Ross Island Lagoon Harmful Algal Bloom Rehabilitation Alternatives

Design team 7

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Client: The City of Portland & Ross Island Sand And Gravel

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Objective

The purpose of this report is to present design alternatives that aim to eliminate or reduce the extent of harmful algal blooms (HABs) in the Ross Island lagoon, in the Willamette River. There are several constraints to consider, including protecting contaminated cells, avoiding capture of the mainstem river through the lagoon; maintaining existing habitats, and cost and practicality considerations. This report evaluates two design alternatives against the no-action alternative: a hydraulic solution and a non-hydraulic solution. These alternatives are then rated for risk and cost, so that the client may compare them directly to other alternatives as they seek a final design.

Site Background

Ross Island is a human-altered land mass within the Willamette River in Portland, Oregon, which has come under recent scrutiny due to algae blooms in its enclosed lagoon. In its present form, Ross Island consists of two historical islands, Ross and Hardtack, which were joined by a man-made earthen dike to form a protected lagoon. The dike was created between 1926-1927, such that Ross Island Sand & Gravel (RISG) could extract materials from the island interior. Years of material extraction resulted in a deep pool replacing much of the previous land area. Starting in 1979, the City of Portland (CoP) required RISG to start reclaiming areas that had been mined. This included a “mosaic of habitats” within the riparian zone, including emergent wetlands, shallow water, and upland forest. In an effort to meet this requirement, RISG began importing material in the 1980s for reclamation. To complicate things, some of this fill was found to be contaminated. This material was subsequently buried, creating “confined aquatic disposal” (CAD) sites. The final reclamation plan was negotiated in 2002, but reclamation is currently incomplete, as it was deemed infeasible to fill the lagoon. The lagoon experiences harmful algal blooms (HABs) during the summer, as a result of the deep, stagnant lagoon becoming stratified. The lagoon has been listed by the Oregon Department of Environmental Quality (ODEQ) as impaired for “aquatic weeds”, due to these HABs. There is not a responsible party identified for this water quality violation, though there are several stakeholders involved with the future of Ross Island.

Methods

Hydraulic Model

In order to first quantify the present extent of stratification of the lagoon, and then determine the ability of the hydraulic alternative to mitigate this stratification, a hydraulic model of the Ross Island lagoon and surrounding river channel is built using HEC-RAS, a public domain model from the US Army Corps of Engineers (USACE). A two dimensional, unsteady model is used due to the transverse channel variability, complex flow, and tidal influence within the system.

The Richardson number will be used to assess the efficacy of the hydraulic solution. The Richardson number is a measure of the stratification of a water body, often used for estuarine systems. Specifically, it is the ratio of buoyancy to the flow shear, or $R = \frac{g}{\rho}\frac{\Delta P/\Delta y}{(\Delta v/\Delta y)^{\ 2}}$. A value of 0.25 or less indicates a well mixed water body, while larger values suggest stratification between water layers may be present. In this case, we use the difference in densities that results from the difference in temperature between the upper layer, the epilimnion, and the next layer down, the metalimnion, in the interest of assessing the mixing of the epilimnion. We assume the epilimnion to be 10 meters thick. On June 05, 2018 this temperature difference was about 6 degrees Celsius (see figure A23 in the appendix).

A high resolution digital elevation model (DEM) is used for the bathymetry. The DEM was built from a number of different sources by Cara Walters at OSU. A grid mesh is created within the area of interest, extending upstream and downstream from Ross Island. A grid cell size of 80 square feet is used. In addition, breaklines are enforced around critical terrain breaks to promote cell orientation and ensure numerical anomalies do no not allow water to flow through barriers. Flow time series are used for the upstream boundary condition, and corresponding stage measurements are used for the downstream boundary condition. A Manning's roughness of 0.03 is used. Calibration of the roughness factor is not performed, as the small distance between the upstream and downstream forcing conditions causes the flow to behave largely independent of the roughness. A variable timestep is used, such that the Courant number does not exceed 0.45. Each simulation is run for 2 days to ensure stability.

