CONDITION REPORT

Dillenbaugh Creek Culvert Assessment

Final

January 2017

City of Chehalis

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Image 1: Exit 77 during Flooding (Washington State Department of Transportation, 2007)

1.0 Executive Summary

This Dillenbaugh Creek Stream Crossing Study and Analysis is comprised of 10,750 acres of drainage basin, 4 miles of creek, and 17 stream crossings. Each of the crossings was documented using a combination of site visit photos, hand measurements, and survey. The crossings were then analyzed for hydraulic capacity by looking at the FEMA Flood Maps (Observed Capacity) to obtain 100-year flood levels, using Manning's Equation to obtain headwater at the 25 and 100-year flood levels, and modeling the flood levels using the US Army Corps of Engineers modeling program HEC-RAS. Each crossing's fish passage suitability was also analyzed using the Stream Simulation Analysis from measured bankfull width. The following stream crossings were considered hydraulically undersized. See Appendix E for a map of stream crossing locations.

High Priority:

DB15 Double Box Culvert Under Bishop Road

DB10 Double Box Culvert under Rice Road

Low Priority:

DB11 Abandoned Farmhouse Access Road

DB09 Abandoned Railroad Bridge

Outside the feasibility of a City of Chehalis Infrastructure Improvement Project

DB13 Double Box Culvert Under I-5 On-Ramp at Exit 74

DT01 Double Box Culvert under I-5 at at Exit 76

DB06 Single Track Timber Railroad Bridge

DB05 Concrete Bridge for I-5 Off-Ramp at Exit 77

2.0 Project Description

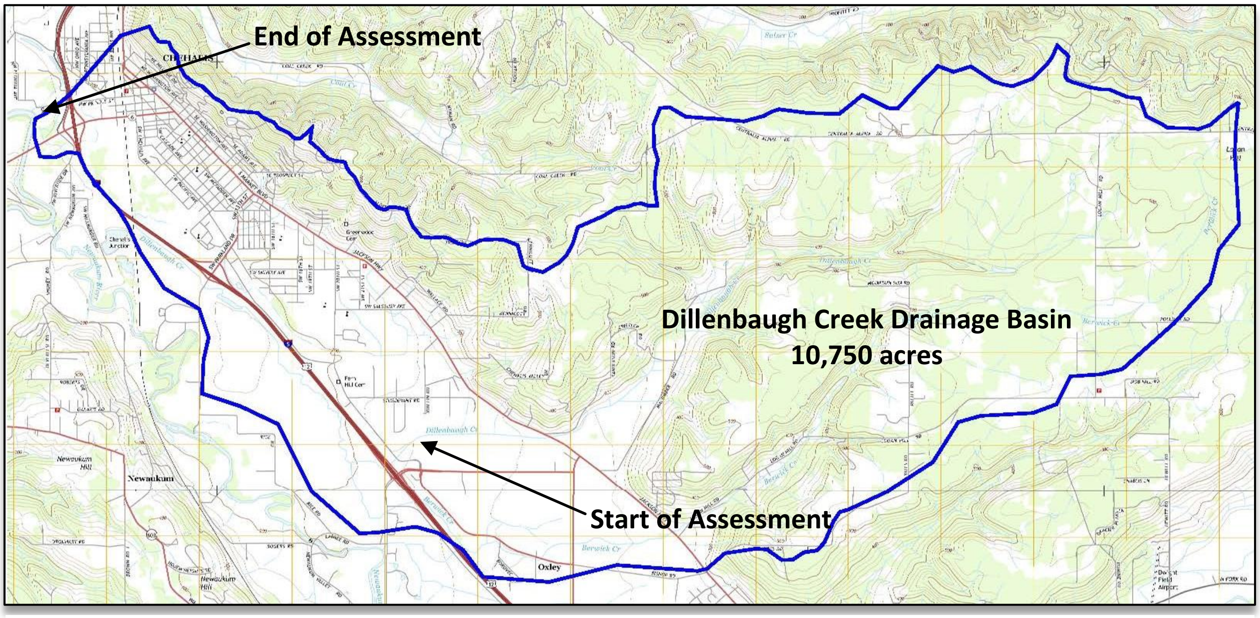

Image 2: Basin Exhibit on USGS Chehalis Quadrangle

Due to a history of flooding, the City of Chehalis contracted Skillings Connolly, Inc to perform an asset inventory and hydraulic analysis of all Dillenbaugh Creek crossings from 46°37’47.25” N, 122°55’49.17” W to 46°39’37.38” N, 122°59’02.54” W. This report documents the results of the study in three sections: explanation of assessment methodology, individual stream crossing results, and recommendations based on analysis results. Each stream crossing will be assessed on condition, hydraulic sizing, and fish passage compliance. This report will assist the City of Chehalis in prioritizing infrastructure improvements to decrease property damage during the rainy season.

Dillenbaugh Creek is located in Lewis County Washington, with the majority of the drainage basin and Creek located within the City of Chehalis. It is a tributary of the Chehalis River and has two tributaries of its own: Berwick Creek and Dilly Twig Creek. The Dillenbaugh Creek drainage basin is approximately 10,750 acres, comprising both urban and rural areas with hydrologic soil types[1] A through D.

[1] **Hydrologic Soil Type**: A classification based on the rate of water infiltration and runoff potential after saturation.

3.0 Basin Description

The 10,750 acre Dillenbaugh Creek Drainage Basin falls within WRIA[2] 23, T13N R01W, and consists primarily of rural farm land, forest lands, and a smaller industrial and urban area near the west border of the basin along Interstate 5. The north border ridge parallels Coal Creek Road and the Centralia Alpha Road. The east border ridge runs south from Logan Hill and separates Berwick Creek and Taylor Creek. The south border ridge parallels Yates Road and continues until Yates becomes Bishop Road. The west basin border is the ridge separating Dillenbaugh creek and the Newaukum River (See Image 2).

Annual precipitation for Dillenbaugh Creek Drainage basin is 40-50 inches (See Appendix A). Dillenbaugh Creek and Berwick Creek are the primary drainage systems of the basin. The two creeks run parallel to each other flowing from east to west. Dillenbaugh Creek is north of Berwick Creek. Berwick Creek flows into Dillenbaugh Creek. The junction of the two streams is located on the west side of Interstate 5 near the Labree Road exit of Interstate 5. Both of these streams are rated as a category 4A under the 303(D) list in the Washington State Department of Ecology Water Quality Assessment Program (Department of Ecology, n.d.). The 303(D) list comprises those waters that are in the polluted water category, for which beneficial uses such as drinking, recreation, aquatic habitat, and industrial use are impaired by pollution. These streams have an active Total Maximum Daily Load (TMDL) in place. These Creeks are actively being monitored by the Washington State Department of Ecology as the streams are being restored to meet the standards set forth under the Federal Clean Water Act.

Berwick creek is approximately 11 miles in length and has approximately 29 surface flowing tributary streams that flow into it. The headwater for Berwick creek is located on Logan Hill at the northeast corner of the basin boundary. This Creek has been identified by the Washington State Department of natural resources (DNR) as fish bearing stream. According to the FPARS/DFW map, five of the streams that contribute to Berwick Creek are Fish bearing streams.

Dillenbaugh creek is approximately 12 miles in length and has approximately 25 surface flowing tributary streams, including Berwick Creek. Approximately 2.4 miles of Dillenbaugh Creek are designated as shorelines of the State by the Washington State Department of natural resources (DNR). Approximately 14 of the streams that contribute to Dillenbaugh creek are fish bearing streams, according to the Forest Practices Application Mapping Tool(FPARS) (Washington State Department of Natural Resources, n.d.).

The Basin has slopes ranging from 0-65%. The Basin is composed of soils that have ranked by the National Resource Conservation Service (NRCS) into hydrologic soil groups based on estimated runoff potential. These hydrologic soil groups are A, B, C, C/D, and D. These ratings indicate the soils infiltration rate. Soils with an “A” rating have a high infiltration rate (low runoff potential) while soils with a “D” rating have a slow rate of infiltration (high runoff potential). Infiltration rates decrease in alphabetical order in this rating system. In the dual classification “C/D” the first letter is for drained areas and the second letter is for undrained areas (See Table 1).

[2] **WRIA**: “Water Resource Inventory Area”; Ecology and other state natural resource agencies have divided the state of Washington into 62 “WRIAs” to delineate the state’s major watersheds (Department of Ecology, n.d.).

Table 1: NRCS Hydrologic Groups and Definitions

NRCS Hydrologic Soil Groups and Definition (NRCS, 2015)	
Soil Group	**Group Definition**
A	Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
B	Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
C	Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
D	Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high-water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.
C/D	If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

Table 2. Basin Soils Slope and NRCS Rating

Soil Type	Slope	NRCS Rating	Percentage of Basin Area
Buckpeak Silt Loam	30-65%	B	7%
Lacamus Silt Loam	0-8%	C/D	17%
Reed Silty Clay Loam	0	D	11%
Prather Silty Clay Loam	0-30%	C	32%
Salkum Silty Clay Loam	0-65%	C	22%
Scamman Silty Clay Loam	0-30%	C/D	3%
Various soil types	0-30%	B,C, & C/D	8%

The main soil types in the drainage basin are Buck peat Silt Loam, Lacamus Silt Loam, Reed Silty Clay Loam, Prather Silty Clay Loam, Salkum Silty Clay Loam, and Scamman Silty Clay Loam. The remainder of the basin is composed of small pockets of various soil types each with Slopes varying from 0-65%. See Table 2 for soil types, slopes, NRCS Rating, and percentage within the basin. The areas of soils with high infiltration rates have a higher probability of transmitting groundwater to the tributary and primary surface streams by inflow (See Figure 1). For a complete soil report, see Appendix D.

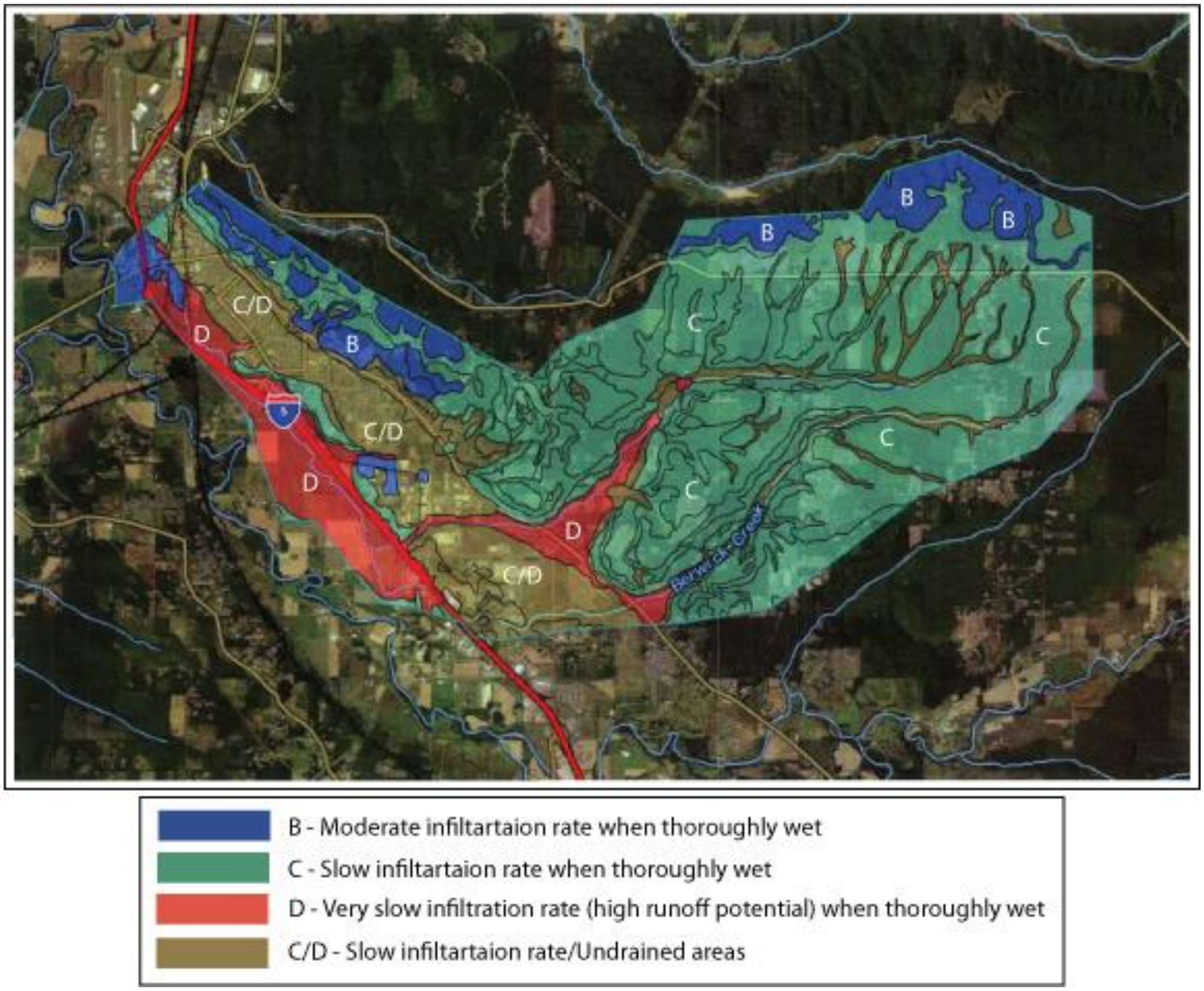

Figure 1: NRCS Soil Survey Map of Dillenbaugh Drainage Basin

Most of the annual precipitation arrives during the winter months when water demand is at its lowest. The streams of this basin depend on surface flow and groundwater inflow. During the summer months demand for water consumption is at its highest. This means that groundwater and surface water levels are at the lowest when the demand is at its highest.

4.0 Site Condition Assessment Methodology

Typical inspection for a more detailed inspection of the bridges would include the following methods:

- Conduct initial visual assessment with hammer sounding[3].
- Obtain moisture content measurements in suspect and decay prone areas.
- Establish baseline non-destructive evaluation (NDE) data by collecting stress wave and resistance micro-drilling data from areas of suspected sound wood
- Investigate marked areas to measure the extent of internal deterioration by utilizing stress wave timer[4] and resistance[5] micro-drilling tool as needed.

Typical inspection for a more detailed inspection would include the following methods:

- Obtain the culvert's length, size, age, height of cover, wheel loading[6] and material type.
- Document type and condition of end treatment, including end sections, headwalls, rip-rap, nothing, etc.
- Document waterway condition, such as inlet blockage/debris affecting hydraulic performance.
- Investigate inlet and outlet scour condition, including erosion parallel to the culvert
- Take detailed measurements of geometry of flexible culverts.
- Analyze culvert wall thickness and condition: cracking, extent of corrosion, spalling[7], and exposed rebar.
- Investigate infiltration and loss of structural backfill through joints, cracks or inlets.
- Document evidence of roadway settlement or repair including pavement distress, cracks or signs of recent repairs and repaving efforts, and guardrail sagging over the culvert.
- Review installation records to obtain backfill requirements or specifications.

[3] **Hammer sounding**: a non-destructive investigative technique where by the quality of sound obtained by striking the surface of the material with a hammer indicates the quality of the material (The Concrete Portal, 2016).
[4] **Stress wave timer**: an investigative technique using a special hammer to emit a low frequency impulse that starts a sound wave through the wood. The device measures the time it takes for sound to travel through the stem (Bob Monk, n.d.).
[5] **Electrical resistance**: an investigative technique using a probe with two wires on the tip to measure electrical resistance (Bob Monk, n.d.).
[6] **Wheel loading**: The amount of weight allotted to any one axel of a vehicle on a given road.
[7] **Spalling**: Flaking of concrete on the surface of a structure.

5.0 Hydraulic Analysis Methodology

The purpose of this study was to assess the adequacy of the existing culverts and bridges along Dillenbaugh Creek during high intensity rain events[8]. Flood water flow, velocity, and stage was analyzed against the existing structures. Two methods of analysis were used to ensure accuracy and redundancy: hand calculations using Manning's Equation and the United States Army Corps of Engineers modeling software HEC-RAS. Both methods produce headwater[9], critical depth[10], and velocity values.

Defining Acceptable Values

A bridge or culvert is expected to accommodate floodwater with a certain headwater value. Depths in excess of these values can cause failure of the culvert, failure of the road and embankment, damage to bridge structure, upstream flooding, or blockage of roads essential to emergency response. For these reasons, the following headwaters are expected:

Table 3: Allowable Headwater Depths

	Bridge, bottomless culvert, or culvert width in excess of 20 ft	Culvert
25 year	HW < Elevation allowing 1 foot of debris clearance to low chord elevation[11]	HW < 1.25D*
100 year	HW < Low chord elevation	HW < Elevation of Centerline of Road**

*D = Distance from culvert/bridge invert to low cord.
**Headwater overtopping the road is allowable if the road:
a) Is not essential for emergency personnel.
b) Is not a state route.
c) Embankment is designed to withstand the depth and velocity of expected 100-year storm flows

Floodwater velocity under bridges or through culverts is expected to fall within the range of 3 ft/s to 10 ft/s. Velocity values below 3 ft/s are prone to sedimentation which, over time, may cause blockage of the culvert flow area. Velocity values above 10 ft/s cause abrasion of culvert walls due to bed load movement[12] and increase the risk of scour holes[13], culvert undermining, and damage to downstream property.

Those culverts or bridges whose headwater and velocity values fall outside the acceptable ranges will be considered inadequate or undersized.

[8] **High Intensity Rain Events**: the 2, 5, 10, 25, 50, and 100-year storms as defined by a 50%, 20%, 10%, 4%, 2%, and 1% chance respectively.
[9] **Headwater**: The depth of water, as measured from the bottom of the upstream end of the culvert.
[10] **Critical Depth**: The depth of flow where energy is at a minimum for a particular discharge.
[11] **Low Chord Elevation**: The lowest point on a bridge that may impede flow.
[12] **Bed Load Movement**: A type of sediment transport along a river bed.
[13] **Scour Holes**: An area of erosion caused by the turbulent flow surrounding an object impeding flow.

Calculation of Expected Flows

Both the hand calculations of the Manning's Equation and the USACE modeling software HEC-RAS require the input of expected flow in cubic feet per second. The following steps were taken to obtain those flows.

1. Basin Delineation and Definition

Using the USGS 7.5 minute maps Centralia Quadrangle Washington-Lewis Co. and Napavine Quadrangle Washington-Lewis Co. (Survey, 2012) the following areas were delineated:

a. The limit of the Dillenbaugh Creek basin.
b. The flat and steep zones with a dividing grade of 10%.
c. The zones of pasture, forest, and urbanization.

2. Soil Type Delineation and Definition.

From the USDA Web Soil Survey (NRCS, 2015), the hydrologic soil types were overlayed on the USGS map and delineated. The soil survey indicated 5 soil types: A, B, C, C/D, and D. Initial flows were estimated assuming type C/D as type C. See Appendix D for complete soil report.

3. WWHM Flow Estimation

Using the Western Washington Hydraulic Model (WWHM), the Dillenbaugh Creek basin was defined by acreage with the following variables: flat/steep, lawn/pasture/forest/roadways, soil types A/B/C/SAT. The density of the City of Chehalis Urban area was such that 95% impervious area[14] was estimated. Therefore, 95% of the area designated as urban was input as "Impervious-Roadway" and 5% of the area designated as urban was input as "Pervious-SAT-Flat-Lawn."

With the above variables defined, WWHM output flow values for the 2/5/10/25/50/100-year storm events.

