APPENDIX A
HYDROLOGIC ANALYSIS AND HYDRAULIC MODELING DETAILS

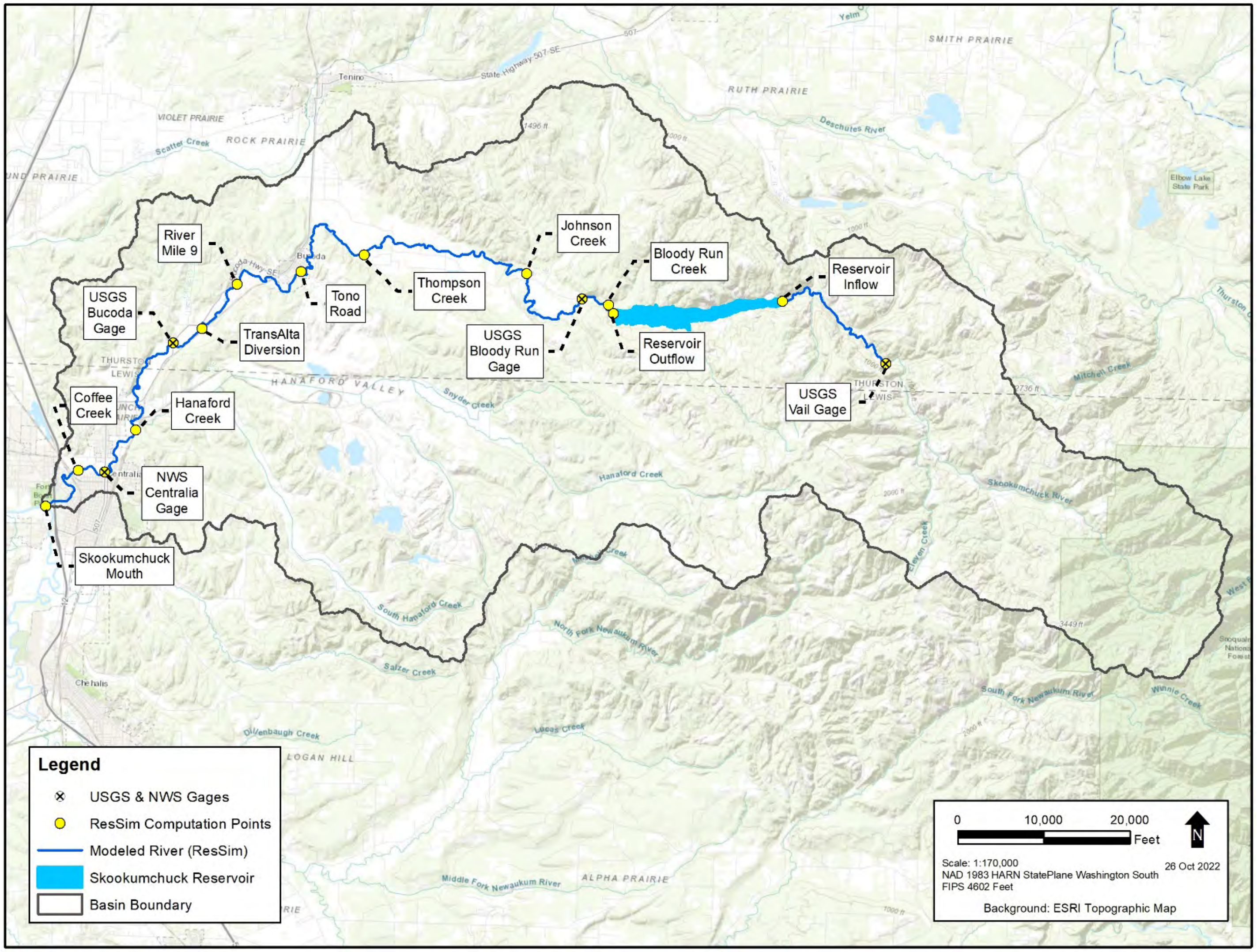
HYDROLOGIC ANALYSIS AND HYDRAULIC MODELING DETAILS

A.1 Hydrologic Analysis

The detailed methods used to develop the hydrology for the Skookumchuck River used in this Phase 2 analysis are described in the following steps:

1. 15-minute data from the Vail, WA, gage (USGS 12025700) were downloaded from the U.S. Geological Survey (USGS) website and processed to infill any gaps in the record via interpolation. This provided a data set of 15-minute values covering the period October 1987 through the beginning of March 2022.
2. Inflows to the Skookumchuck River between Vail and Skookumchuck Dam were developed by scaling the Vail record using basin area and mean annual precipitation. The basin area at Vail is 40.0 square miles and the contributing basin area between Vail and the reservoir is 21.7 square miles, resulting in local inflows equal to 45.6% of the Vail flows after accounting for differences in precipitation.
3. Inflows for Bloody Run Creek were estimated in the same manner as the local inflows to the reservoir, resulting in an inflow time series equal to 8.3% of the Vail flow.
4. Local inflows to the Skookumchuck River between Bloody Run and Bucoda were estimated by taking the difference between the recorded Skookumchuck River below Bloody Run Creek flows (USGS gage 12026150) and Skookumchuck River near Bucoda flows (USGS gage 12026400), accounting for TransAlta and other diversions between the two gages. Flows at Bloody Run were first routed to the Bucoda gage using Muskingum routing in HEC-ResSim to adjust for flow timing between the two gages prior to subtraction from the Bucoda flows. Diversion data were subtracted from the routed upstream flows before subtracting from the Bucoda flows. Diversions by TransAlta were based on daily and monthly data obtained from TransAlta while other diversions were assumed to be made continuously at the maximum permitted rate of the water rights. The 15-minute Bucoda gage record spanned water year (WY) 2008 to 2022, so the calculated local inflows were limited to this period of record.
5. Once the total local inflows between Bloody Run and Bucoda were calculated, they were apportioned to discrete reaches along the Skookumchuck River. Junctions between reaches were selected based on major tributaries (e.g., Johnson Creek, Thompson Creek), geographic location (e.g., Tono Road), or gage location (e.g., Bucoda gage). An additional junction was added at the TransAlta diversion just downstream of Connor Road SE. The 15-minute local inflows at each of these locations were adjusted in time to account for estimated routing time between the input location and the Bucoda gage. Figure A-1 shows a schematic of the Skookumchuck River with reach locations and Table 2 shows computed median monthly flows over the period of analysis (WY 2008 to 2022).

Figure A-1
Skookumchuck River HEC-ResSim Model Layout with Computation Points/Local Inflows



6. A time series of flow reductions (diversions) at the TransAlta diversion point was developed from TransAlta records. Daily data were available from January 2007 through December 2008 and March 2010 through March 2022. Monthly data were available for January 2009 through February 2010. For periods with daily data, it was assumed that the diversion was constant throughout the day. For periods with only monthly data, it was assumed that diversions were constant throughout the month. Other water rights diversions were assumed to be constant throughout the analysis period at the maximum permitted diversion rate. These diversions were subtracted from local inflows at different locations in the model based on the reported point of diversion. In total, these other non-TransAlta diversions have a maximum permitted diversion rate of 10.3 cubic feet per second (cfs).

7. The Centralia gage (operated by the National Weather Service) only provides stage data. Therefore, it is not possible to directly compute local inflows between the Bucoda gage and the mouth. In place of this, the local inflows between the Bloody Run and Bucoda gages were assumed to also be representative of the downstream local inflows. The same method of apportioning local inflows was used for the downstream inflows (i.e., scaled using contributing drainage area and precipitation). Downstream flow inputs were added at Hanaford Creek, Coffee Creek, and between Coffee Creek and the mouth.

8. An additional process was applied to ensure the Hanaford Creek local inflows were as realistic as possible. The Hanaford Valley is broad and has a very low gradient, and previous modeling has shown that discharges from Hanaford Creek to the Skookumchuck River are attenuated by the significant floodplain storage available on this tributary (WSE 2014). To account for this, calculated local inflows from Hanaford Creek were first adjusted by level pool routing before being discharged to the Skookumchuck River. Parameters for the level pool routing, specifically the stage-storage-discharge relationship, were taken from earlier HEC-RAS modeling of the basin (WSE 2014). Routed local inflows from Hanaford Creek for the period of record were computed in an Excel spreadsheet and saved in HEC-DSS for use in the modeling.

9. In addition to creating long time series of reservoir and local inflows as described above, hypothetical design flood event hydrographs were also developed. To generate these hydrographs, flow frequency analyses were performed on the 15-minute historical flow data for the Vail gage (WY 1988 to 2022) and for the local inflows computed as described above (WY 2008 to 2022). Flow frequency analyses were performed using the U.S. Army Corps of Engineers (USACE) HEC-SSP software and the methods of U.S. Water Resources Council Bulletin 17C. Flow frequency analyses were conducted for annual instantaneous peak flows and for 24-hour, 3-day, 7-day, and 15-day durations. The computed flow frequency data were then used in HEC-SSP, together with the flow pattern of the January 2022 flood event, to create “balanced” inflow hydrographs corresponding to the 2-, 10-, 20-, and 100-year recurrence intervals. Balanced inflow hydrographs follow the general

flow pattern of an observed flood, in this case the January 2022 event, but adjust the 15-minute flow data as necessary to ensure that the computed flow volumes from the frequency analysis are matched at all durations. Thus, the 100-year balanced inflow hydrograph incorporates the 100-year peak flow, the 100-year 24-hour flow, and the 100-year 3-, 7-, and 15-day flows all within a single design flood event. Likewise, the 2-, 10-, and 20-year events were configured to match the flow volumes at each of these durations for the corresponding return period.

10. In addition to the existing conditions hydrologic data described above, a second set of data was developed corresponding to projected late-century climate change. For the design flood events, the climate change flows were developed by scaling existing conditions flows up by 60% and then making the flow adjustments and apportioning the flows as described above for existing conditions. The 60% increase for Skookumchuck River flows was based on previous analyses done by Watershed Science & Engineering (WSE) and the University of Washington (UW) Climate Impacts Group for the Chehalis Basin (CIG 2021). Using the same scalar for the Skookumchuck River flows as has been used in other Chehalis Basin Strategy investigations ensures consistency between the studies. For seasonal and low-flow analyses, a different scaling approach was used. Winter flows (November through April) were scaled up by 17% and summer flows (May through October) were scaled down by 30%. These scalars match the adjustments being used for seasonal and low-flow analyses throughout the Chehalis Basin as described in Anchor QEA (2021). Climate adjusted hydrologic data as described herein were used to simulate operational alternatives and evaluate performance of the alternatives under the projected late-century conditions. The results of the analysis with flows adjusted for projected climate change is described below.

A.2 Water Budget

Using the process described above, hydrologic data for modeling and analysis of the Skookumchuck River were developed. These data were also used to inform a water budget for the river. Using HEC-ResSim, a routing model was configured to simulate flows along the mainstem Skookumchuck River from the Bloody Run gage to the mouth of the river. Upstream inflows to the model were taken directly from the Skookumchuck River below Bloody Run gage (USGS 12026150). The ResSim model routed flows down the river to match the observed attenuation of flows between the Bloody Run and Bucoda gage locations. Apportioned local inflows were added to the model and diversions subtracted at the appropriate locations. The result of this process was a 15-minute time series of discharges for ten reaches along the Skookumchuck River downstream of the Bloody Run gage. Note that there is considerable uncertainty in the 15-minute data due to a number of factors including: TransAlta diversion records being limited to daily or monthly data, lack of detailed diversion data for non-TransAlta water rights diversions, uncertainties in the USGS gage data, lack of observed flow data downstream of the Bucoda gage, variations in travel time and attenuation not captured by the channel routing, and a lack of any detailed information on groundwater discharges or recharge in the study reaches. As such, the computed flow data are considered reasonable for estimation of a monthly water budget but should not be used for detailed analyses of historical conditions at shorter time intervals.

Table A-1 summarizes median monthly flows and 10% and 90% exceedance flows by reach based on the recorded historical data from October 2008 to February 2022. The historical condition uses observed historical discharges at the Bloody Run gage, together with computed local inflows and diversions downstream of Bloody Run, to define flows throughout the study area. In addition to the historical condition, water budget analyses were also conducted on simulated conditions using current operating rules for Skookumchuck Dam (e.g., meeting Washington Department of Fish and Wildlife [WDFW]-prescribed discharges from the dam and downstream minimum instream flow requirements), and on a scenario assuming Skookumchuck Dam removal and eliminating the TransAlta diversion. HEC-ResSim modeling of these scenarios is described below. The resultant median monthly flows and 10% and 90% exceedance flows by month by reach for the current operations and dam removal conditions are also shown in Table A-1.

Corresponding water budget data for the late-century climate change conditions are shown in Table A-2. Note that Table A-2 does not include data for historical conditions. Observed “historical” operations and “future” climate change conditions are paradoxical, meaning it is not possible to know how historical operations—which are the result of real-time decision making in response to many considerations (e.g., maintenance activities, drought declarations)—would be altered under a future climate scenario. Therefore, historical operations water budget data under the climate change hydrology cannot be evaluated and are therefore not included in Table A-2. Table A-2 does, however, include data for Current (rules-based) Dam Operations under future climate conditions.

Table A-1 Skookumchuck River Water Budget										
Median Monthly Flow (cfs) and range from P10 to P90 Levels - Based on October 2007 through February 2022										
Historical Conditions Using Observed Flows at Bloody Run Gage as Upstream Model Inflow										
	BLOODY RUN GAGE TO JOHNSON CK	JOHNSON CK TO THOMPSON CK	THOMPSON CK TO TONO ROAD	TONO ROAD TO RIVER MILE 9	RIVER MILE 9 TO DIVERSION	DIVERSION TO BUCODA GAGE	BUCODA GAGE TO HANAFORD CK	HANAFORD CK TO CENTRALIA GAGE	CENTRALIA GAGE TO COFFEE CK	COFFEE CK TO MOUTH
	HISTORICAL	HISTORICAL	HISTORICAL	HISTORICAL	HISTORICAL	HISTORICAL	HISTORICAL	HISTORICAL	HISTORICAL	HISTORICAL
January	573 (386 - 812)	661 (428 - 994)	744 (465 - 1174)	799 (484 - 1268)	822 (491 - 1304)	821 (462 - 1272)	820 (462 - 1268)	1252 (606 - 1939)	1252 (606 - 1937)	1269 (612 - 1963)
February	405 (234 - 679)	505 (265 - 812)	583 (278 - 951)	623 (290 - 1026)	639 (294 - 1056)	639 (266 - 1042)	638 (266 - 1039)	930 (349 - 1584)	930 (349 - 1583)	942 (352 - 1604)
March	289 (145 - 771)	330 (164 - 907)	371 (183 - 1027)	392 (193 - 1097)	400 (197 - 1124)	394 (169 - 1119)	394 (169 - 1115)	568 (240 - 1618)	568 (240 - 1617)	577 (244 - 1637)
April	340 (159 - 535)	391 (178 - 634)	441 (198 - 728)	467 (208 - 779)	477 (212 - 800)	463 (193 - 800)	464 (193 - 803)	652 (256 - 1166)	652 (256 - 1167)	660 (259 - 1183)
May	202 (96 - 314)	221 (103 - 376)	241 (112 - 417)	250 (116 - 438)	254 (117 - 447)	237 (105 - 445)	237 (105 - 446)	292 (136 - 604)	292 (136 - 604)	294 (137 - 611)
June	133 (85 - 202)	137 (93 - 213)	143 (102 - 228)	147 (104 - 239)	149 (104 - 242)	143 (89 - 241)	142 (88 - 240)	179 (102 - 321)	178 (102 - 321)	181 (103 - 325)
July	99 (69 - 165)	100 (70 - 175)	112 (72 - 186)	118 (73 - 189)	120 (73 - 190)	90 (46 - 185)	90 (45 - 185)	107 (51 - 212)	106 (51 - 212)	107 (51 - 213)
August	88 (63 - 125)	91 (64 - 127)	95 (65 - 132)	97 (65 - 135)	97 (65 - 135)	64 (31 - 101)	63 (30 - 101)	78 (35 - 120)	78 (34 - 120)	79 (34 - 121)
September	114 (72 - 138)	119 (72 - 148)	118 (74 - 151)	117 (75 - 155)	116 (74 - 156)	91 (53 - 127)	90 (52 - 126)	97 (57 - 160)	97 (56 - 159)	98 (56 - 161)
October	123 (96 - 150)	130 (101 - 163)	138 (107 - 184)	139 (110 - 196)	139 (110 - 200)	109 (77 - 179)	108 (75 - 178)	121 (91 - 263)	120 (91 - 262)	120 (91 - 266)
November	204 (106 - 426)	249 (115 - 522)	307 (119 - 618)	337 (120 - 665)	349 (120 - 682)	325 (83 - 663)	323 (82 - 661)	543 (93 - 1008)	543 (92 - 1007)	550 (93 - 1020)
December	438 (179 - 879)	519 (218 - 1053)	587 (257 - 1211)	622 (285 - 1293)	636 (295 - 1326)	617 (258 - 1308)	615 (256 - 1306)	869 (421 - 1909)	868 (420 - 1908)	878 (425 - 1932)
Current Conditions Using HEC-ResSIM Simulated outflows from Skookumchuck Dam as Upstream Model Inflow										
	BLOODY RUN GAGE TO JOHNSON CK	JOHNSON CK TO THOMPSON CK	THOMPSON CK TO TONO ROAD	TONO ROAD TO RIVER MILE 9	RIVER MILE 9 TO DIVERSION	DIVERSION TO BUCODA GAGE	BUCODA GAGE TO HANAFORD CK	HANAFORD CK TO CENTRALIA GAGE	CENTRALIA GAGE TO COFFEE CK	COFFEE CK TO MOUTH
	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS
January	670 (413 - 941)	791 (452 - 1127)	883 (512 - 1306)	928 (537 - 1400)	944 (543 - 1436)	921 (519 - 1419)	919 (519 - 1420)	1259 (641 - 2101)	1258 (641 - 2101)	1276 (646 - 2130)
February	465 (229 - 751)	546 (226 - 894)	624 (228 - 1039)	665 (224 - 1115)	681 (220 - 1144)	681 (201 - 1130)	681 (194 - 1127)	973 (246 - 1672)	973 (245 - 1671)	985 (249 - 1692)
March	371 (190 - 881)	413 (208 - 1019)	453 (226 - 1152)	474 (236 - 1221)	482 (239 - 1246)	476 (211 - 1240)	476 (210 - 1235)	635 (282 - 1746)	634 (281 - 1744)	641 (284 - 1763)
April	402 (173 - 624)	468 (187 - 724)	517 (201 - 819)	543 (208 - 870)	553 (211 - 890)	539 (194 - 891)	539 (194 - 894)	728 (247 - 1258)	728 (247 - 1259)	736 (250 - 1275)
May	179 (99 - 368)	197 (106 - 431)	216 (112 - 492)	225 (115 - 518)	228 (116 - 527)	212 (99 - 526)	210 (99 - 526)	281 (121 - 685)	281 (120 - 685)	283 (121 - 692)
June	103 (97 - 292)	110 (101 - 303)	120 (105 - 314)	125 (107 - 320)	127 (107 - 322)	114 (91 - 305)	114 (90 - 305)	145 (105 - 344)	145 (104 - 344)	147 (105 - 346)
July	97 (96 - 107)	100 (94 - 113)	104 (94 - 121)	105 (93 - 126)	105 (92 - 128)	77 (66 - 120)	76 (66 - 120)	91 (74 - 158)	91 (74 - 158)	91 (75 - 160)
August	96 (96 - 97)	99 (93 - 102)	104 (92 - 107)	106 (91 - 110)	106 (90 - 110)	72 (60 - 83)	71 (60 - 82)	87 (61 - 102)	87 (61 - 102)	87 (61 - 103)
September	141 (141 - 143)	144 (138 - 151)	148 (137 - 160)	150 (135 - 165)	150 (134 - 166)	118 (105 - 137)	117 (104 - 136)	128 (107 - 169)	128 (106 - 168)	128 (106 - 170)
October	131 (126 - 140)	136 (131 - 160)	141 (135 - 184)	143 (137 - 196)	143 (137 - 200)	117 (101 - 179)	116 (100 - 178)	140 (111 - 263)	139 (111 - 262)	140 (111 - 266)
November	363 (106 - 546)	415 (110 - 632)	465 (115 - 715)	491 (117 - 758)	501 (117 - 774)	463 (77 - 741)	461 (76 - 741)	652 (91 - 1159)	651 (91 - 1158)	658 (91 - 1171)
December	495 (163 - 860)	568 (200 - 1026)	639 (237 - 1184)	675 (255 - 1267)	689 (265 - 1299)	652 (233 - 1282)	650 (230 - 1281)	904 (434 - 1883)	903 (433 - 1882)	913 (441 - 1907)
Current Conditions Using HEC-ResSIM Simulated outflows from Skookumchuck Dam under minimum instream flow requirements as Upstream Model Inflow										
	BLOODY RUN GAGE TO JOHNSON CK	JOHNSON CK TO THOMPSON CK	THOMPSON CK TO TONO ROAD	TONO ROAD TO RIVER MILE 9	RIVER MILE 9 TO DIVERSION	DIVERSION TO BUCODA GAGE	BUCODA GAGE TO HANAFORD CK	HANAFORD CK TO CENTRALIA GAGE	CENTRALIA GAGE TO COFFEE CK	COFFEE CK TO MOUTH
	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL
January	655 (394 - 955)	776 (456 - 1144)	890 (509 - 1323)	934 (525 - 1417)	951 (531 - 1453)	950 (531 - 1452)	948 (531 - 1448)	1269 (654 - 2118)	1268 (653 - 2118)	1281 (659 - 2146)
February	450 (252 - 747)	531 (253 - 900)	608 (252 - 1045)	648 (245 - 1120)	664 (238 - 1150)	663 (234 - 1149)	662 (232 - 1147)	954 (315 - 1691)	954 (314 - 1690)	965 (317 - 1711)
March	375 (249 - 896)	417 (271 - 1034)	457 (292 - 1167)	478 (301 - 1235)	486 (304 - 1261)	486 (303 - 1259)	485 (302 - 1254)	666 (374 - 1764)	665 (373 - 1762)	674 (376 - 1781)
April	401 (168 - 612)	462 (182 - 712)	511 (196 - 806)	538 (203 - 857)	548 (205 - 878)	548 (205 - 879)	548 (206 - 883)	737 (259 - 1247)	737 (259 - 1249)	745 (261 - 1265)
May	181 (82 - 365)	200 (93 - 428)	218 (103 - 489)	228 (105 - 514)	231 (106 - 522)	230 (106 - 523)	229 (105 - 524)	300 (127 - 682)	299 (127 - 683)	302 (128 - 690)
June	93 (54 - 268)	99 (61 - 279)	105 (67 - 289)	108 (69 - 295)	109 (69 - 297)	109 (69 - 296)	109 (68 - 296)	134 (83 - 335)	134 (82 - 334)	136 (83 - 336)
July	52 (32 - 91)	55 (32 - 98)	60 (31 - 105)	62 (31 - 109)	62 (30 - 110)	62 (30 - 110)	61 (29 - 110)	78 (30 - 147)	78 (29 - 146)	79 (29 - 148)
August	37 (26 - 49)	41 (26 - 52)	45 (25 - 57)	47 (24 - 59)	47 (23 - 59)	46 (23 - 59)	46 (22 - 58)	60 (20 - 80)	59 (20 - 80)	60 (20 - 80)
September	34 (26 - 69)	38 (25 - 77)	44 (25 - 87)	45 (24 - 91)	45 (23 - 92)	45 (22 - 92)	44 (22 - 91)	56 (20 - 124)	56 (19 - 124)	57 (19 - 125)
October	155 (65 - 263)	153 (69 - 307)	155 (75 - 349)	160 (78 - 361)	161 (78 - 362)	161 (78 - 361)	160 (70 - 358)	193 (84 - 407)	193 (83 - 405)	194 (84 - 407)
November	535 (209 - 731)	590 (212 - 865)	644 (217 - 974)	671 (219 - 1022)	682 (219 - 1040)	682 (218 - 1040)	681 (217 - 1038)	863 (233 - 1385)	862 (232 - 1384)	868 (232 - 1398)
December	519 (257 - 884)	572 (293 - 1036)	642 (337 - 1180)	678 (359 - 1262)	692 (367 - 1294)	691 (366 - 1294)	689 (363 - 1293)	944 (515 - 1896)	943 (513 - 1895)	953 (518 - 1919)

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Table A-2 Skookumchuck River Water Budget (Late-Century Climate Change Conditions)

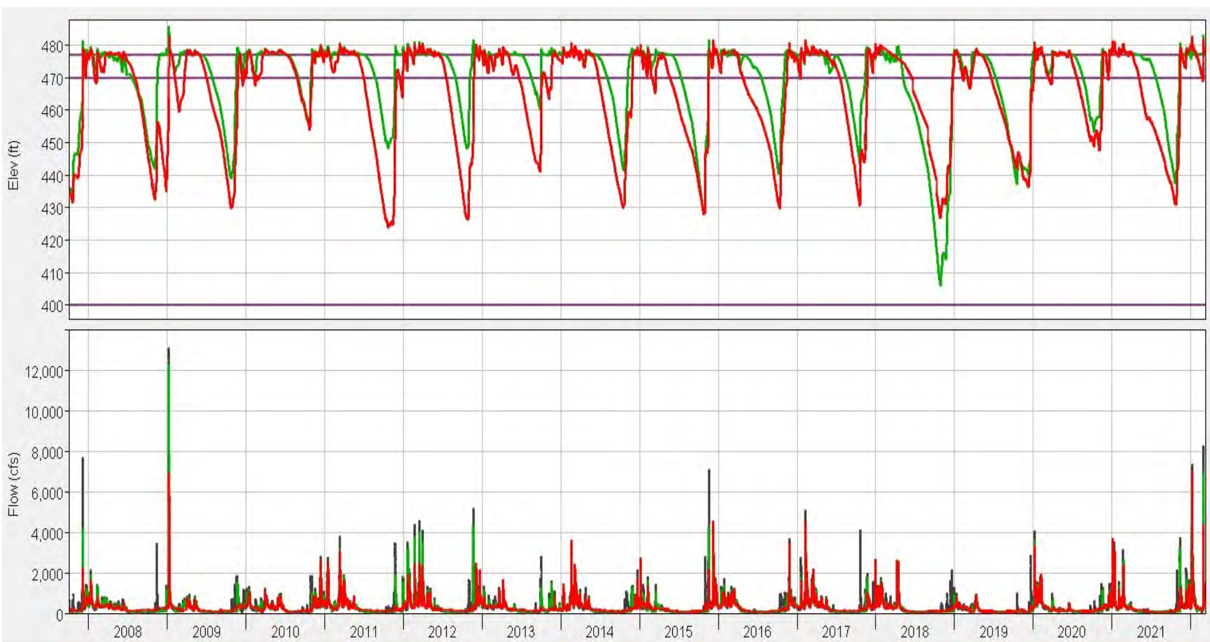
Median Monthly Flow (cfs) and range from P10 to P90 Levels - Based on October 2007 through February 2022

Late-century Climate Conditions Using HEC-ResSIM Simulated outflows from Skookumchuck Dam as Upstream Model Inflow										
	BLOODY RUN GAGE TO JOHNSON CK	JOHNSON CK TO THOMPSON CK	THOMPSON CK TO TONO ROAD	TONO ROAD TO RIVER MILE 9	RIVER MILE 9 TO DIVERSION	DIVERSION TO BUCODA GAGE	BUCODA GAGE TO HANAFORD CK	HANAFORD CK TO CENTRALIA GAGE	CENTRALIA GAGE TO COFFEE CK	COFFEE CK TO MOUTH
	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS	MODELED OPERATIONS
January	775 (474 - 1102)	918 (530 - 1319)	1036 (601 - 1525)	1088 (623 - 1635)	1108 (630 - 1678)	1084 (605 - 1663)	1082 (605 - 1663)	1468 (753 - 2462)	1468 (753 - 2461)	1489 (759 - 2494)
February	535 (273 - 877)	631 (270 - 1048)	722 (273 - 1217)	770 (269 - 1306)	788 (264 - 1341)	788 (244 - 1326)	788 (237 - 1324)	1133 (315 - 1959)	1132 (314 - 1957)	1147 (318 - 1982)
March	433 (250 - 1033)	482 (272 - 1195)	529 (294 - 1350)	554 (305 - 1431)	563 (309 - 1461)	558 (281 - 1454)	557 (281 - 1449)	751 (369 - 2046)	750 (368 - 2044)	758 (372 - 2066)
April	472 (202 - 729)	547 (218 - 846)	604 (235 - 957)	635 (243 - 1017)	647 (247 - 1042)	633 (230 - 1043)	634 (230 - 1046)	860 (297 - 1475)	860 (297 - 1476)	869 (300 - 1495)
May	172 (98 - 296)	183 (102 - 322)	194 (106 - 354)	200 (108 - 372)	202 (108 - 378)	190 (91 - 377)	190 (91 - 378)	238 (110 - 496)	238 (109 - 496)	240 (110 - 502)
June	98 (96 - 208)	103 (98 - 215)	111 (101 - 222)	115 (101 - 226)	115 (101 - 227)	102 (86 - 210)	101 (85 - 210)	123 (97 - 240)	123 (97 - 239)	124 (97 - 241)
July	96 (96 - 98)	98 (93 - 104)	100 (93 - 111)	101 (92 - 115)	100 (91 - 115)	75 (62 - 104)	74 (61 - 103)	85 (70 - 125)	85 (69 - 125)	85 (69 - 125)
August	96 (95 - 96)	97 (93 - 99)	100 (92 - 102)	101 (91 - 104)	101 (90 - 104)	66 (56 - 77)	65 (56 - 76)	80 (60 - 92)	79 (59 - 92)	80 (59 - 92)
September	140 (140 - 142)	142 (137 - 147)	144 (136 - 153)	145 (135 - 156)	145 (134 - 156)	110 (101 - 127)	110 (101 - 126)	122 (106 - 151)	121 (105 - 151)	121 (105 - 151)
October	128 (125 - 132)	131 (127 - 148)	134 (129 - 164)	135 (128 - 172)	135 (127 - 175)	105 (93 - 154)	105 (92 - 153)	126 (99 - 214)	126 (98 - 214)	126 (96 - 216)
November	359 (107 - 510)	420 (113 - 598)	480 (119 - 743)	510 (122 - 820)	521 (122 - 851)	483 (81 - 824)	481 (80 - 825)	708 (102 - 1258)	707 (101 - 1257)	715 (102 - 1272)
December	580 (245 - 1005)	666 (297 - 1199)	749 (340 - 1384)	791 (362 - 1481)	807 (369 - 1520)	771 (341 - 1502)	768 (338 - 1501)	1070 (505 - 2206)	1069 (503 - 2206)	1081 (512 - 2234)
Late-century ClimateConditions Using HEC-ResSIM Simulated outflows from Skookumchuck Dam under minimum instream flow requirements as Upstream Model Inflow										
	BLOODY RUN GAGE TO JOHNSON CK	JOHNSON CK TO THOMPSON CK	THOMPSON CK TO TONO ROAD	TONO ROAD TO RIVER MILE 9	RIVER MILE 9 TO DIVERSION	DIVERSION TO BUCODA GAGE	BUCODA GAGE TO HANAFORD CK	HANAFORD CK TO CENTRALIA GAGE	CENTRALIA GAGE TO COFFEE CK	COFFEE CK TO MOUTH
	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL	DAM REMOVAL
January	766 (461 - 1118)	909 (534 - 1339)	1042 (596 - 1549)	1094 (615 - 1659)	1114 (622 - 1702)	1113 (622 - 1700)	1111 (622 - 1696)	1489 (770 - 2481)	1488 (770 - 2481)	1503 (776 - 2514)
February	527 (295 - 875)	622 (295 - 1053)	712 (295 - 1223)	759 (287 - 1312)	778 (279 - 1346)	777 (275 - 1345)	776 (273 - 1343)	1121 (374 - 1978)	1120 (374 - 1977)	1134 (378 - 2002)
March	439 (292 - 1048)	488 (318 - 1211)	535 (342 - 1366)	560 (353 - 1446)	570 (357 - 1476)	569 (356 - 1474)	569 (355 - 1468)	784 (443 - 2065)	784 (443 - 2063)	794 (446 - 2085)
April	470 (197 - 715)	541 (213 - 832)	599 (230 - 943)	630 (238 - 1003)	642 (241 - 1029)	642 (241 - 1030)	642 (242 - 1035)	869 (308 - 1463)	869 (308 - 1465)	878 (311 - 1484)
May	127 (58 - 257)	140 (65 - 301)	153 (72 - 344)	160 (74 - 364)	162 (74 - 371)	161 (74 - 371)	161 (73 - 373)	214 (92 - 491)	214 (91 - 491)	216 (92 - 497)
June	65 (38 - 188)	68 (42 - 194)	73 (46 - 201)	74 (47 - 205)	75 (47 - 206)	74 (46 - 206)	74 (46 - 205)	94 (58 - 234)	94 (58 - 234)	95 (58 - 235)
July	36 (23 - 64)	38 (21 - 68)	40 (21 - 73)	42 (20 - 75)	42 (19 - 75)	41 (19 - 75)	41 (18 - 75)	55 (19 - 103)	54 (18 - 103)	55 (18 - 104)
August	26 (18 - 34)	27 (17 - 36)	30 (16 - 39)	31 (15 - 40)	31 (14 - 39)	31 (14 - 39)	30 (14 - 39)	42 (11 - 56)	41 (11 - 56)	42 (11 - 56)
September	24 (18 - 48)	26 (17 - 53)	30 (16 - 59)	30 (15 - 62)	30 (14 - 63)	29 (14 - 62)	29 (13 - 61)	39 (11 - 87)	39 (10 - 86)	39 (10 - 87)
October	107 (45 - 185)	105 (48 - 216)	108 (51 - 245)	110 (53 - 250)	111 (53 - 250)	110 (52 - 249)	109 (46 - 247)	135 (58 - 282)	135 (58 - 281)	136 (58 - 282)
November	625 (244 - 852)	689 (248 - 1007)	751 (254 - 1139)	783 (256 - 1194)	795 (256 - 1215)	794 (255 - 1215)	793 (254 - 1213)	1011 (275 - 1618)	1010 (274 - 1617)	1017 (275 - 1633)
December	607 (301 - 1035)	669 (343 - 1213)	752 (395 - 1382)	795 (421 - 1477)	811 (431 - 1515)	810 (429 - 1515)	808 (426 - 1514)	1110 (606 - 2219)	1109 (604 - 2219)	1121 (611 - 2247)

A.3 HEC-ResSim Model Calibration

Figure A-2 shows a comparison of simulated to observed reservoir levels and outflows for the period from 2008 to 2022. Although there were some deviations between simulated and observed data, it was determined that deviations generally occurred when actual operations differed from the rules-based operations configured in the model. This could have happened for several reasons such as maintenance activities at the dam, operational problems with the low-level outlets, or adjustments to instream flow requirements in consultation with the Washington Department of Ecology or WDFW due to drought conditions in the basin.

Figure A-2
HEC-ResSim Current Operations Simulation Results with Reservoir Elevation (top) and Reservoir Flows (bottom)



Note: Simulated values are in green and observed values are in red.

Overall, the validation against observed water levels and flows indicated that the reservoir operations model mimicked historical conditions reasonably well. Significant deviations between the simulated and observed values were investigated and generally found to be the result of actual operations at the dam deviating from the defined “rules,” most likely because of maintenance or other unique conditions. Another reason for differences was due to actual operations making different releases than the rules called for because of drought conditions. Despite the occasional deviations, the model was considered to be well enough calibrated to be used to evaluate the effects of alternative operating scenarios.

A.4 RiverFlow2D Model Details

The next step in the RiverFlow2D model development was to integrate new topographic data for the channel and floodplain. Approximately 50 new channel cross sections were surveyed by Gravity Marine LLC in December 2021. These spanned the reach between the railroad bridge just downstream of the Town of Bucoda to the mouth of the river where channel bathymetric data in the existing RiverFlow2D model were more than 20 years old. Channel cross sections immediately upstream of the railroad bridge and through Bucoda were resurveyed in 2014, and newer topo-bathymetric Light Detection and Ranging (LiDAR) data were available for the reach immediately downstream of the Skookumchuck Dam. Existing cross section data above the Town of Bucoda were adjusted as necessary to match the most recent Skookumchuck River channel alignment and better represent present channel conditions. The cross section data were interpolated to generate a continuous bathymetric surface for the Skookumchuck River channel. This bathymetric surface was merged with the most recently available LiDAR datasets covering the floodplain to form a composite terrain surface for the model. These LiDAR datasets included Grays Harbor County (2012), SWAA (2017), Thurston County (2011), and ASRP (2017) moving from downstream to upstream on the Skookumchuck River.

A.4.1 Mesh Development

Model breaklines were digitized using LiDAR topography and survey-based channel bathymetry to refine the computational mesh along key topographic features, including channel banks and thalwegs, elevated roadway and railroad prisms, terraces, and sloughs. The larger Chehalis River channel was defined by breaklines delineating the low-flow channel and along both banks, while the smaller Skookumchuck River channel was defined by breaklines along both channel banks, inset channel benches, and remnant channel meanders. The resulting mesh for both river channels was generated with node spacing to sufficiently define the channel thalweg, toe, and top of bank within the model.

Breaklines were imported into the SMS model development software and used to generate a triangular mesh of computational nodes and elements. Nominal node spacing was varied depending on proximity to channels and channel width, with the following spacing applied throughout the model:

- Main channel thalweg and toe: 20 to 40 feet
- Main channel banks, sloughs, and side-channels: 40 to 60 feet
- Tops of elevated roadways: 50 to 60 feet
- Floodplain (away from channel): 50 to 70 feet
- Bridge openings: varied, but typically 40 feet or less

The terrain surface and material land coverage were then interpolated onto the triangulated mesh. Additional regional and localized mesh refinements were subsequently made to selectively improve element resolution and nodal terrain representation along tops of elevated roadways, railroads, and levees, as well as within bridge openings and tributary channels.

A.4.2 Hydraulic Structures

Existing hydraulic structures from the basin-wide Chehalis River model within the Skookumchuck River model domain were imported into the model. These include culverts along small tributaries, bridges on the Chehalis and Skookumchuck rivers, and jersey barriers along Interstate 5, which are represented as weirs in the model. Channel cross sections for bridges over the Skookumchuck River were revised to reflect the new channel bathymetry. Additional weirs were defined in the model along levees, road and railroad embankments, and key river banks in the City of Centralia to ensure that the model accurately simulated complex hydraulic conditions in this area with a large number of buildings.

