US Army Corps of Engineers®
Portland District
BUILDING STRONG®

ENVIRONMENTAL SERVICES
CITY OF PORTLAND
working for clean rivers

# LOWER WILLAMETTE RIVER ECOSYSTEM RESTORATION PROJECT

## APPENDIX B: DRAFT HYDROLOGY AND HYDRAULICS TECHNICAL MEMORANDUM

Portland, Oregon

Draft Report
April 2014

Prepared by:

Tetra Tech, Inc.
1020 SW Taylor St.
Suite 530
Portland, OR 97205

# TABLE OF CONTENTS



# List of Tables

## List of Figures



## Appendix

A. Water Surface Elevations for With and Without Project Conditions, 100-year Discharge

# 1. INTRODUCTION

## 1.1 Project Background

The United States Army Corps of Engineers (USACE), Portland District, in partnership with the City of Portland, Oregon, and the Port of Portland, is proposing to restore numerous sites in the Lower Willamette River as part of the Lower Willamette River Ecosystem Restoration Project. The USACE and its partners have prepared the Lower Willamette River General Investigation Study Conceptual Restoration Plan (Tetra Tech 2008), which formulated, evaluated, and screened potential solutions to improve significant ecosystem degradation in the Lower Willamette River watershed. In that document, conceptual restoration plans were prepared for a total of 31 sites.

The next phase of this project was designed to determine the data necessary to assess the feasibility of the proposed project and to evaluate the availability of this data. The Feasibility Work Plan (Tetra Tech 2009) summarized the background information available for each of the recommended project sites. Since the development of that report, further investigation of existing sites has resulted in a reduced number of sites included in the recommended plan. Sites along the mainstem of the Lower Willamette River, Columbia Slough, Johnson Creek, and Tryon Creek were initially assessed for feasibility of restoration. Sites along Johnson Creek have been removed from this planning process because of land ownership constraints or subsequent completion of restoration projects by other entities, and will not be mentioned further. Additional site screening has since occurred, leaving five sites as part of the recommended plan. This report considers the final five sites that have been selected for a full feasibility study (Figure 1.1).

As part of the work required for the completion of a draft feasibility report of the ecosystem restoration alternatives, a feasibility-level, or 35 percent, design is required including design plans, construction cost estimates, and a hydrologic and hydraulic assessment. The analysis presented in this technical memorandum provides the details of the hydrologic and hydraulic assessment component of the draft feasibility report for the remaining sites. It meets the four objectives outlined in the scope of work:

- Update statistical analyses for the five selected design discharges (median summer, median annual, median winter, 2-year, and 100-year) for evaluation of site feasibility.
- Apply HEC-RAS[1] models to evaluate the site on Tryon Creek.
- Investigate the potential impact of boat propeller scour on the sites.
- Compare existing and proposed hydraulic conditions based on modeled results for Tryon Creek.

Personal communication with USACE staff indicated there is a lack of existing impact studies of boat propeller scour that would be relevant to the draft feasibility analysis of the selected restoration sites. It was determined that no additional effort would be applied toward this objective at this time.

[1] HEC-RAS, or Hydrologic Engineering Center-River Analysis System, is a computer program that models the hydraulics of water flow through natural rivers and other channels.

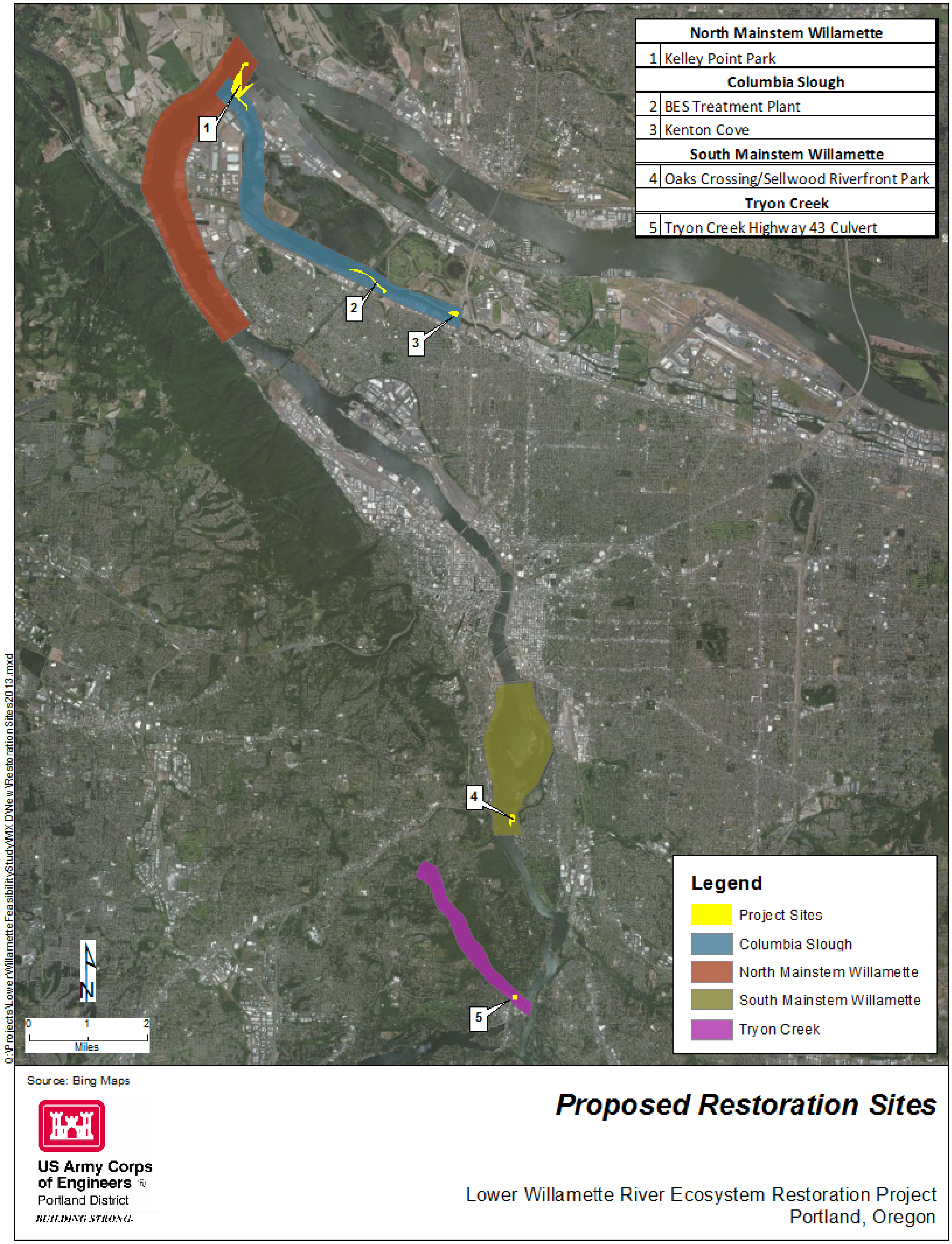


***Figure 1.1. Proposed Restoration Site Locations***

### 1.2 Site Locations and Proposed Restoration Measures

**Mainstem Willamette River**

The restoration project sites adjacent to the banks of the Mainstem of the Willamette River are directly influenced by the hydrology and hydraulics of the river. These sites are located at the confluence of tributaries to the Willamette River, at sloughs, or lakes, and have insignificant water level variation from the water surface elevation of the river. The restoration sites of this study that are within the Mainstem area include:

- Kelley Point Park
- Oaks Crossing/Sellwood Riverfront Park

The restoration measures proposed for these two sites include developing side channels or backwater areas, reducing bank steepness, and revegetating with native species. The hydrologic analyses performed to guide the design elevations for these elements are presented in this report.

**Columbia Slough**

Columbia Slough is a remnant of the historically extensive wetlands along the Columbia River between the mouths of the Sandy River and the Willamette River. The slough has an extensive levee system, enabling development of the floodplain. Several restoration project sites are adjacent to the banks of the lower portion of the Columbia Slough. The lower portion of Columbia Slough is defined by the City of Portland as the 8.5 mile long reach extending downstream of Northeast 18$^{th}$ Avenue to the confluence with the Willamette River (City of Portland 2007a). The restoration sites characterized as Columbia Slough sites are:

- City of Portland Bureau of Environmental Services (BES) Plant Banks
- Kenton Cove

The restoration measures proposed for both of these sites include reshaping of banks and/or side slough areas, revegetating with native species, and the addition of large woody debris (LWD). The hydrologic analyses performed to guide the design elevations for these elements are presented in this report.

**Tryon Creek**

Tryon Creek discharges generally southeast for about 7 miles from its headwaters to its confluence with the Willamette River. While the watershed is entirely within an urbanized area, more than 20 percent of the land within the watershed has been preserved in Tryon Creek State Natural Area (TCSNA). With the high percentage of land protected through preservation and conservation, the Tryon Creek watershed has the possibility to provide one of the largest and protected lengths of fish accessible habitat within the Portland metropolitan area.

A box culvert owned by the Oregon Department of Transportation (ODOT) is located approximately 1200 feet above the Tryon Creek confluence with the Willamette River and provides conveyance for Tryon Creek beneath Highway 43 and the Great Western Railroad. It was originally constructed in the 1920’s and extended in 1955. The roadway elevation above the culvert is at approximately 85 feet above the North American Vertical Datum of 1988 (NAVD88). The existing culvert is 401 feet long with two segments of varying grade and alignment. The upper 100 foot segment of the culvert is sloped at 5.94% from 39.51 feet NAVD88 the to 33.57 feet NAVD88; and, the lower 301 foot segment is sloped at 2.94% from 33.57 feet NAVD88 to 24.72 feet NAVD88 (Figure 1.2). The culvert alignment resulted in a straightening of the natural Tryon Creek channel and loss of approximately 40 to 50 feet of stream length; and, the culvert alignment both increased (to 5.94%) and decreased (to 2.94%) the slope of the culvert segment from an average natural slope of 3.5% (City of Portland 2005). The design drawing for the culvert (ODOT 1955) indicates that the straightened section placed within the existing culvert was constructed through bedrock.

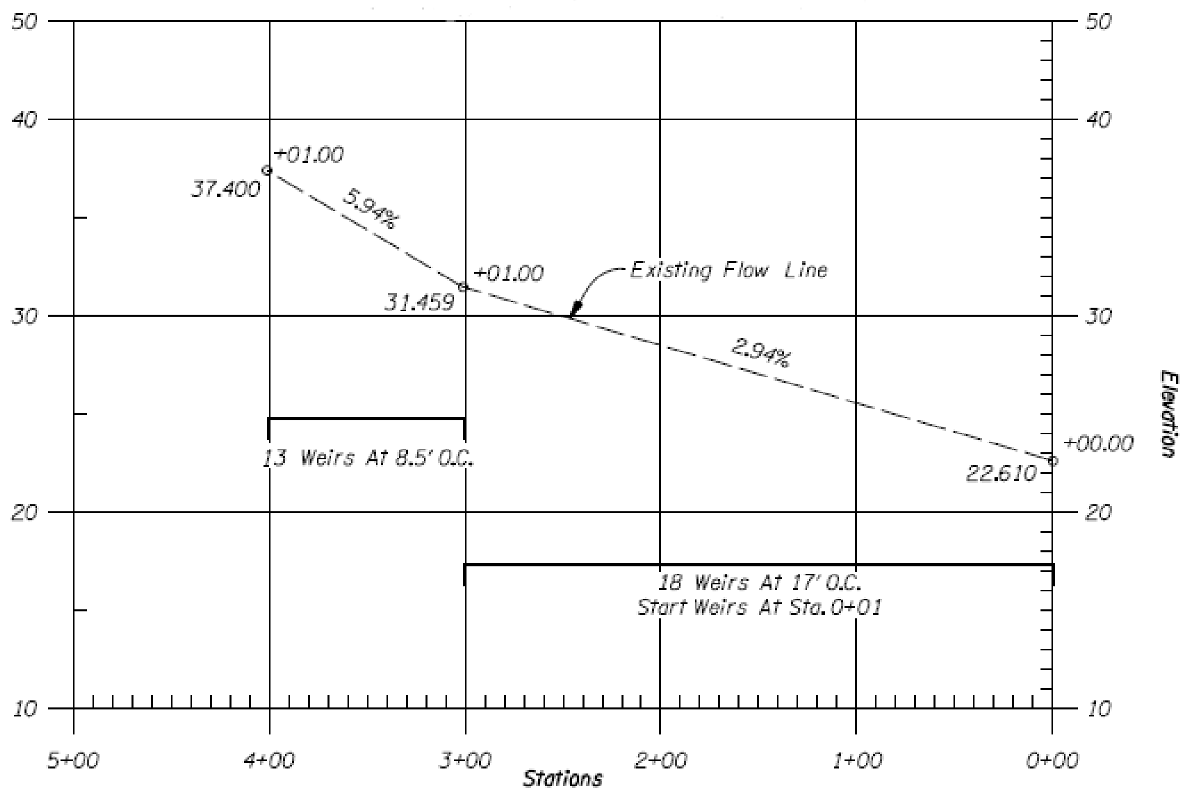


***Figure 1.2. Existing Vertical Alignment of Tryon Creek Culvert***

The culvert and portion of Tryon Creek below the culvert have been identified as a passage barrier for fish to access the middle and upper reaches of Tryon Creek habitat. This is due to higher water velocities and lower depths than what are needed for fish passage and holding within the culvert, and a perched downstream entrance to the culvert that causes a jump impediment. A plunge, or scour, pool that is approximately 4 to 5 feet deep is located below the downstream exit of the culvert, and energy dissipation was recommended to address the scour problem (City of Portland 2005). In 2005, the ODOT classified the Highway 43 culvert as a high priority for fish passage improvements.

