program would realign the Cross Levee to the east of the light-rail alignment to avoid the need for a closure structure on the light-rail alignment. This realigned Cross Levee would cross the new local road extension. A closure structure may be required because the current proposed roadway is a few feet lower than the proposed elevation of the improved levee.

1.1.2.3 Active Transportation

In the Victory Boulevard interchange area (see Figure 1-8), active transportation facilities would be provided along Expo Road between Victory Boulevard and the Expo Center; this would provide a direct connection between the Victory Boulevard and Marine Drive interchange areas, as well as links to the Delta Park and Expo Center MAX Stations.

New shared-use path connections throughout the Marine Drive interchange area would provide access between the Bridgeton neighborhood (on the east side of I-5), Hayden Island, and the Expo Center MAX Station. There would also be connections to the existing portions of the 40-Mile Loop Trail, which runs north of Marine Drive under I-5 through the interchange area. The path would continue along the extension of Expo Road under the interchange to the intersection of Marine Drive and Vancouver Way, where it would connect under Martin Luther King Jr. Boulevard to Delta Park.

East of the Marine Drive interchange, new shared-use paths on Martin Luther King Jr. Boulevard and on the parallel street, Union Court, would connect travelers to Marine Drive and across the arterial bridge to Hayden

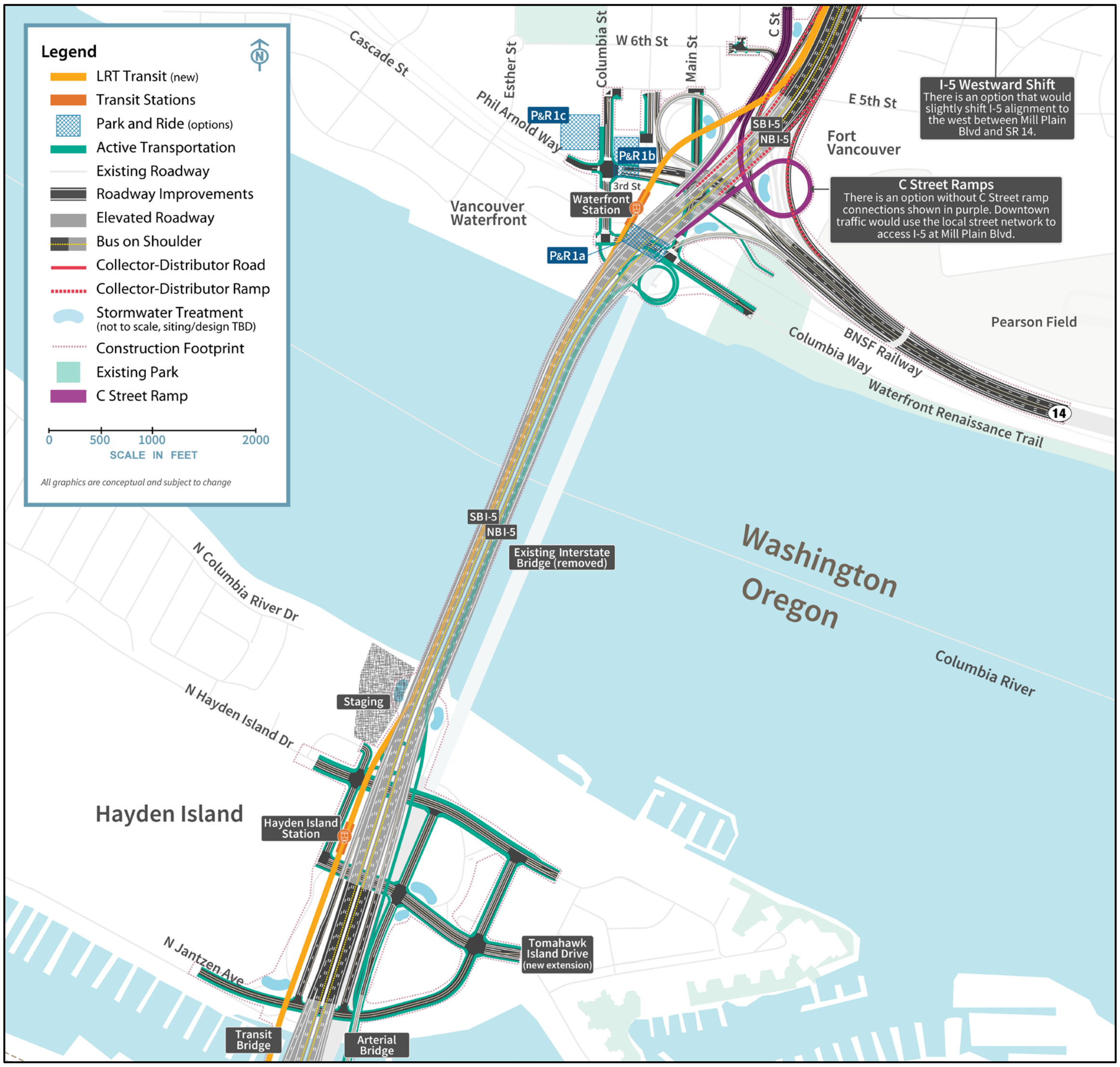
Island. The shared-use facilities on Martin Luther King Jr. Boulevard would provide westbound and eastbound cyclists and pedestrians with off-street crossings of the interchange and would also provide connections to both the Expo Center MAX Station and the 40-Mile Loop Trail to the west.

The new arterial bridge over North Portland Harbor would include a shared-use path for pedestrians and bicyclists (see Figure 1-8). On Hayden Island, pedestrian and bicycle facilities would be provided on Jantzen Avenue, Hayden Island Drive, and Tomahawk Island Drive. The shared-use path on the arterial bridge would continue along the arterial bridge to the south side of Tomahawk Island Drive. A parallel, elevated path from the arterial bridge would continue adjacent to I-5 across Hayden Island and cross above Tomahawk Island Drive and Hayden Island Drive to connect to the lower level of the new double-deck eastern bridge or the outer edge of the new single-level eastern bridge over the Columbia River. A ramp down to the north side of Hayden Island Drive would be provided from the elevated path.

1.1.3 Columbia River Bridges (Subarea B)

This section discusses the geographic Subarea B shown in Figure 1-3. See Figure 1-11 for highway and interchange improvements in Subarea B. Refer to Figure 1-3 for an overview of the geographic subareas.

Figure 1-11. Columbia River Bridges (Subarea B)



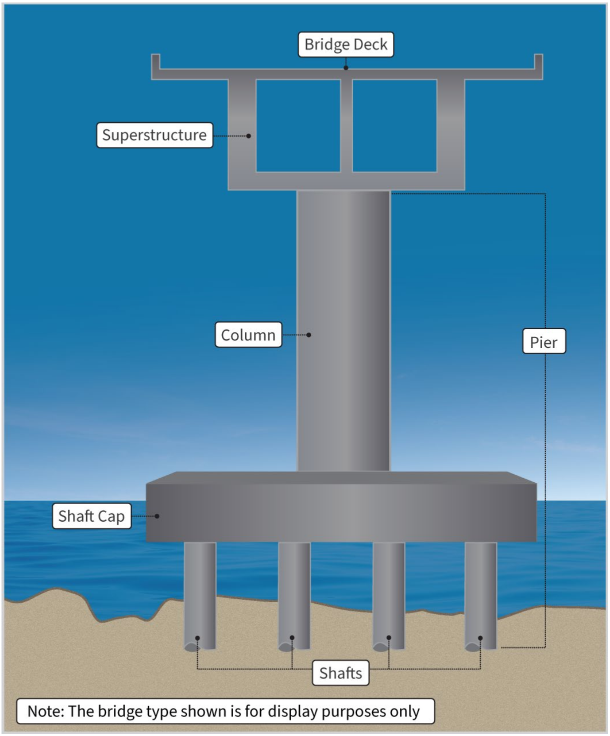
1.1.3.1 Highways, Interchanges, and Local Roadways

The two existing parallel I-5 bridges that cross the Columbia River would be replaced by two new parallel bridges, located west of the existing bridges (see Figure 1-11). The new eastern bridge would accommodate northbound highway traffic and a shared-use path. The new western bridge would carry southbound traffic and two-way light-rail tracks. Whereas the existing bridges each have three lanes with no shoulders, each of the two new bridges would be wide enough to accommodate three through lanes, one or two auxiliary lanes, and shoulders on both sides of the highway. Lanes and shoulders would be built to full design standards.

As with the existing bridge (Figure 1-13), the new Columbia River bridges would provide three navigation channels: a primary navigation channel and two barge channels (see Figure 1-14). The current location of the primary navigation channel is near the Vancouver shoreline where the existing lift spans are located. Under the Modified LPA, the primary navigation channel would be shifted south approximately 500 feet (measured by channel centerlines), and the existing center barge channel would shift north and become the north barge channel. The new primary navigation channel would be 400 feet wide (this width includes a 300-foot congressionally or USACE-authorized channel plus a 50-foot channel maintenance buffer on each side of the authorized channel) and the two barge channels would also each be 400 feet wide.

The existing Interstate Bridge has nine in-water pier sets,[7] whereas the new Columbia River bridges (any bridge configuration) would be built on six in-water pier sets, plus multiple piers on land (pier locations are shown on Figure 1-14). Each in-water pier set would be supported by a foundation of drilled shafts; each group of shafts would be tied together with a concrete shaft cap. Columns or pier walls would rise from the shaft caps and connect to the superstructures of the bridges (see Figure 1-12).

Figure 1-12. Bridge Foundation Concept



Note: The bridge type shown is for display purposes only

BRIDGE CONFIGURATIONS

Three bridge configurations are being considered: (1) double-deck fixed-span (with one bridge type), (2) a single-level fixed-span (with three potential bridge types), and (3) a single-level movable-span (with one bridge type). Both the double-deck and single-level fixed-span configurations would provide 116 feet of vertical navigation clearance at their respective highest spans; the same as the CRC LPA. The CRC LPA included a double-deck fixed-span bridge configuration. The single-level fixed-span configuration was developed and is being considered as part of the IBR Program in response to physical and contextual changes (i.e., design and operational considerations) since 2013 that necessitated examination of a refinement in the double-deck bridge configuration (e.g., ingress and egress of transit from the lower level of the double-deck fixed-span configuration on the north end of the southbound bridge).

Consideration of the single-level movable-span configuration as part the IBR Program was necessitated by the U.S. Coast Guard's (USCG) review of the Program's navigation impacts on the Columbia River and issuance of a Preliminary Navigation Clearance Determination (PNCD) (USCG 2022). The USCG PNCD set the preliminary vertical navigation clearance recommended for the issuance of a bridge permit at 178 feet; this is the current vertical navigation clearance of the Interstate Bridge.

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[7] A pier set consists of the pier supporting the northbound bridge and the pier supporting the southbound bridge at a given location.

Figure 1-13. Existing Navigation Clearances of the Interstate Bridge

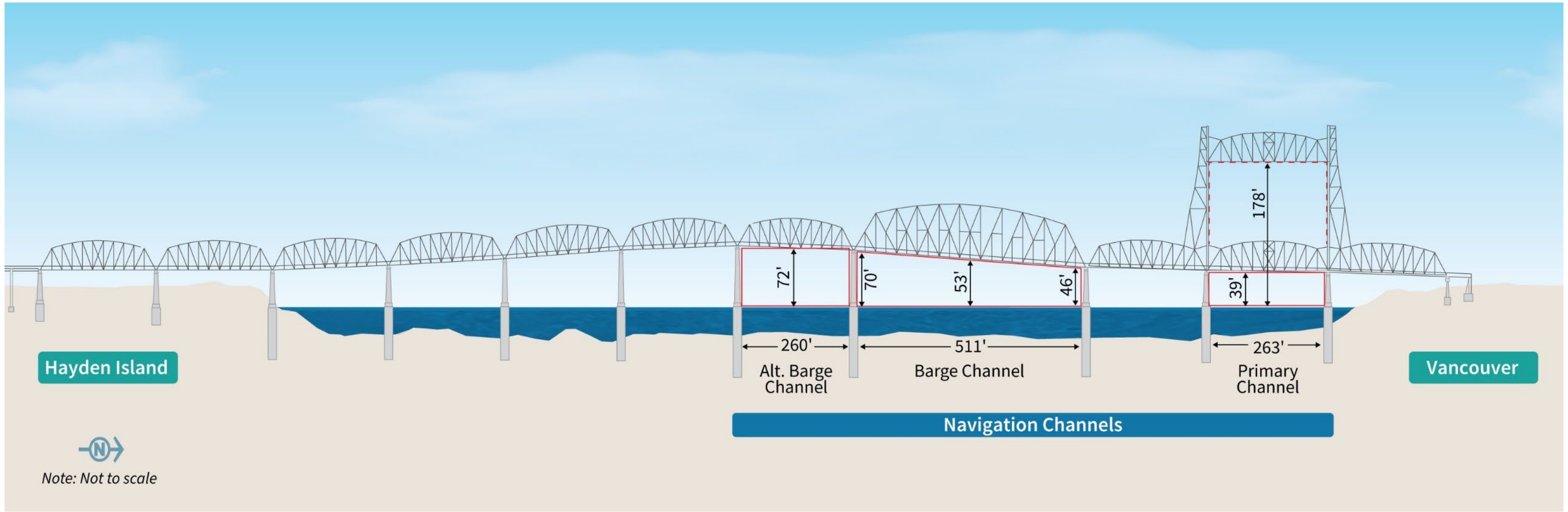
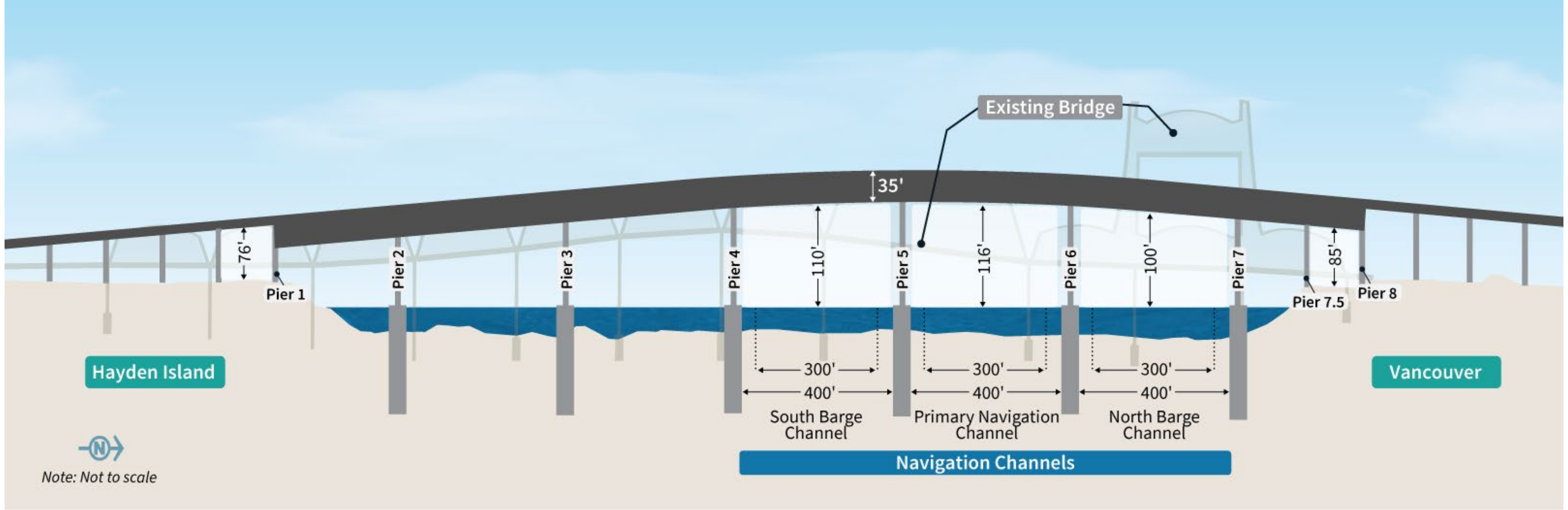


Figure 1-14. Profile and Navigation Clearances of the Proposed Modified LPA Columbia River Bridges with a Double-Deck Fixed-Span Configuration



Note: The location and widths of the proposed navigation channels would be same for all bridge configuration and bridge type options. The three navigation channels would each be 400 feet wide (this width includes a 300-foot congressionally or USACE-authorized channel (shown in dotted lines) plus a 50-foot channel maintenance buffer on each side of the authorized channel). The vertical navigation clearance would vary.

The IBR Program is carrying forward the three bridge configurations to address changed conditions, including changes in the USCG bridge permitting process, in order to ensure a permittable bridge configuration is within the range of options considered. The IBR Program continues to refine the details supporting navigation impacts and is coordinating closely with the USCG to determine how a fixed-span bridge may be permittable. Although the fixed-span configurations do not comply with the current USCG PNCD, they do meet the Purpose and Need and provide potential improvements to traffic (passenger vehicle and freight), transit, and active transportation operations.

Each of the bridge configurations assumes one auxiliary lane; two auxiliary lanes could be applied to any of the bridge configurations. All typical sections for the one auxiliary lane option would provide 14-foot shoulders to maintain traffic during construction of the Modified LPA and future maintenance.

Double-Deck Fixed-Span Configuration

The double-deck fixed-span configuration would be two side-by-side, double-deck, fixed-span steel truss bridges. Figure 1-15 is an example of this configuration (this image is subject to change and is shown as a representative concept; it does not depict the final design). The double-deck fixed-span configuration would provide 116 feet of vertical navigation clearance for river traffic using the primary navigation channel and 400 feet of horizontal navigation clearance at the primary navigation channel, as well as barge channels. This bridge height would not impede takeoffs and landings by aircraft using Pearson Field or Portland International Airport.

The eastern bridge would accommodate northbound highway traffic on the upper level and the shared-use path and utilities on the lower level. The western bridge would carry southbound traffic on the upper level and two-way light-rail tracks on the lower level. Each bridge deck would be 79 feet wide, with a total out-to-out width of 173 feet.[8]

Figure 1-15. Conceptual Drawing of a Double-Deck Fixed-Span Configuration

Note: Visualization is looking southwest from Vancouver.

Figure 1-16 is a cross section of the two parallel double-deck bridges. Like all bridge configurations, the double-deck fixed-span configuration would have six in-water pier sets. Each pier set would require 12 in-water drilled shafts, for a total of 72 in-water drilled shafts. Each individual shaft cap would be approximately 50 feet by 85 feet. This bridge configuration would have a 3.8% maximum grade on the Oregon side of the bridge and a 4% maximum grade on the Washington side.

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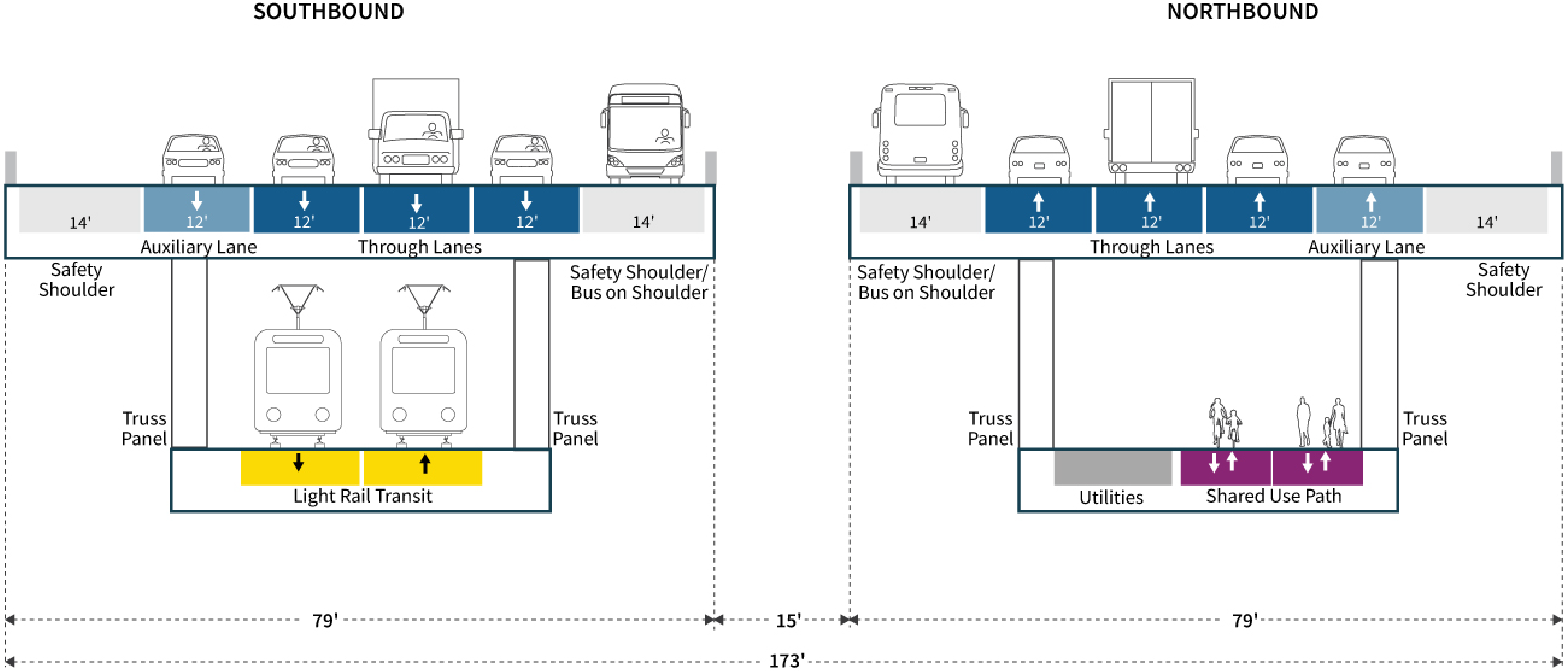
[8] "Out-to-out width" is the measurement between the outside edges of the bridge across its width at the widest point.

Figure 1-16. Cross Section of the Double-Deck Fixed-Span Configuration



Single-Level Fixed-Span Configuration

The single-level fixed-span configuration would have two side-by-side, single-level, fixed-span steel or concrete bridges. This report considers three single-level fixed-span bridge type options: a girder bridge, an extradosed bridge, and a finback bridge. The description in this section applies to all three bridge types (unless otherwise indicated). Conceptual examples of each of these options are shown on Figure 1-17. These images are subject to change and do not represent final design.

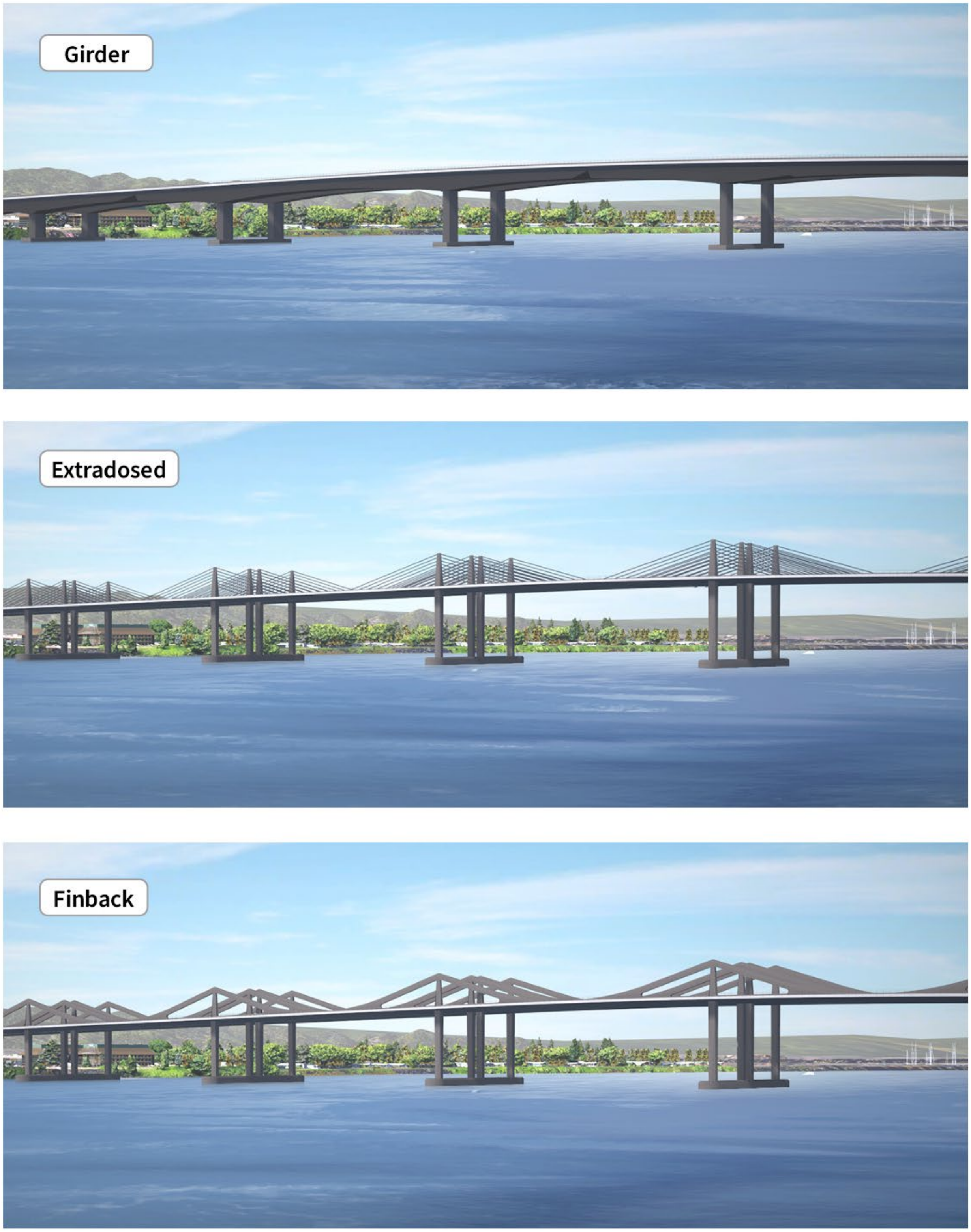
This configuration would provide 116 feet of vertical navigation clearance for river traffic using the primary navigation channel and 400 feet of horizontal navigation clearance at the primary navigation channel, as well as barge channels. This bridge height would not impede takeoffs and landings by aircraft using Pearson Field or Portland International Airport.

The eastern bridge would accommodate northbound highway traffic and the shared-use path; the bridge deck would be 104 feet wide. The western bridge would carry southbound traffic and two-way light-rail tracks; the bridge deck would be 113 feet wide. The I-5 highway, light-rail tracks, and the shared-use path would be on the same level across the two bridges, instead of being divided between two levels with the double-deck configuration. The total out-to-out width of the single-level fixed-span configuration (extradosed or finback options) would be 272 feet at its widest point, approximately 99 feet wider than the double-deck configuration. The total out-to-out width of the single-level fixed-span configuration (girder option) would be 232 feet at its widest point. Figure 1-18 shows a typical cross section of the single-level configuration. This cross section is a representative example of an extradosed or finback bridge as shown by the 10-foot-wide superstructure above the bridge deck; the girder bridge would not have the 10-foot-wide bridge columns shown on Figure 1-18.

There would be six in-water pier sets with 16 in-water drilled shafts on each combined shaft cap, for a total of 96 in-water drilled shafts. The combined shaft caps for each pier set would be 50 feet by 230 feet.

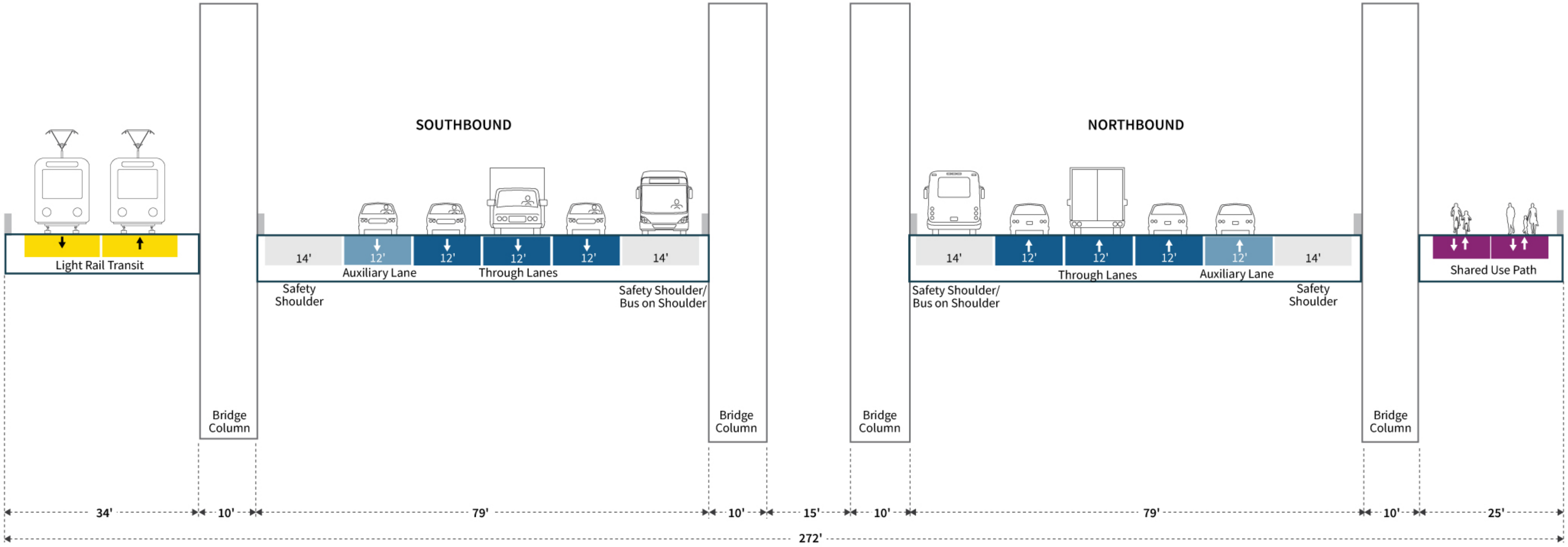
This bridge configuration would have a 3% maximum grade on both the Oregon and Washington sides of the bridge.

Figure 1-17. Conceptual Drawings of Single-Level Fixed-Span Bridge Types



Note: Visualizations are for illustrative purposes only. They do not reflect property impacts or represent final design. Visualization is looking southwest from Vancouver.

Figure 1-18. Cross Section of the Single-Level Fixed-Span Configuration (Extradosed or Finback Bridge Types)



Note: The cross section for a girder type bridge would be the same except that it would not have the four 10-foot bridge columns making the total out-to-out width 232 feet.

Single-Level Movable-Span Configuration

The single-level movable-span configuration would have two side-by-side, single-level steel girder bridges with movable spans between Piers 5 and 6. For the purpose of this report, the IBR Program assessed a vertical lift span movable-span configuration with counterweights based on the analysis in the *River Crossing Bridge Clearance Assessment Report – Movable-Span Options,* included as part of Attachment C in Appendix D, Design Options Development, Screening, and Evaluation Technical Report. A conceptual example of a vertical lift-span bridge is shown in Figure 1-19. These images are subject to change and do not represent final design.

A movable span must be located on a straight and flat bridge section (i.e., without curvature and with minimal slope). To comply with these requirements, and for the bridge to maintain the highway, transit, and active transportation connections on Hayden Island and in Vancouver while minimizing property acquisitions and displacements, the movable span is proposed to be located 500 feet south of the existing lift span, between Piers 5 and 6. To accommodate this location of the movable span, the IBR Program is coordinating with USACE to obtain authorization to change the location of the primary navigation channel, which currently aligns with the Interstate Bridge lift spans near the Washington shoreline.

The single-level movable-span configuration would provide 92 feet of vertical navigation clearance over the proposed relocated primary navigation channel when the movable spans are in the closed position, with 99 feet of vertical navigation clearance available over the north barge channel. The 92-foot vertical clearance is based on achieving a straight, movable span and maintaining an acceptable grade for transit operations. In addition, it satisfies the requirement of a minimum of 72 feet of vertical navigation clearance (the existing Interstate Bridge's maximum clearance over the alternate (southernmost) barge channel when the existing lift span is in the closed position).

In the open position, the movable span would provide 178 feet of vertical navigation clearance over the proposed relocated primary navigation channel.

Similar to the fixed-span configurations, the movable span would provide 400 feet of horizontal navigation clearance for the primary navigation channel and for each of the two barge channels.