A.4.3 Materials Classes and Surface Roughness

Floodplain land cover material classes throughout the model domain were developed using National Agricultural Imagery Program (NAIP) multispectral imagery.[10] NAIP imagery is acquired biennially throughout the nation during agricultural growing seasons. The land cover classification process utilizes the four bands (red, green, blue, and near infrared) of the NAIP imagery and textural analysis to delineate the following six categories of land cover: grass, shrub, forest, pavement, water, developed areas, and buildings. The resulting soil and vegetation material types provide reasonably accurate and up-to-date material type classifications.

River and stream channels were delineated separately from the NAIP floodplain material representations to define main channel roughness. The Skookumchuck River channel was divided into three main segments covering reaches near the upstream, downstream, and mouth of the river to better represent channel roughness values in different parts of the basin and to aide in model calibration. For the larger Chehalis River channel, lines were delineated near the toe of the channel banks resulting in separate material definitions for the low-flow channel bed and the channel banks. A single material type (bank to bank) was delineated for all other tributaries

Manning's n-values (i.e., roughness coefficients) for each land use material type were initially assigned based upon aerial interpretation and engineering judgment, then refined through model calibration (see Section A.4.4 for details). Table A-3 summarizes the land cover material classes corresponding final n-values assigned to each.

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[10] https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

Table A-3
RiverFlow2D Material Definitions and Final Roughness Coefficients

LAND COVER MATERIAL CLASSES	MANNING'S N-VALUE
Grass	0.04
Shrub	0.07
Forest	0.10
Pavement/road	0.02
Water/Pond	0.04
Developed	0.20
Buildings (partial blockage)	0.50
Buildings (full blockage)	0.99
Skookumchuck channel above RM 12.7	0.03
Skookumchuck channel between RM 1.5 and 12.7	0.026
Skookumchuck channel below RM 1.5	0.014
Chehalis River channel bed	0.025
Chehalis River channel banks	0.04
All other channels and side channels	0.04

A.4.4 Model Calibration

During this study, a large flood approximately equal to a 10-year event occurred on the Skookumchuck River in January 2022. In order to evaluate the accuracy of the RiverFlow2D model and refine the model calibration, WSE collected high water mark (HWM) information for the January 2022 flood and recalibrated the hydraulic model. Approximately 30 HWMs were identified in the field between 2nd Avenue in the Town of Bucoda and Harrison Avenue in Centralia. Approximate elevations for these HWMs were determined by comparisons with available LiDAR data and measurements made in the field at the time the marks were set (e.g., measure downs from bridge decks or measure ups on fences and buildings). Hydrologic data for simulating the January 2022 event in the RiverFlow2D model were obtained from the analysis described in previous sections. Inputs were included at key tributaries throughout the study reach. Simulated water levels were compared to observations, and differences between observed and simulated water levels were investigated. Modifications and refinements were made to the model to improve the calibration, including the following:

- Adjusting the inflows from Hanaford Creek: Hanaford Creek inflows were run through a level pool routing routine (previously described) before being input to the hydraulic model to reflect channel and floodplain storage. The level pool routing accounts for floodplain storage that exists upstream of the RiverFlow2D model boundary.
- Model mesh refinement to better account for levees or other hydraulic controls: There are numerous topographic features along the river, such as levees, natural high ground, and elevated road and railroad fills, that restrict or redirect flood flows. These features are typically long and narrow and are often not fully captured by the nominal model mesh spacing that is usually wider than the topographic features. This can result in flow

erroneously leaking through these topographic features during model simulations. Initial calibration runs showed flow leaking through levees and elevated fills in several places where the model mesh was not dense enough to fully capture these. Additional breaklines were added to the model as weirs to densify the mesh and better reflect the hydraulic effects of the topography. The refined model greatly improved the calibration, especially through the City of Centralia where multiple of these topographic features exist.

- Adjustment of the channel under the Harrison Avenue Bridge: Bathymetric data for the Skookumchuck River channel were developed by interpolating between the surveyed cross sections. Under the Harrison Avenue bridge, however, the survey and resulting interpolated channel appeared to create a significant constriction relative to the previous channel configuration and surround terrain outside the channel. Initial calibration runs showed this constriction reduced the capacity through the bridge and cause more flooding upstream of the bridge than the HWM observations indicated. The channel through this reach was therefore refined using a combination of the 2022 survey, earlier cross section data, and a review of additional aerial photography and LiDAR data to better represent current channel conditions. The refined channel created a more open channel and resulted in a much better match to observed conditions, particularly for the HWMs near Harrison Avenue.
- Changes to roughness coefficients: The hydraulic roughness coefficients assigned to different land cover types is a key model calibration parameter. Once the topographic and flow adjustments described above were made, final calibration was achieved through adjusting the modeled roughness values. The HWMs and final modeled floodplain for the January 2022 calibration event is shown in Figure A-3, and final roughness values are included in Table A-4.

Figure A-3
High Water Mark Calibration Data and Modeled Inundation Area for January 2022 Flood Event

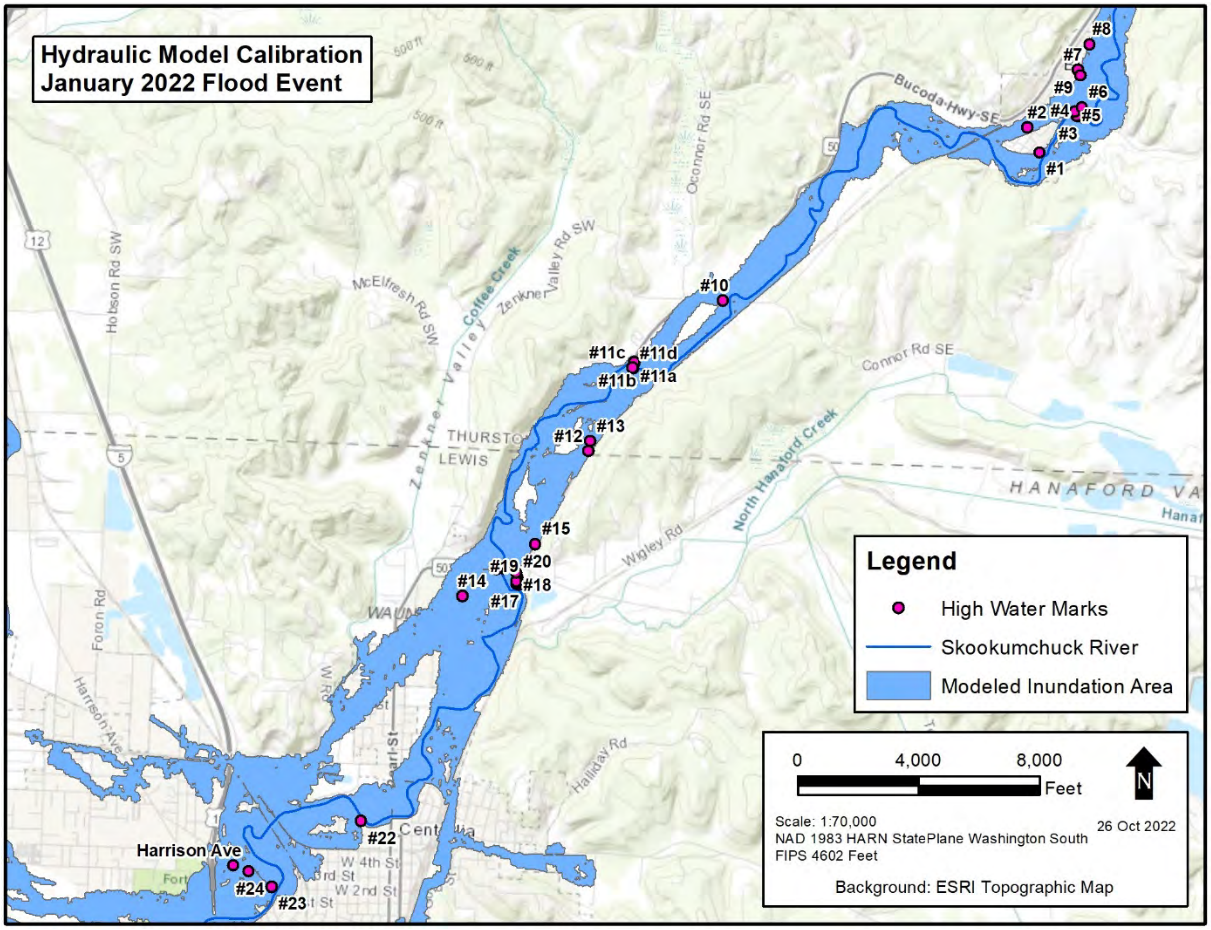

Table A-4
RiverFlow2D Model Calibration Results

HIGH WATER MARK	DESCRIPTION	HWM ELEVATION (FEET)	SIMULATED ELEVATION (FEET)	DIFFERENCE (FEET)
#1	Bucoda near river channel	244.8	245.6	0.8
#2	Bucoda in town (downstream)	244.7	244.7	-0.1
#3	Bucoda near Tono Road bridge	248.1	250.1	2.0
#4	Bucoda near Tono Road bridge	247.5	249.8	2.4
#5	Bucoda near Tono Road bridge	248.6	250.1	1.6
#6	Bucoda near Tono Road bridge	249.9	250.9	1.1
#7	Bucoda in town (upstream)	252.5	252.3	-0.1
#8	Bucoda in town (upstream)	253.2	253.0	-0.2
#9	Bucoda in town (upstream)	252.0	251.9	-0.2
#10	Near Connor Road SE bridge	226.4	225.8	-0.6
#11a	SR 507 bridge near Bucoda gage	217.2	216.7	-0.5

HIGH WATER MARK	DESCRIPTION	HWM ELEVATION (FEET)	SIMULATED ELEVATION (FEET)	DIFFERENCE (FEET)
#11b	SR 507 bridge near Bucoda gage	218.2	217.0	-1.2
#11c	SR 507 bridge near Bucoda gage	217.3	216.6	-0.7
#11d	SR 507 bridge near Bucoda gage	219.3	217.8	-1.5
#12	SR 507 near gravel pits	209.6	210.1	0.4
#13	SR 507 near gravel pits	209.8	210.3	0.5
#14	Howard Ave in Centralia	201.8	202.5	0.7
#15	SR 507 near gravel pits	209.6	208.3	-1.3
#16	Schaefer County Park	205.7	206.0	0.3
#17	Schaefer County Park	205.2	205.8	0.6
#18	Schaefer County Park	205.1	205.8	0.7
#19	Schaefer County Park	205.3	205.9	0.6
#20	Schaefer County Park	205.3	206.0	0.7
#21a	SR 507/Downing Road bridge	206.7	206.8	0.1
#21b	SR 507/Downing Road bridge	206.3	206.0	-0.3
#21c	SR 507/Downing Road bridge	206.3	206.9	0.6
#21d	SR 507/Downing Road bridge	206.2	206.7	0.5
#22	Left bank levee d/s of Pearl Street bridge	189.3	188.8	-0.5
#23	Near Bridge Street in Centralia	178.0	178.9	0.9
#24	Near Lowe Street in Centralia	177.0	178.2	1.3
Bucoda Gage	Peak stage at USGS Bucoda gage	215.9	215.8	-0.2
Centralia Gage	Peak stage at NWS Centralia gage	190.2	189.7	-0.5
Harrison Avenue	HWM estimated from video footage	177.1	178.5	1.4
			Median Difference (ft)	0.4

A.4.5 RiverFlow2D Model Results

A comprehensive suite of RiverFlow2D model results figures is included below to provide additional context for the flood modeling (Figures A-4 through A-22). These figures include Current Operations inundation area for all quantiles (i.e., 2-, 10-, 20-, and 100-year flood events), inundation area from all four alternatives for each quantile, Current Operations 100-year flood depth, and changes in 100-year flood depths from Current Operations to each of the three other alternatives. The first set of figures covers existing climate conditions, and the second set of figures covers future late-century climate conditions. Additional model data and results can be available upon request.

Figure A-4
Inundation Extents for the Existing Climate Condition 2-, 10-, 20-, and 100-Year Flood Events for Current Operations

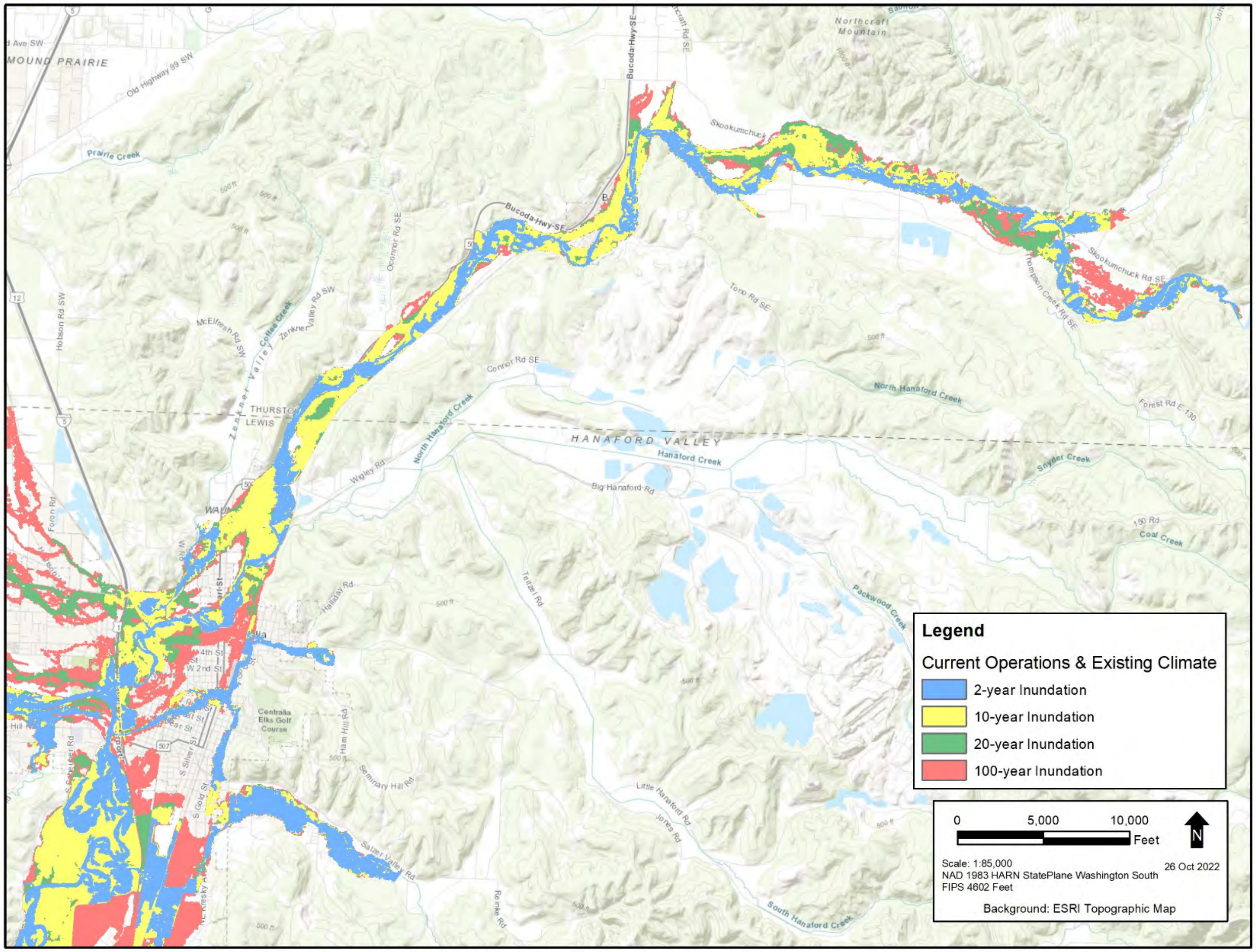

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Figure A-5
Modeled Existing Climate 2-Year Flood Event Inundation Extent for Four Operating Alternatives

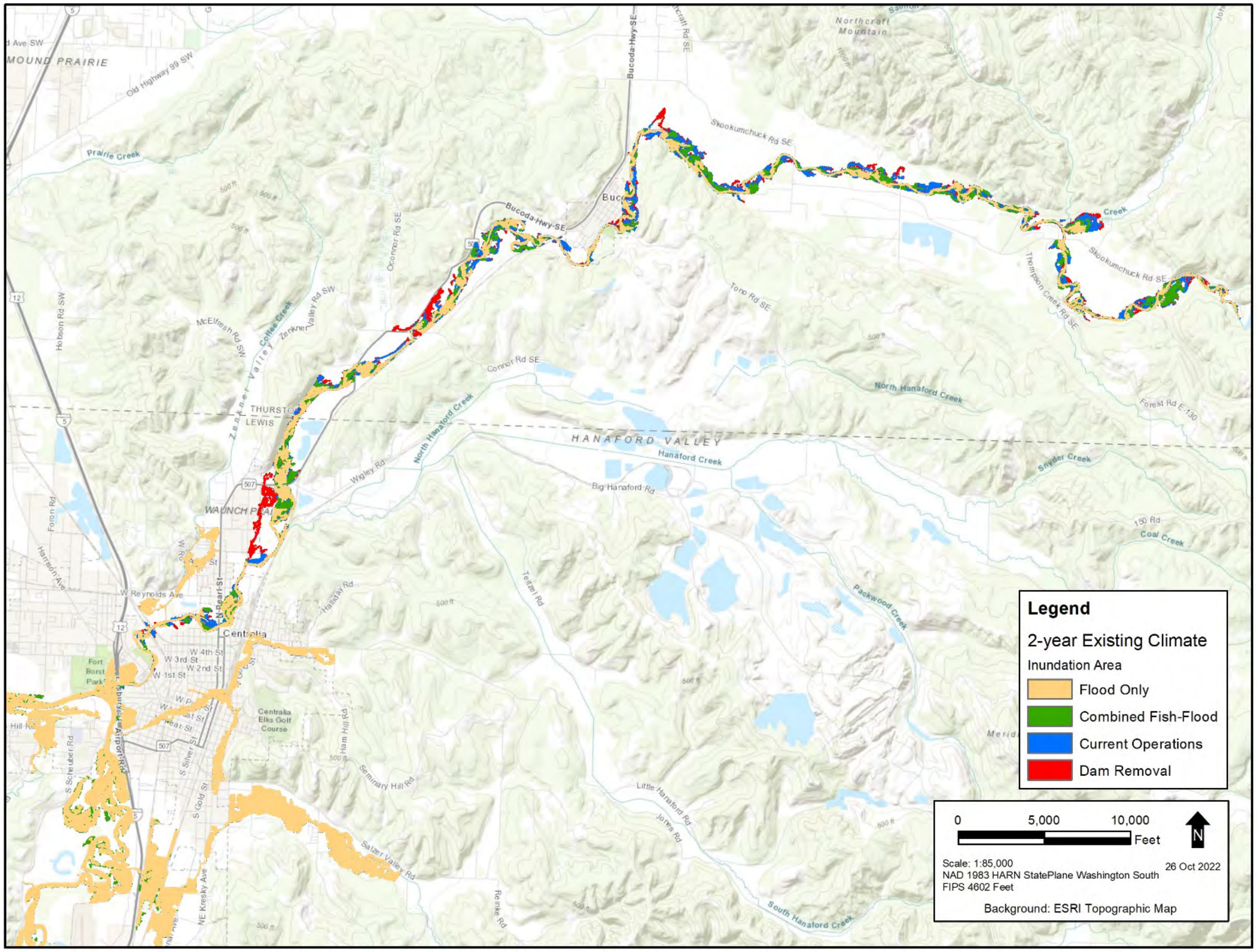


Figure A-6
Modeled Existing Climate 10-Year Flood Event Inundation Extent for Four Operating Alternatives

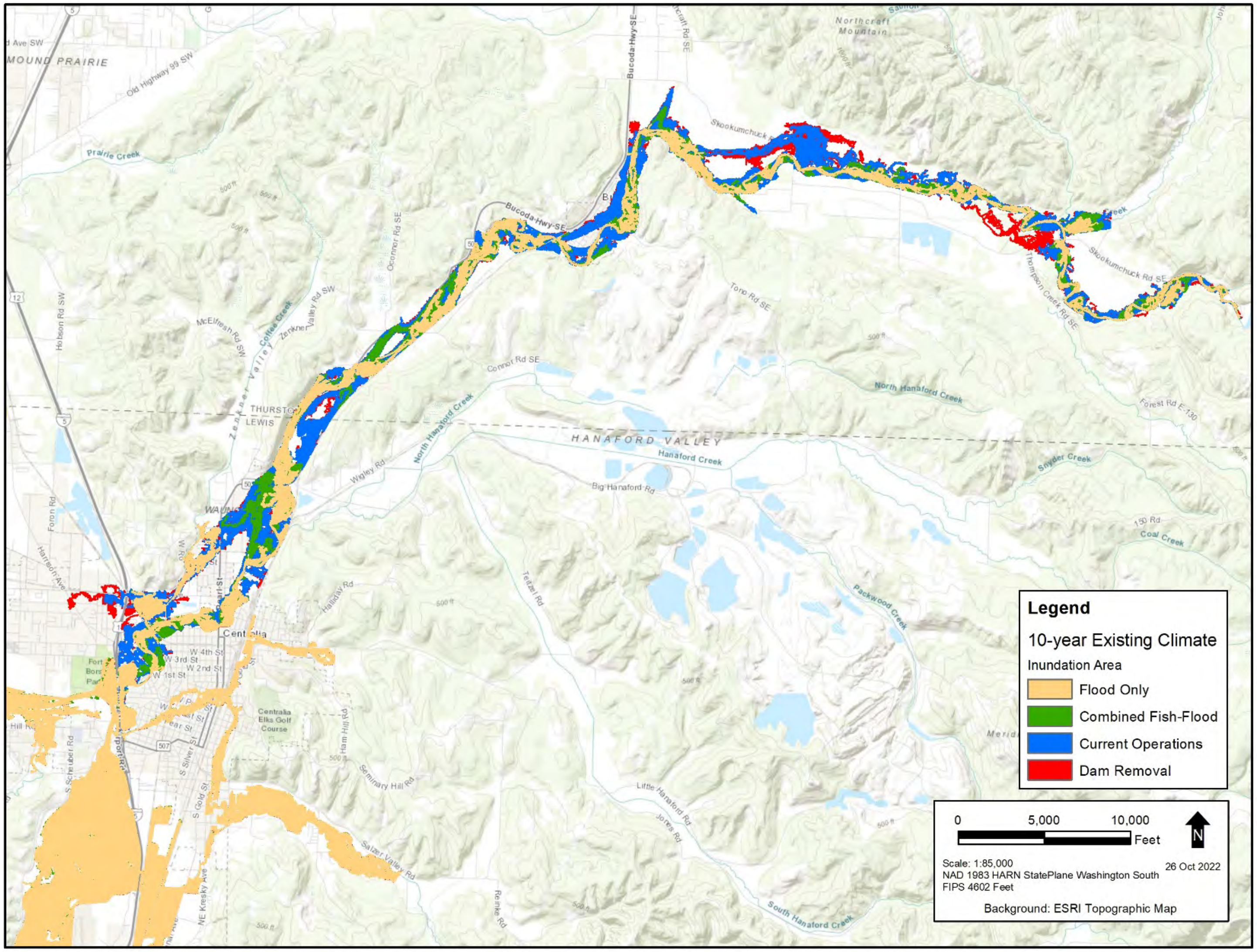


Figure A-7
Modeled Existing Climate 20-Year Flood Event Inundation Extent for Four Operating Alternatives

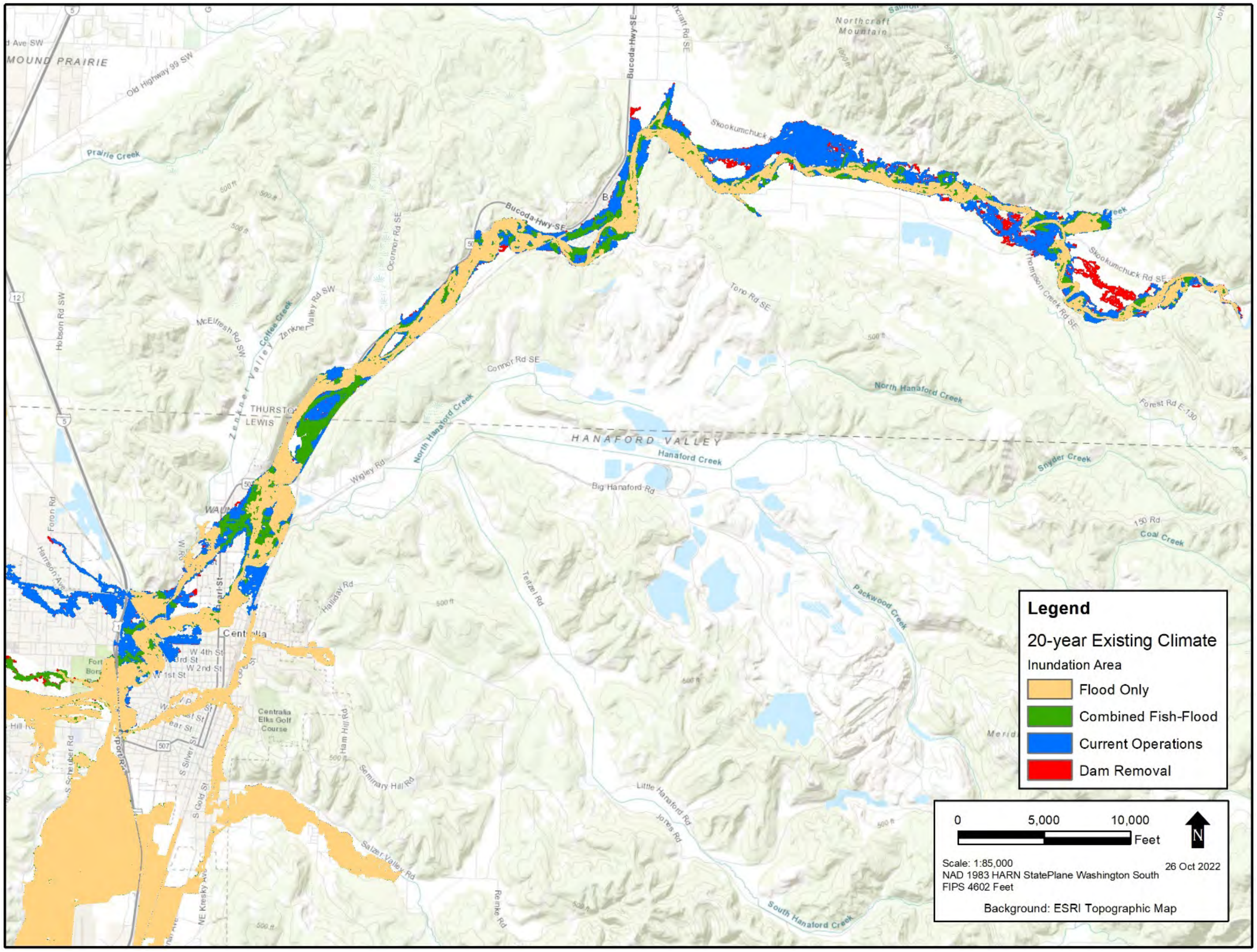


Figure A-8
Modeled Existing Climate 100-Year Flood Event Inundation Extent for Four Operating Alternatives

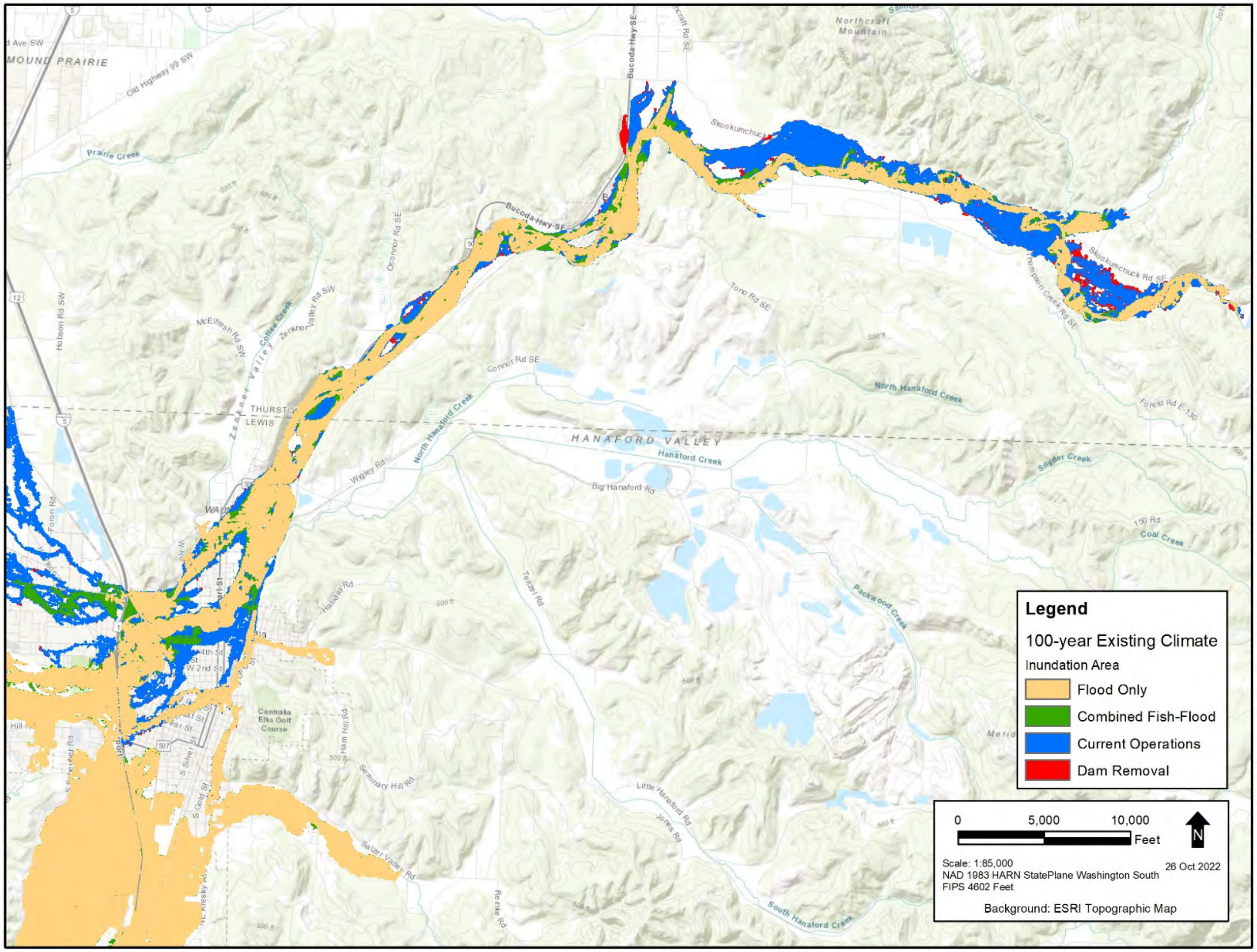


Figure A-9
Modeled Existing Climate Condition 100-Year Flood Depth for Current Operations and Fish Only Alternatives

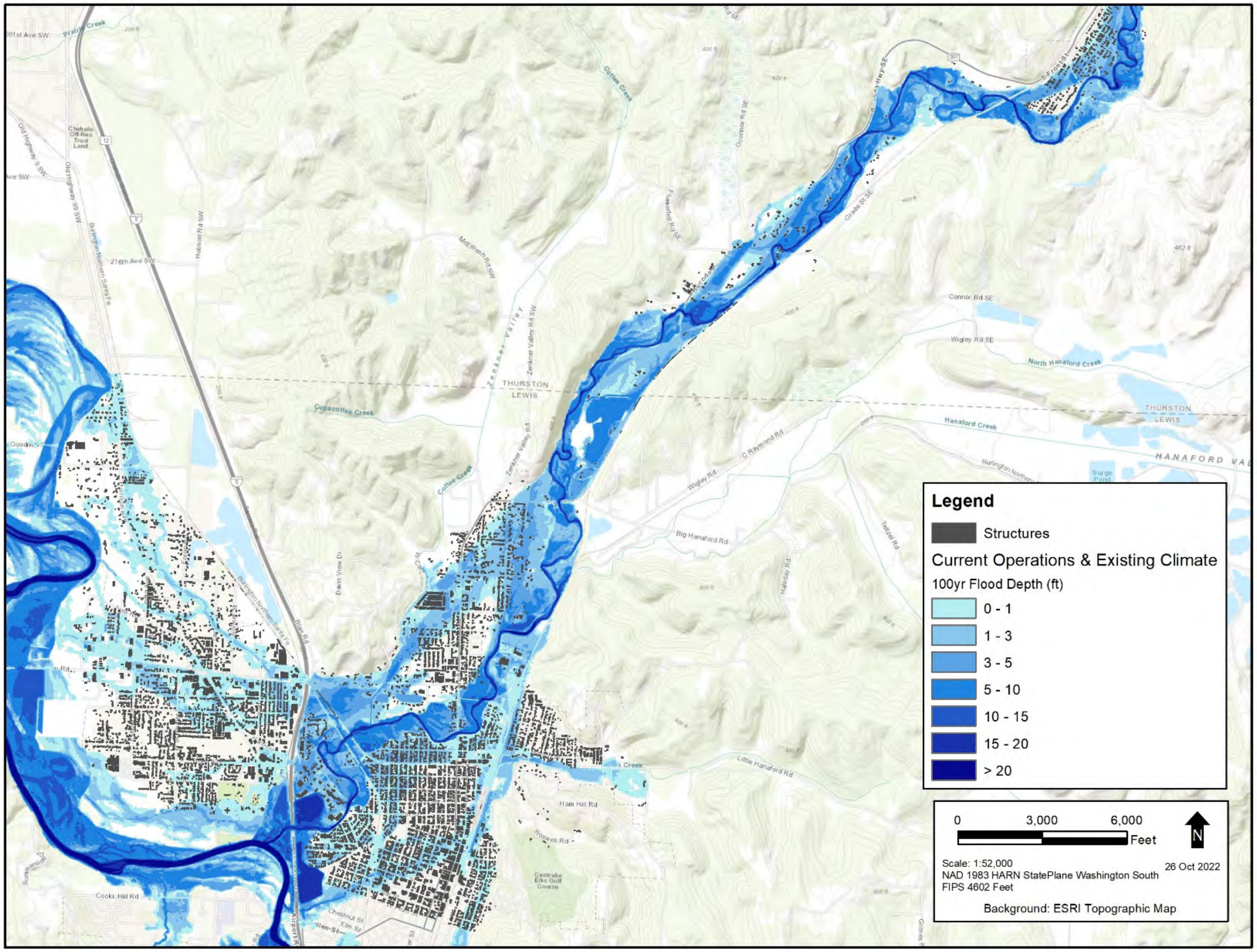


Figure A-10
Modeled Change in 100-Year Flood Depth from Current Operations to the Flood Only Alternative

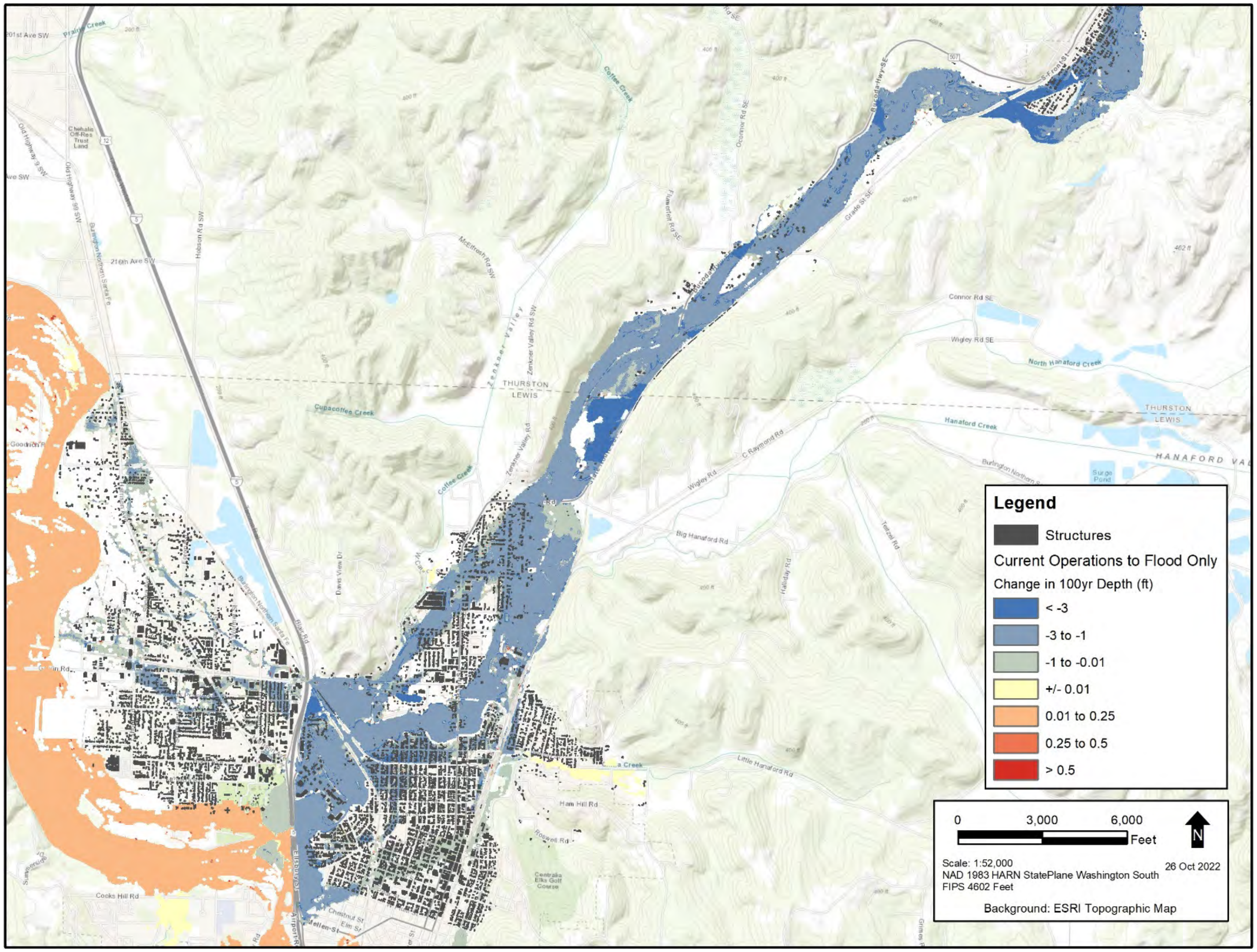


Figure A-11
Modeled Change in 100-Year Flood Depth from Current Operations to the Combined Fish-Flood Alternative