Previous analysis and construction were performed as part of separate projects to improve fish passage below and through the Highway 43 culvert. Analysis of alternative designs for the culvert to provide fish, wildlife, and pedestrian passage was conducted by Henderson Land Services (2007) for the City of Lake Oswego and included an arch span culvert and a bridge. These features were taken to conceptual design but no farther. Downstream of the culvert entrance and as part of a separate study, the City of Portland created a roughened chute, comprised of boulders, streambed cobbles, and sill logs, intended to elevate water surfaces so that fish may swim into the culvert rather than jump to enter the culvert, and also reducing bank steepness (Herrera Environmental Consultants 2007). During the 2013 field reconnaissance surveys for the fluvial geomorphologic evaluation of the proposed restoration sites identified in this report, areas of instability were noted along the restored bank that were evidenced by erosion (Appendix A of the Feasibility Study Report).

Work within the culvert was performed in 2007 by ODOT to create the baffles (Figure 1.3) to provide holding water and suitable velocities for fish passage and a lamprey friendly design (ODFW 2011). The Columbia River Fisheries Program Office of the United States Fish and Wildlife Service (USFWS) has provided monitoring within Tryon Creek for Pacific and western brook lampreys, salmon, steelhead, and coastal cutthroat trout and assessment for distribution, determination of the ability of monitored species for passage through the Highway 43 culvert, and with the goal determining upstream passage efficiency. The USFWS monitoring indicates that following the culvert baffle and lower Tryon Creek work, lamprey and adult fish are not present upstream of the culvert (USFWS 2012).

***Figure 1.3. Modified baffles within Highway 43 culvert (USFWS 2012)***

The restoration site in the Tryon Creek watershed that is the focus the Lower Willamette River Ecosystem Restoration Project is referred to as the Tryon Creek Highway 43 Culvert Replacement.

The restoration measures proposed for replacement of the Highway 43 culvert include removal of the existing 8 foot by 8 foot box culvert and replacement with an open bottom arch span culvert and creation of a natural stream channel within the culvert that provides fish passage meeting the Oregon Department of Fish and Wildlife (ODFW) criteria for the stream simulation option. Providing a fish passable culvert at this location will provide access for adult steelhead trout and cutthroat salmon to upper portion of the watershed. The hydrologic and hydraulic analyses to support the preliminary replacement culvert design meeting the fish passage criteria is presented in this report.

# 2. HYDROLOGY AND HYDRAULICS

This technical memorandum documents existing and proposed project hydrologic and hydraulic conditions for the project sites. Previously documented data and analyses were augmented and updated, and for some sites new data were obtained and analyzed. Existing and proposed characterizations include water levels and depths, velocities, and shear stresses at a level of detail commensurate with the available data and scope of work developed for each site (Tetra Tech 2008).

## 2.1 Mainstem Willamette River

This section describes the flood frequency, flow duration and stage duration analyses that were conducted to describe the hydrologic conditions of the Mainstem Willamette River. The basis for the analyses was the flow and stage data collected at U.S. Geological Service (USGS) Gage 14211720 (Willamette River at Portland, OR), which is located at River Mile (RM) 12.8 of the Willamette River. This gaging station is equipped with a water-stage recorder and an acoustic velocity meter. Flow at this station is affected by upstream reservoirs and is also affected by astronomical tidal conditions. According to the USGS surface water records for this station, daily mean discharge values since Water Year (WY) 2007 are produced from "Godin filtered" instantaneous discharges to remove the effects of the daily tidal cycle. The Godin process resamples the series to hourly increments, on the hour, using linear interpolation, and then applies three moving averages.

The objective of the flood frequency analysis was to quantify the 2-year and 100-year Annual Exceedance Probability (AEP) flow rates and water surface elevations at USGS Gage 14211720. The objective of the flow duration and stage duration analyses was to quantify the annual median flow rate and water surface elevation at USGS Gage 14211720, as well as the median summer and median winter flow rates and water surface elevations.

**Flood Frequency Analysis**

Maximum annual peak streamflow data and maximum annual peak gage height data were obtained for USGS Gage 14211720. Annual peak streamflow data were available for WY 1973 through WY 2013; however, not all of the published annual peak values are true instantaneous values. For many of the water years, the USGS only published annual maximum mean daily flow values instead of instantaneous peak flow values. In these instances, the published annual maximum mean daily flow values were derived from a hydrologic routing analysis. Table 2.1 summarizes the USGS published annual peak streamflow dataset for USGS Gage 14211720. In this table, those values that are true instantaneous peak flow values are differentiated from those that are maximum annual mean daily flow values. The values for WY 1995 through WY 2002 were not available on the USGS website, but instead were obtained directly from the USGS.

***Table 2.1. Annual Peak Discharge for Water Years 1973-2012 for the Willamette River USGS Gage 14211720***

| Water Year | Date of Peak | USGS Published Annual Peak Flows (cfs) [1] | Annual Peak Flow Values used for Flood Frequency Analysis |
|---|---|---|---|
| 1973 | Dec. 24, 1972 | 142,000 | 142,000 |
| 1974 | Jan. 18, 1974 | 283,000 | 283,000 |
| 1975 | Dec. 22, 1974 | 123,000 | 123,000 |
| 1976 | Dec. 04, 1975 | 164,000 | 164,000 |
| 1977 | Mar. 10, 1977 | 58,100 [2] | 61,600 |
| 1978 | Dec. 16, 1977 | 237,000 [2] | 251,000 |
| 1979 | Feb. 13, 1979 | 120,000 [2] | 127,000 |
| 1980 | Jan. 14, 1980 | 217,000 | 217,000 |
| 1981 | Dec. 28, 1980 | 198,000 | 198,000 |
| 1982 | Feb. 21, 1982 | 207,000 | 207,000 |
| 1983 | Jan. 08, 1983 | 170,000 | 170,000 |
| 1984 | Feb. 15, 1984 | 138,000 | 138,000 |
| 1985 | Nov. 29, 1984 | 148,000 [2] | 157,000 |
| 1986 | Feb. 24, 1986 | 213,000 [2] | 226,000 |
| 1987 | Feb. 02, 1987 | 164,000 [2] | 174,000 |
| 1988 | Jan. 16, 1988 | 170,000 [2] | 180,000 |
| 1989 | Jan. 12, 1989 | 112,000 [2] | 119,000 |
| 1990 | Jan. 09, 1990 | 142,000 [2] | 150,000 |
| 1991 | Jan. 15, 1991 | 102,000 [2] | 108,000 |
| 1992 | Feb. 22, 1992 | 105,000 [2] | 111,000 |
| 1993 | Mar. 24, 1993 | 122,000 [2] | 129,000 |
| 1994 | Feb. 25, 1994 | 117,000 | 117,000 |
| 1995 | Jan. 17, 1995 | 180,000 [2] | 191,000 |
| 1996 | Feb. 09, 1996 | 420,000 [2] | 445,000 |
| 1997 | Jan. 02, 1997 | 293,000 [2] | 310,000 |
| 1998 | Jan. 17, 1998 | 146,000 [2] | 155,000 |
| 1999 | Dec. 30, 1998 | 240,000 [2] | 254,000 |
| 2000 | Nov. 28, 1999 | 160,000 [2] | 170,000 |
| 2001 | Dec. 25, 2000 | 53,000 [2] | 56,200 |
| 2002 | Dec. 17, 2001 | 140,000 [2] | 148,000 |
| 2003 | Feb. 01, 2003 | 160,000 [2] | 170,000 |
| 2004 | Jan. 31, 2004 | 136,000 [2] | 144,000 |
| 2005 | Dec. 12, 2004 | 94,300 [2] | 99,900 |
| 2006 | Dec. 31, 2005 | 191,000 | 191,000 |
| 2007 | Dec. 16, 2006 | 146,000 | 146,000 |
| 2008 | Dec. 05, 2007 | 135,000 | 135,000 |
| 2009 | Jan. 02, 2009 | 188,000 | 188,000 |
| 2010 | Jun. 07, 2010 | 115,000 | 115,000 |
| 2011 | Jan. 18, 2011 | 149,000 | 149,000 |
| 2012 | Jan. 21, 2012 | 211,000 | 211,000 |

Notes:
1. The USGS reported annual peak streamflow data includes both instantaneous peak flow values and annual maximum daily flow values
2. Flow value is a maximum annual mean daily flow value

Annual peak gage height data is also available for most, but not all, of the water years between WY 1973 and WY 2013. Due to the tidal influence on the gage, the reported maximum annual peak gage height does not necessarily correspond with the time of occurrence of the maximum annual peak flow value. Additionally, the gage height, even during periods of flood conditions, is influenced not only by the river flow but also the downstream tidal conditions. For this reason, it is not appropriate to conduct a flood frequency analysis on the stage data at this site to quantify the 2-year and 100-year water surface elevations. The Flood Insurance Study for the City of Portland (FEMA 2010) provides a summary of water surface elevations associated with the 10-year, 50-year, 100-year, and 500-year flood events. These values are presented in Table 2.2.

***Table 2.2. Flood related water surface elevations for the Willamette River at Morrison Bridge (FEMA 2010)***

| **Annual Percent Chance Exceedance** | AEP **(years)** | **Water Surface Elevation (ft NAVD88)** |
|---|---|---|
| 0.2 | 500 | 37.2 |
| 1 | 100 | 32.3 |
| 2 | 50 | 30.2 |
| 10 | 10 | 25.5 |

Prior to conducting the flood frequency analysis on the maximum annual peak streamflow dataset, those values that were reported as maximum annual mean daily flow values were first converted to an approximate instantaneous value using a ratio of 1.06. This ratio was determined by computing the ratio between instantaneous peak flow and the corresponding mean daily flow for each annual flood event for which both values were available. This computation was made for the seventeen flood events in Table 2.1 that had reported instantaneous peak flow values. The ratios ranged between 1.02 and 1.15, with a median value of 1.05 and an average value of 1.06.

The statistical software package HEC-SSP (USACE 2010) was used to calculate the 2-year and 100-year AEP flow rates. The 2-year AEP flow rate is also referred to as the flow rate that has a 50 percent chance of being exceeded in any given year. Likewise, the 100-year AEP flow rate is also referred to as the flow rate that has a 1 percent chance of being exceeded in any given year. The method used in HEC-SSP is based on the procedures described in *USGS Bulletin 17B Guidelines for Determining Flood Flow Frequency* (IACW 1982). The results of the analysis are summarized in Table 2.3, which shows that the 2-year AEP flow rate is estimated to be 160,000 cubic feet per second (cfs) and the 100-year AEP flow rate is estimated to be 384,000 cfs. These values are the ordinate values from the computed flood frequency curve, which is shown in Figure 2.1.