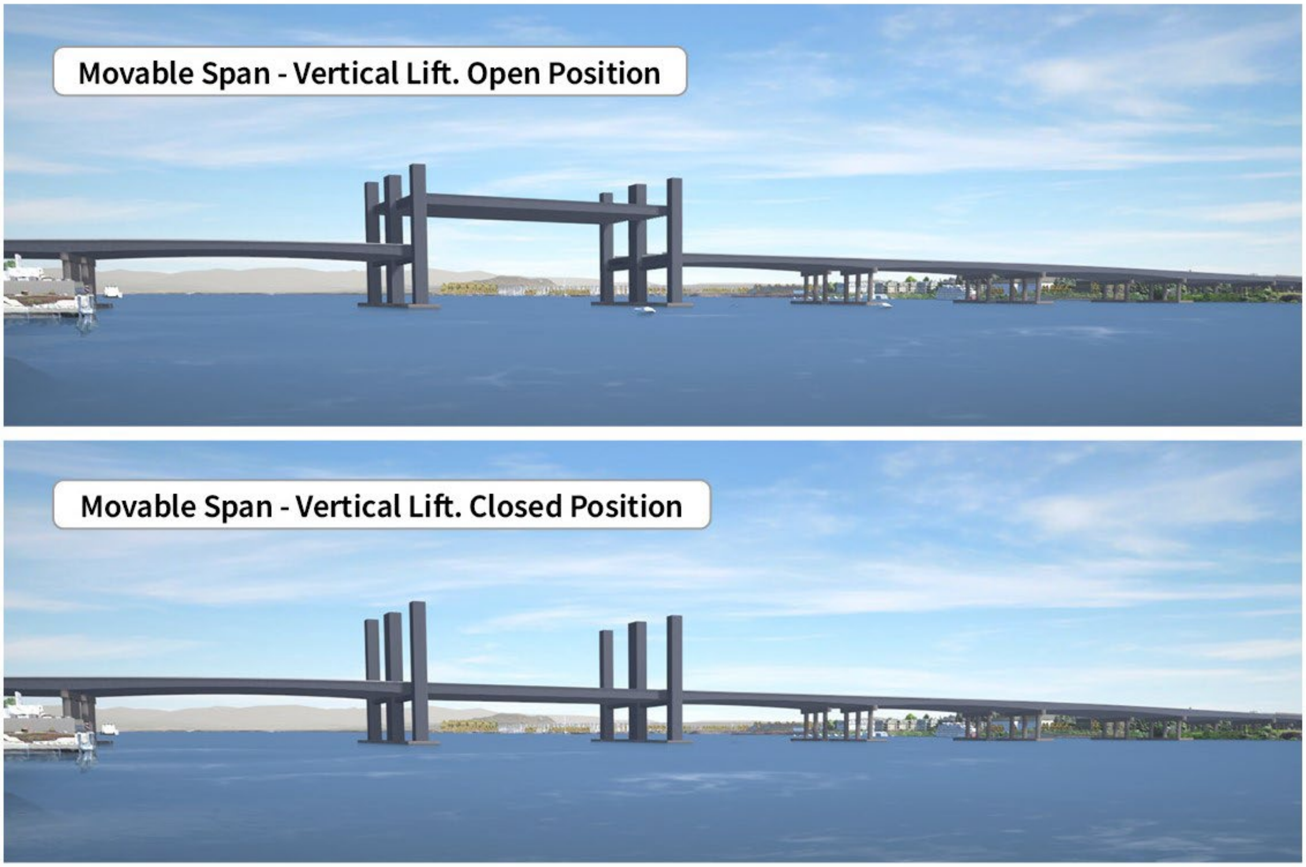
The vertical lift-span towers would be approximately 243 feet high; this is shorter than the existing lift-span towers, which are 247 feet high. This height of the vertical lift-span towers would not impede takeoffs and landings by aircraft using Portland International Airport. At Pearson Field, the Federal Aviation Administration issues obstacle departure procedures to avoid the existing Interstate Bridge lift towers; the single-level movable-span configuration would retain the same procedures.

Similar to the single-level fixed-span configuration, the eastern bridge would accommodate northbound highway traffic and the shared-use path, and the western bridge would carry southbound traffic and two-way light-rail tracks. The I-5 highway, light-rail tracks, and shared-use path would be on the same level across the bridges instead of on two levels as with the double-deck configuration. Cross sections of the single-level movable-span configuration are shown in Figure 1-20; the top cross section depicts the vertical lift spans (Piers 5 and 6), and the bottom cross section depicts the fixed spans (Piers 2, 3, 4, and 7). The movable and fixed cross sections are slightly different because the movable span requires lift towers, which are not required for the other fixed spans of the bridges.

There would be six in-water pier sets and two piers on land per bridge. The vertical lift span would have 22 in-water drilled shafts each for Piers 5 and 6; the shaft caps for these piers would be 50 feet by 312 feet to accommodate the vertical lift spans. Piers 2, 3, 4, and 7 would have 16 in-water drilled shafts each; the shaft caps for these piers would be the same as for the fixed-span options (50 feet by 230 feet). The vertical lift-span configuration would have a total of 108 in-water drilled shafts.

This single-level movable-span configuration would have a 3% maximum grade on the Oregon side of the bridge and a 1.5% maximum grade on the Washington side.

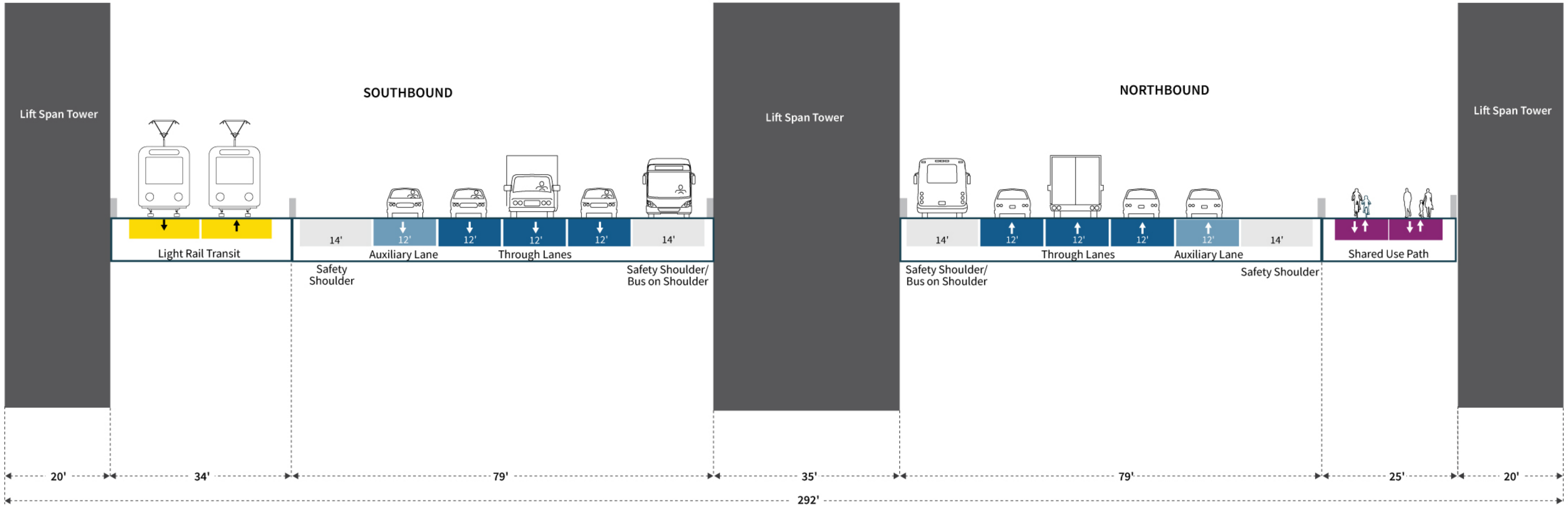
Figure 1-19. Conceptual Drawings of Single-Level Movable-Span Configurations in the Closed and Open Positions



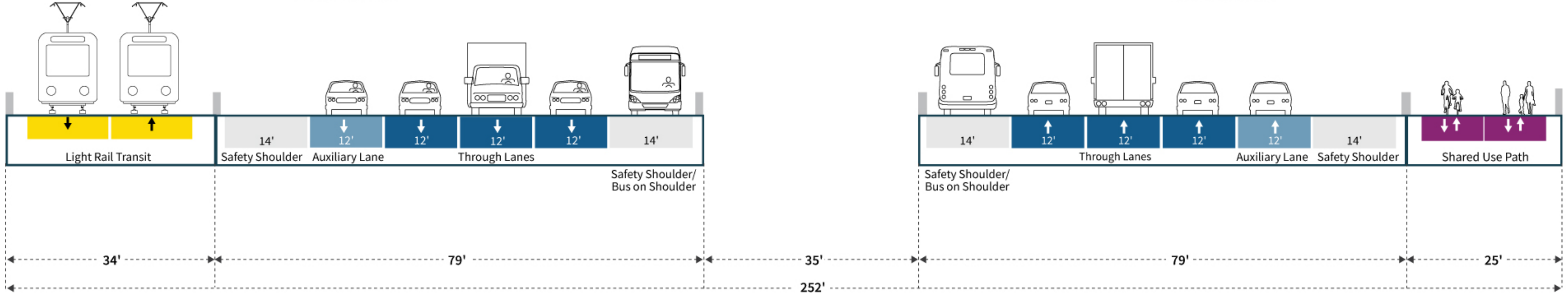
Note: Visualizations are for illustrative purposes only. They do not reflect property impacts or represent final design. Visualization is looking southeast (upstream) from Vancouver.

Figure 1-20. Cross Section of the Single-Level Movable-Span Bridge Type

Single-level Bridge with Movable Span - Vertical Lift Span Cross-section (Piers 5 and 6)



Single-level Bridge with Movable Span - Fixed Spans Cross-section (Piers 2, 3, 4, and 7)



Summary of Bridge Configurations

This section summarizes and compares each of the bridge configurations. Table 1-2 lists the key considerations for each configuration. Figure 1-21 compares each configuration’s footprint. The footprints of each configuration would differ in only three locations: over the Columbia River and at the bridge landings on Hayden Island and Vancouver. The rest of the I-5 corridor would have the same footprint. Over the Columbia River, the footprint of the double-deck fixed-span configuration would be 173 feet wide. Comparatively, the finback or extradosed bridge types of the single-level fixed-span configuration would be 272 feet wide (approximately 99 feet wider), and the single-level fixed-span configuration with a girder bridge type would be 232 feet wide (approximately 59 feet wider). The single-level movable-span configuration would be 252 feet wide (approximately 79 feet wider than the double-deck fixed-span configuration), except at Piers 5 and 6, where larger bridge foundations would require an additional 40 feet of width to support the movable span. The single-level configurations would have a wider footprint at the bridge landings on Hayden Island and Vancouver because transit and active transportation would be located adjacent to the highway, rather than below the highway in the double-deck option.

Figure 1-22 compares the basic profile of each configuration. The lower deck of the double-deck fixed-span and the single-level fixed-span configuration would have similar profiles. The single-level movable-span configuration would have a lower profile than the fixed-span configurations when the span is in the closed position.

Figure 1-21. Bridge Configuration Footprint Comparison

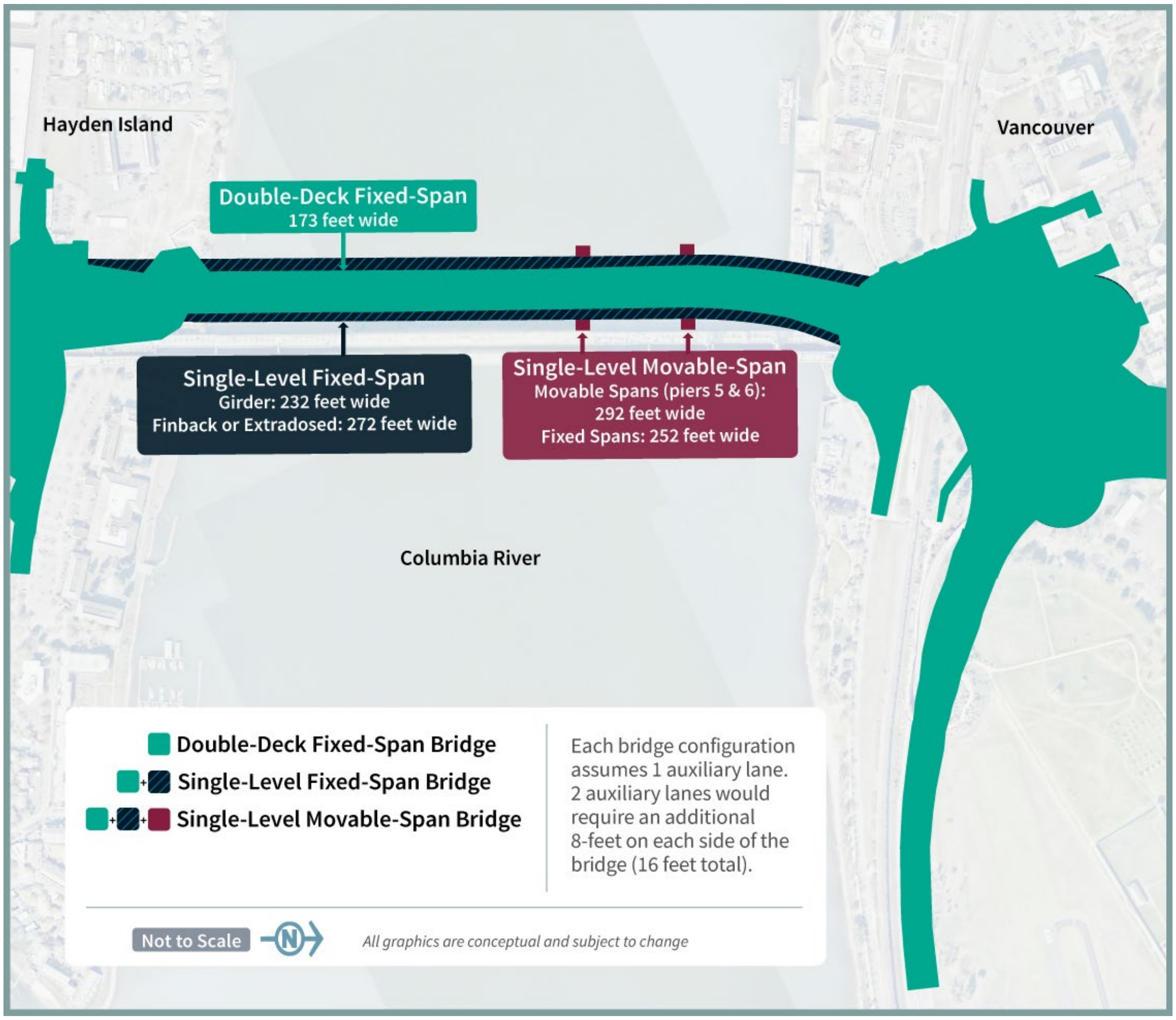
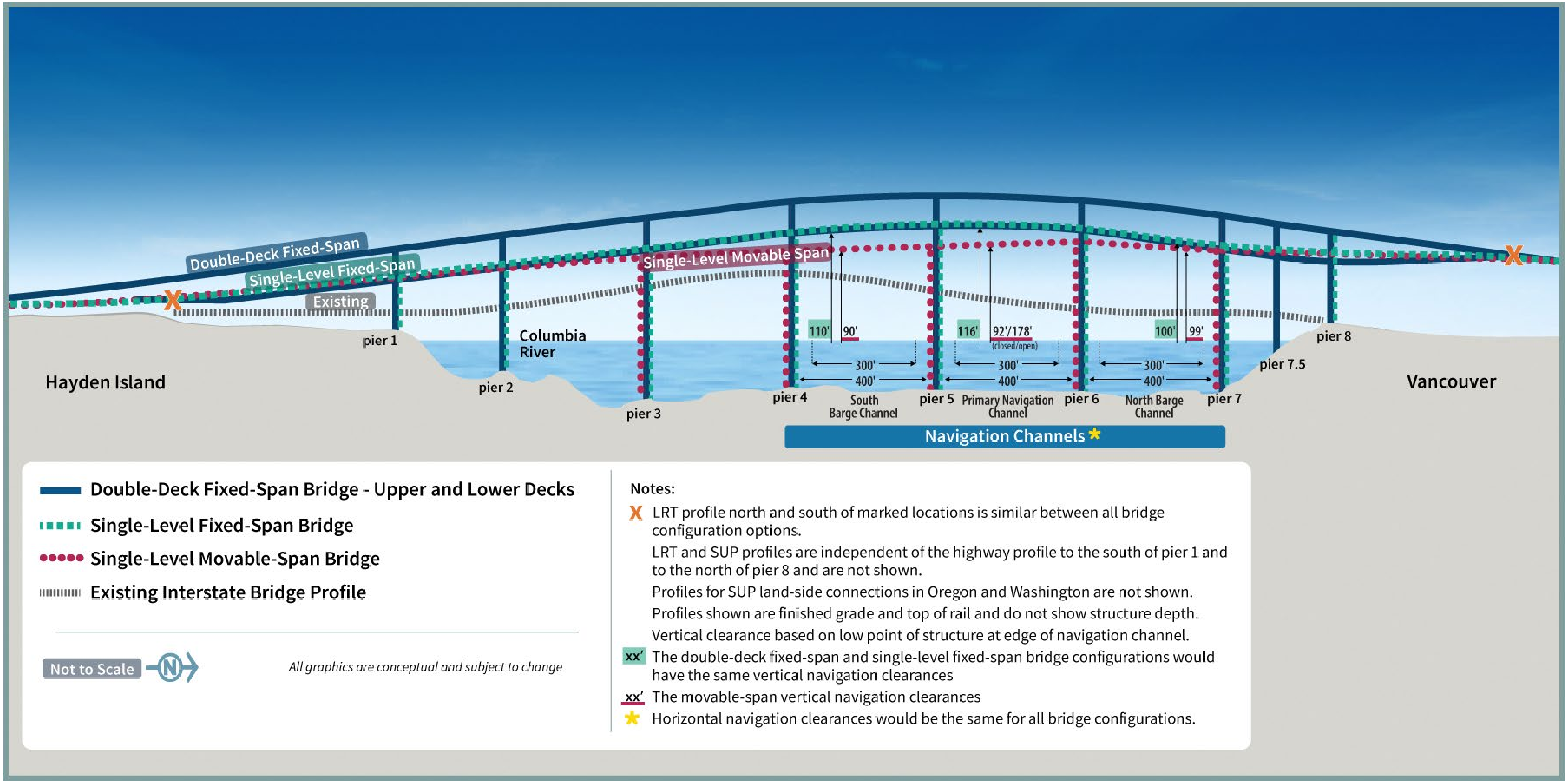


Figure 1-22. Bridge Configuration Profile Comparison



Notes:

X LRT profile north and south of marked locations is similar between all bridge configuration options.

LRT and SUP profiles are independent of the highway profile to the south of pier 1 and to the north of pier 8 and are not shown.

Profiles for SUP land-side connections in Oregon and Washington are not shown.

Profiles shown are finished grade and top of rail and do not show structure depth.

Vertical clearance based on low point of structure at edge of navigation channel.

xx' The double-deck fixed-span and single-level fixed-span bridge configurations would have the same vertical navigation clearances

xx' The movable-span vertical navigation clearances

★ Horizontal navigation clearances would be the same for all bridge configurations.

LRT = light-rail transit; SUP = shared-use path

Table 1-2. Summary of Bridge Configurations

	No-Build Alternative	Modified LPA with Double-Deck Fixed-Span Configuration	Modified LPA with Single-Level Fixed-Span Configuration [a]	Modified LPA with Single-Level Movable-Span Configuration
Bridge type	Steel through-truss spans.	Double-deck steel truss.	Single-level, concrete or steel girders, extradosed or finback.	Single-level, steel girders with vertical lift span.
Number of bridges	Two	Two	Two	Two
Movable-span type	Vertical lift span with counterweights.	N/A	N/A	Vertical lift span with counterweights.
Movable-span location	Adjacent to Vancouver shoreline.	N/A	N/A	Between Piers 5 and 6 (approximately 500 feet south of the existing lift span).
Lift opening restrictions	Weekday peak AM and PM highway travel periods. [b]	N/A	N/A	Additional restrictions to daytime bridge openings; requires future federal rulemaking process and authorization by USCG (beyond the assumed No-Build Alternative bridge restrictions for peak AM and PM highway travel periods).[b] Typical opening durations are assumed to be 9 to 18 minutes [c] for the purposes of impact analysis but would ultimately depend on various operational considerations related to vessel traffic and river and weather conditions. Additional time would also be required to stop traffic prior to opening and restart traffic after the bridge closes.
Out-to-out width [d]	138 feet total width.	173 feet total width.	Girder: 232 feet total width. Extradosed/Finback: 272 feet total width.	• 292 feet at the movable span. • 252 feet at the fixed spans.

	No-Build Alternative	Modified LPA with Double-Deck Fixed-Span Configuration	Modified LPA with Single-Level Fixed-Span Configuration [a]	Modified LPA with Single-Level Movable-Span Configuration
Deck widths	52 feet (SB) 52 feet (NB)	79 feet (SB) 79 feet (NB)	Girder: • 113 feet (SB) • 104 feet (NB) Extradosed/Finback: • 133 feet (SB) • 124 feet (NB)	113 feet SB fixed span. 104 feet NB fixed span.
Vertical navigation clearance	Primary navigation channel: • 39 feet when closed. • 178 feet when open. Barge channel: • 46 feet to 70 feet. Alternate barge channel: • 72 feet (maximum clearance without opening).	Primary navigation channel: • 116 feet maximum. North barge channel: • 100 feet maximum. South barge channel: • 110 feet maximum.	Primary navigation channel: • 116 feet maximum. North barge channel: • 100 feet maximum. South barge channel: • 110 feet maximum.	Primary navigation channel: • Closed position: 92 feet. • Open position: 178 feet. North barge channel: • 99 feet maximum. South barge channel: • 90 feet maximum.
Horizontal navigation clearance	263 feet for primary navigation channel. 511 feet for barge channel. 260 feet for alternate barge channel.	400 feet for all navigation channels (300-foot congressionally or USACE-authorized channel plus a 50-foot channel maintenance buffer on each side).	400 feet for all navigation channels (300-foot congressionally or USACE-authorized channel plus a 50-foot channel maintenance buffer on each side).	400 feet for all navigation channels (300-foot congressionally or USACE-authorized channel plus a 50-foot channel maintenance buffer on each side).
Maximum elevation of bridge component (NAVD 88)[e]	247 feet at top of lift tower.	166 feet.	Girder: 137 feet. Extradosed/Finback: 179 feet at top of pylons.	243 feet at top of lift tower.

	No-Build Alternative	Modified LPA with Double-Deck Fixed-Span Configuration	Modified LPA with Single-Level Fixed-Span Configuration [a]	Modified LPA with Single-Level Movable-Span Configuration
Movable span length (from center of pier to center of pier)	278 feet.	N/A	N/A	450 feet.
Number of in-water pier sets	Nine	Six	Six	Six
Number of in-water drilled shafts	N/A	72	96	108
Shaft cap sizes	N/A	50 feet by 85 feet.	50 feet by 230 feet.	Piers 2, 3, 4, and 7: 50 feet by 230 feet. Piers 5 and 6: 50 feet by 312 feet (one combined footing at each location to house tower/equipment for the lift span).
Maximum grade	5%	4% on the Washington side. 3.8% on the Oregon side.	3% on the Washington side. 3% on the Oregon side.	1.5% on the Washington side. 3% on the Oregon side.
Light-rail transit location	N/A	Below highway on SB bridge.	West of highway on SB bridge.	West of highway on SB bridge.
Express bus	Shared roadway lanes.	Inside shoulder of NB and SB (upper) bridges.	Inside shoulder of NB and SB bridges.	Inside shoulder of NB and SB bridges.

	No-Build Alternative	Modified LPA with Double-Deck Fixed-Span Configuration	Modified LPA with Single-Level Fixed-Span Configuration [a]	Modified LPA with Single-Level Movable-Span Configuration
Shared-use path location	Sidewalk adjacent to roadway in both directions.	Below highway on NB bridge.	East of highway on NB bridge.	East of highway on NB bridge.

a When different bridge types are not mentioned, data applies to all bridge types under the specified bridge configuration.

b The No-Build Alternative assumes existing conditions that restrict bridge openings during weekday peak periods (Monday through Friday 6:30 a.m. to 9 a.m.; 2:30 p.m. to 6 p.m., excluding federal holidays). This analysis estimates the potential frequency for bridge openings for vessels requiring more than 99 feet of clearance.

c For the purposes of the transportation analysis (see the Transportation Technical Report), the movable-span opening time is assumed to be an average of 12 minutes.

d "Out-to-out width" is the measurement between the outside edges of the bridge across its width at the widest point.

e NAVD 88 (North American Vertical Datum of 1988) is a vertical control datum (reference point) used by federal agencies for surveying.

NB = northbound; SB = southbound; USCG = U.S. Coast Guard

1.1.4 Downtown Vancouver (Subarea C)

This section discusses the geographic Subarea C shown in Figure 1-3. See Figure 1-23 for all highway and interchange improvements in Subarea C. Refer to Figure 1-3 for an overview of the geographic subareas.

1.1.4.1 Highways, Interchanges, and Local Roadways

North of the Columbia River bridges in downtown Vancouver, improvements are proposed to the SR 14 interchange (Figure 1-23).

SR 14 INTERCHANGE

The new Columbia River bridges would touch down just north of the SR 14 interchange (Figure 1-23). The function of the SR 14 interchange would remain essentially the same as it is now, although the interchange would be elevated. Direct connections between I-5 and SR 14 would be rebuilt. Access to and from downtown Vancouver would be provided as it is today, but the connection points would be relocated. Downtown Vancouver I-5 access to and from the south would be at C Street as it is today, while downtown connections to and from SR 14 would be from Columbia Street at 3rd Street.

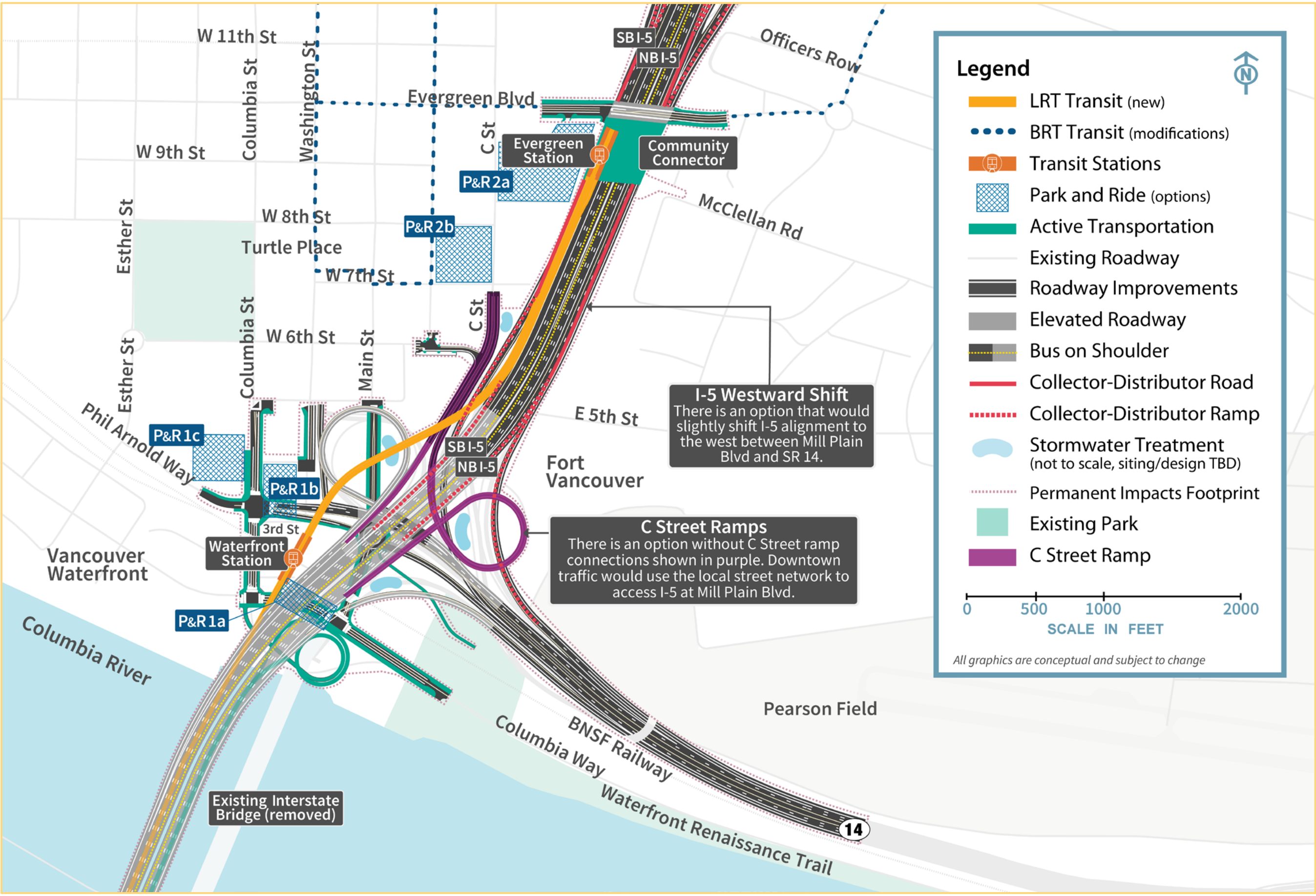
Main Street would be extended between 5th Street and Columbia Way. Vehicles traveling from downtown Vancouver to access SR 14 eastbound would use the new extension of Main Street to the roundabout underneath I-5. If coming from the west or south (waterfront) in downtown Vancouver, vehicles would use the Phil Arnold Way/3rd Street extension to the roundabout, then continue to SR 14 eastbound. The existing Columbia Way roadway under I-5 would be realigned to the north of its existing location and would intersect both the new Main Street extension and Columbia Street with T intersections.

In addition, the existing overcrossing of I-5 at Evergreen Boulevard would be reconstructed.

Design Option Without C Street Ramps

Under this design option, downtown Vancouver I-5 access to and from the south would be through the Mill Plain interchange rather than C Street. There would be no eastside loop ramp from I-5 northbound to C Street and no directional ramp on the west side of I-5 from C Street to I-5 southbound. The existing eastside loop ramp would be removed. This design option has been included because of changes in local planning that necessitate consideration of design options that reduce the footprint and associated direct and temporary environmental impacts in Vancouver.

Figure 1-23. Downtown Vancouver (Subarea C)



I-5 Westward Shift
There is an option that would slightly shift I-5 alignment to the west between Mill Plain Blvd and SR 14.

C Street Ramps
There is an option without C Street ramp connections shown in purple. Downtown traffic would use the local street network to access I-5 at Mill Plain Blvd.

All graphics are conceptual and subject to change

BRT = bus rapid transit; LRT = light-rail transit; NB = northbound; P&R = park and ride; SB = southbound

Design Option to Shift I-5 Westward

This design option would shift the I-5 mainline and ramps approximately 40 feet to the west between SR 14 and Mill Plain Boulevard. The westward I-5 alignment shift could also be paired with the design option without C Street ramps. The inclusion of this design option is due to changes in local planning, which necessitate consideration of design options that that shifts the footprint and associated direct and temporary environmental impacts in Vancouver.

1.1.4.2 Transit

LIGHT-RAIL ALIGNMENT AND STATIONS

Under the Modified LPA, the light-rail tracks would exit the highway bridge and be on their own bridge along the west side of the I-5 mainline after crossing the Columbia River (see Figure 1-23). The light-rail bridge would cross approximately 35 feet over the BNSF Railway tracks. An elevated light-rail station near the Vancouver waterfront (Waterfront Station) would be situated near the overcrossing of the BNSF tracks between Columbia Way and 3rd Street. Access to the elevated station would be primarily by elevator as the station is situated approximately 75 feet above existing ground level. A stairwell(s) would be provided for emergency egress. The number of elevators and stairwells provided would be based on the ultimate platform configuration, station location relative to the BNSF trackway, projected ridership, and fire and life safety requirements. Passenger drop-off facilities would be located at ground level and would be coordinated with the C-TRAN bus service at this location. The elevated light-rail tracks would continue north, cross over the westbound SR 14 on-ramp and the C Street/6th Street on-ramp to southbound I-5, and then straddle the southbound I-5 C-D roadway. Transit components in the downtown Vancouver area are similar between the two SR 14 interchange area design options discussed above.

North of the Waterfront Station, the light-rail tracks would continue to the Evergreen Station, which would be the terminus of the light-rail extension (see Figure 1-23). The light-rail tracks from downtown Vancouver to the terminus would be entirely on an elevated structure supported by single columns, where feasible, or by columns on either side of the roadway where needed. The light-rail tracks would be a minimum of 27 feet above the I-5 roadway surface. The Evergreen Station would be located at the same elevation as Evergreen Boulevard, on the proposed Community Connector, and it would provide connections to C-TRAN's existing BRT system. Passenger drop-off facilities would be near the station and would be coordinated with the C-TRAN bus service at this location.