Stage and tidally filtered flow data are acquired from the USGS gage on the Willamette River at Morrison Street Bridge. Flow data does not include any tidal influences, and is available hourly. Stage data reflects the tidal influence on the system, and is available every 15 minutes. A detailed hydrological analysis to determine return periods is not within the scope of this report. Instead, representative low, high and flood flows are chosen from recent USGS records to determine the performance of the hydraulic alternative over a range of flows. See the appendix for these hydrographs.

A major remaining source of error involves the depth of the lagoon. As this is a two-dimensional, depth averaged model, inflows to the deep lagoon are significantly dissipated, as the flow energy is distributed across the deep water column. In reality, the flow will remain more energetic at the surface as it enters the lagoon, resulting in more mixing.

Alternatives Analysis Calculations

There will be seven criteria used to analyze each alternative for this project, and the way that each criterion will be estimated or calculated is mentioned below. First, the total cost of creating, operating, and maintaining a 12-foot diameter corrugated steel culvert will be estimated by scaling up a similar case study that is found in NRCS field office technical guide for California in 2015. This case study will help to identify components of the project, and the individual costs of those components will be estimated using RS Means data. The non-hydraulic alternative of covering the algae spores (akinetes) in one-foot of clean fill, will be estimated using the cost of river sand per yard from Portland Sand & Gravel, as well as RS means data to estimate the other individual costs of the various processes to spread and transport the material. But, to ensure that this alternative is feasible, it will be compared to the amount of fill that Ross Island Sand & Gravel had been bringing into the lagoon on an annual basis from 2001 to 2010; which is approximately 2.5 million cubic yards per ten years, or 250,000 cubic yards annually (8). Next, to measure the amount of disrupted habitat (or temporarily disrupted habitat for the hydraulic alternative), an ArcGIS model will be used. ArcGIS will also be used to estimate the project area for the non-hydraulic solution, although this alternative is not expected to have any significant impact on critical habitat because the fill will not be spread on any shallow water habitat in the lagoon. The effectiveness of the hydraulic solution will then be determined using a HEC-RAS model and by calculating a Richardson number. The Richardson number is a parameter that is indicative of the amount of mixing that will occur in the lagoon as a result of the flow of water coming through the culvert. The effectiveness of the non-hydraulic solution will be much more difficult to determine because of the lack of studies done on this alternative. However, expert opinions and other related articles will judge the effectiveness of this alternative. The likelihood of failure for both the hydraulic and non-hydraulic solutions will be determined using a Process Failure Modes Analysis (PFMA). The likelihood of failure for the hydraulic solution will also be supplemented with the results of similar case studies. The risk to CAD cells for the hydraulic alternative will be determined using a PFMA and case studies of culvert failure likelihood because erosion at the inlet and outlet is not expected to be any more significant than the "no action" alternative. Therefore, as long as the CAD cells are not directly at the culvert outlet, which can be confirmed beforehand, there would be no significant risk to the CAD cells in this regard. A PFMA will also be used to determine the risk to the CAD cells for the non-hydraulic option, however, it is predicted that there will not be any significant risks. Finally, the species that will be benefited by each alternative will be analyzed and determined in table A10. The analysis will review literature to understand the type of habitat and needs each species has, and then indicate whether the alternatives affect any of those specific conditions to determine if and how a species would benefit. Lastly, to explore any unintended impacts of the alternatives, case studies will be looked at to find any impacts in similar projects, and research will be done on the habitats and diets of various species to see how they could possibly be impacted.

Failure Modes and Effects Analysis

The identification and evaluation of potential failure modes for each alternative is a critical component when weighing the costs and benefits of different solutions for Ross Island. The methodology of this potential failure modes analysis (PFMA) is based on a standardized procedure for dam-safety risk assessment by the US Army Corps of Engineers. The consideration of each process step with potential failure modes, effects, causes, and controls can be seen in Section VI. The risk priority number (RPN) was calculated for each design component to quantify the severity of impact, likelihood of occurrence, and likelihood of detection.