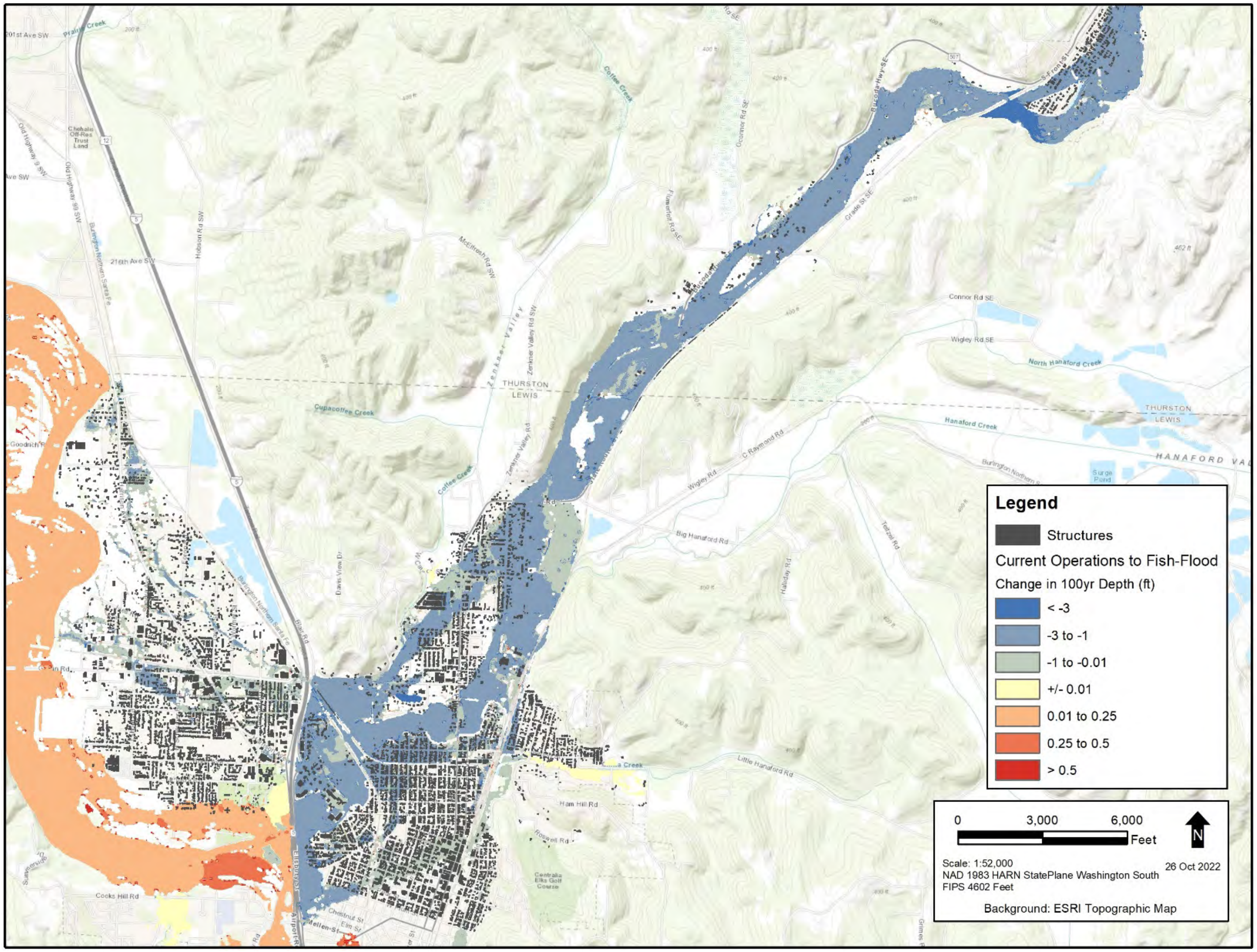


Figure A-12
Modeled Change in 100-Year Flood Depth from Current Operations to the Dam Removal Alternative

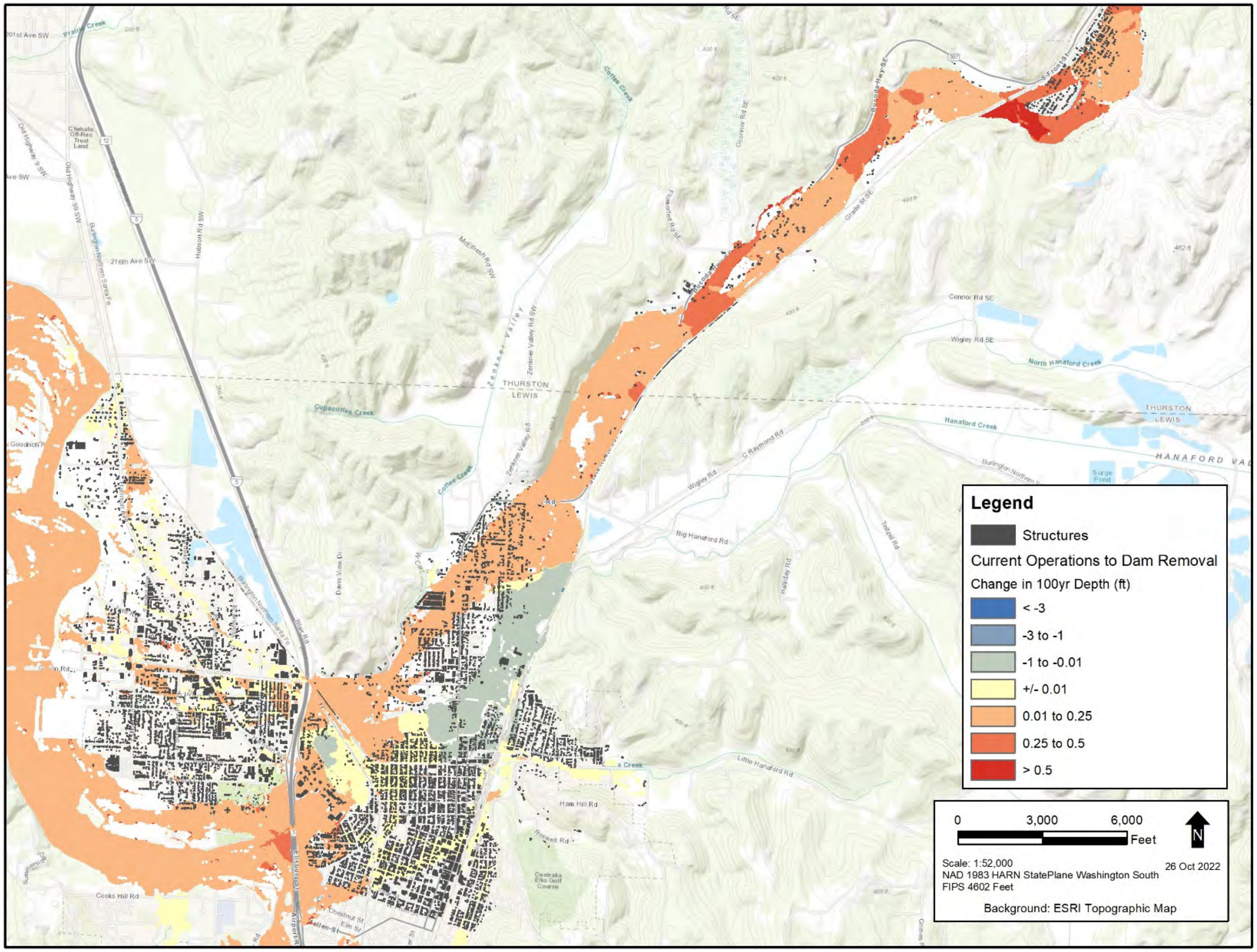


Figure A-13
Inundation Extents for Current Operations Late-Century Climate Condition 2-, 10-, 20-, and 100-Year Flood Events

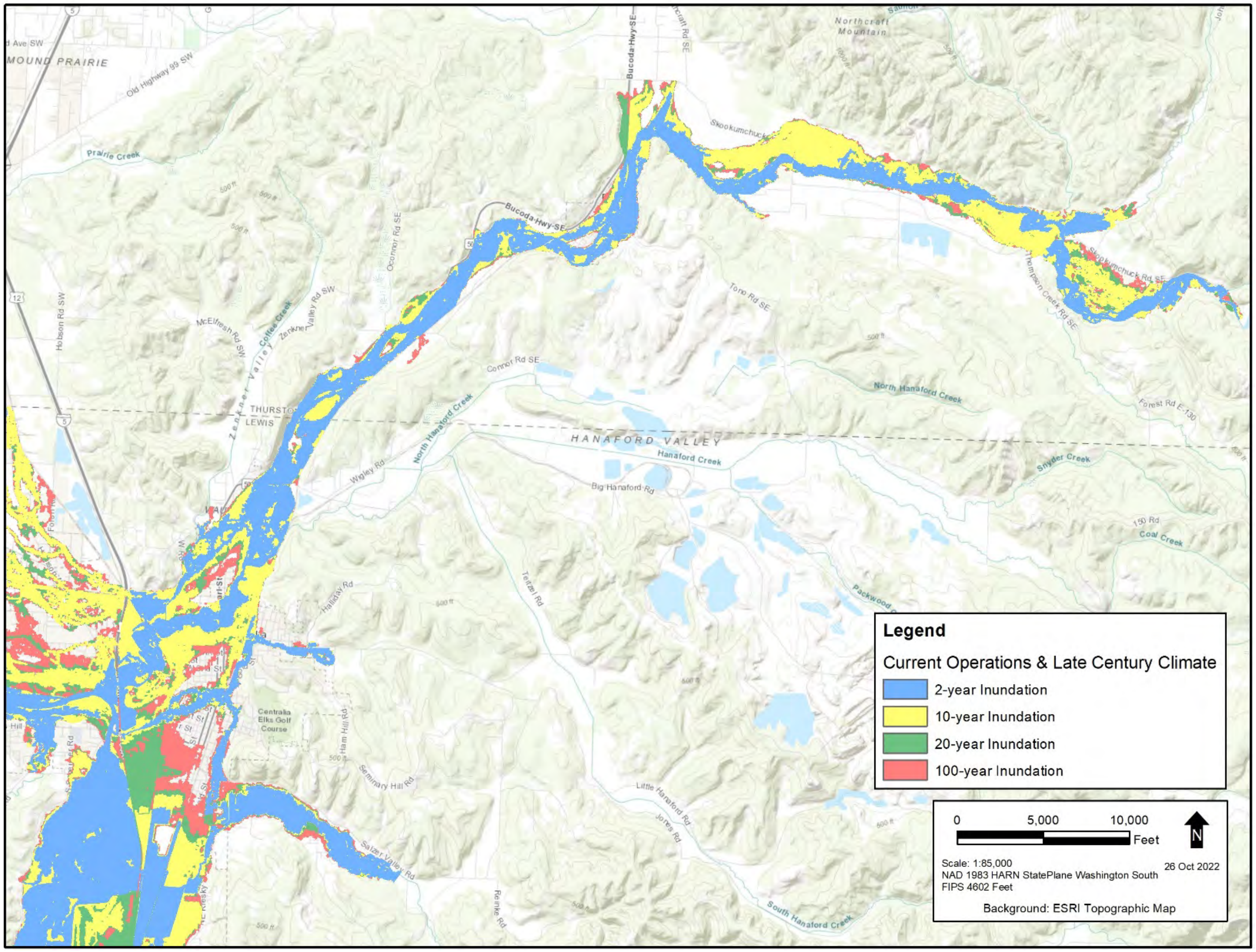


Figure A-14
Modeled Change in Current Operations 100-Year Flood Depth from Existing to Late-Century Climate

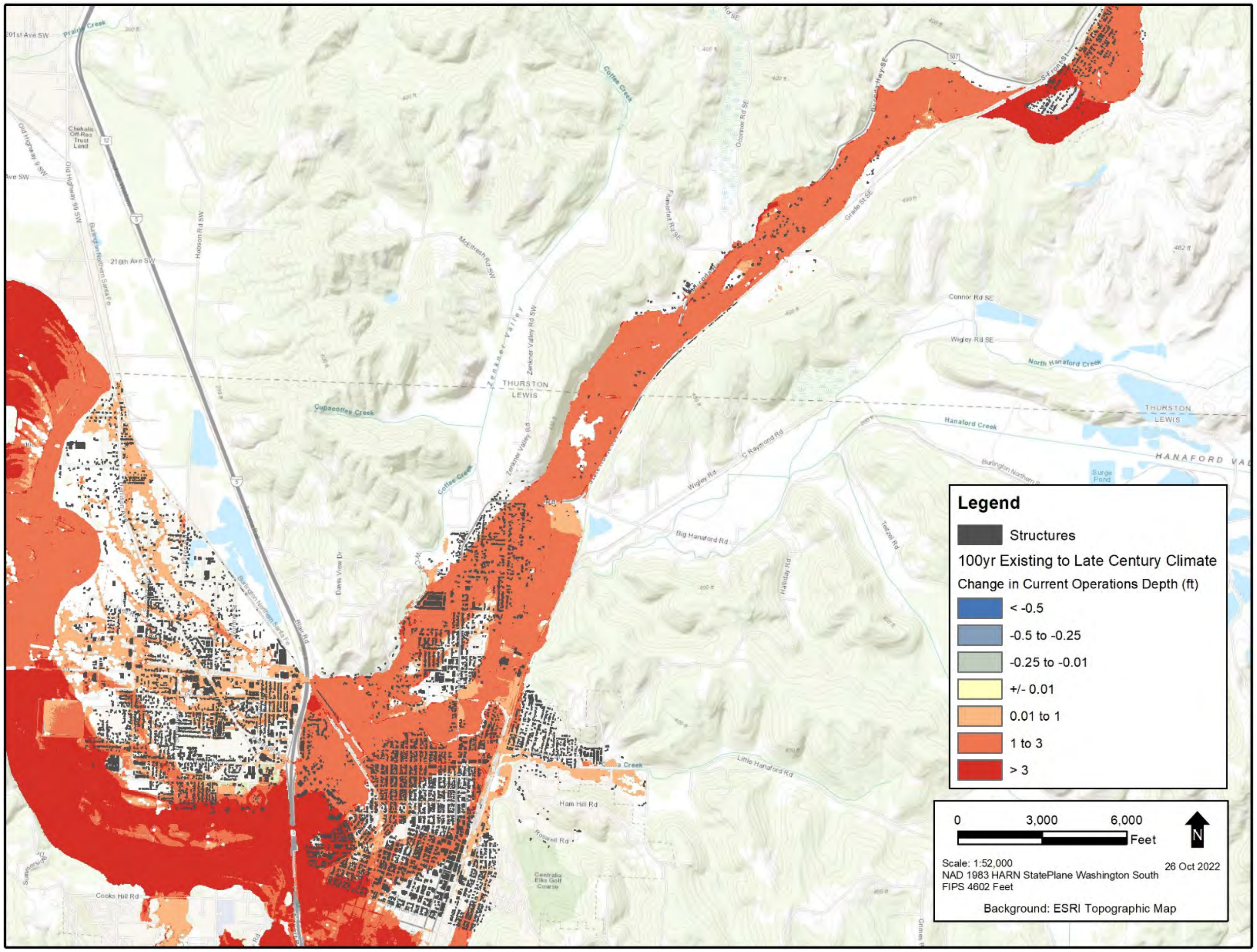


Figure A-15
Modeled Late-Century Climate 2-Year Flood Event Inundation Extents for Four Operating Alternatives

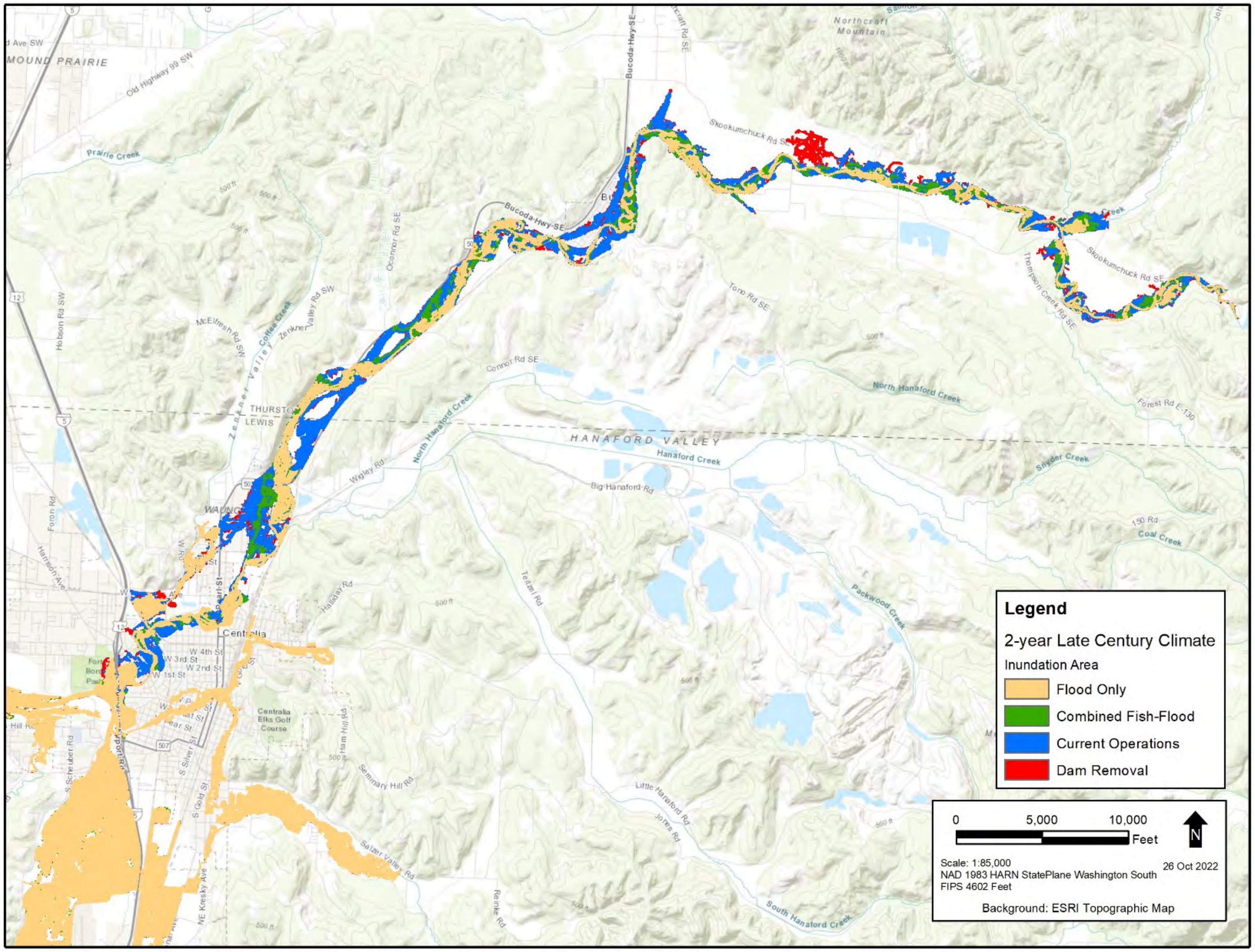


Figure A-16
Modeled Late-Century Climate 10-Year Flood Event Inundation Extents for Four Operating Alternatives

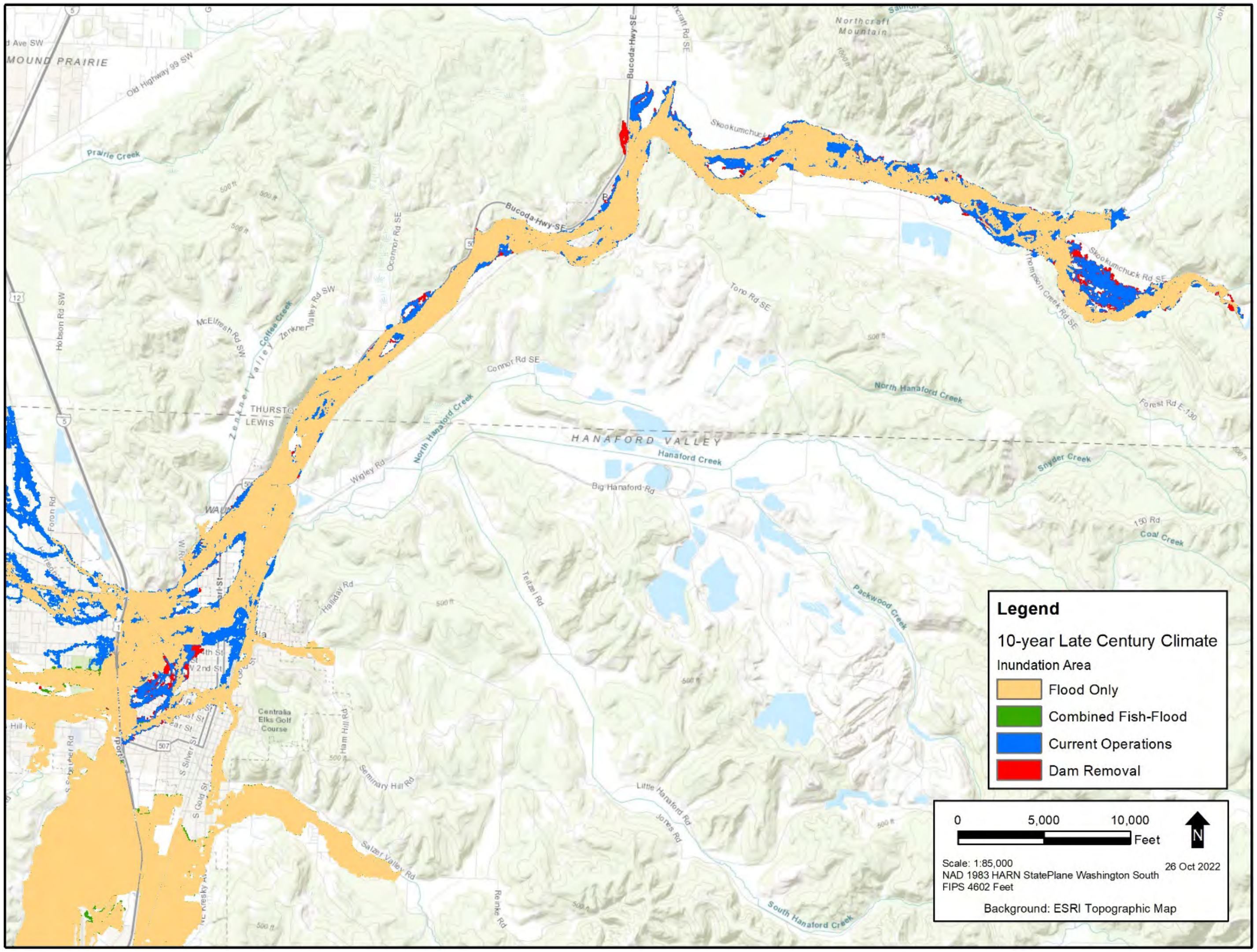


Figure A-17
Modeled Late-Century Climate 20-Year Flood Event Inundation Extents for Four Operating Alternatives

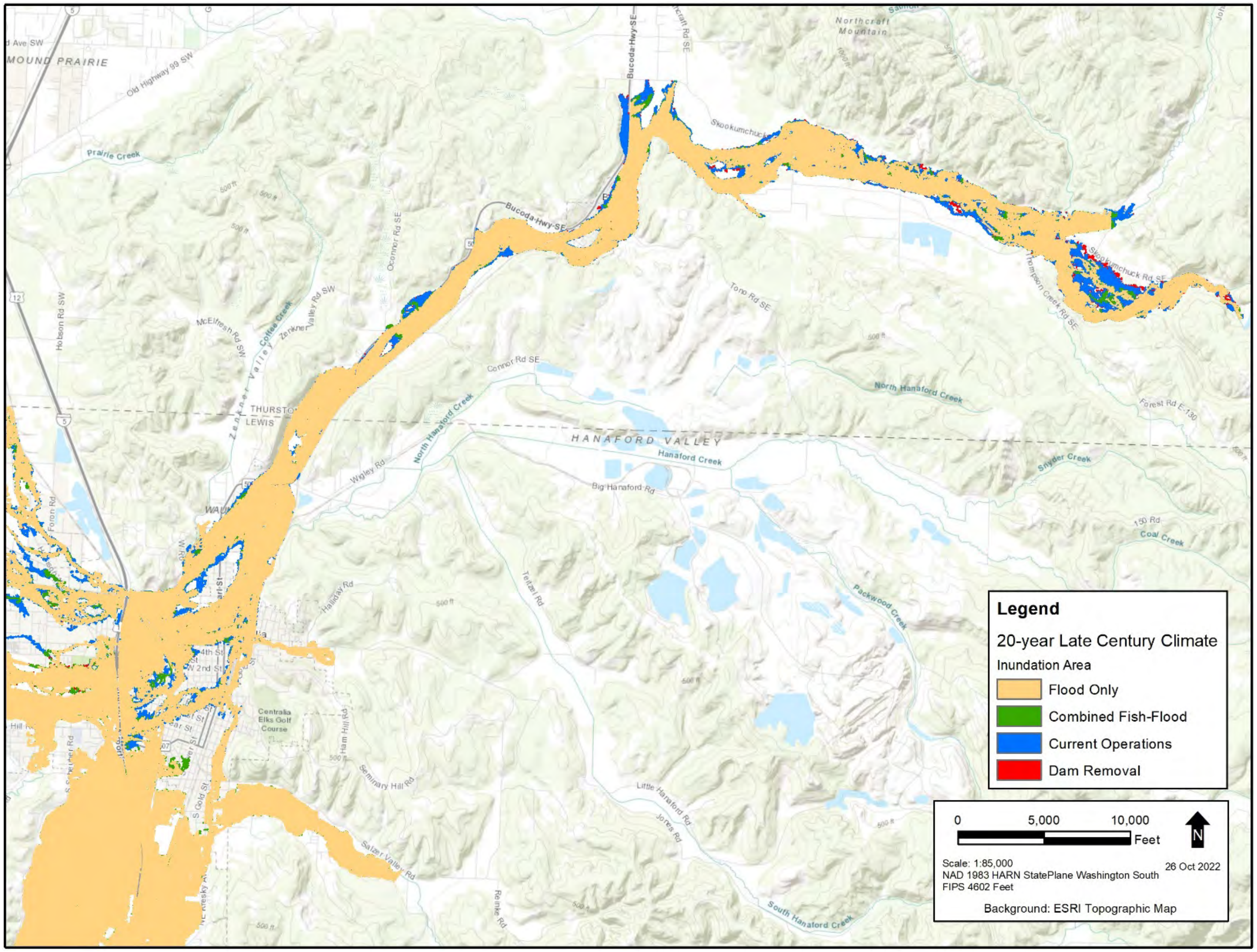


Figure A-18
Modeled Late-Century Climate 100-Year Flood Event Inundation Extents for Four Operating Alternatives

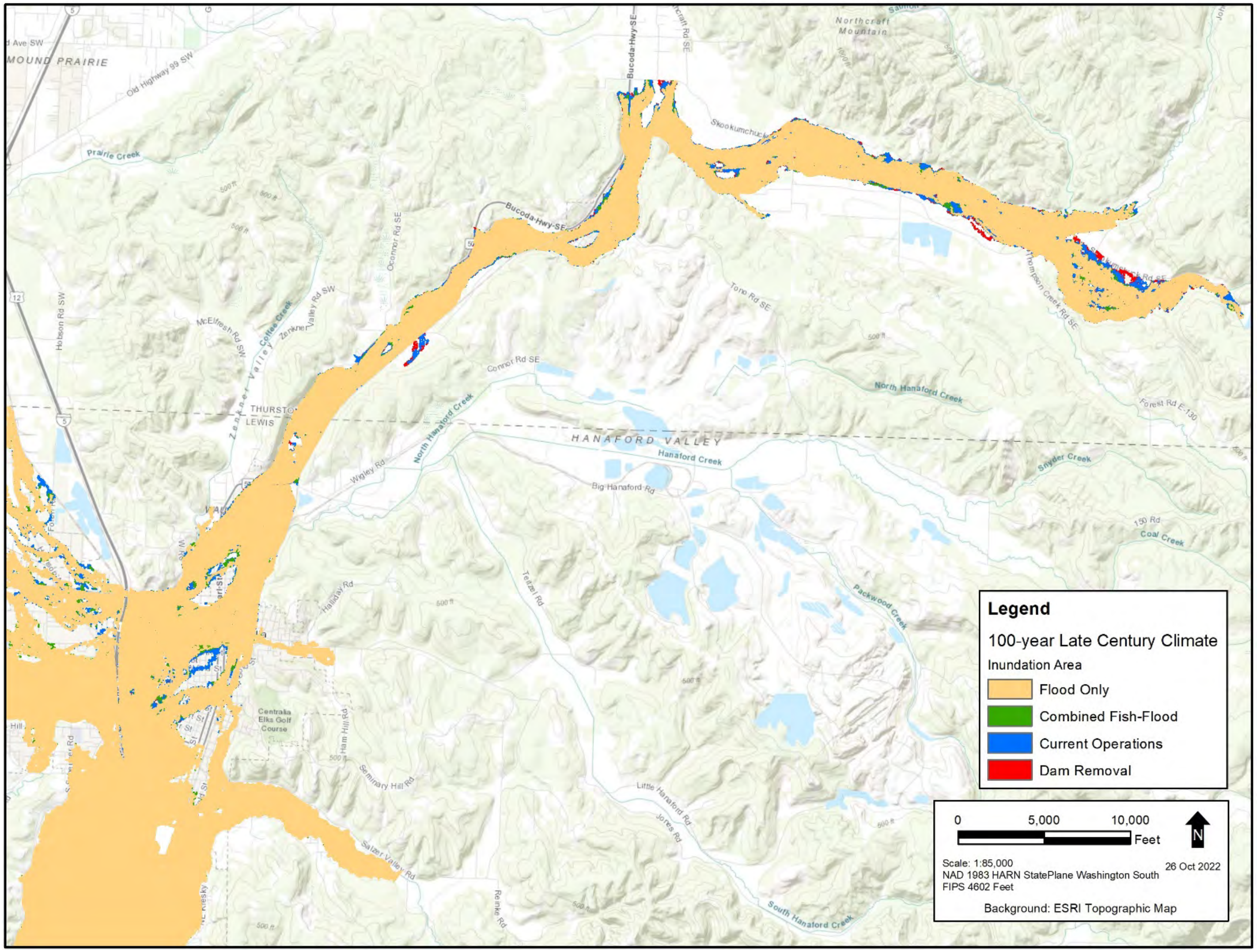


Figure A-19
Modeled 100-Year Late-Century Flood Depth for Current Operations and Fish Only Alternatives

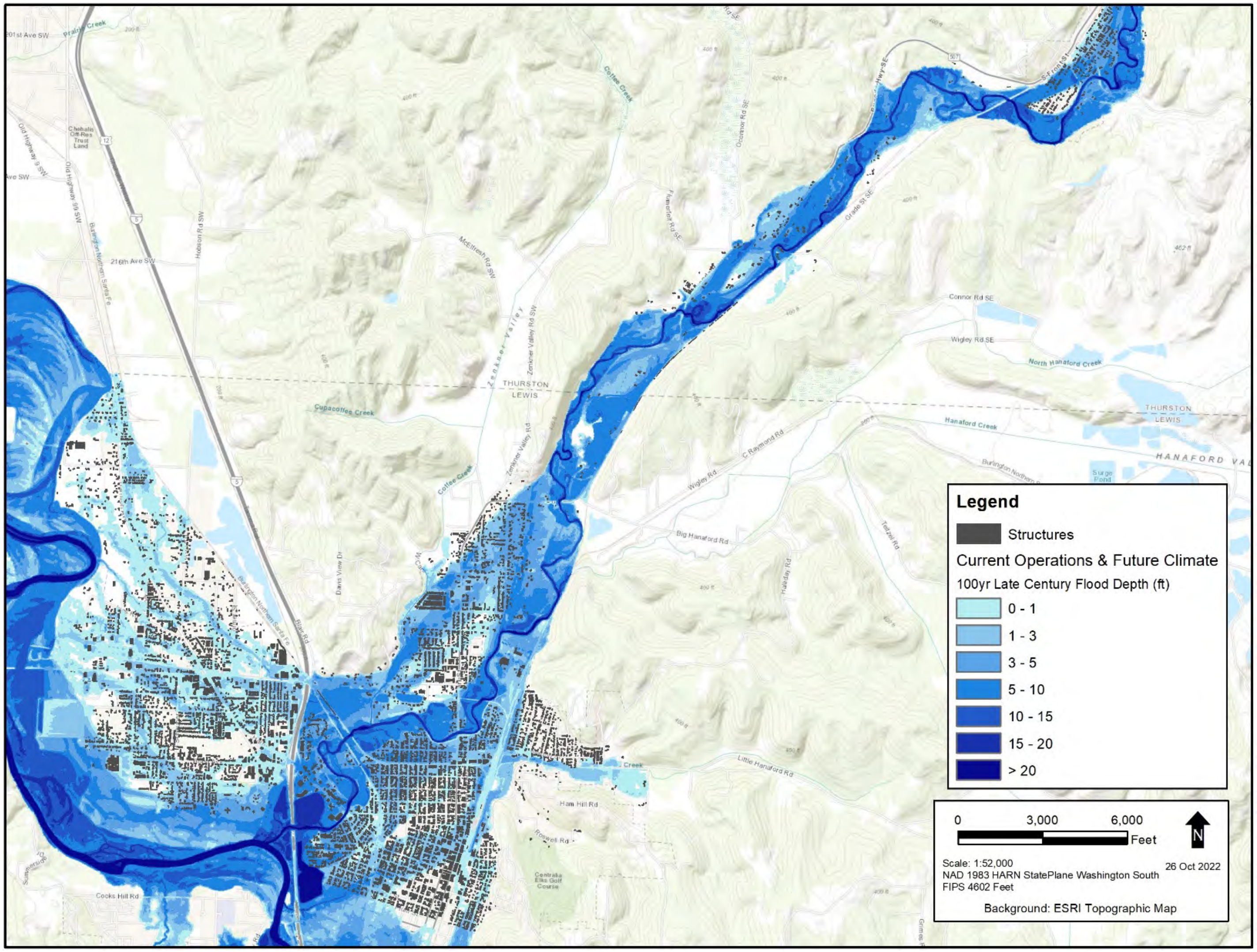


Figure A-20
Modeled Change in 100-Year Late-Century Flood Depth from Current Operations to the Flood Only Alternative

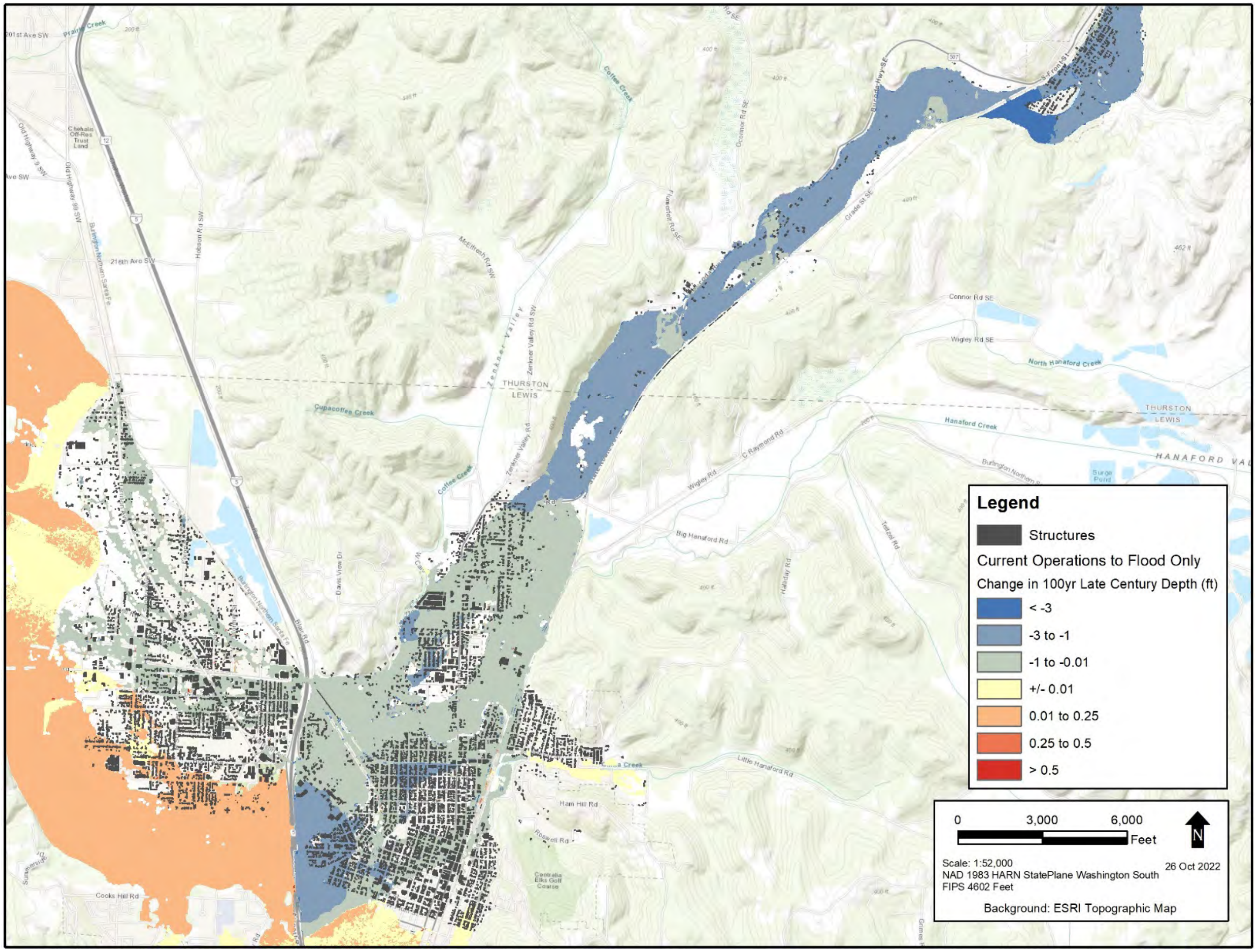


Figure A-21
Modeled Change in 100-Year Late-Century Flood Depth from Current Operations to the Fish-Flood Alternative