PARK AND RIDES

Up to two park and rides could be built in Vancouver along the light-rail alignment: one near the Waterfront Station and one near the Evergreen Station. Additional information regarding the park and rides can be found in the Transportation Technical Report.

> Park and rides can expand the catchment area of public transit systems, making transit more accessible to people who live farther away from fixed-route transit service, and attracting new riders who might not have considered using public transit otherwise.

Waterfront Station Park-and-Ride Options

There are three site options for the park and ride near the Waterfront Station (see Figure 1-23). Each would accommodate up to 570 parking spaces.

1. Columbia Way (below I-5). This park-and-ride site would be a multilevel aboveground structure located below the new Columbia River bridges, immediately north of a realigned Columbia Way.
2. Columbia Street/SR 14. This park-and-ride site would be a multilevel aboveground structure located along the east side of Columbia Street. It could span across (or over) the SR 14 westbound off-ramp to provide parking on the north and south sides of the off-ramp.
3. Columbia Street/Phil Arnold Way (Waterfront Gateway Site). This park-and-ride site would be located along the west side of Columbia Street immediately north of Phil Arnold Way. This park and ride would be developed in coordination with the City of Vancouver's Waterfront Gateway program and could be a joint-use parking facility not constructed exclusively for park-and-ride users.

Evergreen Station Park-and-Ride Options

There are two site options for the park and ride near the Evergreen Station (see Figure 1-23).

1. Library Square. This park-and-ride site would be located along the east side of C Street and south of Evergreen Boulevard. It would accommodate up to 700 parking spaces in a multilevel belowground structure according to a future agreement on City-owned property associated with Library Square. Current design concepts suggest the park and ride most likely would be a joint-use parking facility for park-and-ride users and patrons of other uses on the ground or upper levels as negotiated as part of future decisions.
2. Columbia Credit Union. This park-and-ride site is an existing multistory garage that is located below the Columbia Credit Union office tower along the west side of C Street between 7th Street and 8th Street. The existing parking structure currently serves the office tower above it and the Regal City Center across the street. This would be a joint-use parking facility, not for the exclusive use of park-and-ride users, that could serve as additional or overflow parking if the 700 required parking spaces cannot be accommodated elsewhere.

1.1.4.3 Active Transportation

Within the downtown Vancouver area, the shared-use path on the northbound (or eastern) bridge would exit the bridge at the SR 14 interchange, loop down on the east side of I-5 via a vertical spiral path, and then cross back below I-5 to the west side of I-5 to connect to the Waterfront Renaissance Trail on Columbia Street and into Columbia Way (see Figure 1-23). Access would be provided across state right of way beneath the new bridges to provide a connection between the recreational areas along the City's Columbia River waterfront east of the bridges and existing and future waterfront uses west of the bridges.

Active transportation components in the downtown Vancouver area would be similar without the C Street ramps and with the I-5 westward shift.

At Evergreen Boulevard, a community connector is proposed to be built over I-5 just south of Evergreen Boulevard and east of the Evergreen Station (see Figure 1-23). The structure is proposed to include off-street pathways for active transportation modes including pedestrians, bicyclists, and other micro-mobility modes, and public space and amenities to support the active transportation facilities. The primary intent of the Community Connector is to improve connections between downtown Vancouver on the west side of I-5 and the Vancouver National Historic Reserve on the east side.

1.1.5 Upper Vancouver (Subarea D)

This section discusses the geographic Subarea D shown in Figure 1-3. See Figure 1-24 for all highway and interchange improvements in Subarea D. Refer to Figure 1-3 for an overview of the geographic subareas.

1.1.5.1 Highways, Interchanges, and Local Roadways

Within the upper Vancouver area, the IBR Program proposes improvements to three interchanges—Mill Plain, Fourth Plain, and SR 500—as described below.

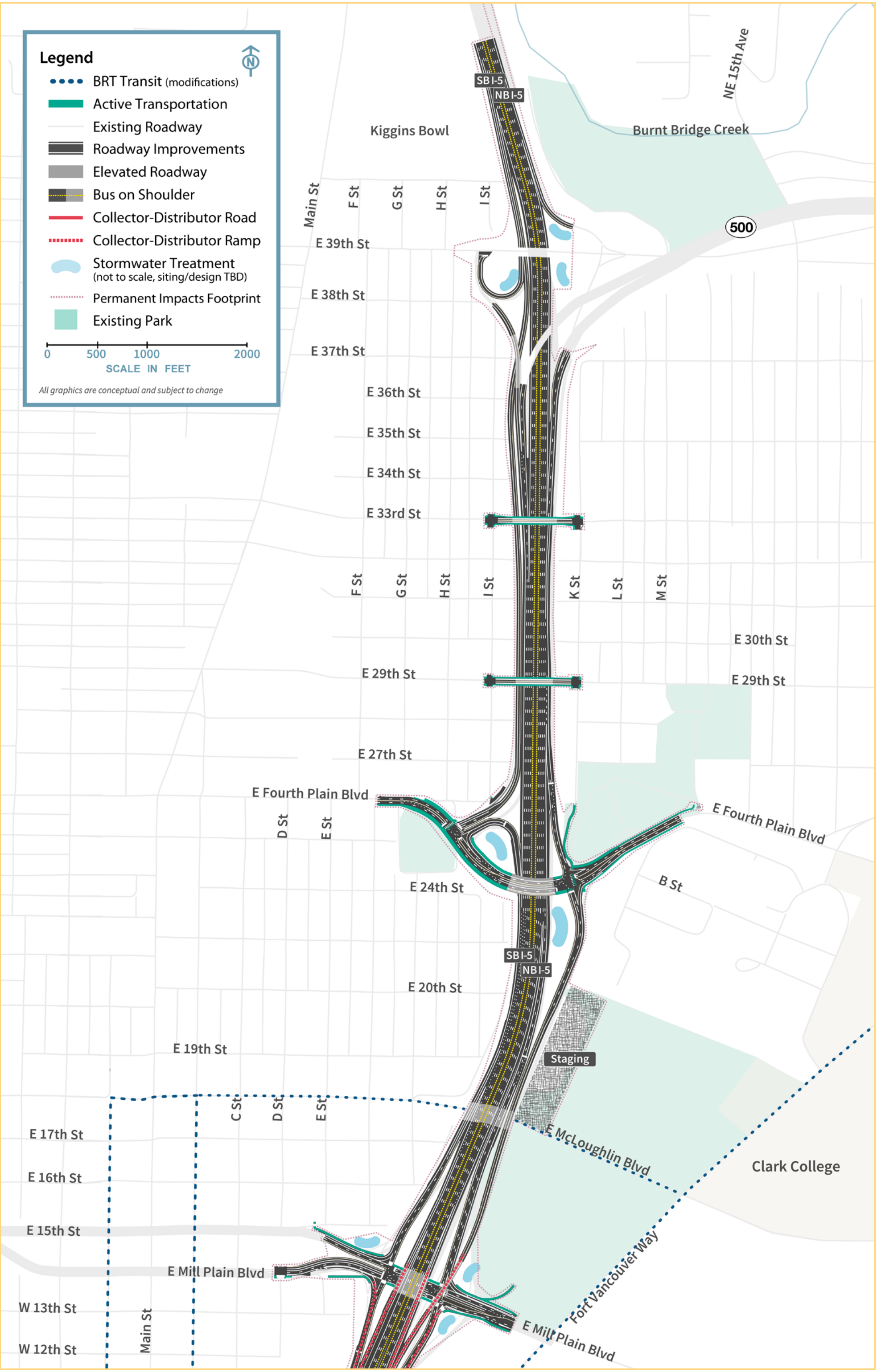
MILL PLAIN BOULEVARD INTERCHANGE

The Mill Plain Boulevard interchange is north of the SR 14 interchange (see Figure 1-24). This interchange would be reconstructed as a tight-diamond configuration but would otherwise remain similar in function to the existing interchange. The ramp terminal intersections would be sized to accommodate high, wide heavy freight vehicles that travel between the Port of Vancouver and I-5. The off-ramp from I-5 northbound to Mill Plain Boulevard would diverge from the C-D road that would continue north, crossing over Mill Plain Boulevard, to provide access to Fourth Plain Boulevard via a C-D roadway. The off-ramp to Fourth Plain Boulevard would be reconstructed and would cross over Mill Plain Boulevard east of I-5, similar to the way it functions today.

FOURTH PLAIN BOULEVARD INTERCHANGE

At the Fourth Plain Boulevard interchange (Figure 1-24), improvements would include reconstruction of the overpass of I-5 and the ramp terminal intersections. Northbound I-5 traffic exiting to Fourth Plain Boulevard would first exit to the northbound C-D roadway which provides off-ramp access to Fourth Plain Boulevard and Mill Plain Boulevard. The westbound SR 14 to northbound I-5 on-ramp also joins the northbound C-D roadway before continuing north past the Fourth Plain Boulevard and Mill Plain Boulevard off-ramps as an auxiliary lane. The southbound I-5 off-ramp to Fourth Plain Boulevard would be braided below the 39th Street on-ramp to southbound I-5. This change would eliminate the existing nonstandard weave between the SR 500 interchange and the off-ramp to Fourth Plain Boulevard. It would also eliminate the existing westbound SR 500 to Fourth Plain Boulevard off-ramp connection. The existing overcrossing of I-5 at 29th Street would be reconstructed to accommodate a widened I-5, provide adequate vertical clearance over I-5, and provide pedestrian and bicycle facilities.

Figure 1-24. Upper Vancouver (Subarea D)



BRT = bus rapid transit; TBD = to be determined

SR 500 INTERCHANGE

The northern terminus of the I-5 improvements would be in the SR 500 interchange area (Figure 1-24). The improvements would primarily be to connect the Modified LPA to existing ramps. The off-ramp from I-5 southbound to 39th Street would be reconstructed to establish the beginning of the braided ramp to Fourth Plain Boulevard and restore the loop ramp to 39th Street. Ramps from existing I-5 northbound to SR 500 eastbound and from 39th Street to I-5 northbound would be partially reconstructed. The existing bridges for 39th Street over I-5 and SR 500 westbound to I-5 southbound would be retained. The 39th Street to I-5 southbound on-ramp would be reconstructed and braided over (i.e., grade separated or pass over) the new I-5 southbound off-ramp to Fourth Plain Boulevard.

The existing overcrossing of I-5 at 33rd Street would also be reconstructed to accommodate a widened I-5, provide adequate vertical clearance over I-5, and provide pedestrian and bicycle facilities.

1.1.5.2 Transit

There would be no LRT facilities in upper Vancouver. Proposed operational changes to bus service, including I-5 bus-on-shoulder service, are described in Section 1.1.7, Transit Operating Characteristics.

1.1.5.3 Active Transportation

Several active transportation improvements would be made in Subarea D consistent with City of Vancouver plans and policies. At the Fourth Plain Boulevard interchange, there would be improvements to provide better bicycle and pedestrian mobility and accessibility; these include bicycle lanes, neighborhood connections, and a connection to the City of Vancouver's planned two-way cycle track on Fourth Plain Boulevard. The reconstructed overcrossings of I-5 at 29th Street and 33rd Street would provide pedestrian and bicycle facilities on those cross streets. No new active transportation facilities are proposed in the SR 500 interchange area. Active transportation improvements at the Mill Plain Boulevard interchange include buffered bicycle lanes and sidewalks, pavement markings, lighting, and signing.

1.1.6 Transit Support Facilities

1.1.6.1 Ruby Junction Maintenance Facility Expansion

The TriMet Ruby Junction Maintenance Facility in Gresham, Oregon, would be expanded to accommodate the additional LRVs associated with the Modified LPA's LRT service (the Ruby Junction location relative to the study area is shown in Figure 1-25). Improvements would include additional storage for LRVs and maintenance materials and supplies, expanded LRV maintenance bays, expanded parking and employee support areas for additional personnel, and a third track at the northern entrance to Ruby Junction. Figure 1-25 shows the proposed footprint of the expansion.

The existing main building would be expanded west to provide additional maintenance bays. To make space for the building expansion, Eleven Mile Avenue would be vacated and would terminate in a new cul-de-sac west of the main building. New access roads would be constructed to maintain access to TriMet buildings south of the cul-de-sac.

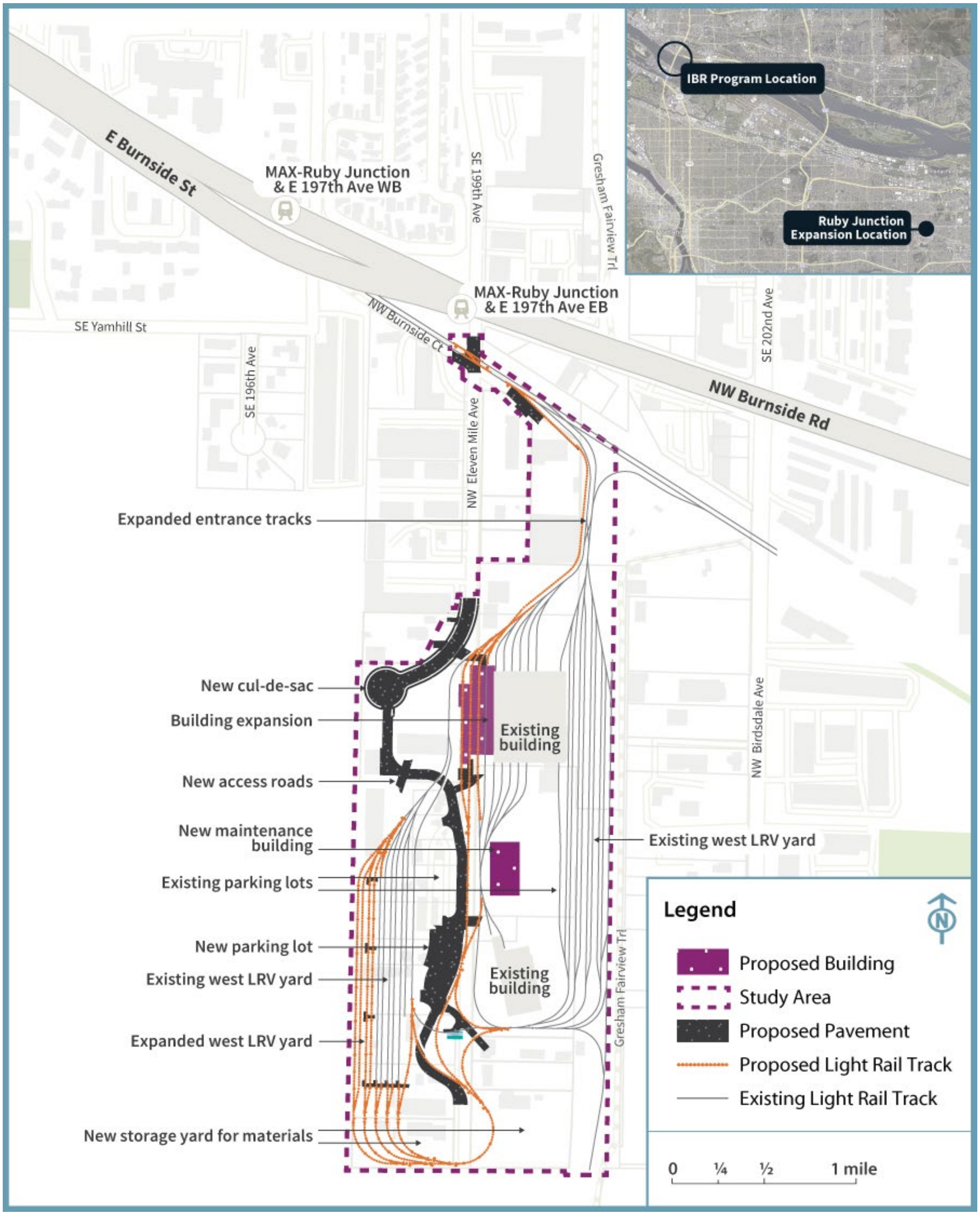
The existing LRV storage yard, west of Eleven Mile Avenue, would be expanded to the west to accommodate additional storage tracks and a runaround track (a track constructed to bypass congestion in the maintenance yard). This expansion would require partial demolition of an existing TriMet building (just north of the LRV storage) and would require relocating the material storage yard to the properties just south of the south building.

All tracks in the west LRV storage yard would also be extended southward to connect to the proposed runaround track. The runaround track would connect to existing tracks near the existing south building. The connections to the runaround track would require partial demolition of an existing TriMet building plus full demolition of one existing building and partial demolition of another existing building on the private property west of the south end of Eleven Mile Avenue. The function of the existing TriMet building would either be transferred to existing modified buildings or to new replacement buildings on site.

The existing parking lot west of Eleven Mile Avenue would be expanded toward the south to provide more parking for TriMet personnel.

A third track would be needed at the north entrance to Ruby Junction to accommodate increased train volumes without decreasing service. The additional track would also reduce operational impacts during construction and maintenance outages for the yard. Constructing the third track would require reconstruction of Burnside Court east of Eleven Mile Avenue. An additional crossover would also be needed on the mainline track where it crosses Eleven Mile Avenue; it would require reconstruction of the existing track crossings for vehicles, bicycles, and pedestrians.

Figure 1-25. Ruby Junction Maintenance Facility Study Area



EB = eastbound; LRV = light-rail vehicle; WB = westbound

1.1.6.2 Expo Center Overnight LRV Facility

An overnight facility for LRVs would be constructed on the southeast corner of the Expo Center property (as shown on Figure 1-8) to reduce deadheading between Ruby Junction and the northern terminus of the MAX Yellow Line extension. Deadheading occurs when LRVs travel without passengers to make the vehicles ready for service. The facility would provide a yard access track, storage tracks for approximately 10 LRVs, one building for light LRV maintenance, an operator break building, a parking lot for operators, and space for security personnel. This facility would necessitate relocation and reconstruction of the Expo Road entrance to the Expo Center (including the parking lot gates and booths). However, it would not affect existing Expo Center buildings.

The overnight facility would connect to the mainline tracks by crossing Expo Road just south of the existing Expo Center MAX Station. The connection tracks would require relocation of one or two existing LRT facilities, including a traction power substation building and potentially the existing communication building, which are both just south of the Expo Center MAX Station. Existing artwork at the station may require relocation.

1.1.6.3 Additional Bus Bays at the C-TRAN Operations and Maintenance Facility

Three bus bays would be added to the C-TRAN operations and maintenance facility. These new bus bays would provide maintenance capacity for the additional express bus service on I-5 (see Section 1.1.7, Transit Operating Characteristics). Modifications to the facility would accommodate new vehicles as well as maintenance equipment.

1.1.7 Transit Operating Characteristics

1.1.7.1 LRT Operations

Nineteen new LRVs would be purchased to operate the extension of the MAX Yellow Line. These vehicles would be similar to those currently used for the TriMet MAX system. With the Modified LPA, LRT service in the new and existing portions of the Yellow Line in 2045 would operate with 6.7-minute average headways (defined as gaps between arriving transit vehicles) during the 2-hour morning peak period. Mid-day and evening headways would be 15 minutes, and late-night headways would be 30 minutes. Service would operate between the hours of approximately 5 a.m. (first southbound train leaving Evergreen Station) and 1 a.m. (last northbound train arriving at the station), which is consistent with current service on the Yellow Line. LRVs would be deadheaded at Evergreen Station before beginning service each day. A third track at this northern terminus would accommodate layovers.

1.1.7.2 Express Bus Service and Bus on Shoulder

C-TRAN provides bus service that connects to LRT and augments travel between Washington and Oregon with express bus service to key employment centers in Oregon. Beginning in 2022, the main express route providing service in the IBR corridor, Route 105, had two service variations. One pattern provides service between Salmon Creek and downtown Portland with a single intermediate stop at the 99th Street Transit Center, and one provides service between Salmon Creek and downtown Portland with two intermediate stops: 99th Street Transit Center and downtown Vancouver. This route currently provides weekday service with 20-minute peak and 60-minute off-peak headways.

Once the Modified LPA is constructed, C-TRAN Route 105 would be revised to provide direct service from the Salmon Creek Park and Ride and 99th Street Transit Center to downtown Portland, operating at 5-minute peak headways with no service in the off-peak. The C-TRAN Route 105 intermediate stop service through downtown Vancouver would be replaced with C-TRAN Route 101, which would provide direct service from downtown Vancouver to downtown Portland at 10-minute peak and 30-minute off-peak headways.

Two other existing C-TRAN express bus service routes would remain unchanged after completion of the Modified LPA. C-TRAN Route 190 would continue to provide service from the Andresen Park and Ride in Vancouver to Marquam Hill in Portland. This route would continue to operate on SR 500 and I-5 within the study area. Route headways would be 10 minutes in the peak periods with no off-peak service. C-TRAN Route 164 would continue to provide service from the Fisher's Landing Transit Center to downtown Portland. This route would continue to operate within the study area only in the northbound direction during PM service to use the I-5 northbound high-occupancy vehicle lane in Oregon before exiting to eastbound SR 14 in Washington. Route headways would be 10 minutes in the peak and 30 minutes in the off-peak.

C-TRAN express bus Routes 105 and 190 are currently permitted to use the existing southbound inside shoulder of I-5 from 99th Street to the Interstate Bridge in Vancouver. However, the existing shoulders are too narrow for bus-on-shoulder use in the rest of the I-5 corridor in the study area. The Modified LPA would include inside shoulders on I-5 that would be wide enough (14 feet on the Columbia River bridges and 11.5 to 12 feet elsewhere on I-5) to allow northbound and southbound buses to operate on the shoulder, except where I-5 would have to taper to match existing inside shoulder widths at the north and south ends of the corridor. Figure 1-8, Figure 1-16, Figure 1-23, and Figure 1-24 show the potential bus-on-shoulder use over the Columbia River bridges. Bus on shoulder could operate on any of the Modified LPA bridge configurations and bridge types. Additional approvals (including a continuing control agreement), in coordination with ODOT, may be needed for buses to operate on the shoulder on the Oregon portion of I-5.

After completion of the Modified LPA, two C-TRAN express bus routes operating on I-5 through the study area would be able to use bus-on-shoulder operations to bypass congestion in the general-purpose lanes. C-TRAN Route 105 would operate on the shoulder for the full length of the study area. C-TRAN Route 190 would operate on the shoulder for the full length of the corridor except for the distance required to merge into and out of the shoulder as the route exits from and to SR 500. These two express bus routes (105 and 190) would have a combined frequency of every 3 minutes during the 2045 AM and PM peak periods. To support the increased frequency of express bus service, eight electric double-decker or articulated buses would be purchased.

If the C Street ramps were removed from the SR 14 interchange, C-TRAN Route 101 could also use bus-on-shoulder operations south of Mill Plain Boulevard; however, if the C Street ramps remained in place, Route 101 could still use bus-on-shoulder operations south of the SR 14 interchange but would need to begin merging over to the C Street exit earlier than if the C Street ramps were removed. Route 101 would operate at 10-minute peak and 30-minute off-peak headways. C-TRAN Route 164 would not be anticipated to use bus-on-shoulder operations because of the need to exit to SR 14 from northbound I-5.

1.1.7.3 Local Bus Route Changes

The TriMet Line 6 bus route would be changed to terminate at the Expo Center MAX Station, requiring passengers to transfer to the new LRT connection to access Hayden Island. TriMet Line 6 is anticipated to travel from Martin Luther King Jr. Boulevard through the newly configured area providing local connections to Marine Drive. It would continue west to the Expo Center MAX Station. Table 1-3 shows existing service and anticipated future changes to TriMet Line 6.

As part of the Modified LPA, several local C-TRAN bus routes would be changed to better complement the new light-rail extension. Most of these changes would reroute existing bus lines to provide a transfer opportunity near the new Evergreen Station. Table 1-3 shows existing service and anticipated future changes to C-TRAN bus routes. In addition to the changes noted in Table 1-3, other local bus route modifications would move service from Broadway to C Street. The changes shown may be somewhat different if the C Street ramps are removed.

Table 1-3. Proposed TriMet and C-TRAN Bus Route Changes

Bus Route	Existing Route	Changes with Modified LPA
TriMet Line 6	Connects Goose Hollow, Portland City Center, N/NE Portland, Jantzen Beach and Hayden Island. Within the study area, service currently runs between Delta Park MAX Station and Hayden Island via I-5.	Route would be revised to terminate at the Expo Center MAX Station. Route is anticipated to travel from Martin Luther King Jr. Boulevard through the newly configured Marine Drive area, then continue west to connect via facilities on the west side of I-5 with the Expo Center MAX Station.
C-TRAN Fourth Plain and Mill Plain bus rapid transit (The Vine)	Runs between downtown Vancouver and the Vancouver Mall Transit Center via Fourth Plain Boulevard, with a second line along Mill Plain Boulevard. In the study area, service currently runs along Washington and Broadway Streets through downtown Vancouver.	Route would be revised to begin/end near the Evergreen Station in downtown Vancouver and provide service along Evergreen Boulevard to Fort Vancouver Way, where it would travel to or from Mill Plain Boulevard or Fourth Plain Boulevard depending on clockwise/counterclockwise operations. The Fourth Plain Boulevard route would continue to serve existing Vine stations beyond Evergreen Boulevard.
C-TRAN #2 Lincoln	Connects the 99th Street Transit Center to downtown Vancouver via Lincoln and Kaufman Avenues. Within the study area, service currently runs along Washington and Broadway Streets between 7th and 15th Streets in downtown Vancouver.	Route would be modified to begin/end near C Street and 9th Street in downtown Vancouver.

Bus Route	Existing Route	Changes with Modified LPA
C-TRAN #25 St. Johns	Connects the 99th Street Transit Center to downtown Vancouver via St. Johns Boulevard and Fort Vancouver Way. Within the study area, service currently runs along Evergreen Boulevard, Jefferson Street/Kaufman Avenue, 15th Street, and Franklin Street in downtown Vancouver.	Route would be modified to begin/end near C Street and 9th Street in downtown Vancouver.
C-TRAN #30 Burton	Connects the Fisher's Landing Transit Center with downtown Vancouver via 164th/162nd Avenues and 18th, 25th, 28th, and 39th Streets. Within the study area, service currently runs along McLoughlin Boulevard and on Washington and Broadway Streets between 8th and 15th Streets.	Route would be modified to begin/end near C Street and 9th Street in downtown Vancouver.
C-TRAN #60 Delta Park Regional	Connects the Delta Park MAX station in Portland with downtown Vancouver via I-5. Within the study area, service currently runs along I-5, Mill Plain Boulevard, and Broadway Street.	Route would be discontinued.

1.1.8 Tolling

Tolling cars and trucks that would use the new Columbia River bridges is proposed as a method to help fund the bridge construction and future maintenance, as well as to encourage alternative mode choices for trips across the Columbia River. Federal and state laws set the authority to toll the I-5 crossing. The IBR Program plans to toll the I-5 river bridge under the federal tolling authorization program codified in 23 U.S. Code Section 129 (Section 129). Section 129 allows public agencies to impose new tolls on federal-aid interstate highways for the reconstruction or replacement of toll-free bridges or tunnels. In 2023, the Washington State Legislature authorized tolling on the Interstate Bridge, with toll rates and policies to be set by the Washington State Transportation Commission (WSTC). In Oregon, the legislature authorized tolling giving the Oregon Transportation Commission the authority to toll I-5, including the ability to set the toll rates and policies. Subsequently, the Oregon Transportation Commission (OTC) is anticipated to review and approve the I-5 tollway project application that would designate the Interstate Bridge as a "tollway project" in 2024. At the beginning of 2024, the OTC and the WSTC entered into a bi-state tolling agreement to establish a cooperative process for setting toll rates and policies. This included the formation of the I-5 Bi-State Tolling Subcommittee consisting of two commissioners each from the OTC and WSTC and tasked with developing toll rate and policy recommendations for joint consideration and adoption by each state's commission. Additionally, the two states plan to enter into a separate agreement guiding the sharing and uses of toll revenues, including the order of uses (flow of funds) for bridge construction, debt service, and other required expenditures. WSDOT and ODOT also plan to enter into one or more agreements addressing implementation logistics, toll collection, and operations and maintenance for tolling the bi-state facility.

The Modified LPA includes a proposal to apply variable tolls on vehicles using the Columbia River bridges with the toll collected electronically in both directions. Tolls would vary by time of day with higher rates during peak travel periods and lower rates during off-peak periods. The IBR Program has evaluated multiple toll scenarios generally following two different variable toll schedules for the tolling assessment. For purposes of this NEPA analysis, the lower toll schedule was analyzed with tolls assumed to range between $1.50 and $3.15 (in 2026 dollars as representative of when tolling would begin) for passenger vehicles with a registered toll payment account. Medium and heavy trucks would be charged a higher toll than passenger vehicles and light trucks. Passenger vehicles and light trucks without a registered toll payment account would pay an additional $2.00 per trip to cover the cost of identifying the vehicle owner from the license plate and invoicing the toll by mail.

The analysis assumes that tolling would commence on the existing Interstate Bridge—referred to as pre-completion tolling—starting April 1, 2026. The actual date pre-completion tolling begins would depend on when construction would begin. The traffic and tolling operations on the new Columbia River bridges were assumed to commence by July 1, 2033. The actual date that traffic and tolling operations on the new bridges begin would depend on the actual construction completion date. During the construction period, the two commissions may consider toll-free travel overnight on the existing Interstate Bridge, as was analyzed in the Level 2 Toll Traffic and Revenue Study, for the hours between 11 p.m. and 5 a.m. This toll-free period could help avoid situations where users would be charged during lane or partial bridge closures where construction delays may apply. Once the new I-5 Columbia River bridges open, twenty-four-hour tolling would begin.

Tolls would be collected using an all-electronic toll collection system using transponder tag readers and license plate cameras mounted to structures over the roadway. Toll collection booths would not be required. Instead, motorists could obtain a transponder tag and set up a payment account that would automatically bill the account holder associated with the transponder each time the vehicle crossed the bridge. Customers without transponders, including out-of-area vehicles, would be tolled by a license plate recognition system that would bill the address of the owner registered to that vehicle’s license plate. The toll system would be designed to be nationally interoperable. Transponders for tolling systems elsewhere in the country could be used to collect tolls on I-5, and drivers with an account and transponder tag associated with the Interstate Bridge could use them to pay tolls in other states for which reciprocity agreements had been developed. There would be new signage, including gantries, to inform drivers of the bridge toll. These signs would be on local roads, I-5 on-ramps, and on I-5, including locations north and south of the bridges where drivers make route decisions (e.g., I-5/I-205 junction and I-5/I-84 junction).

1.1.9 Transportation System- and Demand-Management Measures

Many well-coordinated transportation demand-management and system-management programs are already in place in the Portland-Vancouver metropolitan region. In most cases, the impetus for the programs comes from state regulations: Oregon's Employee Commute Options rule and Washington's Commute Trip Reduction law (described in the sidebar).

The physical and operational elements of the Modified LPA provide the greatest transportation demand-management opportunities by promoting other modes to fulfill more of the travel needs in the corridor. These include:

- Major new light-rail line in exclusive right of way, as well as express bus routes and bus routes that connect to new light-rail stations.
- I-5 inside shoulders that accommodate express buses.
- Modern bicycle and pedestrian facilities that accommodate more bicyclists and pedestrians and improve connectivity, safety, and travel time.
- Park-and-ride facilities.
- A variable toll on the new Columbia River bridges.

In addition to these fundamental elements of the Modified LPA, facilities and equipment would be implemented that could help existing or expanded transportation system management measures maximize the capacity and efficiency of the system. These include:

- Replacement or expanded variable message signs in the study area. These signs alert drivers to incidents and events, allowing them to seek alternate routes or plan to limit travel during periods of congestion.
- Replacement or expanded traveler information systems with additional traffic monitoring equipment and cameras.
- Expanded incident response capabilities, which help traffic congestion to clear more quickly following accidents, spills, or other incidents.
- Queue jumps or bypass lanes for transit vehicles where multilane approaches are provided at ramp signals for on-ramps. Locations for these features will be determined during the detailed design phase.

State Laws to Reduce Commute Trips

Oregon and Washington have both adopted regulations intended to reduce the number of people commuting in single-occupancy vehicles (SOVs). Oregon's Employee Commute Options Program, created under Oregon Administrative Rule 340-242-0010, requires employers with over 100 employees in the greater Portland area to provide commute options that encourage employees to reduce auto trips to the work site. Washington's 1991 Commute Trip Reduction (CTR) Law, updated as the 2006 CTR Efficiency Act (Revised Code of Washington §70.94.521) addresses traffic congestion, air pollution, and petroleum fuel consumption. The law requires counties and cities with the greatest traffic congestion and air pollution to implement plans to reduce SOV demand. An additional provision mandates "major employers" and "employers at major worksites" to implement programs to reduce SOV use.

- Active traffic management including strategies such as ramp metering, dynamic speed limits, and transit signal priority. These strategies are intended to manage congestion by controlling traffic flow or allowing transit vehicles to enter traffic before single-occupant vehicles.