4. Base Flow Estimation

While WWHM outputs surface flow values for rain events, it does not produce base flow values resulting from year-round groundwater seepage. These flows are obtained through historical flow records. The average minimum groundwater seepage for the wet season of November to March is considered the base flow.

The Washington State Department of Ecology River and Stream Flow Monitoring Program (Clishe, 2016) records flow (cfs), stage (feet), water temperature (°C), and air temperature (°C) at each station. Select stations also record rainfall, turbidity, dissolved oxygen, pH, conductivity, and nitrogen. As of May 2016, the Department of Ecology (ECY) installed a river monitoring station for Dillenbaugh Creek at Riverside Drive, Site 14 of this study.

As this site does not yet have recorded values for the months of November to March, a nearby river monitoring station of similar composition was used to estimate base flow values. Dillenbaugh Creek

[14] **Impervious Area**: A section of ground covered by impenetrable surfacing such as concrete, asphalt, or rooftops.

at Riverside Drive has an average monthly minimum daily mean (MMDM) of 1.49 cfs for the available months of May to September. Salzer Creek at Airport Road has an average MMDM of 0.94 cfs for the same months of May to September. These values indicate that Dillenbaugh Creek base flows should be 1.59x that of Salzer Creek base flows. The average MMDM for Salzer Creek during the wet season is 25.6 cfs. Using a factor of 1.59, the average MMDM for Dillenbaugh Creek is expected to be 40.6 cfs.

5. Flow Estimation Adjustment using Historic Values and Rain Event Site Visits

Using 10-year flows as calculated above, the estimated headwater was found to be significantly below the 10-year storm level as witnessed during a December 2015 Chehalis rain event. Upon reevaluation of methodology, soil types A, B, C, and C/D were assumed to be saturated. This assumption was made for two reasons:

a. A 25 or 100-year flood event would most likely take place during the wet season when the soil is saturated from repeated rain events.
b. The City of Chehalis is in a flood plain where groundwater elevations are historically high (Ecology, 2016).

Using the updated flows, the HEC-RAS model returned the flooding at the expected elevation for a 10-year flood event.

Modeling Dillenbaugh Creek Flows Using Manning's Equation Hydraulic Calculations

Two types of flow were evaluated: culvert flow and open channel flow. Each creek cross was evaluated individually. Double barrel box culverts were evaluated as single barrel culverts, neglecting the dividing wall.

For culverts, both inlet[15] and outlet control[16] headwater was calculated. The greater resulting headwater dictated the method of velocity calculation. Critical depth was calculated assuming outlet control.

For open channel flow, headwater and velocity were calculated using an iterative method in Excel.

This method is limited in its usefulness in that there are only 3 outputs: headwater, critical depth, and velocity. This method does not give any indication as to what is occurring in the area directly surrounding the creek crossing.

Modeling Dillenbaugh Creek Flows Using USACE HEC-RAS

The study area of Dillenbaugh Creek was modeled as one system rather than as individual culverts. For this project, both the River tab in AutoCAD Civil 3D 2016 and HEC-RAS 5.0 were used

[15] **Inlet Control**: The condition under which the inlet is controlling the amount of flow that will pass through the culvert. Nothing downstream of the culvert entrance will influence the amount of headwater required to pass the design flow (Design Office, Engineering and Regional Operations Division, 2015).

[16] **Outlet Control**: The condition under which the outlet conditions or barrel are controlling the amount of flow passing through the culvert. The inlet, barrel, or tailwater characteristics, or some combination of the three will determine the amount of headwater required to pass the design flow (Design Office, Engineering and Regional Operations Division, 2015).

The first step in this method is to model the topography of the study area using LiDAR files[17] from the Puget Sound Lidar Consortium (Martinez, 2012). Using this surface and an approximate flow path, sections were set every 50 feet at 300 feet in width. Culverts and bridges are defined using an upstream and downstream section. Using the same inputs required by the hand calculations, the model can supply numerous outputs. For the purposes of this study, the following outputs were used: headwater, tailwater, critical depth, section profile, flow path profile, flood mapping, and velocity.

The River tab is limited in that flow input is constant throughout the flow path. This is an inaccurate representation of events as the contributing basin increases downstream. Flood basin mapping can be approximated by running a flow analysis at each stream crossing's expected sub basin flows and interpolating the extents. The remaining outputs are best acquired by exporting the project from River Tab Civil 3D to HEC-RAS 5.0. In HEC-RAS, data input is more difficult but flows can be directed to increase along a flow path. Additionally, the output values and graphics are clearer and easier to use.

6.0 Fish Passage Analysis Methodology

Design of fish passage along road crossings follows guidelines from the Washington State Department of Fish and Wildlife (WDFW). The Stream Simulation design approach is to "Simulate" the adjacent natural channel. Fish passage is based on the premise that if fish can move through the natural channel, they can move through a simulated channel within the culvert. The Stream Simulation method is best applied to small, stable, moderately confined channels with limited need for profile adjustment. Dillenbaugh Creek is a fairly small sub-basin and the use of the Stream Simulation method is appropriate to determine fish passage sizing requirements.

While the assessment of road culverts along Dillenbaugh Creek does not include design of culverts, the assessment includes evaluation of the natural condition of the stream at each crossing, including bankfull width and slope. While other stream aspects (e.g. cobble size) were observed, it was not used to evaluate existing fish passage.

To determine bankfull width, multiple measurements were taken upstream and downstream of each road crossing. Measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet.

While the slope of each crossing was evaluated, it was not used as a significant factor in determining fish passage sizing. Fish passage sizing focused on structure width, both to determine if the existing structure currently provides for a simulated channel and to determine the structure size needed to meet fish passage requirements if the structure requires replacement due to other structural needs.

[17] **LiDAR**: Light detection and ranging is a method of gathering topographic data using a combination of lasers and light detection receivers. This type of surveying is typically done for an area prohibitive in size or accessibility to traditional survey methods.

7.0 Existing Conditions and Analysis

DB16: Railroad Bridge

Image 3: DB16 Railroad Bridge Near Exit 74

Specifications	
Type	Timber Bridge
Span	29.5 feet
Low Chord Height	8.83 feet
Length	10 feet
Bank Full Width	26.5 feet

Model Values	
Creek Base Width *b*	15 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Flows	
2-year	353
5-year	605
10-year	753
25-year	910
50-year	1006
100-year	1087

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	208.18 feet
Bridge Deck Elevation	219.49 feet
USGS Map Centralia Quadrangle	
Site Elevation	222 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	212 feet

Image 4: DB16 Aerial Image

Site Condition:

The timber truss railroad bridge over Dillenbaugh Creek near Bishop Road is a single track structure. There are no obvious signs of serious deterioration above the current water line. There are typical cracks often associated with timber beams and pilings but as the timbers are creosote[18] treated, there is minimal impact from the freshwater creek. The metal hardware has typical signs of surface rust, but none of the bolts appear to be missing or compromised. This visual inspection was conducted through image and video analysis. Typical inspection for a more detailed inspection would include the following methods:

- Conduct initial visual assessment with hammer sounding.
- Obtain moisture content measurements in suspect and decay prone areas.
- Establish baseline NDE data by collecting stress wave and resistance micro-drilling data from areas of suspected sound wood
- Investigate marked areas to measure the extent of internal deterioration by utilizing stress wave timer and resistance micro-drilling tool as needed.

[18] **Creosote**: A product created by high-temperature treatment of beech and other woods, coal, or from the resin of the creosote bush. Coal tar creosote is the most widely used wood preservative in the United States (Department of Ecology, State of Washington, n.d.).

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map (FEMA, 2010), revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRMs use NAVD88[19] rather than NGVD29[20], used by the current FEMA FIRMs. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 3.82 feet with an allowable depth of 8.83 feet. For this method of analysis, the bridge is suitably sized and not an area of concern.

Calculated Capacity:

Table 4: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	13.31 ft	<7.83 ft
	Velocity of Flow	1.24 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.76 ft	-
100 Year Rain Event	Depth of Flow	14.38 ft	<8.83 ft
	Velocity of Flow	1.30 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.14 ft	-

These calculations were based using the trapezoidal open channel flow method. Based on the calculated values, the 25-year rain event has a flow depth 5.48 feet greater than the allowable value and the 100-year rain event has a flow depth 5.55 feet greater than the allowable value. These values are very conservative and assume the channel values are continuous up and downstream. In reality, the creek bed up and downstream is three to four times the width of the bridge and there is a pond just south east of the bridge. Both of these characteristics would provide flood storage and additional flood area. For these reasons, this model is not an accurate method of determining the suitability of this bridge.

[19] **NAVD88**: The North American Vertical Datum of 1988 is the vertical control datum established in 1991 that references the International Great Lakes Datum of 1985 local mean sea level height value (National Geodatic Survey, 2016).
[20] **NGVD29**: Also known as the Sea Level Datum of 1929, the National Geodetic Vertical Datum of 1929 is a vertical control datum set by the general adjustment of 1929 (National Geodetic Survey, 2016).

Modeled Capacity

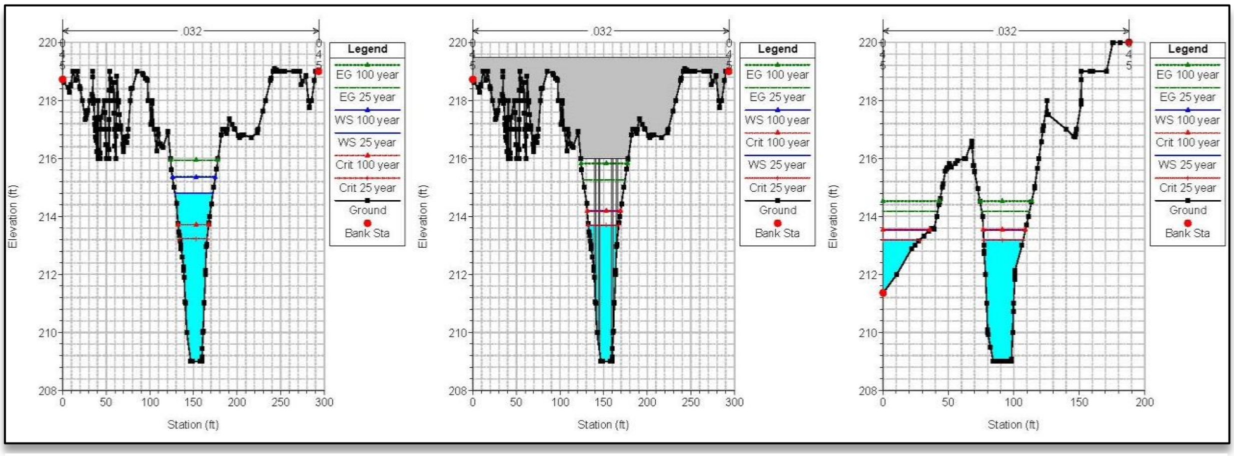

Figure 2: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium (Martinez, 2012), survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account. The model not only showed a base flood elevation similar to the 2007 observed values, but showed the expected flood storage in the adjacent pond.

Table 5: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	**Depth of Flow**	4.69 ft	<7.83 ft
	Velocity of Flow	10.03 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.69 ft	-
100 Year Rain Event	**Depth of Flow**	5.19 ft	<8.83 ft
	Velocity of Flow	10.26 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	5.19 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 3.14 feet less than the allowable value and the 100-year rain event has a flow depth 3.64 feet less than the allowable value. These values are in the range expected given the observed flows of 2007. The downstream cross sections show tailwater[21] elevations of 3.68 feet and 3.90 feet for the 25 and 100-year event respectively. The velocity values for both the 25 and 100-year event are outside the preferred range, but not unexpected given the large flows.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation

[21] **Tailwater**: The depth of water, as measured from the bottom of the downstream end of the culvert.

sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This Rail Road Bridge crossing has average Bank Full Width of 26.5 feet. Fish Passage criteria requires 33.8 feet of bridge span at this site with an existing bridge span of 29.5 feet.

Conclusion:

The timber railroad bridge of DB16 is hydraulically sized for the 25 and 100-year storm events. The flow velocity for both evaluated rain events is just above the preferred values, but site conditions do not indicate an issue with bridge scour or erosion downstream. If future site conditions show indications of deterioration, energy dissipaters or embankment protection could be considered. The bridge is currently undersized to provide adequate fish passage. Should future development be considered, the bridge span should be sized at a minimum of 33.8 feet.

DB15: Double Box Culvert under Bishop Road

Image 5: DB15: Double Box Culvert under Bishop Road

Specifications	
Type	D. Box Culvert
Span	10 ft,10 ft
Height	6.5 feet
Length	68 feet
Bank Full Width	19.2 feet

Model Values	
Culvert Base Width *b*	15 feet
Culvert Height	6.5 feet
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.015

Flows	
2-year	361
5-year	615
10-year	764
25-year	922
50-year	1018
100-year	1099

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	198.66 feet
Bridge Deck Elevation	214.76 feet
USGS Map Centralia Quadrangle	
Site Elevation	215 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	204 feet

Image 6: DB15 Aerial Image

Site Condition:

The double box culvert over Dillenbaugh Creek at Bishop Road is a bottomless, concrete structure in an established creekbed. A visual inspection of the box culvert was completed through field documented photographs and video. The box culvert shows no signs of cracking, corrosion, spalling or exposed rebar in any sections of the culvert. However, signs of water penetration, water stained concrete and light spalling can be seen in and around the joints. Typical inspection for a more detailed inspection would include the following methods:

- Obtain the culvert's length, size, age, height of cover, wheel loading and material type.
- Document type and condition of end treatment, including end sections, headwalls, rip-rap, nothing, etc.
- Document waterway condition, such as inlet blockage/debris affecting hydraulic performance.
- Investigate inlet and outlet scour condition, including erosion parallel to the culvert
- Take detailed measurements of geometry of flexible culverts.
- Analyze culvert wall thickness and condition: cracking, extent of corrosion, spalling, and exposed rebar.
- Investigate infiltration and loss of structural backfill through joints, cracks or inlets.
- Document evidence of roadway settlement or repair including pavement distress, cracks or signs of recent repairs and repaving efforts, and guardrail sagging over the culvert.
- Review installation records to obtain backfill requirements or specifications.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 5.34 ft with an allowable depth of 6.5 ft. For this method of analysis, the culvert is suitably sized and not an area of concern.

Calculated Capacity:

Table 6: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	6.60 ft	<5.5 ft
	Velocity of Flow	7.09 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.00 ft	-
100 Year Rain Event	Depth of Flow	7.43 ft	<6.5 ft
	Velocity of Flow	8.45 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.50 ft	-

These calculations were based using the outlet control box culvert method. Based on the calculated values, the 25-year rain event has a flow depth 1.10 ft greater than the allowable value and the 100-year rain event has a flow depth 0.93 ft greater than the allowable value. These values are very conservative and assume the channel values are continuous up and downstream. In reality, the creek bed up and downstream is two to three times the width of the bridge and would provide flood storage and additional flood area. The velocities calculated by this method are within the allowable range and are not a cause for concern.

Modeled Capacity

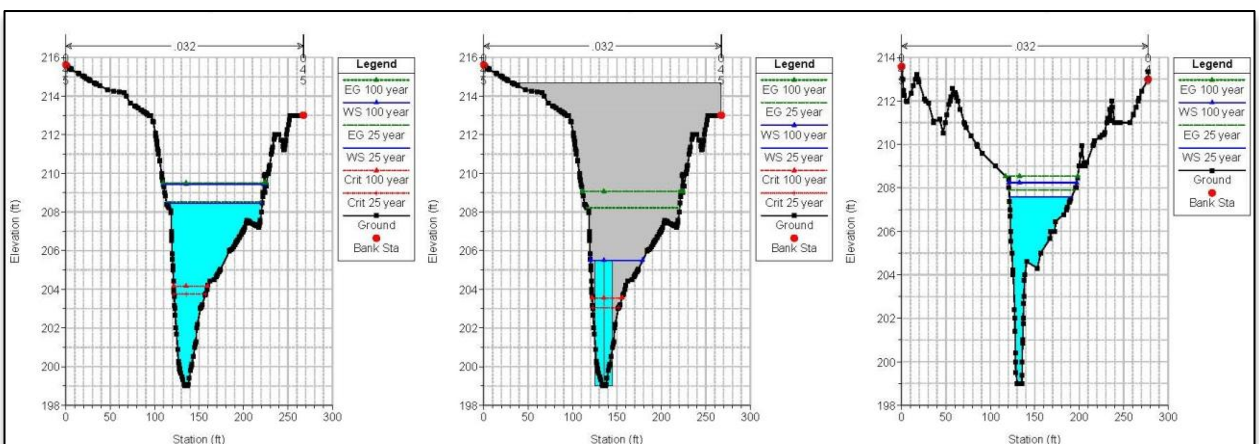

Figure 3: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the culvert could be taken into account.

Table 7: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	9.54 ft	<5.5 ft
	Velocity of Flow	7.9 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.04 ft	-
100 Year Rain Event	Depth of Flow	10.51 ft	<6.5 ft
	Velocity of Flow	8.86 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.36 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 4.4 ft greater than the allowable value and the 100-year rain event has a flow depth 4.1 ft greater than the allowable value. These values are greater than the observed flows of 2007 but not improbable given the large flows. The downstream cross sections show tailwater elevations of 8.69 ft and 9.35 ft for the 25 and 100-year event respectively. The velocity values for both the 25 and 100-year event are within the allowable range and comparable to the Manning's equation calculated values.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This double box culvert has average Bank Full Width of 19.2 feet. Fish Passage criteria requires 25.04 feet of span at this site with an existing span of 20 feet.

Conclusion:

The bottomless, double box culvert of DB15 is hydraulically undersized for the 25 and 100-year storm events according to both the Manning's equation calculations and the HEC-RAS hydraulic model. The flow depth for both evaluated rain events is greater than the height of the culvert which restricts debris passage and can cause damage to the culvert and road embankment. The flow velocity for both evaluated rain events is within the allowable values and site conditions do not indicate an issue with culvert undermining or erosion downstream. There is minor river rock build up at the entrance of the north barrel but an increase in design velocity is not recommended. The culvert is currently undersized to provide adequate fish passage. Should future development be considered, the culvert span should be sized at a minimum of 25.04 feet.