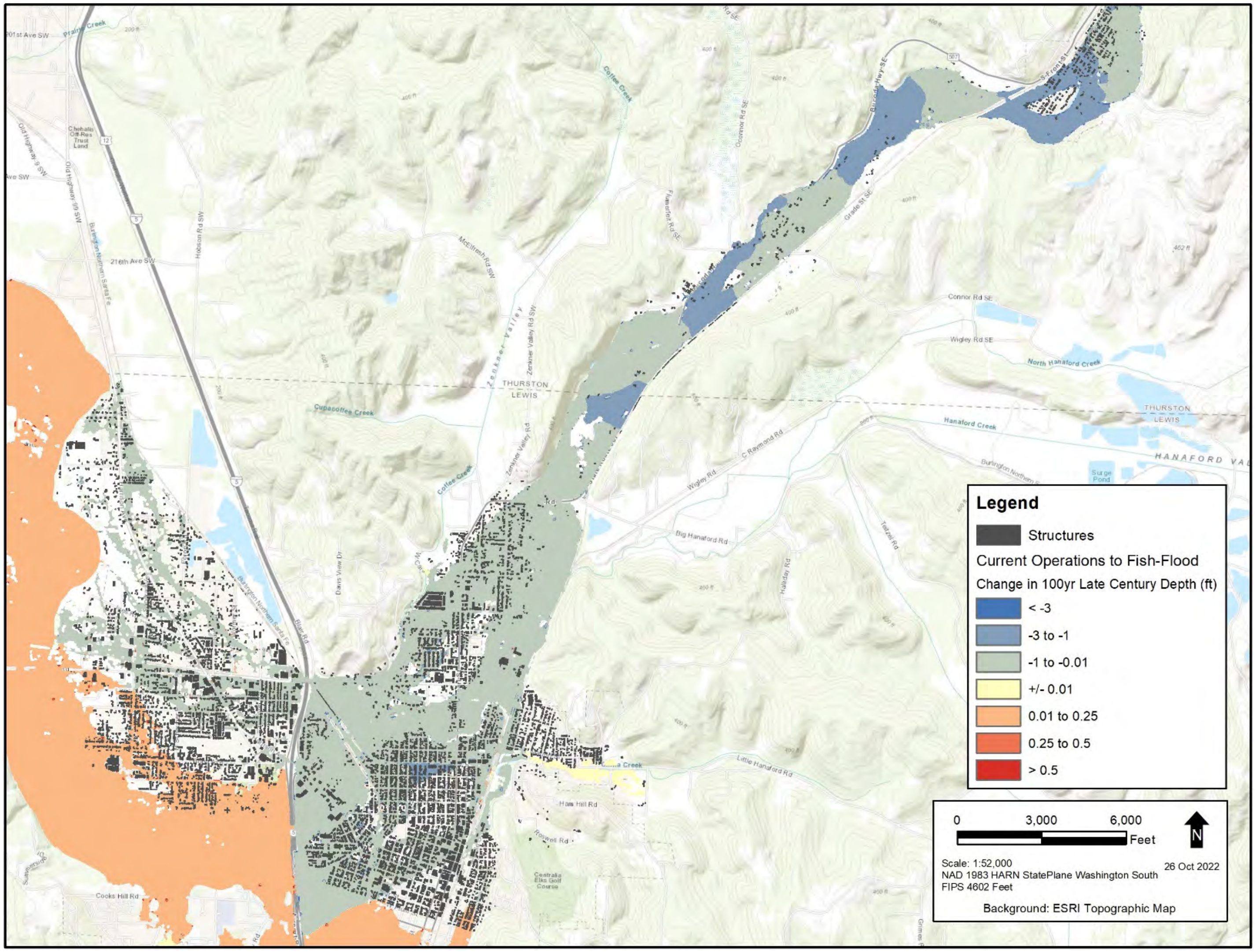
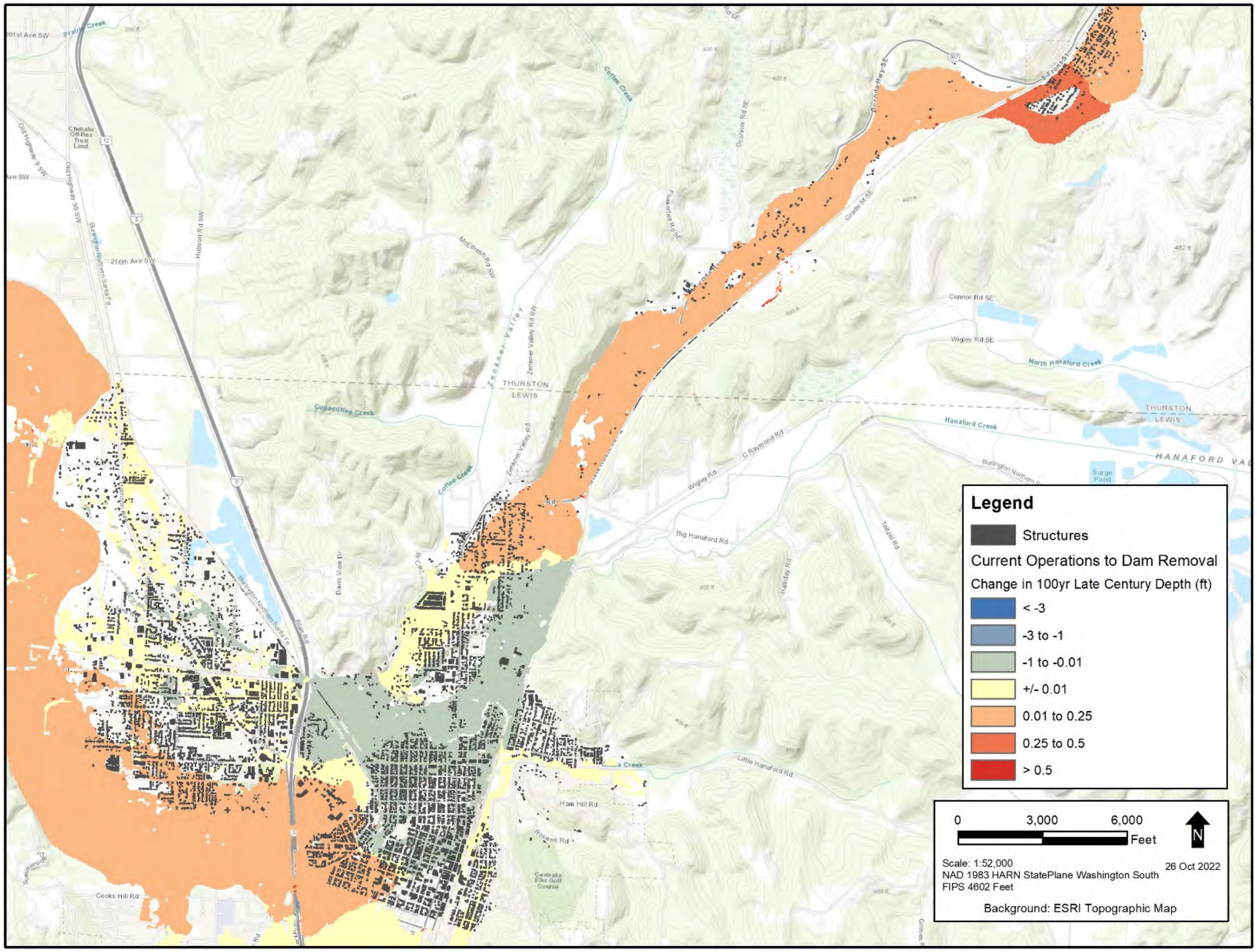


Figure A-22
Modeled Change in 100-Year Late-Century Flood Depth from Current Operations to the Dam Removal Alternative



A.5 CFD Modeling

A.5.1 Model Geometry

A simple 2D HEC-RAS model was used to evaluate the approach conditions to the fish sluice and to inform the boundary conditions of the CFD model. The mesh extended approximately 1,000 feet upstream into the reservoir from the dam. The majority of the reservoir was modeled with 10-foot computational cells, with the cell size gradually refining in the approach the sluice. The area directly in front of the fish sluice used 0.5-foot mesh cells. The fish sluice was represented as a simple gate through a hydraulic structure into a downstream storage area. This allowed for a specified 65 cfs outflow through the gate. The model used a Manning's n roughness value of 0.02 for the entire reservoir.

The 2D model terrain surface used a combination of data sources. These included high-resolution drone survey in the approach to the sluice collected in 2022, 2017 LiDAR with 3-foot cells for the dam and surrounding areas, and a surface constructed using a 1959 pre-dam contour map from the USGS for reservoir bathymetry. This terrain surface was then altered to reflect potential alternatives to improve the approach for fish passage. These alterations included removing obstructions from the approach channel, removing the hummock from the dam on the north side of the approach channel, and funneling and smoothing the entire approach towards the fish sluice.

The dam was represented in the flow 3D model based on the available plan drawings. The same terrain from the 2D model was used for the approach to the sluice. The concrete structures were assigned a roughness height of 0.001 foot while the ground surface had a roughness height of 0.042 foot. The CFD model domain consisted of several nested mesh blocks. The largest mesh block extended 192 feet into the reservoir with a cell size of 1 foot. The next mesh extended 44 feet away from the sluice with a cell size of 0.5 foot. Another mesh block extended 16 feet from the sluice with a cell size of 0.25 foot. The final mesh covered the area from 4 feet in front of the sluice and all the way through the sluice using a mesh size of 0.125 foot. This mesh cell size was small enough to capture the sharp edges of the interior sluice and gate geometry. The downstream boundary condition at the sluice outlet was a free outflow.

An alternative fish sluice design was also modeled using FLOW-3D. The geometry of the dam was altered to include the designed fish sluice through the dam abutment wall. The existing sluice remained in the model, but the gate was fully shut so that flow could not pass through the existing sluice. The terrain used for the alternative fish sluice included smoothing of the approach and filling of the corner between the new and existing sluices to streamline flows through the new sluice. The model set up was the same as for the existing sluice CFD model, with the exception of the removal of the outmost 1-foot cell size mesh block. The downstream boundary condition with a reservoir elevation of 467 feet was a free outflow, whereas the downstream boundary condition for reservoir elevations 470 and 477 feet was a volume flow rate of 65 cfs, which implies a flow control downstream in the pipe.

A.5.2 Model Results

Both the 2D and 3D models of the existing and proposed conditions were modeled at reservoir elevations of 467, 470, and 477 feet, which are 3, 6, and 13 feet above the sluice inlet at 464 feet. One result of the CFD modeling was identifying that at reservoir elevation 467 feet, the sluice entrance controls flow. As such, the maximum flow at reservoir elevation 467 feet is 50 cfs with the existing sluice and 53 cfs with the alternative fish sluice design. The results of the modeling for each reservoir elevation for the 2D and 3D hydraulic models are shown in the following figures.

Figure A-23
2D Model Results and Flow Vectors for the Existing Sluice at Reservoir Elevation 467 Feet

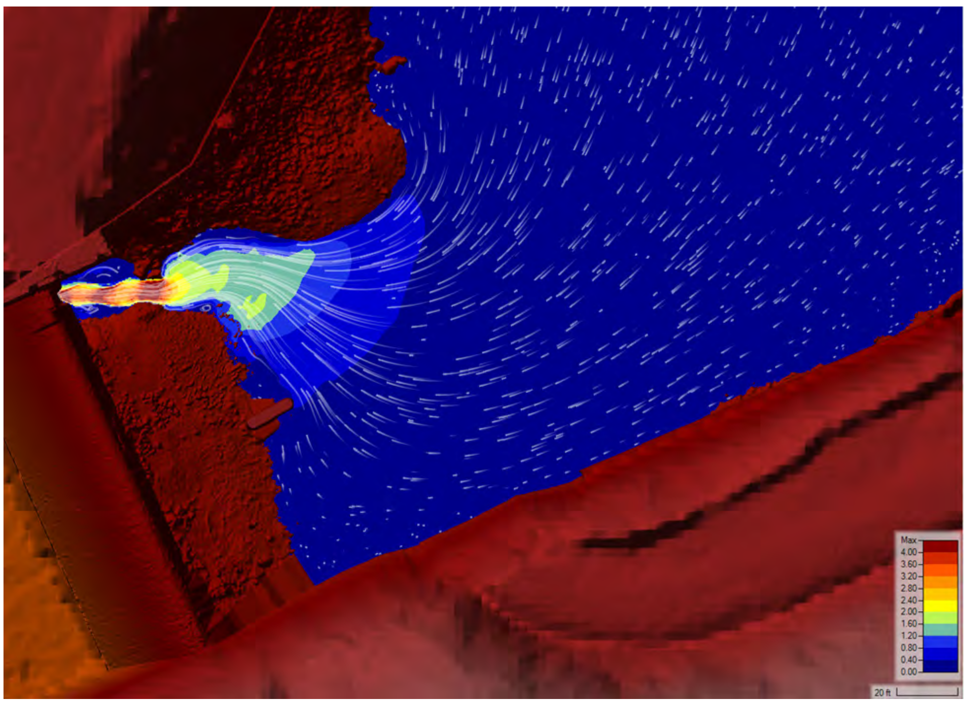
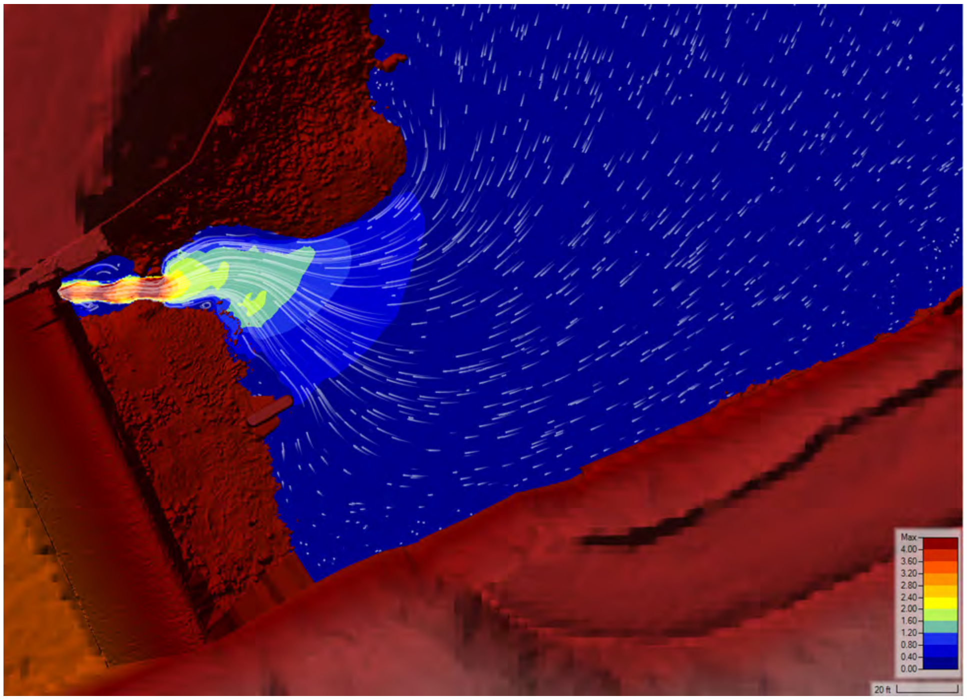
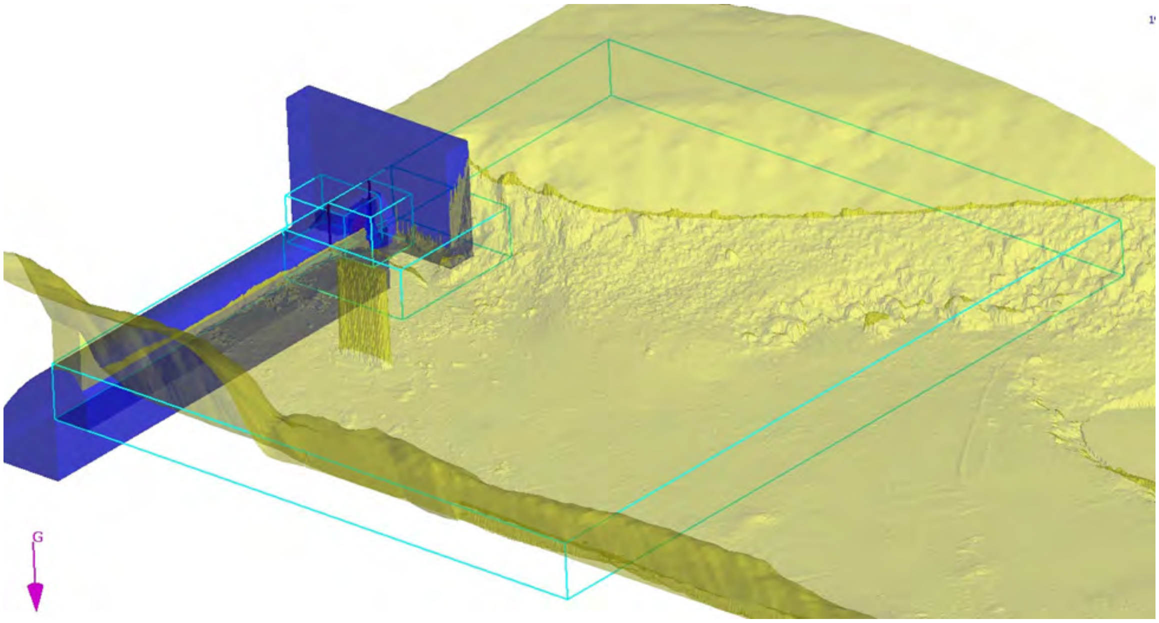


Figure A-24
2D Model Results and Flow Vectors for the Existing Sluice at Reservoir Elevation 470 Feet



The 3D model included fine details of the existing fish sluice geometry (internal geometry and gate) as well as the detailed forebay topography for both existing topography and smoothed topography as shown in Figure A-25.

Figure A-25
3D CFD Model Geometry and Computational Mesh Block Boundaries



Note: Solid blue block represents the concrete spillway structure.

Figure A-26
2D Model Results and Flow Vectors for the Existing Sluice at Reservoir Elevation 477 Feet

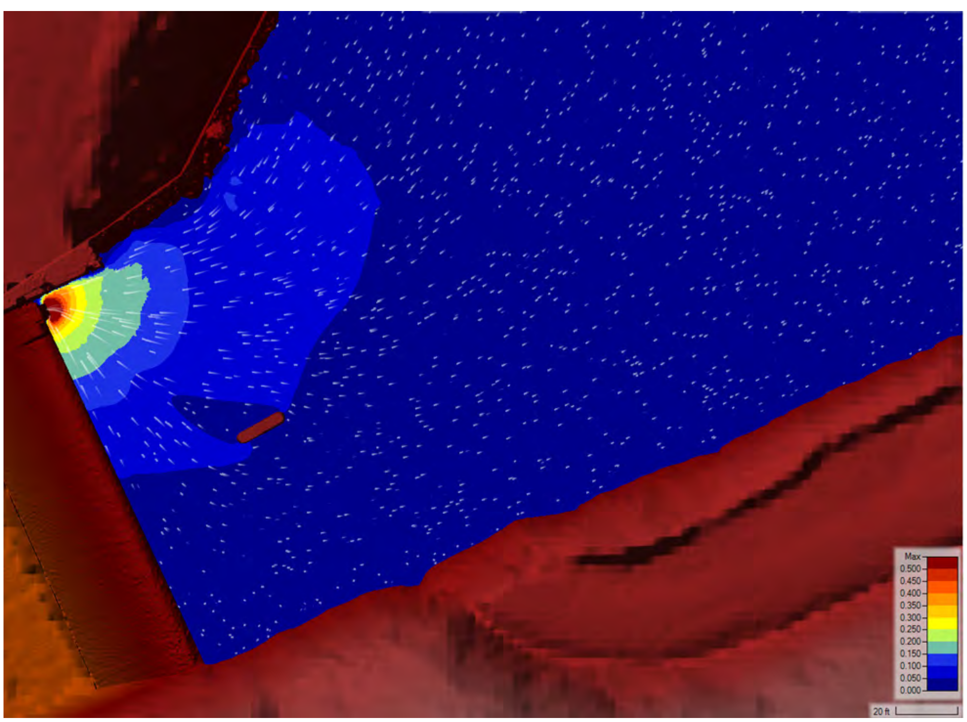


Figure A-27
Reservoir Elevation 467 Feet, Horizontal Slice at 464.5 Feet of Existing Sluice

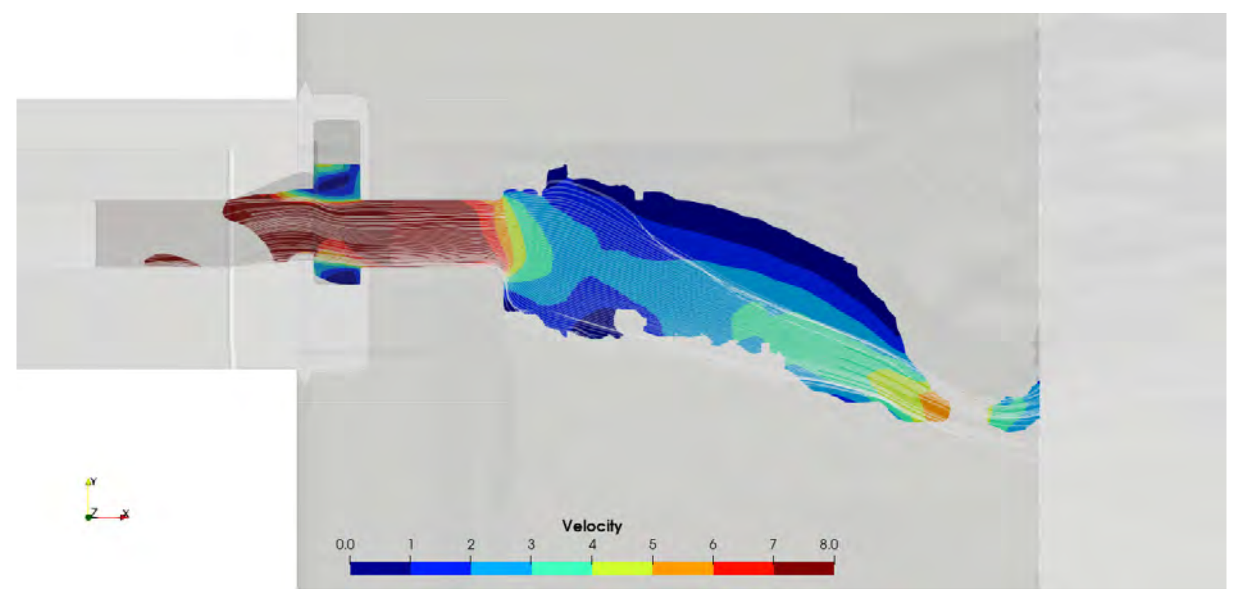


Figure A-28
Reservoir Elevation 467 Feet, Horizontal Slice at 465.5 Feet of Existing Sluice

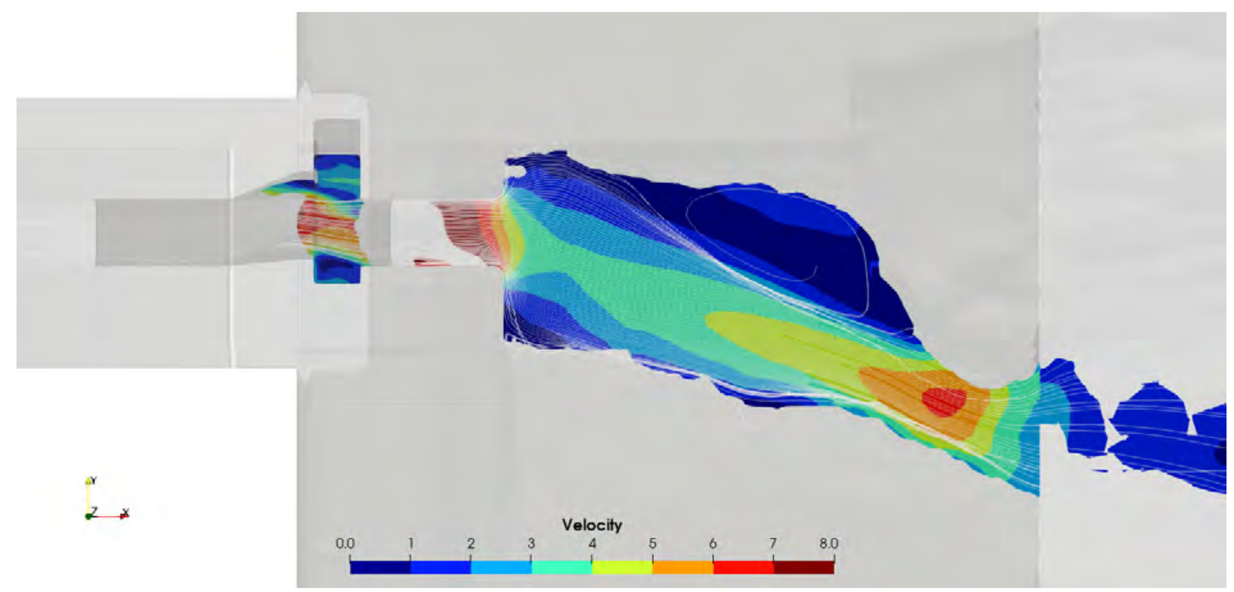


Figure A-29
Reservoir Elevation 467 Feet, Horizontal Slice at 466 Feet of Existing Sluice

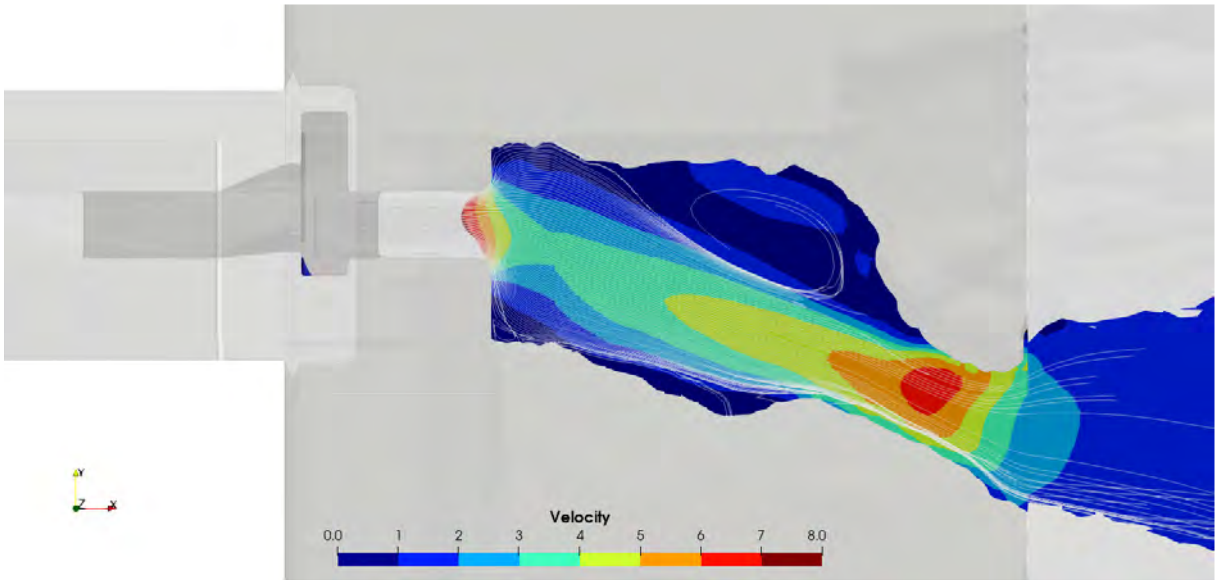


Figure A-30
Reservoir Elevation 467 Feet, Plan View of Existing Sluice Streamlines

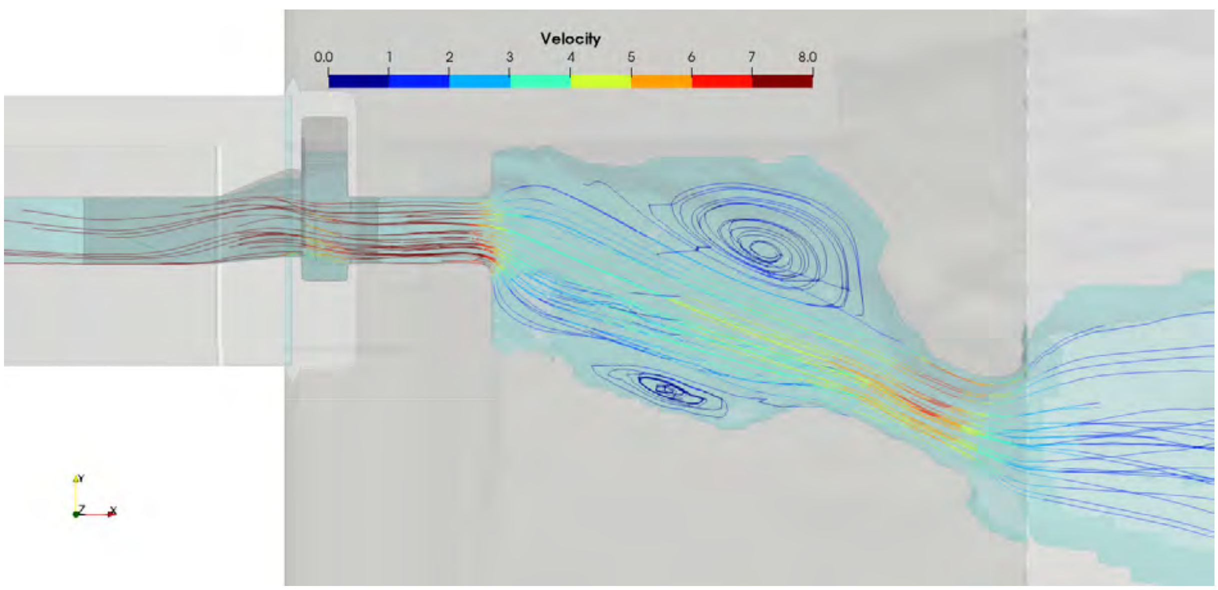


Figure A-31
Reservoir Elevation 467 Feet, Vertical Slice Through Center of Existing Sluice Entrance

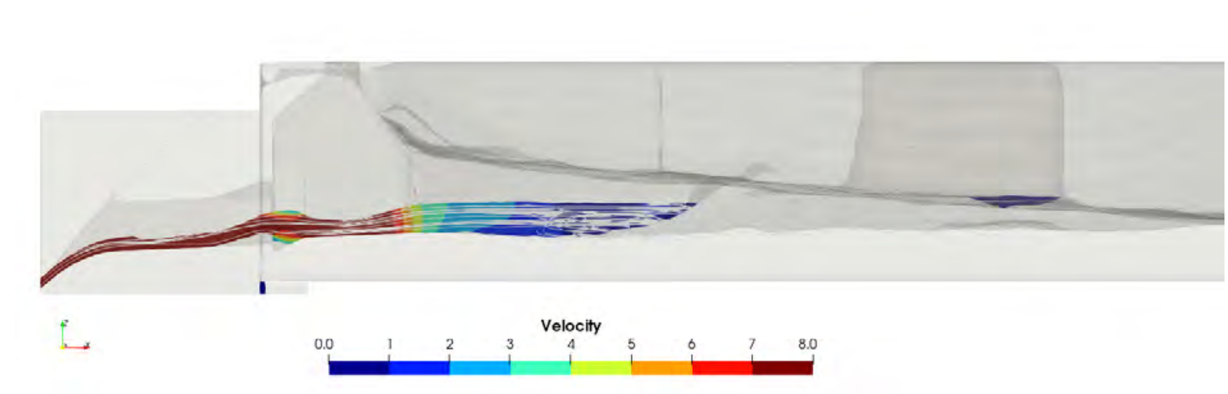


Figure A-32
Reservoir Elevation 470 Feet, Horizontal Slice at 464.5 Feet of Existing Sluice

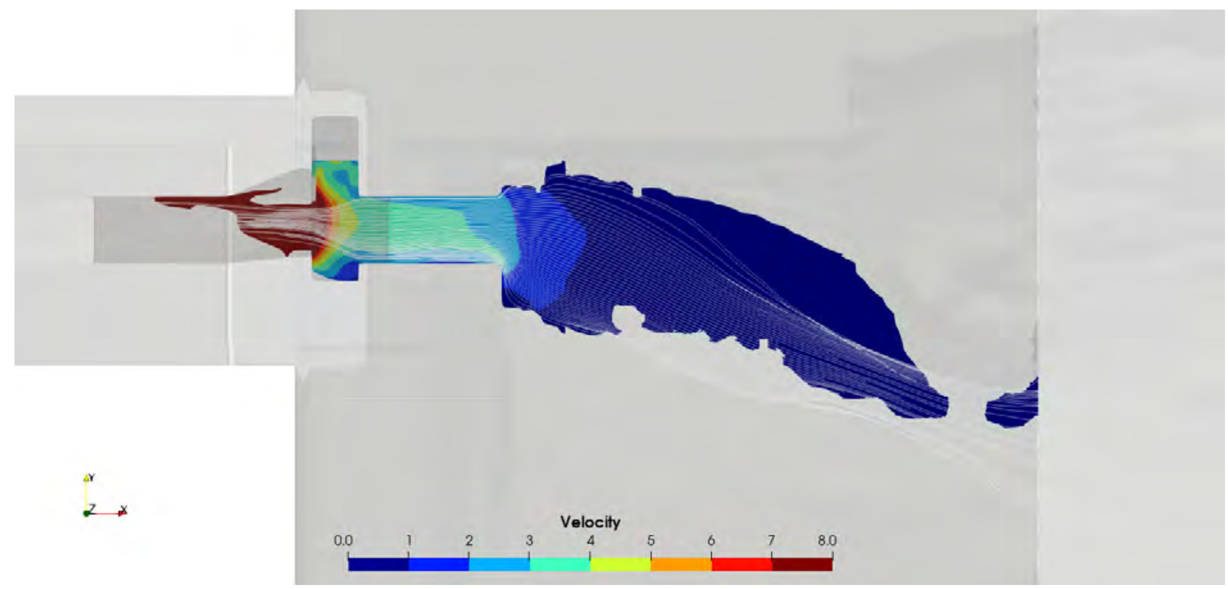


Figure A-33
Reservoir Elevation 470 Feet, Horizontal Slice at 467 Feet of Existing Sluice

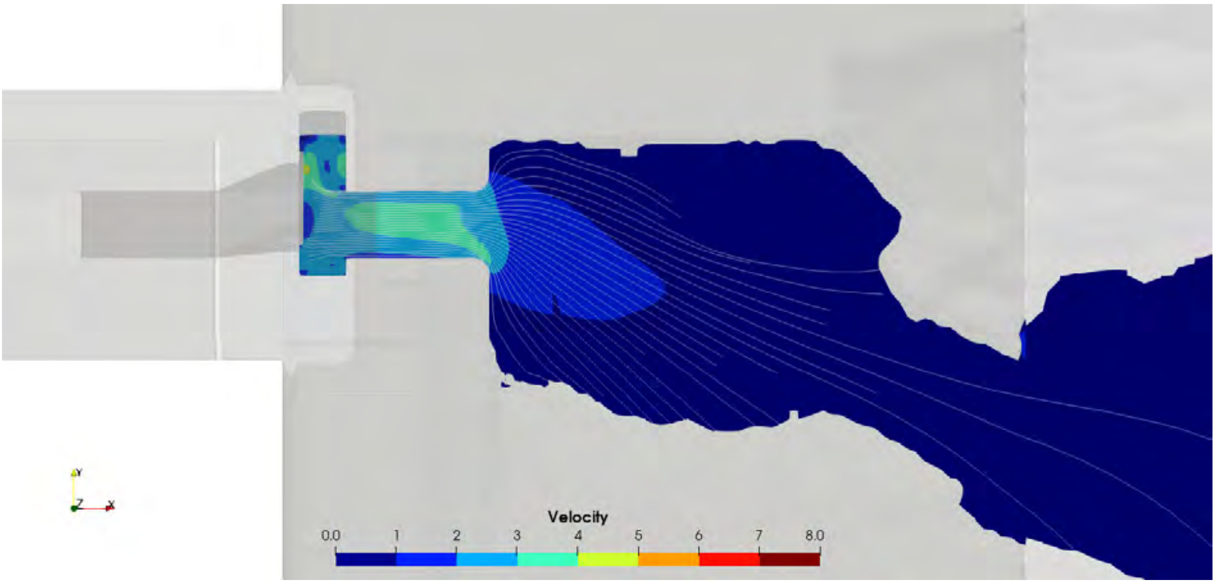


Figure A-34
Reservoir Elevation 470 Feet, Horizontal Slice at 469 Feet of Existing Sluice

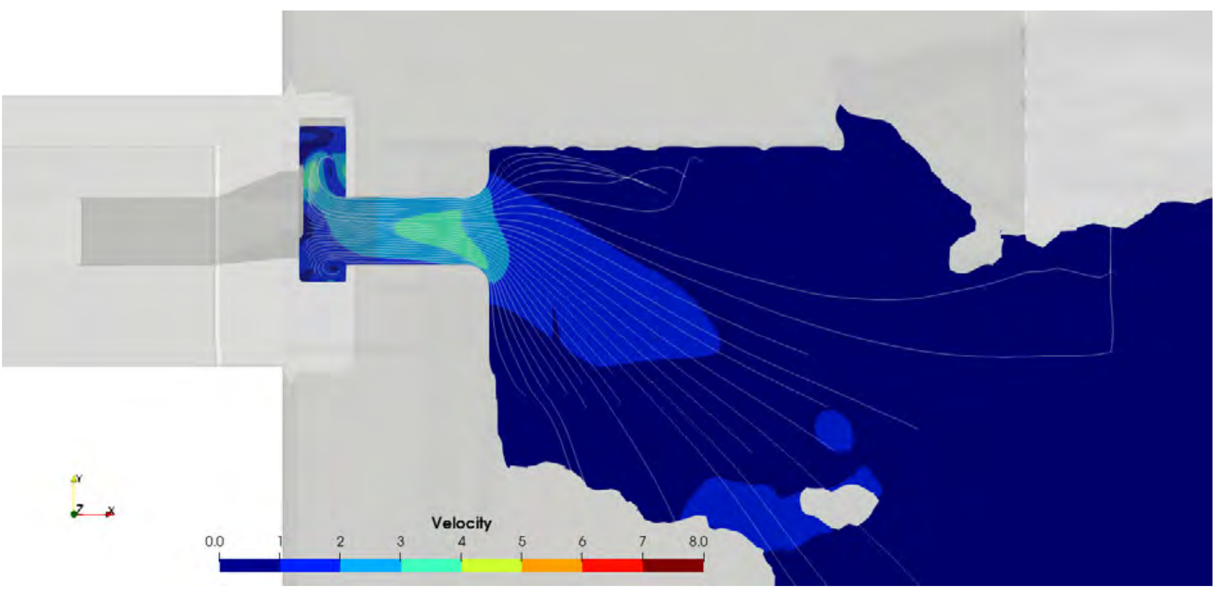


Figure A-35
Reservoir Elevation 470 Feet, Plan View of Existing Sluice Streamlines