1.2 Modified LPA Construction

The following information on the construction activities and sequence follows the information prepared for the CRC LPA. Construction durations have been updated for the Modified LPA. Because the main elements of the IBR Modified LPA are similar to those in the CRC LPA (i.e., multimodal river crossings and interchange improvements), this information provides a reasonable assumption of the construction activities that would be required.

The construction of bridges over the Columbia River sets the sequencing for other Program components. Accordingly, construction of the Columbia River bridges and immediately adjacent highway connections and improvement elements would be timed early to aid the construction of other components. Demolition of the existing Interstate Bridge would take place after the new Columbia River bridges were opened to traffic.

Electronic tolling infrastructure would be constructed and operational on the existing Interstate Bridge by the start of construction on the new Columbia River bridges. The toll rates and policies for tolling (including pre-completion tolling) would be determined after a more robust analysis and public process by the OTC and WSTC (refer to Section 1.1.8, Tolling).

1.2.1 Construction Components and Duration

Table 1-4 provides the estimated construction durations and additional information of Modified LPA components. The estimated durations are shown as ranges to reflect the potential for Program funding to be phased over time. In addition to funding, contractor schedules, regulatory restrictions on in-water work and river navigation considerations, permits and approvals, weather, materials, and equipment could all influence construction duration and overlap of construction of certain components. Certain work below the ordinary high-water mark of the Columbia River and North Portland Harbor would be restricted to minimize impacts to species listed under the Endangered Species Act and their designated critical habitat.

Throughout construction, active transportation facilities and three lanes in each direction on I-5 (accommodating personal vehicles, freight, and buses) would remain open during peak hours, except for short intermittent restrictions and/or closures. Advanced coordination and public notice would be given for restrictions, intermittent closures, and detours for highway, local roadway, transit, and active transportation users (refer to the Transportation Technical Report, for additional information). At least one navigation channel would remain open throughout construction. Advanced coordination and notice would be given for restrictions or intermittent closures to navigation channels as required.

Table 1-4. Construction Activities and Estimated Duration

Component	Estimated Duration	Notes
Columbia River bridges	4 to 7 years	• Construction is likely to begin with the main river bridges. • General sequence would include initial preparation and installation of foundation piles, shaft caps, pier columns, superstructure, and deck.
North Portland Harbor bridges	4 to 10 years	• Construction duration for North Portland Harbor bridges is estimated to be similar to the duration for Hayden Island interchange construction. The existing North Portland Harbor bridge would be demolished in phases to accommodate traffic during construction of the new bridges.
Hayden Island interchange	4 to 10 years	• Interchange construction duration would not necessarily entail continuous active construction. Hayden Island work could be broken into several contracts, which could spread work over a longer duration.
Marine Drive interchange	4 to 6 years	• Construction would need to be coordinated with construction of the North Portland Harbor bridges.
SR 14 interchange	4 to 6 years	• Interchange would be partially constructed before any traffic could be transferred to the new Columbia River bridges.
Demolition of the existing Interstate Bridge	1.5 to 2 years	• Demolition of the existing Interstate Bridge could begin only after traffic is rerouted to the new Columbia River bridges.
Three interchanges north of SR 14	3 to 4 years for all three	• Construction of these interchanges could be independent from each other and from construction of the Program components to the south. • More aggressive and costly staging could shorten this timeframe.

Component	Estimated Duration	Notes
Light-rail	4 to 6 years	- The light-rail crossing would be built with the Columbia River bridges. Light-rail construction includes all of the infrastructure associated with light-rail transit (e.g., overhead catenary system, tracks, stations, park and rides).
Total construction timeline	9 to 15 years	- Funding, as well as contractor schedules, regulatory restrictions on in-water work and river navigation considerations, permits and approvals, weather, materials, and equipment, could all influence construction duration.

1.2.2 Potential Staging Sites and Casting Yards

Equipment and materials would be staged in the study area throughout construction generally within existing or newly purchased right of way, on land vacated by existing transportation facilities (e.g., I-5 on Hayden Island), or on nearby vacant parcels. However, at least one large site would be required for construction offices, to stage the larger equipment such as cranes, and to store materials such as rebar and aggregate. Criteria for suitable sites include large, open areas for heavy machinery and material storage, waterfront access for barges (either a slip or a dock capable of handling heavy equipment and material) to convey material to the construction zone, and roadway or rail access for landside transportation of materials by truck or train.

Two potential major staging sites have been identified (see Figure 1-8 and Figure 1-23). One site is located on Hayden Island on the west side of I-5. A large portion of this parcel would be required for new right of way for the Modified LPA. The second site is in Vancouver between I-5 and Clark College. Other staging sites may be identified during the design process or by the contractor. Following construction of the Modified LPA, the staging sites could be converted for other uses.

In addition to on-land sites, some staging activities for construction of the new Columbia River and North Portland Harbor bridges would take place on the river itself. Temporary work structures, barges, barge-mounted cranes, derricks, and other construction vessels and equipment would be present on the river during most or all of the bridges' construction period. The IBR Program is working with USACE and USCG to obtain necessary clearances for these activities.

A casting or staging yard could also be required for construction of the overwater bridges if a precast concrete segmental bridge design is used. A casting yard would require access to the river for barges, a slip or a dock capable of handling heavy equipment and material, a large area suitable for a concrete batch plant and associated heavy machinery and equipment, and access to a highway or railway for delivery of materials. As with the staging sites, casting or staging yard sites may be identified as the design progresses or by the contractor and would be evaluated via a NEPA re-evaluation or supplemental NEPA document for potential environmental impacts at that time.

1.3 No-Build Alternative

The No-Build Alternative illustrates how transportation and environmental conditions would likely change by the year 2045 if the Modified LPA is not built. This alternative makes the same assumptions as the Modified LPA regarding population and employment growth through 2045, and it assumes that the same transportation and land use projects in the region would occur as planned.

Regional transportation projects included in the No-Build Alternative are those in the financially constrained 2018 *Regional Transportation Plan* (2018 RTP) adopted in December 2018 by the Metro Council (Metro 2018) and in March 2019 (RTC 2019) by the Southwest Washington Regional Transportation Council (RTC) Board of Directors is referred to as the 2018 RTP in this report. The 2018 RTP has a planning horizon year of 2040 and includes projects from state and local plans necessary to meet transportation needs over this time period; financially constrained means these projects have identified funding sources. The Transportation Technical Report lists the projects included in the financially constrained 2018 RTP.

The implementation of regional and local land use plans is also assumed as part of the No-Build Alternative. For the IBR Program analysis, population and employment assumptions used in the 2018 RTP were updated to 2045 in a manner consistent with regional comprehensive and land use planning. In addition to accounting for added growth, adjustments were made within Portland to reallocate the households and employment based on the most current update to Portland’s comprehensive plan, which was not complete in time for inclusion in the 2018 RTP.

Other projects assumed as part of the No-Build Alternative include major development and infrastructure projects that are in the permitting stage or partway through phased development. These projects are discussed as reasonably foreseeable future actions in the IBR Cumulative Effects Technical Report. They include the Vancouver Waterfront project, Terminal 1 development, the Renaissance Boardwalk, the Waterfront Gateway Project, improvements to the levee system, several restoration and habitat projects, and the Portland Expo Center.

In addition to population and employment growth and the implementation of local and regional plans and projects, the No-Build Alternative assumes that the existing Interstate Bridge would continue to operate as it does today. As the bridge ages, needs for repair and maintenance would potentially increase, and the bridge would continue to be at risk of mechanical failure or damage from a seismic event.

2. METHODS

This section describes the methods and approach that have been used to:

- Identify the study area and relevant laws and regulations.
- Collect relevant data for this analysis, including information on soils, geologic hazards (steep slope areas, landslides, and earthquake-hazard-prone areas), seismic hazards, groundwater, and mineral resources.
- Evaluate the long-term and temporary effects that geologic hazards may have on the Modified LPA. The analysis assessed construction impacts (including erosion and sediment transport, stability, groundwater impacts, settlement, vibration, and staging areas) and potential operation impacts (including seismic hazards, excavation, stability, and settlement).
- Assess potential effects that construction and operation of the Modified LPA may have on mineral and groundwater resources.
- Evaluate the beneficial and adverse impacts of the Modified LPA and possible mitigation measures.

The methods and analysis comply with NEPA and relevant federal, state, and local laws and are based on those developed for the CRC project. Compared to the CRC project's methodology, the methods used for this analysis have been updated for the IBR Program as follows:

- Updated data and information on increased risk for seismicity associated with a potential Cascadia Subduction Zone (CSZ) event.
- Additional consideration for geologic strata in the study area to accommodate new seismic standards.
- Updated assessments of the long-term and temporary effects of geologic hazards on the Modified LPA.
- Updated engineering to address geological and seismic conditions, including new design requirements that the Washington State Department of Transportation (WSDOT) and the Oregon Department of Transportation (ODOT) established in 2020.
- Changes to the design of the CRC project's LPA to develop a Modified LPA, including design options.

2.1 Study Area

Figure 2-1 shows the geology and groundwater study area for the Modified LPA, which includes a 5-mile segment of I-5 (between approximately the I-5/Columbia Boulevard interchange in Oregon and the SR 500 interchange in Washington) and the area around Tri-County Metropolitan Transportation District's (TriMet's) existing Ruby Junction Maintenance Facility in Gresham, Oregon. The study area includes temporary construction easements that would be established directly adjacent to proposed construction areas and the potential locations of larger staging areas and casting yards.

The study area is located within the complex, active geologic region of the Pacific Northwest. The Pacific Northwest region is subject to serious geologic hazards such as earthquakes, floods, and volcanic eruptions that can put people and infrastructure at risk. Bridges, which are vital links in the transportation system, can be especially vulnerable during seismic events. The study area contains specific geologic and groundwater conditions that will influence the design, location, and construction techniques. Understanding relevant geologic and groundwater conditions is critical for ensuring the safety of those who will build and use the infrastructure, reducing or eliminating impacts to natural resources, and minimizing potential schedule delays and cost increases.

2.2 Relevant Laws and Regulations

There are no specific laws or regulations addressing geology, hydrogeology, or geotechnical investigations in the study area. However, generally accepted industry practice has been established by procedure manuals and guidelines published by the Federal Highway Administration (FHWA), WSDOT, and ODOT.

With respect to transportation facilities, the following procedures and guidelines have been established by government agencies to protect the public from the effects of geologic hazards and resulting unsafe conditions:

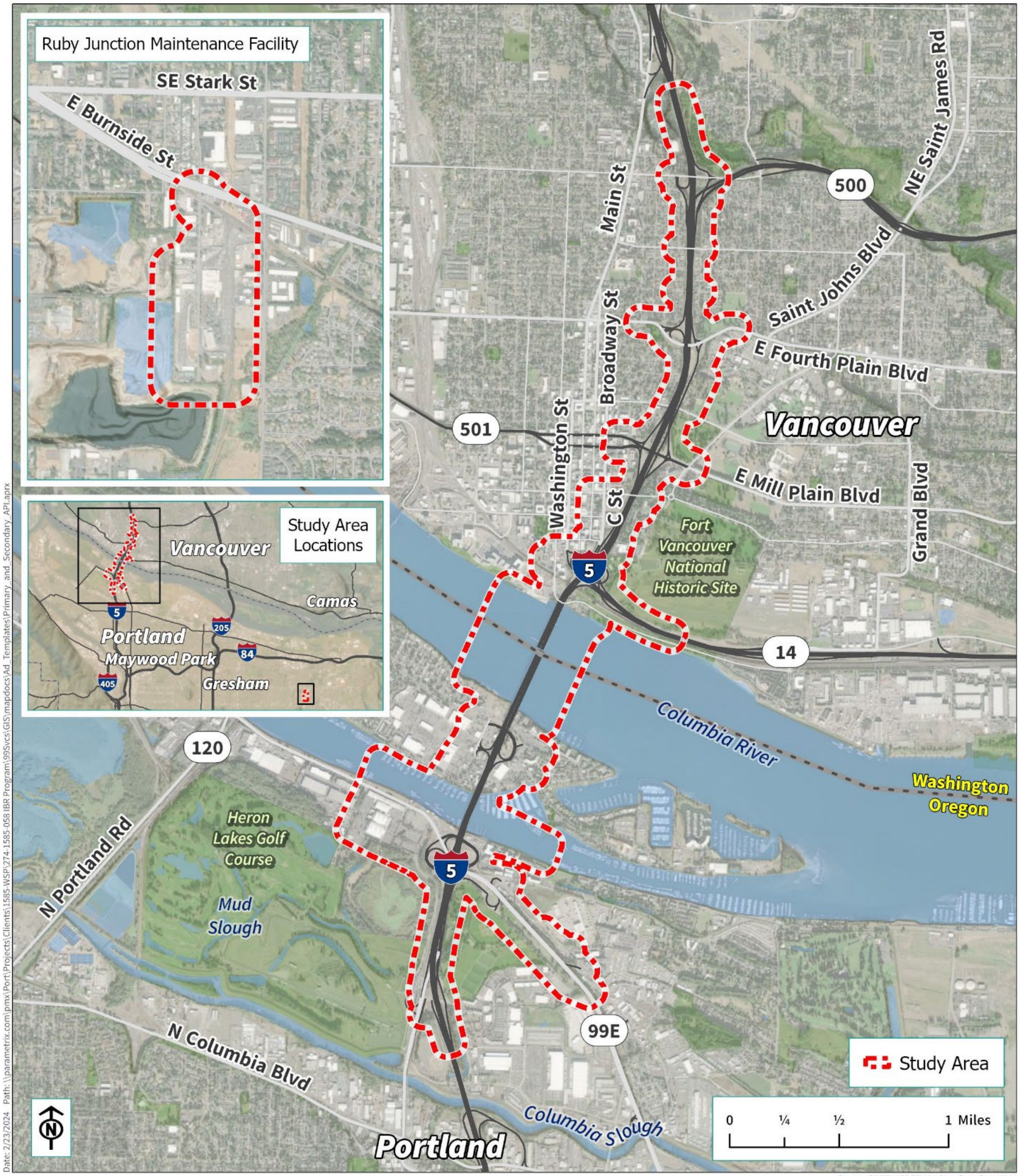
- FHWA, Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications. Publication No. FHWA ED-88-053. August 1988, revised February 2003.
- American Association of State Highway and Transportation Officials (AASHTO) Design Specifications.
- WSDOT, Environmental Procedures Manual M31–11.23, October 2020.
- WSDOT, Geotechnical Design Manual M46-03, December 2020.
- ODOT, Draft Environmental Procedures Manual, May 2002.

Special permits may be required during construction of the Modified LPA. These permits would be related to development and zoning stipulations of federal, state, and local entities. Potential design types were assessed to determine permit requirements.

2.3 Data Sources and Data Collection Methods

This section describes the types of data used in the assessment, data sources, and how the data were collected to complete the evaluation of the Modified LPA.

Figure 2-1. Geology and Groundwater Study Area



Source: ODOT, WSDOT, Mapbox, OpenStreetMap

2.3.1 General Methods

Existing maps and technical reports published by the U.S. Geological Survey, Oregon Department of Geology and Mineral Industries, Washington State Department of Natural Resources Division of Geology and Earth Resources, and Natural Resource Conservation Service were reviewed for pertinent geologic, hydrogeologic, seismic, and soils information.

Data on the geologic units present within the study area were obtained from existing geotechnical reports for the study area and work conducted for the CRC project. Groundwater-level data were collected to address concerns relating to drainage from springs, creek channel stability, seepage, and high or intensely fluctuating groundwater levels.

Because the scientific understanding of the study area's seismic conditions (e.g., proximity, length, and magnitude of earthquake-generating faults) has changed since the CRC project design, this evaluation includes a project-specific seismic design criterion that combined the recommendations of WSDOT and ODOT recurrence intervals. The effects analysis includes consideration of the following for understanding seismic issues for design: depth to rock, risk of liquefaction, lateral spread, surface rupture, and ground motion amplification.

As design progresses, additional field investigations may be required to fill in existing data gaps. The field investigations would be performed to identify geologic hazards (landslides, soft foundation areas, and slope hazards) that may impact elements of the Modified LPA (e.g., roadways, navigation, interchanges, bridges, retaining walls, cut slopes, and fills or embankments).

2.4 Effects Guidelines

The impacts assessment considered how the Modified LPA could expose people or structures to damage, loss, injury, or death. Such impacts could result from severe ground shaking and/or liquefaction associated with a seismic event, construction on expansive soils, and landslides or severe bridge support scouring due to flooding. Another important factor was whether the Modified LPA design contributes to substantial erosion or causes a stable geologic unit to become unstable. The IBR Program adopted the project-specific seismic design criteria and the design of the Modified LPA implemented measures in accordance with WSDOT and ODOT requirements (ODOT 2020; WSDOT 2020).

2.4.1 Long-Term Operational Impacts Approach

Long-term operational impacts were assessed by evaluating the results of previously conducted subsurface investigations in proposed construction areas. The analysis considered how built structures would perform over their expected lifetimes.

2.4.2 Short-Term Construction Impacts Approach

Similar to the long-term impacts assessment methods described above, short-term impacts were assessed by evaluating the results of previously conducted subsurface investigations in proposed construction areas. A preliminary slope stability assessment was conducted for areas of large embankments or where walls are to be built to ensure that stability problems (such as settlement or vibration) do not impact adjacent facilities or wetlands.

2.4.3 Future Geotechnical Investigations

As the design progresses, additional geotechnical investigations would be conducted to inform and quantify the potential long-term operational impacts and the potential short-term construction impacts of existing geologic and hydrogeologic conditions on the Modified LPA. These geotechnical investigations would include drilling activities to evaluate soil samples and ground conditions and preliminary analyses of liquefaction and lateral spreading. If excavations are required (e.g., for bridge footings), a preliminary assessment of dewatering needs may be conducted. Geotechnical investigations, analyses, and recommendations would establish the locations for proposed:

- Cut and fill slopes
- Foundations and retaining walls
- Subsurface drainage
- Pavement
- Material sources

3. AFFECTED ENVIRONMENT

This section presents the existing geologic and hydrogeologic conditions within the study area.

3.1 Climate

The study area is located in a temperate climate where summers are generally warm and dry, with average highs in August of approximately 80° Fahrenheit (F) (27° Celsius [C]) and lows of 58°F (14°C). Winter temperatures can be mild to cold, and very moist, with average highs in January of 46°F (8°C) and lows of 35°F (3°C). Precipitation averages 43.5 inches per year.

3.2 Geologic Setting

The study area is located within the CSZ, a convergent plate boundary system that accommodates 75 to 80 percent of the relative plate motion associated with the subduction of the Juan de Fuca Oceanic Plate descending beneath the North American Continental Plate at 36 to 50 millimeters (1.41 to 1.97 inches) per year. The main plate boundary is located approximately 70 miles off the coast of Northern California, Oregon, and Washington. The oblique convergence of the two tectonic plates has created northwest-trending fault zones and crustal blocks (Baldwin 1976). The major regional structures are shown in Figure 3-1.

Specifically, the study area is located within the Willamette Valley geologic province of Oregon and the Portland Basin geologic province of Washington. The area is characterized as a catch basin (called the Portland Basin) between the Coast Range and the Cascade Mountain Range, through which the Columbia River has carved a channel. The Portland Basin developed in the Neogene Period as a northwest-trending structural basin due to faulting and folding of the underlying Eocene to Miocene basement rocks during the regional tectonic compressional regime (described below). The basin encompasses approximately 1,310 square miles and is characterized by relatively low topographic relief with areas of buttes and valleys containing steep slopes into which deposition has continued through the Holocene (McFarland and Morgan 1996). The basin is bordered to the east by the foothills of the Cascade Mountains, to the west by the Tualatin Mountains, to the south by the Clackamas River, and to the north by the Lewis River. Figure 3-2 shows the topographic relief and major drainages for the Portland Basin.

The same tectonic processes contributed to the formation of the Tualatin Mountains west of the study area, as well as the Portland Basin and Cascade Mountains east of the study area. Sedimentary deposits have filled the topographic depressions created by crustal down-warping of the basin. These sedimentary deposits generally consist of conglomerate, gravel, sand, and silt, with some clay from volcanic, fluvial, and lacustrine material (Pratt et al. 2001). Late Pleistocene catastrophic flood deposits cover much of the study area surface (Waitt 1985; Phillips 1987; Madin 1994). Deposits originating from an ancestral Columbia River underlie the catastrophic flood deposits. These sedimentary deposits then overlie Miocene basalt flows of the Columbia River Basalt Group (CRBG) (Swanson et al. 1993). The CRBG overlies lava flows and volcanic breccias of Oligocene age (Schlicker and Finlayson 1979).

The study area has relatively flat topography, with steeper slopes in the northern portion near Burnt Bridge Creek. The study area and surrounds are underlain by unconsolidated deposits of granular material such as sand, gravel, cobbles, and boulders. Bedrock of volcanic origin is expected at some depth beneath the surface.

3.3 Geologic Units

Geologic units in the study area are shown Figure 3-1. These units are described below by increasing age. Several subsurface investigations were previously conducted for the CRC project to evaluate the subsurface conditions and provide recommendations to support the design type, size, and location (Shannon & Wilson 2008; Parsons Brinckerhoff 2009). Figure 3-4 displays the lithologic contacts based on analysis of these previously completed borings.

3.3.1 Artificial Fill (af)

Artificial fill material was used to modify existing topographic relief and typically consists of sand and silt, with some gravel and debris and local areas of sawdust and mill ends. Fill areas mapped with inferred contacts represent lakes and marshes that may have been drained rather than filled. Fill material ranges in thickness up to 45 feet in Oregon and 25 feet in Washington and is common in developed areas of the Willamette River and Columbia River floodplains. However, thickness and distribution are highly variable (Wells et al. 2020).

3.3.2 Alluvium (Qa)

Alluvial deposits, Holocene in age, include material derived from present day streams and rivers, their floodplains, and abandoned channels. The alluvial deposits are typically Holocene to upper Pleistocene in age. Alluvial material consists of unconsolidated gravel, medium to fine sand, silt, and organic-rich clay. Cobble-sized material may be present within existing or abandoned stream channels. Thickness is typically less than 45 feet but may be up to 150 feet thick locally. Within the study area, alluvium is exposed at the surface from just south of the Columbia Slough in Oregon to approximately 1/4 mile north of the Columbia River in Washington (Phillips 1987; Beeson et al. 1991).

3.3.3 Missoula Flood Deposits (Qf/Qfc)

The fine- and coarse-grained Missoula Flood deposits (Qf and Qfc, respectively) are from the Pleistocene-aged Missoula Floods, which occurred due to the repeated failure of ice dams on the Clark Fork River in northwestern Montana (Bretz et al. 1956). The flood deposits underlie much of Portland and the Tualatin and Willamette Valleys, and form an undulating, low-relief surface (Wells et al. 2020).

The glacial Lake Missoula was formed by ice dams from the advancing front of the Purcell Trench lobe of the Cordilleran ice sheet. The floods released approximately 500 cubic miles of water, flooding portions of eastern Washington, the Columbia Gorge, and the northern Willamette Valley (Bretz et al. 1956; Allen, Burns, and Sargent 1986; Allen, Burns, and Burns 2009). The flooding occurred at least 40 times during the Pleistocene (16,000 to 12,000 years ago), depositing boulders, cobbles, gravel, sand, and silt (Waitt 1985). The largest flows reached stages of about 400 feet above mean sea level (msl) in the Willamette and Tualatin Valleys, leaving exotic, ice-rafted boulders and cobbles stranded on upland slopes (Wells et al. 2020).

As flood water velocities were reduced, sediment loads were deposited in foreset bedded gravel and sand similar to delta deposition (Robinson, Noble, and Carr, Inc. 1980).

Both Qf and Qfc are present in the study area. The finer sediments consist primarily of coarse sand to silt. The coarser sediments consist of pebble to boulder gravel with a coarse sand to silt matrix. Coarse sediments are subangular to well-rounded and are poorly sorted. The unit is exposed at the surface, beginning south of Lombard Street and extending to the southern limit of the study area in Oregon. In Washington, the coarse-grained facies begins north of SR 14 and extends to Burnt Bridge Creek. Qfc deposits are also found to the east in Gresham, where the Ruby Junction Maintenance Facility is located.

3.3.4 Troutdale Formation (Tt)

The Troutdale Formation (Miocene to Pliocene in age) underlies the Missoula Flood deposits and consists of fine- to coarse-grained fluvial sedimentary rock derived from the ancestral Columbia River (Trimble 1963). The unit is a friable to moderately strong conglomerate with minor sandstone, siltstone, and mudstone. Pebbles and cobbles are composed of Columbia River Basalt, exotic volcanic, metamorphic, and plutonic rocks. The matrix and interbeds are composed of feldspathic, quartzo-micaceous, and volcanic lithic and vitric sediments. The formation exhibits cementation mantling on some of the grains. Thickness of the Troutdale Formation typically ranges between 200 and 300 feet in the study area (Beeson et al. 1991) and is present between 100 and 200 feet below the ground surface (Figure 3-4).

3.3.5 Miocene and Older Rocks

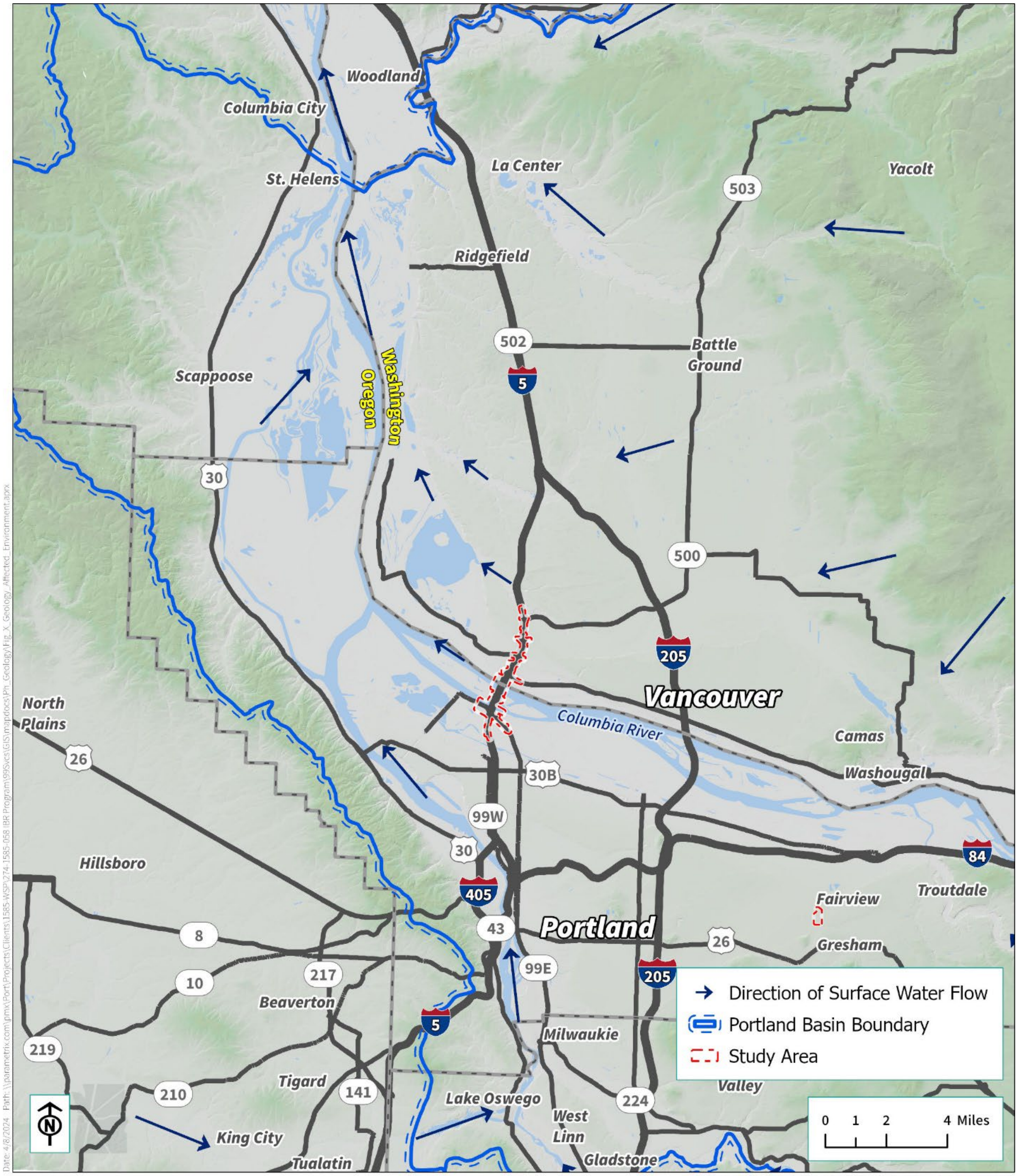
The CRBG (late Miocene and early Pliocene in age) consists of numerous basaltic lava flows, which cover approximately 63,000 square miles and extend to thicknesses greater than 6,000 feet. The CRBG is composed of dark gray to black, variably vesicular, aphyric to sparsely plagioclase-phyric tholeiitic flood basalt and basaltic andesite flows. The flows deposited during the eruption of fissure vents east of the Cascade Range predominantly between 16.7 and 15.9 million years ago (Kasbohm and Schoene 2018). The lava then flowed down an ancestral Columbia River drainage into the Portland area (Wells et al. 2020).

Beneath the CRBG are upper Eocene to lower Miocene volcanic and marine sedimentary rocks. The volcanic rocks typically consist of altered basalt, basaltic andesite, and pyroclastic rocks. The marine sedimentary rocks typically consist of fossiliferous tuffaceous shale and sandstone with minor conglomerate lenses (Madin 1994).