Hydraulic Conditions in the Lagoon

Presently, the lagoon has a single opening on the east side of the island. This baseline geometry is run for each of the three hydrologic scenarios, and results that closely match expected hydraulic behavior. The majority of the lagoon experiences no flow from the Willamette River, outside of the area immediately surrounding the existing inlet. We observe the highest velocities in the main stem of the Willamette, while the Ross Island lagoon is nearly entirely stationary, regardless of flow in the main channel. The high flow model shows flow within the lagoon occurring only within a few hundred feet of the inlet. The volume of the lagoon also fluctuates with the tide in all scenarios except the flood, varying 2 to 4 feet over a tidal cycle. Results are attached in the appendix.

It is interesting to note that tidal action is more effective at mixing the lagoon at lower flows. At higher flows, there is a smaller change in water surface elevation of the lagoon over a tidal cycle. For example, at low flows, the WSE of the lagoon changes from 6.3' to 10.3' in 10 hours over the course of a tidal cycle, a fairly rapid change that induces velocities approaching 0.06 ft/s throughout most of the lagoon. This WSE delta is reduced to about 3 feet in the high flow scenario, with lagoon velocities of 0.04 ft/s, and the tidal influence is not present at all in the flood scenario, with velocities of .0015 ft/s. However, this tidal effect, even at low flow, is not enough to mix the lagoon. The low flow Richardson number is about 30,000, well stratified. However, this behavior is important, because it shows that under baseline conditions, high winter flows, and even large flood events, do not provide any additional mixing to the lagoon. The Richardson numbers for these high flow and flood events are 2x and 14x the low flow number, respectively, showing even greater stratification. However, these larger flows do have lower Richardson numbers near the lagoon entrance, nearly approaching 0.25, showing that they do mix a portion of the lagoon (6 at high flow, 0.8 at flood). Thus, low summer flows best mix the entire lagoon, though not enough to stop stratification, and the influence of high flows is only near the lagoon entrance, where they are able to mix a small portion of the lagoon.

Details of Each Alternative

Hydraulic Alternative

Description:

The hydraulic alternative consists of a 12 foot diameter corrugated steel culvert placed through the southwest bank of Ross Island. The 300 ft culvert will pass through the berm at the low point, which is at an elevation of 29 ft. The culvert invert elevation will be -5 feet on both ends. See the appendix for conceptual designs of this alternative.

The purpose of the culvert is to induce higher velocities within the lagoon and promote mixing to reduce stratification in the water column. This is achieved as momentum of the flow in the main channel of the Willamette pushes flow through the culvert into the lagoon, which creates a current through the lagoon towards the east inlet. At low flows, the culvert serves as an additional outlet to either fill or drain the lagoon, as its water surface elevation lags behind that of the main tidally influenced channel.

Model results:

Model results show increased mixing in the lagoon under the hydraulic alternative, although the extent to which this mixing is capable of reducing stratification remains uncertain. Results are presented in table A2 in the appendix. Velocities near the culvert exit range from 0.2 ft/s at low flow to 0.4 ft/s at high flow. Strictly according to the Richardson number, the culvert does not break the stratification in the lagoon. However, these new values are greatly reduced: at low flows, the Richardson number is reduced from 30,000 to 40. At high flows, it is reduced from 70,000 to 7. It is important to consider the limitations of the 2D model here. In the model, exit velocities from the culvert are immediately spread across the entire vertical water column in the lagoon, diluting the effect of the concentrated flow. In reality, the flow would likely be constrained to the near-surface, thus preserving higher flow velocities across more of the lagoon surface. In conclusion, though the Richardson number-based analysis does not result in conclusive proof of mixing, these results suggest the possibility of substantial mixing by breaching the island with a large culvert. This is enough to justify the use of a 3D model to further investigate how a culvert may affect flows within the lagoon.

GIS analysis:

Figure A2 in the appendix shows the impacts of a culvert on shallow water habitat in the lagoon. The total impacted area is 0.01 acres (517 ft^2) which is 0.04% of the total shallow water habitat in the lagoon.

This map was created using a raster terrain file (.tif file) of elevations around Ross Island Lagoon. An additional raster file of the Ross Island Datum showed that the datum was at an elevation of 0.825 ft. Thus, shallow water habitat was defined as the area with an elevation of -19.75 ft to +1.825 ft, which is the equivalent of -20 ft to +1 ft in the Ross Island Datum. The symbology of the terrain file was altered to show shallow water habitat in a different color than the surrounding area, and the file was manually traced to create shapefiles quantifying shallow water habitat. The culvert was placed using coordinates and diameter information from HEC-RAS.