***Table 2.3. Flood Frequency Analysis Results, Willamette River USGS Gage 14211720, WY 1973 to WY 2012***

| Annual Percent Chance Exceedance | AEP (years) | Computed Flood Frequency Curve Ordinate (cfs) |
|---|---|---|
| 0.2 | 500 | 480,000 |
| 0.5 | 250 | 424,000 |
| 1.0 | 100 | 384,000 |
| 2.0 | 50 | 344,000 |
| 5.0 | 20 | 293,000 |
| 10.0 | 10 | 255,000 |
| 20.0 | 5 | 217,000 |
| 50.0 | 2 | 160,000 |

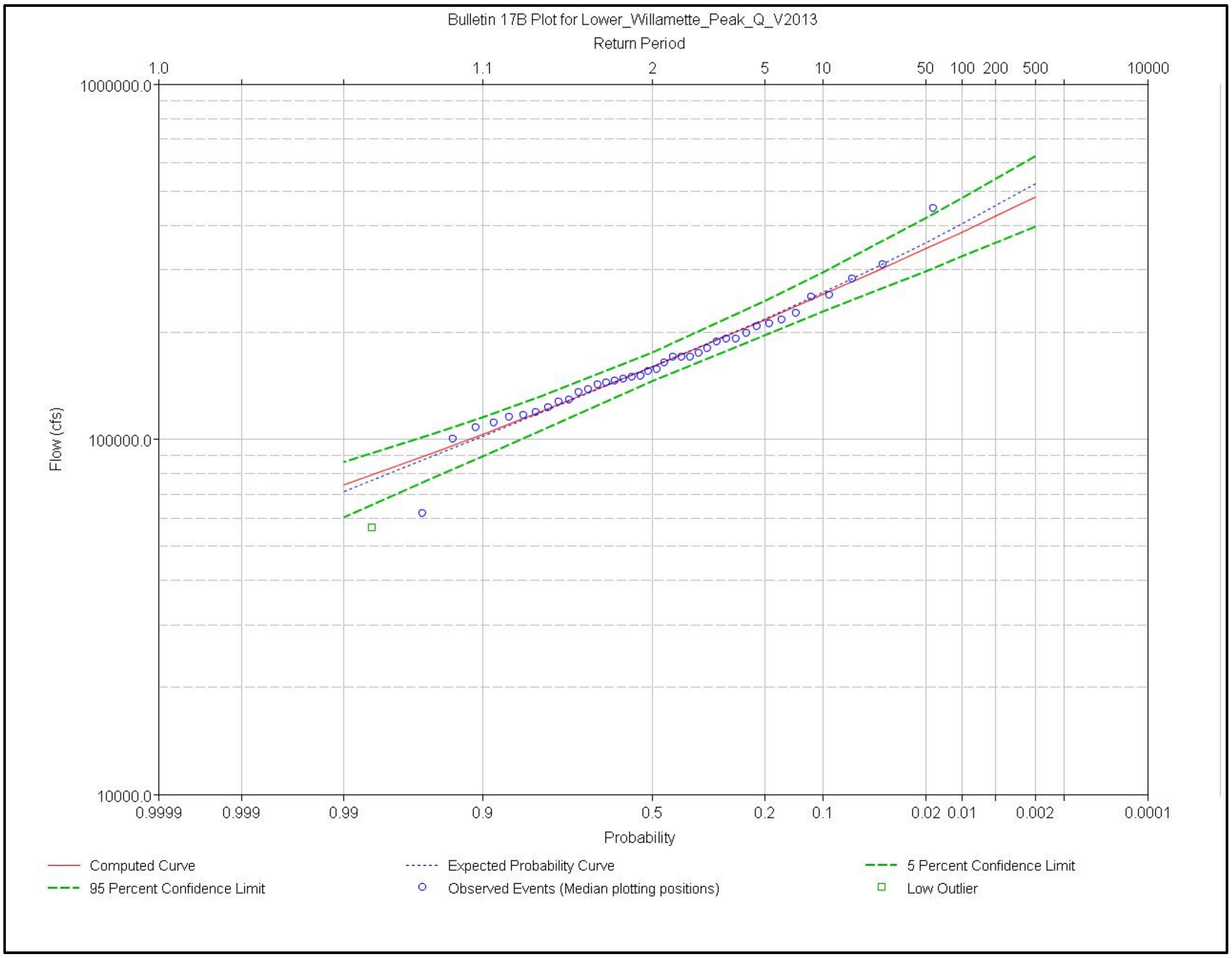


***Figure 2.1. Flood Frequency Curve, Willamette River USGS Gage 14211720, WY 1973 to WY 2012***

### Flow and Stage Duration Analysis

A flow and stage duration analysis was conducted to characterize the hydrologic conditions in the Willamette River at USGS Gage 1421172. Specifically, the hydrologic conditions of interest were the annual, spring/summer seasonal and fall/winter seasonal median (50-percent exceedance) flow rates and water surface elevations. The spring/summer period was defined as May through September, inclusive, and the fall/winter period was defined as October through April, inclusive. Mean daily flow data was available for the time period from October 1, 1972 through March 28, 2013 and mean daily stage data was available for the time period October 11, 1987 through March 28, 2013. Both the flow and stage duration analysis were therefore conducted using these mean daily data sets. Because of the tidally influenced nature of the river at the gage location, it would be more appropriate to use hourly data for the stage duration analysis. However historical hourly stage data are not available at this site.

The median summer, annual and winter period flow rates and water surface elevation, as determined from the daily flow and stage duration analysis are summarized in Table 2.4. The water surface elevations in Table 2.4 are expressed relative to NAVD88. The raw stage data at the USGS gage is reported relative to a gage datum. According to the on-line station information for this gage, 1.55 feet is added to the gage height to convert gage height to an elevation relative to the National Geodetic Vertical Datum of 1929 (NGVD29). Using VERTCON, a computer program created by the National Geodetic Survey, it was determined that the conversion of elevation from NGVD29 to NAVD88 is 3.48 feet. Therefore the equation that was used to convert raw stage data to elevation data relative to the NAVD88 vertical datum was as follows:

NAVD88 (feet) = Gage Height (feet) + 1.55 feet + 3.48 feet

***Table 2.4. Median Discharge and Water Surface Elevations for Summer, Annual and Winter Periods, Willamette River USGS Gage 14211720***

| Period | Discharge (cfs) [1] | Water surface elevation (feet NAVD88) [2] |
|---|---|---|
| Summer | 11,100 | 9.6 |
| Annual | 21,600 | 9.8 |
| Winter | 34,000 | 9.9 |

Notes:
1. Median discharge for period based on published mean daily flows between October 1, 1972 and March 28, 2013
2. Median water surface elevation for period based on published mean daily gage heights between October 11, 1987 and March 28, 2013

### Hydraulics

As stated previously, the hydrology of the mainstem Willamette River is affected by oceanic tide fluctuations and inflow from the upstream portions of the watershed, and the flow conditions are also influenced by the backwatering of the Columbia River. The USGS Gage 14211720 is located 12.3 miles upstream of Kelley Point Park and 3.7 miles downstream of Oaks Crossing/Sellwood Riverfront Park. Since the restoration site at Kelley Point Park is located less than 1 mile from the USGS Gage 14211820 on Columbia Slough and the conditions observed at this gage reflect conditions in the nearby mainstem

Willamette River, as discussed in Section 2.2 Columbia Slough (below), the analyses at the Columbia Slough gage were used to design the conditions at Kelley Point Park. The restoration measures for both of the restoration sites on the Mainstem Willamette River are focused on providing inundation at the median winter level side channel/backwater areas and are primarily dependent upon water surface elevations. Therefore the results from the flow and stage duration analysis were utilized in the design of these sites, and no hydraulic modeling was performed for these sites.

## 2.2 Columbia Slough

This section describes the flood frequency, flow duration and stage duration analyses that were conducted to describe the hydrologic conditions in the vicinity of the two Columbia Slough Sites - the Bureau of Environmental Services (BES) Treatment Plant Site and the Kenton Cove Site. The basis for the analyses was the flow and stage data collected at USGS Gage 14211820 (Columbia Slough at Portland, OR), which is located 0.6 miles upstream of the mouth of the Columbia Slough and 1.25 miles upstream from the Willamette River and Columbia River confluence. This gaging station is equipped with a water-stage recorder and an acoustic velocity meter. Flow at this station is affected by astronomical tidal conditions, which can cause reverse flow during tidal cycle. According to the USGS surface water records for this station, daily mean discharge values since WY 2007 are produced from "Godin filtered" instantaneous discharges to remove the effects of the daily tidal cycle. The Godin process resamples the series to hourly increments, on the hour, using linear interpolation, and then applies three moving averages.

The objective of the flood frequency analysis was to quantify the 2-year and 100-year AEP flow rates. The objective of the flow duration and stage duration analyses was to quantify the annual median flow rate and water surface elevation at USGS Gage 14211820, as well as the median summer and median winter flow rates and water surface elevations.

**Flood Frequency Analysis**

Maximum annual peak streamflow data and maximum annual peak gage height data were obtained for USGS Gage 14211820. Annual peak streamflow data were available for WY 1990 through WY 2012. All of the published annual peak values are annual maximum mean daily flow values as opposed to instantaneous peak flow values. Table 2.5 summarizes the USGS published annual peak streamflow dataset for USGS Gage 14211820.

The statistical software package HEC-SSP (USACE 2010) was used to calculate the 2-year and 100-year AEP flow rates. The 2-year AEP flow rate is also referred to as the flow rate that has a 50 percent chance of being exceeded in any given year. Likewise, the 100-year AEP flow rate is also referred to as the flow rate that has a 1 percent chance of being exceeded in any given year. The method used in HEC-SSP is based on the procedures described in *USGS Bulletin 17B Guidelines for Determining Flood Flow Frequency* (IACW 1982). The results of the analysis are summarized in Table 6. It is noted that the flood frequency analysis was conducted using the maximum annual mean daily flow dataset. Therefore, the flood frequency analysis ordinates summarized in Table 2.6 are mean daily flow values, not instantaneous peak flow values. Table 2.6 shows that the mean daily flow rate that has a 50 percent chance of being exceeded in any given year (2-year AEP) is 600 cfs. The mean daily flow rate that has a 1 percent chance of being exceeded in any given year is 3,250 cfs.

The reliability of the flood frequency curve gradually decreases for more extreme flood events and the period of record for the sample is the main controlling factor concerning the reliability of the flood frequency curve. A general rule of thumb presented in Cudworth (1989), which is supported by statistical calculations, indicates that frequency curves are reasonably reliable out to AEPs of no more than twice the period of record of the sample. Hence, given the relatively short 23-year period of record for the annual flood series, the flood frequency results summarized in Table 2.6 and in Figure 2.2 are reasonably reliable out to approximately the 50-yr AEP.

***Table 2.5. Annual Peak Discharge for Water Years 1990-2012 for the Columbia Slough USGS Gage 14211820***

| Water Year | Date of Peak | USGS Published Annual Peak Flows (cfs) [1] |
|---|---|---|
| 1990 | Jan. 28 1990 | 1,570 |
| 1991 | Jun. 20 1991 | 424 |
| 1992 | Feb. 23 1992 | 366 |
| 1993 | Dec. 10 1992 | 340 |
| 1994 | Feb. 27 1994 | 327 |
| 1995 | Oct. 27 1994 | 560 |
| 1996 | Dec. 5 1995 | 2,400 |
| 1997 | Jan. 5 1995 | 2,080 |
| 1998 | Jun. 2 1998 | 394 |
| 1999 | Mar. 1 1999 | 956 |
| 2000 | Nov. 28 1999 | 497 |
| 2001 | Dec. 15 2000 | 307 |
| 2002 | Feb. 10 2002 | 311 |
| 2003 | Feb. 4 2003 | 873 |
| 2004 | Feb. 1 2004 | 422 |
| 2005 | Dec. 19 2004 | 331 |
| 2006 | Jan. 15 2006 | 1,190 |
| 2007 | Nov. 11 2006 | 502 |
| 2008 | Jun. 8 2008 | 507 |
| 2009 | Jan. 11 2009 | 421 |
| 2010 | Jun. 14 2010 | 854 |
| 2011 | Apr. 8 2011 | 875 |
| 2012 | Apr. 5 2012 | 1,270 |

Notes:
1. All flow values are maximum annual mean daily flow rates

***Table 2.6. Flood Frequency Analysis Results, Columbia Slough USGS Gage 14211820, WY 1990 to WY 2012***

| Annual Percent Chance Exceedance | AEP (yrs) | Computed Flood Frequency Curve Ordinate (cfs) [1] |
|---|---|---|
| 0.2 | 500 | 5,210 |
| 0.5 | 250 | 4,010 |
| 1.0 | 100 | 3,250 |
| 2.0 | 50 | 2,600 |
| 5.0 | 20 | 1,890 |
| 10.0 | 10 | 1,440 |
| 20.0 | 5 | 1,050 |
| 50.0 | 2 | 600 |

Notes:

1. Flood frequency analysis was conducted on maximum annual mean daily flow values, so the flood frequency ordinates are mean daily flow values