Figure 3-1. Major Regional Structures

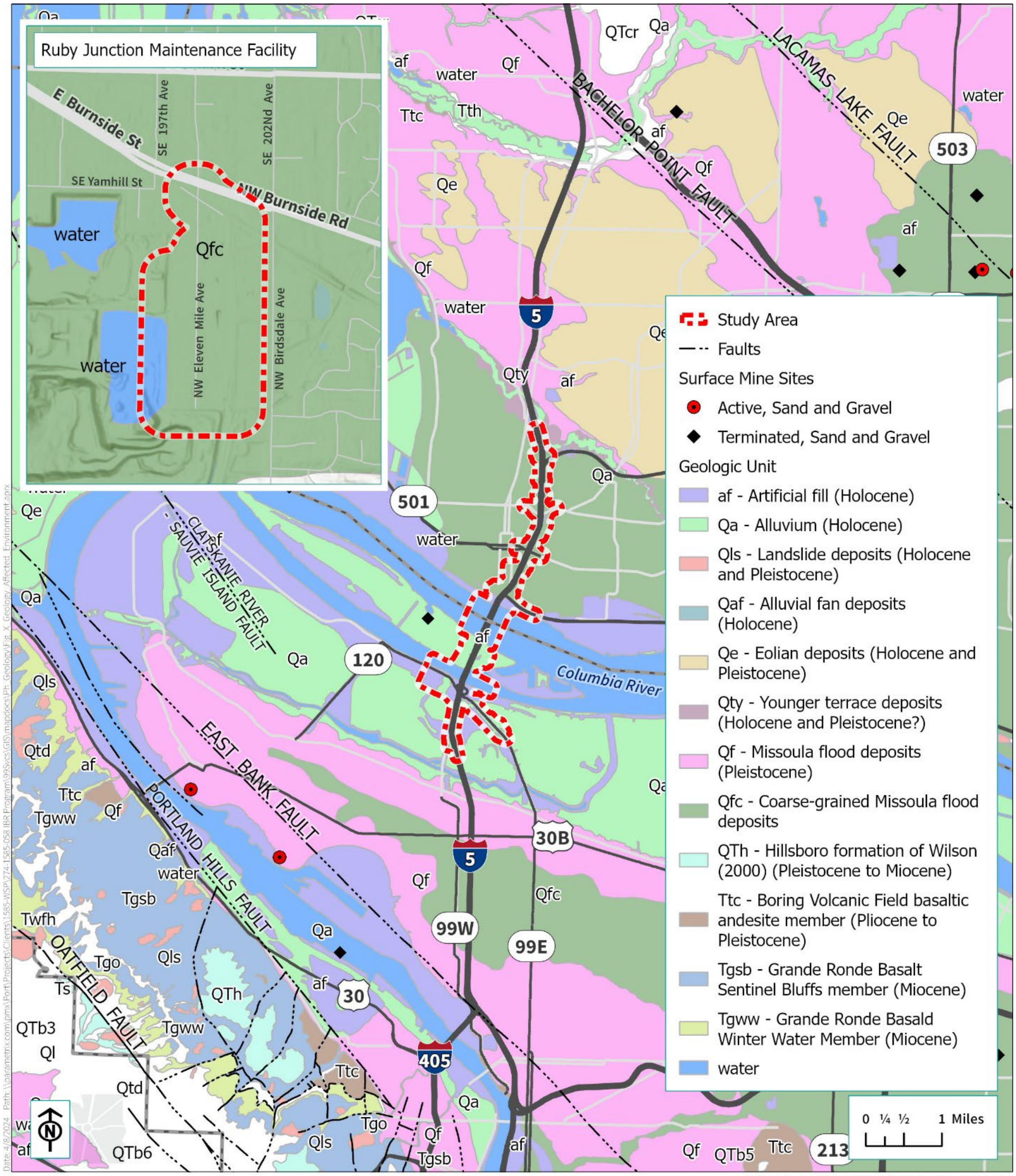
USGS, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

Figure 3-2. Topography and Drainage



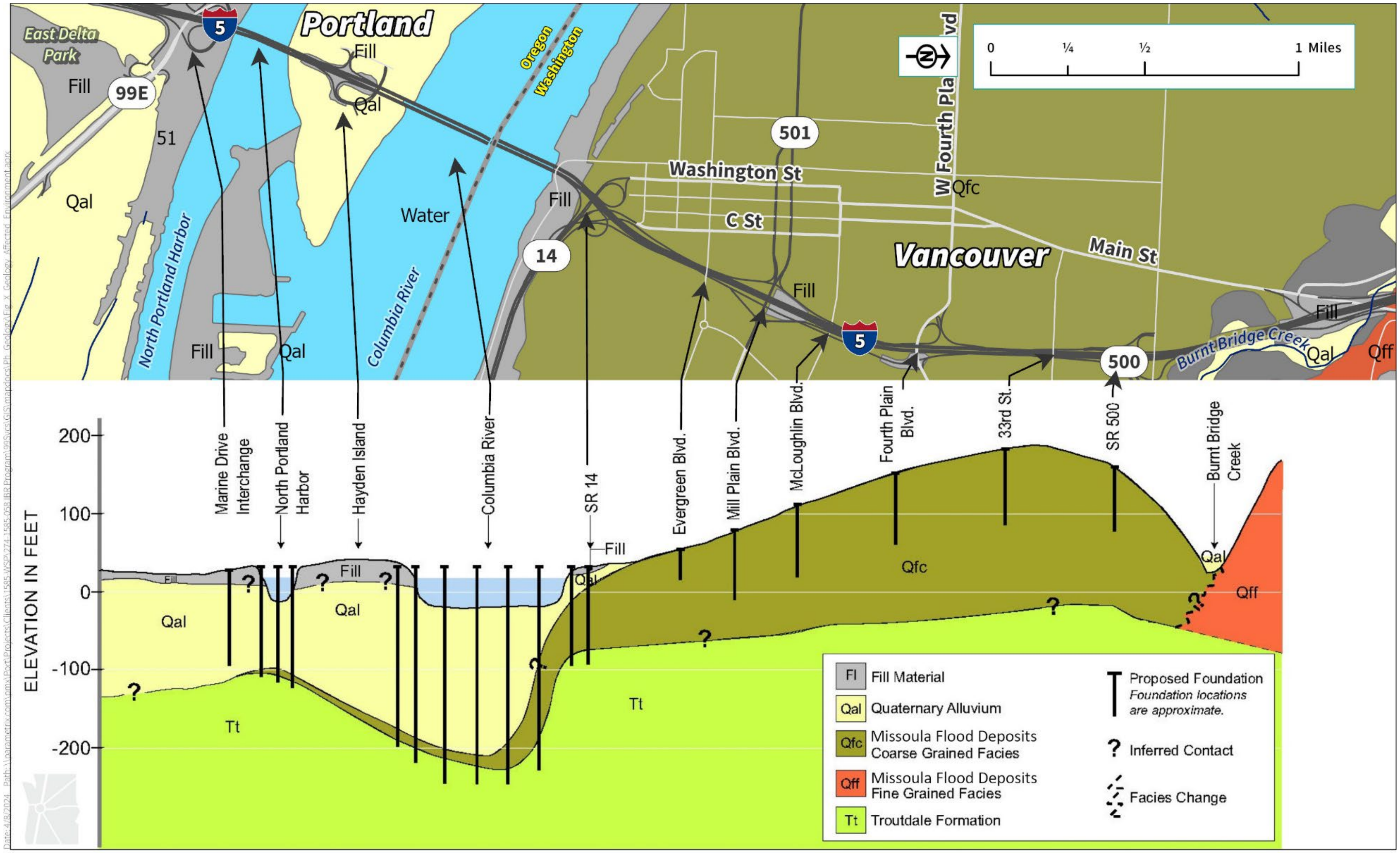
Source: Columbia River Crossing, USGS, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

Figure 3-3. Geologic Units and Crustal Fault Locations



Source: Wells et al. (2020), ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

Figure 3-4. Generalized Schematic Subsurface Profile



Source: Columbia River Crossing, Wells et al. (2020), ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

3.4 Soil

Soil is a general term used to describe the unconsolidated layers of mineral and organic matter that covers most of the earth's land surface. The soil in the study area is formed by the physical and chemical weathering or breakdown of the upper portion of the geologic unit parent material (described in Section 3.3) by interaction with the climate, micro- and macro-organisms, and the characteristics of the parent material (Singer and Munns 1999). The soil types identified at the ground surface in the study area are shown in Figure 3-5.

3.4.1 Natural Resources Conservation Service - Clark County Soil Survey

Based on the Natural Resources Conservation Service (NRCS 1972) information for Clark County, the following soils have been identified in the study area (McGee 1972).

Hillsboro silt loam, 0 to 3 percent slopes (HiA) - This soil is moderately well-drained, the surface runoff is very slow, and the hazard of erosion is none to slight. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil. The shrink-swell potential characteristics require extra design precautions for structures.

Hillsboro silt loam, 3 to 8 percent slopes (HoB) - This soil is well-drained and moderately permeable. Surface runoff is slow and the erosion hazard is slight, but HoB may erode easily if not protected with vegetation or mechanical means. There is a high risk of corrosion to uncoated steel and concrete when placed in this soil. The shrink-swell potential characteristics require extra design precautions for structures.

Lauren gravelly loam, 0 to 8 percent slopes (LgB) - This soil is somewhat excessively drained. Permeability generally is moderately rapid, but it is rapid in the substratum. Surface runoff is slow, and the erosion hazard is slight. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil.

Lauren gravelly loam, 8 to 20 percent slopes (LgD) - This soil is similar to Lauren gravelly loam, 0 to 8 percent slopes, except that the surface layer is 1 to 2 inches thinner. Surface runoff is medium, and the erosion hazard is moderate.

Wind River sandy loam, 0 to 8 percent slopes (WnB) - This soil is somewhat excessively drained and easily tilled. Permeability is moderately rapid in the upper part of the soil, but water tends to perch above a depth of 24 inches. Permeability is rapid in the substratum. Surface runoff is slow, and the hazard of erosion is slight. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil.

Wind River sandy loam, 8 to 20 percent slopes (WnD) - This soil is similar to 0 to 8 percent slopes, except that it is steeper and the surface layer in most places is 1 to 2 inches thinner. Surface runoff is medium, and the hazard of erosion is moderate if the surface is left bare. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil.

Wind River sandy loam, 30 to 65 percent slopes (WnG) - This soil is similar to Wind River sandy loam, 0 to 8 percent slopes, except that the surface layer is 2 to 4 inches thinner. This soil is on slopes that lead into drainage ways and streams. Surface runoff is rapid to very rapid, and the hazard of erosion is severe to very severe if the surface is left bare in winter.

Wind River gravelly loam, 0 to 8 percent slopes (WrB) - This is the dominant soil in the area between Vancouver and Orchards. In most places, the slope is nearly level and is generally less than 3 percent. It is similar to Wind River sandy loam, 0 to 8 percent slopes, except for the texture of the surface layer. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil.

Wind River gravelly loam, 12 to 50 percent slopes (WrF) - This soil is similar to Wind River sandy loam, 0 to 8 percent slopes, except that 15 to 50 percent of it is gravel, and the surface layer is generally 1 to 2 inches thinner. Surface runoff is medium to very rapid, and the hazard of erosion is moderate to very severe.

Sauvie silt loam, 0 to 3 percent slopes (SmA) - This soil is moderately well-drained, surface runoff is very slow, and erosion hazard is slight, but the soil erodes easily if not protected with vegetation or mechanical means. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil. The shrink-swell potential characteristics require extra design precautions for structures.

3.4.2 Natural Resources Conservation Service - Multnomah County Soil Survey

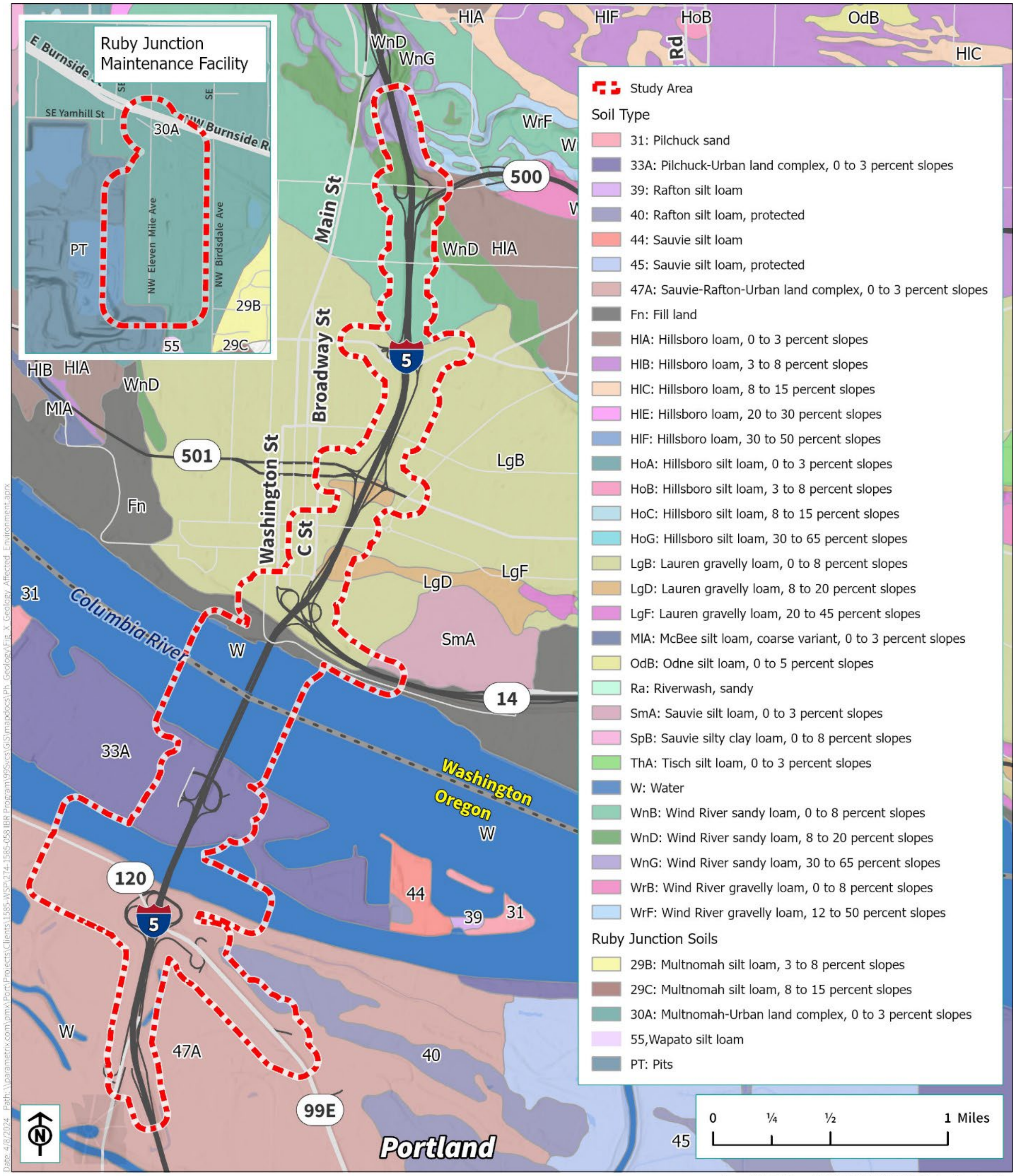
Based on the information in the Multnomah County Soil Survey, the following soils have been identified in the study area (Green 1983).

Multnomah-Urban land complex, 0 to 3 percent slopes (30A) - This complex mainly consists of well-drained Multnomah soils. In most areas of this complex, the soils have been graded, cut, filled, or otherwise disturbed. In areas where the soils are relatively undisturbed, permeability is moderate. In areas dominated by cuts, fills, and urban land, permeability and available water capacity are variable.

Pilchuck-Urban land complex, 0 to 3 percent slopes (33A) - This complex consists of excessively drained soil on floodplains of the Columbia and Willamette Rivers. This soil formed in sandy alluvium or sandy dredge spoils. In most areas of this complex, the soils have been graded, cut, filled, or otherwise disturbed. In areas of undisturbed Pilchuck soils, permeability is very rapid and available water capacity is 3 to 6 inches. The hazard of soil blowing is moderate in areas not protected by vegetative cover.

Rafton silt loam, protected (40) - This hydric soil is very poorly drained and is present on broad flood plains of the Columbia River. It formed in recent alluvium with some mixing of volcanic ash. Permeability is moderate. Runoff is very slow, and the hazard of erosion is slight. The soils are protected from flooding by dikes and levees but are subject to frequent ponding from December to April. The main limitations for urban development are frequent ponding and very poor drainage. These soils have been identified as having hydric soil characteristics. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil.

Figure 3-5. Study Area Soil Types



Source: Web Soil Survey (NRCS), ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

Sauvie-Rafton-Urban land complex, 0 to 3 percent slopes (47A) - This hydric soil consists of poorly drained Sauvie soils and very poorly drained Rafton soils. Large areas of these soils have been filled, graded, cut, or otherwise disturbed. They have been covered by as much as 10 feet of fill material. The fill material is generally transported and consists of soil, as well as concrete, asphalt, and other impervious materials. Permeability is moderately slow in the Sauvie soil. Runoff is slow, and the hazard of erosion is slight. The main limitations of these soils for urban development are the seasonal high-water table and moderately slow permeability. These soils have been identified to have hydric soil characteristics. There is a moderate risk of corrosion to uncoated steel and concrete when placed in this soil.

3.4.3 Potential Construction Issues Due to Soil

The NRCS (2004) has identified 26 different types of soil hazards that typically impact construction projects because they affect the design, installation, and maintenance of many built structures. The following soil hazard types that may contribute to construction issues have been identified in the study area. The locations of these soils are presented on Figure 3-5. A summary of these characteristics is presented in Table 3-1.

Hydric soils, or wet soils, are described as having a groundwater table or perched water that occurs within 1.5 feet of the ground surface. This condition likely occurs during the wetter months of the year. The high-water table creates areas of standing water and can fill excavation sites with water. These soils are mapped throughout much of the study area. Hydric soils in Oregon occur from the Columbia River south to the southern bank of the Columbia Slough in the Rafton silt loam and the Sauvie-Rafton-Urban land complex. In Washington, hydric soils have not been identified within the study area.

Erosion is the detachment and movement of soil particles, primarily by water, down slope. Soils can contain fine-grained material that may be low in density, rendering them more susceptible to erosion when exposed to high velocity flow of water, severe wind conditions, or intense precipitation events. These soil units generally consist of permeable, low-density soils such as young alluvium and other surficial deposits that occur within the study area. The Lauren gravelly loam, 8 to 20 percent slopes; Wind River sandy loam, 8 to 20 percent slopes; Wind River sandy loam, 30 to 65 percent slopes; and Wind River gravelly loam, 12 to 50 percent slopes have been identified in the study area to have moderate to severe erosion hazard.

Shrink-Swell Soils are clay-rich soils that can experience changes in volume of up to 30 percent or more, depending on moisture, clay type and content, and wetting/drying cycles. Foundations placed in expansive soils may lift structures during periods of high moisture and settle during periods of low moisture. Expansive soil will also exert pressure on the vertical face of a foundation or retaining wall, resulting in lateral movement. Hillsboro silt loam, 3 to 8 percent slopes, and Sauvie silt loam, 0 to 3 percent slopes, have been identified as soils possessing some characteristics of shrink-swell soils that may require special consideration during design.

Corrosive soils are soils where soil chemistry, moisture, texture, acidity, and soluble salts are contributing factors that relate to construction materials' susceptibility to corrosion. Concrete and steel structures in soil may degrade more rapidly in corrosive soils. The Hillsboro silt loam 0 to 8 percent slope soil has been identified as having a high risk of corrosion to uncoated steel and concrete when placed in this soil. The Lauren gravelly loam, 0 to 8 percent slopes; Wind River sandy loam, 0 to 8 percent slopes; Wind River sandy loam, 8 to 20 percent slopes; Wind River gravelly loam, 0 to 8 percent slopes; Hillsboro loam, 0 to 3 percent slopes; Sauvie silt loam, 0 to 3 percent slopes; Rafton silt loam, protected; and Sauvie-Rafton-Urban land complex, 0 to 3 percent slopes have been identified as having a high to moderate risk of corrosion to uncoated steel and concrete when placed in these soils.

Table 3-1. Properties of Study Area Soils

Soil Unit	Map Label	USCS	AASHTO	Slopes (%)	Erosion Hazard Rating	Corrosive Rating	Shrink-Swell Issues	Hydric Features
Hillsboro silt loam	HiA	ML, SM	A-2, A-4	0 to 3	Slight	High	Yes	No
Hillsboro silt loam	HoB	ML	A-4	3 to 8	Moderate	High	Yes	No
Lauren gravelly loam	LgB	ML, GM, SM	A-1, A-2, A-4	0 to 8	Slight	Moderate	No	No
Lauren gravelly loam	LgD	ML, GM, SM	A-1, A-2, A-4	8 to 20	Moderate	Moderate	No	No
Wind River sandy loam	WnB	SM	A-1, A-2, A-4	0 to 8	Moderate	Moderate	No	No
Wind River sandy loam	WnD	SM	A-1, A-2, A-4	8 to 20	Severe	Moderate	No	No
Wind River sandy loam	WnG	SM	A-1, A-2, A-4	30 to 65	Severe	Moderate	No	No
Wind River gravelly loam	WrB	SM	A-1, A-2, A-4	0 to 8	Slight	Moderate	No	No
Wind River gravelly loam	WrF	SM	A-1, A-2, A-4	12 to 50	Severe	Moderate	No	No
Sauvie silt loam	SmA	ML, SM	A-4, A-6	0 to 3	Slight	Moderate	Yes	No
Multnomah-Urban Land	30A	SM	A-2	0 to 3	Slight	Moderate	No	No
Pilchuck-Urban land	33A	SM	A-2	0 to 3	Slight	Moderate	No	Yes
Rafton silt loam, protected	40	ML, CL	A-4, A-6	0 to 2	Slight	Moderate	No	Yes
Sauvie-Rafton-Urban land	47A	ML, CL	A-4, A-6	0 to 3	Slight	Moderate	No	Yes

Note: The ratings (slight, fair, moderate, etc.) are as classified by the NRCS (McGee 1972; Green 1983) based on specific criteria determined by NRCS. These ratings do not necessarily reflect the opinions of the IBR Program.

AASHTO = American Association of State Highway and Transportation Officials

NRCS = Natural Resources Conservation Service

USCS = Unified Soil Classification System

3.5 Geologic Resources

A geologic resource is defined as a mineral-bearing rock or other deposit (aggregate) that can be extracted profitably under present economic conditions or a deposit that is not currently recoverable but may eventually become available. Either known deposits that are not recoverable at present or unknown deposits that may be inferred to exist but have not yet been discovered are considered geologic resources. Minerals include soil, coal, clay, stone, sand, gravel, metallic ore, and other solid material or substance excavated for commercial, industrial, or construction use from natural deposits. Aggregate resources are naturally occurring and readily available sand, gravel, and quarry rock resources commonly used in road building or other construction. Figure 3-3 presents the locations of the 33 permitted and active mining operations identified within 10 miles of the study area.

3.5.1 Washington

Active mining operations are not identified in the immediate vicinity of the Modified LPA in Washington (DGER 2008). An inactive gravel deposit of good grade and quality has been identified, but the area appears to be highly developed with residential and commercial properties (Johnson et al. 2005). Twenty-eight active mines have been identified in the state of Washington within 10 miles of the Modified LPA.

3.5.2 Oregon

No active mining operations have been identified within the study area in Oregon. The closest resources to the Modified LPA are sand and gravel pits located along US 30 south of the Portland International Airport, approximately 5 miles southeast (Gray et al. 1978; MLRR 2009). Five active mines have been identified in the state of Oregon within 10 miles of the Modified LPA.

3.6 Hydrogeology

Hydrogeology relates to the occurrence, distribution, and effect of groundwater in the subsurface. Hydrogeologic conditions are critical if there is a potential to contact groundwater during construction. This section presents an overview of the hydrogeologic units in the Portland Basin and describes how these units interact to create the hydrogeologic system in the study area. This section further describes important physical characteristics of the hydrogeologic system, which can be used to identify areas to be excavated during construction where dewatering may be required. This information helps determine the depth of dewatering wells (if needed), pumping rates, and the time frame for depressing the local groundwater table during construction.

3.6.1 Hydrogeologic Units

A hydrogeologic unit is a soil or rock unit that displays distinct properties regarding its ability to store or influence groundwater movement. Within the Portland Basin the designation of the hydrogeologic units closely resembles that of the geologic units. Hydrogeologic units are directly influenced by the environment in which geologic materials were deposited, the type of material, its thickness, and its extent. In general, these physical attributes and their spatial relationships to each other help define the hydrogeologic setting. Detailed descriptions of the hydrogeologic units can be found in Swanson et al. (1993).

Within these hydrogeologic units, in the Vancouver portion of the study area, lies the Environmental Protection Agency–designated Troutdale sole source aquifer (TSSA). Figure 3-6 illustrates a comparison of geologic units and hydrogeologic units for the Portland Basin. The following eight hydrogeologic units are present in the Portland Basin:

- Unconsolidated Sedimentary Aquifer (USA)
- Troutdale Gravel Aquifer (TGA) or Consolidated Gravel Aquifer
- Confining Unit 1 (CU1)
- Troutdale Sandstone Aquifer (TSA)
- Confining Unit 2 (CU2)
- Sand and Gravel Aquifer (SGA)
- Older rocks
- Undifferentiated fine-grained sediments

The eighth unit—undifferentiated fine-grained sediment deposit—occurs in the basin where the TSA and SGA are absent or where there is insufficient information to characterize the aquifer units within the lower Troutdale member. Where this occurs, CU1 and CU2 cannot be separated and are mapped as undifferentiated fine-grained sediments. The older rock subsystem, consisting of older volcanic and marine sedimentary rocks of generally low permeability, is present at depths estimated to range up to 1,600 feet in the central area of the basin. With the exception of lava flows associated with the CRBG, these older rocks are poor aquifers and too deep to be used as a primary source of water in the region. Due to these conditions, no further discussion is presented regarding the older rock units.

The Portland Basin aquifer system can also be grouped into three major subsystems:

- Upper sedimentary subsystem (USA and TGA)
- Lower sedimentary subsystem (CU1, TSA, CU2, and SGA)
- Older rocks

This grouping is based on regionally continuous contacts between units of different lithologic and hydrogeologic characteristics (Swanson et al. 1993). For the purposes of this report, only the upper sedimentary subsystem is described further. This is because the upper sedimentary system is the primary source of groundwater within the Portland-Vancouver area, and aquifers in the lower sedimentary system are confined due to the regional presence of CU1. Proposed subsurface construction activities only pertain to the upper system.

3.6.2 Upper Sedimentary Subsystem

The upper sedimentary subsystem consists of the USA and the underlying TGA. The USA is composed of unconsolidated material associated with the Pleistocene-aged catastrophic flood deposits and Quaternary alluvium deposits. The TGA is composed of unconsolidated, semi-cemented, and/or cemented material associated with the Pleistocene-aged Troutdale Formation.

Both the TGA and the overlying USA are composed of coarse-grained materials, predominantly sands and gravels that can be difficult to differentiate on the basis of drilling conditions and/or the presence of cementation or a sandy matrix. The base of the USA is most commonly identified by the transition to the underlying conglomerate or weathered gravel of the Pleistocene-aged Troutdale Formation. Deposition of the TGA was followed by a period of erosion and subsequent deposition of unconsolidated sediments. The contact between the TGA and the overlying USA is also marked by a permeability contrast, although both aquifers are permeable and productive.

The thickness of the USA in Portland typically is between 50 and 100 feet, with local accumulations of greater than 250 feet (Snyder 2008). The generally high permeability of the USA in Portland varies substantially due to the high degree of heterogeneity of the aquifer materials, which can result in some local areas of perched groundwater. The relatively high permeability TGA also contains large variations (McFarland and Morgan 1996).

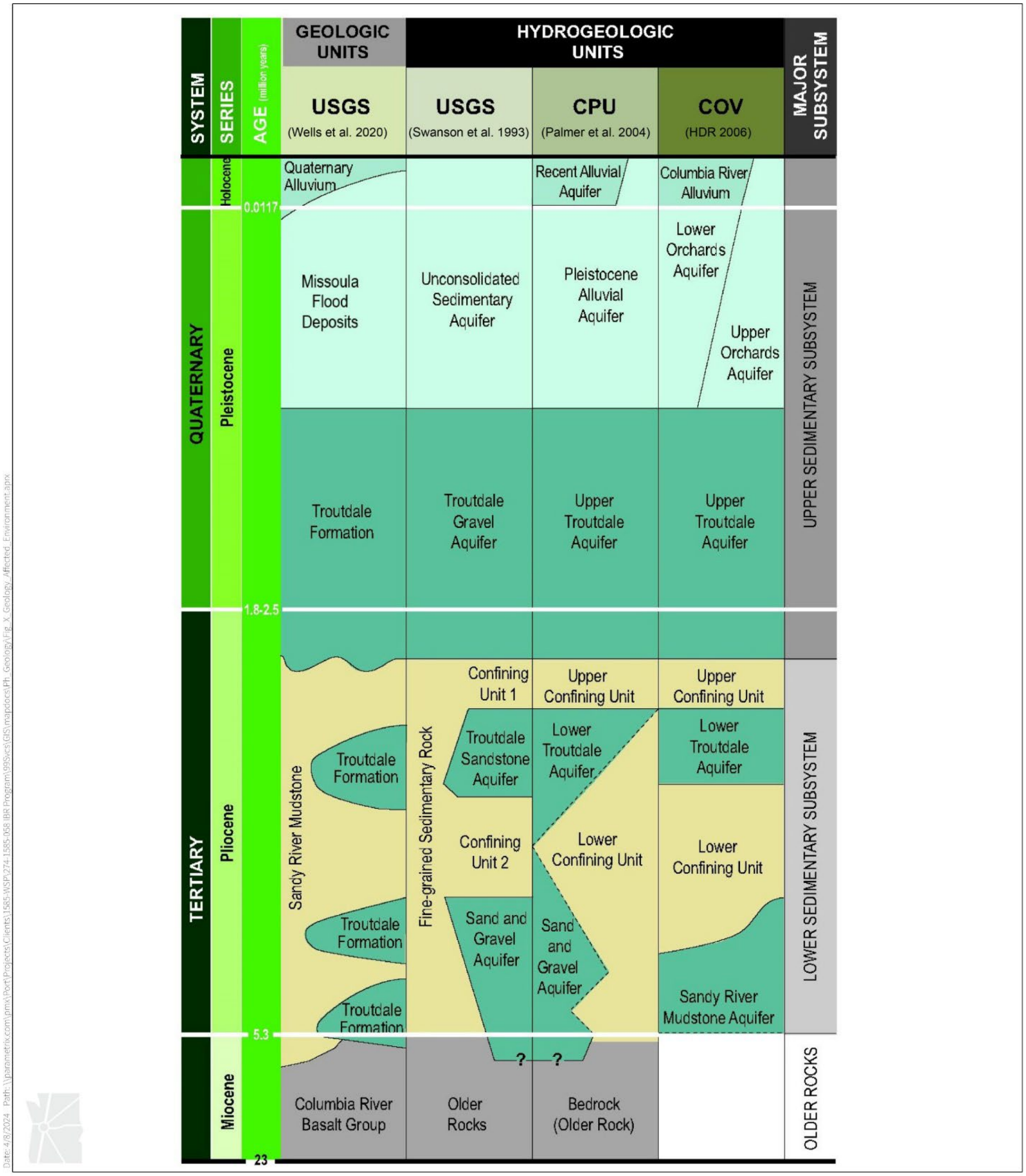
The USA and TGA contain the majority of water supply wells, are the primary aquifers for drinking water, and will continue to be the source of water supply as demands increase. In Clark County, over 90 percent of the 7,111 wells inventoried are completed in the USA or TGA and are less than 300 feet in depth (Gray & Osborne, Inc. 1996). In addition, a majority of municipal water supply wells for the city of Vancouver are completed in the USA (HDR 2006). These aquifers supplied more than 80 percent of groundwater extracted from the Portland area in 1987 to 1988 (Collins and Broad 1993).

Different terminology for the USA has been used in the South Clark County area to further differentiate the unit based on lithology, depositional environment, or groundwater levels. Robinson, Noble and Carr, Inc. (1980) refer to the USA in the South Clark County area as the Orchards Aquifer. They further subdivide this aquifer into upper and lower units based on the separation of the aquifer into two distinct geographic areas with greatly differing water level elevations. The lower Orchards Aquifer has water levels that are near the elevation of the Columbia River, while the upper Orchards Aquifer is described as the part of the Orchards Aquifer with a water level above 50 feet elevation (Robinson, Noble and Carr 1980). The transition zone between the upper and lower aquifers occurs along the northeast side of Vancouver Lake, extends along Burnt Bridge Creek, and continues along the west side of McLoughlin Heights.

3.6.2.1 Hydrogeologic Characteristics of the USA and TGA

Wells completed in the USA have maximum yields between 1,000 and 6,000 gallons per minute (gpm). The most productive area of the USA appears to be in the lower floodplain area of the Columbia River. Wells completed in the consolidated TGA commonly yield up to 1,000 gpm (Swanson et al. 1993).

Figure 3-6. Geologic Units and Comparison of Hydrogeologic Unit Terminology



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Source: DOGAMI, Columbia River Crossing, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

The USA's ability to transmit and yield groundwater is the result of its relatively high intrinsic permeability and saturated thickness (i.e., its transmissivity). Mundorff (1964) estimated that the transmissivity of the lower Orchards Aquifer ranges from 1,900,000 to 3,500,000 gallons per day per foot (gpd/ft), based on aquifer tests completed at the former ALCOA facility located approximately 3 miles west of the Modified LPA. The aquifer tests indicate that the aquifer's transmissivity is fairly uniform throughout the facility's well field. The calculated transmissivities for Vancouver Water Station (WS) 1, WS-3, and WS-4, all producing from the USA, are 2,000,000, 878,900, and 586,000 gpd/ft, respectively (Robinson, Noble, and Carr 1980).

Based on a review of transmissivities calculated for the Vancouver water stations and estimated from reported pump test yields and drawdown, Swanson and Leschuk (1991) assign a hydraulic conductivity of 1,000 feet per day (ft/day) to the lower Orchards Aquifer, and a hydraulic conductivity of 390 ft/day to the upper Orchards Aquifer in the area of Vancouver WS-8, WS-9, WS-14, and WS-15. Swanson and Leschuk (1991) assign a slightly lower hydraulic conductivity value (300 ft/day or 100 ft/day) to the upper Orchards Aquifer in areas where the aquifer thins to less than 40 feet or may be unsaturated due to the rising elevation of the underlying Troutdale Formation.

McFarland and Morgan (1996) assigned storage coefficients to the USA and TGA system based on aquifer tests and published information. The storage coefficients for the USA and the TGA system are 0.003 and 0.0008 (unitless), respectively. Based on specific capacity data, McFarland and Morgan (1996) estimated a median hydraulic conductivity of the USA of 200 ft/day with a range of 0.03 to 70,000 ft/day and the TGA system with a median value of 7 ft/day and range from 0.02 to 1,700 ft/day.

3.6.2.2 Groundwater Recharge and Discharge Areas

Recharge to the USA and TGA occurs from precipitation, infiltration from the Columbia River and streams, infiltration from pervious surfaces, and contributions from drywells and underground sewage disposal. Principal precipitation recharge areas for groundwater in the study area, except for Hayden Island, are the upland areas of the Boring Hills and Western Cascade Mountains (Figure 3-7 and Figure 3-8). Groundwater recharge on Hayden Island is primarily infiltration from the Columbia River. The combined average recharge rate is estimated to be about 22 inches per year (Snyder et al. 1994) for the Portland Basin. The highest rates (up to 49 inches per year) occur in the Cascade Range, and the lowest rates (near 0 inches per year) at the Columbia and Willamette Rivers. Seasonal fluctuations in precipitation affect groundwater elevations and aquifer saturated thickness. Heavy spring and winter precipitation increase groundwater elevation and aquifer saturated thickness, and lower precipitation in the summer and fall months decreases groundwater elevations and aquifer saturated thickness. Changes in groundwater elevations and saturated thickness affect the rate and direction of groundwater discharge. In general, groundwater locally discharges to the Columbia and Willamette Rivers, North Portland Harbor, and Burnt Bridge Creek.