DB14: Box Culvert under I-5 On-Ramp @ Exit 74

Image 7: DB14: Box Culvert under I-5 On-Ramp @ Exit 74

Specifications	
Type	Box Culvert
Span	26 feet
Height	8.25 feet
Length	43 feet
Bank Full Width	21 feet

Model Values	
Culvert Base Width *b*	26 feet
Culvert Height	8.25 feet
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.015

Flows	
2-year	366
5-year	621
10-year	771
25-year	929
50-year	1025
100-year	1106

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	196.84 feet
Bridge Deck Elevation	220.80 feet
USGS Map Centralia Quadrangle	
Site Elevation	213 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	202 feet

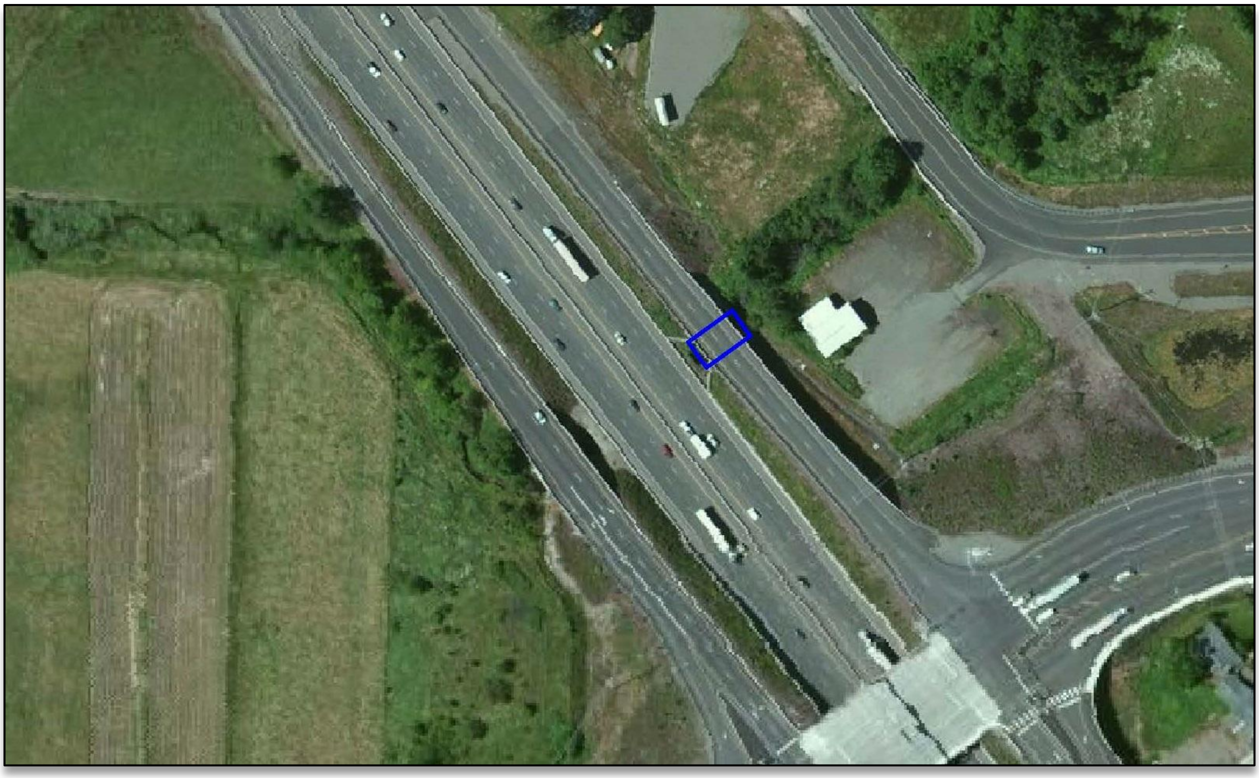

Image 8: DB14 Aerial Image

Site Condition:

The culvert over Dillenbaugh Creek at Interstate 5 is a bottomless, concrete structure in an established creekbed. A visual inspection of the box culvert was completed through field documented photographs and video. The box culvert shows no signs of cracking, corrosion, spalling or exposed rebar in any section of the culvert. However, signs of water penetration, water stained concrete and light spalling can be seen in and around the joints. Typical inspection for a more detailed inspection would include the following methods:

- Obtain the culvert's length, size, age, height of cover, wheel loading and material type.
- Document type and condition of end treatment, including end sections, headwalls, rip-rap, nothing, etc.
- Document waterway condition, such as inlet blockage/debris affecting hydraulic performance.
- Investigate inlet and outlet scour condition, including erosion parallel to the culvert
- Take detailed measurements of geometry of flexible culverts.
- Analyze culvert wall thickness and condition: cracking, extent of corrosion, spalling, and exposed rebar.
- Investigate infiltration and loss of structural backfill through joints, cracks or inlets.
- Document evidence of roadway settlement or repair including pavement distress, cracks or signs of recent repairs and repaving efforts, and guardrail sagging over the culvert.
- Review installation records to obtain backfill requirements or specifications.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 5.16 ft with an allowable depth of 7.25 ft. For this method of analysis, the culvert is suitably sized and not an area of concern.

Calculated Capacity:

Table 8: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	6.31 ft	<7.25 ft
	Velocity of Flow	5.66 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.40 ft	-
100 Year Rain Event	Depth of Flow	6.77 ft	<8.25 ft
	Velocity of Flow	6.28 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.80 ft	-

These calculations were based using the outlet control box culvert method. Based on the calculated values, the 25-year rain event has a flow depth 0.94 ft less than the allowable value and the 100-year rain event has a flow depth 1.48 ft less than the allowable value. The velocities calculated by this method are within the allowable range and are not a cause for concern. Based on Manning's calculations this culvert is hydraulically sized.

Modeled Capacity

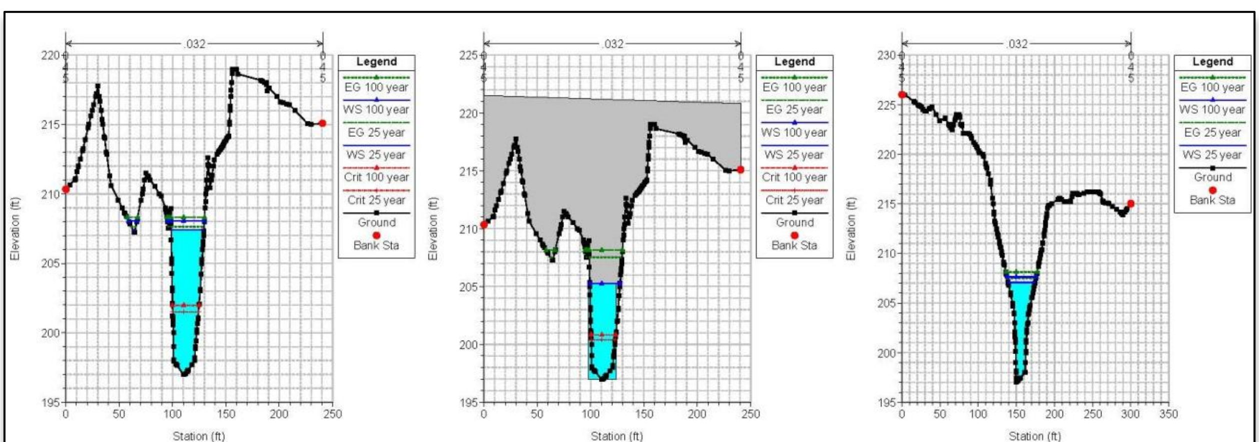

Figure 4: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings

Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the culvert could be taken into account.

Table 9: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	**Depth of Flow**	7.96 ft	<7.25 ft
	Velocity of Flow	4.33 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.12 ft	-
100 Year Rain Event	**Depth of Flow**	7.96 ft	<8.25 ft
	Velocity of Flow	5.16 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.80 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 0.71 ft greater than the allowable value and the 100-year rain event has a flow depth 0.29 ft less than the allowable value. These values are greater than the observed flows of 2007 but not improbable given the large flows. The velocity values for both the 25 and 100-year event are within the allowable range and comparable to the Manning's equation calculated values.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This box culvert has average Bank Full Width of 21 feet. Fish Passage criteria requires 27.20 feet of span at this site with an existing span of 26 feet.

Conclusion:

The bottomless, box culvert of DB14 is hydraulically sized for the 25 and 100-year storm events according to both the preliminary FEMA flood maps and Manning's equation calculations. The HEC-RAS hydraulic model shows the 25 year storm at slightly higher than the allowable value but this is not a concern as the other two methods share similar allowable values. The flow velocity for both evaluated rain events is within the allowable values and site conditions do not indicate an issue with culvert undermining or erosion downstream. There is minor river rock build up at the exit of the culvert but an increase in design velocity is not recommended. The culvert is currently undersized to provide adequate fish passage. Should future development be considered, the culvert span should be sized at a minimum of 27.20 feet.

DB13: Double Box Culvert under I-5

Image 9: DB13: Double Box Culvert under I-5

Specifications	
Type	D. Box Culvert
Span	10 ft,10 ft
Height	5.83 feet
Length	138 feet
Bank Full Width	12.5 feet

Flows	
2-year	366
5-year	621
10-year	771
25-year	929
50-year	1025
100-year	1106

Model Values	
Culvert Base Width *b*	20 feet
Culvert Height	5.83 feet
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.015

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	196.92 feet
Bridge Deck Elevation	204.20 feet
USGS Map Centralia Quadrangle	
Site Elevation	213 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	202 feet

Image 10: DB13 Aerial Image

Site Condition:

The double box culvert over Dillenbaugh Creek at Interstate 5 is a bottomless, concrete structure. A visual inspection of the box culvert was completed through field documented photographs and video. The box culvert shows no signs of cracking, corrosion, spalling or exposed rebar in any section of the culvert. However, signs of water penetration, water stained concrete and light spalling can be seen in and around the joints. Typical inspection for a more detailed inspection would include the following methods:

- Obtain the culvert's length, size, age, height of cover, wheel loading and material type.
- Document type and condition of end treatment, including end sections, headwalls, rip-rap, nothing, etc.
- Document waterway condition, such as inlet blockage/debris affecting hydraulic performance.
- Investigate inlet and outlet scour condition, including erosion parallel to the culvert
- Take detailed measurements of geometry of flexible culverts.
- Analyze culvert wall thickness and condition: cracking, extent of corrosion, spalling, and exposed rebar.
- Investigate infiltration and loss of structural backfill through joints, cracks or inlets.
- Document evidence of roadway settlement or repair including pavement distress, cracks or signs of recent repairs and repaving efforts, and guardrail sagging over the culvert.
- Review installation records to obtain backfill requirements or specifications.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 5.08 feet with an allowable depth of 5.83 feet. For this method of analysis, the culvert is suitably sized and not an area of concern.

Calculated Capacity:

Table 10: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	6.75 ft	<4.83 ft
	Velocity of Flow	6.13 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.95 ft	-
100 Year Rain Event	Depth of Flow	7.69 ft	<5.83 ft
	Velocity of Flow	7.30 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.50 ft	-

These calculations were based using the outlet control box culvert method. Based on the calculated values, the 25-year rain event has a flow depth 1.92 ft greater than the allowable value and the 100-year rain event has a flow depth 1.86 ft greater than the allowable value. These values are very close to the observed values of the 2007 flood. It should be noted that this culvert directly follows the box culvert of Site 3 and this calculation does not take this condition into account. The velocities calculated by this method are within the allowable range and are not a cause for concern.

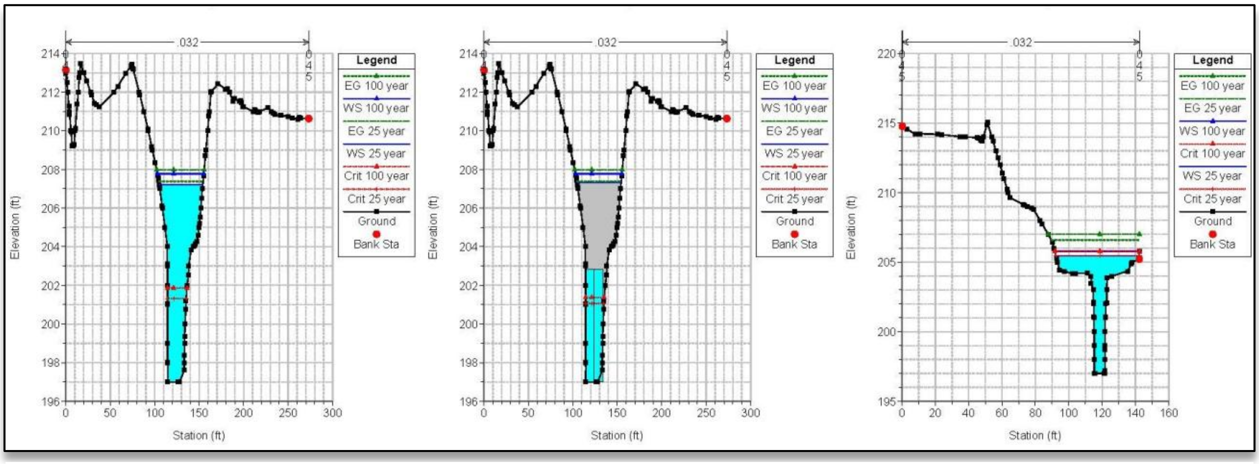

Figure 5: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the culvert could be taken into account.

Table 11: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	10.31 ft	<4.83 ft
	Velocity of Flow	7.95 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.06 ft	-
100 Year Rain Event	Depth of Flow	10.77 ft	<5.83 ft
	Velocity of Flow	8.89 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.37 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 5.37 ft greater than the allowable value and the 100-year rain event has a flow depth 4.94 ft greater than the allowable value. These values are greater than the observed flows of 2007 but not improbable given the large flows. Most important to note is that these depths indicate that the flood waters overtop the road, in this case I-5. The downstream cross sections show tailwater elevations of 10.30 ft and 10.61 ft for the 25 and 100-year event respectively. The velocity values for both the 25 and 100-year event are within the allowable range and comparable to the Manning's equation calculated values.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This double box culvert has average Bank Full Width of 12.5 feet. Fish Passage criteria requires 17.00 feet of span at this site with an existing span of 20 feet.

Conclusion:

The bottomless, double box culvert of DB13 is hydraulically undersized for the 25 and 100-year storm events according to both the Manning's equation calculations and the HEC-RAS hydraulic model. The flow depth for both evaluated rain events is greater than the height of the culvert and the road which restricts debris passage, can cause damage to the culvert and road embankment, and restrict emergency access on I-5. The flow velocity for both evaluated rain events is within the allowable values and site conditions do not indicate an issue with culvert undermining or erosion downstream. There is minor river rock build up at the entrance of the north barrel but an increase in design velocity is not recommended. The culvert is currently sized to provide adequate fish passage.

DB12: Box Culvert under I-5 Off-Ramp @ Exit 74

Image 11: DB12: Box Culvert under I-5 Off-Ramp @ Exit 7

Specifications	
Type	Box Culvert
Span	26 feet
Height	8.25 feet
Length	43 feet
Bank Full Width	13.84 feet

Model Values	
Culvert Base Width *b*	26 feet
Culvert Height	8.25 feet
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.015

Flows	
2-year	366
5-year	621
10-year	771
25-year	929
50-year	1025
100-year	1106

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	196.67 feet
Bridge Deck Elevation	220.80 feet
USGS Map Centralia Quadrangle	
Site Elevation	213 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	202 feet

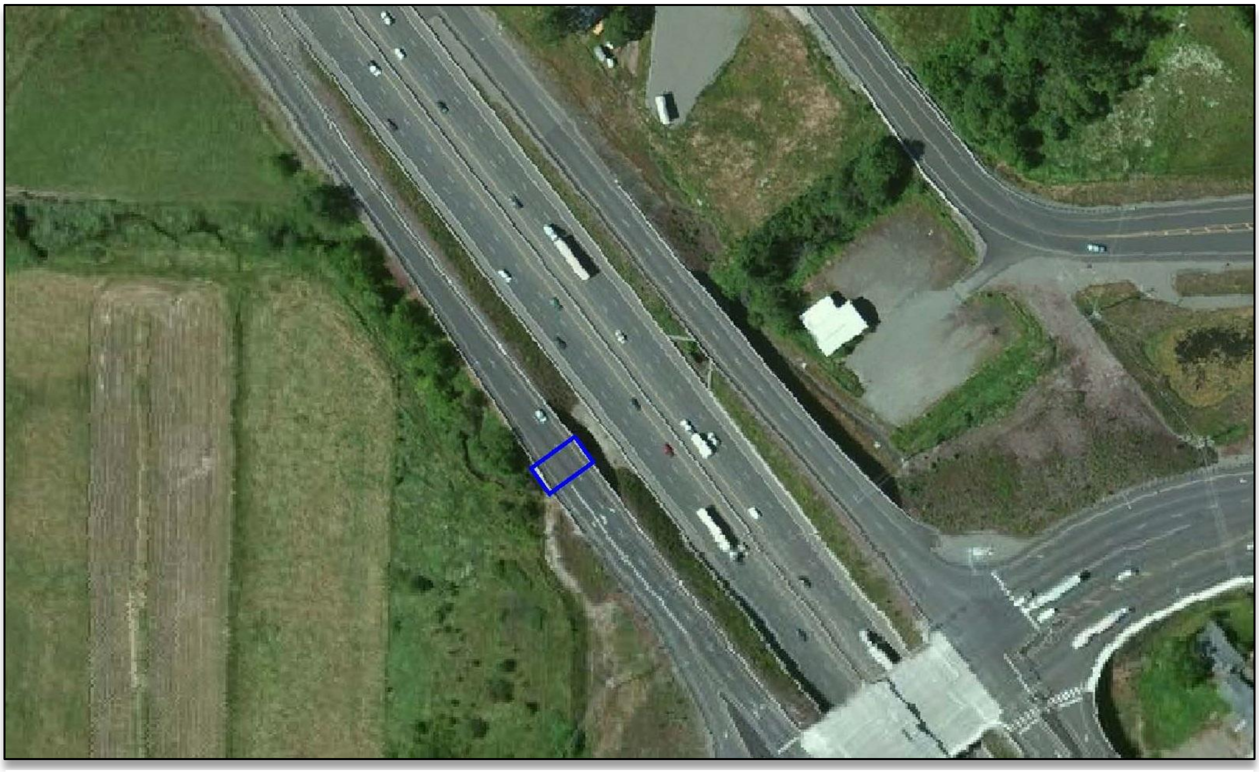

Image 12: DB12 Aerial Image

Site Condition:

The box culvert over Dillenbaugh Creek at Interstate 5 is a bottomless, concrete structure. A visual inspection of the box culvert was completed through field documented photographs and video. The box culvert shows no signs of cracking, corrosion, spalling or exposed rebar in any section of the culvert. However, signs of water penetration, water stained concrete and light spalling can be seen in and around the joints. Typical inspection for a more detailed inspection would include the following methods:

- Obtain the culvert's length, size, age, height of cover, wheel loading and material type.
- Document type and condition of end treatment, including end sections, headwalls, rip-rap, nothing, etc.
- Document waterway condition, such as inlet blockage/debris affecting hydraulic performance.
- Investigate inlet and outlet scour condition, including erosion parallel to the culvert
- Take detailed measurements of geometry of flexible culverts.
- Analyze culvert wall thickness and condition: cracking, extent of corrosion, spalling, and exposed rebar.
- Investigate infiltration and loss of structural backfill through joints, cracks or inlets.
- Document evidence of roadway settlement or repair including pavement distress, cracks or signs of recent repairs and repaving efforts, and guardrail sagging over the culvert.
- Review installation records to obtain backfill requirements or specifications.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 5.33 feet with an allowable depth of 7.25 feet. For this method of analysis, the culvert is suitably sized and not an area of concern.

Calculated Capacity:

Table 12: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	6.31 ft	<7.25 ft
	Velocity of Flow	5.66 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.40 ft	-
100 Year Rain Event	Depth of Flow	6.77 ft	<8.25 ft
	Velocity of Flow	6.28 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.80 ft	-

These calculations were based using the outlet control box culvert method. Based on the calculated values, the 25-year rain event has a flow depth 0.94 ft less than the allowable value and the 100-year rain event has a flow depth 1.48 ft less than the allowable value. The velocities calculated by this method are within the allowable range and are not a cause for concern. Based on Manning's calculations this culvert is hydraulically sized.