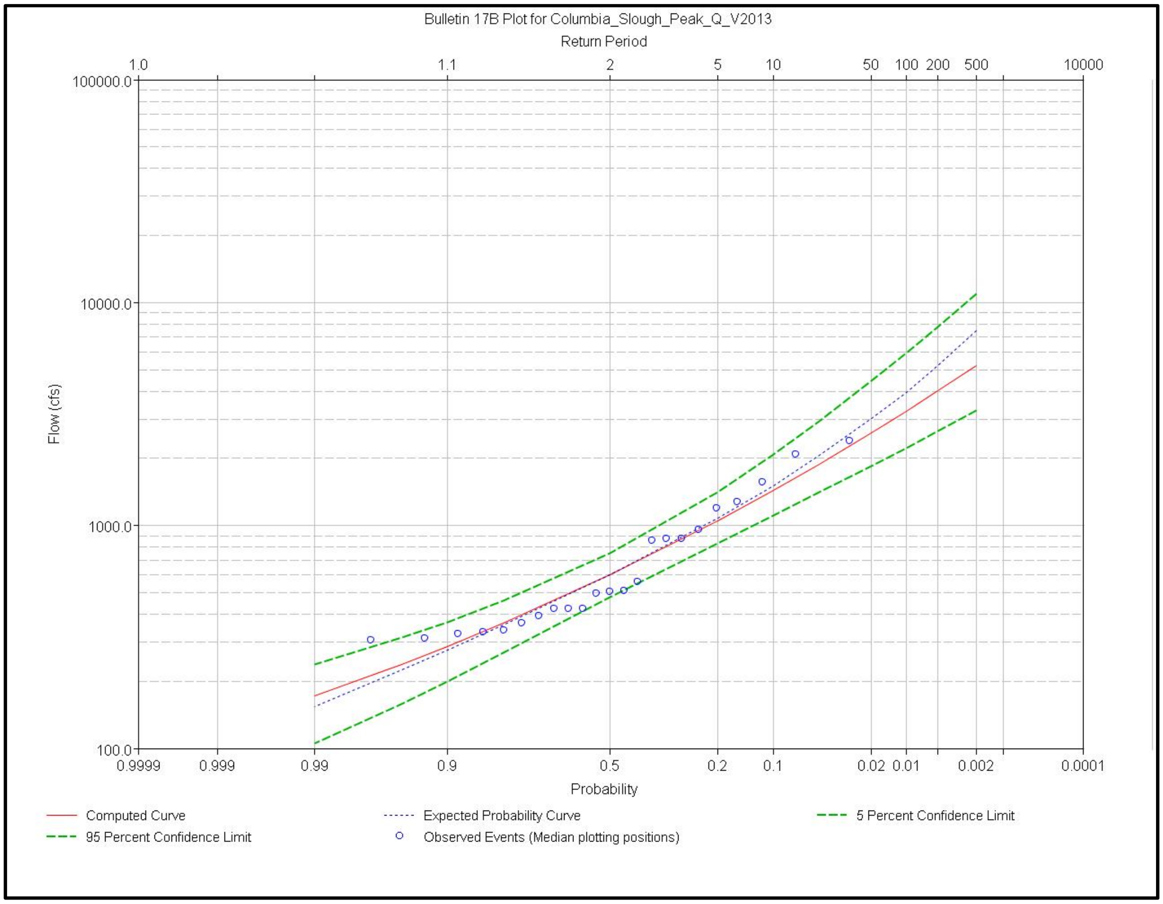


***Figure 2.2. Flood Frequency Curve, Columbia Slough USGS Gage 14211720, WY 1990 to WY 2012***

### Flow and Stage Duration Analysis

A flow and stage duration analysis was conducted to characterize the hydrologic conditions in the Columbia Slough at USGS Gage 14211820. Specifically, the hydrologic conditions of interest were the annual, spring/summer seasonal and fall/winter seasonal median (50-percent exceedance) flow rates and water surface elevations. Mean daily flow data was available for the time period from October 14, 1988 through March 28, 2013 and mean daily stage data was available for the time period October 12, 2002 through March 28, 2013. Both the flow and stage duration analysis were therefore conducted using these mean daily data sets. Because of the tidally influenced nature of the river at the gage location, it would be more appropriate to use hourly data for the stage duration analysis. However historical hourly stage data are not available at this site.

The median summer, annual and winter period flow rates and water surface elevation, as determined from the daily flow and stage duration analysis are summarized in Table 2.7. The water surface elevations in Table 2.7 are expressed relative to NAVD88. The raw stage data at the USGS Gage is reported relative to a gage datum. According to the on-line station information for this gage, 1.53 feet is added to the gage height to convert gage height to an elevation relative to NGVD29. Again, using VERTCON, it was determined that the conversion of elevation from NGVD29 to NAVD88 is 3.39 feet. Therefore the equation that was used to convert raw stage data at this gage to elevation data relative to the NAVD88 vertical datum was as follows:

NAVD88 (feet) = Gage Height (feet) + 1.53 feet + 3.39 feet

***Table 2.7. Median Discharge and Water Surface Elevations for Summer, Annual and Winter Periods, Columbia Slough USGS Gage 14211820***

| **Period** | **Discharge (cfs)** [1] | **Water surface elevation (feet NAVD88)** [2] |
|---|---|---|
| Summer | 66 | 9.3 |
| Annual | 92 | 9.6 |
| Winter | 114 | 9.7 |

Notes:
1. Median discharge for period based on published mean daily flows between October 14, 1988 and March 28, 2013
2. Median water surface elevation for period based on published mean daily gage heights between October 12, 2002 and March 28, 2013

### Hydraulics

The water surface elevations of the lower portion of Columbia Slough are primarily affected by the backwatering of the Columbia River and the Willamette River flow conditions, and also from oceanic tidal water surface fluctuations propagated up the Columbia River and Willamette River (City of Portland 2007a). The lower portion of Columbia Slough, having a median annual discharge that is over 200 times lower than the median annual discharge of the Willamette River, does not experience high discharges, or the associated high velocities and shear stresses observed in the Willamette River. Since the restoration measures for the Columbia Slough sites, including the desired median winter inundation level of side slough areas and elevation zones for with native vegetation species planting are primarily dependent upon water surface elevations, the results from the flow and stage duration analysis were utilized in the design of these sites. Therefore, no hydraulic modeling was performed for the Columbia Slough sites.

## 2.3 Tryon Creek

### Flood Frequency Analysis

Flood frequency analysis for Tryon Creek was developed for the final pre-design report for the Boones Ferry Road Culvert Replacement Project (Tetra Tech 2007). The discharges presented in that report are reproduced in Table 2.8.

***Table 2.8. Flood Frequency Results for Tryon Creek***

| Annual Percent Chance Exceedance | AEP (yrs) | Discharge (cfs) |
|---|---|---|
| 1.0 | 100 | 544 |
| 2.0 | 50 | 445 |
| 4.0 | 25 | 379 |
| 10.0 | 10 | 330 |
| 20.0 | 5 | 294 |
| 50.0 | 2 | 264 |

### Flow Duration Analysis

Median seasonal discharges were also developed for the Boones Ferry Road Culvert Replacement Project (Tetra Tech 2007). These discharges are provided in Table 2.9.

***Table 2.9. Summary of Frequency Analysis for Tryon Creek Watershed Restoration Sites***

| Site | Median Summer Discharge (cfs) | Median Annual Discharge (cfs) | Median Winter Discharge (cfs) |
|---|---|---|---|
| Highway 43 Culvert | 1 | 5 | 10 |

### Hydraulics

Hydraulic analysis was performed to support the feasibility level design of a replacement culvert for Tryon Creek at the Highway 43 crossing. The purpose of this analysis was to provide proof of concept for a replacement culvert that meets the State of Oregon's fish passage criteria based on the stream simulation option for an open-bottomed road-stream crossing structure (OAR 2013a) as determined during the conceptual phase of the Lower Willamette River Ecosystem Restoration Project. During the conceptual phase of the project, a cost analysis was completed and conceptual designs were prepared to assess the differences between replacing the existing culvert with an arch span culvert and a bridge. This previous work determined that the arch span culvert was the most cost effective replacement solution and recommended this conceptual design for further analysis in the Feasibility Study.

A HEC-RAS hydraulic model was developed by the City of Portland (2007b) for the Highway 43 culvert on Tryon Creek and a second model for the segment of Tryon Creek downstream of the culvert to the confluence with the Willamette River (City of Portland 2007c). This first model was created and used previously for the design of baffles within the Highway 43 culvert to enhance fish passage by providing holding water between the baffles for fish. The model was obtained from ODOT. The second model was created and used previously for the Lower Tryon Creek Stream Enhancement Design (Herrera Environmental Consultants 2007), and was obtained from the City of Portland. The Lower Tryon Creek Stream Enhancement Design project resulted in the creation of a roughened chute located downstream of a plunge pool at the exit of the culvert. The roughened chute was designed to maintain a water depth of 1 foot at the exit of the culvert, for a Tryon Creek discharge of 1.4 cfs, to allow fish to swim into the culvert rather than jump into the culvert. Roughness coefficients used in the Herrera model varied between n = 0.03 and n = 0.06. Contraction and Expansion coefficients were left at the default values of 0.1 and 0.3, respectively. The roughened chute was modeled by adjusting the cross sectional geometry to reflect the design of the chute. Bed elevations were increased 1.5-2 ft while the roughness coefficients were increased from n = 0.038 to n = 0.04 within the channel. The cross sections in the roughened chute were spaced 2- 7.75 ft apart, with an average spacing of 4.75 ft. Downstream of the roughened chute, cross sections were spaced 8-25 ft apart with an average spacing of 17.4 ft.

The two previous HEC-RAS models were merged to create a continuous model of Tryon Creek extending from the upstream inlet of the Highway 43 culvert to the confluence with the Willamette River. Elevations within the provided models were referenced to the City of Portland's vertical datum, which is approximately 2.11 feet below NAVD88. The elevations of the merged model were increased by 2.11 feet to convert to NAVD88. Additional cross section and thalweg survey data were collected during 2008 and 2009, and were supplemented with LiDAR data (Watershed Sciences 2009). This information was used to extend the length of Tryon Creek that was modeled upstream of the Highway 43 culvert in order to better estimate the upstream hydraulic conditions. The two modeled cross sections were spaced 500 ft apart, with the downstream cross section spaced 40 ft upstream of the culvert entrance. Roughness coefficients in the two upstream cross sections were set at a constant n = 0.05. The most upstream cross section used the default contraction and expansion coefficients of 0.1 and 0.3, respectively, while the downstream cross section used contraction and expansion coefficients of 0.6 and 0.8, respectively, to account for the transition to the culvert.

The existing hydraulic conditions were modeled using the five discharge conditions, including the 2-year, the 100-year, the median summer, median winter, and median annual. Downstream boundary conditions were set to known water surface elevations for the Willamette River for each of the corresponding discharge events. The elevations used for the median summer, median winter, and median annual conditions were determined in Section 2.1 Mainstream Willamette River of this report as 9.6, 9.9, and 9.8 feet NAVD88, respectively. The elevations used for the 2-year and 100-year conditions were those cited by Herrera Environmental Consultants (2007), as 15.5 and 37.4 feet NAVD88, respectively.

The State of Oregon fish passage criteria used to guide the culvert sizing and hydraulic analysis requires that the culvert be wide enough to accommodate the active channel width which according to OAR (2013a) can be defined as the stream width between the channel bankfull elevations. The existing conditions model was used to estimate upstream hydraulic conditions for the 2-year discharge corresponding to an approximate the bankfull elevation (OAR 2013b) of 47.2 feet NAVD88. Using the estimated bankfull elevation an active channel width of 20.2 feet was determined. Chapter 6 of the ODOT Hydraulics Manual (ODOT 2011) provides a conservative approach (Case 2) for sizing the minimum width of a culvert as a span equal to 125% of the active channel width plus 2 feet, which for the Highway 43 culvert results in a span of 27.25 feet (20.2 feet * 1.25 + 2 feet = 27.25 feet). To increase efficiency during construction and reduce costs, it was assumed during the conceptual phase of the project that the arch culvert designed would be a pre-cast structure. The pre-cast arch culvert size large enough to accommodate this span width is 30 feet wide (Contech 2013) with a rise of 12.3 feet. The State of Oregon's fish passage criteria requires that a minimum of 3 feet of vertical clearance be provided from the active channel width elevation to the inside top of the structure. For the proposed structure, 14.8 feet of vertical clearance will be provided from the active channel width elevation to the inside top of the structure. A maximum interior width of 30 feet will provide capacity to pass large debris, such as wood and boulders, through the culvert. Therefore, a width of 20.2 feet was used to define the low flow channel width and a width of 30 feet used to define the high flow channel width proposed for the interior of the replacement culvert. This cross section is illustrated in Figure 2.3.