3.6.2.3 Flow Direction and Gradient

The movement of groundwater (flow direction and gradient) is generally controlled by topography, river levels, and supply well pumping. However, due to the high transmissivity of the USA, groundwater gradients in the study area remain relatively flat. Figure 3-7 and Figure 3-8 indicate that groundwater at elevations approximately 250 feet above msl in the Cascade Mountain Range foothills generally flows west toward the Columbia or Willamette River.

The groundwater table elevation along the banks of the Columbia River and North Portland Harbor is influenced by river stage elevation, which is in turn influenced by tidal fluctuations, precipitation events, and upstream dam releases. The rapid response between changes in river stage and corresponding changes in groundwater levels indicates a high interconnectivity between the river, the USA, and the upper portion of the TGA (Parametrix et al. 2008). Groundwater table fluctuations due to river stage changes are less significant with increasing distance from the Columbia River.

WASHINGTON

Groundwater elevations within the study area in Washington are typically less than 50 feet above msl just south of the Burnt Bridge Creek drainage and decrease to approximately 20 feet above msl at the Columbia River. Water level elevations sharply increase north of the Burnt Bridge Creek drainage to approximately 150 feet above msl. The large observed drop in groundwater levels south of Burnt Bridge Creek suggests that low permeability conditions exist in the area of the creek. This lower permeability condition functions to reduce the volume of groundwater recharge to the area south of Burnt Bridge Creek. Groundwater flow direction in Washington is influenced by municipal groundwater pumping, discussed further in Section 3.6.2.4 (Figure 3-8).

OREGON

Groundwater elevation on the Oregon side of the study area generally ranges between 10 and 30 feet above msl. The generalized groundwater levels within the study area are typically less than 20 feet in elevation near the Columbia River and North Portland Harbor. Water level elevations generally increase with distance from the river (McFarland and Morgan 1996; Snyder 2008). Groundwater flow direction in the vicinity of the Marine Drive interchange is generally from south to north, discharging to North Portland Harbor. Based on available information, groundwater flow direction is more difficult to determine on Hayden Island, but likely flows generally from the center of the island toward the Columbia River and North Portland Harbor (Figure 3-7).

3.6.2.4 Influence on Groundwater Flow from Pumping

Groundwater flow in downtown Vancouver is influenced by water supply wells. These wells include Vancouver drinking water supply wells at WS-1 and WS3; the Port of Vancouver (POV) groundwater pump and treat interim action (GPTIA) extraction well, and Great Western Malting Company supply wells No. 4 and No. 5.

Figure 3-9 displays simulated groundwater flow and direction that result from the pumping of these supply wells. Figure 3-9 indicates that most of the groundwater flow in the downtown Vancouver area is influenced by wells at WS-1. No drinking water supply wells are currently used within the Oregon side of the Modified LPA. Therefore, groundwater within the study area in Oregon is not influenced by pumping.

Figure 3-7. Groundwater Elevation Contour Map, Oregon

USGS (2008), City of Portland, the City of Gresham, Clackamas County's Water Environment Services, Multnomah County, and the Oregon Department of Human Services

Figure 3-8. Groundwater Elevation Contour Map, Washington

Clark County

CITY OF VANCOUVER

Vancouver pumps an average of 28.3 million gallons per day (mgd) from the USA, Troutdale, and Sand and Gravel Aquifers, with peak demands up to approximately 61.4 mgd in 2021 (Craney 2022). Vancouver maintains 11 water stations but only extracts groundwater from 10 water stations, each with several production wells (City of Vancouver 2015).

Based on the anticipated population growth for Vancouver, average demand on the water system is estimated to increase 35 mgd by 2034. This increased demand will increase stress to the aquifer. Replacement wells would likely be installed and three decommissioned at WS-1. Extraction rates for city water supply wells vary seasonally based on user demand. Water demands on the system are highest during the summer and lowest during the winter (Craney 2022).

Water Station 1

WS-1, located on East Fourth Plain Boulevard in Waterworks Park, is the largest water station in Vancouver's water system. There are 12 wells at WS-1, all of which tap the lower Orchards Aquifer. A large air stripping treatment facility is located at WS-1 to remove volatile organic compounds (more specifically, tetrachloroethylene) from water produced at the wells. The wells at WS-1 have an annual reliable well capacity of 18.6 mgd (City of Vancouver 2022).

Water Station 3

WS-3, located along Northwest Washington Street at Northwest 43rd Street, has three wells that tap the lower Orchards Aquifer. The annual reliable well capacity of WS-3 is 8.9 mgd (City of Vancouver 2022).

PORT OF VANCOUVER

Design and placement of the POV GPTIA extraction well is based on a groundwater flow model developed through a combined effort completed on behalf of the POV and Clark Public Utilities (Parametrix et al. 2008). The well was installed to remove and hydraulically control solvent-contaminated groundwater. Start-up of the well occurred in June 2009, pumping at a rate of 2,500 gpm (3.6 mgd) on a continuous basis. Groundwater from the well is treated using air stripping towers. Since 2009, the system has removed 12.8 billion gallons of water, significantly reducing the solvent-contaminated groundwater plume.

Based on the anticipated population growth for Vancouver, average demand on the water system is estimated to increase between approximately 34 and 38 mgd by 2034. This increase in demand will increase stress to the aquifer. Replacement wells would likely be installed and three decommissioned at WS-1. Extraction rates for city water supply wells vary seasonally based on user demand. Water demands on the system are highest during the summer and lowest during the winter (Craney 2022).

GREAT WESTERN MALTING COMPANY

Great Western Malting Company currently operates two production wells, No. 4 and No. 5, which influence groundwater flow in the western portion of downtown Vancouver. Groundwater from the wells is treated using an air stripper tower. Treated water is used for germination of malt and as process water for cooling. The wells are capable of producing 4,000 gpm but are currently extracting water at a combined rate of 3,600 gpm (5.2 mgd).

3.7 Current and Future Groundwater Beneficial Use Survey

The purpose of a groundwater beneficial use survey is to identify the current use of groundwater in the vicinity of the Modified LPA. A review of available well information identified approximately 73 potential wells in Washington and 49 in Oregon within 1 mile of the Modified LPA. Figure 3-9 displays the locations and source information of identified supply wells in the vicinity of the study area.

3.7.1 Oregon

The city of Portland primarily uses Bull Run watershed surface water for domestic drinking water supply. The Bull Run watershed is a 102-square-mile municipal watershed located about 26 miles east of downtown Portland and is within the Mount Hood National Forest. Rain provides 90 to 95 percent of the water in the watershed, averaging 130 inches a year. Occasionally, groundwater from the Columbia South Shore Well Field east of the Portland International Airport augments drinking water supply in summer and early fall as needed, depending on Bull Run water supply or when winter storms increase the turbidity above acceptable levels. The well field extracts groundwater primarily from the lower sedimentary groundwater system that consists of the TSA and SGA (Portland Water Bureau 2020).

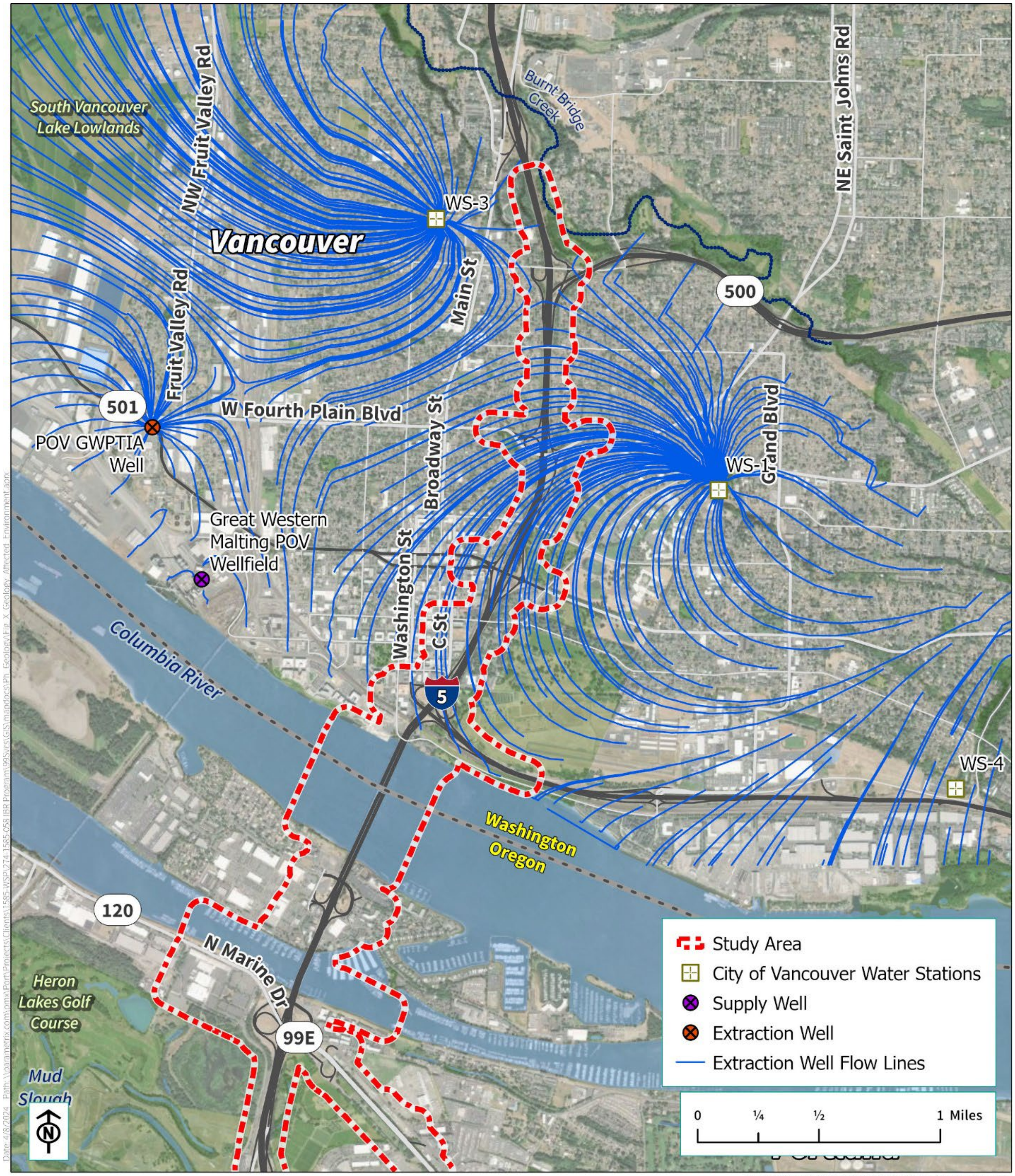
3.7.2 Washington

The city of Vancouver relies on groundwater extracted from the USA, TGA, and SGA for its domestic water supply. The city of Vancouver pumps an average of 28 mgd from the aquifers, with peak demands up to approximately 61 mgd in 2021. Vancouver extracts groundwater from 10 water stations, each with several production wells. The service area of the city of Vancouver water supply system is primarily within the city limits, with some service extending beyond the northeast city limit boundary. The area north of the city, and most of Clark County, is served by Clark Public Utilities, which uses wells located throughout its service area. Based on Vancouver’s anticipated population growth, demand on the water system was estimated to increase to between 34 and 38 mgd by 2034 (City of Vancouver 2015). These increases in demand will add stress to the aquifer.

SOLE SOURCE AQUIFER DESIGNATION AND CRITICAL AQUIFER RECHARGE AREA

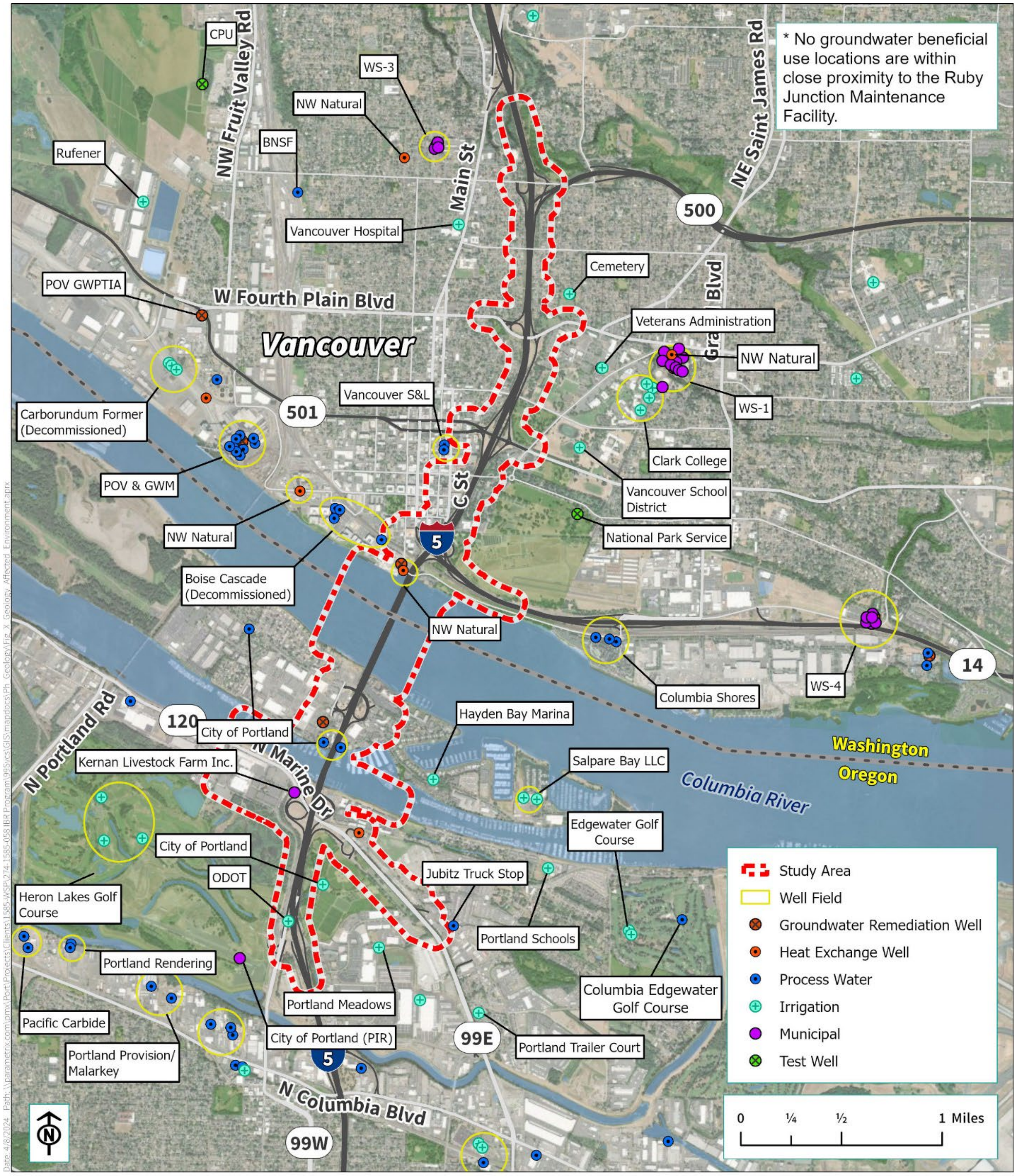
The U.S. Environmental Protection Agency (EPA) designated the Troutdale Aquifer System, Clark County, Washington, as a sole source aquifer in July 2006 (EPA 2006). A sole source aquifer is defined as “an aquifer or aquifer system which supplies at least 50 percent of the drinking water consumed to the area overlying the aquifer and for which there is no alternative source or combination of drinking water sources which could physically, legally and economically act to supply those dependent upon the aquifer” (EPA 2006).

Figure 3-9. Extraction Well Simulated Flow Path Map (City of Vancouver)



Source: Parametrix (2008), ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

Figure 3-10. Groundwater Beneficial Use Locations



Source: Columbia River Crossing, City of Vancouver, City of Portland, USGS ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

Prior to the EPA's designation of the Troutdale Aquifer System as a sole source aquifer, the City of Vancouver recognized its dependence on the aquifer and the importance of protecting the resource. The City of Vancouver has designated the entire area within the city boundaries as a Critical Aquifer Recharge Area as specified the Water Resources Protection Ordinance Vancouver Municipal Code (VMC) Title 14 Section 26, dated 2002 (VMC 14.26). The ordinance requires minimum standards to protect the critical aquifer, establishes compliance standards for business and industry to manage hazardous materials, and creates special protection areas around city well heads. Special protection areas are defined as areas that are 1,900 radial feet from a municipal water supply well. The City of Vancouver applies development restrictions to activities inside the special protection areas, pursuant to VMC 14.26.135. These restrictions mainly address Class I and II Operations, septic systems, and infiltration systems.

3.8 Groundwater Quality

Contaminants from commercial and industrial activities in Vancouver and Portland have resulted in areas of diminished groundwater quality. Information available from the Oregon Department of Environmental Quality (https://www.oregon.gov/deq/hazards-and-cleanup/env-cleanup/pages/ecsi.aspx) and Washington Department of Ecology (https://ecology.wa.gov/Spills-Cleanup/Contamination-cleanup/Cleanup-sites) indicates that contaminants such as chlorinated solvents, petroleum products, and metals are found in groundwater at various locations in the study area.

As stipulated in the Safe Drinking Water Act and Washington Administrative Code Chapter 290, suppliers of drinking water must monitor for and meet primary and secondary drinking water standards. Beginning in approximately January 1979, the City of Vancouver has sampled and analyzed groundwater from its wells for the following classes of compounds: inorganics, volatile organic compounds, herbicides, pesticides, insecticides, radionuclides, fumigants, dioxins, and nitrate. Analytical results for all Vancouver water stations are tabulated at: http://https://fortress.wa.gov/doh/eh/portal/odw/si/SingleSystemViews/SourceSingleSys.aspxwww4.doh.wa.gov/SentryInternet/SingleSystemViews/SamplesSingleSys.aspx.

A review of water quality data by the Washington State Department of Health indicates that no analytes have been detected at or above their respective maximum contaminant limits or secondary maximum contaminant limits in groundwater at WS-1 at any City of Vancouver water stations, since remediation of tetrachloroethylene from its discovery in the 1980s.

3.9 Geologic Hazards

Geologic hazards are natural geologic processes that can create environmental conditions that endanger human lives and threaten property. Geologic hazards include steep slopes, landslides, ground settlement, earthquakes, and volcanoes, as discussed below.

3.9.1 Steep Slopes, Soil Erosion, and Landslides

Steep slope hazard areas are areas with slopes equal to or greater than 25 percent. These areas have the potential to experience slope instability, soil erosion, and uncontrolled stormwater runoff.

No landslides have been mapped in the study area. However, outside of the study area one landslide is mapped along the north slope of Burnt Bridge Creek approximately 2 miles northwest of the SR 500 interchange, and two landslides are located on the north slope of Salmon Creek west of I-5. These mapped landslides, which are not expected to impact the Modified LPA, are within the fine-grained facies of the catastrophic flood deposits and are bordered by slopes that exceed 25 percent.

The steep slopes found within the Burnt Bridge Creek area have landslide potential, particularly during a significant earthquake event (Figure 3-11). In addition, soils with moderate to very severe erosion potential have been identified on the steep slopes along Burnt Bridge Creek. Additional steep slopes exhibiting a moderate to high landslide hazard are identified on Oregon Department of Geology and Mineral Industries mapping along the entire current I-5 corridor south of the Columbia River (Figure 3-12). These areas appear to be the slopes immediately adjacent to I-5 where it is elevated on an embankment. These slopes are presumably composed of engineered and compacted fills.

The Ruby Junction Maintenance Facility site itself is relatively flat; however, it is bound to the west and south by a gravel pit with some steep slopes in the bordering property. Some of the pits are now apparently closed and are flooded. These slopes are not expected to be impacted by the planned work.

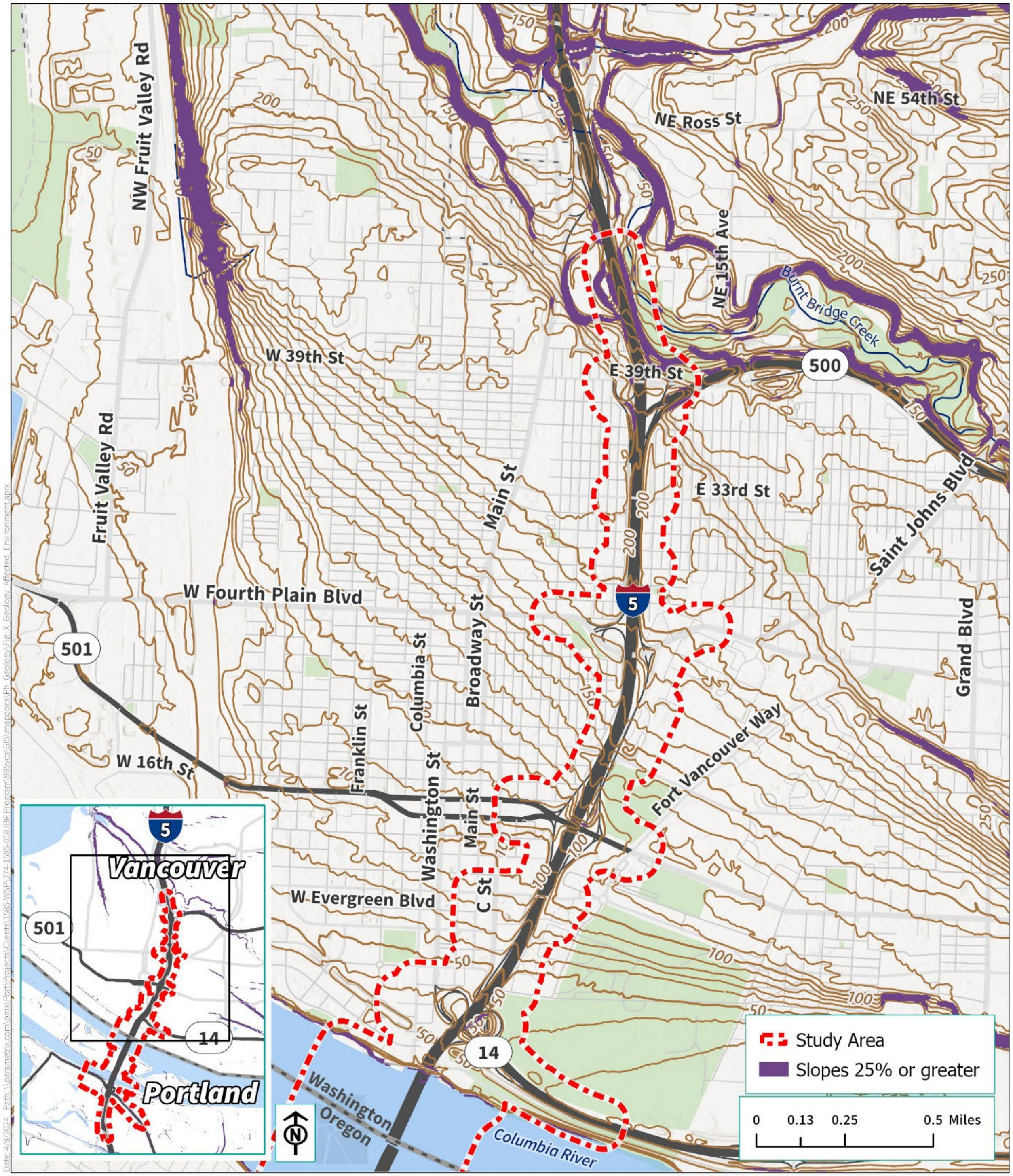
3.9.2 Non-Seismic Ground Settlement

Non-seismic settlement or consolidation occurs in loose, soft soil material. A structure has the potential to settle after construction due to the introduction of added load (Johnson and DeGraff 1988). Settlement generally occurs slowly but over time can create differential settlement conditions that structures may not tolerate. Building settlement could lead to structural damage such as cracked foundations and misaligned or cracked walls and windows. In the Portland area, there are a number of flood control levees located within the study area. These levees could be impacted by the proposed construction and settlements could generate low spots in the levee system. Settlement problems are site-specific and can generally be remedied through standard engineering applications. Settlement for the Modified LPA would be evaluated by site-specific geotechnical investigations conducted in accordance with applicable regulations and building codes set forth by the City of Portland, the City of Vancouver, WSDOT, and ODOT.

3.9.3 Earthquake Processes

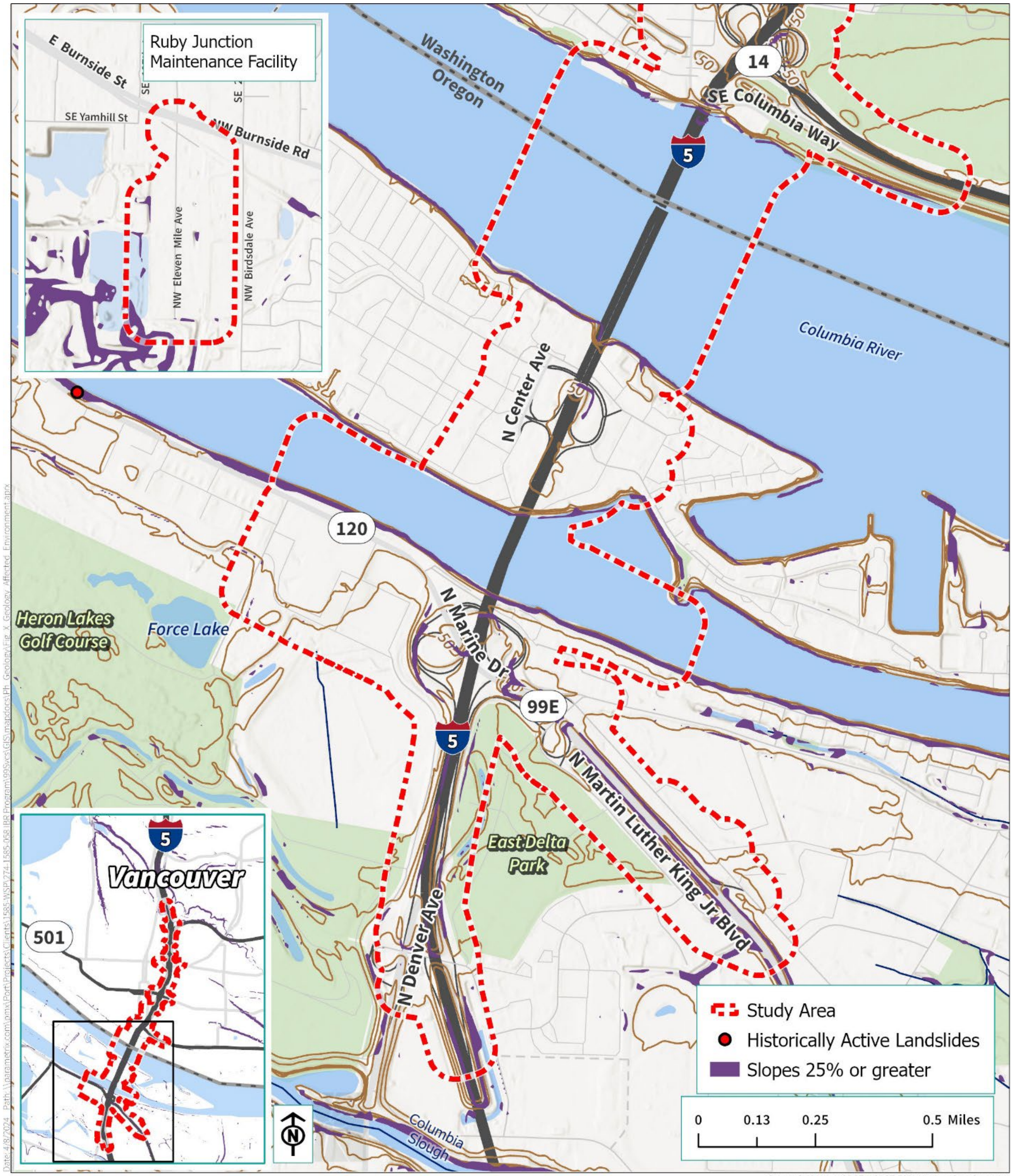
Figure 3-13 shows a map of the relative earthquake hazard ratings in the study area. These ratings consider a variety of potential earthquake effects, with A being the most hazardous areas and D being the least. Earthquake effects include ground motion amplification, slope instability, and soil liquefaction, all of which have a high potential to impact public safety and cause structural damage and economic disruption.

Figure 3-11. Steep Slopes and Landslides – Washington



Source: Clark County, The National Map, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

Figure 3-12. Steep Slopes and Landslides – Oregon



Source: RLIS Metro, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

3.9.3.1 Sources and Types of Earthquakes

Earthquakes result from sudden movement along a fault or fault systems from tectonic and/or volcanic forces. Relative movement along a fault is resisted by friction along the fault plane, resulting in stress generation around the fault and accumulated potential energy over time. When the potential energy overcomes frictional resistance, the sudden release of energy generates seismic waves, the propagation of which is the primary cause of the ground motions felt during an earthquake.

The study area is in the Pacific Northwest regional tectonic regime tectonic setting, which is capable of producing earthquakes of moment magnitude (M_W) 9 or greater. Figure 3-13 presents a generalized schematic of the Pacific Northwest tectonic regime. The convergence of the two crustal plates generates the regional tectonic regime that results in folding and faulting of rocks and volcanic activity in the vicinity of the study area. Earthquakes result from sudden movement along a fault or fault systems from tectonic and/or volcanic forces. The movement along a fault is hampered by frictional resistance as potential energy is accumulated over time around the volume of the fault surface. When the potential energy overcomes frictional resistance, the sudden release of energy generates seismic waves, heat, and cracking of the rock. The propagation of these waves through the ground causes the ground motion felt during an earthquake. In general, three primary types of earthquakes are known to occur in the Pacific Northwest tectonic setting: 1) CSZ interface earthquakes, 2) CSZ intraplate earthquakes, and 3) crustal earthquakes. All three types of earthquakes can cause damage to roadway and bridge structures by strong ground shaking and by secondary effects such as ground surface ruptures, landslides, and liquefaction.

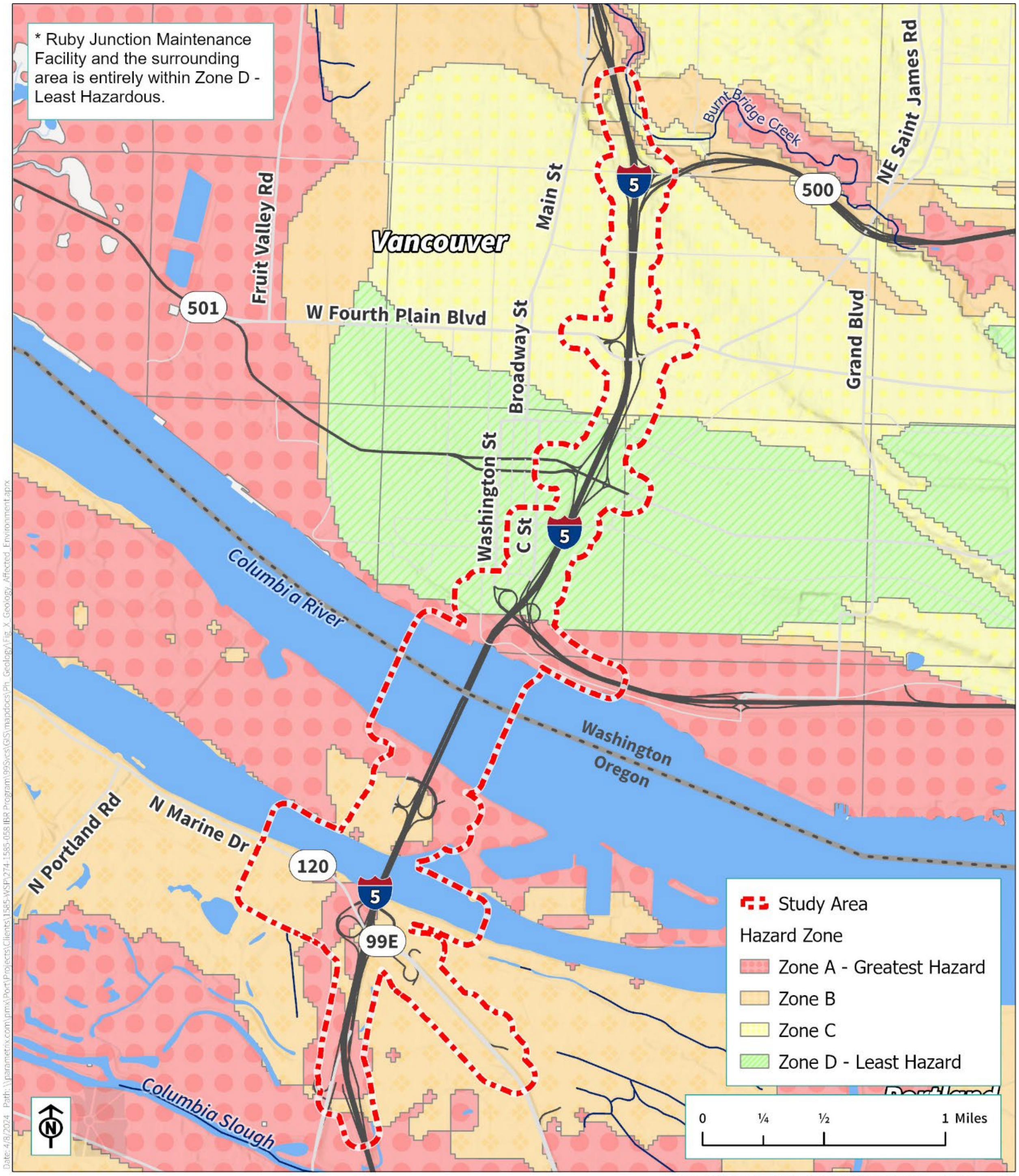
Historical records of seismic events in the Vancouver and Portland areas include earthquakes at magnitudes of M_W 5.3 in 1877, M_W 5.5 in 1962, and M_W 5.6 during the Scotts Mills earthquake in 1993. Several crustal faults are mapped by Beeson et al. (1991) and Madin (2004) to the southwest and by Phillips (1987) to the northeast of the study area (Figure 3-3). Pratt et al. (2001) indicate that these late Pleistocene to Holocene faults may still be active but suggest that other interpretations are possible. There are no known seismically active faults that cross the Modified LPA (USGS 2022).