Non-Hydraulic Alternative

Description

The non-hydraulic alternative will be to bury the cyanobacteria colonies in one-foot of clean sand when their akinetes (spores) settle into the existing sediment on the lagoon floor during the winter. Akinetes rely on turbulence to move them out of the sediment when winter is over, so this would theoretically prevent them from reaching the water surface and contributing to summer algal blooms. The sand will be dispersed only in the deeper parts of the lagoon to avoid the disruption of shallow water habitat.

GIS analysis

Figure A3 in the appendix shows the impact of adding fill to the lagoon on shallow water habitat. Ideally, fill would not be placed over any areas of shallow water habitat. However, it may not be possible to avoid shallow water habitat away from the edges of the lagoon. This habitat represents 2.36% of the total shallow water habitat in the lagoon, or 0.71 acres (30,736 ft^2). None of this habitat would be raised out of the shallow water zone by adding fill. However, small areas around the edge of the lagoon would be raised into the shallow water zone, which would potentially increase habitat.

This map was created in the same way as the hydraulic alternative map, using a raster terrain file (.tif file) of elevations around Ross Island Lagoon. An additional raster file of the Ross Island Datum showed that the datum was at an elevation of 0.825 ft. Thus, shallow water habitat was defined as the area with an elevation of -19.75 ft to +1.825 ft, the equivalent of -20 ft to +1 ft in the Ross Island Datum. The symbology of the terrain file was altered to show shallow water habitat in a different color than the surrounding area, and the file was manually traced to create shapefiles quantifying shallow water habitat.

No Action Alternative

Description

This alternative explores the future potential impacts that would occur to Ross Island Lagoon if there is no action taken to combat these recurring algal blooms. If the algae continue to persist in the lagoon, the toxins produced can kill fish, mammals, and birds, and may even cause human illness and death in extreme cases. They may continue to clog the gills of fish and invertebrates, use the dissolved oxygen in the lagoon, or cover shallow water habitat and vegetation. Aesthetic concerns include discolored water and odorous piles in shallow water or on the shoreline. Although the short-term monetary cost of "No Action" appears to be minimal if anything, the long-term ramifications of continued algal blooms may increase costs in the future.

Alternatives Analysis

Hydraulic Alternative

The approximate total cost of this alternative would be $263,621.40 per hour which includes the total cost of the materials as well. For just the labor however, it would cost roughly $88,620.29 per hour. However, due to a lack of industry knowledge, it is difficult to determine how many hours would actually be required for such a project. Assuming that this scale of a project would take four months, the total cost would become $14,354,247.25. The cost of operating and managing this culvert is approximately $10,623.23 for each time that the culvert would be cleaned/repaired. The approximate habitat disruption for this alternative is 4.7 acres, however because the culvert is subsurface, most of the habitat that will be disrupted, will then be restored after installation; leaving a negligible (0.1 acre) area of impacted habitat. The effectiveness of this alternative remains largely unknown, however, strictly basing the result off of the Richardson number, it does not appear that the stratification was broken; and therefore this alternative does not appear to be effective. However, because the 2-D model used assumes that the flow of water exiting the culvert automatically gets spread over the whole water column, and because of the greatly reduced resulting Richardson numbers, there is precedence to use a 3-D model to evaluate the situation instead, for it is possible that the culvert could actually break the stratification. Due to this, this alternative would have a medium likelihood of being effective against the algal blooms. The likelihood of failure for this alternative appears to be on the lower end (an average rating of 3 out of 7), with the most likely failure being blockage of the inlet which would cause reduced flows. The likelihood of failure for this alternative is relatively low because regardless of flood events, the maximum amount of water that passes through the culvert is capped; therefore it is unlikely that more water or even higher velocities would cause this structure to fail. The risk to the CAD cells appears to be minimal for this alternative because of the armoring at the entrance of the culvert and because of the durability of the material. According to Rinker Materials, the life expectancy for corrugated steel pipes is 10-35 years, but other sources have shown that these pipes can last up to 50 years (11). Therefore, it would be safe to say that the risk for the CAD cells would be relatively low and therefore has a ranking of 3 out of 7 in the PFMA. As shown in table A10 below, this alternative also benefits a wide range of species including Chinook, coho, and chum salmon, steelhead, lamprey, and even the bird populations because of the introduction of low flows to the area. A couple of unintended impacts would be erosion of the pipe at a faster rate than is shown by other studies due to the large volume of water constantly passing through, a disruption of soil which could negatively impact the lamprey species, and exposure of CAD cells due to a rupture in the middle of the pipe.