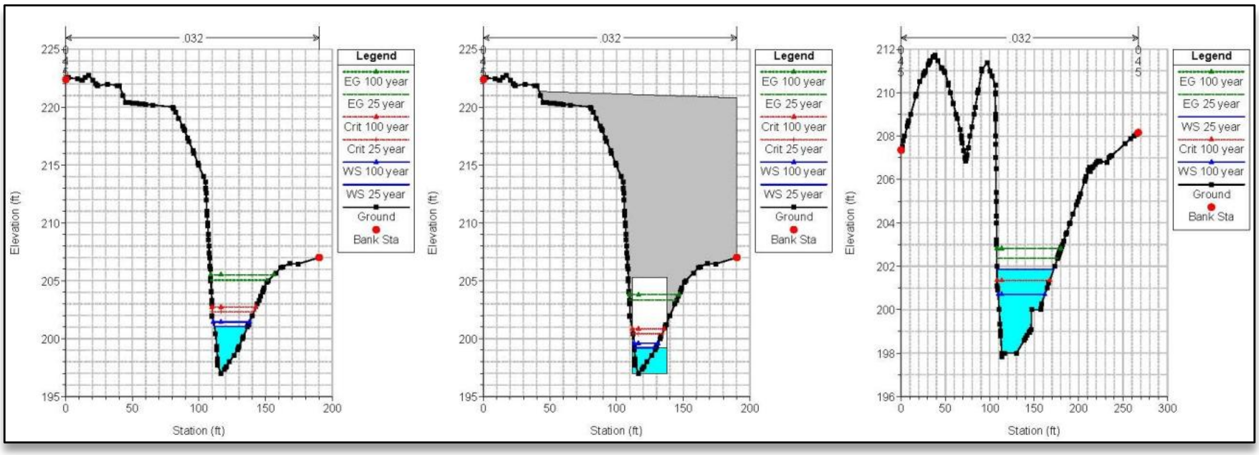

Figure 6: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the culvert could be taken into account.

Table 13: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	1.93 ft	<7.25 ft
	Velocity of Flow	16.27 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.14 ft	-
100 Year Rain Event	Depth of Flow	2.32 ft	<8.25 ft
	Velocity of Flow	16.45 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.56 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 5.32 ft less than the allowable value and the 100-year rain event has a flow depth 5.93 ft less than the allowable value. These values are less than the observed flows of 2007 but not improbable given the restricted flow of DB13. The velocity values for both the 25 and 100-year event are outside the allowable range but the site had no signs of damage from high velocity flows.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This box culvert has average Bank Full Width of 13.84 feet. Fish Passage criteria requires 18.61 feet of span at this site with an existing span of 26 feet.

Conclusion:

The bottomless, box culvert of DB12 is hydraulically sized for the 25 and 100-year storm events according to all three methods of analysis. The HEC-RAS hydraulic model shows both the 25 and 100-year storm events at significantly lower values due to the restricted flow of DB13. The flow velocity for both evaluated rain events is within the allowable values for the Manning's equation values and outside of the allowable values for the HEC-RAS model. Given the lack of erosion of the site and the allowable depth values for all three methods, the flow velocity is not a concern. The culvert is currently sized to provide adequate fish passage.

DB11: Abandoned Farmhouse Access Road

Image 13: DB11: Abandoned Farmhouse Access Road

Specifications	
Type	Timber & Concrete Bridge
Span	32 feet
Low Chord Height	6 feet
Length	11 feet
Bank Full Width	23.5 feet

Flows	
2-year	862
5-year	1334
10-year	1637
25-year	2002
50-year	2259
100-year	2502

Model Values	
Creek Base Width *b*	32 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	183 feet
Bridge Deck Elevation	192.29 feet
USGS Map Centralia Quadrangle	
Site Elevation	198 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	192 feet

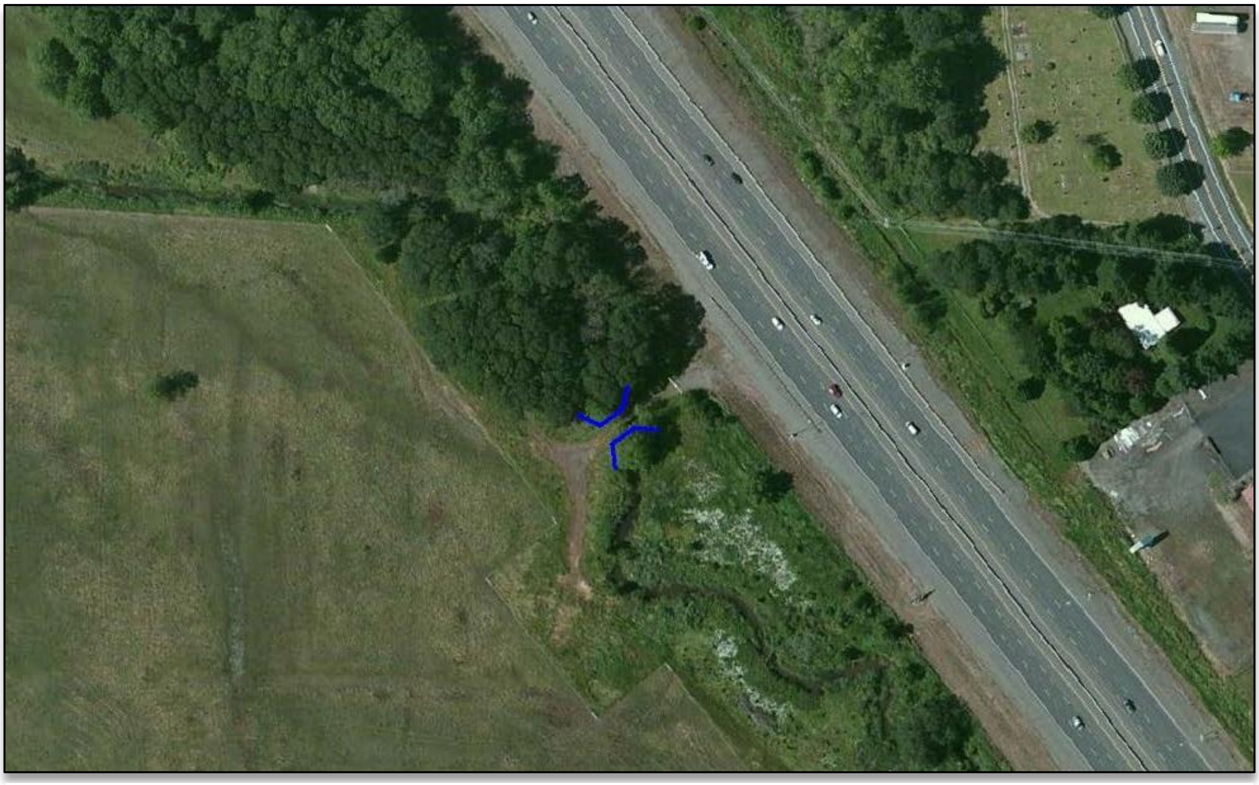

Image 14: DB11 Aerial Image

Site Condition:

The timber and steel bridge over Dillenbaugh Creek is an abandoned driveway near Interstate 5. A visual inspection of the bridge was completed through field documented photographs and video. The condition assessment of this structure shows deterioration to timber cross members. Timber is decayed with a substantial number of cracks and wood rot. Some cross members are missing completely. The steel I beams rest atop a concrete footing which shows signs of undercutting from high water levels. The concrete has deteriorated showing aggregate within. The steel I-beams are rusted but appear to be in place.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 9 ft with an allowable depth of 6 ft. For this method of analysis, the bridge is undersized and completely submerged.

Calculated Capacity:

Table 14: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	20.63 ft	<5 ft
	Velocity of Flow	3.03 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.95 ft	-
100 Year Rain Event	Depth of Flow	24.56 ft	<6 ft
	Velocity of Flow	3.18 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	5.74 ft	-

These calculations were done using the rectangular open channel flow method. Based on the calculated values, the 25-year rain event has a flow depth 15.63 ft greater than the allowable value and the 100-year rain event has a flow depth 18.56 ft greater than the allowable value. The Manning's trapezoidal open channel flow equation does not take into account the top of the embankment and assumes an infinite possible depth. The channel has a depth of 9 feet with a very flat surrounding area so any calculated depth above 9 feet has spilled over into the surrounding farm fields. Here the creek has overtopped the bridge deck and flooded the surrounding area. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The velocity is within the allowable range and is not a cause for concern.

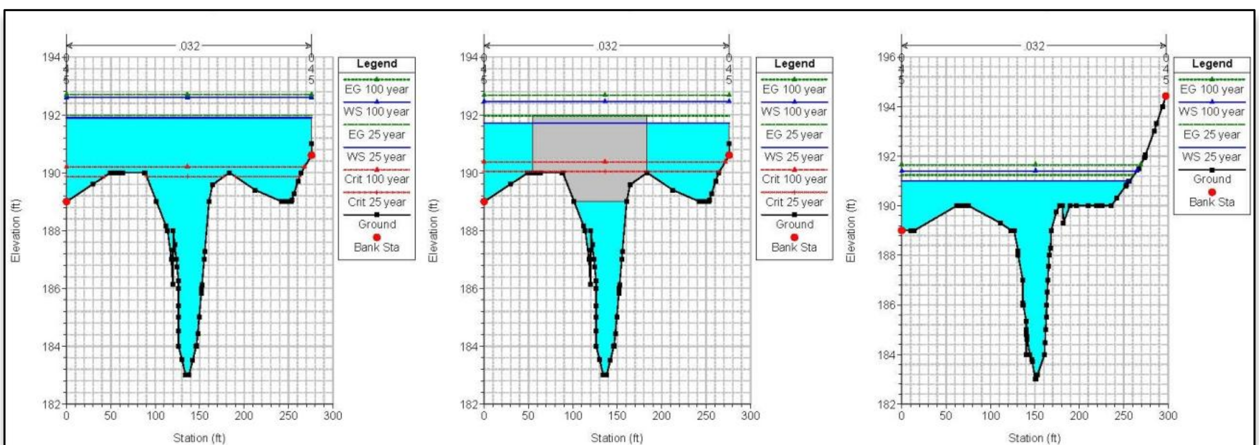

Figure 7: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 15: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	8.72 ft	<5.00 ft
	Velocity of Flow	8.94 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.04 ft	-
100 Year Rain Event	Depth of Flow	9.46 ft	<6.00 ft
	Velocity of Flow	10.25 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.37 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 3.72 ft greater than the allowable value and the 100-year rain event has a flow depth 3.46 ft greater than the allowable value. These values are in the range expected given the observed flows of 2007. The downstream cross sections show tailwater elevations of 7.55 ft and 7.82 ft for the 25 and 100-year event respectively. The velocity values for the 100-year event are outside the preferred range, but not unexpected given the large flows.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This bridge has average Bank Full Width of 23.50 feet. Fish Passage criteria requires 30.20 feet of span at this site with an existing span of 32 feet.

Conclusion:

The concrete and timber bridge of Site 5.5 is in poor condition and not suitable for vehicular use. The bridge is located in a flat area prone to flooding and the deck is set at the elevation of the surrounding ground. During significant rain events, the area surrounding and including the bridge will be underwater. If the bridge is to be repaired and recommissioned it would do little good to raise or widen the bridge, but rather it must be structurally designed to withstand the flooding characteristic to its location. It is more significant to note that the change in flow depth from upstream to downstream shows the bridge does have an effect on flow. Additionally, the flood map generated by the HEC-RAS model show an increase in flood zone width at this point. One could conclude that the bridge is an obstruction to high water flows and flooding in the immediate area could be decreased by removal of the bridge. The bridge is currently sized to provide adequate fish passage.

DT01: Double Box Culvert under I-5 @ Exit 76

Image 15: DT1: 1 Double Box Culvert under I-5 @ Exit 7

Specifications	
Type	D. Box Culvert
Span	7 ft, 7 ft
Height	7 feet
Length	220 feet
Bank Full Width	20 feet

Model Values	
Culvert Base Width *b*	14 feet
Culvert Height	7 feet
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.015

Flows	
2-year	349
5-year	453
10-year	519
25-year	599
50-year	655
100-year	711

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	173.25 feet
Bridge Deck Elevation	188 feet
USGS Map Centralia Quadrangle	
Site Elevation	198 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	188 feet

Site Condition:

The double box culvert over Dilly Twig Creek at Exit 76 is a bottomless structure in a low lying area with a pond on the upstream end. A visual inspection of the box culvert was completed through field documented photographs and video. The box culvert shows no signs of cracking, corrosion, spalling or exposed rebar in any section of the culvert. However, signs of water penetration, water stained concrete and light spalling can be seen in and around the joints. Typical inspection for a more detailed inspection would include the following methods:

- Obtain the culvert's length, size, age, height of cover, wheel loading and material type.
- Document type and condition of end treatment, including end sections, headwalls, rip-rap, nothing, etc.
- Document waterway condition, such as inlet blockage/debris affecting hydraulic performance.
- Investigate inlet and outlet scour condition, including erosion parallel to the culvert
- Take detailed measurements of geometry of flexible culverts.
- Analyze culvert wall thickness and condition: cracking, extent of corrosion, spalling, and exposed rebar.
- Investigate infiltration and loss of structural backfill through joints, cracks or inlets.
- Document evidence of roadway settlement or repair including pavement distress, cracks or signs of recent repairs and repaving efforts, and guardrail sagging over the culvert.
- Review installation records to obtain backfill requirements or specifications.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 14.75 ft with an allowable depth of 7 ft. For this method of analysis, the culvert is undersized.

Calculated Capacity:

The Washington Department of Transportation Hydraulic Manual calculations were based on the following values using the outlet control box culvert method:

Table 16: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	6.38 ft	<6 ft
	Velocity of Flow	6.11 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.8 ft	-
100 Year Rain Event	Depth of Flow	7.08 ft	<7 ft
	Velocity of Flow	7.26 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.4 ft	-

These calculations were done using the outlet control box culvert method. Based on the calculated values, the 25-year rain event has a flow depth 0.38 ft greater than the allowable value and the 100-year rain event has a flow depth 0.08 ft less than the allowable value. These values are much lower than the observed values of the 2007 flood as these calculations only consider the input of the Dilly Twig Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River and Dillenbaugh Creek have overtopped their banks and flooded the surrounding area, to include this culvert location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River, Dillenbaugh Creek, and Dilly Twig Creek. The velocities calculated by this method are within the allowable range and are not a cause for concern.

Modeled Capacity

As the scope of this study was limited to Dillenbaugh Creek, Dilly Twig Creek and its culverts were not modeled using the United States Army Corps of Engineers modeling program HEC-RAS. It is included in this report as a possible contributor to the floodwater depth and velocity in the Dillenbaugh Creek. For more information on Dilly Twig Creek and its culverts, see the Gibbs and Olsen Hydrology Report included in Appendix B.

Conclusion:

The bottomless double box culvert of Site DT01 is hydraulically undersized for the 25 and 100-year storm events according to both the FEMA FIRMs and Manning's equation calculations. According to the observed flows of 2007, the flow overtopped the roadway which can cause damage to the culvert and road embankment and restricts emergency access on I-5. By Manning's equation calculations, which does not account for backwater flooding from the Dillenbaugh or Chehalis River, this culvert is barely undersized for both the 25 and 100-year rain events which restricts debris passage and can cause damage to the culvert and road embankment. The flow velocity for both evaluated rain events is within the allowable values and site conditions do not indicate an issue with culvert undermining or erosion downstream. This site was not evaluated for fish passage capacity.

DB10: Double Box Culvert under Rice Road

Image 16: DB10: Double Box Culvert under Rice Road

Specifications	
Type	D. Box Culvert
Span	8 ft, 8 ft
Height	8 feet
Length	110 feet
Bank Full Width	19.67 feet

Model Values	
Culvert Base Width *b*	16 feet
Culvert Height	8 feet
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.015

Flows	
2-year	874
5-year	1357
10-year	1669
25-year	2044
50-year	2309
100-year	2559

Elevations		
Survey Completed August 2016		
	Creek Bed Elevation	171.47 feet
	Bridge Deck Elevation	197.65 feet
USGS Map Centralia Quadrangle		
	Site Elevation	190 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)		
	Base Flood (100-year) Elevation	188 feet

Image 17: DB10 Aerial Image

Site Condition:

The double box culvert over Dillenbaugh Creek at Rice Road is a four-sided structure in a low lying area. A visual inspection of the box culvert was completed through field documented photographs and video. The box culvert shows no signs of cracking, corrosion, spalling or exposed rebar in any section of the culvert. However, signs of water penetration, water stained concrete and light spalling can be seen in and around the joints. Typical inspection for a more detailed inspection would include the following methods:

- Obtain the culvert's length, size, age, height of cover, wheel loading and material type.
- Document type and condition of end treatment, including end sections, headwalls, rip-rap, nothing, etc.
- Document waterway condition, such as inlet blockage/debris affecting hydraulic performance.
- Investigate inlet and outlet scour condition, including erosion parallel to the culvert
- Take detailed measurements of geometry of flexible culverts.
- Analyze culvert wall thickness and condition: cracking, extent of corrosion, spalling, and exposed rebar.
- Investigate infiltration and loss of structural backfill through joints, cracks or inlets.
- Document evidence of roadway settlement or repair including pavement distress, cracks or signs of recent repairs and repaving efforts, and guardrail sagging over the culvert.
- Review installation records to obtain backfill requirements or specifications.

Observed Capacity:

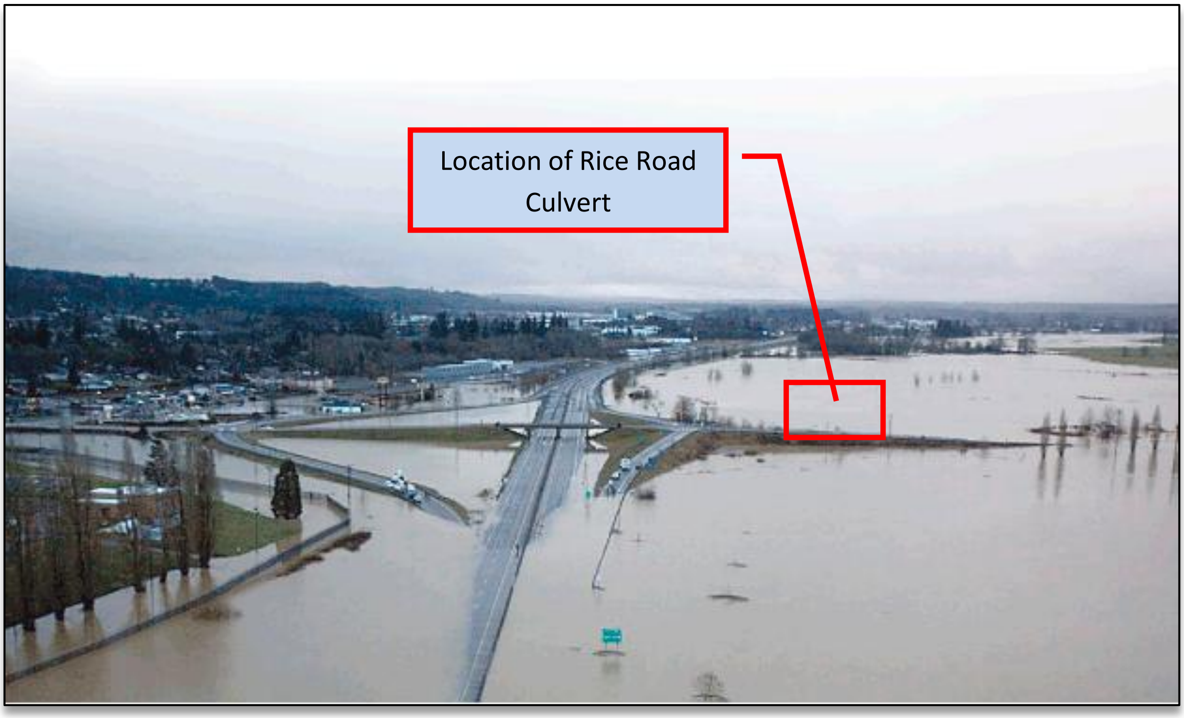

Image 18: Location of Rice Road Culvert

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 16.53 ft. with an allowable depth of 26 ft. For this method of analysis that considers only the 100-year flow, the culvert is adequately sized.