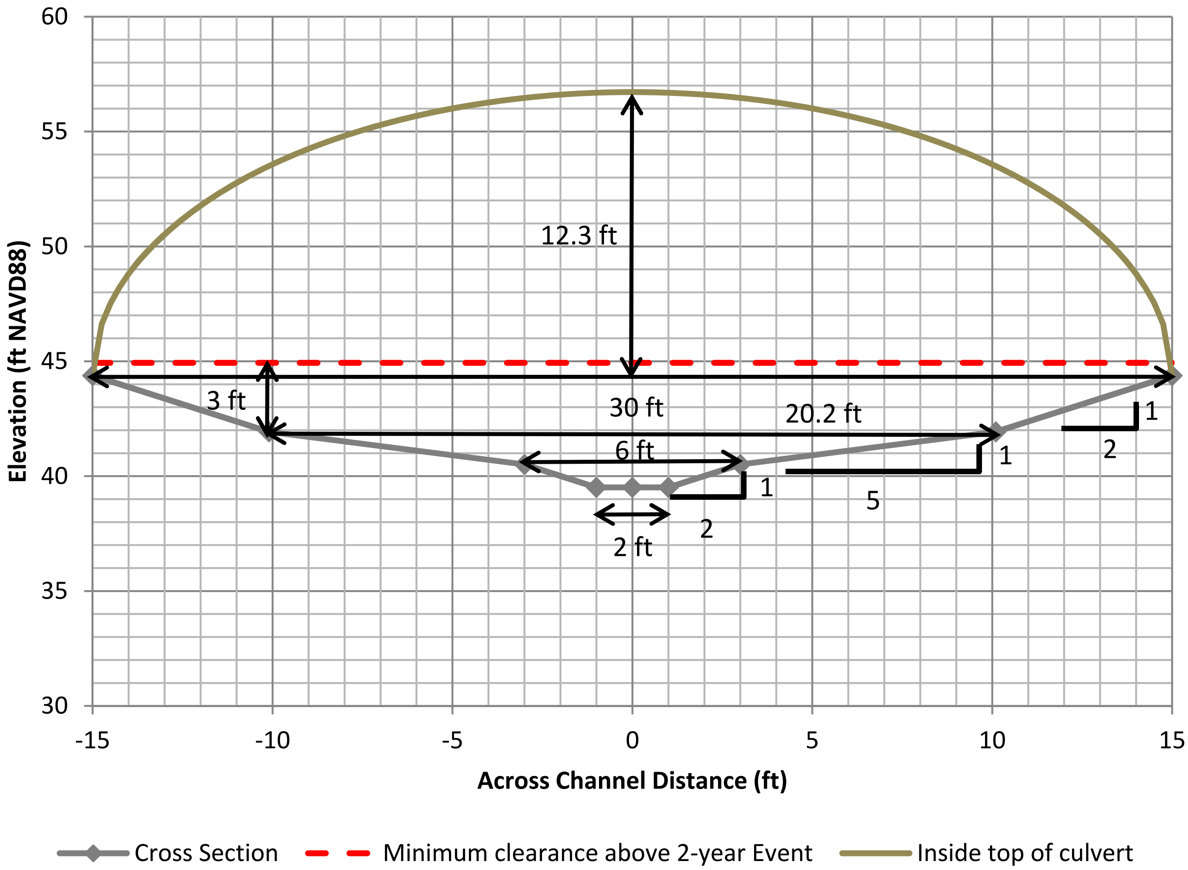


***Figure 2.3. Channel cross section geometry inside of replacement culvert at Highway 43***

The State of Oregon fish passage criteria specifies that the structure shall have a slope equal to that of the surrounding stream profile and have elevations that are continuous with this profile. Previous analysis indicates that the natural streambed slope is 3.5%, that the existing culvert has a variable slope of 5.94% and 2.94%, and that the plunge pool downstream of the existing culvert is seen as a scour problem. Therefore, the proposed profile will extend from the upstream elevation of the existing culvert of 39.51 feet NAVD88 to the top of the roughened chute downstream of the plunge pool to the existing elevation of 23.4 feet NAVD88, and achieve a continuous streambed slope of 3.4%. The resulting streambed slope is closer to the overall natural streambed slope of 3.5% (City of Portland 2005) than the existing culvert slopes, is continuous with upstream and downstream existing elevations, and eliminates the plunge pool downstream of the existing culvert by the proposed grading. The filled-in plunge pool was modeled by copying the cross section downstream of the pool and adjusting the elevations to account for the slope. The existing and proposed streambed slopes are illustrated in Figure 2.4.

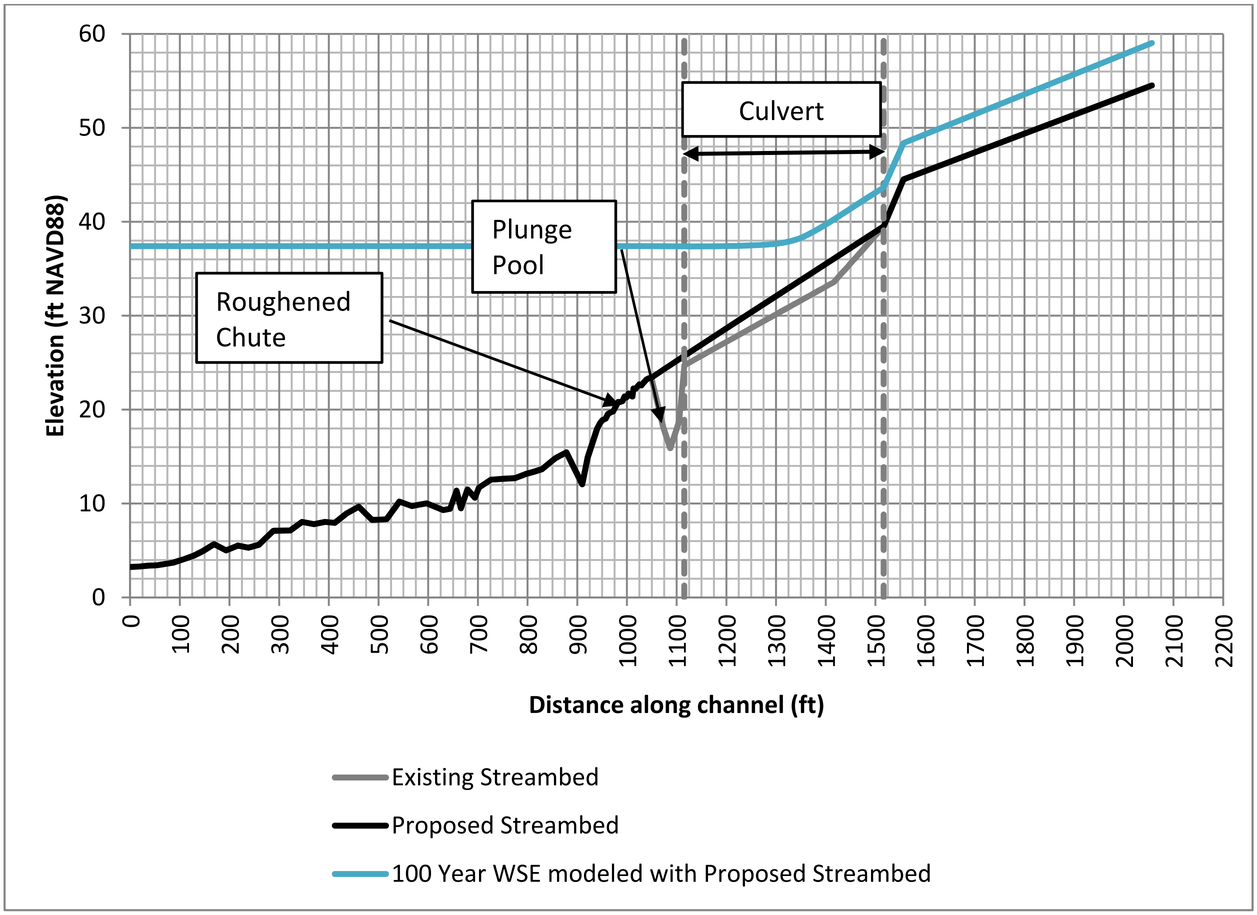


***Figure 2.4. Profiles for the existing and proposed streambeds used for hydraulic analysis***

The State of Oregon's fish passage criteria requires that the bed material placed within the structure be stable, mechanically placed, composed of similarly sized and graded material as the natural surrounding stream, and for closed-bottom road-stream crossing structures contain partially-buried over-sized rock. Therefore the hydraulic model roughness factors for cross sections representing the natural channel design within the open bottomed culvert were adjusted following USACE guidance (USACE 1994) for obstructions and set to the Manning's n value of 0.06. Interpolated cross sections were inserted in the model at 10 ft intervals over the 400 ft length of the culvert. The culvert was modeled as an open channel, with contraction and expansion coefficients increased to 0.6 and 0.8, respectively, to account for the transition to varied stream bed.

The cross section layout for the proposed conditions is shown in Figure 2.5. The five discharge and water surface elevation steady state boundary conditions were then simulated for the proposed culvert. The resulting flood extents are shown in Figure 2.6. Modeled water surface elevations were used to delineate the flood extents of the 100 year discharge upstream of the culvert. Downstream of the culvert, the modeled WSE was a steady 37.4 ft, corresponding to the 100 year WSE of the Willamette River. These extents were mapped by filling all areas within the 37.4 ft contour. A table of water surface elevations at the cross section locations under with and without project conditions for the 100-year discharge appears as Appendix A.