CSZ INTERFACE EARTHQUAKES

Large subduction zone (megathrust) earthquakes result from the rupture at the interface between the subducting Juan de Fuca and overriding North American plate. The western plate boundaries are located off the Pacific coast and extend from Northern California to Vancouver Island, Canada. The Juan de Fuca Plate steepens from a dip of 5 degrees in the west at the subduction zone to 24 degrees at 30 miles beneath the volcanic arc (McCrory et al. 2012). Refer to Figure 3-1 for a generalized schematic of the CSZ boundary relative to the study area.

An evaluation of subduction zone earthquake recurrence, based on historical and geologic evidence (Nelson et al. 1995, 1996; Atwater and Hemphill-Haley 1997; Wong et al. 2000), indicates that these earthquakes have occurred roughly every 250 to 700 years for the past 7,000 years (Kelsey et al. 2005). Similar to major subduction zone events recorded elsewhere (e.g., Tohoku Japan in 2011, M_W 9.1), an estimated maximum credible earthquake magnitude of M_W 9 or greater could result from a full rupture interface event on the CSZ.

Figure 3-13. Relative Earthquake Hazards



Source: USGS, Clark County, City of Portland, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

CSZ INTRAPLATE EARTHQUAKES

CSZ intraplate, or Wadati-Benioff zone, earthquakes result from stresses within the Juan de Fuca Plate or North American Plate as subduction occurs. Intraplate fault displacement occurs at pre-existing zones of weakness typically called failed rifts.

Significant intraplate earthquakes have occurred in the Pacific Northwest in 1949, 1965, and 2001. These M_W 7.1, M_W 6.5, and M_W 6.8 earthquakes, respectively, had epicenters in the Puget Sound area approximately 125 miles from the study area. However, some damage did occur in Portland during the 1949 event (Mabey et al. 1994). While no intraplate earthquakes greater than M_W 5.5 have occurred beneath northern Oregon or Southwestern Washington in the last 150 years, Wong (2005), Mabey et al. (1993), and Barnett et al. (2009) suggest that intraplate earthquakes epicenters of significant magnitude could occur near the study area.

CRUSTAL EARTHQUAKES

Crustal earthquakes result from the rupture of shallow faults in the earth's crust at depths up to approximately 15 miles below the ground surface. Several shallow crustal faults are mapped within the vicinity of the study area; however, none are mapped as crossing the Modified LPA (Phillips 1987; Mabey et al. 1993; Madin 1994, 2004; Mabey, Madin, and Palmer 1994; Geomatrix Consultants 1995; Personius et al. 2003; Wong 2005). The characteristics of these faults are not well understood since there are few surface features and little historical activity.

In Oregon, the East Bank Fault, Portland Hills Fault, and Oatfield Fault are mapped southwest and the Grant Butte Fault is mapped southeast, and in Washington the Lacamas Lake Fault is mapped northeast of the study area (Phillips 1987; Beeson et al. 1991; Madin 1994; Personius et al. 2003; Madin 2004). The East Bank, Portland Hills, and Oatfield Faults shown in Figure 3-1 are part of the Portland Hills Fault Zone at distances of 4, 7, and 10 kilometers, respectively, southwest of the study area. The Lacamas Lake fault is located approximately 11 kilometers northeast of the study area. The Grants Butte fault is located approximately 16 kilometers southeast of the study area. Additional information on these crustal faults and possible earthquake sources is given in Table 3-2.

It is difficult to estimate the activity and typical recurrence of potential local seismic sources because many of the mapped local faults are poorly understood. This is due to the general lack of surface expressions of the faults; faults are buried under hundreds of feet of recent alluvial deposits, and there is a limited recorded history of earthquakes in only approximately 150 years. However, several seismicity studies[9] conducted in the region over the past 30 years have indicated that the maximum magnitude for local shallow crustal earthquakes is thought to range from M_W 6.5 (Mabey et al. 1993) to up to M_W 7.1 (Wong et al. 2000).

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[9] Bott and Wong (1993); Mabey, Black, Madin, et al. (1993); Mabey, Madin, and Palmer (1994); Atwater and Hemphill-Haley (1997); Mabey Madin, Youd, et al. (1997); Wong et al. (2000); Pratt et al. (2001); Palmer et al. (2004); USGS (2022)

Table 3-2. Possible Earthquake Sources in the Study Area

Earthquake Source	Distance from Study Area (km)[a,c]	Magnitude Max (M_W)[a]	Length (km)[a]	Dip[a,b,c]	Slip Rate (mm/yr)[c]	Most Recent Deformation (years ago)[b,c]
CSZ						
Interface	100–200	9.0	1,100	9°–11°E	>5	300
Intraplate	40–60	7.5	~1,000	>9°E	>5	>150
Crustal						
Portland Hills Fault	6	6.6–7.1	49	70°SW	<0.2	<1.6Ma
East Bank Fault	4	6.8–7.1	29	70°NE	<0.2	<15 Ka
Oatfield Fault	10	6.5–6.9	29	70°SW	<0.2	<1.6Ma
Lacamas Lake Fault	11	6.5–6.9	24	>75° SW	<0.2	<750Ka
Grant Butte Fault	16	6.2–6.5	10	90°	<0.2	<750Ka

[a] Wong et al. 2000.

[b] Gregor et al. 2002.

[c] Personius et al. 2003; information is approximate.

CSZ = Cascadia Subduction Zone
Ka = thousand years
km = kilometer
Ma = million years
mm/yr = millimeters per year
M_W = moment magnitude

3.9.3.2 Earthquake Effects

Effects from earthquakes result from: 1) ground motion, 2) soil liquefaction, 3) lateral spreading, 4) seismic-generated water waves, and 5) earthquake-induced landslides, as discussed below.

GROUND MOTION

Ground motion relates to the type, frequency, amplitude, and dominant orientation of ground shaking at a particular site following fault rupture and seismic wave propagation. The experience of ground motions at a particular site is inherently related to the characteristics of the fault source, the distance to that source, the nature of the crustal materials between the source and the site, and the near-surface and deeper subsurface materials at the site. For example, seismic waves traveling through bedrock can be amplified and have their periods altered when being transmitted into softer/looser materials. These higher-amplitude, longer-period waves can be more damaging to structures than the higher frequency movements in bedrock or bedrock overlain with very shallow or well consolidated soils.

Based on data collected during previous investigations for the CRC project, the subsurface conditions in the study area range from AASHTO site class C (dense soils [360 to 760 meters per second]) to class E (soft soils [< 180 meters per second]) (Shannon & Wilson 2008; Parsons Brinkerhoff 2009). Where site class E conditions are present, such as at Hayden Island, the risk for ground motion amplification to occur is higher than in areas north of the Columbia River coastal band in Vancouver, where site class C or D conditions are found.

LIQUEFACTION AND SETTLEMENT

Liquefaction is a process whereby saturated, non-plastic to low-plasticity soils lose shear strength during and immediately after seismic shaking. Shear stresses transmitted through the soil column cause particles to dislodge and contract or collapse, increasing pore pressures if the water cannot drain quickly enough. This increase in pore pressure causes a decrease in frictional resistance at particle interfaces, resulting in an effective loss of shear strength and ground settlement.[10] The strength loss and ground movement associated with liquefaction can cause structures to tilt, sink, or collapse.

Soil liquefaction hazard is greatest within mapped Artificial Fill (af) and Quaternary Alluvium (Qal) areas from Columbia Boulevard in Oregon north to approximately Fourth Street, Burnt Bridge Creek, and Salmon Creek in Washington. Missoula Flood deposits (Qf and Qfc) are typically too dense to be considered liquefiable soils. Figure 3-14 presents the liquefaction susceptibility of the study area. Consistent with this hazard mapping, previous studies of the study area indicate that ground south of the Columbia River may be subject to liquefaction during a design earthquake event (Parsons Brinkerhoff 2009). However, in the area of the Ruby Junction Maintenance Facility, the dense Missoula Flood deposits (Qfc) would not be considered liquefiable.

LIQUEFACTION-INDUCED LATERAL SPREADING

Lateral spreading occurs as strength loss in liquefied materials, located in sloping ground or proximate to unsupported slope faces, leads to flow-type material migration from areas of higher stress (e.g., upslope) to areas of lower stress (e.g., downslope) (Bartlett and Youd 1992). Lateral spreading can compress or buckle building foundations, bridge footings, roadways, pipelines, and other utilities built on or across the failure (Youd 1993). In cases where non-liquefied materials are present at the surface above liquefied materials, this non-liquefied “crust” may translate downslope, causing increased damage to surface and near-surface structures.

Previous studies in the study area indicate that significant liquefaction-induced lateral spreading may occur during a design seismic event (Parsons Brinkerhoff 2009). Lateral spreading could occur along the north and south banks of the Columbia River, North Portland Harbor, and Columbia Slough in Oregon; in Burnt Bridge Creek, Salmon Creek, and the Mocks Bottom area in Washington; and near in-water piers.

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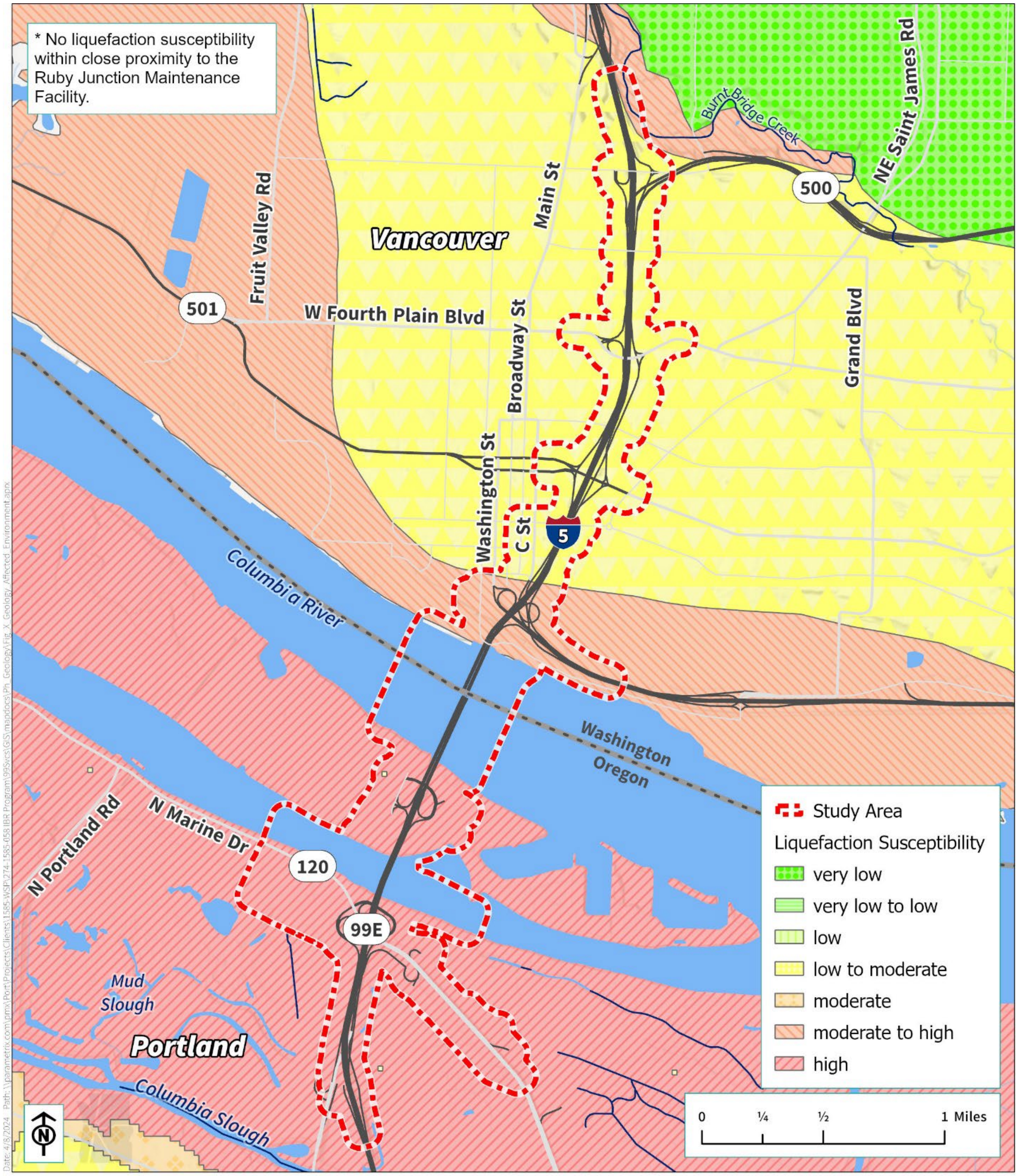
[10] While granular soils that are not saturated are not susceptible to liquefaction, depending on their relative density they may be subject to seismic densification and settlement during an earthquake (Mabey et al. 1993).

Figure 3-14. Liquefaction Susceptibility Map



* No liquefaction susceptibility within close proximity to the Ruby Junction Maintenance Facility.

Source: Clark County, City of Portland, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

LANDSLIDE HAZARDS

In the event of a major CSZ earthquake, there is the possibility that landslides along the Columbia River upstream from the study area would occur and would contribute material into the river that would affect the flow. Variations in the Columbia River flow and sediment loads have the potential to affect scour rates to the banks and structures within the river.

RATING OF EARTHQUAKE HAZARDS

The earthquake hazards discussed above have been given a quantitative rating scale by Mabey et al. (1993); Mabey et al. (1994); and Mabey et al. (1997). Each hazard is given a rating of A to D (A for areas with the greatest hazard and D for areas with the least hazard). This rating is based on the greatest or least likelihood of damage by a combination of earthquake hazards. Relative earthquake hazards are shown above in Figure 3-13 and are categorized according to the methodology described in Mabey et al. (1994).

Relative earthquake hazard analysis for the Modified LPA was conducted with maps published for the Vancouver 1:24,000 quadrangle by Mabey et al. (1994) and for the Portland 1:24,000 quadrangle by Mabey et al. (1993).[11,12] Figure 3-13 indicates that high earthquake hazard ratings of A and B were given to North Portland Harbor, Hayden Island, and the north embankment of the Columbia River. Lower earthquake hazard ratings (C and D) were given to Vancouver City Center north to the Burnt Bridge Creek drainage.

3.9.4 Volcanoes

Volcanic hazards from regional volcanoes include ash fall, pyroclastic flows, lava flows, debris avalanches, and lahars. Regional hazards related to local active volcanoes are presented in Figure 3-15.

3.9.4.1 Volcanic Hazards

Volcanic ash (tephra) consists of small, pulverized pieces of rock and glass ejected during an eruption. Ash is hard, abrasive, and mildly corrosive. Ash has a low density and small particle size, which gives it the ability to be spread over broad areas by wind. The ash begins to fall when the energy needed to keep the particles in the air diminishes. The size of ash particles that fall to the ground generally decreases exponentially with increasing distance from the volcanic vent in the prevailing

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[11] An updated earthquake hazard map has been published for Clark County at a scale of 1:100,000 (Palmer et al. 2004). The City of Vancouver uses this map for land use planning. However, the 2004 Clark County map was not used for this analysis. The 2004 Clark County Site Class map employs a different hazard evaluation method than the 1993 and 1994 maps. An updated map for the Portland area, using hazard evaluation similar to the 2004 Clark County map, has not been published. As a result, a consistent comparison could not be made using these different map sets. In addition, the 1993 and 1994 maps are more useful for analysis because they have a higher resolution.

[12] Cited maps should not be used to make construction design decisions for the Modified LPA. Only a site-specific geotechnical investigation performed by a qualified geologist or engineer can adequately assess the potential for damage from soil liquefaction, ground motion amplification, or earthquake induced landslides. The 1993 and 1994 relative earthquake hazard maps are intended to provide a source of comparable information.

wind direction (Wolfe and Pierson 1995; Scott et al. 1997). Ashfall from a nearby Cascade Range volcanic eruption (e.g., Mount St. Helens, Mount Hood, Mount Adams, Mount Jefferson, etc.) is generally carried northeast with the dominant wind direction. However, in the event of an eruption, there is a 1 to 2 percent chance of ash fall accumulation of 4 inches or more within the study area.

Pyroclastic flows are avalanches of very hot mixtures of volcanic rock fragments and gases that descend a volcano's flanks at speeds of more than 200 miles per hour (Wolfe and Pierson 1995; Scott et al. 1995, 1997). Pyroclastic flows are generally denser than the surrounding air and typically follow topographic low areas like valley bottoms but are also capable of overtopping ridges. Pyroclastic flows can travel several miles.

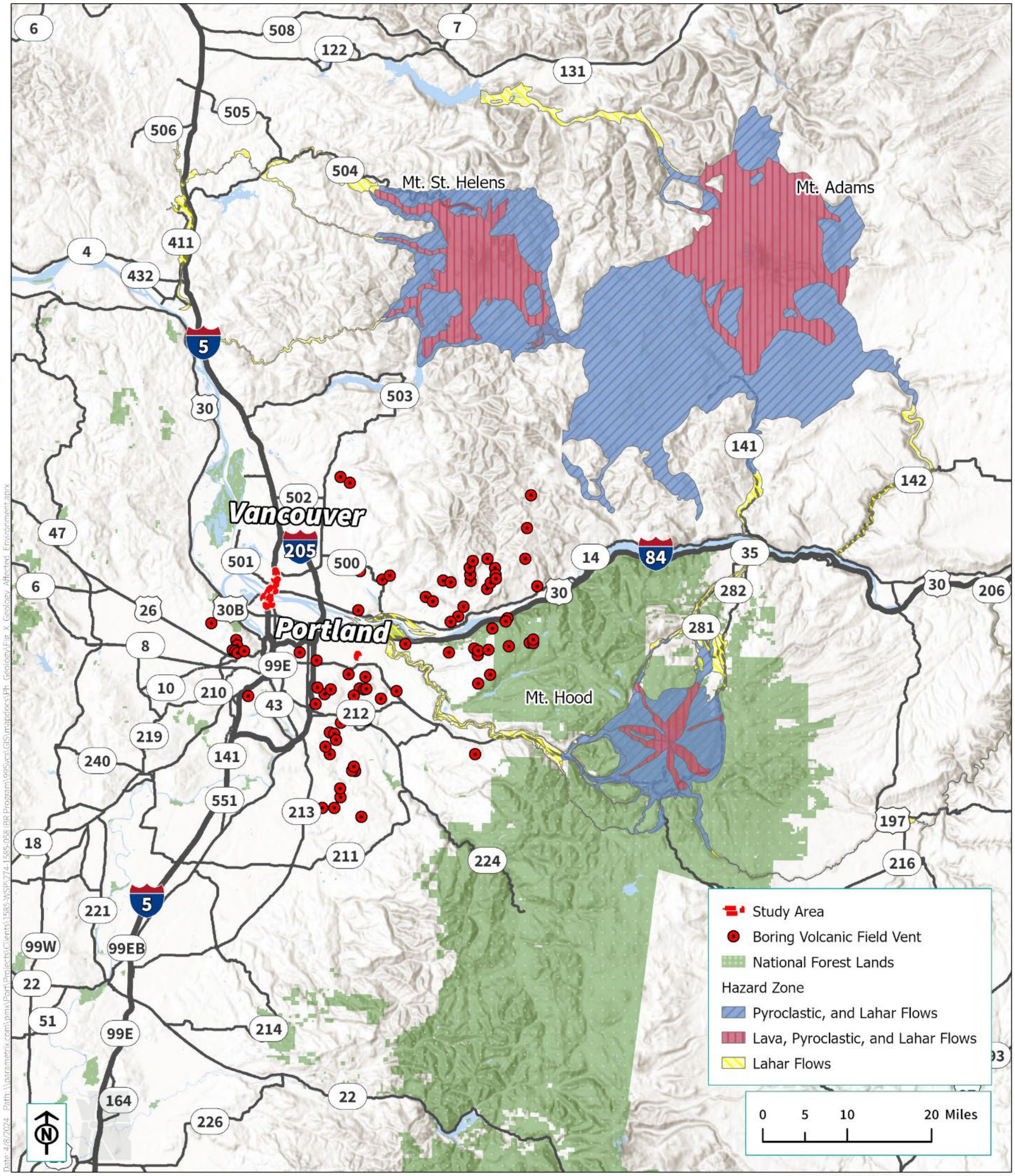
Lava flows are streams of molten rock that erupt from a volcanic vent. The lava typically follows topographic low areas and moves slowly downslope. The distance a lava flow can travel depends on viscosity, volume, slope, and obstructions to the flow (Miller 1989). Because lava flows from Cascade volcanoes are typically high-viscosity and made of andesite, dacite, and rhyolite, they tend to form short, thick flows or domes close to the volcanic vent (Scott et al. 1995; Wolfe and Pierson 1995).

Debris avalanches are sudden and very rapid movements of a massive landslide as a result of volcanic activity. The magma beneath the volcano produces warm, acidic groundwater that circulates in cracks and porous zones inside volcanoes (Wolfe and Pierson 1995). The acidic water weakens the rock. Volcanic activities such as earthquakes or eruptions can trigger a catastrophic failure of large portions of the weak volcanic edifice and create chaotic mixtures of water, soil, and rock debris that move rapidly downslope away from the volcano (Miller 1989; Myers and Brantley 1995; Scott et al. 1995).

Lahars (debris flows or mudflows) are mixtures of water, rock, sand, and mud that are gravity-controlled flows channeled into valleys as they move downhill (Scott et al. 1995). They contain a high concentration of rock debris, giving them a consistency resembling freshly mixed concrete to very muddy water. The rock (60 to 90 percent by weight) to water ratio provides them the internal strength necessary to transport huge boulders, buildings, and bridges and exert extremely high-impact forces against objects in their paths (Myers and Brantley 1995; Wolfe and Pierson 1995; Scott et al. 1995). They can travel between 20 and 40 miles per hour for more than 50 miles and increase in volume three to five times as they move downstream. Structural damage can result from the impact of large boulders or logs carried in the flows, from high drag and buoyancy forces imposed by the dense fluid, by abrasion, and by burial (Wolfe and Pierson 1995).

Deposits of lahars from Mount Hood have been mapped on the Oregon and Washington sides of the Columbia River near the mouth of the Sandy River (Scott et al. 1997). The Lewis and Clark expedition noted conditions at the mouth of the Sandy River in 1805 and 1806 that have been interpreted to indicate that a recent event, possibly a volcaniclastic flow or a lahar event, had added a significant amount of sediment to the river system at the mouth shortly before their observations (USGS 2022). Lahars from Mount Hood could inject a significant amount of sediment-rich flood water containing large rocks and woody debris into the Columbia River upstream of the study area (Wolfe and Pierson 1995). Lahars can cause severe bank erosion or could create upstream lahar dams that could breach and create conditions for significant scour around bridge piers.

Figure 3-15 Volcanic Hazards in the Study Area and Region



Source: USGS, ODOT, WSDOT, ESRI, Mapbox, OpenStreetMap

3.9.4.2 Nearby Volcanoes

Mount St. Helens is located approximately 46 miles northeast of the study area. Mount St. Helens is known to have had several large explosive eruptions in its past. The most recent notable explosive eruption occurred on May 18, 1980. Volcanic activity at Mount St. Helens is capable of producing eruptions of ash (tephra), lava flows, pyroclastic flows, and lahars. The probability that 4 or more inches of tephra from a large eruption will fall as far as 40 miles directly east of Mount St. Helens is 20 percent; the probability that such an eruption would deposit 4 or more inches 40 miles west of Mount St. Helens is between 1 and 2 percent. Lava flows and pyroclastic flows would be confined to the general vicinity of the vent (Wolfe and Pierson 1995). Lahars would be confined to established drainages from the mountain. The southernmost drainage for Mount St. Helens is the Lewis River, which is downstream from the study area.

Mount Adams is located approximately 70 miles northeast of the study area. The history of Mount Adams has shown a smaller range of eruptive styles. Large explosive eruptions from Mount Adams are rare. More commonly, Mount Adams generates lava flows, smaller ash eruptions (less than a few miles extent), and lahars. Lava flows and ash eruptions have been restricted to the immediate vicinity of the mountain during past events. Mount Adams has erupted little during the past 10,000 years. Consequently, much of the mountain has been subjected to erosion that has created steep, unstable slopes capable of producing debris flows (Scott et al. 1995). Lahars and debris flows from Mount Adams could travel to the Columbia River through the Wind and Klickitat Rivers approximately 60 miles upstream of the study area.

Mount Hood is located approximately 50 miles east of the study area. It has produced volcanic eruptions for thousands of years, principally as lava, pyroclastic flows, and lahars, though numerous debris avalanches have also occurred. The eruptive history over the last 30,000 years has been dominated by the growth and collapse of lava domes, which can generate pyroclastic flows and lahars (Scott et al. 1997). Episodes of ash eruptions have been noted but would have impacts similar to those produced by Mount St. Helens. The prevailing wind direction is to the east 70 percent of the time (Scott et al. 1997). Lahars and debris avalanches produced from Mount Hood have been mapped reaching the Columbia River upstream of the study area. Numerous lahars have been mapped in the Sandy River, White River, and, to a lesser extent, Hood River. Lahars and sediment-rich floods down the Sandy River formed the delta at the mouth of the Sandy River in the Columbia River near Troutdale, Oregon. The delta has narrowed the Columbia River and pushed it against the Washington shore. Future lahars are likely to expand the delta and further narrow the existing channel, which could lead to progressive bank erosion and inundation of land in Washington (Scott et al. 1997). A lahar from an eruption at Mount Hood would enter the Columbia River approximately 10 miles upstream from the study area (Figure 3-15).

The Boring Volcanic Field consists of up to 90 volcanic centers that occurred in the Portland-Vancouver metropolitan area from 2.7 million to less than 500,000 years ago (Evarts et al. 2009). Most of these were originally small cinder cones, while some are low, broad lava shield volcanoes. All of the volcanic centers that have been identified are extinct, but the volcanic field may be quiescent. The most recent eruption at the eastern edge of the field occurred 57,000 years ago. However, the probability of an eruption is low and the occurrence would likely be preceded by earthquakes that would provide advance warning.

4. LONG-TERM EFFECTS

Long-term effects are defined as future effects on the completed project from geologic hazards or the effects from the completed project on geologic resources. Geologic hazards include earthquakes, landslides, steep slopes, and soil erosion. Geologic resources include rock and aggregate and groundwater resources. For the Modified LPA the effects are discussed in comparison to the No-Build Alternative.

4.1 No-Build Alternative

4.1.1 Geologic Hazards

The No-Build Alternative would maintain the existing I-5 infrastructure in the study area and would not provide seismic improvements to the Interstate Bridge or other I-5 structures. A mega-earthquake could cause substantial damage to the Interstate Bridge over the Columbia River because they are approximately 64 and 105 years old, before state and federal seismic codes were in place, and are nearing their designed lifespans. In addition, an earthquake could result in substantial damage to other I-5 structures, which do not meet current state or federal seismic codes.

The No-Build Alternative would not address the potential for landslides within the areas of steeper slopes within the study area. The No-Build Alternative would not modify or improve the existing infrastructure or stormwater management to reduce the potential geologic hazards that could occur from steep slopes. However, it has not been determined that adverse effects, such as landslides or soil erosion, would occur in the Burnt Bridge Creek area where steep slopes are present.

The No-Build Alternative would not address the risks of increased scour from potential flooding and sediment load due to lahar effects upstream from regional volcanic activity.

4.1.2 Geologic Resources

The No-Build Alternative would have limited need for geologic resources for I-5 operation and maintenance. The No-Build Alternative would not create a strain on local surface mining resources. However, the No-Build Alternative would also not result in the potential benefit of expanding local quarries.

4.1.3 Groundwater Resources

Current conditions of stormwater management would continue, which does not include treating pollutants in roadway runoff, and would continue to degrade groundwater quality in the study area.

4.2 Modified Locally Preferred Alternative

4.2.1 Geologic Hazards

4.2.1.1 Earthquakes

At least one mega-earthquake of up to magnitude M_w9 is anticipated to occur in the Pacific Northwest in the next 50 to 300 years. Compared to the No-Build Alternative, the Modified LPA would have the long-term benefit of reducing the effects of earthquakes. Long-term benefits of the Modified LPA include improving public safety, minimizing damage to infrastructure, and limiting potential economic disruption.

The Modified LPA would replace the existing Interstate Bridge over the Columbia River, and other interchange and highway improvements, with new structures built to modern seismic safety standards and would address almost all I-5-related seismic safety issues within its footprint. Design of the Modified LPA would apply advancements in earthquake engineering, structural safety standards, and site-specific geological and seismic risk information in the study area, which would improve public safety and structural stability during an earthquake. To meet current design standards, the Columbia River bridges with the Modified LPA would include more substantial foundation elements than the existing Interstate Bridge.

Through ground improvements, such as soiling mixing and stone columns, the Modified LPA would stabilize weak soils along the Columbia River, on Hayden Island, around Marine Drive, and around Burnt Bridge Creek that are susceptible to liquefaction during future seismic events.

The existing location and the proposed expansion of the Ruby Junction Maintenance Facility lies entirely within an area classified as Seismic Hazard Zone D – Least Hazard. No additional impacts or benefits are anticipated with construction of the Modified LPA since this area is classified as Seismic Hazard Zone D.

4.2.1.2 Non-Seismic Settling

In the Portland area, there are a number of flood control levees located within the study area. Additionally, enhancements to the levee system and some new structures that will be a part of the levee system are in the planning stages. The Modified LPA includes structures and significant fills placed in the vicinity of the existing or planned levee sections, which could induce longer term settling of soils that may cause a reduction in the overflow elevations for the levees. Structure foundation elements that penetrate the levees can compromise the ability of the levee to retain water and increase seepage.

In areas on both sides of the Columbia River, Hayden Island, and throughout the study area, the placement of construction fill, retaining walls, or other structures for the Modified LPA could result in non-seismic soil settling. The potential for non-seismic settling would be addressed as a part of the geotechnical design for the Modified LPA.

4.2.1.3 Steep Slopes, Soil Erosion, and Landslides

Compared to the No-Build Alternative, the Modified LPA may have some long-term benefits, including reduced potential damage to the I-5 infrastructure from landslides and steep slope instability. No previous landslides have been identified in the area of the Modified LPA; the only steep slopes are within the Burnt Bridge Creek drainage area.

The Modified LPA would mostly avoid construction on steep slopes, including in the Burnt Bridge Creek area. However, where construction would occur in areas of steep slopes, the design of the Modified LPA would include retaining walls or other stabilization techniques to reduce soil erosion and the potential for slope failure. In addition to the use of retaining walls and cut/fill grading, the Modified LPA would include a stormwater management and conveyance system built to current design standards. The improved management of stormwater would result in a reduced rate of soil erosion and a lower potential for soil slump or slides in areas of steep slopes. The Modified LPA would stabilize steep slopes and reduce soil erosion in the Burnt Bridge Creek drainage area through grading slope angles, managing stormwater volume and flow, and vegetative planting.