Calculated Capacity:

Table 17: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	15.49 ft	<10 ft
	Velocity of Flow	15.97 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.8 ft	-
100 Year Rain Event	Depth of Flow	19.94 ft	<26 ft
	Velocity of Flow	19.99 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	9.3 ft	-

These calculations were done using the outlet control box culvert method. Based on the calculated values, the 25-year rain event has a flow depth 5.49 ft greater than the allowable value and the 100-year rain event has a flow depth 6.06 ft less than the allowable value. These values are very close to the observed values of the 2007 flood. It should be noted that this culvert is approximately 800 feet downstream from site DT1, the double box culvert under I-5 that carries flows from the Dilly Twig Creek tributary. The flow restriction at this site may indicate that the calculated values for site DB10 are slightly higher than actual flows as the calculated values assume natural flows from the Dilly Twig Creek sub basin. Additionally, the high downstream velocities of culvert DB10 are calculated assuming natural flows from the Dilly Twig Creek sub basin and the actual velocities may be higher. As the calculated velocities exceed the allowable values by as much as 100%, a higher than assumed upstream velocity would only exacerbate the potential for scour, undermining, and downstream erosion.

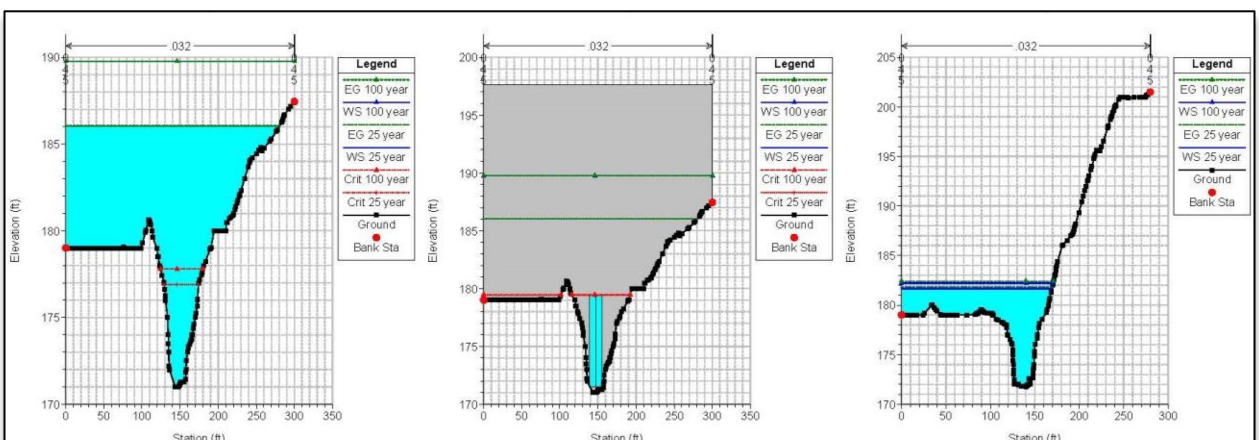

Figure 8: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings

Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the culvert could be taken into account.

Table 18: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	15.06 ft	<10 ft
	Velocity of Flow	15.97 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.98 ft	-
100 Year Rain Event	Depth of Flow	18.78 ft	<26 ft
	Velocity of Flow	19.99 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	8.00 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 5.06 ft greater than the allowable value and the 100-year rain event has a flow depth 7.22 ft less than the allowable value. These values are similar to both the observed flows and the calculated flows. While these values indicate compliance with the 100-year rain event headwater depth, the model show the big picture. For a 100-year storm event, the floodwater is at 190 ft elevation while Rice Road reaches a low point of 181 ft directly southwest of the site. As the headwater does ultimately overtop Rice Road, albeit not at the culvert location, this culvert is out of the compliance for both the 25 and 100 year storm. The downstream cross sections show tailwater elevations of 181.65 ft and 182.21 ft for the 25 and 100-year event respectively. The velocity values for both the 25 and 100-year event exceed the allowable range and comparable to the Manning's equation calculated values.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This double box culvert has average Bank Full Width of 19.67 feet. Fish Passage criteria requires 25.60 feet of span at this site with an existing span of 16 feet.

Conclusion:

The double box culvert of DB10 is hydraulically undersized for the 25 and 100-year storm events according to both the Manning's equation calculations and the HEC-RAS hydraulic model. The upstream flow depth for both evaluated rain events is greater than the height of Rice Road directly to the south west of the site. The flow velocities in the culvert for both the 25 and 100-year storm events exceed the allowable 10 ft/s. If the culvert size was increased in both height and width, the headwater depth would decrease and the culvert velocity would most closely match the natural channel velocity of approximately 3 ft/s found up and downstream of the site. However, the tailwater elevations of 181.65

and 182.21 for the 25 year and 100-year rain events indicate a natural channel elevation that would still overtop the 181 ft elevation of Rice Road. In order to bring the creek crossing into compliance, the culvert would need to be increased in size and portions of Rice Road would need to be raised. The culvert is currently undersized to provide adequate fish passage. Should future development be considered, the culvert span should be sized at a minimum of 25.60 feet.

DB09: Abandoned Railroad Bridge

Image 19: DB09: Abandoned Railroad Bridge

Specifications	
Type	Steel Bridge
Span	26 feet
Low Chord Height	8.67 feet
Length	17.5 feet
Bank Full Width	26.5 feet

Flows	
2-year	874
5-year	1357
10-year	1669

Model Values	
Creek Base Width *b*	26 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Elevations		
Survey Completed August 2016		
	Creek Bed Elevation	169.19 feet
	Bridge Deck Elevation	179.30 feet
USGS Map Centralia Quadrangle		

25-year	2044
50-year	2309
100-year	2559

	Site Elevation	190 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)		
	Base Flood (100-year) Elevation	188 feet

Image 20: DB09 Aerial Image

Site Condition:

The steel railroad bridge over Dillenbaugh Creek near Rice Road is an abandoned, single track structure. A visual inspection of the bridge was completed through field documented photographs and video. The entirety of the top decking is missing. The steel I-beams have a significant amount of rust and corrosion on some of its members. Due to the high water level, the condition of the concrete footings is unclear. Further investigation would need to be completed to understand the condition of the footings that support the I beams.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 18.81 ft with an allowable depth of 8.67 ft. For this method of analysis, the bridge is undersized and completely submerged.

Calculated Capacity:

Table 19: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	26.49 ft	<7.67 ft
	Velocity of Flow	2.97 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	5.76 ft	-
100 Year Rain Event	Depth of Flow	31.91 ft	<8.67 ft
	Velocity of Flow	3.08 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	6.69 ft	-

These calculations were done using the rectangular open channel flow method. Based on the calculated values, the 25-year rain event has a flow depth 18.82 ft greater than the allowable value and the 100-year rain event has a flow depth 23.24 ft greater than the allowable value. The Manning's rectangular open channel flow equation does not take into account the top of the embankment and assumes an infinite possible depth. The channel has a depth of 10.11 feet with a very flat surrounding area so any calculated depth above 10.11 feet has spilled over into the surrounding farm fields. Here the creek has overtopped the bridge deck and flooded the surrounding area. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The velocity is within the allowable range and is not a cause for concern.

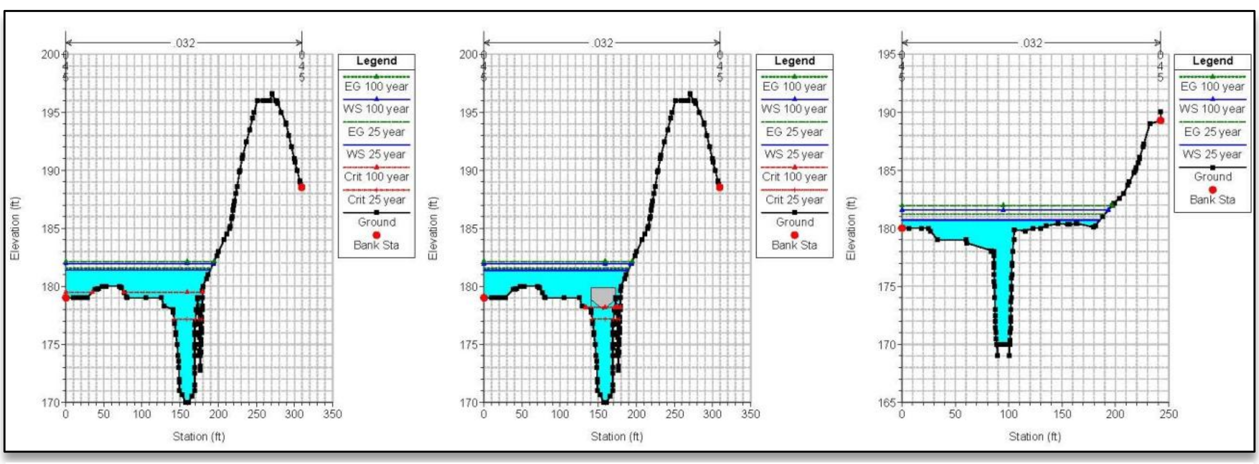

Figure 9: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 20: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	11.36 ft	<7.67 ft
	Velocity of Flow	5.31 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.18 ft	-
100 Year Rain Event	Depth of Flow	11.93 ft	<8.67 ft
	Velocity of Flow	5.02 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	8.18 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 3.69 ft greater than the allowable value and the 100-year rain event has a flow depth 3.26 ft greater than the allowable value. These values are lower than the observed flows of 2007 as this model only considers the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100 year storm event, the Chehalis River has overtopped its banks and floods the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by both the Chehalis River and Dillenbaugh Creek. The downstream cross sections of this model show tailwater depths of 11.03 ft and 11.68 ft for the 25 and 100-year event respectively. The velocity values for the 100-year event are within the allowable range and are not a cause for concern.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This bridge has average Bank Full Width of 26.50 feet. Fish Passage criteria requires 33.80 feet of span at this site with an existing span of 26 feet.

Conclusion:

The I beam bridge of DB09 is missing the bridge decking and is not currently suitable for use. The bridge is located in a flat area prone to flooding and the deck is set at the elevation of the surrounding ground. During significant rain events, the area surrounding and including the bridge will be underwater. If the bridge is to be repaired and recommissioned it would do little good to raise or widen the bridge, but rather it must be structurally designed to withstand the flooding characteristic to its location. It is more significant to note that the minor change in flow depth from upstream to downstream shows the bridge does have an effect on flow. While this effect would be negligible during 25 and 100-year storm events, one could conclude that the bridge is an obstruction to high water flows and flooding in the immediate area could be decreased by removal of the bridge. The abandoned bridge is currently undersized to provide adequate fish passage. Should future development be considered, the bridge span should be sized at a minimum of 33.80 feet.

DB08: Bridge for I-5

Image 21: DB08: Bridge for I-5

Specifications	
Type	Reinforced Concrete Bridge
Span	500 feet
Length	100 feet

Model Values	
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Flows	
2-year	874
5-year	1362
10-year	1676
25-year	2054
50-year	2319
100-year	2572

Elevations		
Survey Completed August 2016		
	Creek Bed Elevation	170 feet
USGS Map Centralia Quadrangle		
	Site Elevation	190 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)		
	Base Flood (100-year) Elevation	187 feet

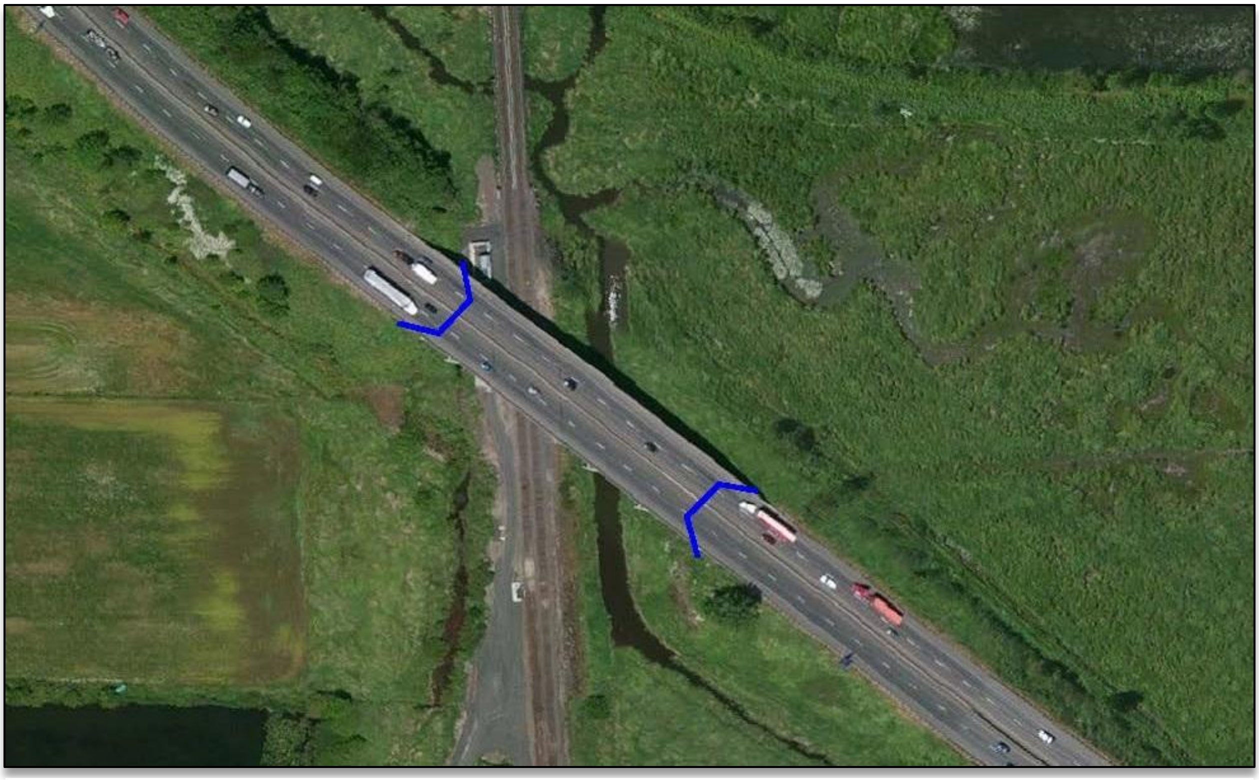

Image 22: DB08 Aerial Image

Site Condition:

The reinforced concrete bridge of I-5 between exit 76 and exit 77 is a passageway for two railroad tracks and Dillenbaugh Creek. The scale of the bridge was prohibitive to inspection for the sake of this report. Visual inspection at the site visit on July 7th revealed no conspicuous damages from floodwater.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey on the nearby DB07 is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 17 ft and did not overtop the roadway. For this method of analysis, the bridge is adequately sized.

Conclusion:

The bridge of I-5 is hydraulically sized for both the 25 and 100 year storm events. Further analysis using survey and modeling was considered unnecessary due to the oversized character of the bridge. The concrete bridge is adequately sized to provide fish passage.

DB07: Railroad Bridge

Image 23: DB07: Railroad Bridge

Specifications	
Type	Concrete & Steel Bridge
Span	224 feet
Low Chord Height	12.5 feet
Length	33 feet
Bank Full Width	18 feet

Model Values	
Creek Base Width *b*	174 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Flows	
2-year	966
5-year	1469
10-year	1798
25-year	2201
50-year	2490
100-year	2769

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	170.00 feet
Bridge Deck Elevation	185.50 feet
USGS Map Centralia Quadrangle	
Site Elevation	190 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	187 feet

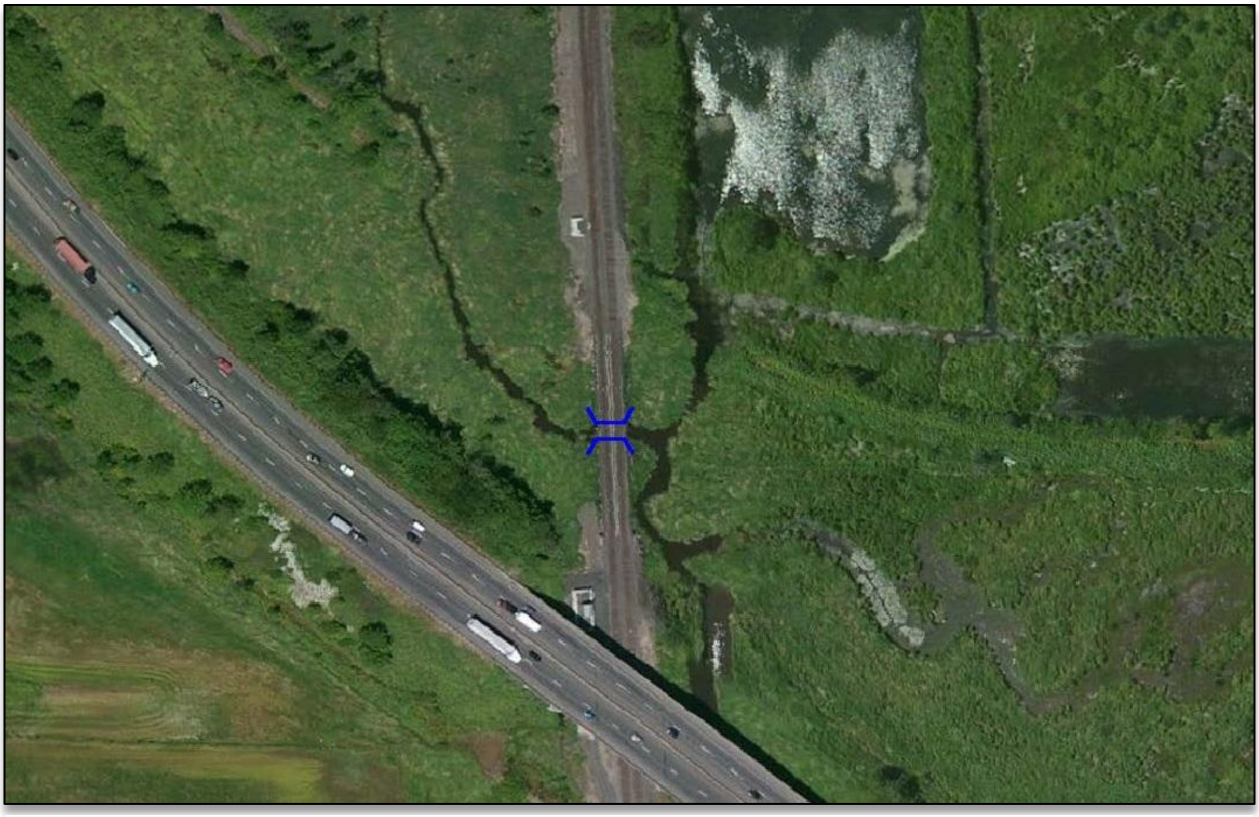

Image 24: DB07 Aerial Image

Site Condition:

The concrete and steel railroad bridge over Dillenbaugh Creek between exit 76 and exit 77 is a double-track structure of frequent use. The bridge is utilized and maintained by BNSF Railway and Union Pacific so the structural condition is outside of the scope of this report. Visual inspection at the site visit on July 7th revealed no conspicuous damages from floodwater.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 17 ft with an allowable depth of 12.5 ft to bridge low chord height. By this standard, the bridge is undersized. However, flood waters are permitted to overtop a roadway provided that it is not an emergency route and the structure and embankment are designed to withstand the flows. For the purposes of this report, we will assume BNSF Railway and Union Pacific designed the bridge to withstand the floodwaters of Dillenbaugh Creek.