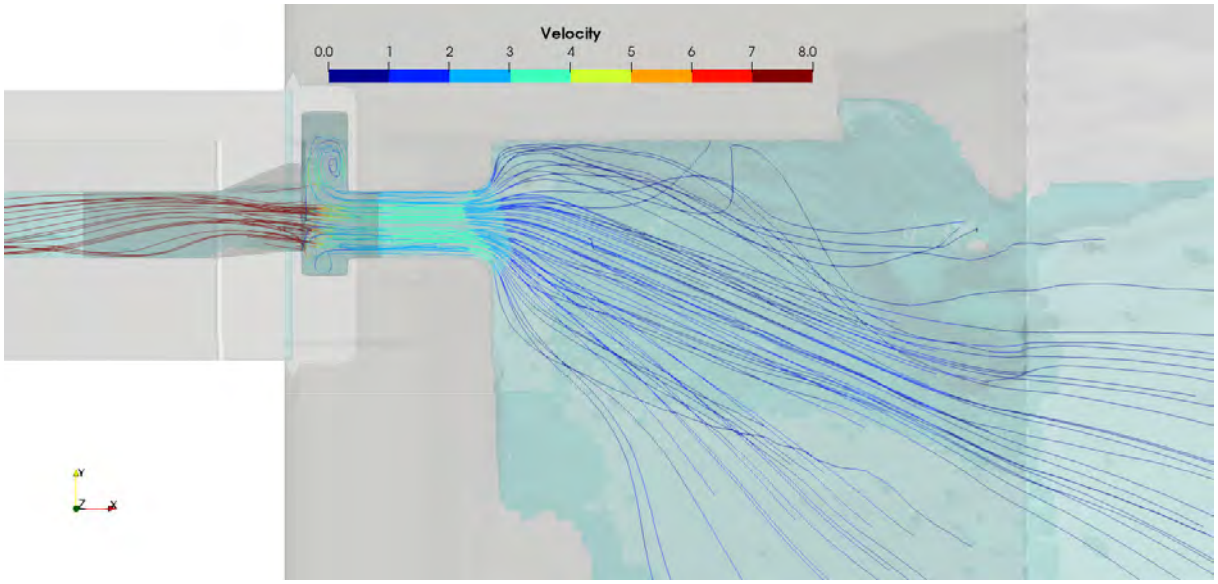


Figure A-36
Reservoir Elevation 470 Feet, Vertical Slice Through Center of Existing Sluice Entrance

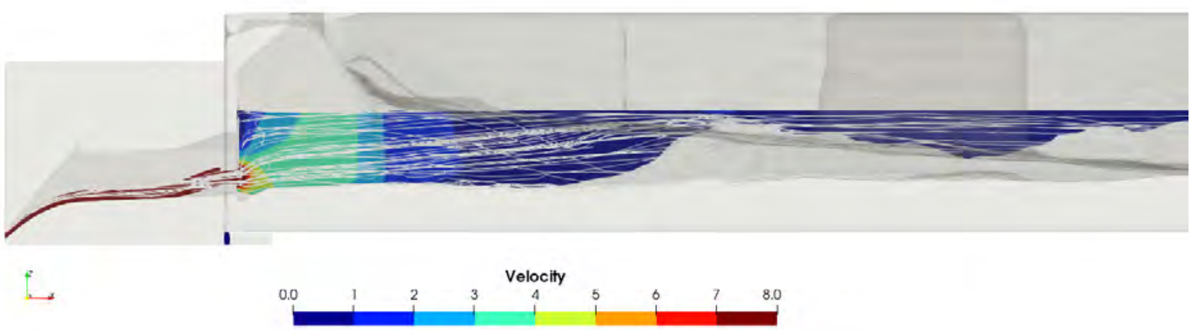


Figure A-37
Reservoir Elevation 477 Feet, Horizontal Slice at 464.5 Feet of Existing Sluice

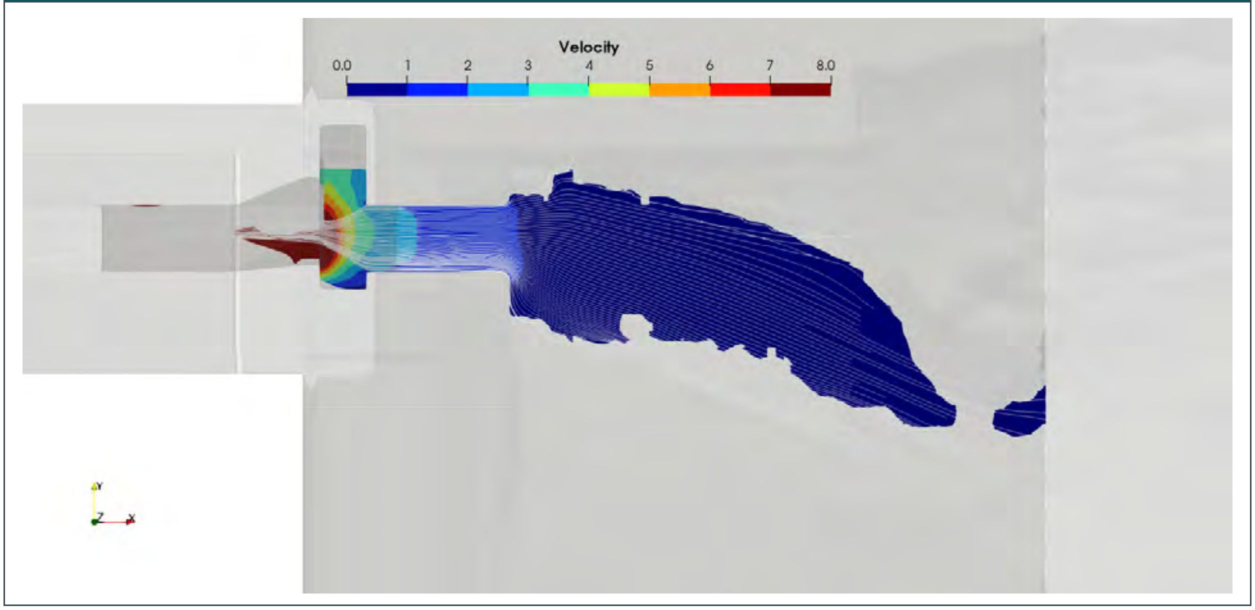


Figure A-38
Reservoir Elevation 477 Feet, Horizontal Slice at 470.5 Feet of Existing Sluice

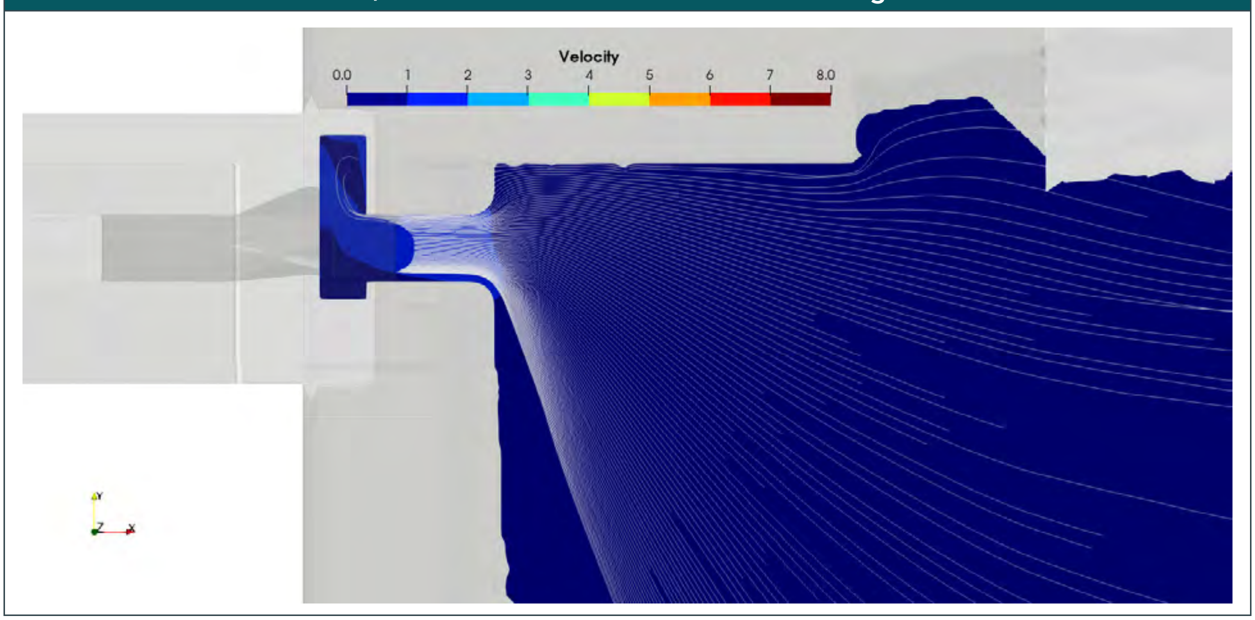


Figure A-39
Reservoir Elevation 477 Feet, Horizontal Slice at 476 Feet of Existing Sluice

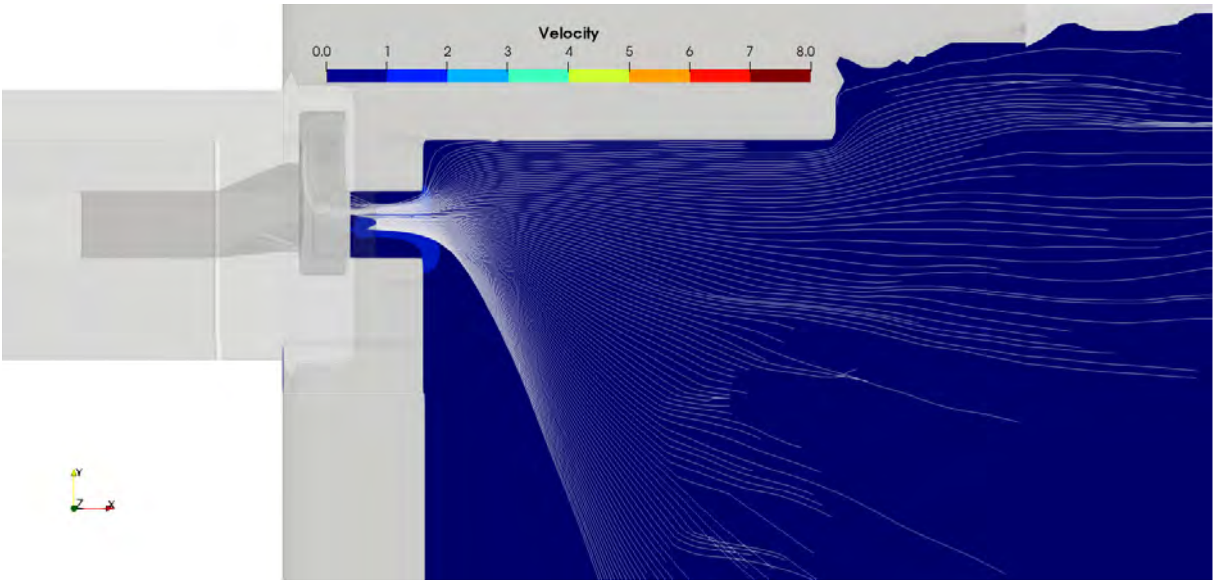


Figure A-40
Reservoir Elevation 477 Feet, Plan View of Existing Sluice Streamlines

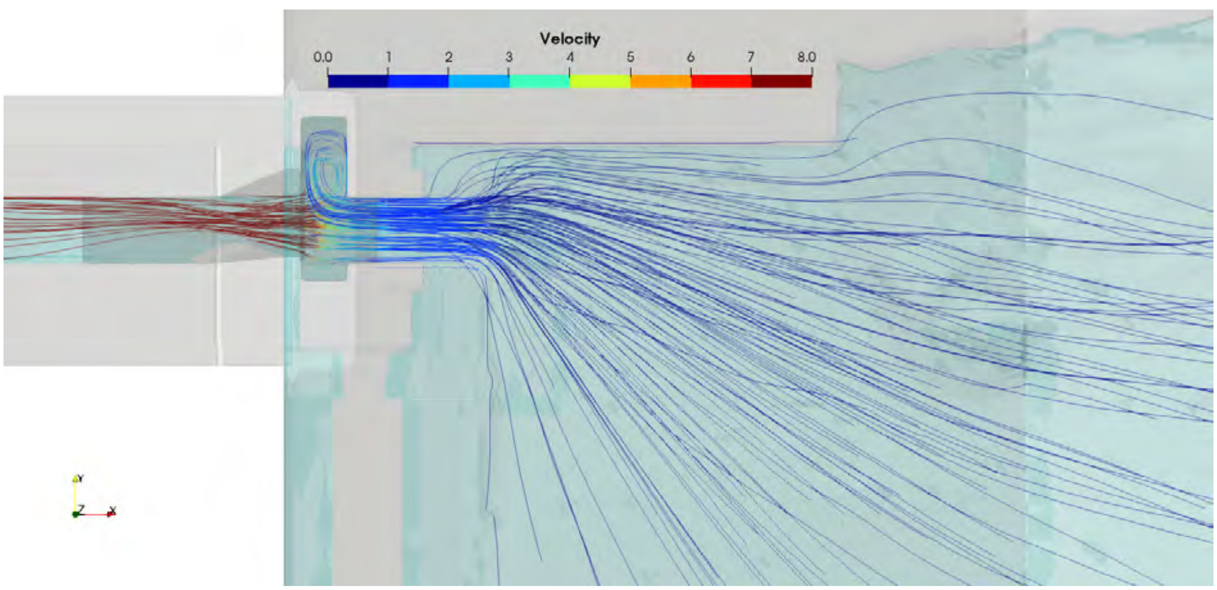


Figure A-41
Reservoir Elevation 477 Feet, Vertical Slice Through Center of Existing Sluice Entrance

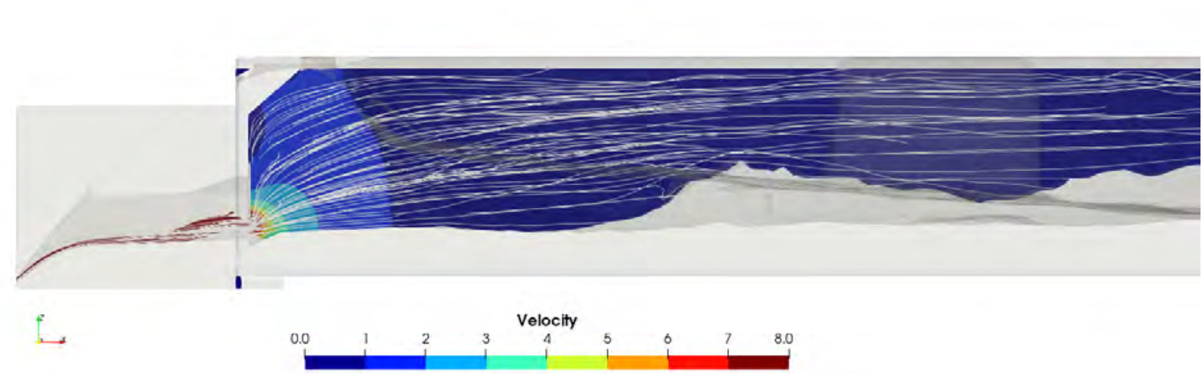
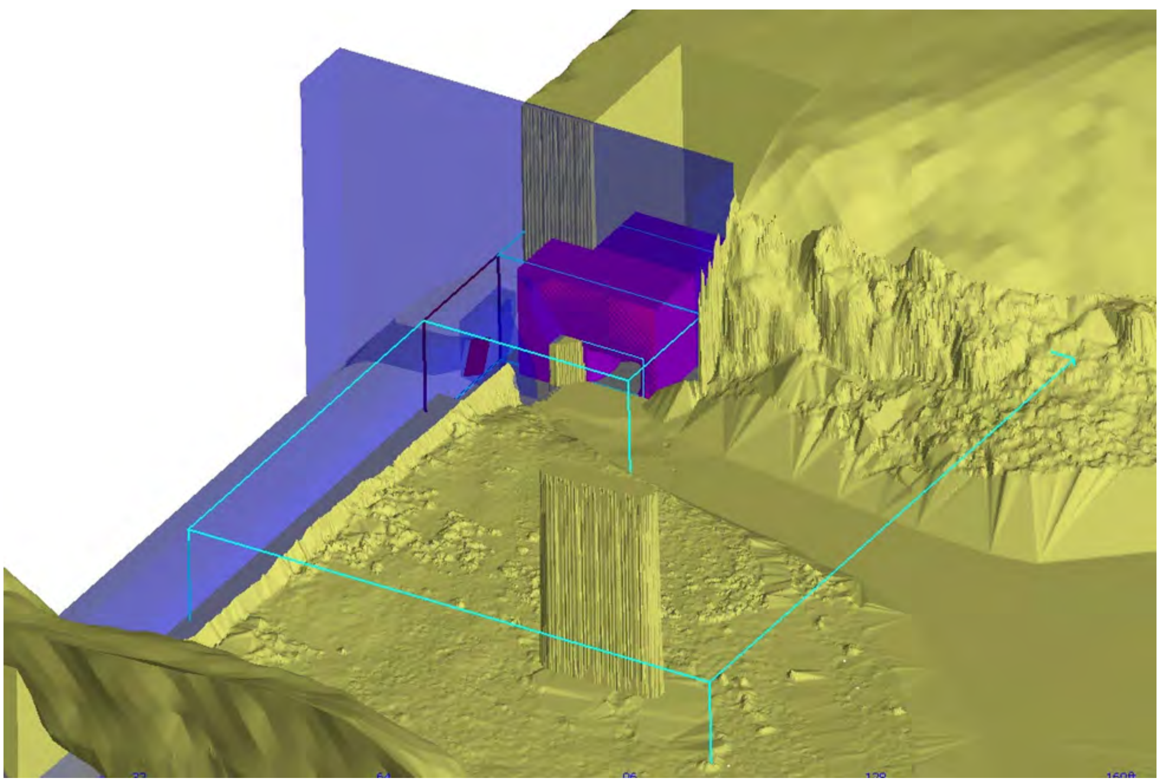


Figure A-42
CFD Model Geometry and Mesh Boundaries for the Proposed Alternative Fish Sluice



Note: Blue blocks represent the concrete spillway structure, with the purple added new sluiceway going through the concrete and bedrock left dam abutment.

Figure A-43
Reservoir Elevation 467 Feet, Plan View of Streamlines Through Proposed Sluice Alternative

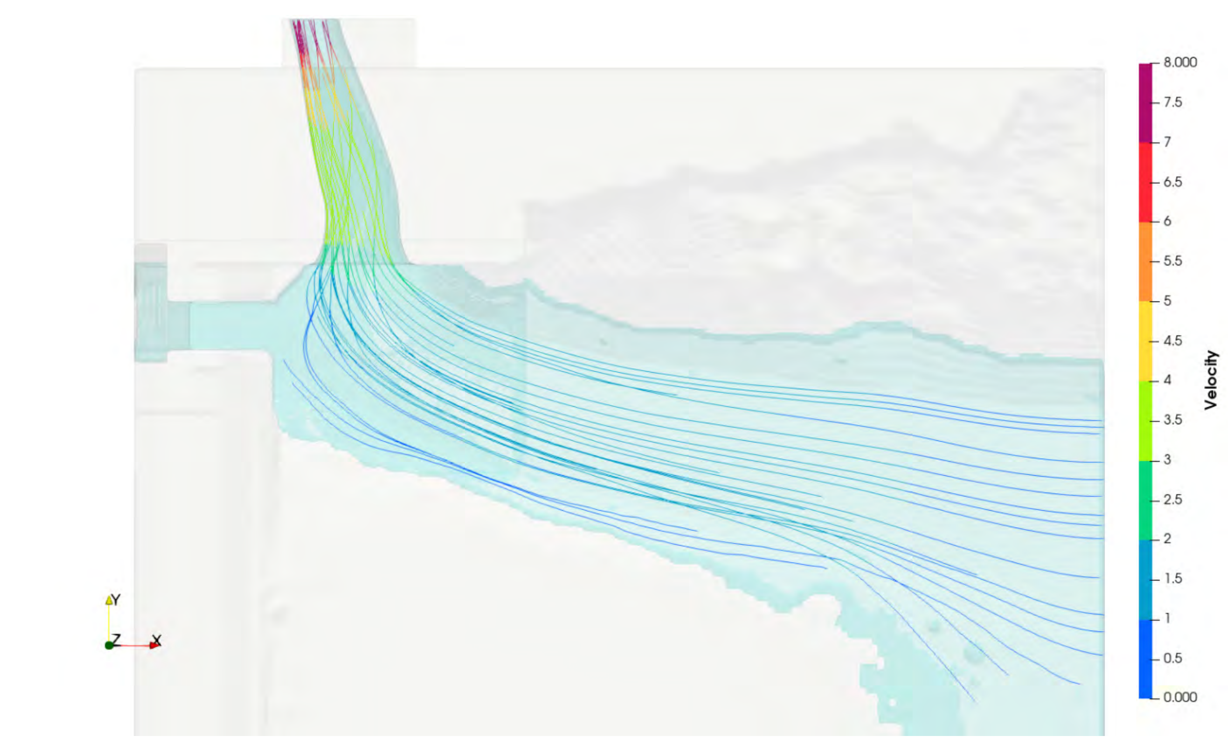


Figure A-44
Reservoir Elevation 467 Feet, Side View of Streamlines Through Proposed Sluice Alternative

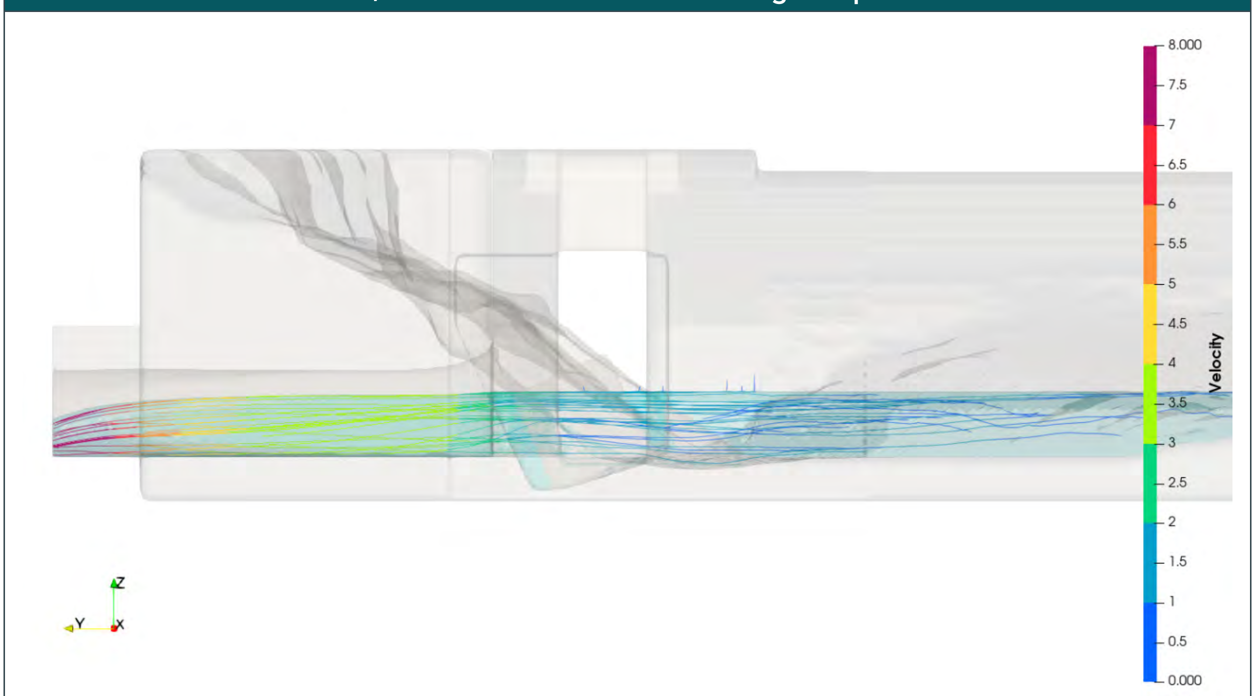


Figure A-45
Reservoir Elevation 470 Feet, Plan View of Streamlines Through Proposed Sluice Alternative

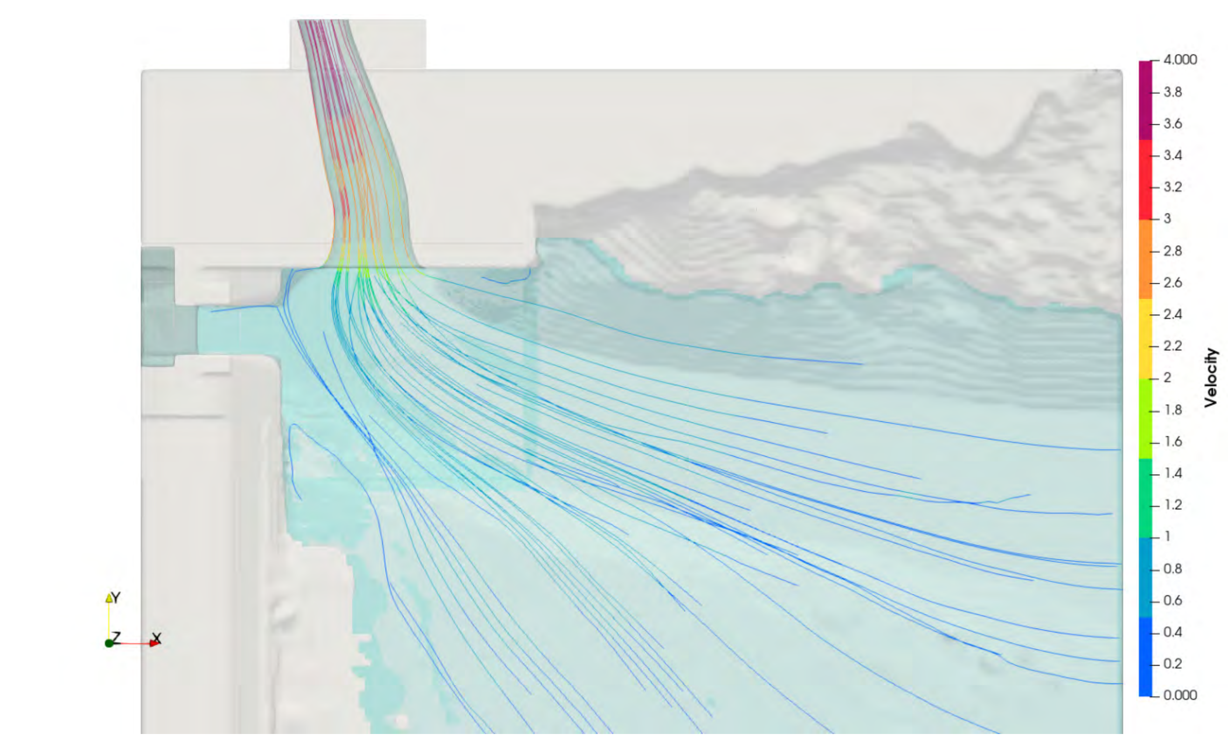


Figure A-46
Reservoir Elevation 470 Feet, Side View of Streamlines Through Proposed Sluice Alternative

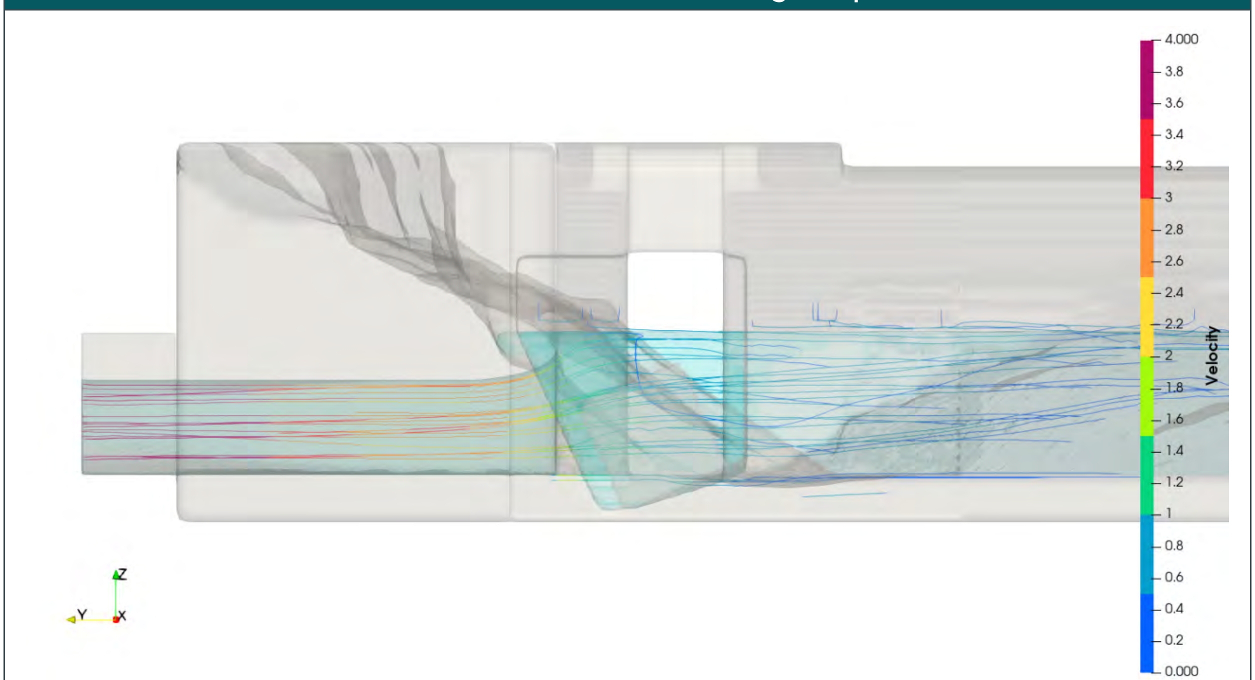


Figure A-47
Reservoir Elevation 477 Feet, Plan View of Streamlines Through Proposed Sluice Alternative

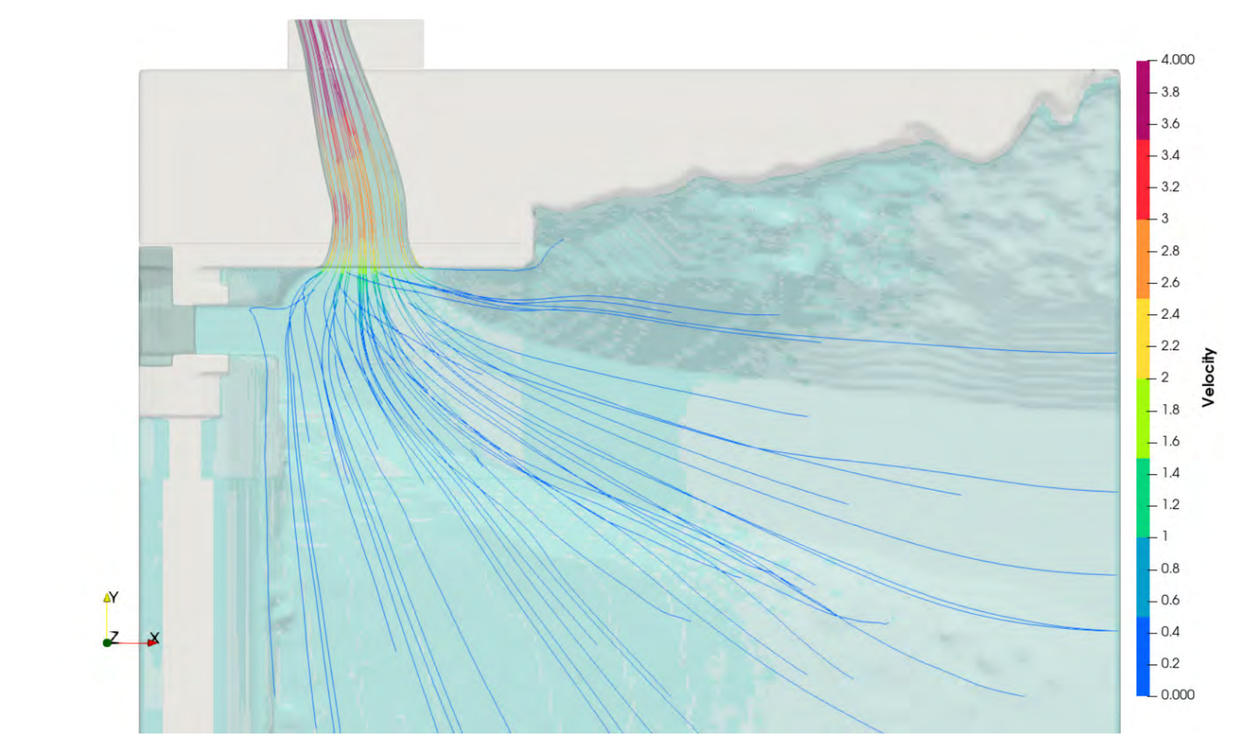
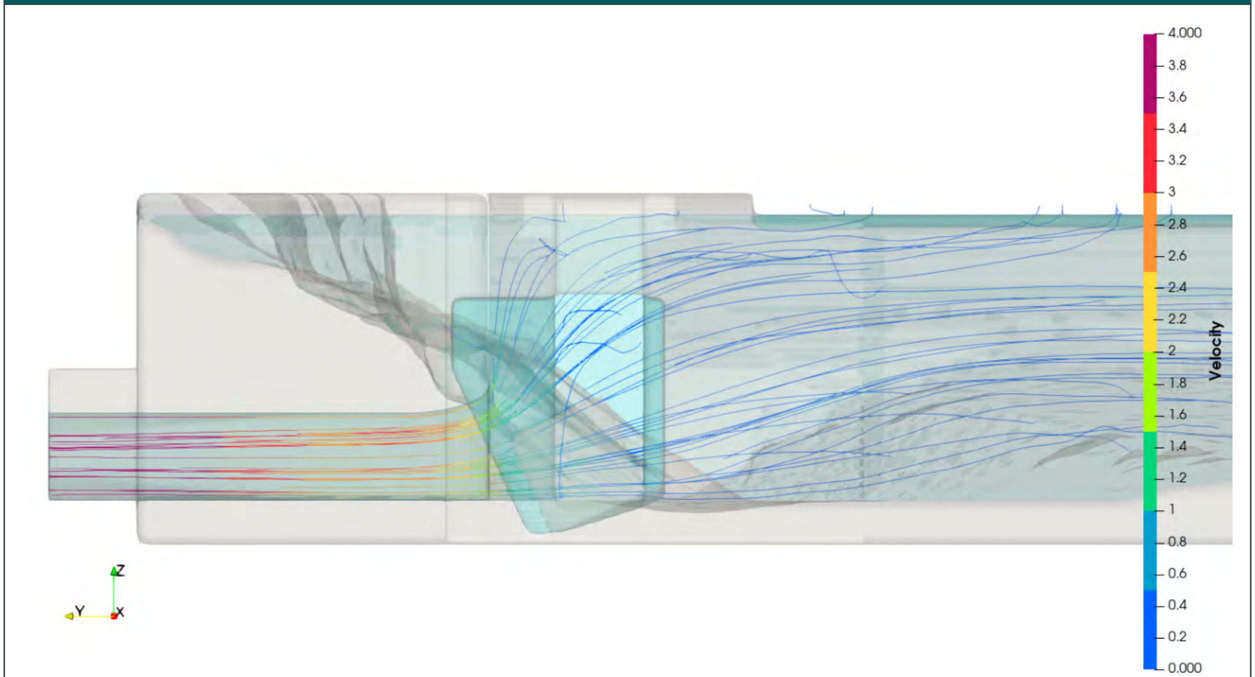


Figure A-48
Reservoir Elevation 477 Feet, Side View of Streamlines Through Proposed Sluice Alternative



A.6 Appendix A References

Anchor QEA, 2021. Climate Change Streamflows and Reservoir Elevation Exceedances for the Flood Retention Expandable (FRE) Facility under Existing and Future Conditions. August 17, 2021.

CIG (University of Washington Climate Impacts Group), 2021. Chehalis Basin: Extreme Precipitation Projections. Prepared by Guillaume Maugher, CIG, February 4, 2021.

APPENDIX B
ADULT TRAP OPERATION MEMORANDUM

MEMORANDUM

Date: March 14, 2022
To: Nat Kale, Office of Chehalis Basin
From: John Ferguson
cc: Merri Martz (Anchor QEA), Mike Scharpf (Washington Department of Fish and Wildlife)
Re: Skookumchuck Dam Adult Trap Operation Site Visit

On February 16, 2022, I met Mike Scharpf of the Washington Department of Fish and Wildlife (WDFW) and WDFW and Chehalis Tribe staff at the trap to observe steelhead collection, spawning, sorting, holding, and loading for truck transport operations. The purpose of the visit was to identify any needed repairs and upgrades to the equipment and facility to improve adult fish handling and processing. I also toured the trap and steelhead rearing ponds earlier in the Skookumchuck fish passage and flood storage evaluation project. Based on these site visits and discussions with the TransAlta trap operator and WDFW staff, the following observations are provided:

1. Overall Observations

The trap operates well in its current configuration. Fish appear to readily use the entrance and pass up the Denil and enter a holding tank. Denil fishways were first developed in 1908, provide excellent energy dissipation properties, and work well in situations such as this trap where water supply volumes are controlled through valves (Clay 1995). Holding and loading tank capacities are somewhat limited but meet WDFW's needs for broodstock collection at this time and current steelhead run size.