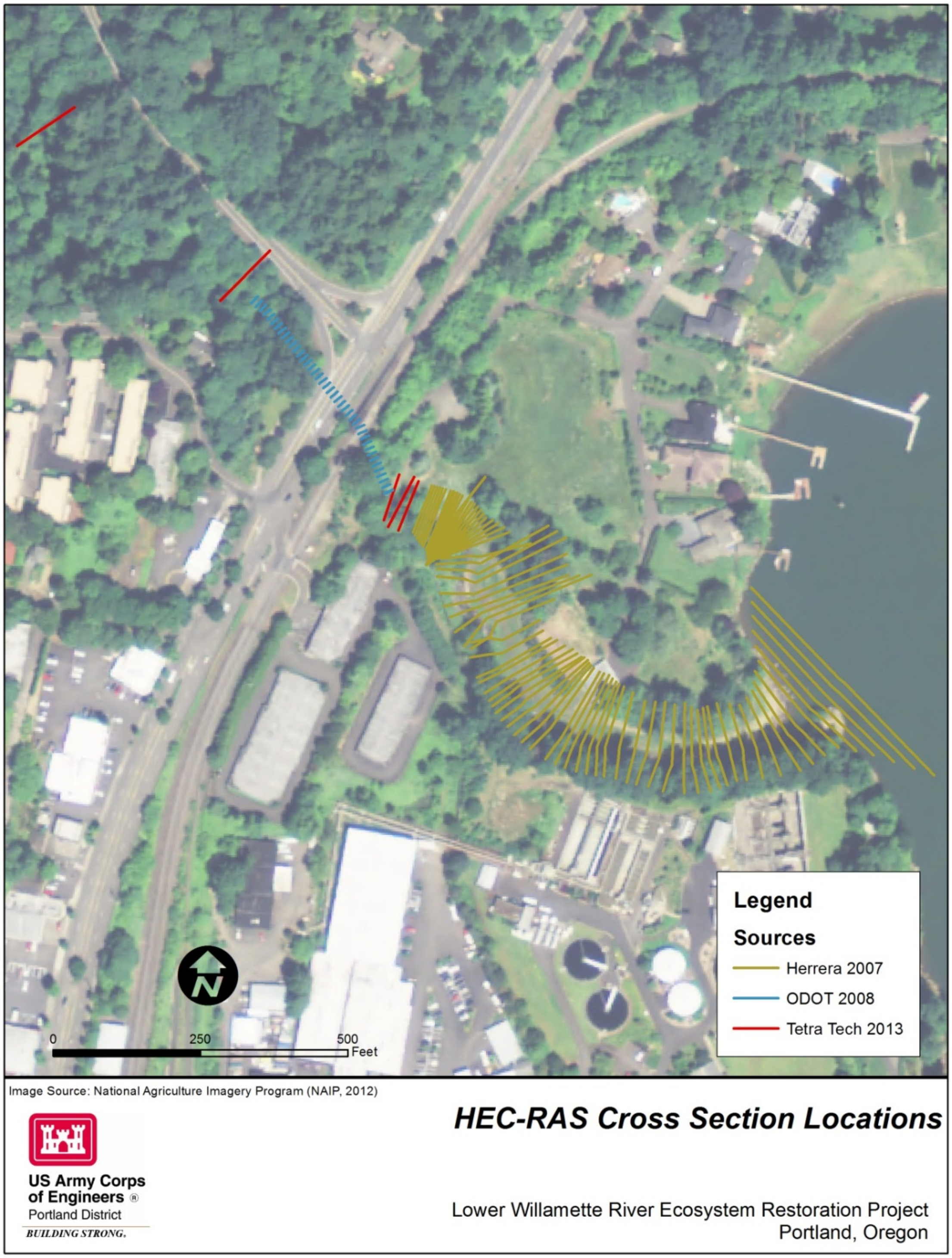


***Figure 2.5. Cross sectional layout and sources for the proposed conditions model***

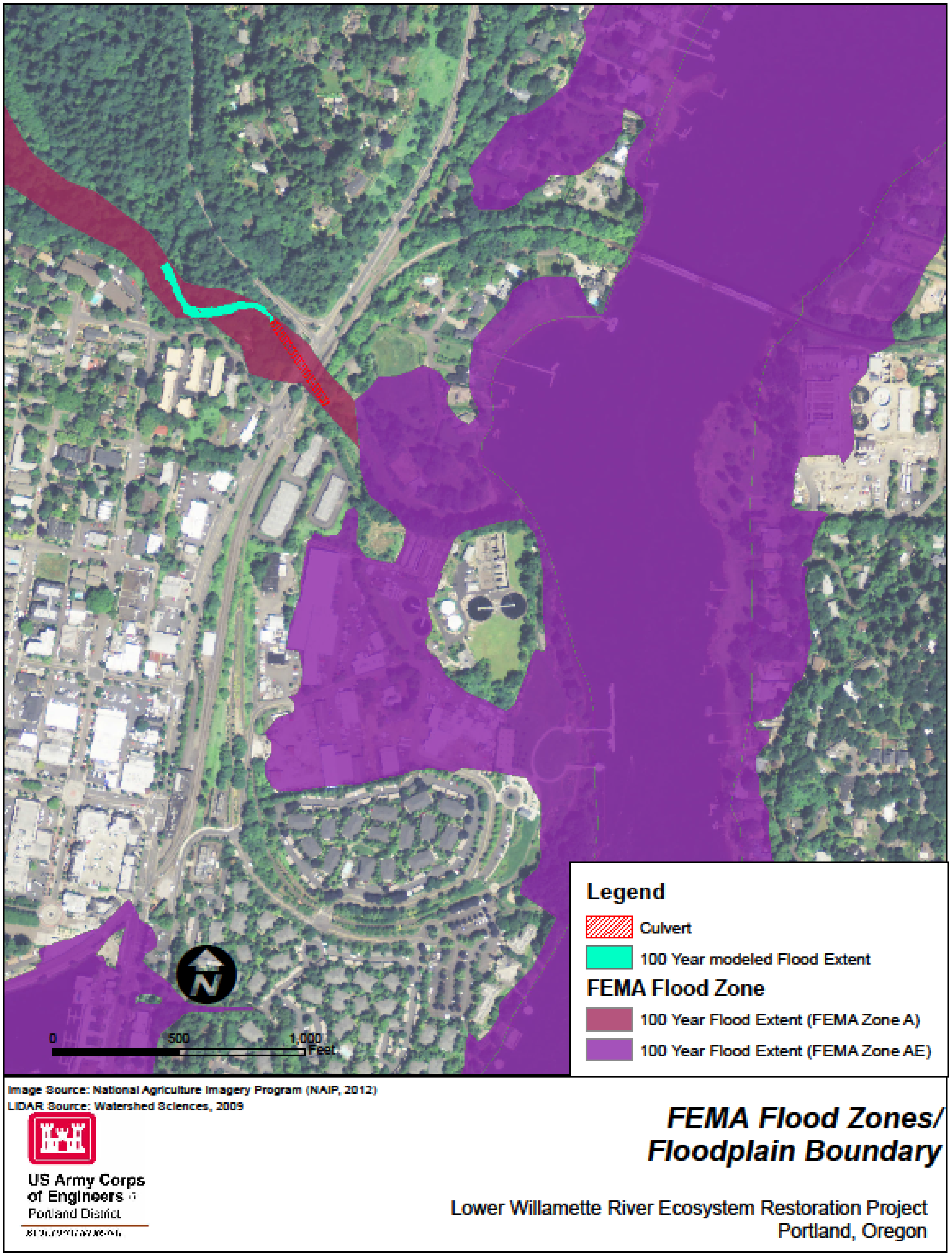


*Figure 2.6. Willamette River and Tryon Creek Base Flood Zones*

Comparisons of velocity and depth results for the hydraulic simulations at representative cross sections are presented in Table 2.10 and Table 2.11. The State of Oregon's fish passage criteria requires that average water depths and velocities of the surrounding stream channel are maintained within the road-stream crossing structure. Fish passage for the proposed design is considered a priority for the median winter conditions, which correspond to the period of migration for adult steelhead trout and cutthroat salmon. For these conditions, the model results indicate that the water depths and velocities predicted inside of the proposed culvert fall within the range of the surrounding stream.

**FEMA Boundaries**

The 100-year flood water surface elevation of the Willamette River at this site has been delineated at 37.4 feet NAVD88 (FEMA 2010) (Figure 2.5). No fill will be placed at or below this elevation. A floodway has not been designated along Tryon Creek, which is in a FEMA Zone A. The water surface elevation associated with the base flood will not be increased in this area because 21,000 cubic yards of material will be removed and 17,000 cubic yards of material will be backfilled as part of the culvert replacement, resulting in increased conveyance capacity. Furthermore, at 30 feet wide and 12 feet high, the replacement culvert will be substantially larger than the existing culvert, which measures approximately 8'x 8'. A detailed HEC-RAS model has shown that there would be no rise in surface elevations in the culvert under the 100-year flood discharge rate (Table 2.11), and a no-rise analysis for the roughened chute downstream of the culvert has been completed (Herrera 2009). However, a no-rise analysis may be prepared for the culvert replacement during later stages of planning and design.

***Table 2.10. Comparison of existing and proposed condition modeled velocities***

| Flow Condition | Location | Velocity (feet/s) | | |
|---|---|---|---|---|
| | | Existing | Proposed | Difference (Proposed-Existing) |
| **2-Year** | **Upstream of Culvert** | 7.49 | 7.55 | 0.06 |
| | **Middle of Culvert** | 6.35 | 6.88 | 0.53 |
| | **Near Downstream Entrance to Culvert** | 5.54 | 5.54 | 0 |
| **100-Year** | **Upstream of Culvert** | 8.99 | 9 | 0.01 |
| | **Middle of Culvert** | 8.05 | 6.45 | -1.60 |
| | **Near Downstream Entrance to Culvert** | 0.94 | 0.94 | 0 |
| **Median Summer** | **Upstream of Culvert** | 2.19 | 2.15 | -0.04 |
| | **Middle of Culvert** | 1.18 | 1.56 | 0.38 |
| | **Near Downstream Entrance to Culvert** | 1.49 | 1.49 | 0 |
| **Median Winter** | **Upstream of Culvert** | 3.43 | 3.45 | 0.02 |
| | **Middle of Culvert** | 2.17 | 3.1 | 0.94 |
| | **Near Downstream Entrance to Culvert** | 1.94 | 1.94 | 0 |
| **Median Annual** | **Upstream of Culvert** | 3 | 2.98 | -0.02 |
| | **Middle of Culvert** | 1.73 | 2.56 | 0.83 |
| | **Near Downstream Entrance to Culvert** | 1.85 | 1.85 | 0 |

***Table 2.11. Comparison of existing and proposed condition modeled depths***

| Flow Condition | Location | Depth (feet) | | |
|---|---|---|---|---|
| | | Existing | Proposed | Difference (Proposed-Existing) |
| 2-Year | Upstream of Culvert | 2.73 | 2.71 | -0.02 |
| | Middle of Culvert | 5.06 | 3.19 | -1.87 |
| | Near Downstream Entrance to Culvert | 1.69 | 1.69 | 0 |
| 100-Year | Upstream of Culvert | 3.87 | 3.87 | 0 |
| | Middle of Culvert | 9.25 | 5.14 | -4.11 |
| | Near Downstream Entrance to Culvert | 14 | 14 | 0 |
| Median Summer | Upstream of Culvert | 0.28 | 0.29 | 0.01 |
| | Middle of Culvert | 0.57 | 0.26 | -0.31 |
| | Near Downstream Entrance to Culvert | 0.16 | 0.16 | 0 |
| Median Winter | Upstream of Culvert | 0.71 | 0.71 | 0 |
| | Middle of Culvert | 1.03 | 0.86 | -0.17 |
| | Near Downstream Entrance to Culvert | 0.37 | 0.37 | 0 |
| Median Annual | Upstream of Culvert | 0.54 | 0.54 | 0 |
| | Middle of Culvert | 0.82 | 0.61 | -0.21 |
| | Near Downstream Entrance to Culvert | 0.28 | 0.28 | 0 |

**Incipient Motion and Bed Stability**

A reconnaissance level geomorphic survey of the study area was completed in 2013 (see Appendix A of the main feasibility study). The survey found that in the proximity of the culvert, the channel has a pool-riffle planform and the bed is composed of gravel- to cobble-sized material with an approximate median size (D50) of 30-40 mm. Boulder-sized material line the margins of the channel. The channel width typically varies from 10 to 20 feet and the average channel slope is approximately 2 percent. No studies have been conducted to assess the mobility of the bed material or the sediment load along Tryon Creek. Field observations indicate that the bed material is periodically mobilized and erosion of the channel banks and valley walls contributes fine sediment to the creek.

An incipient motion analysis was conducted to support the sizing of the bed material within the culvert opening. The analysis was conducted using the HEC-RAS results from the 2-yr and 100-yr AEP design flow conditions for the proposed conditions. Specifically, the inputs to the analysis were the reach averaged energy slope and reach averaged hydraulic radius through the length of the proposed culvert.

First, the reach averaged total shear stress was computed based on the following equation:

$$\tau_o = \gamma_w \times R \times S$$

Where:

$\tau_o =$ reach averaged total shear stress (pounds per square foot)

$\gamma_w =$ specific weight of water (62.4 pounds per cubic foot)

$R$ = reach averaged hydraulic radius (feet)

$S$ = reach averaged energy slope (feet/foot)

The total shear stress computed with the above relationship represents the total force acting on the wetted boundary of the channel. However, only a portion of this force acts on the moveable grains in the bed and results in transport of bedload sediment. This component of the total shear stress is referred to as the grain shear stress. The remainder of the total shear stress acts on other things such as channel bends, large woody debris, and obstructions in the channel. For this analysis, it was conservatively assumed that the entire computed total shear stress was available for bed material transport.

The grain size capable of being mobilized by the computed total shear stress was then estimated using the Shields relation. This relation is expressed as the following equation:

$$\tau_c = F_* \times (\gamma_s - \gamma_w) \times D_c$$

Where:

$\tau_c$ = critical shear stress (pounds per square foot)

$F_*$ = dimensionless Shields parameter (assumed to equal 0.047)

$\gamma_s$ = specific weight of sediment (165 pounds per cubic foot)

$\gamma_w$ = specific weight of water (62.4 pounds per cubic foot)

$D_c$ = critical grain size (feet)

Setting the computed total shear stress equal to the critical shear stress, the grain size that would be at the threshold of mobilization, the critical grain size, was computed. The results are summarized in Table 2.12.

***Table 2.12. Incipient motion results for proposed conditions***

| Design Flow Condition | Reach Averaged Hydraulic Radius (R) (ft) | Reach Averaged Energy Grade Line (S) (feet/foot) | Reach Averaged Total Shear Stress ($\tau_o$) (lb/sf) | Critical Grain Size ($D_c$) (ft) | Critical Grain Size ($D_c$) (inches) |
|---|---|---|---|---|---|
| 2-yr | 1.6 | 0.03217 | 3.3 | 0.68 | 8 |
| 100-yr | 4.3 | 0.02989 | 4.3 | 0.89 | 11 |

# 3. RECOMMENDATIONS

The purpose of the work documented in this technical memorandum was to determine hydrologic and hydraulic conditions for the design of the selected restoration sites. The design is discussed in a separate appendix to the feasibility report (Appendix H of the Feasibility Study report). When available from other sources, hydrologic and hydraulic information was obtained and compiled for this task. Additional information needed beyond what was available from existing sources was developed.

Each of these sites includes the design elements of bank grading, floodplain reconnections, and/or side channels. For the feasibility level design of these elements, the median winter water surface elevation has been designated as the design criteria. The evaluation presented in Sections 2.1 and 2.2 of this report determined the proximity of the four restoration sites to the gage used for the hydrologic analysis and the elevation that should provide the most representative median winter water surface elevation at each site. These design elements serve to provide fish habitat and high flow refugia during flow events higher than the median water surface elevation. In order to provide fish habitat based on the State of Oregon’s criteria, a minimum of 6 inches of water depth is needed. Therefore, it is recommended that the thalweg or lower bank elevation for these sites be designed to allow inundation of 6 inches at the median winter elevation. The elevations for each site and reference gage are provided in Table 3.1.

***Table 3.1. Recommended design elevations to provide fish habitat and refugia for median winter conditions***

| Site | Median Winter Water Surface Elevation<br>(ft NAVD88) | Thalweg or Lower Bank Elevation<br>(ft NAVD88) | Gage Referenced for Site Design Criteria |
|---|---|---|---|
| **Kelley Point Park** | 9.2 | 9.7 | USGS Gage 14211820 (Columbia Slough at Portland, OR) |
| **BES Plant Banks** | 9.2 | 9.7 | USGS Gage 14211820 (Columbia Slough at Portland, OR) |
| **Kenton Cove** | 9.2 | 9.7 | USGS Gage 14211820 (Columbia Slough at Portland, OR) |
| **Oaks Crossing/Sellwood Riverfront Park** | 9.4 | 9.9 | USGS Gage 14211720 (Willamette River at Portland, OR) |

Hydraulic modeling was not performed for the two Mainstem Willamette River sites or the two Columbia Slough sites because no existing conditions hydraulic model was available and not enough information was available within the scope of the performed analysis to develop hydraulic models for these sites. A geomorphologic assessment was performed for the feasibility study (Appendix A of the Feasibility Study report) and indicated that during higher flow conditions sand-sized material is transported in the river and in the overbanks. Future phases of design for these sites should consider the potential deposition of this sand-sized material and the associated loss of fish habitat and refugia function if the aggradation should cause water depths less than 6 inches for the median winter conditions.