Calculated Capacity:

Table 21: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	8.68 ft	<11.5 ft
	Velocity of Flow	1.27 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	1.69 ft	-
100 Year Rain Event	Depth of Flow	9.91 ft	<12.5 ft
	Velocity of Flow	1.37 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	1.96 ft	-

These calculations were done using the outlet control box culvert method. Based on the calculated values, the 25-year rain event has a flow depth 2.82 ft less than the allowable value and the 100-year rain event has a flow depth 2.59 ft less than the allowable value. These values are much lower than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. The velocities calculated by this method are within the allowable range and are not a cause for concern.

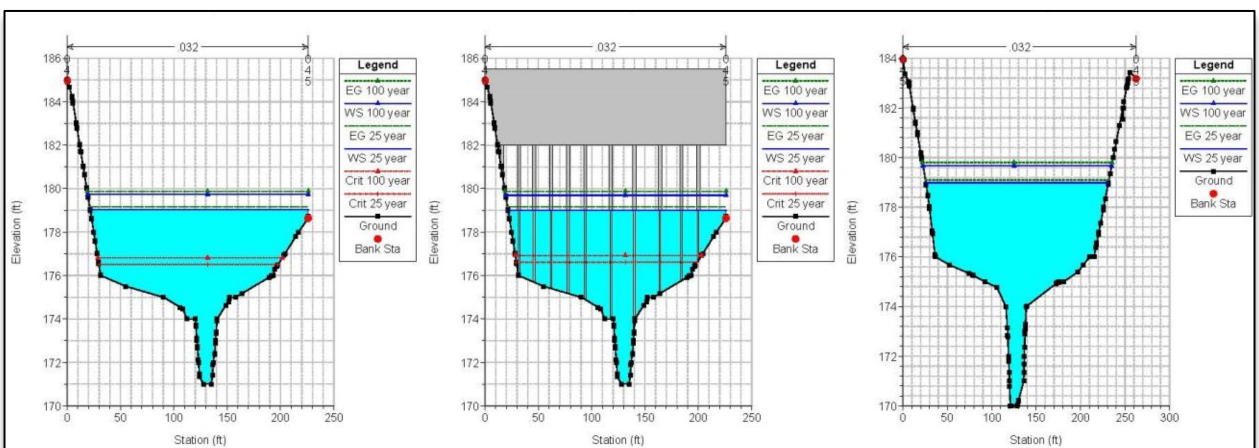

Figure 10: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 22: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	8.01 ft	<11.5 ft
	Velocity of Flow	3.13 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	5.61 ft	-
100 Year Rain Event	Depth of Flow	8.70 ft	<8.8 ft
	Velocity of Flow	3.36 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	5.92 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 3.49 ft less than the allowable value and the 100-year rain event has a flow depth 0.10 ft less than the allowable value. These values are lower than the observed flows of 2007 but reasonable given the model did not include the backwater effects of the Chehalis River. The downstream cross sections do not show a reduction in flow depth indicating the bridge is not an obstruction to creek flow and not responsible for local area flooding. The velocity values for both the 25 and 100-year event are within the preferred range and not an area of concern.

Conclusion:

The concrete and steel railroad bridge of DB07 is hydraulically sized for the 25 and 100-year storm events when analyzed using Manning's equation or the HEC-RAS modeling program. The Preliminary FEMA FIRMs show 100-year flood waters overtopping the bridge but do not appear to be retained or obstructed by the structure. The flow velocity for both evaluated rain events is within the preferred values. The concrete railroad bridge is adequately sized to provide fish passage.

DB06: Railroad Bridge

Image 25: DB06: Railroad Bridge

Specifications	
Type	Timber Bridge
Span	137 feet
Low Chord Height	12 feet
Length	10 feet
Bank Full Width	20 feet

Flows	
2-year	984
5-year	1491
10-year	1821
25-year	2224
50-year	2513
100-year	2791

Model Values	
Creek Base Width *b*	89 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	167.56 feet
Bridge Deck Elevation	181.40 feet
USGS Map Centralia Quadrangle	
Site Elevation	190 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	185 feet

Image 26: DB06 Aerial Image

Site Condition:

The timber railroad bridge over Dillenbaugh Creek near Exit 77 a single-track structure of minor use. A visual inspection of the bridge was completed through field documented photographs and video. There are no obvious signs of serious deterioration above water for the timber truss bridge. There are typical cracks often associated with timber beams and pilings but as the timbers are creosote[22] treated, there is minimal impact from the freshwater creek. The metal hardware has typical signs of surface rust, but none of the bolts appear to be missing or compromised. Typical inspection for a more detailed inspection would include the following methods:

- Conduct initial visual assessment with hammer sounding.
- Obtain moisture content measurements in suspect and decay prone areas.
- Establish baseline NDE data by collecting stress wave and resistance micro-drilling data from areas of suspected sound wood
- Investigate marked areas to measure the extent of internal deterioration by utilizing stress wave timer and resistance micro-drilling tool as needed.

[22] **Creosote**: A product created by high-temperature treatment of beech and other woods, coal, or from the resin of the creosote bush. Coal tar creosote is the most widely used wood preservative in the United States (Department of Ecology, State of Washington, n.d.).

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 17.44 ft with an allowable depth of 11 ft. For this method of analysis, the bridge is undersized.

Calculated Capacity:

Table 23: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	12.23 ft	<11 ft
	Velocity of Flow	1.45 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	2.61 ft	-
100 Year Rain Event	Depth of Flow	13.83 ft	<12 ft
	Velocity of Flow	1.55 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	3.02 ft	-

Based on the calculated values, the 25-year rain event has a flow depth 1.23 ft greater than the allowable value and the 100-year rain event has a flow depth 1.83 ft greater than the allowable value. These values are slightly lower than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The velocity is within the allowable range and is not a cause for concern.

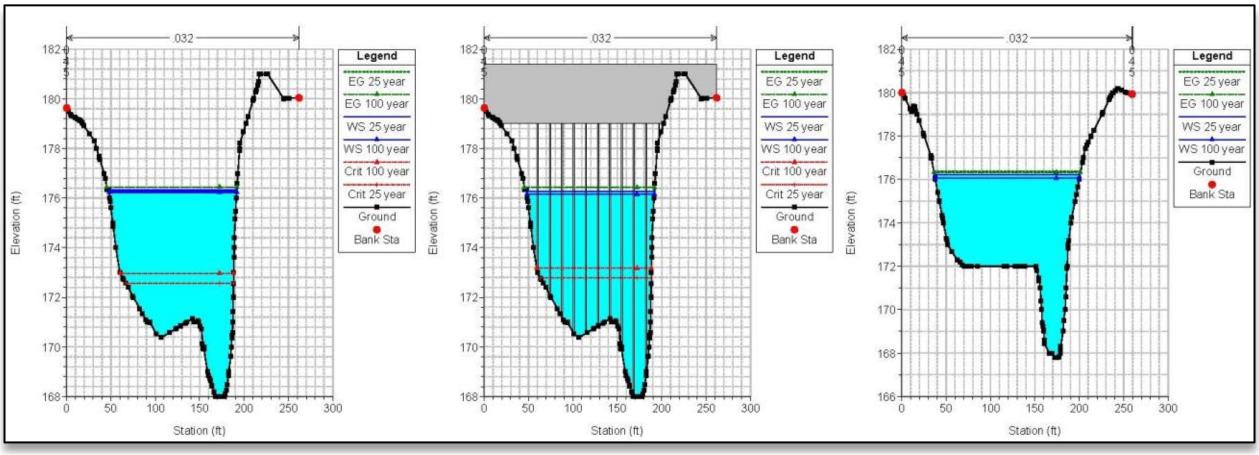

Figure 11: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 24: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	8.27 ft	<11 ft
25 Year Rain Event	Velocity of Flow	3.48 ft/s	3 ft/s < V < 10 ft/s
25 Year Rain Event	Critical Depth of Flow	4.78 ft	-
100 Year Rain Event	Depth of Flow	8.16 ft	<12 ft
100 Year Rain Event	Velocity of Flow	4.52 ft/s	3 ft/s < V < 10 ft/s
100 Year Rain Event	Critical Depth of Flow	5.17 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 2.73 ft less than the allowable value and the 100-year rain event has a flow depth 3.84 ft less than the allowable value. These values are slightly lower than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The velocity is within the allowable range and is not a cause for concern.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This railroad bridge has average Bank Full Width of 20 feet. Fish Passage criteria requires 26.0 feet of span at this site with an existing span of 137 feet.

Conclusion:

The timber railroad bridge of DB06 is hydraulically undersized for the 25 and 100-year storm events. The bridge is located in a flat area prone to flooding and the deck is set at the elevation of the surrounding ground. According to the FEMA FIRMs and the Manning's Equation calculations, the area surrounding and including the bridge will be underwater during significant rain events. It must be structurally designed to withstand the flooding characteristic to its location. By the analysis of the HEC-RAS model, the bridge is adequately sized to allow floodwaters to flow with adequate freeboard. The difference in values from the observed values to the modeled values can be attributed to the backwater flooding of the Chehalis River during the 100-year rain event. There is little change in flow depth across the bridge so one could conclude that the bridge is not an obstruction to high water flows and is not the cause of local area flooding. The conclusion of this report is that it is hydraulically undersized for the Dillenbaugh Creek flows and should be structurally reinforced to withstand the backwater flooding of the Chehalis River during the 100-year storm. The timber bridge is adequately sized to provide fish passage.

DB05: Bridge for I-5 Off-Ramp @ Exit 77

Image 27: DB05: Bridge for I-5 Off-Ramp @ Exit 7

Specifications	
Type	Concrete Bridge
Span	130 feet
Low Chord Height	16 feet
Length	30 feet
Bank Full Width	17 feet

Flows	
2-year	1027
5-year	1541
10-year	1872
25-year	2276
50-year	2563
100-year	2840

Model Values	
Creek Base Width *b*	19 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	163.42 feet
Bridge Deck Elevation	186.70 feet
USGS Map Centralia Quadrangle	
Site Elevation	185 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	185 feet

Image 28: DB05 Aerial Image

Site Condition:

The reinforced concrete bridge over Dillenbaugh Creek at Exit 77 supports the I-5 off-ramp. A visual inspection of the bridge was completed through field documented photographs and video. The structure shows no signs of major defects, spalling or cracking through images and video reviewed. Columns look to be in place with no undercutting from erosion.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 21.58 ft with an allowable depth of 16 ft. For this method of analysis, the bridge is undersized.

Calculated Capacity:

Table 25: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	19.07 ft	<15 ft
25 Year Rain Event	Velocity of Flow	1.57 ft/s	3 ft/s < V < 10 ft/s
25 Year Rain Event	Critical Depth of Flow	5.67 ft	-
100 Year Rain Event	Depth of Flow	20.96 ft	<16 ft
100 Year Rain Event	Velocity of Flow	1.66 ft/s	3 ft/s < V < 10 ft/s
100 Year Rain Event	Critical Depth of Flow	6.37 ft	-

Based on the calculated values, the 25-year rain event has a flow depth 4.07 ft greater than the allowable value and the 100-year rain event has a flow depth 4.96 ft greater than the allowable value. These values are slightly less than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The velocity is within the allowable range and is not a cause for concern.

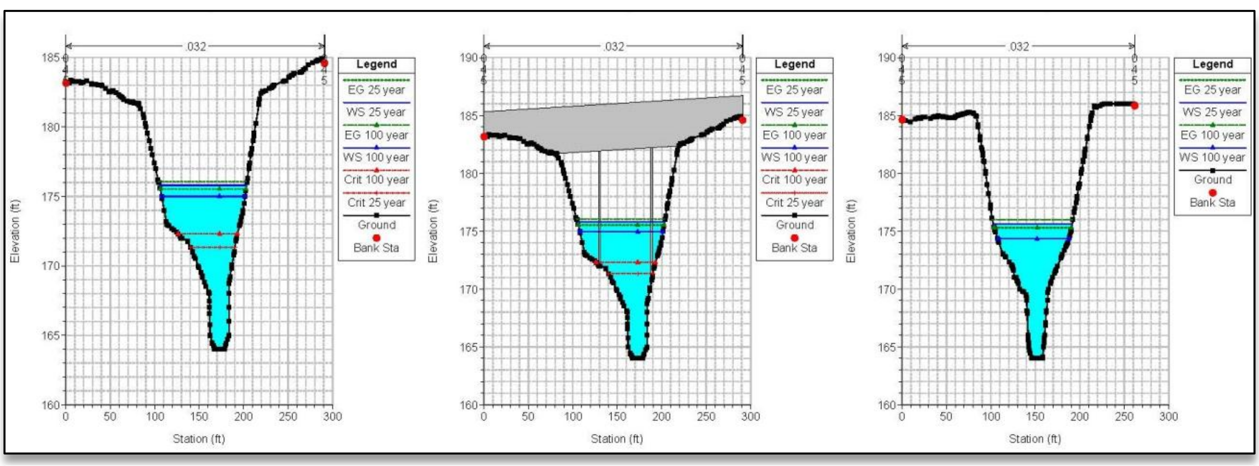

Figure 12: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 26: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	11.78 ft	<15 ft
	Velocity of Flow	4.97 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.33 ft	-
100 Year Rain Event	Depth of Flow	10.94 ft	<16 ft
	Velocity of Flow	7.92 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	8.30 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 3.22 ft less than the allowable value and the 100-year rain event has a flow depth 5.06 ft less than the allowable value. These values are lower than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows. Using this method of analysis, the bridge is adequately sized. The velocity is within the allowable range and is not a cause for concern.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This bridge has average Bank Full Width of 17 feet. Fish Passage criteria requires 22.4 feet of span at this site with an existing span of 130 feet.

Conclusion:

The reinforced concrete bridge of DB05 is hydraulically undersized for the 25 and 100-year storm events as indicated by the FEMA FIRMs and the Manning's equation analysis. The bridge is located in an area prone to flooding and it should be assumed the bridge deck will be submerged during the 25 and 100-year rain events. It must be structurally designed to withstand the flooding characteristic to its location. There is little change in flow depth across the bridge so one could conclude that the bridge is not an obstruction to high water flows and is not the cause of local area flooding. The conclusion of this report is that it is hydraulically undersized for the Dillenbaugh Creek flows and should be structurally reinforced to withstand the backwater flooding of the Chehalis River during the 100-year storm. The concrete bridge is adequately sized to provide fish passage.

DB04: Bridge for I-5 @ Exit 77

Image 29: DB04: Bridge for I-5 Off-Ramp @ Exit 77

Specifications	
Type	Concrete Bridge
Span	160 feet
Low Chord Height	20 feet
Length	85 feet
Bank Full Width	15.5 feet

Flows	
2-year	1027
5-year	1541
10-year	1872
25-year	2276
50-year	2563
100-year	2840

Model Values	
Creek Base Width *b*	31.5 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	162.94 feet
Bridge Deck Elevation	184.3 feet
USGS Map Centralia Quadrangle	
Site Elevation	185 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	185 feet

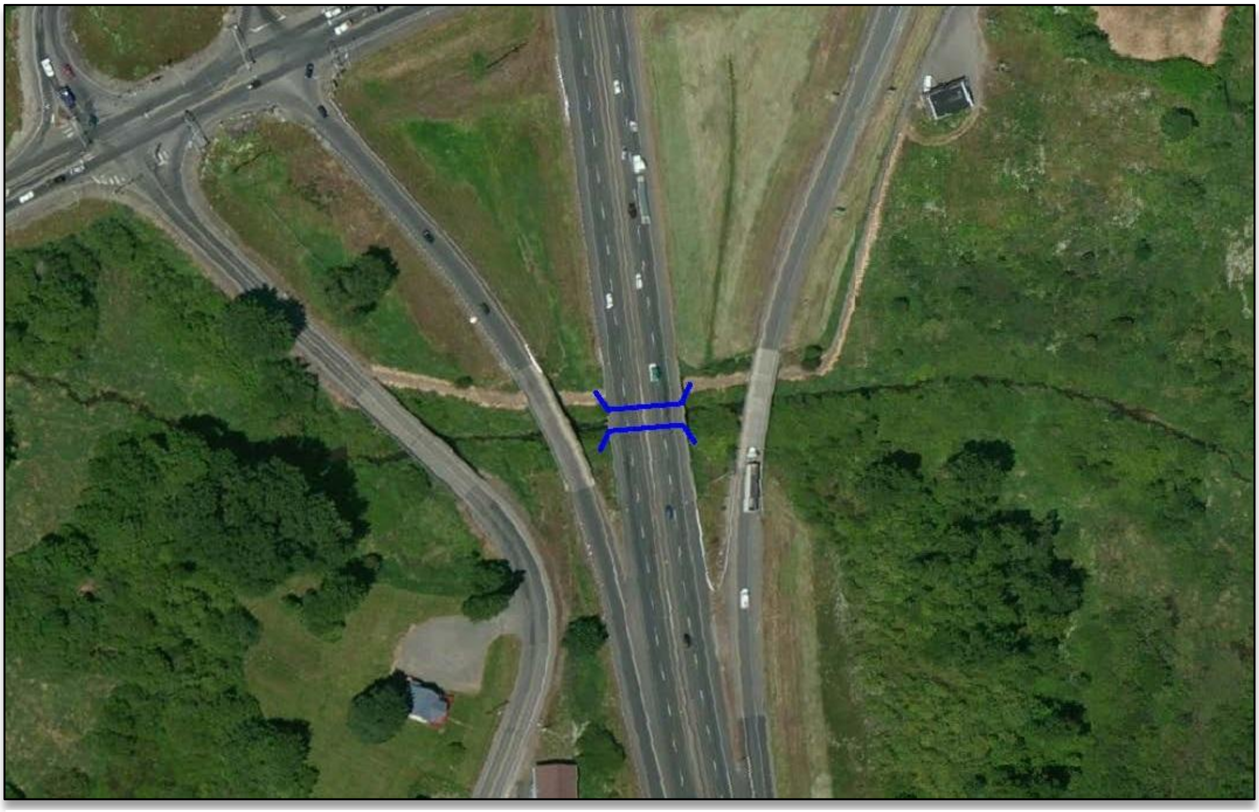

Image 30: DB04 Aerial Image

Site Condition:

The reinforced concrete bridge over Dillenbaugh Creek at Exit 77 supports Interstate 5. A visual inspection of the bridge was completed through field documented photographs and video. The structure shows no signs of major defects, spalling or cracking through images and video reviewed. Columns look to be in place with no undercutting from erosion.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 22.06 ft with an allowable depth of 20 ft. For this method of analysis, the bridge is undersized.

Calculated Capacity:

Table 27: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	17.44 ft	<19 ft
	Velocity of Flow	1.56 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	4.67 ft	-
100 Year Rain Event	Depth of Flow	19.29 ft	<20 ft
	Velocity of Flow	1.65 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	5.30 ft	-

Based on the calculated values, the 25-year rain event has a flow depth 1.56 ft less than the allowable value and the 100-year rain event has a flow depth 0.71 ft less than the allowable value. These values are less than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The calculated velocity is lower than the allowable range, but site visits showed no sign of sedimentation.