Unlike the No-Build Alternative, the Modified LPA would address the risks of increased scour that could result from potential landslides upstream caused by a major CSZ event. New bridge pier design would decrease the chance of bridge damage in the event of changes in river flow and/or sediment loads due to upstream landslides in the Columbia River.

The existing location and the proposed expansion of the Ruby Junction Maintenance Facility in the Modified LPA is in a generally flat area without steep slopes. No long-term effects from or on geologic hazards are anticipated in this area.

4.2.1.4 Volcanoes

As noted above, the Modified LPA would include design measures to address the risks of increased scour from potential volcano-related impacts and decrease the risk of damage to the new Columbia River bridges due to lahar effects upstream of the study area.

In the event of a volcanic eruption within the nearby Cascade region, the prevailing wind patterns would carry the majority of ash to the northeast away from the study area. There, ash accumulation is not anticipated to pose risks to the Interstate Bridge or the bridges under the Modified LPA.

4.2.2 Groundwater Resources

Compared to the No-Build Alternative, the Modified LPA would provide long-term benefits to groundwater as a result of stormwater management and treatment throughout the study area. Groundwater resources include the Troutdale Aquifer, which is designated a sole source aquifer by the EPA and a Critical Aquifer Recharge Area by the City of Vancouver. The TSSA provides the main source of drinking water to the City of Vancouver and supplements the City of Portland’s drinking water supply. Because the TSSA is accessible and productive, it is a significant and unique geologic resource. However, due to these attributes, the TSSA is vulnerable to pollution and anthropogenic effects. Stormwater from roadways can contain pollutants such as metals, oil and grease, and microbes. Stormwater from these pollution-generating impervious surfaces (PGIS) can infiltrate to the water table and diminish groundwater quality if not managed or treated correctly. City of Portland Code (CPC) requires mitigation for project impacts to climate and stormwater.

The Modified LPA would provide long-term management and treatment of stormwater generated from PGIS associated with roadways. The Modified LPA would:

- Improve the management of stormwater volume and flow rates.
- Increase and improve existing stormwater treatment facilities.

The Modified LPA would also provide long-term management and treatment of stormwater generated from PGIS associated with the expanded railyard and associated facilities at the Ruby Junction Maintenance Facility.

The Modified LPA would likely result in improved local groundwater quality for the TSSA and surface water quality for drainage areas around the Columbia River and Burnt Bridge Creek. This is in sharp contrast to the No-Build Alternative, which has limited source control, management, and treatment facilities for stormwater generated from PGIS.

4.2.3 Design Options

The Modified LPA's options for one or two auxiliary lanes, the SR 14 interchange with or without the C Street ramps, the option to shift the I-5 mainline west or keep it centered, and the park and ride site options would not change the effects to geologic resources and groundwater. The Modified LPA with the double-deck fixed-span configuration would have the same effect to geologic resources and groundwater as the Modified LPA with the single-level fixed-span configuration. The single-level movable-span configuration would require more substantial river piers and pier foundations to support the span because the movable parts are more sensitive to foundation settlement. However, the same discussions would apply, and no additional impacts would be anticipated.

5. TEMPORARY EFFECTS

Temporary effects are defined as short-term effects on the Modified LPA from geologic hazards or the effects from the completed project on geologic resources that would occur during construction of the Modified LPA. For the Modified LPA the effects are discussed in comparison to the No-Build Alternative.

5.1 No-Build Alternative

5.1.1 Geologic Hazards

The No-Build Alternative would not modify existing structures within the Program footprint and would have no temporary effects on existing conditions. There would be a lower risk of uncontrolled erosion and non-seismic settling from construction activities. Some non-seismic settling around structures has already occurred, and may continue to occur, for the No-Build Alternative. The No-Build Alternative would not include construction that would result in soil-disturbing activities.

5.1.2 Geologic Resources

Local surface mining activities would not experience the increased demand for geologic materials for construction under the No-Build Alternative.

5.1.3 Groundwater Resources

Groundwater resources would similarly not be exposed to hazards from ground disturbing activities; however, the existing conditions could continue to have a deleterious effect on water quality, as discussed in the Water Quality and Hydrology Technical Report.

5.2 Modified Locally Preferred Alternative

5.2.1 Geologic Hazards

5.2.1.1 Earthquakes

Construction of the Modified LPA would follow AASHTO standards. Temporary structures would incorporate appropriate seismic design. Although this would not provide the same level of resiliency as the completed infrastructure, it would minimize risks from earthquakes during construction.

5.2.1.2 Non-Seismic Settling

Although the design of the Modified LPA would address potential non-seismic settlement, if not correctly designed and constructed, new structures with the Modified LPA could experience settling during construction. Settling around structures occurs as soil conditions adjust to the weight of new structures. Settling can result in various adverse effects, such as roadway cracks and compromised foundations, which would require repair during construction. The greatest potential for settling is likely to occur on Hayden Island and along the shoreline of the Columbia River, where fill materials were previously used to extend shorelines and fill depressions. Of particular concern would be the flood control levee system located along the southern edge of the Oregon Slough where settlements could compromise the levee system. Potential non-seismic settlement could be present in areas of the Modified LPA where retaining walls and other structures are planned.

Proper design and planning would minimize this risk. Settling issues could be present in other areas where retaining walls are planned. Construction of retaining walls and backfilling could result in adverse effects from settling if not properly engineered and compacted. In addition, ground improvement methods could be used during construction to provide beneficial structural performance in the Modified LPA. In areas where retaining walls are proposed, the Modified LPA would comply with current standards for geotechnical assessment, design, and construction to minimize the potential for settlement on adjacent properties. With the correct design and construction methods, the risks of settlement would be minimal.

The Modified LPA would have little effect on settlement at the Ruby Junction Maintenance Facility because the soil conditions there are not conducive to non-seismic settlement.

5.2.1.3 Soil Erosion

Unlike the No-Build Alternative, soil erosion could occur during construction of the Modified LPA if not correctly mitigated. Construction activities could expose erosive soils to wind and stormwater. Adverse effects from soil erosion include:

- Plugging of stormwater catch basins.
- Deposition of soil surface water on roadways.
- Diminished surface water quality at the Columbia River, Vanport Wetland, and Burnt Bridge Creek.
- Potential to undermine existing roadway and structures.

The Modified LPA would expose approximately 415 acres of near-surface soils to potential erosion from excavation, fill, clearing, and grading during construction. Mitigation includes, but is not limited to, preparing and implementing stormwater pollution prevention plans and grading plans; performing hydroseeding; managing stockpile fill; and incorporating best management practices.

5.2.2 Geologic Resources

The Modified LPA would require large amounts of geologic resources during construction, including topsoil, fill, aggregate, and rock. Program-created demand could require existing aggregate mines to expand or new mine sites to be developed. Local geologic resources are not unique but are limited in number and material types and volumes; approximately 33 mine sites are within 10 miles of the study area.

5.2.3 Groundwater Resources

The Modified LPA would have no distinct short-term effects on groundwater resources. Best management practices for the deep foundations would include drilled shafts for piles that would be performed under slurry; the amount of dewatering would be extremely limited and would not have a significant adverse impact to groundwater resources. In areas where roadway sections are depressed where there is a shallow water table, shallow local dewatering may be needed for shallow foundations; however, the amount of water produced is expected to be very small and would come from shallow depths that are not contiguous with groundwater resource production, and thus are not expected to cause any short-term effects.

During construction, stormwater protection measures, including spill prevent plans, and best management practices would be in place.

5.2.4 Design Options

The design options would have the same temporary effects as the Modified LPA as they would be similar in scale compared to the size and scope of the geological features and hazards and groundwater resources. The design options, like the Modified LPA, would be constructed in accordance with the standards and seismic design described under the Modified LPA.

6. INDIRECT EFFECTS

Indirect impacts include those that are not a direct result of a project but would occur later in time or farther in distance as a result of a project.

Groundwater quality can be affected by infiltration of untreated stormwater runoff. Over time, as land develops and changes around transit stations that would be constructed under the Modified LPA, the stormwater facilities associated with new development are likely to result in an improvement in stormwater treatment as they would be constructed to current regulations and treatment requirements. Improvements to stormwater treatment would likely result in increased local groundwater quality, including the TSSA, which currently receives local recharge from untreated stormwater in the study area.

A flood protection system consisting of levees and flood walls is presently located on the southern edge of the Oregon Slough. The Modified LPA would necessarily cross these embankments and structures. Construction for the Modified LPA could introduce additional loads on the ground around these and cause some settlements, potentially generating low spots in the flood control system. Proper design and planning for the foundation elements would minimize these risks. In addition, the Program would carefully design foundation elements that might be required to penetrate any levee elements or affect the stability of the levees in any way.

The greatest risk from earthquakes under the Modified LPA occurs on Hayden Island and near the Columbia River and North Portland Harbor. Earthquake effects include ground motion amplification and soil liquefaction, which have a high potential to impact public safety, cause structural damage, and result in economic disruption. Compared to the No-Build Alternative, the Modified LPA may attract development near the waterfront in Vancouver and on Hayden Island, which is consistent with local land use plans. Though earthquake risk is higher in these areas relative to the overall study area, new and retrofitted buildings and structures would be built to current seismic safety standards, which could potentially increase overall public safety and decrease the likelihood of structural damage and economic disruption.

7. PROPOSED MITIGATION

To prevent or minimize effects to geologic and groundwater resources, or the effects to structures and landforms from geologic hazards, the following potential mitigation and minimization measures were identified for the Modified LPA.

7.1 Long-Term Effects

7.1.1 Regulatory Requirements

- Design structures to comply with federal, state, and city building seismic codes and standards and apply advancements in earthquake science and construction materials and updates in the conceptual model.
- Design systems to minimize contamination of groundwater resources in compliance with Vancouver Municipal Code Chapter 14.26 Water and Sewers – Water Resources Protection and Portland City Code Title 21.35, Well Head Protection, and any applicable Washington and Oregon regulations.

7.1.2 Program-Specific Mitigation

- Design structures to consider stormwater infiltration or other changed conditions near shallow footings, retaining walls, and other structures that could increase the potential for soil liquefaction during a future seismic event.
- Design the Modified LPA to accommodate a range of future conditions resulting from climate change to provide resilience for geologic concerns, such as increased erosion and scour, as feasible.
- Conduct site-specific assessments of existing geologic hazards such as, but not limited to, faults, ancient landslides, steep cut slopes, non-seismic settlements, and soil liquefaction during design of the Modified LPA, as feasible. Site-specific assessments should include the use of geotechnical drilling, test pitting, material testing, geophysical techniques, subsurface displacement monitoring (inclinometers) and monitoring well installation, as feasible. Assessment would include recommended options for avoiding or mitigating geologic hazards.
- Consider the use of light weight fills or geoform in areas adjacent to existing flood control levees and structures to minimize the potential for settlements.
- Assess soil stabilization techniques to minimize the potential for soil liquefaction and non-seismic settlements during design of the Modified LPA. Stabilization techniques may include, but are not limited to, the use of soil mixing, compaction grouting, jet grouting, and stone columns.

- Locate stormwater treatment facilities, to the extent possible, away from City of Vancouver well head protection zones for WS-1 and WS-3, and the Cascade Expansion groundwater protection area in Gresham for the Ruby Junction location.

7.2 Temporary Effects

7.2.1 Regulatory Requirements

- Prepare and implement erosion control and stormwater pollution prevention plans and grading plans during construction. Plans would adhere to ODOT and WSDOT guidelines.
- Prepare and implement stormwater discharge permits for construction.
- Conduct inspection and observation monitoring of all Modified LPA elements during construction and long-term operations to ensure that appropriate construction and maintenance measures are being taken.

7.2.2 Program-Specific Mitigation

- Evaluate local geologic resources for future material needs.
- Recycle or reuse aggregate, quarry rock, asphalt, and concrete materials to the extent practical.

8. PERMITS AND APPROVALS

The following provides a summary of potential permits and approvals regarding geologic hazards and/or geologic and groundwater resources that would be needed for the Modified LPA. Permits and/or approvals may overlap across federal, state, and local requirements.

8.1 Federal Permits

- FHWA
  - Design, construct, and inspect piles and shafts following federal guidelines in Publication Nos. FHWA-HI-97-013 and FHWA NHI-03-018.
  - Mechanically stabilize soils following federal guidelines in Publication No. FHWA-SA-96-071.
- U.S. Army Corps of Engineers
  - Section 404 Permit for any activities that place or remove fill in "waters of the U.S." Exact permit requirements would depend on circumstances and activity. Coordination with the U.S. Army Corps of Engineers indicates the Modified LPA may occur under a Nationwide Permit. However, the final decision has not been determined.
  - Joint Aquatic Resources Permit Application for Washington waters and Joint Permit Application for Oregon waters.
- EPA
  - Provide information on the groundwater system underlying the area in Washington and Oregon, including information about the federally designated TSSA and an evaluation of the potential impacts of the Modified LPA on the groundwater resource.

8.2 State Permits

- Oregon Department of State Lands
  - A permit would be required for removal or fill of over 50 cubic yards in Oregon waters.
  - An easement would likely be required to place structure in the Columbia River within the state of Oregon.
- Washington Department of Natural Resources
  - An easement would likely be required to place structure in the Columbia River within the state of Washington.
- Washington Department of Ecology and Oregon Department of State Lands
  - General construction stormwater permits issued by the states based on federal guidance within the National Pollutant Discharge Elimination System under Section 402 of the Clean Water Act.

- Oregon Water Resources Department and Washington Department of Ecology
    - “Start cards” for geotechnical boreholes that install monitoring wells, piezometers, and injection wells.

8.3 Local Permits

- City of Portland
    - All permit applications must comply with CPC Title 24.10.070 Permit Applications.
    - Grading, cut, fill, and stockpiling must comply with CPC Title 24.10 Grading Permit Fees and CPC Title 24.70 Clearing Grading and Erosion Control.
    - Seismic upgrades to existing buildings must conform to CPC Title 24.85 Building Regulations.
    - Building in frequently flooded areas or causing increased flood heights is prohibited under CPC Title 24.50.
    - Erosion prevention and sediment control must be conducted under CPC Title 10 Erosion and Sediment Control Regulations.
    - Stormwater must be controlled under CPC Title 17.38, Drainage and Water Quality.
    - Groundwater resources must be protected under CPC Title 21.35, Well Head Protection.
- Urban Flood Safety & Water Quality District
    - Manages the levee system in Peninsular Drainage Districts 1 and 2, which are separated by I-5 in the study area. Drainage districts are a special purpose local government organized under Oregon Revised Statute Chapter 547. The Urban Flood Safety & Water Quality District provides for the uniform management of the entire levee-protected area from the railroad embankment adjacent to North Portland Road on the west, eastward to the Sandy River. Oregon Revised Statute Chapters 190 and 195 require that the drainage districts, state agencies, and local governments in the area cooperate and coordinate their activities.
- City of Vancouver
    - Pre-application conference must be conducted for all projects subject to VMC Chapter 20.740 Critical Areas Protection, unless waived by the planning office.
    - Permit is required for grading, cut, fill and stockpiling under VMC Chapter 20.210.090, Decision Making Procedures.
    - Construction must conform to VMC Chapter 20.740.130, Critical Areas Protection - Geologic Hazard Areas.
    - Construction must conform to VMC Chapter 20.740.120 Critical Areas Protection - Frequently Flooded Areas.
    - Erosion prevention and sediment control be conducted under VMC Chapter 14.24 Water and Sewers – Erosion Control.

- Stormwater control must be conducted under VMC Chapter 14.25 Water and Sewers - Stormwater Control.
- Surface, storm, and groundwater resources must be protected under VMC Chapter 14.26 Water and Sewers – Water Resources Protection.

9. REFERENCES

Allen, J.E., M. Burns, and S.C. Sargent. 1986. Cataclysms on the Columbia. Timber Press, Portland, Oregon.

Allen, J.E., S.F. Burns, and M. Burns. 2009. Cataclysms on the Columbia. Ooligan Press, Portland, Oregon.

Atwater, B.F., and E. Hemphill-Haley. 1997. Recurrence Intervals for Great Earthquakes of the Past 3,500 Years at Northeastern Willapa Bay, Washington. U.S. Geological Survey, Professional Paper 1576.

Baldwin, E. 1976. Geology of Oregon. Kendall Hunt Publishing Company, Dubuque, Iowa. Bartlett, S.F., and T.L. Youd. 1992. Case Histories of Lateral Spreads Caused by the 1964 Alaska Earthquake in Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes: National Center for Earthquake Engineering Research Technical Report NCEER-92-0002, v. 2.

Barnett, E.A., C.S. Weaver, K.L. Meagher, R.A. Haugerud, Z. Wang, I.P. Madin, Y. Wang, R.E. Wells, R.J. Blakely, D.B. Ballantyne, and M. Darienzo. 2009. Earthquake Hazards and Lifelines in the Interstate 5 Urban Corridor: Woodburn, Oregon, to Centralia, Washington. U.S. Geological Survey, Scientific Investigations Map 3027. Scale 1:150,000. Available at <http://pubs.usgs.gov/sim/3027>. Accessed: January 30, 2023.

Bartlett, S.F., and T.L. Youd. 1992. Case Histories of Lateral Spreads Caused by the 1964 Alaska Earthquake in Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes: National Center for Earthquake Engineering Research Technical Report NCEER-92-0002, v. 2.

Beeson, M.H., T.L. Tolan, and I.P. Madin. 1991. Geologic Map of the Portland Quadrangle, Multnomah and Washington Counties, Oregon, and Clark County, Washington. Geologic Map Series 75. Oregon Department of Geology and Mineral Industries. Salem, Oregon. Scale 1:24,000.

Bott, J.D.J., and I.G. Wong. 1993. Historical earthquakes in and around Portland, Oregon. Oregon Geology. 55(5):116–122.

Bretz, H.J., H.T. Smith, and G.E. Neff. 1956. Channeled scablands of Washington: New data and interpretations. Geological Society of America. Bulletin. 67(8):957–1049.

City of Vancouver. 2015. City of Vancouver Comprehensive Water System Plan December 2015. Available at <https://www.cityofvancouver.us/sites/default/files/fileattachments/public_works/page/12392/final_cwsp_chapters.pdf > Accessed September 7, 2022.

City of Vancouver. 2022. 2022 Amendment to the 2016 Water System Plan 4-Year Extension Update. Available at <https://www.cityofvancouver.us/sites/default/files/fileattachments/public_works/page/12392/water_system_plan_amendment_-_signed.pdf> Accessed September 7, 2022.

Collins, C.A., and T.M. Broad. 1993. Estimated average annual ground-water pumpage in the Portland Basin, Oregon and Washington. 1987–1988: U.S. Geological Survey Water-Resources Investigations Report 91-4018, 26.

Craney, Patrick. 2022. Project Engineer, City of Vancouver. Personal communication. Telephone call with Conrad Fischer, Geology and Groundwater Technical Report Author, Interstate Bridge Replacement Program. September 7, 2022.

DGER (Washington Division of Geology and Earth Resources). 2008. Mine Permit Sites. Olympia, Washington.

EPA (U.S. Environmental Protection Agency). 2006. Final Support Documents for Sole Source Aquifer Designation of the Troutdale Aquifer System. Region 10, Seattle Washington. July 2006.

Evarts, R.C., R.M. Conrey, R.J. Fleck, and J.T. Hagstrum. 2009. The Boring Volcanic Field of the Portland-Vancouver area, Oregon and Washington: Tectonically anomalous forearc volcanism in an urban setting, in O'Conner, J.E., Dorsey, R.J., and Madin, I.P., Volcanoes to Vineyards: Geologic Field Trips through the Dynamic Landscape of the Pacific Northwest: The Geological Society of America Field Guide 15 (2009): 253–270.

Geomatrix Consultants. 1995. Final Report: Seismic Design Mapping, State of Oregon. Prepared for Oregon Department of Transportation. Salem, Oregon. Personal Services Contract 11688. January 1995. Project No. 2442.

Gray, J.J., G.R. Allen, and G.S. Mack. 1978. Rock and Mineral Resources of Clackamas, Columbia, Multnomah, and Washington Counties, Oregon.

Gray & Osborne, Inc. 1996. Water System Comprehensive Plan. City of Vancouver. November 1996.

Green, G.L. 1983. Soil Survey of Multnomah County, Oregon. U.S. Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office. P. 146.

Gregor, N.J., W.J. Silva, I.G. Wong, and R.R. Youngs. 2002. Ground-motion attenuation relationships for Cascadia Subduction Zone megathrust earthquakes based on a stochastic finite-fault model. Bulletin of the Seismological Society of America 91(5): 1923–1932, June 2002.

HDR Engineering, Inc. (HDR). 2006. Draft Water System Comprehensive Plan – 2006. City of Vancouver, Washington. March 2006.

Johnson, R.B., and J.V. DeGraff. 1988. Principles of Engineering Geology. John Wiley and Sons. New York, New York.

Johnson, C.N., S.P. Palmer, and J.L. Poelstra. 2005. Rock Aggregate Resources Lands Inventory Map for Clark County, Washington. Washington Division of Geology and Earth Resources. Resource Map 1. October 2005.

Kasbohm, J., and B. Schoene. 2018. Rapid eruption of the Columbia River flood basalt and correlation with the mid-Miocene climate optimum. Scientific Advances, 4(9) September 19, 2018. DOI: 10.1126/sciadv.aat82.

Kelsey, H.M., A.R. Nelson, R.C. Witter, and E. Hemphill-Haley. 2005. Tsunami history of an Oregon coastal lake reveals a 4,600-year record of great earthquakes on the Cascadia Subduction Zone, Geological Society of America Bulletin 117:1009–1032.

Mabey, M.A., G. Black, I.P. Madin, D. Meier, T.L. Youd, C. Jones, and B. Rice. 1997. Relative Earthquake Hazard Map for the Portland Metro Region, Clackamas, Multnomah and Washington Counties, Oregon. Oregon Department of Geology and Mineral Industries. Special Paper #3.

Mabey, M.A., I.P. Madin, and S.P. Palmer. 1994. Relative Earthquake Hazard Map for the Vancouver, Washington Urban Region. Washington Division of Geology and Earth Resources. Geologic Map GM-42.

Mabey, M.A., I.P. Madin, T.L. Youd, and C.F. Jones. 1993. Earthquake Hazard Maps of the Portland Quadrangle, Multnomah and Washington Counties, Oregon, and Clark County, Washington. Oregon Department of Geology and Mineral Industries Geologic. Map Series 79.

Madin, I.P. 1994. Geologic Map of the Damascus Quadrangle, Clackamas and Multnomah Counties, Oregon. Oregon Department of Geology and Mineral Industries Geologic. Map Series 60.

Madin, I.P. 2004. Preliminary Digital Geologic Compilation Map of the Portland Urban Area, Oregon: Oregon Department of Mineral Industries, Open File Report O-04-2.

McFarland, W.D. and D.S. Morgan. 1996. Description of the Groundwater Flow System in the Portland Basin, Oregon, and Washington. U.S. Geological Survey Water Supply. Paper 2470-A.

McCrory, Patricia, Blair, J., F. Waldhauser, and D. Oppenheimer. 2012. Juan de Fuca slab geometry and its relation to Wadati-Benioff zone seismicity. Journal of Geophysical Research (Solid Earth). 117, B09306, DOI: 10.1029/2012JB009407.

McFarland, W.D., and Morgan, D.S. 1996, Description of the Ground-water Flow System in the Portland Basin, Oregon and Washington: U.S. Geological Survey Water-Supply Paper 2470-A. Available at <http://pubs.er.usgs.gov/usgspubs/wsp/wsp2470A> Accessed April 23, 2022.

McGee, D.A. 1972. Soil Survey of Clark County, Washington. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office. p. 71.

Metro. 2018. 2018 Regional Transportation Plan. Available at <https://www.oregonmetro.gov/regional-transportation-plan>. Accessed April 5, 2023.

Miller, D.C. 1989. Potential Hazards from Future Volcanic Eruptions in California: U.S. Geological Survey. Bulletin 1847.

MLRR (Mineral Land Regulation and Reclamation Program). 2009. List of Existing Mining Permits. Oregon Department of Geology and Mineral Industries. Excel Spreadsheet. Updated September 1, 2009.

Mundorff, M.J. 1964. Geology and Ground-Water Conditions of Clark County, Washington, with a Description of a Major Alluvial Aquifer along the Columbia River. U.S. Geological Survey. Paper 1600. Washington D.C.

Myers, B. and S. Brantley. 1995. Volcano Hazards Fact Sheet: Hazardous Phenomena at Volcanoes. U.S. Geological Survey. Open-File Report 95-231.

Nelson, A.R., and S.F. Personius. 1996. Great-Earthquake Potential in Oregon and Washington--an Overview of Recent Coastal Geologic Studies and Their Bearing on Segmentation of Holocene Ruptures, Central Cascadia Subduction Zone: in Roger, A. M., Walsh, T. J., Kockelman, W. J., and Priest, G. R., eds., Assessing Earthquake Hazards and Reducing Risk in the Pacific Northwest, U.S. Geological Survey, Professional Paper 1560.

Nelson, A.R., B.F. Atwater, P.T. Bobrowsky, L.A. Bradley, J.J. Claque, G.A. Carver, M.E. Darienzo, W.C. Grant, HW. Drueger, R. Sparks, T.W. Stafford, Jr., and M. Stulver. 1995. Radiocarbon evidence for extensive plate-boundary rupture about 300 years ago at the Cascadia Subduction Zone. Letters to Nature. 378(23): 372–374.

NRCS (Natural Resources Conservation Service). 1972. Soil Survey of Clark County, Washington.

NRCS. 2004. Understanding Soil Risks and Hazards. Using Soil Survey to Identify Areas with Risks and Hazards to Human Life and Property. Edited by Gary Muckel. U.S. Department of Agriculture. Soil survey publication. Lincoln, Nebraska.

ODOT (Oregon Department of Transportation). 2020. Bridge Design Manual. June 1, 2020. Available at: <https://www.oregon.gov/odot/Bridge/Docs_BDDM/2020-06-BDM.pdf > Accessed May 12, 2021.

Palmer, S.P., S.L. Magsino, J.L. Poelstra, and R.A. Niggemann. 2004. Alternative Liquefaction Susceptibility Map of Clark County. Washington Based on Swanson's Groundwater Model. State Department of Natural Resources, Division of Geology and Earth Resources. September 2004.

Parametrix, S.S. Papadopulos & Associates, Pacific Groundwater Group, and Keta Waters. 2008. Vancouver Lake Lowlands Groundwater Model Summary Report. Prepared for Port of Vancouver and Clark Public Utilities February 2008.

Parsons Brinckerhoff. 2009. Oregon Landslide Bridges & Walls. Columbia River Crossing. Multnomah County, Oregon, Task AE Draft Preliminary Geotechnical Report. March 16, 2009.

Personius, S.F., R.L. Dart, L.A. Bradley, and K.M. Haller. 2003. Map of Quaternary Faults and Folds in Oregon. U.S. Geological Survey. Open-File Report 03-095, v.1.1, Scale: 1:750,000.

Phillips, W.M. 1987. Geologic map of the Vancouver Quadrangle, Washington and Oregon. Washington Division of Geology and Earth Resources. Open File Report 87-10.

Portland Water Bureau, 2020 Water Management and Conservation Plan. Available at: <https://www.portland.gov/sites/default/files/2020/wmcp-layout_2020-09-15_web_0.pdf> Accessed September 2022.

Pratt, T.L., J. Odum, W. Stephenson, R. Williams, S. Dadisman, M. Holmes, and B. Haug. 2001. Late Pleistocene and Holocene tectonics of the Portland Basin, Oregon and Washington, from high-resolution seismic profiling. Bulletin of the Seismological Society of America. 4(9).

Robinson, Noble and Carr, Inc. 1980. City of Vancouver, Ground Water Source and Use Study. Volumes I and II. July 1980.

RTC (Regional Transportation Commission). 2019. Regional Transportation Plan for Clark County. Available at <https://www.rtc.wa.gov/programs/rtp/clark/>. Accessed June 6, 2023.

Schlicker, H.G., and C.T. Finlayson. 1979. Geology and Geologic Hazards of Northwestern Clackamas County, Oregon. Oregon Department of Geology and Mineral Industries, Bulletin 99.

Scott, W.E., T.C. Pierson, S.P. Schilling, J.E. Costa, C.A. Gardner, J.W. Vallance, and J.J. Major. 1997. Volcano Hazards in the Mount Hood Region, Oregon. U.S. Geological Survey Open File Report 97-89.

Scott, W.E., R.M. Iverson, J.W. Vallance, and W. Hildreth. 1995. Volcano Hazards in the Mount Adams Region, Washington. U.S. Geological Survey. Open-File Report 95-492.

Shannon & Wilson, Inc. 2008. Geotechnical Report Columbia River Crossing Project–Interstate 5. Preliminary Foundation Evaluation Main Span (In-Water Piers) Vancouver, WA, and Portland, OR. August 2008.

Singer, M.J., and D.N. Munns. 1999. Soils: An Introduction. Fourth Edition. Prentice-Hall. New York, New York.

Snyder, D.T. 2008. Estimated Depth to Ground Water and Configuration of the Water Table in the Portland, Oregon Area. U.S. Geological Survey. Scientific Investigations Report 2008–5059.

Snyder, D.T., D.S. Morgan, and T.S. McGrath. 1994. Estimation of Ground-water Recharge from Precipitation, runoff into Drywells, and On-site Waste-Disposal Systems in the Portland Basin, Oregon, and Washington. U. S. Geological Survey. Water Resources Investigation Report 92-4010. Portland, Oregon.

Swanson, R.D., and I. Leschuk. 1991. Orchards Aquifer, Two-Dimensional Finite Difference Numerical Model. Intergovernmental Resources Center. November 1991.

Swanson, R.D., J.B. McFarland, J.B. Gonthier, and J.M. Wilkinson. 1993. A Description of Hydrogeologic Units in the Portland Basin, Oregon and Washington. U.S. Geological Survey. Water Resources Investigative Report 90-4196.

Trimble, D.E. 1963. Geology of Portland, Oregon, and Adjacent Areas. U.S. Geological Survey. Bulletin 1119.

USCG (U.S. Coast Guard). 2022. Preliminary Navigation Clearance Determination for the Interstate Bridge Replacement Program. Letter to Thomas D. Goldstein, PE, IBR Program Oversight Manager, FHWA, from B. J. Harris, Chief, Waterways Management Branch, Coast Guard District 13. June 17. Available at

<https://www.interstatebridge.org/media/fi2b3xei/ibr_next_steps_bridge_permitting_june2022_remediated.pdf>. Accessed September 25, 2023.

USGS (U.S. Geological Survey). 2022. National Seismic Hazard Maps. Available at: <http://eqhazmaps.usgs.gov>. Accessed August 2022.

Waitt, R.B. 1985. Case for periodic, colossal jokulhlaups from Pleistocene glacial Lake Missoula. Geological Society of America Bulletin 96(10).

Wells, R.E., R. A. Haugerud, A.R. Niem, W. A. Niem, L. Ma, R. C. Evarts, J.E. O'Connor, I.P. Madin, D.R. Sherrod, M.H. Beeson, T.L. Tolan, K.L. Wheeler, W.B. Hanson, and M.G. Sawlan. 2020. Geologic map of the greater Portland metropolitan area and surrounding region, Oregon and Washington: U.S. Geological Survey Scientific Investigations Map 3443, pamphlet 55 p., 2 sheets, scale 1:63,360. Available at: <https://doi.org/10.3133/sim3443>. Accessed January 30, 2023.

Wolfe, E.D., and T.C. Pierson. 1995. Volcanic-Hazard Zonation for Mount St. Helens, Washington. U. S. Geological Survey. Open-File Report 95-497.

Wong, I.G., W. Silva, J. Bott, D. Wright, P. Thomas, N. Gregor, S. Li M. Mabey, A. Sojourner, and Y. Wang. 2000. Earthquake Scenario and Probabilistic Ground Shaking Maps for the Portland, Oregon, Metropolitan Area. Oregon Department of Geology and Mineral Industries. Interpretive Map Series IMS-16.

Wong, I.G. 2005. Low Potential for Large Intraslab Earthquakes in the Central Cascadia Subduction Zone. Seismological Society of America. Bulletin. 95(5): 1880–1902, October 2005.

WSDOT (Washington Department of Transportation). 2020. Bridge Design Manual. September 2020. Available at: <https://www.wsdot.wa.gov/publications/manuals/fulltext/M23-50/BDM.pdf>. Accessed May 12, 2021.

Youd, T.L. 1993. Liquefaction, Ground Failure and Consequent Damage during the 22 April 1991 Costa Rica Earthquake. Abridged from EERI Proceedings. U.S. Costa Rica Workshop. 1993.