The existing culvert for Tryon Creek at Highway 43 and the Portland and Western Railroad was identified as a priority for fish passage improvements in 2005. Two previous projects have been designed and constructed to enhance fish entrance (Herrera Environmental Consultants 2007) and passage (ODOT 2007). The analysis presented as part of the Feasibility Study considers a replacement of the culvert with a 30 ft arch span culvert that meets the State of Oregon’s fish passage criteria. Hydraulic analysis using the HEC-RAS model was performed to determine the culvert span required to accommodate the active channel width, and the proposed culvert was modeled to assess passage velocities and depths. Additionally, the model results were to perform an incipient motion analysis to determine the specification of the required oversized rock and for the streambed gradation. Both of these are required to meet the State of Oregon’s fish passage criteria for stability of the proposed streambed. A minimum diameter of 18 to 20 inches is recommended for the rock placed for stream grade control cross weirs within the culvert structure. The proposed culvert has a continuous slope of 3.4%, which results in partial reduction of the existing culvert slope and providing an overall segment slope closer to that of the natural stream.

Additional work is recommended for future design phases for the replacement culvert. A scour analysis should be performed to determine the appropriate culvert footing elevation. The extent of bedrock around the existing culvert should be determined through a geotechnical investigation to better understand constraints on constructability and potential revisions to the proposed culvert alignment. Additional upstream survey data should be obtained to better delineate the active channel width and construction quantities. Some survey data that may be utilized for the next phase of this project was recently acquired by BergerABAM on behalf of the City of Portland’s Tryon Creek Trunk Sewer Upgrade project, but is not yet available for distribution. Construction issues related to possible need to realign the trunk sewer to accommodate the replacement culvert, and preliminary analysis of traffic control and temporary bypasses for both road and railroad traffic should be considered.

The proposed culvert is designed to pass 100-year flows and large debris, including trees. The risk of blockage is minimal due to the large size of the culvert and because the relatively sparse riparian area does not contribute extensive large trees, therefore a trash rack is not proposed at this location, reducing maintenance. Periodic maintenance inspections to ensure that footings and wingwalls are not being undercut by scour are recommended, although the culvert would be built into bedrock so such an effect is unlikely. The main risk associated with this configuration is that the rock weirs that will be installed for grade control will dislodge during high flows, allowing for increased velocities and reduction in plunge pools that are necessary for fish passage. Although it is assumed that the weirs will be designed to withstand peak flows, occasional inspection of these structures is recommended, particularly after sustained or high flows.

# 4. REFERENCES

City of Portland. 2005. Draft Technical Memorandum: Preliminary Information on Tryon Creek, Highway 43 Culvert Crossing for the Retrofit Project Predesign Work. October 25, 2005.

City of Portland. 2007a. Columbia Slough Watershed Long-Term Monitoring Plan.

City of Portland. 2007b. Unpublished hydraulic model (HEC-RAS) for Tryon Creek Highway 43 culvert. Provided by Bruce Council, ODOT.

City of Portland. 2007c. Unpublished hydraulic model (HEC-RAS) for Lower Tryon Creek Restoration below Highway 43. Provided by Greg Savage, City of Portland.

Contech. 2013. BEBO Arch Systems 30' span x 12'-4" rise.

Cudworth, A.G. 1989. Flood Hydrology Manual. United States Department of the Interior, Bureau of Reclamation.

Federal Emergency Management Agency (FEMA). 2010. Flood Insurance Study – City of Portland (Multnomah, Clackamas, and Washington Counties). Federal Emergency Management Agency, Community Number 410183V000B, Revised November 26, 2010.

Henderson Land Services. 2007. Tryon Creek @ Hwy 43 Culvert Alternatives Analysis, prepared for the City of Lake Oswego, Oregon. June.

Herrera Environmental Consultants. 2007. Basis of Design Technical Memorandum; Lower Tryon Creek Stream Enhancement Design, prepared for the City of Portland, Oregon. March 13.

Herrera Environmental Consultants. 2009. Floodplain and Floodway Impacts Evaluation: Tryon Creek Confluence Habitat Enhancement Project. Prepared for City of Portland, Bureau of Environmental Services.

Interagency Advisory Committee on Water Data (IACW). 1982. *Bulletin 17B, "Guidelines for Determining Flood Flow Frequency"*. Published by the U.S. Department of the Interior, Geologic Survey.

Oregon Administrative Rules (OAR). 2013a. Chapter 635, Division 412 – Fish Passage. OAR 635-412. Available at: http://arcweb.sos.state.or.us/pages/rules/oars_600/oar_635/635_412.html

OAR. 2013b. Chapter 141, Division 85 – Administrative Rules Governing the Issuance and Enforcement of Removal-Fill Authorizations within Waters of Oregon Including Wetlands. OAR 141-085. Available at: http://arcweb.sos.state.or.us/pages/rules/oars_100/oar_141/141_085.html

Oregon Department of Fish and Wildlife (ODFW). 2011. Tryon Creek Urban Watershed Restoration. A poster presented, at the 2011 ODOT Environmental Conference – Poster Session, by Jim Brick, ODFW.

Oregon Department of Transportation (ODOT). 1955. Tryon Creek Culvert over Tryon Creek – Clackamas Co. on Pacific Highway General Drawing. Drawing No. 3849. Provided by David McDonald.

ODOT. 2007. Proposed Tryon Creek Fish Weir Project; Highway 43; Figure No. 1A.

ODOT. 2011. Hydraulics Manual 2011 version.

Tetra Tech. 2007. Tryon Creek at Boones Ferry Road Culvert Replacement Project – Final Pre-Design Report. Unpublished report, prepared for the U.S. Army Corps of Engineers, Portland, Oregon. October 15.

Tetra Tech. 2008. Lower Willamette River Restoration General Investigation Study - Conceptual Restoration Plan. Unpublished report, prepared for the U.S. Army Corps of Engineers, Portland, Oregon.

Tetra Tech. 2009. Lower Willamette River Ecosystem Restoration General Investigation Study: Feasibility Work Plan. Unpublished report, prepared for the U.S. Army Corps of Engineers, Portland, Oregon. June.

United States Army Corps of Engineers (USACE). 1994. Hydraulic Design of Flood Control Channels. Ch. 5. Methods for Predicting n Values for the Manning Equation.

United States Army Corps of Engineers (USACE). 2010. HEC-SSP Statistical Software Package; User's Manual; Version 2.0. Computer Program Documentation (CPD) Report Number 86. October 2010.

United States Fish and Wildlife Service (USFWS). 2012. Tryon Creek: Restoration Monitoring and Assessment. Fact Sheet.

Watershed Sciences. 2009. Columbia River LIDAR Project. Prepared for David Evans and Associates and U.S. Army Corps of Engineers, Portland District.

# Appendix A:

# Water Surface Elevations for With and Without Project Conditions, 100-year Discharge

*This page left blank intentionally*

**Water Surface Elevations under Without Project Conditions**

| Reach | River Sta | Profile | W.S. Elev (ft.) |
|---|---|---|---|
| OR43 Culvert | 941 | 100-Yr | 59.03 |
| OR43 Culvert | 441 | 100-Yr | 48.38 |
| OR43 Culvert | 401 | 100-Yr | 47.83 |
| OR43 Culvert | 400.5 | 100-Yr | 47.83 |
| OR43 Culvert | 399.5 | 100-Yr | 47.35 |
| OR43 Culvert | 394 | 100-Yr | 47.41 |
| OR43 Culvert | 393 | 100-Yr | 46.82 |
| OR43 Culvert | 385.5 | 100-Yr | 46.9 |
| OR43 Culvert | 384.5 | 100-Yr | 46.32 |
| OR43 Culvert | 377 | 100-Yr | 46.39 |
| OR43 Culvert | 376 | 100-Yr | 45.81 |
| OR43 Culvert | 368.5 | 100-Yr | 45.89 |
| OR43 Culvert | 367.5 | 100-Yr | 45.3 |
| OR43 Culvert | 360 | 100-Yr | 45.38 |
| OR43 Culvert | 359 | 100-Yr | 44.8 |
| OR43 Culvert | 351.5 | 100-Yr | 44.88 |
| OR43 Culvert | 350.5 | 100-Yr | 44.28 |
| OR43 Culvert | 343 | 100-Yr | 44.36 |
| OR43 Culvert | 342 | 100-Yr | 43.8 |
| OR43 Culvert | 334.5 | 100-Yr | 43.88 |
| OR43 Culvert | 333.5 | 100-Yr | 43.31 |
| OR43 Culvert | 326 | 100-Yr | 43.39 |
| OR43 Culvert | 325 | 100-Yr | 42.85 |
| OR43 Culvert | 317.5 | 100-Yr | 42.93 |
| OR43 Culvert | 316.5 | 100-Yr | 42.46 |
| OR43 Culvert | 309 | 100-Yr | 42.53 |
| OR43 Culvert | 308 | 100-Yr | 42.12 |
| OR43 Culvert | 301 | 100-Yr | 42.18 |
| OR43 Culvert | 299 | 100-Yr | 41.82 |
| OR43 Culvert | 290.5 | 100-Yr | 41.84 |
| OR43 Culvert | 289.5 | 100-Yr | 41.46 |
| OR43 Culvert | 273.5 | 100-Yr | 41.49 |
| OR43 Culvert | 272.5 | 100-Yr | 41.15 |
| OR43 Culvert | 256.5 | 100-Yr | 41.18 |
| OR43 Culvert | 255.5 | 100-Yr | 40.85 |
| OR43 Culvert | 239.5 | 100-Yr | 40.88 |
| OR43 Culvert | 238.5 | 100-Yr | 40.55 |
| OR43 Culvert | 222.5 | 100-Yr | 40.58 |

**Water Surface Elevations under With Project Conditions**

| Reach | River Sta | Profile | W.S. Elev (ft) |
|---|---|---|---|
| OR43 Culvert | 941 | 100-Yr | 59.03 |
| OR43 Culvert | 441 | 100-Yr | 48.38 |
| OR43 Culvert | 401 | 100-Yr | 43.68 |
| OR43 Culvert | 391.* | 100-Yr | 43.33 |
| OR43 Culvert | 381.* | 100-Yr | 42.99 |
| OR43 Culvert | 371.* | 100-Yr | 42.65 |
| OR43 Culvert | 361.* | 100-Yr | 42.3 |
| OR43 Culvert | 351.* | 100-Yr | 41.96 |
| OR43 Culvert | 341.* | 100-Yr | 41.62 |
| OR43 Culvert | 331.* | 100-Yr | 41.27 |
| OR43 Culvert | 321.* | 100-Yr | 40.93 |
| OR43 Culvert | 311.* | 100-Yr | 40.59 |
| OR43 Culvert | 301.* | 100-Yr | 40.26 |
| OR43 Culvert | 291.* | 100-Yr | 39.92 |
| OR43 Culvert | 281.* | 100-Yr | 39.59 |
| OR43 Culvert | 271.* | 100-Yr | 39.28 |
| OR43 Culvert | 261.* | 100-Yr | 38.97 |
| OR43 Culvert | 251.* | 100-Yr | 38.69 |
| OR43 Culvert | 241.* | 100-Yr | 38.44 |
| OR43 Culvert | 231.* | 100-Yr | 38.22 |
| OR43 Culvert | 221.* | 100-Yr | 38.05 |
| OR43 Culvert | 211.* | 100-Yr | 37.9 |
| OR43 Culvert | 201.* | 100-Yr | 37.79 |
| OR43 Culvert | 191.* | 100-Yr | 37.71 |
| OR43 Culvert | 181.* | 100-Yr | 37.64 |
| OR43 Culvert | 171.* | 100-Yr | 37.59 |
| OR43 Culvert | 161.* | 100-Yr | 37.55 |
| OR43 Culvert | 151.* | 100-Yr | 37.51 |
| OR43 Culvert | 141.* | 100-Yr | 37.49 |
| OR43 Culvert | 131.* | 100-Yr | 37.46 |
| OR43 Culvert | 121.* | 100-Yr | 37.45 |
| OR43 Culvert | 111.* | 100-Yr | 37.43 |
| OR43 Culvert | 101.* | 100-Yr | 37.42 |
| OR43 Culvert | 90.9999* | 100-Yr | 37.41 |
| OR43 Culvert | 81.* | 100-Yr | 37.4 |
| OR43 Culvert | 71.0000* | 100-Yr | 37.39 |
| OR43 Culvert | 61.* | 100-Yr | 37.39 |