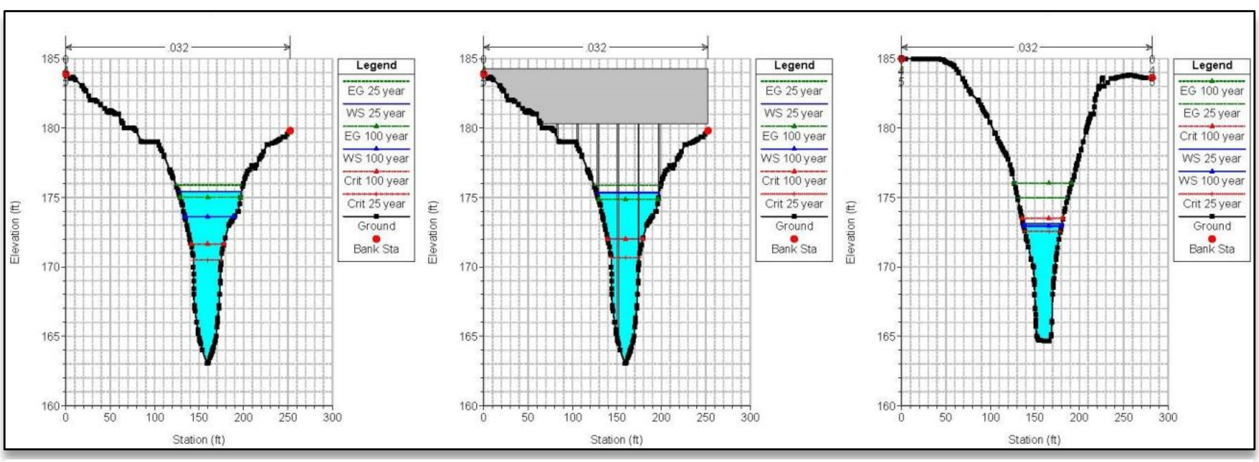

Figure 13: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements by Skillings Connolly, Inc taken on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 28: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	12.26 ft	<19 ft
	Velocity of Flow	11.97 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.58 ft	-
100 Year Rain Event	Depth of Flow	8.93 ft	<20 ft
	Velocity of Flow	13.55 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	8.93 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 6.74 ft less than the allowable value and the 100-year rain event has a flow depth 11.07 ft less than the allowable value. These values are lower than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows. Using this method of analysis, the bridge is adequately sized. However, the velocity is outside the allowable range and a cause for concern.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This bridge has average Bank Full Width of 15.5 feet. Fish Passage criteria requires 20.60 feet of span at this site with an existing span of 160 feet.

Conclusion:

The reinforced concrete bridge of DB04 is hydraulically undersized for the 25 and 100-year storm events as indicated by the FEMA FIRMs and the HEC-RAS model analysis. The bridge is located in an area prone to flooding and it should be assumed the bridge deck will be submerged during the 100-year rain events. The HEC-RAS model analysis shows high velocity flows of 11.97 ft/s and 13.55 ft/s for the 25 and 100 year rain events respectively. The site has evidence of scour and undermining of bridge piers. This may also be influence by the absence of site vegetation. While DB05 directly upstream and DB03 and DB02 directly downstream are heavily vegetated, DB04 is mostly bare earth with concrete debris in the creek bed. By restoring the area to a natural state, the Manning's coefficient will increase and cause a dissipation of flow energy. The concrete bridge is adequately sized to provide fish passage.

It is the conclusion of this report that the DB04 bridge should be structurally designed to withstand the flooding characteristic to its location. We recommend installation of native vegetation and energy dissipaters in order to reduce flow velocity and scour. It is important to note that this may increase flows through this area.

DB03: Bridge for I-5 On-Ramp @ Exit 77

Image 31: DB03: Bridge for I-5 Off-Ramp @ Exit 77

Specifications	
Type	Concrete Bridge
Span	152 feet
Low Chord Height	22 feet
Length	30 feet
Bank Full Width	16 feet

Flows	
2-year	1027
5-year	1541
10-year	1872
25-year	2276
50-year	2563
100-year	2840

Model Values	
Creek Base Width *b*	19 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	161.84 feet
Bridge Deck Elevation	186.30 feet
USGS Map Centralia Quadrangle	
Site Elevation	185 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	185 feet

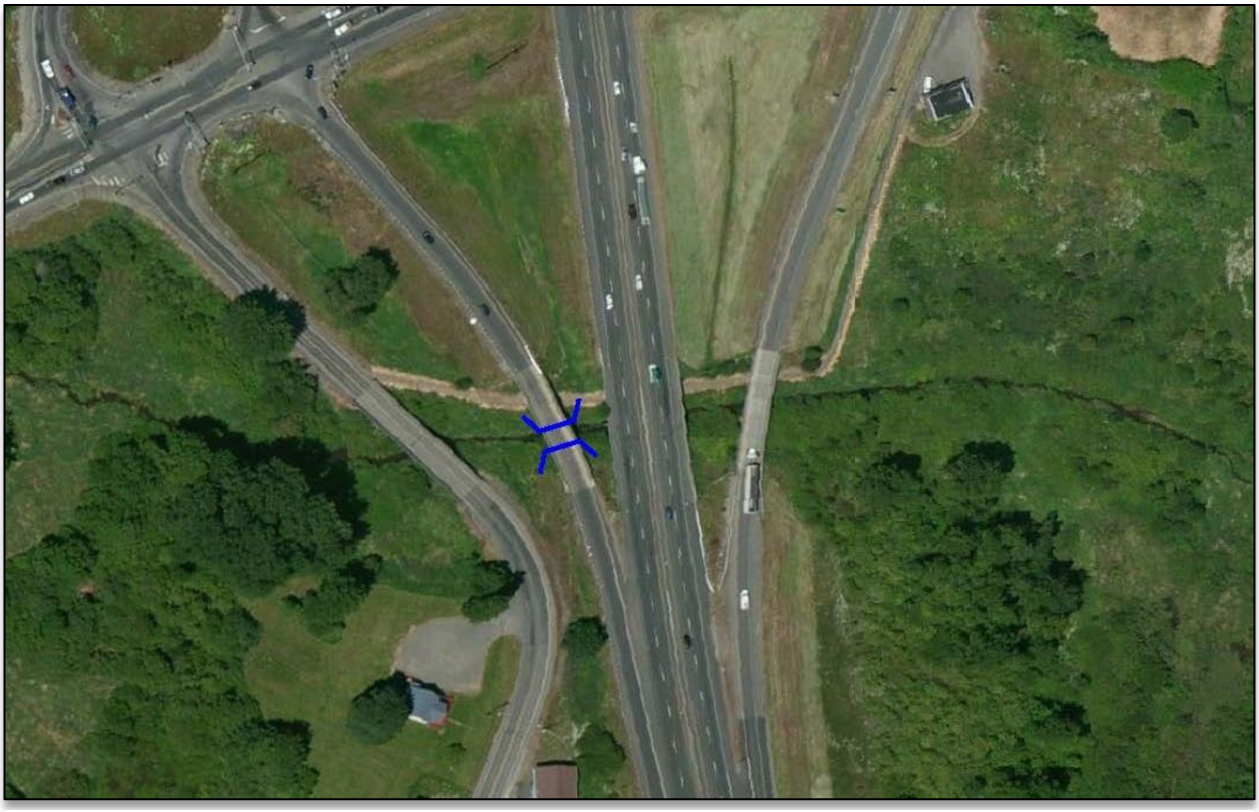

Image 32: DB03 Aerial Image

Site Condition:

The reinforced concrete bridge over Dillenbaugh Creek at Exit 77 supports the I-5 on-ramp. A visual inspection of the bridge was completed through field documented photographs and video. The structure shows no signs of major defects, spalling or cracking through images and video reviewed. Columns look to be in place with no undercutting from erosion.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 23.16 ft with an allowable depth of 22 ft. For this method of analysis, the bridge is undersized.

Calculated Capacity:

Table 29: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	19.07 ft	<21 ft
	Velocity of Flow	1.57 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	5.68 ft	-
100 Year Rain Event	Depth of Flow	20.96 ft	<22 ft
	Velocity of Flow	1.66 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	6.37 ft	-

Based on the calculated values, the 25-year rain event has a flow depth 1.93 ft less than the allowable value and the 100-year rain event has a flow depth 1.04 ft less than the allowable value. These values are slightly less than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The velocity is within the allowable range and is not a cause for concern.

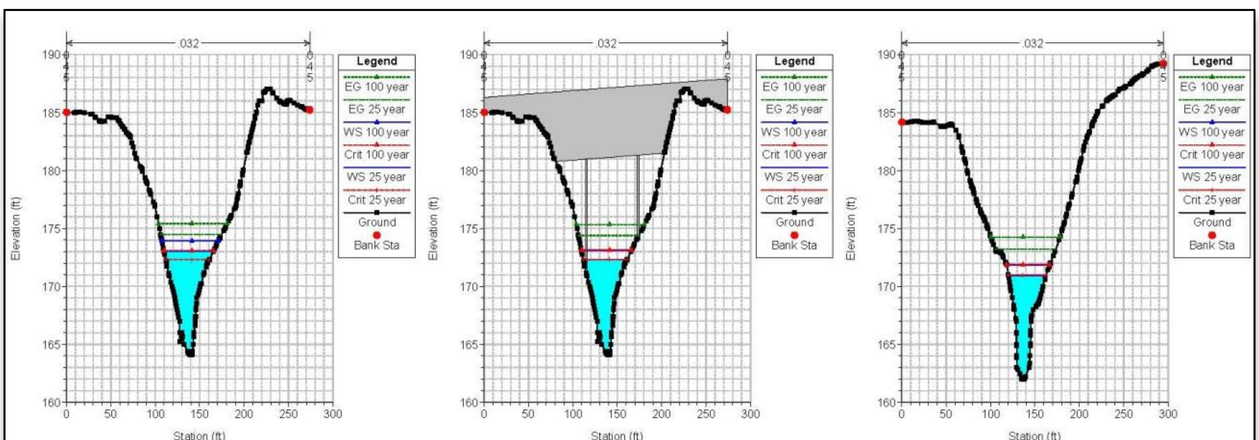

Figure 14: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 30: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	8.23 ft	<21 ft
	Velocity of Flow	15.92 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	8.23 ft	-
100 Year Rain Event	Depth of Flow	9.05 ft	<22 ft
	Velocity of Flow	16.11 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	9.05 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 12.77 ft less than the allowable value and the 100-year rain event has a flow depth 12.95 ft less than the allowable value. These values are lower than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The modeled velocity is higher than the allowable range, but site visits showed no sign of erosion or scour. However, the site should be closely watched for signed of deterioration due to high water flows and velocity. Using this method of analysis, the bridge is adequately sized.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This bridge has average Bank Full Width of 16 feet. Fish Passage criteria requires 21.20 feet of span at this site with an existing span of 152 feet.

Conclusion:

The reinforced concrete bridge of DB03 is hydraulically undersized for the 25 and 100-year storm events as indicated by the FEMA FIRMs. The bridge is located in an area prone to flooding and it should be assumed the bridge deck will be submerged during the 25 and 100-year rain events. It must be structurally designed to withstand the flooding characteristic to its location. The HEC-RAS model analysis shows high velocity flows of 15.92 ft/s and 16.11 ft/s for the 25 and 100-year rain events respectively. The site has no evidence of scour or undermining of bridge piers. However, the site should be monitored for future erosion as high velocity flows could quickly cause significant damage. Additionally, the site may benefit from additional vegetation. By restoring the area to a natural state, the Manning's coefficient will increase and cause a dissipation of flow energy. The concrete bridge is adequately sized to provide fish passage.

It is the conclusion of this report that the site 12 bridge should be structurally designed to withstand the flooding characteristic to its location. We recommend installation of native vegetation and energy dissipaters in order to reduce flow velocity and scour. It is important to note that this may increase flows through this area.

DB02: Bridge for SW Riverside Drive

Image 33: DB02: Bridge for SW Riverside Drive

Specifications	
Type	Concrete Bridge
Span	164 feet
Low Chord Height	22 feet
Length	35 feet
Bank Full Width	16 feet

Model Values	
Creek Base Width *b*	16 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Flows	
2-year	1027
5-year	1541
10-year	1872
25-year	2276
50-year	2563
100-year	2840

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	161.83 feet
Bridge Deck Elevation	183.90 feet
USGS Map Centralia Quadrangle	
Site Elevation	185 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	185 feet

Image 34: DB02 Aerial Image

Site Condition:

The reinforced concrete bridge over Dillenbaugh Creek supports Riverside Dr. A visual inspection of the bridge was completed through field documented photographs and video. The structure shows no signs of major defects, spalling or cracking through images and video reviewed. Columns look to be in place with no undercutting from erosion.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 23.17 ft with an allowable depth of 22 ft. For this method of analysis, the bridge is undersized.

Calculated Capacity:

Table 31: Manning's Equation Calculation Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	19.50 ft	<21 ft
	Velocity of Flow	1.57 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	6.06 ft	-
100 Year Rain Event	Depth of Flow	21.39 ft	<22 ft
	Velocity of Flow	1.66 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	6.78 ft	-

Based on the calculated values, the 25-year rain event has a flow depth 1.50 ft less than the allowable value and the 100-year rain event has a flow depth 0.61 ft less than the allowable value. These values are less than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows and the resulting floodwater elevations. At this location during a 25 or 100-year storm event, the Chehalis River has overtopped its banks and flooded the surrounding area, to include this bridge location. The observed values as documented by the Preliminary FIRMs reflect floodwater elevations influence by the Chehalis River and Dillenbaugh Creek. It may not be accurate to say the bridge is undersized, but rather it must be structurally designed to withstand the flooding characteristic to its location. The calculated velocity is lower than the allowable range, but site visits showed no sign of sedimentation.

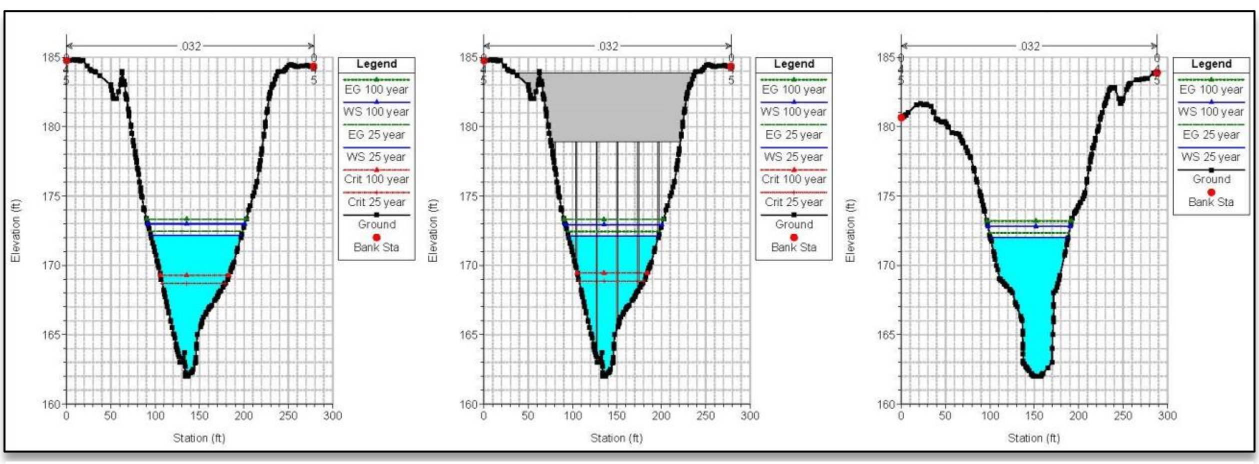

Figure 15: HEC-RAS Upstream, Bridge, and Downstream Cross Sections

Modeled Capacity

The final method analysis used the United States Army Corps of Engineers modeling program HEC-RAS. The topographic model was constructed using LiDAR files from the Puget Sound Lidar Consortium, survey data taken by Skillings Connolly, Inc on August 4th, 2016, and measurements taken by Skillings Connolly, Inc on July 13th, 2016. Using this method of analysis, the topography surrounding the bridge could be taken into account.

Table 32: HEC-RAS Model Results

		Existing Condition Value	Allowable Values
25 Year Rain Event	Depth of Flow	10.11 ft	<21 ft
	Velocity of Flow	4.92 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	6.86 ft	-
100 Year Rain Event	Depth of Flow	10.93 ft	<22 ft
	Velocity of Flow	5.37 ft/s	3 ft/s < V < 10 ft/s
	Critical Depth of Flow	7.45 ft	-

Based on the modeled values, the 25-year rain event has a flow depth 10.89 ft less than the allowable value and the 100-year rain event has a flow depth 11.07 ft less than the allowable value. These values are lower than the observed values of the 2007 flood as these calculations only consider the input of the Dillenbaugh Creek flows. Using this method of analysis, the bridge is adequately sized. The velocity is within the allowable range and is not a cause for concern.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This bridge has average Bank Full Width of 16 feet. Fish Passage criteria requires 21.20 feet of span at this site with an existing span of 164 feet.

Conclusion:

The reinforced concrete bridge of DB02 is hydraulically undersized for the 25 and 100-year storm events as indicated by the FEMA FIRMs and the HEC-RAS model analysis. The bridge is located in an area prone to flooding and it should be assumed the bridge deck will be submerged during the 100-year rain events. The Manning's equation analysis and the HEC-RAS model analysis shows velocities lower than expected given the high velocities of the sites directly upstream. Despite the moderate 100-year velocities of 1.66 ft/s and 5.37 ft/s, one should consider this site at the same risk for erosion and scour damage as DB03-DB05. The concrete bridge is adequately sized to provide fish passage.

It is the conclusion of this report that the DB02 bridge should be structurally designed to withstand the flooding characteristic to its location. We recommend installation of native vegetation and energy dissipaters in order to reduce flow velocity and scour. It is important to note that this may increase flows through this area.

DB01: Bridge for State Route 6

Image 35: DB01: Bridge for State Route 6

Specifications	
Type	Timber Truss Bridge
Span	1000 feet
Low Chord Height	30 feet
Length	30 feet
Bank Full Width	20.3 feet

Model Values	
Creek Base Width *b*	20 feet
Side Slopes *1:Z*	3
Creek Bed Slope *S*	0.00005 ft/ft
Manning's Roughness Coefficient *n*	0.032

Flows	
2-year	877
5-year	1362
10-year	1676
25-year	2054
50-year	2319
100-year	2572

Elevations	
Survey Completed August 2016	
Creek Bed Elevation	161.83 feet
USGS Map Centralia Quadrangle	
Site Elevation	178 feet
Preliminary FEMA Flood Insurance Rate Map(FIRM)	
Base Flood (100-year) Elevation	184 feet

Image 36: DB01 Aerial Image

Site Condition:

The timber bridge of State Route 6 near exit 77 is a passageway for Dillenbaugh Creek and connects to a steel truss bridge over the Chehalis River. The scale of the bridge was prohibitive to inspection for the sake of this report.

Observed Capacity:

In determining base flood water elevation, the Preliminary FEMA Flood Insurance Rate Map, revised in 2010, was used. This updated map was drawn following the Chehalis Flood of 2007 and uses observed values. Additionally, the preliminary FEMA FIRM uses NAVD88 rather than NGVD29. Our survey on the nearby site 14 is done in NAVD88, so the creek bed elevation and the base flood elevation coincide.

Based on the base flood elevation values observed in 2007, the depth of flow is 22.17 ft and did not overtop the roadway. For this method of analysis, the bridge is adequately sized.