On this day a total of 180 adult steelhead had been collected during the previous week of trap operation and were processed. Processing was initiated around 0900 hours and completed at approximately 1130 hours. Fish used as broodstock were spawned at the trap and the eggs were transported to Skookumchuck Hatchery, fish relocated for harvest were loaded into tanks on trucks and transported to two lakes located in the western region of the basin, surplus fish were euthanized and picked up by Chehalis Tribe representatives, and immature fish were opercula punched and returned to the Skookumchuck River and allowed to continue their maturation and re-enter the trap and be processed later in the spawning season. Biological and pathological sampling was completed on subsampled fish at the trap. Trap mechanical and electrical systems operated properly (no component issues were identified by TransAlta).

The configuration of the trap is shown in Figure 1. Fish enter the trap from the river through an entrance located at the base of the dam (not shown) and pass into a resting pool at the base of the Denil ladder (narrow turbulent passageway shown in the left panel). Fish swim up the Denil ladder under their own timing and volition and enter a holding tank located in the background of the right panel behind the concrete wall with the yellow signage and hold here until crowded and processed.

Figure 1
Skookumchuck Dam Adult Fish Trap Configuration

2. Inspect steelhead rearing pond exclusion barrier

During an earlier tour, I observed adult steelhead holding just upstream of the rearing pond exclusion barrier. The picket fence or barrier is located where water leaving the rearing pond enters the Skookumchuck River (Figure 2). Fish were observed holding upstream of the exclusion barrier and against the left-hand concrete wall shown in the photograph. When the ponds are dewatered, the barrier should be inspected because steelhead appear to be able to migrate into the pond from the river and are not contributing to hatchery broodstock and harvest objectives.

Figure 2
Rearing Pond Exclusion Barrier

3. Replace CO_2 anesthesia with electrosedation

The current method of bringing multiple steelhead at a time from the holding area and into a small anesthetic tank for sedation using CO_2 and processing is inefficient and potentially harmful. Sedating broodstock fish with electricity is a proven and commonly used method at hatcheries to anesthetize large numbers of fish quickly and inexpensively without the use of chemicals. WDFW identified this modification as one of their top priorities. Currently, fish are brought into the anesthetic tank and the lid is then closed. Fish are very active in this crowded condition until the CO_2 takes effect, after which time the lid is opened and the fish are processed manually (Figure 3).

Figure 3
Anesthetic Tank

4. Install larger hopper for loading fish onto trucks

WDFW identified the need for a larger hopper for loading fish onto transportation trucks. The current hopper can hold approximately 50 adult fish. We did not discuss how much fish holding capacity needs to be increased but to do so would require modifying the following: 1) the superstructure under which the transportation truck parks to allow for larger tanker trucks; and 2) the capacity of the hoist used to lift the holding tank up and out of its parked position and transit over to and above the transportation truck tank (Figure 4).

Figure 4
Transport Truck Loading Hopper and Hoist

5. Install return chute for immature fish

WDFW requested that a chute be installed to return fish from the anesthetic tank to the holding tank for processing in subsequent weeks rather than returning them to the river. See the right panel in Figure 1. The chute would be installed to convey fish from the anesthetic tank processing area back to the holding tank behind the concrete wall.

6. Redesign the anesthetic tank

WDFW requested that the anesthetic tank be enlarged and somewhat deepened. Their primary concern was with staff safety and the need for personnel to bend over and reach down to process each anesthetized fish, although enlarging the tank would also be helpful (Figure 3). Raising the tank once the fish are anesthetized or lowering the work area staff stand on would address the tank height safety issue. If CO_2 continues to be used, the new tank should be notched so the hose to the tank is not crimped when the lid is closed. A measuring trough should be included in any new tank, similar to the current design (Figure 3, right panel; the trough is under the left hand of the person reaching into the tank).

7. Install a table for pathological sampling

Pathology samples are taken following broodstock egg collection. Currently, this is done on the ground and not under the roof of the sorting facility (Figure 5). WDFW requests that a table be installed for processing fish for pathology purposes in a manner that is protected from the elements.

Figure 5
Pathology Sampling

8. Construct larger broodstock collection rack

WDFW requests that a larger rack be constructed for holding female and male adult steelhead that are euthanized and set aside for broodstock collection, which occurs after all sorting has been completed (Figure 6).

Figure 6
Hatchery Broodstock Rack

9. Purchase a lay-flat, flexible, transport truck release hose

Currently, WDFW fish transport trucks used to release fish above Skookumchuck Dam carry and use large, corrugated plastic pipes to transfer fish from the truck to the river (Figure 7). The pipes are cumbersome and require a couple of people to manage. A flexible hose that fits to the release tank and can be rolled out and handled by one person and requires no support would increase the efficiency of the operation and safety to personnel (Figure 8). WDFW requests that a 10-inch-diameter hose be purchased that could be fitted with a quick-release, cam-lock fitting that mates to the fitting on the hatchery trucks used to transport adult steelhead above Skookumchuck Dam.

Figure 7
Current Truck Release Hose

Figure 8
Requested Flexible Truck Release Hose

References

Clay, C., 1995. *Design of fishways and other fish facilities*. CRC Press, Inc. Boca Raton, Florida.

APPENDIX C
WHOOSH CONCEPTUAL ADULT PASSAGE REPORT

Whooshh Innovations
Port of Seattle, Pier 91, Bldg. 156
Seattle WA 98119

Technical Memorandum

Date:	September 30, 2022
Project:	Skookumchuck Dam – Upstream Fish Passage
To:	Merri Martz, John Ferguson, AnchorQEA
From:	Whooshh Innovations
Subject:	Whooshh Fish Passage

Whooshh Innovations
Port of Seattle, Pier 91, Bldg. 156
Seattle WA 98119

Adult Upstream Fish Passage Concepts for Skookumchuck Dam

Prepared by: Whooshh Innovations, Inc.

For: Anchor QEA and Office of the Chehalis Basin

Contents

Executive Summary

The Skookumchuck Dam is a 160 ft hydraulic height dam located in SW Washington, near the town of Bucoda. The dam is situated along the Skookumchuck River at river mile 22. The dam is owned by Transalta Resources, who currently use their water rights to supply their steam plant which is scheduled to remain operational until 2025, after which they intend to manage a water bank, supplying water to, among others, the City of Centralia. The Office of the Chehalis Basin (OCB) is currently examining options for the future of the dam, including ways to improve fish passage.

This technical memorandum is prepared by Whooshh Innovations to evaluate scenarios of pneumatic live fish transport technology as a potential alternative solution for upstream fish passage. Three conceptual scenarios are presented, all of which are feasible based upon a preliminary review of the site characteristics and the anadromous species being requested for passage consideration (steelhead first, then coho and chinook).

Whooshh live fish transport technology uses pneumatic pressure differentials to transport fish in misted tubes up and over barriers such as dams. This equipment is modular and scalable and has been used in various configurations by the Washington Department of Fish & Wildlife (WDFW), the Department of Fisheries & Oceans Canada, Constellation Energy and several Native American organizations. The US National Marine Fisheries Service (NMFS) examines the use of such technology on a case-by-case basis.

Each of the three solutions provided herein are conceptual and are to be used to support the ongoing development of an effective and cost-efficient fish passage and flood control program at Skookumchuck Dam. Each of the three solutions provides a proposed layout that originates at the existing fish trap facility situated at the base of the dam, and extends upward over the dam and terminates within the reservoir. One of the proposed concepts features a hand-loaded entry; the other two of the proposed concepts feature volitional entry such that the fish do not experience handling or delay. Approximate costs, layouts and equipment needs for each are summarized in this technical memorandum. Review, modification, permitting and approval by dam owners, regulatory authorities, and fish facility operators would be necessary before plans can be fully developed and implemented.

The three passage scenarios each require 480V power, internet connectivity, two approximately 900’ misted tubing lanes, a road crossing for the dam crest road, and a floating exit platform. Each allows for safe and efficient passage of live fish from the area of the fish trap facility and into the Skookumchuck reservoir. The three passage concepts are detailed in this technical memorandum and summarized below, as follows:

Red – This is a volitional entry system, following the layout of the existing fish trap facility. Fish enter the trap as they do currently, and rather than enter a hand sorting bin, they instead enter the Whooshh scanner. There, data is automatically gathered and they are then sized and routed up and over the dam, exiting the system via a platform that floats in order to accommodate the fluctuating levels of the reservoir. Approximate cost: $1,666,500.

<u>Blue</u> – This is a manual load system, again following the layout of the existing fish trap facility. Fish enter the trap as they do currently, landing into the existing sorting bin. Here, personnel hand sort and determine which fish are to be passed over the dam and which are not. Those that are selected for passage are then hand-loaded into the system, which then transports them up and over the dam, exiting the system via the above-described floating platform. Approximate cost: $ 635,000.

<u>Yellow</u> - This is a volitional entry system, following a portion of the layout of the existing fish trap facility. Fish enter the trap as they do currently, and are directed from the existing holding pool and into Whooshh equipment situated just adjacent and approximately perpendicular to the facility, where they enter the Whooshh scanner. There, data is automatically gathered and they are then sized and routed up and over the dam, exiting the system via the above-described floating exit platform. Approximate cost: $1,481,500.

At the current stage of alternate development, we view all three of the above concepts as feasible for the initially-proposed steelhead passage (and also later for coho and chinook). Based on prior installation experience, installing equipment under any of the three concept scenarios would not be a complex endeavor. Recognizing the pros and cons of each scenario, and based on analysis of species, site characteristics and equipment, it is our recommendation that the yellow option be pursued for further development as it provides state-of-the-art fish passage, free of handling and delay, and can be implemented with limited impact to the existing fish trap facility.

1. Introduction

The objective of this technical memorandum is to evaluate the potential use of fish transport tube technology as an alternative solution to providing upstream adult fish passage at the Skookumchuck Dam that can accommodate a number of anadromous species. The purpose of this document is to summarize the results of a preliminary review of the site characteristics as they relate to the proposed initial fish tube passage concepts described along with preliminary cost estimates. The fish passage solution options described herein are conceptual in nature and are to be used to support the ongoing development of an effective and cost-efficient fish passage and flood control program at Skookumchuck Dam. The solution options presented provide safe and efficient adult salmonid transport. Additional considerations and costs would be incurred to make these installations permanent. Review, modification, permitting and approval by dam owners, regulatory authorities, and fish facility operators will also be necessary before plans can be fully developed and implemented.

2. Scope of Document

This report provides preliminary descriptions of three potential independent solutions integrating state-of-the-art live fish transport technology systems to provide direct upstream adult fish passage from the fish handling facility below the Skookumchuck Dam to the reservoir above the dam.

The following tasks were performed during the preparation of this document.

- Review of salient, publicly available information to establish a background understanding of the site, the fish, water use and flood control, the parties involved, the current state of preferences and options relating to fish passage at Skookumchuck Dam and previous projects involving installation of Whooshh fish passage equipment. [1]
- Summarization of site fish passage requirements as understood; and
- Development of preliminary fish passage concepts incorporating the use of Whooshh live fish transport technologies in various forms and configurations.

These activities and resulting outcomes inform the contents of this document. This technical memorandum offers a description of project considerations and criteria and includes conceptual options for upstream fish passage with anticipated costs and performances associated with the design elements of these concepts.

The document is organized into several sections. First is a general description of the key physical and topographic characteristics of the Skookumchuck Dam. Biological considerations for passage are then briefly addressed. The next section deals with the features involved in three independent fish passage concepts. For each concept the features are described detailing the modular Whooshh technology components, noting the defining attributes of the different approaches in addressing the particular passage challenges that the geographic, and site-specific features pose. The elements of each conceptual solution proposed are then discussed and evaluated. Finally, some initial budgetary projections of project costs are included for each proposed concept scenario.

3. Background

The Skookumchuck Dam has several stakeholders, many with varying interests including fish passage, fisheries restoration, water rights, flood control, water storage, power generation, and more. Proposed solutions to improve fish passage and/or flood storage range from complete or partial dam removal at one end of the spectrum, to leaving the dam in place and making fish passage improvements at the other. The dam is owned by Transalta Resources, who currently use their water rights to supply their steam plant which is scheduled to remain operational until 2025, after which they intend to manage a water bank, supplying water to, among others, the City of Centralia. Other water rights holders also exist downstream. The Skookumchuck Dam can also serve to aid in flood control, helping to contain and regulate flows. The Washington State Department of Fish & Wildlife (WDFW) also maintains an interest in the dam, with respect to the operation of the fish facility situated at the base of the dam. WDFW would like to see either state-of-the-art improvements made for fish passage at the dam or consider partial or full removal for the benefit of the fish.

3.1 Key Project Characteristics

Table 1. Summary of Key Project Characteristics

Characteristic	Description
Dam crest road elevation	497 feet
Typical forebay (reservoir) fluctuation range	Up to 50 feet
Nominal hydraulic height	160 feet
Dam crest road width	30 feet
Dam crest span	1330 feet

3.2 Site Map

Fig. 1. Site Map, Skookumchuck Dam. *Source: AnyplaceAmerica.com/Lewis-County*

4. Site-Specific Topographic Challenges to Passage

General

The Skookumchuck reservoir has ~33,000 acre-feet of storage, is roughly 5.5 km long and ~0.5 km at the widest point, positioned elongated in an east to west orientation. The Skookumchuck River enters the reservoir at the eastern-most side, whereas the dam is positioned on the western side.

As a regulated water body with an ungated spillway, the reservoir is both managed via intakes and naturally via spill. Throughout the year the reservoir water level can fluctuate greatly, typically dropping in the late summer months as much as 27 ft but extremes can lead to drops of up to 50 feet. The spillway crest is at 477 ft and the fish sluice spans from 477 ft to 464 ft. When the water level drops below 464 ft reservoir to river connectivity is lost, aside from the water intake pipes. The site poses challenges to traditional upstream fish passage solutions such as fish lifts and fish ladders. The dam height does not readily lend itself to a fish lift and the reservoir water level fluctuations, specifically the low water periods, would render a ladder inoperable and therefore impractical as a fish passage solution.

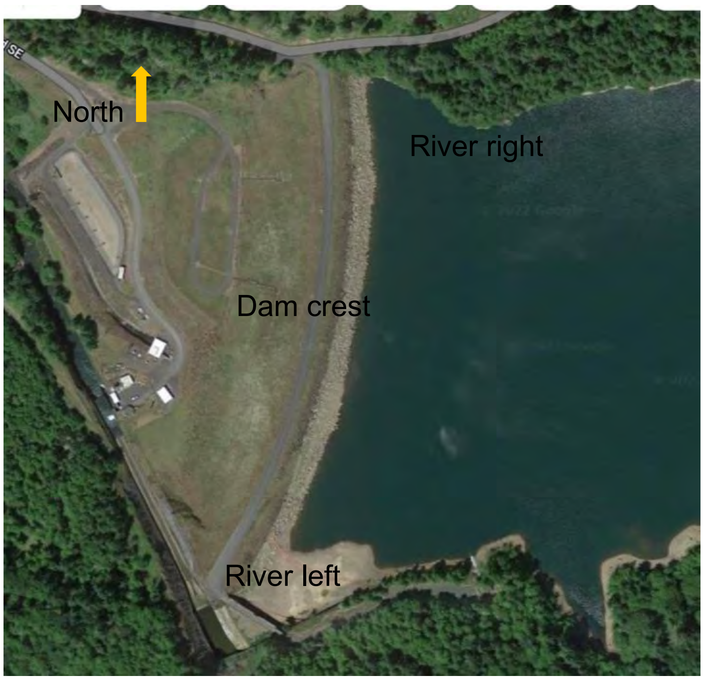


Fig. 2: West end of Skookumchuck Reservoir. Skookumchuck dam and spillway.

River right:

The reservoir area at river right, in the northwest corner of the reservoir, is an area of low velocity. The water flows east to west across the reservoir and then exits over the spillway at the southwest corner of the reservoir. If a fish passage solution were to pass fish into the low flow northwest corner, there is a risk of migration delays as the lower velocity may be insufficient to provide directional guidance to navigate through the reservoir toward cooler waters and upstream spawning grounds.

River left:

In the reservoir area at river left, in the southwest corner of the reservoir, lies the spillway. Just east of the spillway on the south side of the reservoir lie the intakes for the dam. The risk to successful upstream fish passage terminating in this location is that there is an increased potential for fallback either with the spill flow over the spillway crest, or to a lesser extent, through the intakes.

Dam Crest:

Across the top and length of the dam lies a 30' wide dam crest road, providing vehicular access across the dam, connecting access of the northside of the reservoir to the southside of the reservoir. The road presents a challenge for the structural design of a fish passage solution. The design should not impede vehicular access, but rather incorporate the requirement in order to maintain a functional roadway.

5. Biological Considerations for Upstream Passage

Target Species

Adult chinook, steelhead and coho salmon are all known to migrate up the Skookumchuck river with historical suggestions, pre-dam, upstream of the current day reservoir spawning habitat. WDFW has active hatchery programs at Skookumchuck for steelhead and coho. Steelhead are the initial target species for passage, though all three species have been considered as target species for the proposed passage system design. The individual species behavior, migration patterns, timing and size characteristics are used in informing specific design elements, features and dimensions.

Period of Migration

The timing of the migratory runs of the target fish species spans the entire year, with steelhead typically moving between December and June, coho between November and January, spring chinook from April to Mid-October and fall chinook from late September to mid-December.

An important biological consideration for automated upstream passage is that with a fully automated, volitional entry system, a great deal more delay-free fish passage can be achieved. Currently the fish trap is operated for broodstock collection between February and Mid-April, and within that period, only on certain days. As an example, steelhead were collected only one day in February of 2021, four days in March and four days in April for a total of nine days out of the three-month period. WDFW could operate the existing fish trap over a much longer period if desired based on management goals.

6. Formulation and Description of Fish Passage Concepts

Based on prior installation experience, deploying equipment at the Skookumchuck dam would not be an overly complex undertaking. Whooshh Innovations has developed technologies to provide transport solutions for live fish over distances of as much as 1700 feet and over barriers exceeding 650 feet. Temporary and permanent installations have been tested on live fish ranging from various species of salmon and steelhead to American shad and sturgeon. Results show no significant injury or mortality as a result of transport through the Whooshh system. [2., 3] The US National Marine Fisheries Service approves the use of such technology on a case-by-case basis.

Recently the Company's Passage Portal system was deployed by Fisheries and Oceans Canada on the Fraser River at the Big Bar rockslide, where several thousand sockeye and chinook were safely and volitionally transported past the slide. Data resulting from numerous studies and deployments show that fish passage through the Whooshh systems can be done safely[3.,4] (fix citations) and can accommodate a rapid deployment timeline. It can also be scaled to large volumes.

The Whooshh Passage Portal (WPP) system utilizes flexible Migrator™ tube(s) that are connected to an air blower. In the tube, a pressure differential of about 1-2 PSI is introduced between the front and the back of the fish, thereby creating a lower pressure in front of the fish allowing it to be gently and safely pushed through the tube. Misters located within the tube keep the inside surface wet and relatively frictionless, allowing for the fish to travel with a bolus of water that also serves to keep the gills wet. The blower speed is regulated to ensure safe passage and exit speeds of less than 25 feet per second. The fish exit the tube directly into the desired body of water upstream of the passage barrier, with the floating exit platform ensuring accommodation of fluctuating reservoir levels. As fish are transported they glide through the tube with no measurable loss of slime or scale or any physical damage to the fish. In addition, biochemical evaluations have shown no significant stress impact on fish associated with Whooshh fish transport. [4]

The Whooshh systems can transport a variety of fish species of different sizes. There are five tube sizes each with overlapping specification for use ranges based predominantly on the fish girth. For the Skookumchuck dam fish passage project and the initial target fish, steelhead, a minimum of two tube sizes are recommended. The size variability of migrating steelhead necessitates system components across a substantial girth size range. The range that two tubes provide should ensure passage of the vast majority of adult steelhead under the current steelhead passage program. Precise sizing and configuration requirements will need to be assessed based on additional customer-provided size data.

As described above, the Whooshh system is scalable. As the scope of the project increases over time to accommodate other species, additional tubes and supporting equipment can be added as modules to the existing baseline configuration to accommodate other fish sizes and/or significant increases in the number of fish requiring passage. Efforts to establish precise fish size ranges, sized by girth, of additional target species, should be pursued. Weight and forklength measurements are somewhat helpful however neither correlate directly with girth. The morphological changes and energy expenditures that occur during maturation and migration can influence the girth and weight of the fish while forklength remains a constant during migration.

Three different concepts for transporting fish over the dam crest are being proposed. Each of these concepts are presented in greater detail in section 8, below. The concepts differ primarily at how, and locally where, the fish engage the Whooshh fish transport technologies. In all cases it is assumed that the Whooshh system will be engaged within or adjacent to the existing fish handling facility at the base of the dam. Migrating fish will enter the facility as they do currently, ascending the existing steeppass near the base of the spillway, and volitionally entering the existing holding and/or sorting areas within the fish facility. Under two of the passage concepts being presented, the fish will enter the Whooshh system volitionally and be transported immediately by the system to the reservoir. Under the other passage concept being presented, operators will still be required to manually load the fish into a simpler version of the transport system.

Once into the system, a high-volume, low-pressure blower is used to provide temperature-controlled air at the accelerator entrance to facilitate movement of the fish through the transport tube(s). The tubes are lubricated by introducing water droplets at defined intervals along the tubes, which become a mist when the blower air is applied providing a wet, smooth, relatively friction-free surface along which the fish glide, propelled forward via the air stream. To minimize thermal stress on the fish the motive air is chilled prior to being directed through the accelerator and Migrator™ tubes. Additionally, the water used for lubrication is pumped from the tailrace providing additional thermal consistency. Additionally, environmental shielding is placed around the Migrator™ tubes to reflect sunlight and retard local warming.

Instrumentation tracks the velocity of each fish being transported, and controls are used to decelerate the fish to an appropriate speed for entry into the lake. At the distal end of the tube the fish are directed through an appropriate re-entry device that delivers them safely and correctly angled for reentry into the water at speeds typically below 20-25 feet per second. At the exit end, the fish travel through the water to approximately 2 fish lengths, before they regain full control and start swimming post transport. It is recommended that the fish exit into water that is a minimum of 3 feet in depth, and that there are no obstacles in the water within 6-8 feet of the re-entry point. It is further recommended that the reentry device be situated on a floating platform to accommodate the fluctuations in reservoir levels. It is anticipated that these requirements will be readily achieved at the site being considered.

Ancillary components include several control cabinets, air compressor, water manifold and filtration, the air temperature control and blower components, and communications for remote monitoring. The transport tubes are typically routed using tensioned cables, hangers/carriers and towers.

The following utilities will need to be provided to the Whooshh equipment by the other project implementors (i.e., WDFW, dam owner/operator):

- 480 V 3 phase power
- A small quantity of water for lubrication of the transport tubes (50gpm, approx. 6.5 cfm or 0.1cfs)
- Remote internet access (10MBit/10MBit upload/down) Starlink and Verizon are two potential services. Whooshh has utilized satellite-based systems for remote locations in the past.

Data

The Whooshh FishL™ Recognition System is the imaging and data processing component of the system. This 1.5-meter-long component contains six high-definition cameras, three pairs. Each pair has a visible light and a near infrared (NIR) camera. Each pair is housed in a “camera box” which is positioned at a specific angle relative to the scanner bed on which the fish slides through. They are commonly referred to as the left, center and right camera boxes. All are positioned on the same cross-sectional plane such that as a fish slides down the scanner bed all six cameras function simultaneously to collect a series of three images each. Fish typically slide though at a rate of 2-3 m/sec. The optimized algorithms and processing system enables identification of the unrestrained, sliding fish from the background of the captured images and computational size analysis to be completed before the fish exits the scanner. The outcomes of the size analysis are immediately applied as the input to direct the sorting decisions; opening and closing gates as the fish continues sliding without handling or delay to the appropriately sized accelerator and into the Whooshh tube for immediate passage.

Within about 0.5 seconds the 18 images of the fish are taken, uploaded, associated, analyzed and information applied to direct sorting. In addition, a sequentially named image file of the 18 associated images is stored for post analysis. Additional data including computed fork length, circumference, orientation, speed and time stamp are linked to each image file and stored sequentially in a separate daily spreadsheet along with the daily fish count.

The immediate utility of the data gathered is toward accurately directing the sorting decisions to ensure effective, efficient and safe passage. The longer term utility of the data gathered is that it is collected without handling of the fish, and thus no stress, harm or delay, and no manpower is required to acquire the data. The system functions autonomously, can be run 24/7 and is triggered by the volitional passage of the fish over the false weir. The permanent recorded files are collected and stored in a format that does not require manual data input. Manual post analysis of the high-resolution fish images can be used to assess the overall condition of the fish, note pinniped or fishing-related damage, identify exterior tags (floy tags, gastric acoustic tag antenna extending from the mouth), fungal growth etc.

In addition, an optional PIT tag reader can be integrated with the system, and the associated PIT ID of tagged fish recorded synchronously with the other data from the scanner for additional post passage analysis.

Table 2. Summary of anticipated fish passage system functional elements –

Inclusion of these elements vary depending on passage option chosen

Project Element	Function and Intent
Scanning System	"FishL™ Recognition System" used to image each fish and provide size, species and other information to WPP. A pictorial record along with timestamp and sizing data is logged for every individual fish and can be used for reporting.
False Weir	Provides means to isolate and partially dewater fish prior to transport
PIT tag reader	A third-party PIT tag reader (Biomark) can be integrated into the system if desired.
Sorting system	Directs fish to appropriate passage lane or back to river or holding pond depending on scanner data, PIT tag data and installation settings. Any fish that is of inappropriate size to safely transport through the tube sizes as installed will be returned to the tailrace or holding pond. In addition, those fish not of the target species, or with out of range/incorrect PIT tag values will also be returned.
Auxiliary bypass	An additional sorting lane can be provided to a holding tank located adjacent to the sorting system. Based on daily settings, this can permit a programmable selection of fish to be routed for example, to an area for additional workup.
Accelerator system	Functions as an "airlock" to introduce fish to be transported through the Migrator™ tube. Accelerators are arranged in modular increments supporting up to 3 lanes per subassembly. Up to six can be supported in a single installation. Sensors ensure doors operate ahead of the fish allowing for an uninterrupted slide through the accelerator system.

Project Element	Function and Intent
Whooshh Migrator™ fish transport tubes	Convey fish to a distal exit. 5 tube sizes available to accommodate a variety of fish girth sizes. Supported on stands or overhead cabling and covered with environmental shroud.
Support and control skids	Modular equipment frames for blowers, temperature control, support equipment and controls systems.
Floating exit	Ensures fish exit the transport tube safely to the forebay (reservoir) surface at a desired location, angle and depth. Accommodates forebay fluctuation anticipated to occur during the period of migration.
Support cables, optional booms	Depending on precise configuration, bathymetry and anchoring locations, the overwater tube routing to floating exits will need to be designed. This may use any combination of floating booms, cable anchors and tensioning mechanisms.
Optional considerations for winter operations (if needed)	For operation during months when outside temperatures could be below freezing, localized heating will need to be provided to keep equipment above freezing. Optional heat tape addition to the transport tube is a consideration that could potentially be used to prevent localized freezing of the misters.

7. Key Installation Requirements and Structures

For each of the three passage configuration concepts contemplated in this document (see detailed discussion in Section 8, below), all feature tubing runs that travel up the face of the dam, and out to a floating exit platform in order to be able to continue to pass fish even at low reservoir stages. The tube routing to the floating exit platform will be directed toward the center area of the dam crest, allowing the fish the best opportunities for homing in on water from upstream, and avoiding the risk of fallback via the spillway on river left during high water levels, and the lower flow velocity area situated at river right. This routing would be directed across the 30’ wide dam crest road, and would apply under all three passage concepts. If trenching under the road is not a possibility, an over the road passage structure will be required to accommodate existing access provision for over-height vehicles. Precise height requirements are outside the scope of this document but should be incorporated into more detailed design activity, as needed. Further discussion on tube routing and exit is continued below.

Tube hanging on land

The Migrator™ tubes will be attached to tensioned support cables which in turn are attached to support anchors. These anchors will be positioned along the land route chosen consistent with slope and clearance constraints, following the routing up the face of the dam and toward the pass-through point at center-crest. An example of a support stand is shown in Fig. 3. Environmental housings can also be provided for tubes as illustrated in Fig.4

Fig 3. Simple support stand for over land tube section

Environmental Protection

To ensure consistent and safe fish passage as well as Whooshh equipment longevity it is important to consider and account for temperatures. As shown in Fig. 2 above, the Whooshh fish tube is wrapped in an environmental protection sleeve which serves a dual purpose. First, it protects the Migrator™ tube from UV rays extending the service life of the tube, and second, it helps deflect the heat of direct sun exposure on the tube reducing sun-related temperature increases inside the tube. Detailed analysis of expected temperature extremes is outside the scope of this document and would be needed to determine if and what additional temperature control measures are required.

Additionally, a conceptual environmental protection enclosure for the tube routing could be utilized. This would allow for protection from weather as well as vandalism. The design would incorporate access panels to allow tube access for any maintenance. See Fig 4, below.

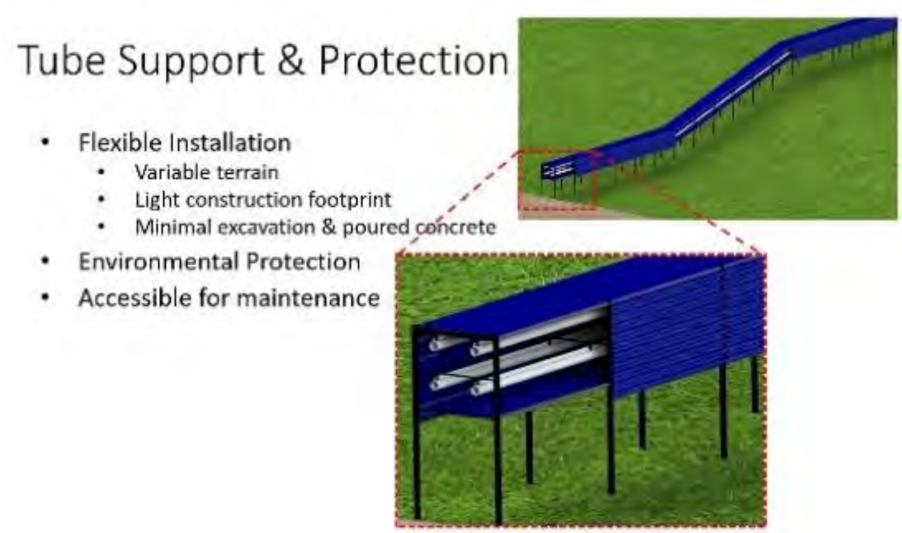


Fig 4. Environmental housing concept

Tube passage under road

Based on instruction given during the site visit, it is assumed for this project that it will be permissible to excavate a trench across the dam crest road to allow for the tube routing to pass under, and not hinder traffic usage on the road itself. This would be an approximately 3 foot deep by 3 foot wide trench through which the Migrator tubing ascending the face of the dam would pass at center-crest and exit into the reservoir toward the floating exit at the distal end. It is anticipated that the trench at the road surface would be covered by steel plates, allowing traffic to pass unimpeded as well as allowing system access if needed.

Tube passage over road

Should the excavation of a shallow passage trench not be permissible, an over-the-road structure would be used. At road crossings, a simple fish transport tube support gantry bridge can be constructed to maintain existing vehicular access to power houses and spillways. Precise height and width will be tailored to suit site requirements. Longer spans can be implemented with towers and tensioned cables. An illustration of a temporary road crossing structure is provided in Fig. 5.

Fig. 5. Simple over-road tube hanging structure

Tube hanging over water

Within the reservoir, the tube(s) will be suspended over water by a free span of tensioned support cable(s) as shown in Fig. 6. Fig 7. shows the same installation at low water. Depending on the length of the overwater section, the deployment may benefit from integration of additional floating booms. These can be used to distribute anchor loads, assist with tube profile at different water stages, and reduce the total cable tension required. Precise installation recommendations can be provided at a later stage once the bathymetry, geology and other constraints of the sites are understood. That is outside the scope of this current document.

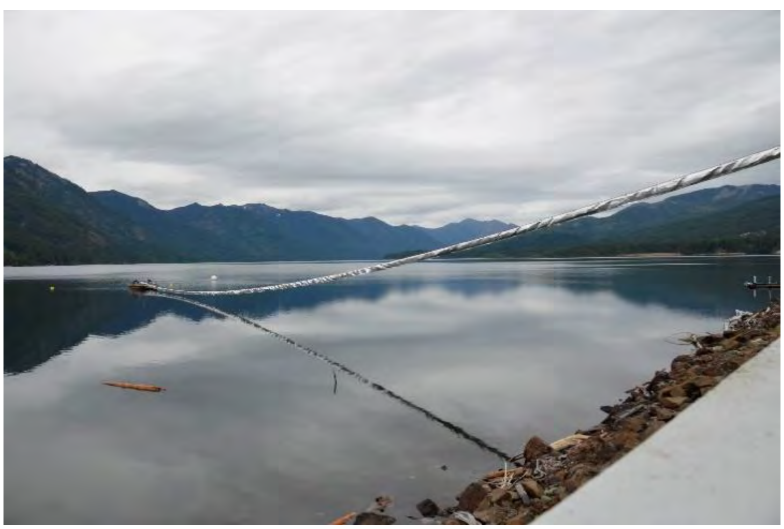


Fig 6. Over water tube routing, high water

Fig.7. Over water tube routing, low water.

Fish exit

Due to the variable stage height of the Skookumchuck reservoir during the operating months, the fish exit will need to be on a floating structure. To allow for safe fish re-entry into the reservoir, the transport tube ends are redirected to ensure that fish enter the water at a 30-degree angle as close to the water surface as practicable on the upstream side of the floating structure. Fish typically travel at less than 25 feet/sec when they reenter the water at surface level. Exact distance will be calculated to accommodate historical reservoir fluctuations and dam slope within the forebay reservoir, and can be scaled to accommodate further fluctuations if requirements change. An example of such a floating structure is provided in Fig.8.

Fig 8. Fish exit barge configured for single Migrator™ tube.

Communications

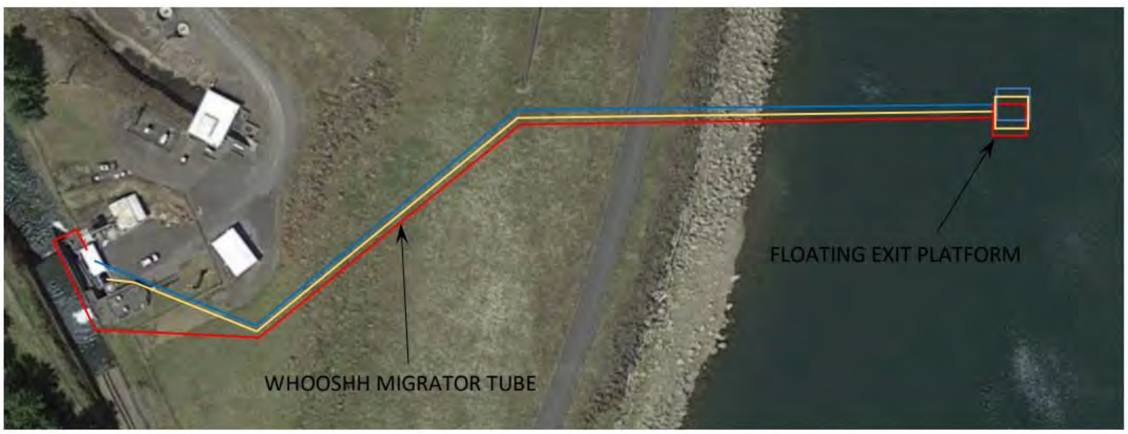
A 10MBit/10MBit internet linkage is required to facilitate remote monitoring and daily fish passage reporting.

Power requirements

480V 3 phase power is required to operate the blowers, control cabinets, air chiller and compressor subassemblies. System remains idle (quiescent) when no fish are being transported.

8. Installation-Specific Considerations

Three different potential routing scenarios are being proposed. Each of these originates from different points at the existing adult fish handling facility. As described in section 7, above, and as shown in Fig. 9, below, all three routing options then consider the same routing across the face of the dam, across the dam crest road, and out at the distal end to the floating platform in the reservoir.



WHOOSHH INNOVATIONS	**SKOOKUMCHUCK DAM** **WHOOSHH FISH PASSAGE ROUTING OPTIONS**
	WHOOSHH INNOVATIONS **2001 W GARFIELD ST STE C126** **SEATTLE, WA 98119**
	Scale: not to scale — Rev: A

Fig 9. Routing concept scenarios.

8.1. Fish Passage Concept 1 – Red Routing

This concept option contemplates a fully automated system that scans/sorts and transports fish out of the adult fish facility in the downriver direction, makes a 180 degree loop and heads back upriver and contemplates the possibility of hanging the tubes along the facility wall/fence line to a point about 50 yards up, where they bear left and onward up the face of the dam, cross the dam crest road, and out to the distal end on the floating platform in the reservoir.

Under this red routing option, fish would enter the facility as they do now, ascending the steeppass from the river and into the holding pool within the fish handling facility. They would then ascend the false weir as they do now, except they would not fall forward into the sorting bin, they would instead slide forward through the Whooshh FishL Recognition™ scanning system and then be sorted based on the scan results. Once sorted, the fish would then be routed via the appropriate misted tube lane (or bypassed back to river) and proceed forward in the downriver direction for approximately 15-20 feet before turning left toward the spillway and left again in the upriver direction. The route would utilize the spillway wall and fence line as support for approximately 50 yards before bearing diagonally left away from the wall and up the face of the dam for approximately 900 feet to a point where it would bear right for the final stretch directly up to cross the dam crest road, and exit out to the floating platform where they are then released into the reservoir at a distance of approximately 50-100 feet from shore. Exact distance will be calculated to accommodate historical reservoir fluctuations, and can be scaled to accommodate further fluctuations if requirements change.