| | | | |
|---|---|---|---|
| OR43 Culvert | 221.5 | 100-Yr | 40.27 |
| OR43 Culvert | 205.5 | 100-Yr | 40.29 |
| OR43 Culvert | 204.5 | 100-Yr | 39.99 |
| OR43 Culvert | 188.5 | 100-Yr | 40.01 |
| OR43 Culvert | 187.5 | 100-Yr | 39.74 |
| OR43 Culvert | 171.5 | 100-Yr | 39.76 |
| OR43 Culvert | 170.5 | 100-Yr | 39.49 |
| OR43 Culvert | 154.5 | 100-Yr | 39.5 |
| OR43 Culvert | 153.5 | 100-Yr | 39.24 |
| OR43 Culvert | 137.5 | 100-Yr | 39.25 |
| OR43 Culvert | 136.5 | 100-Yr | 38.99 |
| OR43 Culvert | 120.5 | 100-Yr | 39 |
| OR43 Culvert | 119.5 | 100-Yr | 38.75 |
| OR43 Culvert | 103.5 | 100-Yr | 38.76 |
| OR43 Culvert | 102.5 | 100-Yr | 38.52 |
| OR43 Culvert | 86.5 | 100-Yr | 38.54 |
| OR43 Culvert | 85.5 | 100-Yr | 38.3 |
| OR43 Culvert | 69.5 | 100-Yr | 38.3 |
| OR43 Culvert | 68.5 | 100-Yr | 38.08 |
| OR43 Culvert | 52.5 | 100-Yr | 38.08 |
| OR43 Culvert | 51.5 | 100-Yr | 37.87 |
| OR43 Culvert | 35.5 | 100-Yr | 37.88 |
| OR43 Culvert | 34.5 | 100-Yr | 37.67 |
| OR43 Culvert | 18.5 | 100-Yr | 37.68 |
| OR43 Culvert | 17.5 | 100-Yr | 37.48 |
| OR43 Culvert | 1.5 | 100-Yr | 37.49 |
| OR43 Culvert | 0 | 100-Yr | 37.31 |
| OR43 Culvert | -10.6 | 100-Yr | 37.4 |
| OR43 Culvert | -28.6 | 100-Yr | 37.4 |
| OR43 Culvert | -42.6 | 100-Yr | 37.4 |
| OR43 Culvert | -66.6 | 100-Yr | 37.4 |
| OR43 Culvert | -71.6 | 100-Yr | 37.4 |
| OR43 Culvert | -76.6 | 100-Yr | 37.4 |
| OR43 Culvert | -81.6 | 100-Yr | 37.4 |
| OR43 Culvert | -86.6 | 100-Yr | 37.4 |
| OR43 Culvert | -90.6 | 100-Yr | 37.4 |
| OR43 Culvert | -98.6 | 100-Yr | 37.4 |
| OR43 Culvert | -102.6 | 100-Yr | 37.4 |
| OR43 Culvert | -104.6 | 100-Yr | 37.4 |
| OR43 Culvert | -108.6 | 100-Yr | 37.4 |
| OR43 Culvert | 51.0000* | 100-Yr | 37.38 |
| OR43 Culvert | 41.* | 100-Yr | 37.38 |
| OR43 Culvert | 31.0000* | 100-Yr | 37.37 |
| OR43 Culvert | 20.9999* | 100-Yr | 37.37 |
| OR43 Culvert | 11.* | 100-Yr | 37.36 |
| OR43 Culvert | .999989* | 100-Yr | 37.36 |
| OR43 Culvert | 0 | 100-Yr | 37.36 |
| OR43 Culvert | -10.6 | 100-Yr | 37.39 |
| OR43 Culvert | -28.6 | 100-Yr | 37.39 |
| OR43 Culvert | -42.6 | 100-Yr | 37.39 |
| OR43 Culvert | -66.6 | 100-Yr | 37.4 |
| OR43 Culvert | -71.6 | 100-Yr | 37.4 |
| OR43 Culvert | -76.6 | 100-Yr | 37.4 |
| OR43 Culvert | -81.6 | 100-Yr | 37.4 |
| OR43 Culvert | -86.6 | 100-Yr | 37.4 |
| OR43 Culvert | -90.6 | 100-Yr | 37.4 |
| OR43 Culvert | -98.6 | 100-Yr | 37.4 |
| OR43 Culvert | -102.6 | 100-Yr | 37.4 |
| OR43 Culvert | -104.6 | 100-Yr | 37.4 |
| OR43 Culvert | -108.6 | 100-Yr | 37.4 |
| OR43 Culvert | -112.6 | 100-Yr | 37.4 |
| OR43 Culvert | -116.6 | 100-Yr | 37.4 |
| OR43 Culvert | -120.6 | 100-Yr | 37.4 |
| OR43 Culvert | -124.6 | 100-Yr | 37.4 |
| OR43 Culvert | -129.6 | 100-Yr | 37.4 |
| OR43 Culvert | -133.6 | 100-Yr | 37.4 |
| OR43 Culvert | -138.6 | 100-Yr | 37.4 |
| OR43 Culvert | -143.6 | 100-Yr | 37.4 |
| OR43 Culvert | -148.6 | 100-Yr | 37.4 |
| OR43 Culvert | -153.6 | 100-Yr | 37.4 |
| OR43 Culvert | -158.6 | 100-Yr | 37.4 |
| OR43 Culvert | -164.6 | 100-Yr | 37.4 |
| OR43 Culvert | -169.6 | 100-Yr | 37.4 |
| OR43 Culvert | -175.6 | 100-Yr | 37.4 |
| OR43 Culvert | -194.6 | 100-Yr | 37.4 |
| OR43 Culvert | -205.6 | 100-Yr | 37.4 |
| OR43 Culvert | -221.6 | 100-Yr | 37.4 |
| OR43 Culvert | -237.6 | 100-Yr | 37.4 |
| OR43 Culvert | -259.6 | 100-Yr | 37.4 |
| OR43 Culvert | -273.1 | 100-Yr | 37.4 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| OR43 Culvert | -112.6 | 100-Yr | 37.4 | | OR43 Culvert | -286.6 | 100-Yr | 37.4 |
| OR43 Culvert | -116.6 | 100-Yr | 37.4 | | OR43 Culvert | -302.6 | 100-Yr | 37.4 |
| OR43 Culvert | -120.6 | 100-Yr | 37.4 | | OR43 Culvert | -318.6 | 100-Yr | 37.4 |
| OR43 Culvert | -124.6 | 100-Yr | 37.4 | | OR43 Culvert | -341.6 | 100-Yr | 37.4 |
| OR43 Culvert | -129.6 | 100-Yr | 37.4 | | OR43 Culvert | -364.6 | 100-Yr | 37.4 |
| OR43 Culvert | -133.6 | 100-Yr | 37.4 | | OR43 Culvert | -389.6 | 100-Yr | 37.4 |
| OR43 Culvert | -138.6 | 100-Yr | 37.4 | | OR43 Culvert | -413.6 | 100-Yr | 37.4 |
| OR43 Culvert | -143.6 | 100-Yr | 37.4 | | OR43 Culvert | -421.6 | 100-Yr | 37.4 |
| OR43 Culvert | -148.6 | 100-Yr | 37.4 | | OR43 Culvert | -436.6 | 100-Yr | 37.4 |
| OR43 Culvert | -153.6 | 100-Yr | 37.4 | | OR43 Culvert | -449.6 | 100-Yr | 37.4 |
| OR43 Culvert | -158.6 | 100-Yr | 37.4 | | OR43 Culvert | -458.6 | 100-Yr | 37.4 |
| OR43 Culvert | -164.6 | 100-Yr | 37.4 | | OR43 Culvert | -471.6 | 100-Yr | 37.4 |
| OR43 Culvert | -169.6 | 100-Yr | 37.4 | | OR43 Culvert | -485.6 | 100-Yr | 37.4 |
| OR43 Culvert | -175.6 | 100-Yr | 37.4 | | OR43 Culvert | -502.1 | 100-Yr | 37.4 |
| OR43 Culvert | -194.6 | 100-Yr | 37.4 | | OR43 Culvert | -518.6 | 100-Yr | 37.4 |
| OR43 Culvert | -205.6 | 100-Yr | 37.4 | | OR43 Culvert | -533.6 | 100-Yr | 37.4 |
| OR43 Culvert | -221.6 | 100-Yr | 37.4 | | OR43 Culvert | -548.6 | 100-Yr | 37.4 |
| OR43 Culvert | -237.6 | 100-Yr | 37.4 | | OR43 Culvert | -573.6 | 100-Yr | 37.4 |
| OR43 Culvert | -259.6 | 100-Yr | 37.4 | | OR43 Culvert | -586.6 | 100-Yr | 37.4 |
| OR43 Culvert | -273.1 | 100-Yr | 37.4 | | OR43 Culvert | -599.6 | 100-Yr | 37.4 |
| OR43 Culvert | -286.6 | 100-Yr | 37.4 | | OR43 Culvert | -614.1 | 100-Yr | 37.4 |
| OR43 Culvert | -302.6 | 100-Yr | 37.4 | | OR43 Culvert | -628.6 | 100-Yr | 37.4 |
| OR43 Culvert | -318.6 | 100-Yr | 37.4 | | OR43 Culvert | -642.1 | 100-Yr | 37.4 |
| OR43 Culvert | -341.6 | 100-Yr | 37.4 | | OR43 Culvert | -655.6 | 100-Yr | 37.4 |
| OR43 Culvert | -364.6 | 100-Yr | 37.4 | | OR43 Culvert | -678.6 | 100-Yr | 37.4 |
| OR43 Culvert | -389.6 | 100-Yr | 37.4 | | OR43 Culvert | -703.6 | 100-Yr | 37.4 |
| OR43 Culvert | -413.6 | 100-Yr | 37.4 | | OR43 Culvert | -723.6 | 100-Yr | 37.4 |
| OR43 Culvert | -421.6 | 100-Yr | 37.4 | | OR43 Culvert | -745.6 | 100-Yr | 37.4 |
| OR43 Culvert | -436.6 | 100-Yr | 37.4 | | OR43 Culvert | -769.6 | 100-Yr | 37.4 |
| OR43 Culvert | -449.6 | 100-Yr | 37.4 | | OR43 Culvert | -793.6 | 100-Yr | 37.4 |
| OR43 Culvert | -458.6 | 100-Yr | 37.4 | | OR43 Culvert | -810.6 | 100-Yr | 37.4 |
| OR43 Culvert | -471.6 | 100-Yr | 37.4 | | OR43 Culvert | -827.6 | 100-Yr | 37.4 |
| OR43 Culvert | -485.6 | 100-Yr | 37.4 | | OR43 Culvert | -842.1 | 100-Yr | 37.4 |
| OR43 Culvert | -502.1 | 100-Yr | 37.4 | | OR43 Culvert | -856.6 | 100-Yr | 37.4 |
| OR43 Culvert | -518.6 | 100-Yr | 37.4 | | OR43 Culvert | -877.6 | 100-Yr | 37.4 |
| OR43 Culvert | -533.6 | 100-Yr | 37.4 | | OR43 Culvert | -898.6 | 100-Yr | 37.4 |
| OR43 Culvert | -548.6 | 100-Yr | 37.4 | | OR43 Culvert | -922.6 | 100-Yr | 37.4 |
| OR43 Culvert | -573.6 | 100-Yr | 37.4 | | OR43 Culvert | -946.6 | 100-Yr | 37.4 |
| OR43 Culvert | -586.6 | 100-Yr | 37.4 | | OR43 Culvert | -969.6 | 100-Yr | 37.4 |
| OR43 Culvert | -599.6 | 100-Yr | 37.4 | | OR43 Culvert | -987.6 | 100-Yr | 37.4 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| OR43 Culvert | -614.1 | 100-Yr | 37.4 | | OR43 Culvert | -1007.6 | 100-Yr | 37.4 |
| OR43 Culvert | -628.6 | 100-Yr | 37.4 | | OR43 Culvert | -1029.6 | 100-Yr | 37.4 |
| OR43 Culvert | -642.1 | 100-Yr | 37.4 | | OR43 Culvert | -1045.6 | 100-Yr | 37.4 |
| OR43 Culvert | -655.6 | 100-Yr | 37.4 | | OR43 Culvert | -1061.6 | 100-Yr | 37.4 |
| OR43 Culvert | -678.6 | 100-Yr | 37.4 | | OR43 Culvert | -1079.6 | 100-Yr | 37.4 |
| OR43 Culvert | -703.6 | 100-Yr | 37.4 | | OR43 Culvert | -1097.6 | 100-Yr | 37.4 |
| OR43 Culvert | -723.6 | 100-Yr | 37.4 | | OR43 Culvert | -1115.6 | 100-Yr | 37.4 |
| OR43 Culvert | -745.6 | 100-Yr | 37.4 | | * Represent Interpolated Cross Sections | | | |
| OR43 Culvert | -769.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -793.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -810.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -827.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -842.1 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -856.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -877.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -898.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -922.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -946.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -969.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -987.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -1007.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -1029.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -1045.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -1061.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -1079.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -1097.6 | 100-Yr | 37.4 | | | | | |
| OR43 Culvert | -1115.6 | 100-Yr | 37.4 | | | | | |