Fish Passage Criteria:

In addition to hydraulic capacity, each stream crossing has been assessed on fish passage capacity. Fish Passage criteria is based on bankfull width determined by multiple measurements taken upstream and downstream of each road crossing. These measurements were then used to develop an average bankfull width for Dillenbaugh Creek at each culvert or bridge identified in this study. Average bankfull widths were then used to determine the overall width of the crossing structure. The Stream Simulation sizing criteria width of structure is: 1.2 * Average Bankfull Width + 2 feet. This bridge has average Bank

Full Width of 20.3 feet. Fish Passage criteria requires 26.36 feet of span at this site with an existing span of 1000 feet.

Conclusion:

The bridge of State Route 6 is hydraulically sized for both the 25 and 100-year storm events. Further analysis using survey and modeling was considered unnecessary due to the oversized character of the bridge. The timber bridge is adequately sized to provide fish passage.

8.0 Conclusion

This Dillenbaugh Creek Stream Crossing Study and Analysis is comprised of 10,750 acres of drainage basin, 4 miles of creek, and 17 stream crossings. Each of the crossings was documented using a combination of site visit photos, hand measurements, and survey. The crossings were then analyzed for hydraulic capacity by looking at the FEMA Flood Maps (Observed Capacity) to obtain 100-year flood levels, using Manning's Equation to obtain headwater at the 25 and 100-year flood levels, and modeling the flood levels using the US Army Corps of Engineers modeling program HEC-RAS. Each crossing's fish passage suitability was also analyzed using the Stream Simulation Analysis from measured bankfull width.

Table 33 Results of Stream Crossing Analysis

Site #	Description	FEMA Flood Map Analysis	Calculated Capacity Analysis	Modeled Capacity Analysis	Fish Passage Criteria Analysis
DB16	Single Track Timber Rail Road Bridge	Pass	Fail	Pass	Fail
DB15	Double Box Culvert	Pass	Fail	Fail	Fail
DB14	Box Culvert	Pass	Pass	Fail	Fail
DB13	Double Box Culvert	Pass	Fail	Fail	Pass
DB12	Box Culvert	Pass	Pass	Pass	Pass
DB11	Abandoned Farmhouse Access Driveway	Fail	Fail	Fail	Pass
DT01	Double Box Culvert	Fail	Fail		
DB10	Double Box Culvert	Pass	Fail	Fail	Fail
DB09	Abandoned Rail Road Bridge	Fail	Fail	Fail	Fail
DB08	Concrete Bridge	Pass	Pass	Pass	Pass
DB07	Double Track Concrete Rail Road Bridge	Fail	Pass	Pass	Pass
DB06	Single Track Timber Rail Road Bridge	Fail	Fail	Pass	Pass
DB05	Concrete Bridge	Fail	Fail	Pass	Pass
DB04	Concrete Bridge	Fail	Pass	Pass	Pass
DB03	Concrete Bridge	Fail	Pass	Pass	Pass
DB02	Concrete Bridge	Fail	Pass	Pass	Pass
DB01	Timber Bridge	Pass			Pass

= Pass = Fail

*DB = Dillenbaugh Creek, DT = Dilly Twig Creek

As no method is without limitations, there were fluctuations in floodwater depth resulting from each analysis. For example, the FEMA Flood Analysis only accounts for 100-year flood elevation. It is possible to pass the 100-year flood elevation standard while failing the lower 25-year flood elevation. This is the case for DB10 (Double Box Culvert) where 100-year flood waters at the site were at an acceptable level for all three methods of analysis but 25-year flood waters were as much as 50% greater than allowable levels. For this reason, and for the purposes of this report, a stream crossing will be considered hydraulically undersized if two out of the three methods of analysis show failure flood levels (See Table 33 Results of Stream Crossing Analysis). The following stream crossings were considered hydraulically undersized.

DB15 Double Box Culvert Under Bishop Road

The bottomless, double box culvert of DB15 is hydraulically undersized for the 25 and 100-year storm events according to both the Manning's equation calculations and the HEC-RAS hydraulic model. The flow depth for both evaluated rain events is greater than the height of the culvert which restricts debris passage and can cause damage to the culvert and road embankment. The flow velocity for both evaluated rain events is within the allowable values and site conditions do not indicate an issue with culvert undermining or erosion downstream. There is minor river rock build up at the entrance of the north barrel but an increase in design velocity is not recommended. The culvert is currently undersized to provide adequate fish passage. Should future development be considered, the culvert span should be sized at a minimum of 25.04 feet.

DB13 Double Box Culvert Under I-5 On-Ramp at Exit 74

The bottomless, double box culvert of DB13 is hydraulically undersized for the 25 and 100-year storm events according to both the Manning's equation calculations and the HEC-RAS hydraulic model. The flow depth for both evaluated rain events is greater than the height of the culvert and the road which restricts debris passage, can cause damage to the culvert and road embankment, and restrict emergency access on I-5. The flow velocity for both evaluated rain events is within the allowable values and site conditions do not indicate an issue with culvert undermining or erosion downstream. There is minor river rock build up at the entrance of the north barrel but an increase in design velocity is not recommended. The culvert is currently sized to provide adequate fish passage.

DB11 Abandoned Farmhouse Access Road

The concrete and timber bridge of Site 5.5 is in poor condition and not suitable for vehicular use. The bridge is located in a flat area prone to flooding and the deck is set at the elevation of the surrounding ground. During significant rain events, the area surrounding and including the bridge will be underwater. If the bridge is to be repaired and recommissioned it would do little good to raise or widen the bridge, but rather it must be structurally designed to withstand the flooding characteristic to its location. It is more significant to note that the change in flow depth from upstream to downstream shows the bridge does have an effect on flow. Additionally, the preliminary FEMA FIRM and flood map generated by the HEC-RAS model show an increase in flood zone width at this point. One could conclude that the bridge is an obstruction to high water flows and flooding in the immediate area could be decreased by removal of the bridge. The bridge is currently sized to provide adequate fish passage.

DT01 Double Box Culvert under I-5 at at Exit 76

The bottomless double box culvert of Site DT1 is hydraulically undersized for the 25 and 100-year storm events according to both the FEMA FIRMs and Manning's equation calculations. As the scope of this study was limited to Dillenbaugh Creek, Dilly Twig Creek and its culverts were not modeled using the United States Army Corps of Engineers modeling program HEC-RAS. It is included in this report as a possible contributor to the floodwater depth and velocity in the Dillenbaugh Creek. For more information on Dilly Twig Creek and its culverts, see the Gibbs and Olsen Hydrology Report included in Appendix B. According to the observed flows of 2007, the flow overtopped the roadway which can cause damage to the culvert and road embankment and restricts emergency access on I-5. By Manning's equation calculations, which does not account for backwater flooding from the Dillenbaugh or Chehalis River, this culvert is barely undersized for both the 25 and 100-year rain events which restricts debris passage and can cause damage to the culvert and road embankment. The flow velocity for both evaluated rain events is within the allowable values and site conditions do not indicate an issue with culvert undermining or erosion downstream. DT01 was not evaluated for fish passage capacity.

DB10 Double Box Culvert under Rice Road

The double box culvert of DB10 is hydraulically undersized for the 25 and 100-year storm events according to both the Manning's equation calculations and the HEC-RAS hydraulic model. The upstream flow depth for both evaluated rain events is greater than the height of Rice Road directly to the south west of the site. The flow velocities in the culvert for both the 25 and 100-year storm events exceed the allowable 10 ft/s. If the culvert size was increased in both height and width, the headwater depth would decrease and the culvert velocity would most closely match the natural channel velocity of approximately 3 ft/s found up and downstream of the site. However, the tailwater elevations of 181.65 and 182.21 for the 25 year and 100-year rain events indicate a natural channel elevation that would still overtop the 181 ft elevation of Rice Road to the west of the site. In order to bring the creek crossing into compliance, the culvert would need to be increased in size and portions of Rice Road would need to be raised. The culvert is currently undersized to provide adequate fish passage. Should future development be considered, the culvert span should be sized at a minimum of 25.60 feet.

DB09 Abandoned Railroad Bridge

The I beam bridge of DB09 is missing the bridge decking and is not currently suitable for use. The bridge is located in a flat area prone to flooding and the deck is set at the elevation of the surrounding ground. During significant rain events, the area surrounding and including the bridge will be underwater. If the bridge is to be repaired and recommissioned it would do little good to raise or widen the bridge, but rather it must be structurally designed to withstand the flooding characteristic to its location. It is more significant to note that the minor change in flow depth from upstream to downstream shows the bridge does have an effect on flow. While this effect would be negligible during 25 and 100-year storm events, one could conclude that the bridge is an obstruction to high water flows and flooding in the immediate area could be decreased by removal of the bridge. The abandoned bridge is currently undersized to provide adequate fish passage. Should future development be considered, the bridge span should be sized at a minimum of 33.80 feet.

DB06 Single Track Timber Railroad Bridge

The timber railroad bridge of DB06 is hydraulically undersized for the 25 and 100-year storm events. The bridge is located in a flat area prone to flooding and the deck is set at the elevation of the surrounding ground. According to the FEMA FIRMs and the Manning's Equation calculations, the area surrounding and including the bridge will be underwater during significant rain events. It must be structurally designed to withstand the flooding characteristic to its location. By the analysis of the HEC-RAS model, the bridge is adequately sized to allow floodwaters to flow with adequate freeboard. The difference in values from the observed values to the modeled values can be attributed to the backwater flooding of the Chehalis River during the 100-year rain event. There is little change in flow depth across the bridge so one could conclude that the bridge is not an obstruction to high water flows and is not the cause of local area flooding. The conclusion of this report is that it is hydraulically undersized for the Dillenbaugh Creek flows and should be structurally reinforced to withstand the backwater flooding of the Chehalis River during the 100-year storm. The timber bridge is adequately sized to provide fish passage.

DB05 Concrete Bridge for I-5 Off-Ramp at Exit 77

The reinforced concrete bridge of DB05 is hydraulically undersized for the 25 and 100-year storm events as indicated by the FEMA FIRMs and the Manning's equation analysis. The bridge is located in an area prone to flooding and it should be assumed the bridge deck will be submerged during the 25 and 100-year rain events. It must be structurally designed to withstand the flooding characteristic to its location. There is little change in flow depth across the bridge so one could conclude that the bridge is not an obstruction to high water flows and is not the cause of local area flooding. The conclusion of this report is that it is hydraulically undersized for the Dillenbaugh Creek flows and should be structurally reinforced to withstand the backwater flooding of the Chehalis River during the 100-year storm. The concrete bridge is adequately sized to provide fish passage.

9.0 Recommendations

The recommendations of this report have been evaluated based on the following criteria:

1. Hydraulic and Fish Passage Sizing – Is this stream crossing undersized for one or both of these items?
2. Condition – Is the structure and/or surrounding area showing signs of deterioration?
3. Ownership/Location – Is this structure under the jurisdiction of the City of Chehalis or is it located on WSDOT or private property? Is it located under a major or essential roadway that would make upsizing prohibitive?

Stream Crossings of High Priority (In order upstream to downstream)

DB15 Double Box Culvert under Bishop Road

While the FEMA Flood Maps show this double box culvert meets 100-year flood elevation requirements, it does not meet 25 or 100-year flood elevation requirements by the Manning's Equation or the HEC-RAS Model. Additionally, it does not meet fish passage requirements for culvert span. The structure appears to be in good condition and the surrounding areas do not indicate scour from high velocities. This double box culvert is under the jurisdiction of the City of Chehalis and Bishop Road is not considered a major arterial roadway for the region. Resizing this culvert has the potential to decrease area flooding, increase fish spawning upstream, and will not pose a prohibitive impediment to local travel during construction.

DB10 Double Box Culvert under Rice Road

While the FEMA Flood Maps show this double box culvert meets 100-year flood elevation requirements, it does not meet 25 or 100-year flood elevation requirements by the Manning's Equation or the HEC-RAS Model. Additionally, the section of Rice Road immediately to the west of the site floods during high intensity rain events. Therefore, a project to increase the hydraulic capacity of DB10 would also include raising the elevation of sections of Rice Road. In addition, it does not meet fish passage requirements for culvert span. The structure appears to be in good condition and the surrounding areas do not indicate scour from high velocities. This double box culvert is under the jurisdiction of the City of Chehalis and Rice Road is not considered a major arterial roadway for the region. Resizing this culvert and raising sections of Rice Road has the potential to decrease area flooding, increase fish spawning upstream, and will not pose a prohibitive impediment to local travel during construction.

Stream Crossings of Low Priority (In order upstream to downstream)

DB11 Abandoned Farmhouse Access Road

This bridge does not meet 25 or 100-year flood elevation requirements according to the FEMA Flood Maps, Manning's Equation, or the HEC-RAS Model. Additionally, the flood map generated by the HEC-RAS model show an increase in flood zone width at this point. One could conclude that the bridge is an obstruction to high water flows and flooding in the immediate area could be decreased by removal of the bridge. The stream crossing does meet fish passage requirements for bridge span. The structure is in poor condition and, in its current condition, not suitable for vehicular use. This bridge is under the jurisdiction of WSDOT and is located in the right of way of I-5 near exit 74. At this time, resizing this bridge has little advantage for the City of Chehalis and surrounding areas. It may be of some benefit to remove the structure entirely, but this is not recommended as a priority project.

DB09 Abandoned Railroad Bridge

This bridge does not meet 25 or 100-year flood elevation requirements according to the FEMA Flood Maps, Manning's Equation, or the HEC-RAS Model. The stream crossing does meet fish passage requirements for bridge span. The structure is in poor condition and, in its current condition, not suitable for use. This bridge is under the jurisdiction of WSDOT and is located in the right of way of I-5 near exit 76. At this time, resizing this bridge has little advantage for the City of Chehalis and surrounding areas. It may be of some benefit to remove the structure entirely, but this is not recommended as a priority project.

Stream Crossings outside the feasibility of a City of Chehalis Infrastructure Improvement Project (In order upstream to downstream)

DB13 Double Box Culvert Under I-5 On-Ramp at Exit 74

This culvert does not meet 25 or 100-year flood elevation requirements according to both Manning's Equation and the HEC-RAS Model. The HEC-RAS model additionally shows the floodwaters overtopping I-5. Additionally, it does not meet fish passage requirements for culvert span. The structure appears to be in good condition and the surrounding areas do not indicate scour from high velocities. However, this double box culvert is under the jurisdiction of the WSDOT and is under Interstate 5. While resizing this culvert has the potential to decrease area flooding and increase fish spawning upstream, it is outside the feasibility of a City of Chehalis infrastructure improvement project.

DT01 Double Box Culvert under I-5 at at Exit 76

This culvert does not meet 25 or 100-year flood elevation requirements according to the FEMA Flood Maps or the Manning's Equation. Additionally, it does not meet fish passage requirements for culvert span. The structure appears to be in good condition and the surrounding areas do not indicate scour from high velocities. However, this double box culvert is under the jurisdiction of the WSDOT and is under Interstate 5. While resizing this culvert has the potential to decrease area flooding and increase fish spawning upstream, it is outside the feasibility of a City of Chehalis infrastructure improvement project.

DB06 Single Track Timber Railroad Bridge

This bridge does not meet 25 or 100-year flood elevation requirements according to the FEMA Flood Maps or Manning's Equation. The FEMA Flood Maps indicate the structure is entirely submerged during a 100-year flood event. The stream crossing does meet fish passage requirements for bridge span. While the structure is still in use, it is in poor condition and provides access to a dead-end railroad. This bridge is under the jurisdiction of WRL, LLC, a railway company that leases and operates a 26-mile line of railroad. While resizing this bridge has the potential to decrease area flooding, it would require extensive coordination and permission from WRL, LLC.

DB05 Concrete Bridge for I-5 Off-Ramp at Exit 77

This bridge does not meet 25 or 100-year flood elevation requirements according to the FEMA Flood Maps or the Manning's Equation. It does meet fish passage requirements for bridge span. The structure appears to be in good condition and the surrounding areas do not indicate scour from high velocities. However, this bridge is under the jurisdiction of WSDOT and is under Interstate 5. While resizing this bridge has the potential to decrease area flooding, it is outside the feasibility of a City of Chehalis infrastructure improvement project.

10.0 Glossary

Bed Load Movement	A type of sediment transport along a river bed.
Creosote	A product created by high-temperature treatment of beech and other woods, coal, or from the resin of the creosote bush. Coal tar creosote is the most widely used wood preservative in the United States (Department of Ecology, State of Washington, n.d.).
Critical Depth	The depth of flow where energy is at a minimum for a particular discharge.
Electrical Resistance	An investigative technique using a probe with two wires on the tip to measure electrical resistance (Bob Monk, n.d.).
Hammer Sounding	A non-destructive investigative technique where by the quality of sound obtained by striking the surface of the material with a hammer indicates the quality of the material (The Concrete Portal, 2016).
Headwater	The depth of water, as measured from the bottom of the upstream end of the culvert.
High Intensity Rain Events	the 2, 5, 10, 25, 50, and 100-year storms as defined by a 50%, 20%, 10%, 4%, 2%, and 1% chance respectively.
Hydrologic Soil Type	A classification based on the rate of water infiltration and runoff potential after saturation.
Impervious Area	A section of ground covered by impenetrable surfacing such as concrete, asphalt, or rooftops.
Inlet Control	The condition under which the inlet is controlling the amount of flow that will pass through the culvert. Nothing downstream of the culvert entrance will influence the amount of headwater required to pass the design flow (Design Office, Engineering and Regional Operations Division, 2015).
LiDAR	Light detection and ranging is a method of gathering topographic data using a combination of lasers and light detection receivers. This type of surveying is typically done for an area prohibitive in size or accessibility to traditional survey methods.
Low Chord Elevation	The lowest point on a bridge that may impede flow.

NAGVD29	Also known as the Sea Level Datum of 1929, the National Geodetic Vertical Datum of 1929 is a vertical control datum set by the general adjustment of 1929 (National Geodatic Survey, 2016).
NAVD88	The North American Vertical Datum of 1988 is the vertical control datum established in 1991 that references the International Great Lakes Datum of 1985 local mean sea level height value (National Geodatic Survey, 2016).
Outlet Control	The condition under which the outlet conditions or barrel are controlling the amount of flow passing through the culvert. The inlet, barrel, or tailwater characteristics, or some combination of the three will determine the amount of headwater required to pass the design flow (Design Office, Engineering and Regional Operations Division, 2015).
Scour Holes	An area of erosion caused by the turbulent flow surrounding an object impeding flow.
Spalling	Flaking of concrete on the surface of a structure.
Stress Wave Timer	An investigative technique using a special hammer to emit a low frequency impulse that starts a sound wave through the wood. The device measures the time it takes for sound to travel through the stem (Bob Monk, n.d.).
Tailwater	The depth of water, as measured from the bottom of the downstream end of the culvert.
Wheel Loading	The amount of weight allotted to any one axel of a vehicle on a given road.
WRIA	"Water Resource Inventory Area"; Ecology and other state natural resource agencies have divided the state of Washington into 62 "WRIAs" to delineate the state's major watersheds (Department of Ecology, n.d.).

11.0 References

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APPENDIX A

Washington State Mean Annual Precipitation Map

APPENDIX B

Dilly Twig Creek Basin Stormwater Management Plan
by Gibbs & Olson

APPENDIX C

FEMA Flood Insurance Rate Map- Preliminary November 11, 2010

APPENDIX D

Dillenbaugh Creek Basin Web Soil Survey Report

APPENDIX E

Undersized Stream Crossing Location Map

APPENDIX F

Department of Ecology River Monitoring Station Data