	SKOOKUMCHUCK DAM WHOOSHH FISH PASSAGE ROUTING OPTIONS RED OPTION CONCEPTUAL SKETCH		
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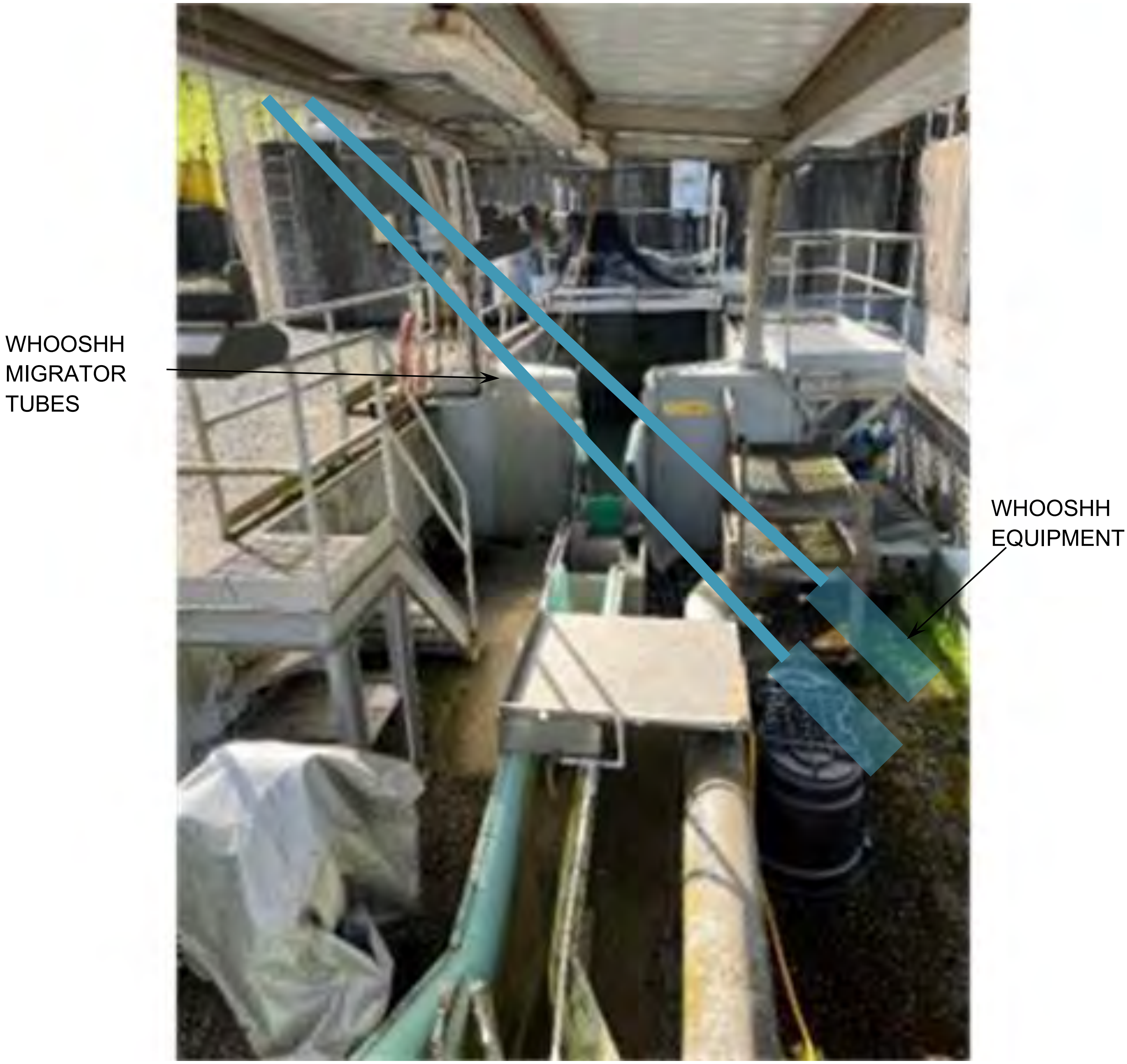
		Scale: not to scale	Rev: A

Required elements: This option would require Whooshh equipment (scanner, sorting gates, accelerator) to be aligned from the point where the fish cross the false weir toward the area where the footing for the existing gantry crane is located. Additional equipment would include chiller, control cabinet, misted tubing lanes, mounting stanchions, floating exit. Given the length of the equipment and the space available, it is likely that unless the equipment could be set at enough of an angle to allow for clearance, structural modifications would be needed to allow for the tubing to exit the facility as planned toward the river and turn back toward the outer wall to begin ascending upward along the fence line. Such structural modifications could include relocating the existing false weir to a point 5 feet or more back, or relocating the footing for the existing gantry crane. Given that such structural modification is somewhat impractical, this option is considered less desirable at the current time, unless it could be worked into upcoming fish facility design upgrades.

8.2. Fish Passage Concept 2 – Blue Routing

This concept contemplates a simpler hand-loaded system that stands adjacent to the existing sorting area. The concept here is that after hand sorting, personnel would then hand-load selected fish into an accelerator(s) for onward transport over the dam. While this option is less equipment-intensive, fish will still experience anesthetization and handling by personnel.

Under this blue routing option, fish would enter the facility as they do now, ascending the steeppass from the river and into the holding pool within the fish handling facility. They would then ascend the false weir as they do now and would then slide forward into the sorting bin. At this point personnel would make a manual decision on which fish to send onward over the dam, and which to bypass back to river. They would then manually pick up each fish and place it into the appropriate accelerator tube directed out of the fish handling facility. The fish would be transported up the face of the dam for approximately 900 feet to a point where the routing would bear right for the final stretch directly up to the trenched area at or near center-crest, cross the crest road, and exit out to the floating platform where they are then released into the reservoir at a distance of approximately 50-100 feet from shore. Exact distance will be calculated to accommodate historical reservoir fluctuations, and can be scaled to accommodate further fluctuations if requirements change.



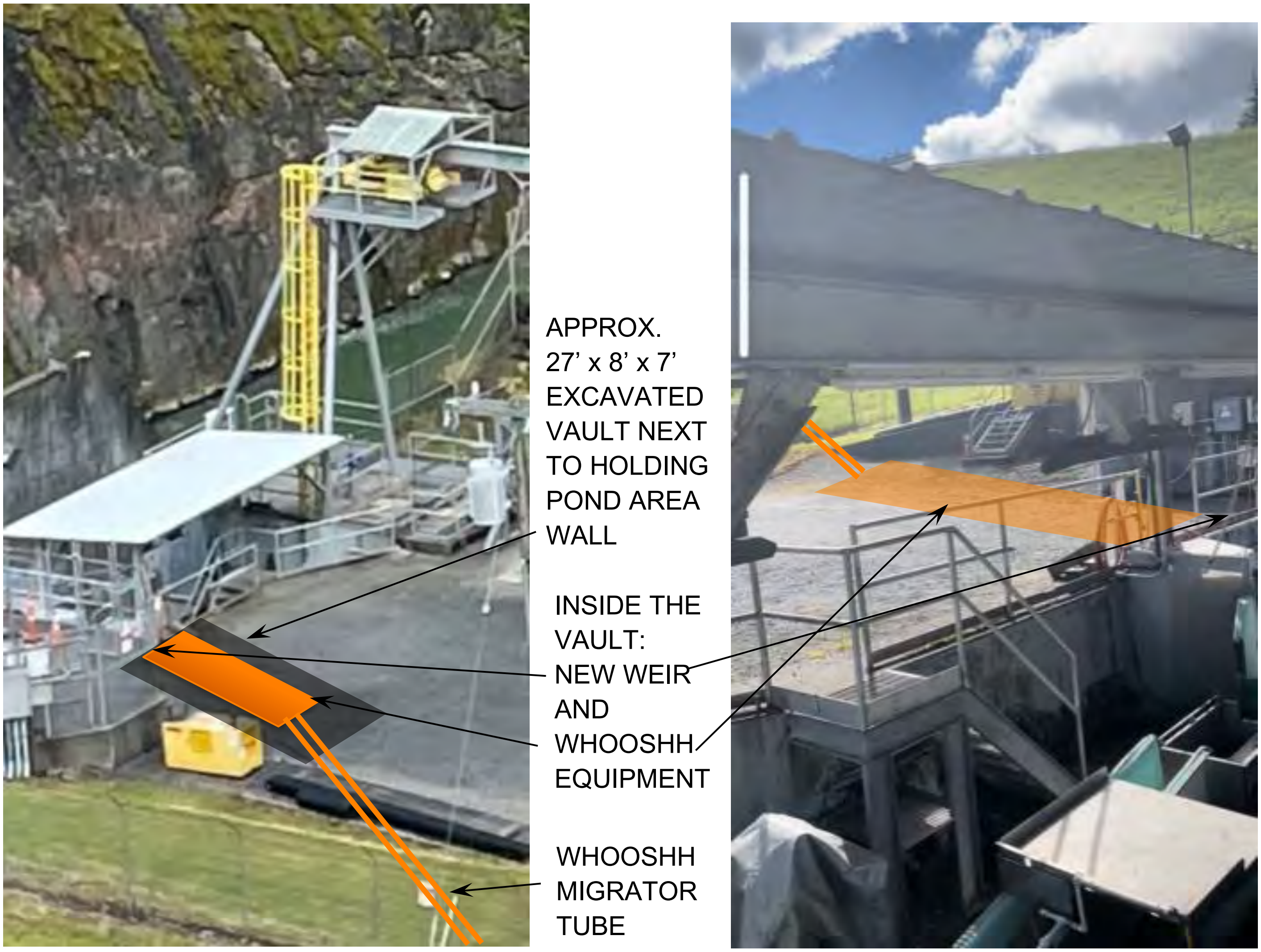
WHOOSHH INNOVATIONS	SKOOKUMCHUCK DAM WHOOSHH FISH PASSAGE ROUTING OPTIONS BLUE OPTION CONCEPTUAL SKETCH
	WHOOSHH INNOVATIONS **2001 W GARFIELD ST STE C126** **SEATTLE, WA 98119**
	Scale: not to scale | Rev: A

Required elements: Whooshh accelerator(s), misted tubing, instrumentation, mounting stanchions, floating exit platform. Under this option, Whoosh hand-loaded accelerator(s) would need to be situated adjacent to the existing sorting bin. The current brood rack would be moved to the other side of the sorting bin and the accelerators would be sited in the area just forward from the area where the rack currently sits. The tubing run(s) would exit the facility from the accelerator(s) directed outward over the parking lot and onward up the face of the dam. For this option, no significant structural modifications to the existing fish facility would be needed.

8.3. Fish Passage Concept 3 – Yellow Routing

The yellow routing option is for a fully automated, volitional-entry system that scans/sorts and transports fish out of the facility in the same general direction as the hand-loaded option does. The starting point for this option, however, is from a point perpendicular to the holding pool (just behind the current sorting area). Here a separate false weir would be installed for fish to volitionally cross, enter the Whooshh scanner, to be sorted and transported up and over the dam (or bypassed).

Under this yellow routing option, fish would enter the facility as they do now, ascending the steeppass from the river and into the holding pool within the fish handling facility. The current false weir and sorting bin/chute would remain intact and useable. A gate would direct them to either ascend the existing false weir as is done currently, or to a separate (new), false weir situated perpendicular to the existing weir, along the NE side wall of the holding pool abutting the existing parking lot. The two false weirs would be plumbed such that they operate independently, one at a time to avoid competing and conflicting flow streams. When fish passage is desired, the new false weir would be watered up and fish allowed to volitionally enter the fish passage system by swimming over the new false weir. Should manual, current-day sorting and assessment be desired, the original false weir could be watered up and fish crowded and allowed to volitionally swim over the false weir into the sorting bin for manual assessment as is done today. Operation would be similar to the Red option, but the tube would initially route outward in the direction of the parking lot diagonally away from the wall and up the face of the dam before following the same path up to the dam crest road crossing and then on to the floating exit.



WHOOSHH INNOVATIONS

SKOOKUMCHUCK DAM

WHOOSHH FISH PASSAGE ROUTING OPTIONS
YELLOW OPTION CONCEPTUAL SKETCH

WHOOSHH INNOVATIONS
2001 W GARFIELD ST STE C126
SEATTLE, WA 98119

Scale: not to scale | Rev: A

Required elements: This option would require Whooshh equipment (scanner, sorting gates, accelerator) to be situated perpendicular to the current holding pool area. This would require structural modification, though only in the form of excavation of a vault in which to place the system. This would be approximately 10 feet deep and be situated just outside of the existing fish facility, running outward from the holding pool wall, extending approximately 30 feet along the upper edge of the existing parking area. Additional equipment would include false weir, chiller, control cabinet, misted tubing lanes, mounting stanchions, and floating exit.

9. Operational Theory

For the red and yellow volitional-entry options, during normal operation water will be coming over the false weir. Fish, having already ascended the existing steeppass, and presented with the flow from either of the false weirs (depending on option) will have a natural tendency to clear the false weir individually. After dewatering at the top of the false weir, they go through the scanner on a wetted gravity slide. As they enter the scanner, the control system activates the accelerator and tube misting and the propulsion blowers. Fig.10 shows multiple sockeye in the flowbox singulating over the false weir.

Fig.10. Sockeye singulating over false weir.

The scanner captures images used to computationally derive fish sizes and informs the control system, directing chute gate operations such that the fish slide through without delay to the appropriate accelerator and tube for passage. Fish images and scanned data are automatically recorded with assigned sequential file names and time/date of imaging captured. An example of scan processing is provided in Fig. 11, and of a scanned chinook salmon in Fig. 12.

Fig. 11 Scanning system measurement

Fig. 12. Mature wild chinook imaged by scanner. Note adipose fin, and characteristic black mouth, with spots on body and tail.

The control system confirms all systems are on and working correctly, and then using the scan information directs the fish via sorting gates to the appropriate accelerator, or to the bypass which returns the fish to the tailrace (or holding pond depending on specific configuration). Fish are only nominated for transport when the scanning system is able to provide valid scanned size, species and hatchery/wild data. Any fish not scanned will therefore also be bypassed and returned to the tailrace or holding pond.

The control system is also capable of integrating other external input into the decision making, including PIT tag values read in real time that fall within a predefined range, provided a suitable reader is integrated into the decision array.

An optional side sampling chute is also available, that can be locally programmed to deliver specific numbers and/or selected species to a suitably located holding tank next to the scanning and sorting system. Fish directed to these tanks can be used for additional workup or auxiliary trap and haul operations.

Having entered the accelerator, the fish selected for transport in that lane continues its gravity slide to the mouth of the transport tube. The accelerator acts as an air lock and facilitates the introduction of the blower stream behind the fish providing the motive force for transport.

The entire sequence from false weir to tube entry takes typically 2-3 seconds.

10. Anticipated Performance

The systems are designed to be able to accommodate more than one fish in a tube at one time. It is anticipated for this project that each tube will be able to accommodate a fish every 7 seconds. Given the relatively small number of salmonids that currently migrate up the Skookumchuck, we anticipate no capacity issues and note that the systems are scalable. Throughput will be regulated by the control system to a maximum of 5 fish per tube section simultaneously. Transit time for each individual fish will be on the order of 36-60 seconds. It is important to note that the fish is always travelling with a bolus of water, so this is not equivalent physiologically to that period in free air.

The equipment has been designed with relatively few moving parts, and these are typically readily sourced industrial components with good mean time between failures (MTBF) values and reliability. Other parts are solid state with long life expectancy. Some routine maintenance is required, but equipment failures have been very infrequent within the current installed base for Whooshh equipment.

Scalability - Additional capacity can be provided by the system infrastructure as designed by augmenting blower and sorting capacity to support additional accelerator/tube subsystems up to a total of six lanes. At this time the maximum theoretical capacity of each system with multiple tubes installed is approximately 20-24 fish per minute. This translates to a maximum of 1200 fish per hour, or in the region of 13,000 fish per day during average daylight hours per system. The system is fully automated and capable of 24/7 fish passage. Fish, however, do not tend to migrate at the same rates at all hours of the day and night.

11. Deployment Construction Sequence and Duration

Deployment construction should be completed in four stages. Note these estimates are purely for the deployment construction activity and do not include any time for fabrication, manufacturing, procurement of long lead items, contracting, or transit from Seattle to the site. In addition, there is a detailed design activity and permitting that will be required prior to any deployment.

1. First would be site preparation, staging, performing excavation work for dam crest pass-through (if permissible), and vault area (yellow option only)

   Preliminary Estimate: 3-4 weeks

2. Next the supporting infrastructure should be installed. This would include any equipment pads, under or over-road structures, support stands/towers, floating exit, any booms required

and overwater anchoring. Also completed at this stage would be any power provisioning or gravity fed water piping required. It would be advantageous to schedule this well in advance of the expected target fish run schedule to ensure completion and to allow installation considerations relative to variable water level fluctuations and flow conditions.

Preliminary Estimate: 3-4 weeks

3. Whooshh equipment and tube hanging takes place after site preparation is complete.

   Preliminary Estimate: 1-2 weeks

4. Commissioning and Q/C testing. Should be conducted in suitable time before anticipated fish arrival, as well as during first week of fish passage.

   Preliminary Estimate: 2-3 weeks.

12. Summary of Costs

Opinion of Probable Cost

	-time Equipment and Construction Costs	Fish Facility Modifications		Annual Maintenance	
Red Option					
1. 2-tube Whooshh Passage Portal System	$1,286,500	$250,000		$25,000	
2. Road Crossing and Exit Platform	$105,000				
Blue Option					
1. 2 Salmon Cannon Portable Systems	$520,000			$10,000	
2. Crest Excavation Road Crossing and Exit Platform	$105,000				
Yellow Option					
1. 2-tube Whooshh Passage Portal System	$1,286,500				
2. Road Crossing and Exit Platform	$105,000	$65,000		$25,000	

Operation and Maintenance Costs

Operation and maintenance costs include those reoccurring or one-time costs that are incurred over the life of the project.

Operational costs are costs associated with items such as staffing required to keep the facilities functioning, power costs, and periodic inspection.

Maintenance costs are the costs associated with keeping system components functioning and actions that allow system components to achieve their optimal useful life, such as painting, lubrication of moving parts, repair of damage, replacement of broken or non-functional parts, updating electronic components, and improving PLC programming (depending on option chosen). Expendables as well as equipment and electrical power costs are incorporated to the extent possible given the level of detail formulated as part of preliminary alternative development. An allowance has also been made for evaluation and data analysis of passage data and reporting.

Estimates of annual operating and maintenance costs are inclusive of all labor, materials, expendables, and electrical costs assuming a local supply source at currently prevailing rates. Parts for systems under all three options are standard industrial grade and typically available locally.

No attempt has been made to estimate additional expertise required such as fisheries biologists to adaptively manage the overall fish management above the dam, which would be identical for any passage solution.

13. Summary of Tradeoffs

Features	Concept 1: Red Option	Concept 2: Blue Option	Concept 3: Yellow Option
Volitional Entry	Advantage	Disadvantage	Advantage
No Handling/Delay	Advantage	Partial	Advantage
Scalable	Advantage	Advantage	Advantage
Lower Capital Cost (Relative to Other Concept Options)	Disadvantage	Advantage	Partial
Flexibility for Adaptive Management/Modification	Advantage	Advantage	Advantage
Power/Internet Connectivity Needed	Disadvantage	Partial	Disadvantage
Remote Access Fish Data Automatically Gathered/Retained	Advantage	Partial	Advantage
No Fish Trap Facility Modifications Needed	Disadvantage	Advantage	Partial
Eliminate Need for Trap/Haul	Advantage	Advantage	Advantage
No Impact to Current Fish Facility Operations	Disadvantage	Advantage	Partial
No Manpower Needed to Operate	Advantage	Disadvantage	Advantage

= Advantage

= Disadvantage

= Partial

14. Conclusion

All three of the fish passage concept scenarios that are the subject of this Technical Memorandum are feasible for the initially-proposed steelhead passage (and also later for coho and chinook). It should also be noted that other routings could also be considered (along spillway and under bridge, for example). Based on prior installation experience, installing equipment under any of the three concept scenarios would not be a complex endeavor. Implementing would require approximately three months' time, regulatory permissions, and capital expenditure, and all would contribute to stakeholder goals such as safe and effective fish passage and flood control, among others. Recognizing the pros and cons of each scenario, and based on analysis of species, site characteristics and equipment, it is our recommendation that the yellow option be pursued for further development as it provides state-of-the-art fish passage, free of handling and delay, and can be implemented with little impact to the existing fish trap facility.

References*:

1. T.J. Koch, S.C. Evans, A.C. Hansen et al. (2017). Evaluation of Sockeye Salmon after Passage through an Innovative Upstream Fish-Passage System at Cle Elum Dam. USGS Open File Report, 2017-1116

2. D.R. Geist, A.H. Colotelo, T.J. Linley, K.A. Wagner, A.L. (2016). Effects of a Novel Fish Transport System on the Health of Adult Fall Chinook Salmon. *Journal of Fish and Wildlife Management* (2016) 7 (2): 347–358.

3. L. Garavelli, T. J. Linley, B. J. Bellgraph, B. M. Rhode, J. M. Janak, A. H. Colotelo (2018). Evaluation of passage and sorting of adult Pacific salmonids through a novel fish passage technology. Fisheries Research 212 (2019) 40-47. https://doi.org/10.1016/j.fishres.2018.12.010

4. Erikson, U. et al., 2016. Evaluation of the Whooshh Fish Transport System for Transfer of Atlantic Salmon Broodstock Between Two Tanks. Conducted by SINTEF. Whooshh Study 2016.

*Additional Whooshh study projects and testing results can be found at www.whooshh.com/thescience.

APPENDIX D
EDT MODELING DETAILS

EDT MODELING DETAILS

D.1 Lower Skookumchuck Restoration Reaches Update

Restoration actions have been completed or are in progress on three Ecosystem Diagnosis and Treatment (EDT)-defined reaches in the lower Skookumchuck River: Skookumchuck-5, Skookumchuck-6, and Skookumchuck-9. Actions include large wood placement, reconnection of floodplain and off-channel habitat, and riparian restoration.

In Skookumchuck reaches 5 and 6, an Aquatic Species Restoration Plan (ASRP) reach-scale project will restore multiple habitat attributes. Large wood loading will be conducted to meet 75% of historic guidelines; this was reflected in the EDT model by improving the large wood attribute and refining model habitat types (additional pools/ riffles). Floodplain and side-channel habitat will also be restored; in the EDT model the artificial confinement attribute was changed to reflect less confinement and the percent of side channels and amount of off-channel habitat was increased. Riparian habitat will also be restored under this alternative; in the model this was reflected by some improvement in the riparian habitat attribute in the current time period and additional improvement in late-century due to growth of the riparian area. The project also includes removal of four culverts along the EDT reach RB Trib 0794-1, increasing accessible habitat.

Approximately 35% of Skookumchuck-9 was restored in 2021. Large wood was added to the reach; this was reflected in the model through improvement of the large wood attribute and refining model habitat types (additional pools/ riffles). Floodplain and off-channel habitats were reconnected; this was reflected in the EDT model by increasing the percent and amount of side channels and also increasing seasonally inundated floodplain. Riparian habitat was also restored under this alternative; in the model this was reflected by some improvement in the riparian habitat attribute in the current time period and additional improvement in late-century due to growth of the riparian area.

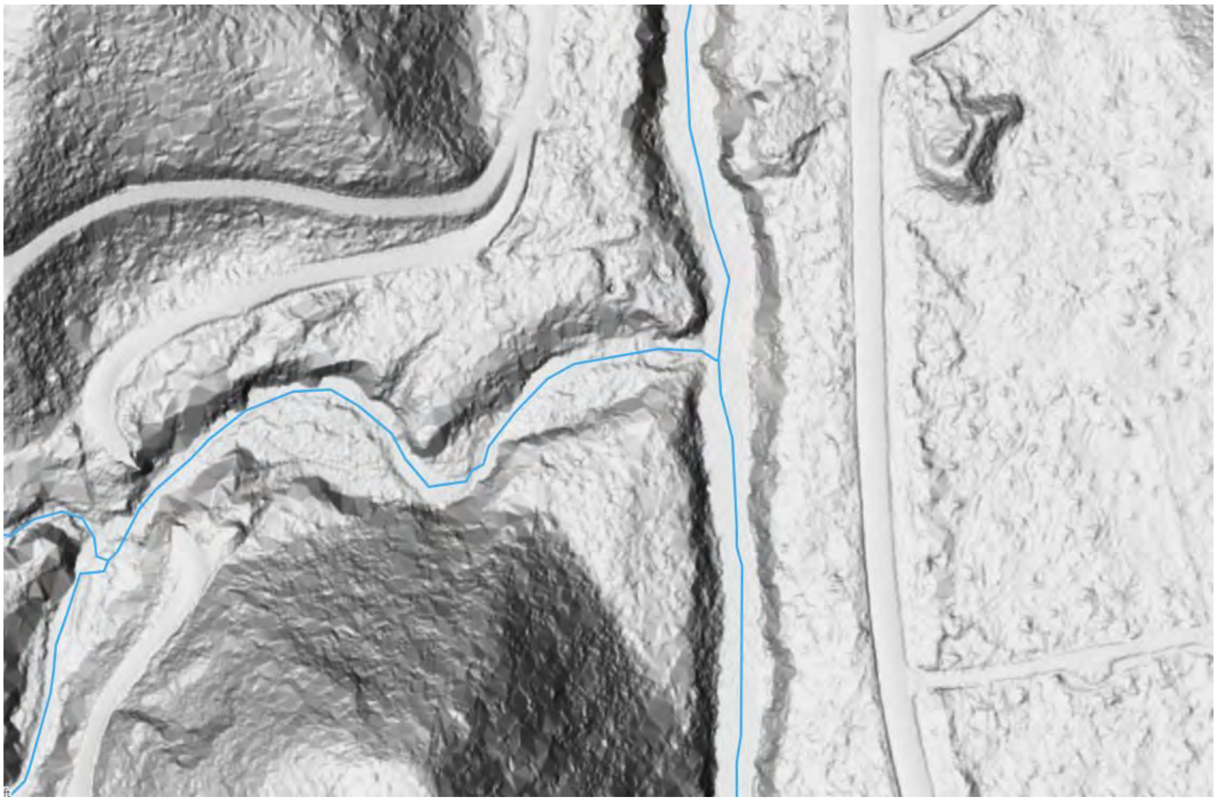
D.2 Upper Skookumchuck Reaches Aerial Photography Update

Light Detection and Ranging (LiDAR) and high-resolution aerial photography from the head of the Skookumchuck Reservoir along the upper mainstem Skookumchuck River to approximately river mile (RM) 37 was obtained for this study by GeoTerra in May and June 2022, respectively. Anchor QEA staff performed an analysis of the LiDAR and aerial photography that included documenting all wood observed below bankfull width of the river channel (both individual counts and log jam counts and areas); measurements of riffles, pools, glides, and cascades; documenting reach lengths, bankfull widths and valley widths; visually documenting the riparian condition (tree type and height); and documenting, where visible or from the LiDAR, obvious waterfalls that are likely to be barriers on the tributary streams. Habitat features on the tributaries were not documented. The width of the river channel and canopy cover made documentation less accurate for EDT reaches Skookumchuck-15 and Skookumchuck-16. Figures D-1 and D-2 show segments of the high-resolution photography and Figure D-3 shows the LiDAR hillshade.

Figure D-1
EDT Reach Skookumchuck-12 Upstream of Pheeny Creek

Figure D-2
EDT Reach Skookumchuck-13 Upstream of Laramie Creek

Figure D-3
LiDAR Hillshade of Confluence of Eleven Creek with the Upper Skookumchuck River



The results of this analysis were incorporated into the EDT model. EDT reaches Skookumchuck-11 through Skookumchuck-16 were updated using these data. Attributes updated in the model based on analysis of the photographs included channel length, channel width, riparian condition, large wood, habitat types, and channel confinement. In late-century, attribute updates were made to include "riparian maturation" hypotheses that were present in the late-century baseline from the ASRP analysis.

D.3 Fish Passage at Skookumchuck Dam Among Alternatives

Fish passage varied by species, direction of movement, and life stage among alternatives. Passage values included in the scenarios are outlined in Table D-1. The Current Operations adult upstream passage is based on the relative percentage of steelhead that the Washington Department of Fish and Wildlife (WDFW) passes upstream of the dam using the fish collection facility and the downstream passage for juveniles and adults is based on the observations of the fish sluice conditions but has not been documented. For the Fish Passage Only alternative, it was assumed that a larger percentage of steelhead that return to the fish collection facility would be passed upstream, while still providing broodstock for the hatchery and fish for other purposes as currently distributed. Downstream passage of steelhead adults and juveniles was estimated to be

93% because the vast majority of the fish would find and use a fish sluice that meets National Marine Fisheries Service (NMFS) passage criteria and survival would be high. Coho and Chinook salmon adult upstream passage was based on an assumption that all coho or Chinook salmon that enter the fish collection facility would be passed upstream, whereas no fall Chinook salmon would be passed upstream; juvenile downstream passage would be similar as for steelhead. Because the Flood Storage Only alternative was modeled with no changes to the existing fish passage facilities or operations, it is the same as Current Operations. For the Dam Removal alternative, there would be unhindered passage for steelhead, coho salmon, and spring-run Chinook salmon, both adults and juveniles, but fall-run Chinook salmon are not modeled as spawning upstream of the dam.

Table D-1
Passage Values Included at Skookumchuck Dam for all Species and Scenarios

ALTERNATIVE	SPECIES	ADULTS UPSTREAM	ADULTS DOWNSTREAM	JUVENILES DOWNSTREAM
Current Operations and Flood Storage Only	Steelhead	5%	5%	15%
	Chinook Salmon, Coho Salmon	0	N/A	0
Fish Passage Only	Steelhead	33%	93%	93%
	Coho Salmon	100%	N/A	93%
	Spring-Run Chinook Salmon	100%	N/A	93%
	Fall-Run Chinook Salmon	0	N/A	0
Dam Removal	Steelhead	100%	100%	100%
	Chinook Salmon, Coho Salmon	100%	100%	100%

Note:
The same values among an alternative were used for both time periods of analysis.

D.4 Flow, Width, and Floodplain Among Alternatives

Both HEC-ResSim and RiverFlow2D modeling results received from Watershed Science & Engineering (WSE) were used to construct environmental attribute ratings that were input into the EDT model to describe potential flow conditions that salmon are exposed to as they move through the system. Additional modeling by WSE provided channel widths within in-channel bankfull limits as well as widths that exceeded bankfull limits, representing floodplain, throughout the year. These data were used to calculate monthly estimates of maximum channel width and floodplain area by alternative for Skookumchuck reaches downstream of the dam.

The methods used to convert the modeling results for flow and widths to EDT ratings for high and low-flow environmental attributes, monthly maximum channel widths, and monthly floodplain area estimates are described in the following sections for both existing and late-century climate conditions under the four scenarios: Current Operations, Dam Removal, Fish Passage Only, and Flood Storage Only. The combination of the two climates modeled and the four scenarios results in eight different scenarios modeled using EDT: Existing Climate Current Operations, Existing Climate Fish Passage Only, Existing Climate Flood Storage Only, Existing Climate Dam Removal, Late-Century Current Operations, Late-Century Dam Removal, Late-Century Fish Passage Only, and Late-Century Flood Storage Only. Example graphs of flow and width attributes were made for Skookumchuck-1 (lowest reach, from mouth to the junction of Coffee Creek), Skookumchuck-4 (near the middle of the modeled area), and Skookumchuck-9 (just below the dam).

D.4.1 Flow Ratings

For each scenario, daily flow of Skookumchuck River was modeled in 15-minute increments from October 2007 to March 2022, providing 15 years of modeled flow data for segments downstream of Skookumchuck Dam to the mouth of Skookumchuck where it joins the Chehalis River. There were seven HEC-ResSim segments modeled within this stretch of river. Average daily flow was calculated for each segment and EDT flow ratings were applied for both high-flow and low-flow conditions. The locations of the HEC-ResSim-modeled segments were then matched to those of EDT reaches Skookumchuck-1 through Skookumchuck-9, which are downstream of the current site of Skookumchuck Dam, and flow ratings were finalized for those EDT reaches. When one HEC-ResSim segment fell within one EDT reach, the ratings for that segment were used directly for that reach. When several HEC-ResSim segments fell within an EDT reach (when more than 50% of a ResSim segment was within the reach), the average of the ratings for those segments was used.

Changes in the timing and quantity of flow due to land uses and flow regulation can affect responses of salmonids leading to changes in overall performance of their populations (Lestelle 2005). In EDT, both high and low flows are rated based on changes in flow from a historic or unregulated state and describe the relative change in flow during high-flow and low-flow periods related to land use effects on hydrological patterns. For the purposes of the EDT modeling for this area, the Current Dam Removal scenario was used as the best-available data representing an unregulated state. There is a two-part process for calculating the ratings for the high-flow and low-flow attributes for a reach within a scenario. First, the highest rating possible for a reach is determined based on the modeled flow and then a monthly pattern-scalar is established that is used to calculate the other months' ratings. The month with the highest (for High Flow) or lowest (for Low Flow) flow are assigned a scalar of 1; the other months' ratings are scaled appropriately based on their flow relative to the maximum-month ratings.

D.4.2 Changes in Inter-Annual Variability in High Flows

To assess changes in inter-annual variability of high flows for a scenario, the change in peak annual flows of a scenario were evaluated relative to the unregulated flow represented by the

Current Climate Dam Removal scenario. The index values for the high-flow EDT attribute are scaled to the unregulated state, which are assigned a Rating Index 2 (Table D-2). Hence, the Current Climate Dam Removal scenario was assigned a peak rating of 2 and a scalar of 1 was applied to January, which had the highest average-flow in the HEC-ResSim flow data for each reach. For the other months of the year, ratings for the Current Climate Dam Removal scenario were scaled based on their monthly flow, meaning January would have a maximum rating of 2 and other months would have a rating of less than 2. For High Flow monthly ratings for the other seven scenarios, shifts toward a higher peak discharge than that of the Current Climate Dam Removal scenario would be represented by increases toward ratings of 3 and 4 and shifts toward reduced peaks by values of 0 and 1.

Table D-2
EDT Ratings (Index Values) for Changes in Inter-Annual Variability in High Flows

Index 0	Index 1	Index 2	Index 3	Index 4
Peak annual flows expected to be strongly reduced relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >40% and <100% decrease in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known by regulated flow levels. This condition is associated with flow regulation or water diversion projects.	Peak annual flows expected to be moderately reduced relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >20% and <40% decrease in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known by regulated flow levels. This condition is associated with flow regulation or water diversion projects.	Peak annual flows expected to be comparable to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR <20% change in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR <5% reduction in average T_{Qmean} compared to the undeveloped watershed state.	Peak annual flows expected to be moderately increased relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >20% and <40% increase in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR >5% and <15% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemplified in some forested watersheds with high road density that experience significant rain on snow events, as the North Fork Stillaguamish River (Pess and others *in review*). Note: many managed forested watersheds in the Pacific Northwest exhibit slight, if any, increases in peak annual flows since logging commenced (see Ziemer and Lisle 1998).	Peak annual flows expected to be strongly increased relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >40% and <110%+ increase in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR >15% and <45% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemplified in watersheds with significant urbanization (e.g., >20%).

Source: Lestelle 2005

D.4.3 Changes in Inter-Annual Variability in Low Flows

For each scenario, changes in the inter-annual variability in low flows were also evaluated relative to Current Climate Dam Removal scenarios as the best-possible available data for an undisturbed watershed (Table D-3). A rating Index of 2 and a scalar of 1 were assigned to August for the Current Climate Dam Removal scenario, which had the lowest average-flow in the HEC-ResSim modeling for all reaches and scenarios. Ratings higher than 2 indicate a shift toward more inter-annual variability and/or lower flow discharge (lower flows during low-flow periods) and ratings less than 2 indicate less flow variability and/or increased low flows (higher flows during low-flow periods).

Table D-3
EDT Ratings (Index Values) for Changes in Inter-Annual Variability in Low Flows

Index 0	Index 1	Index 2	Index 3	Index 4
Average daily low flows expected to be strongly increased compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >75% increase in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be moderately increased compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >20% and <75% increase in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be comparable to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR <20% change in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state).	Average daily low flows expected to be moderately reduced compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >20% and <50% reduction in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be severely reduced compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >50% and <=100% reduction in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.

Source: Lestelle 2005

D.4.4 Flow Ratings for Skookumchuck Reaches

Within a scenario, January had the highest High Flow ratings within a year. Within a modeled climate (current or late-century), the Dam Removal scenarios also had the highest ratings as compared to the Fish Passage Only, Flood Storage Only, or Current Operations scenarios (Figure D-4). The Dam Removal scenarios also had the highest low-flow ratings, particularly in Skookumchuck-4 and Skookumchuck-9.

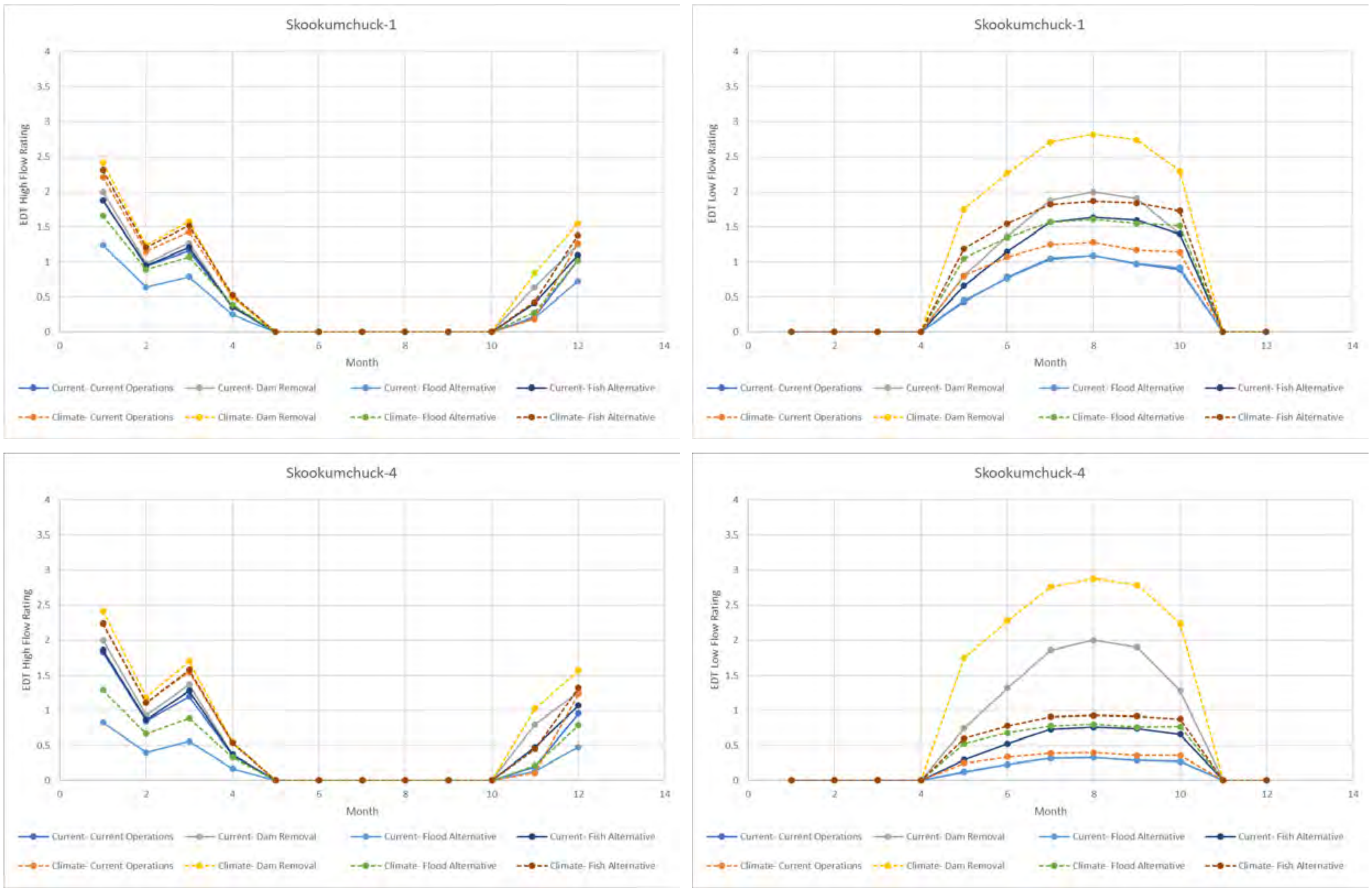
D.4.5 Monthly Channel Widths

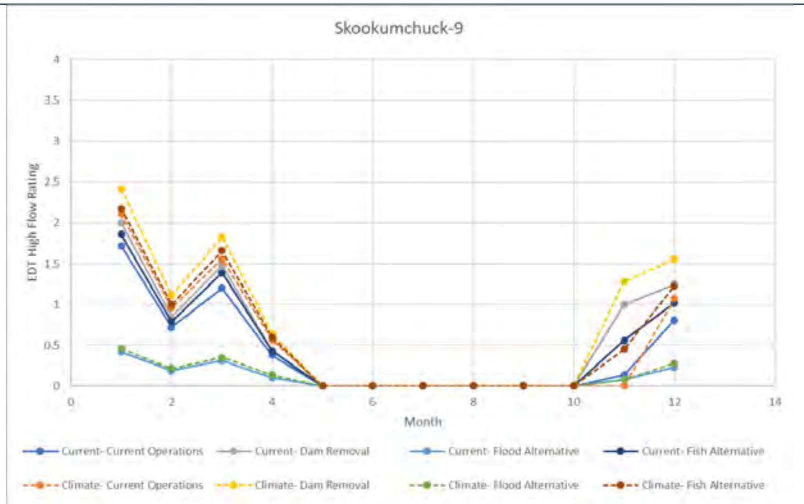
For each scenario and timeline, monthly channel widths confined within the bankfull channel were modeled for each EDT reach below Skookumchuck Dam in 15-minute increments for the same 15-year period as the modeled flow. For each reach, the maximum monthly channel width was extracted for within the period modeled (15 years) and the average of the maximum monthly widths was used as a representative monthly channel width for a reach in EDT.

D.4.6 Floodplain Area

For each scenario and timeline, monthly channel widths that were allowed to exceed a reach's defined bankfull width, referred to as the total width, were also modeled in 15-minute increments for the 15-year period from 2007 to 2022 for the EDT reaches below Skookumchuck Dam. For each reach, the maximum monthly total-width was taken for each year, and the average of each month's maximum total width for the 15-year period was used as the representative total width for that month/reach. To calculate the floodplain area, the defined bankfull width for a reach was subtracted from the average maximum monthly total width to determine the wetted width that exceeded bankfull width (the flooded area exceeding the channel). The flooded width for a month was multiplied by the reach length to calculate an estimate of floodplain area square meters, which was then converted to acre area.

Figure D-4
High (left column) and Low (right column) Flow Ratings for EDT Reaches Skookumchuck-1, Skookumchuck-4, and Skookumchuck-9




Skookumchuck-9
EDT High Flow Rating
Month
Current- Current Operations
Current- Dam Removal
Current- Flood Alternative
Current- Fish Alternative
Climate- Current Operations
Climate- Dam Removal
Climate- Flood Alternative
Climate- Fish Alternative

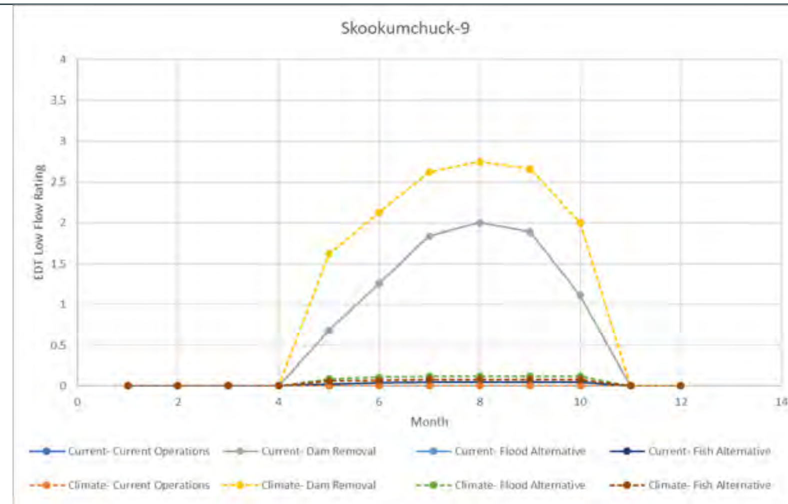
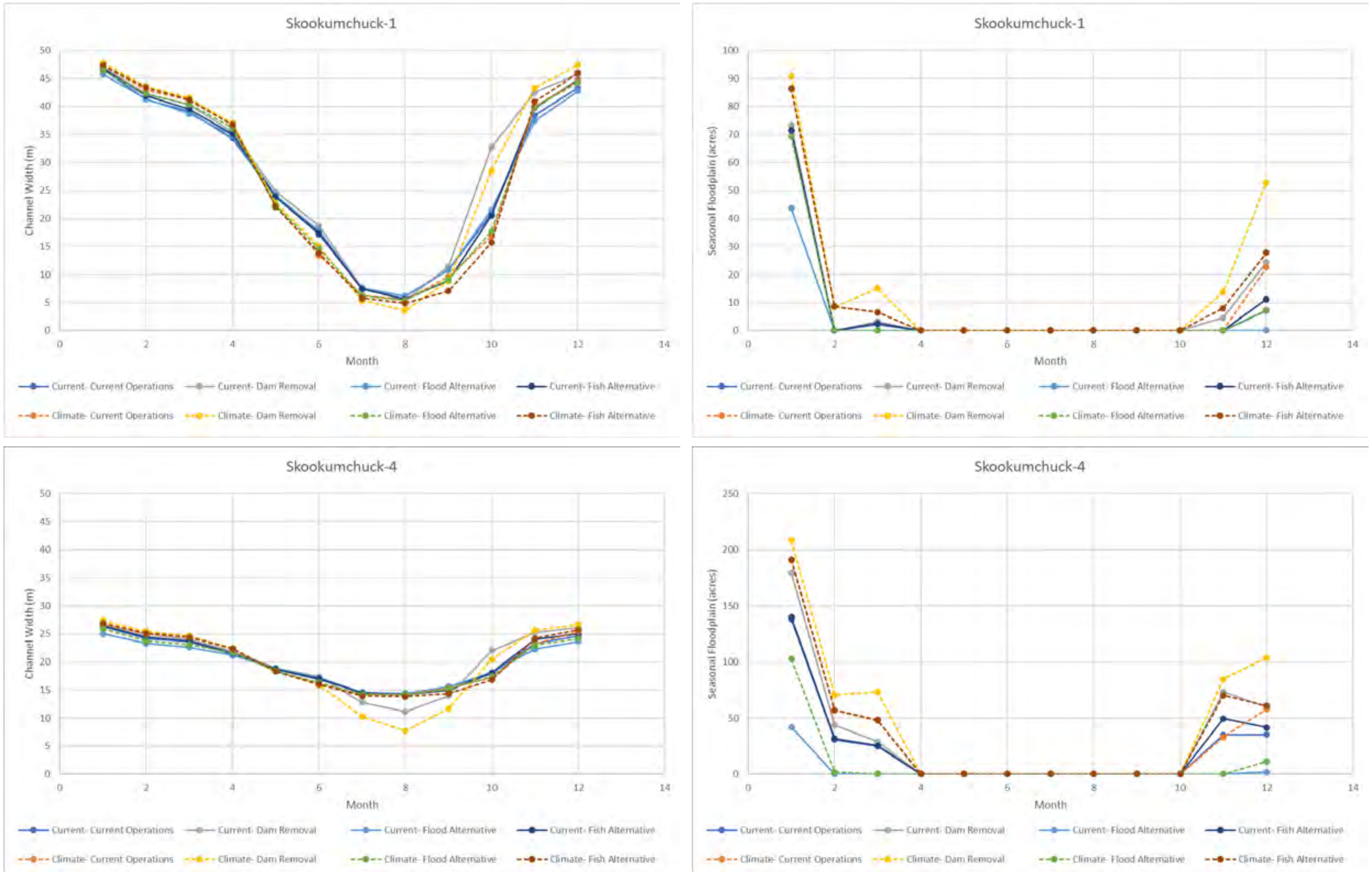
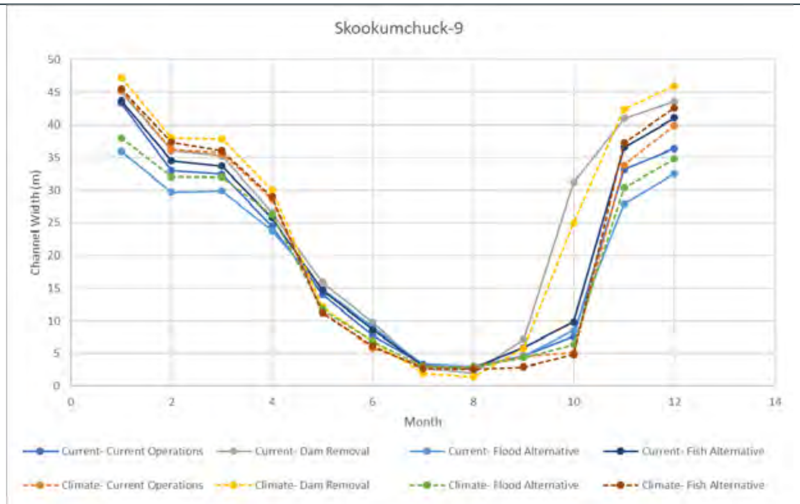
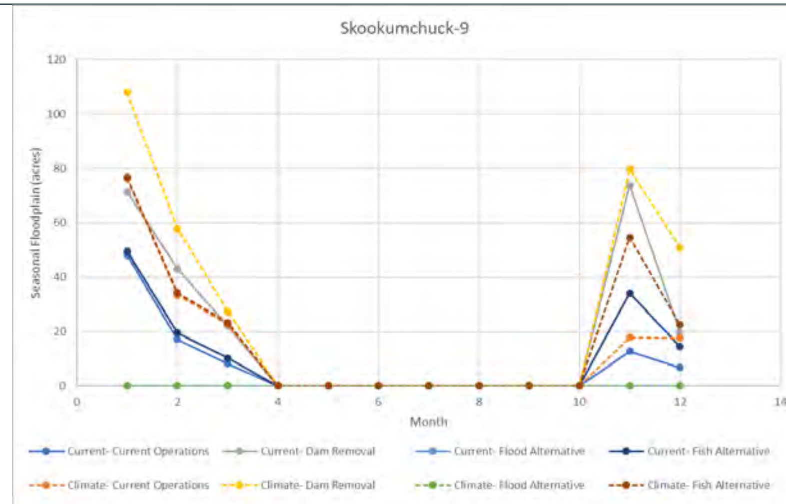

Skookumchuck-9
EDT Low Flow Rating
Month
Current- Current Operations
Current- Dam Removal
Current- Flood Alternative
Current- Fish Alternative
Climate- Current Operations
Climate- Dam Removal
Climate- Flood Alternative
Climate- Fish Alternative

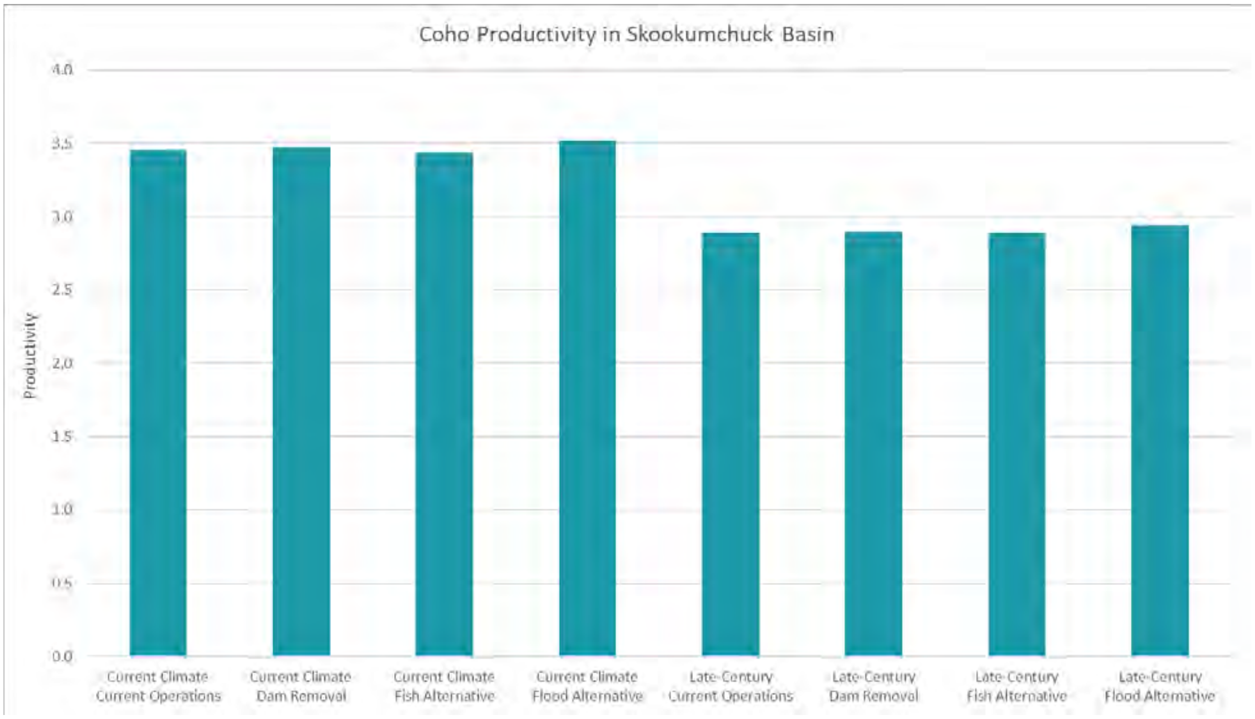
Figure D-5
Channel Width in Meters (left column) and Floodplain Area in Acres (right column) for EDT Reaches Skookumchuck-1, Skookumchuck-4, and Skookumchuck-9

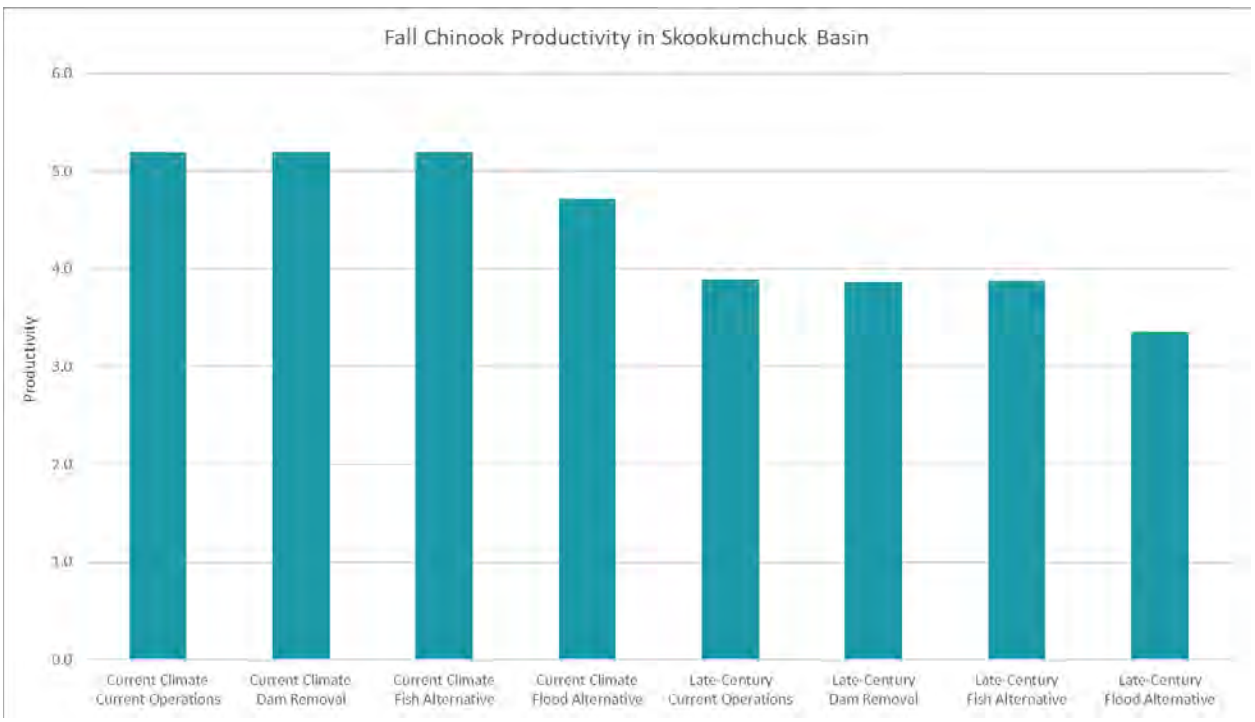


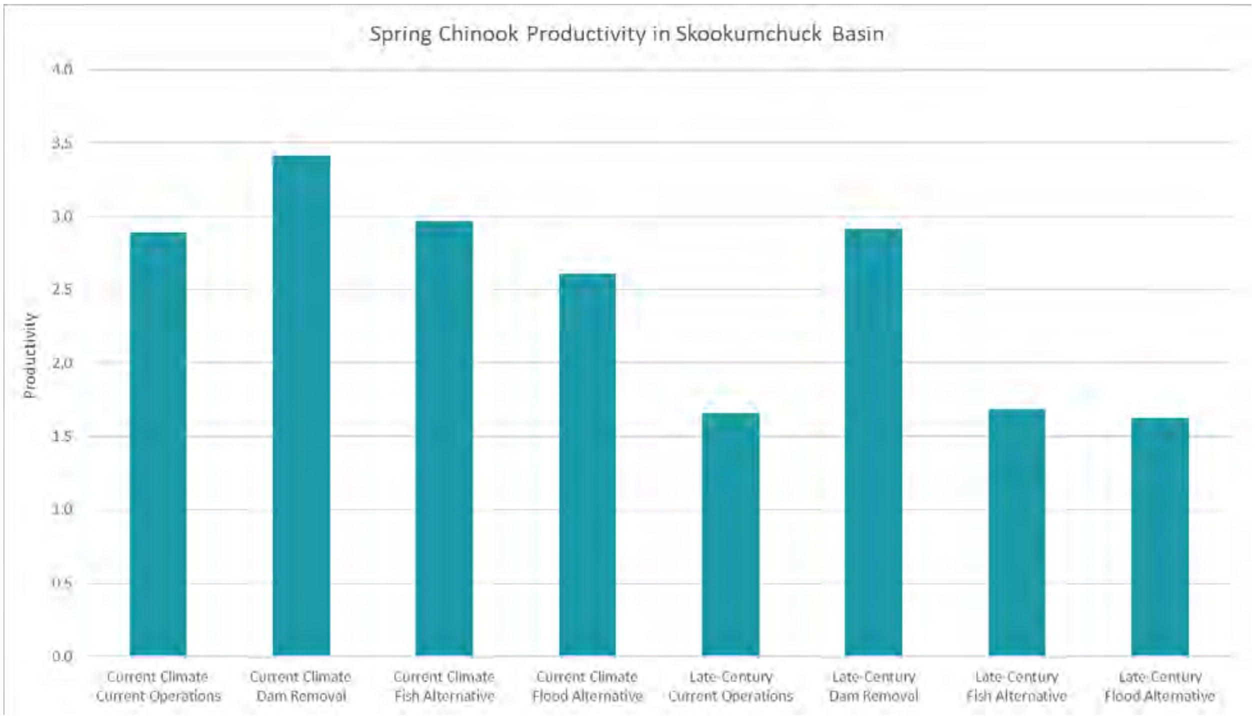

Skookumchuck-9
Channel Width (m)
Month
Current- Current Operations
Current- Dam Removal
Current- Flood Alternative
Current- Fish Alternative
Climate- Current Operations
Climate- Dam Removal
Climate- Flood Alternative
Climate- Fish Alternative

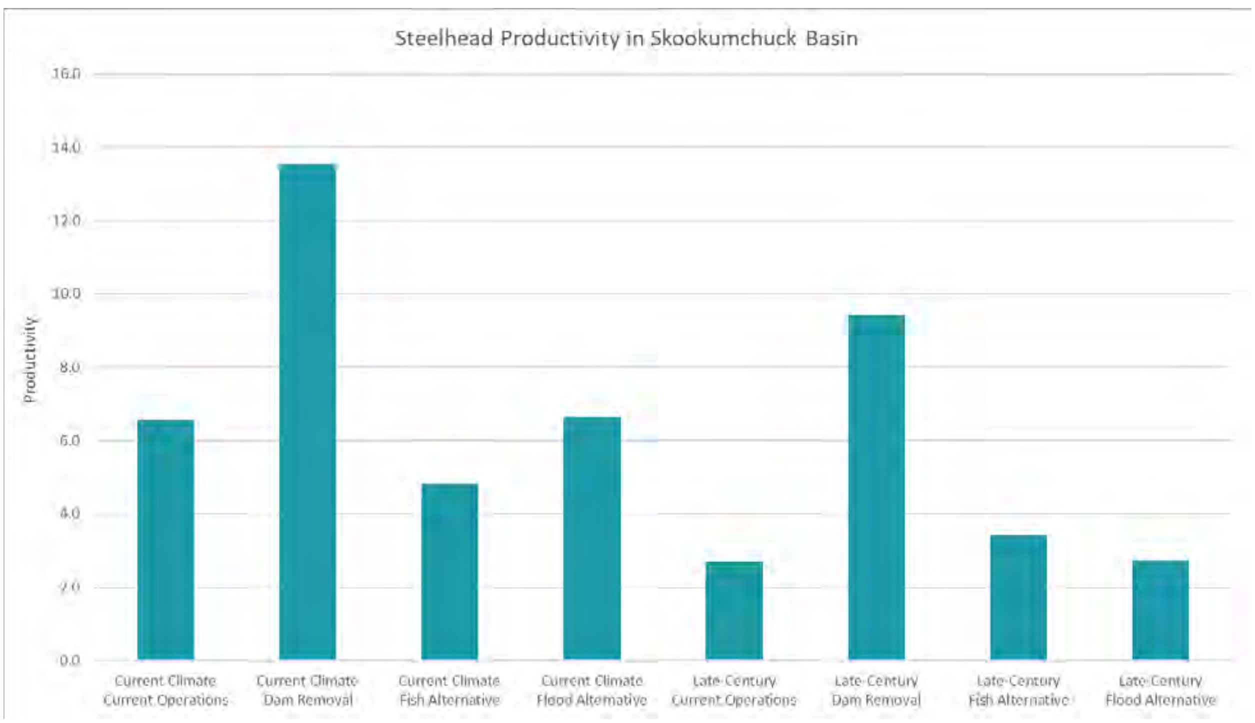

Skookumchuck-9
Seasonal Floodplain (acres)
Month
Current- Current Operations
Current- Dam Removal
Current- Flood Alternative
Current- Fish Alternative
Climate- Current Operations
Climate- Dam Removal
Climate- Flood Alternative
Climate- Fish Alternative

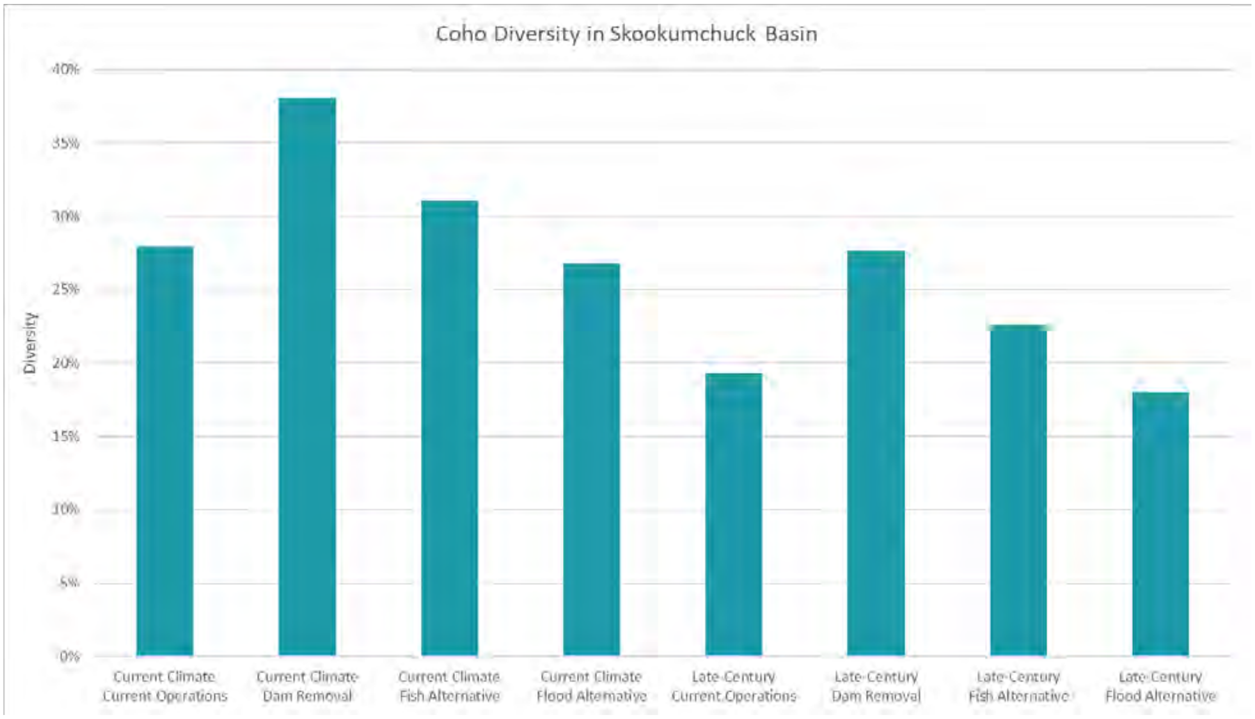
D.5 Productivity and Diversity Results Among Alternatives

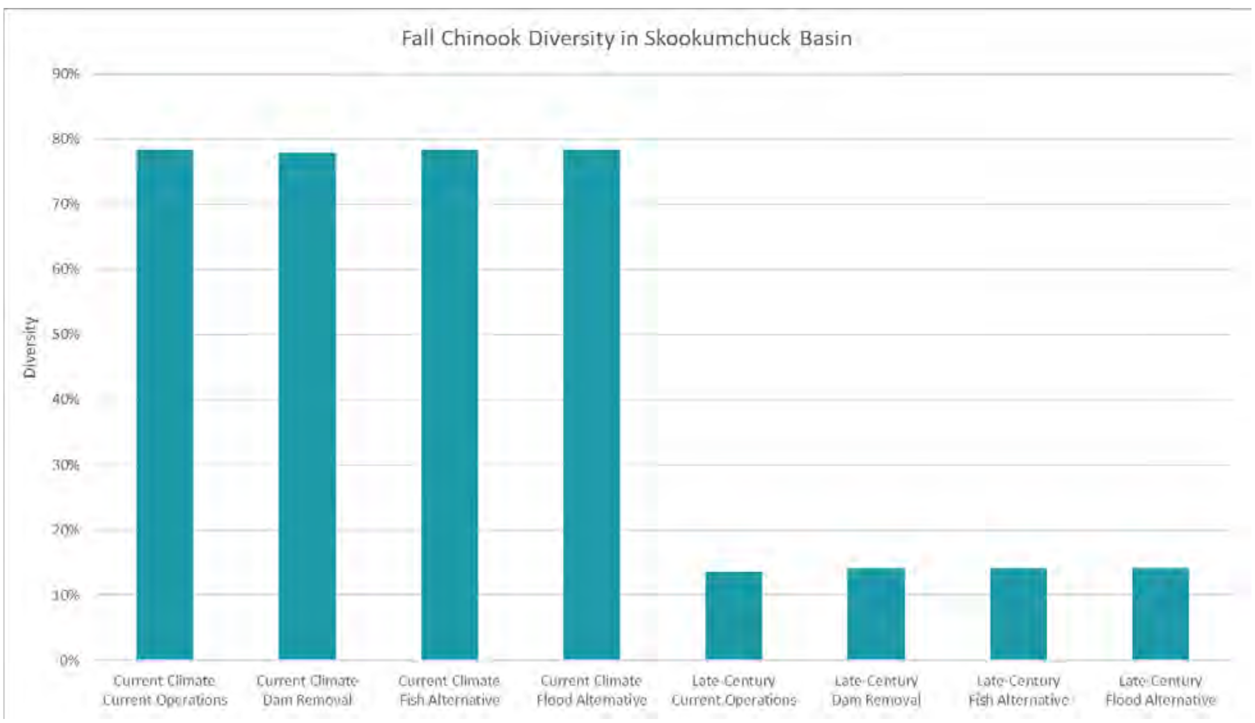


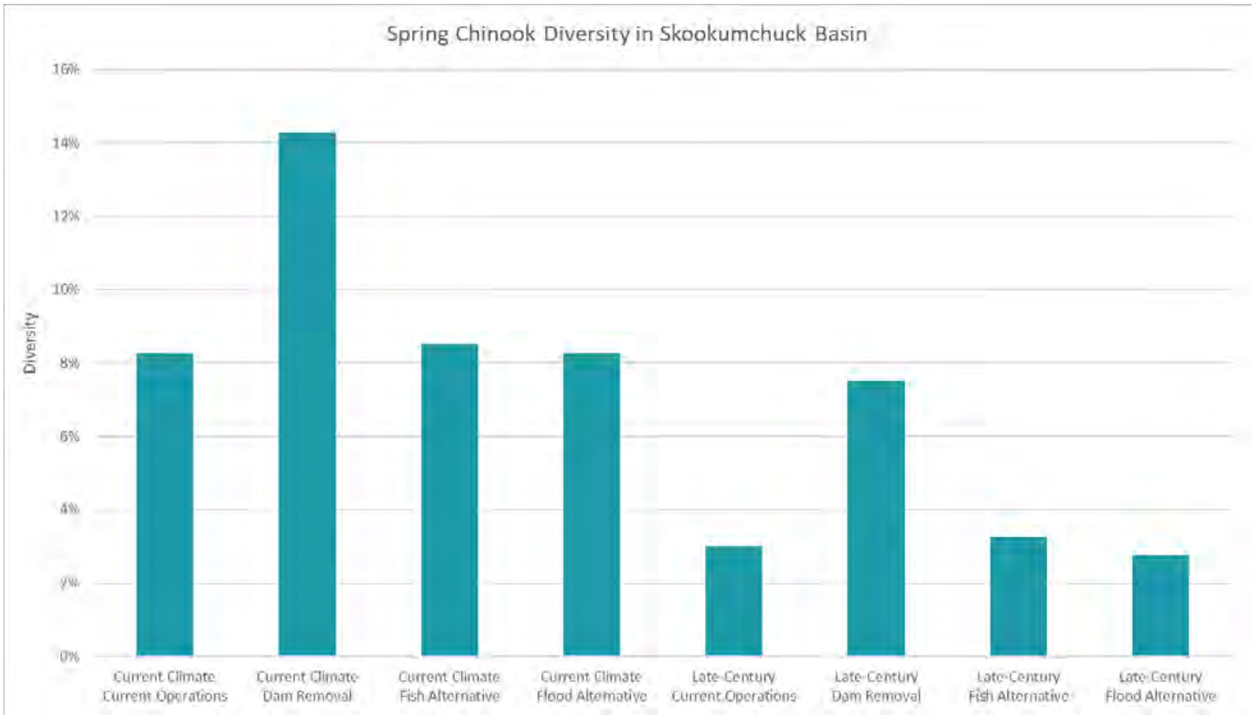


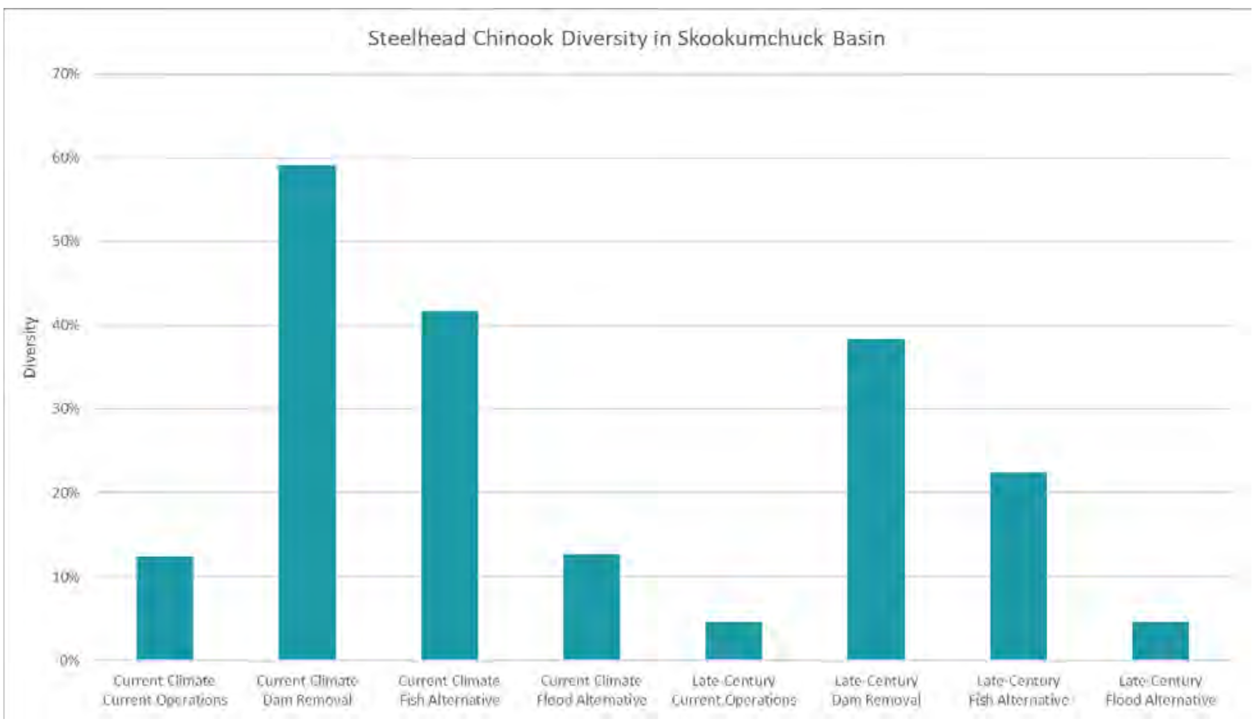

Spring Chinook Productivity in Skookumchuck Basin
Productivity
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Current Climate Current Operations
Current Climate Dam Removal
Current Climate Fish Alternative
Current Climate Flood Alternative
Late-Century Current Operations
Late-Century Dam Removal
Late-Century Fish Alternative
Late-Century Flood Alternative


Steelhead Productivity in Skookumchuck Basin
Productivity
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Current Climate Current Operations
Current Climate Dam Removal
Current Climate Fish Alternative
Current Climate Flood Alternative
Late-Century Current Operations
Late-Century Dam Removal
Late-Century Fish Alternative
Late-Century Flood Alternative


Coho Diversity in Skookumchuck Basin
Diversity
40%
35%
30%
25%
20%
15%
10%
5%
0%
Current Climate Current Operations
Current Climate Dam Removal
Current Climate Fish Alternative
Current Climate Flood Alternative
Late-Century Current Operations
Late-Century Dam Removal
Late-Century Fish Alternative
Late-Century Flood Alternative


Fall Chinook Diversity in Skookumchuck Basin
Diversity
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Current Climate Current Operations
Current Climate Dam Removal
Current Climate Fish Alternative
Current Climate Flood Alternative
Late-Century Current Operations
Late-Century Dam Removal
Late-Century Fish Alternative
Late-Century Flood Alternative


Spring Chinook Diversity in Skookumchuck Basin
Diversity
16%
14%
12%
10%
8%
6%
4%
2%
0%
Current Climate Current Operations
Current Climate Dam Removal
Current Climate Fish Alternative
Current Climate Flood Alternative
Late-Century Current Operations
Late-Century Dam Removal
Late-Century Fish Alternative
Late-Century Flood Alternative


Steelhead Chinook Diversity in Skookumchuck Basin
Diversity
70%
60%
50%
40%
30%
20%
10%
0%
Current Climate Current Operations
Current Climate Dam Removal
Current Climate Fish Alternative
Current Climate Flood Alternative
Late-Century Current Operations
Late-Century Dam Removal
Late-Century Fish Alternative
Late-Century Flood Alternative

D.6 Appendix D References

Lestelle, L.C., 2005. Guidelines for Rating Level 2 Environmental Attributes in Ecosystem Diagnosis and Treatment (EDT). Jones & Stokes Associates, Inc.