Non-Hydraulic Alternative

The total cost for this alternative would be $25,583.09 per hour, but would be $6,563,670.63 including the fill and the excavators to move the fill. Although at first glance, this alternative seems cheaper, the application (which could possibly be annually) would be a lengthy process (approximately 3-4 months) to move all of the sand and transport it to Ross Island. Not only that, but each year (possibly) the same price would have to paid to reapply the same amount of material to mitigate the algal bloom. Therefore, this alternative quickly passes the hydraulic alternative in long-term cost. This alternative does appear to be feasible in terms of the amount of sand required (192,067 cubic yards is less than 250,000 cubic yards), however the overhanging cost of reapplication is daunting. If fill was applied over the full center of the lagoon, excluding shallow water areas around the edges of the lagoon but not in the center, then this alternative would cause very little disruption of shallow water habitat (0.71 acres) and would not remove any area from the shallow water zone. It raises a small amount of area into the shallow water zone (see figure A3), which could create new habitat. The effectiveness of this alternative is widely unknown due to the lack of previous studies on this method. In fact, even to experts like Dr. Theo Dreher, it is unknown if the cyanobacteria that inhabit the lagoon are the species that create spores and therefore this method could have no impact at all. Since the sand will be spread across the deep parts of the lagoon, the likelihood of it failing during a flood event would be low. With the lagoon being over 50-feet deep in most places, it would stand to reason that only the top part of the water column would be affected by a flood event and that the effects wouldn’t stretch far enough down to alter the fill. There is no increase in risk to the CAD cells when compared to the “no action” alternative because there would be no increase in flow or excavation for this alternative and therefore no erosion. The only species that would certainly benefit from this alternative would be the lamprey. With the introduction of finer sediment to the area, it would be a valuable place for juvenile lamprey to bury themselves and mature (2). A couple of unintended impacts would be the burial of other current residing species such as mussels and lamprey and/or creating more turbid water if the sand that is used has finer grains than those that would settle to the bottom.

No Action Alternative

Harmful algal blooms are notorious for causing problems to various ecosystems. A few of the main species that would be negatively affected if the blooms are left unchecked would be the bird populations, the salmon and steelhead populations, and even amphibians. The salmon, steelhead, and amphibians would all be affected for a few similar reasons. First, the algal blooms consume oxygen as they decompose; therefore lowering the amount of dissolved oxygen in the water and theoretically suffocating the fish. The fish species and amphibians mentioned above especially need cold, flowing, and oxygen-rich water to survive. Therefore, left unchecked, the algal blooms have the potential to grow and decrease the dissolved oxygen as a result; killing many fish. Next, the fish abundance of algae could clog the gills of fish which would suffocate them. Another possible thing that could happen is that the cyanobacteria that release toxins become introduced into the lagoon. This would wreak havoc on fish as well as other aquatic organisms because these toxins have been known to be potent enough to kill dogs, as well as cause illness and on rare occasion death to humans. Therefore, if fish and other aquatic organisms die; this would have a large negative effect on the birds that also rely on these organisms for food. Lastly it would also be problematic if the algal blooms potentially leaked out of the lagoon and floated downstream where they would cause identical problems to similar species further down the river. This could also cause an inability to use the river recreationally if the blooms and toxins get swept downstream, because there would be a significant risk of illness to the public.

Failure Modes Analysis

Two “action” alternatives for Ross Island are shown. First, the burying of HABs consists of the material (soil or otherwise) deposited on the lagoon floor, and the application process that includes the range of distribution and impact of watercraft required (Figure A25). The second alternative involves the implementation of a culvert, which may have the potential for failure due to the components that make up the system or construction process itself (Figure A24).

The highest RPN of 30 was determined for the pipe in the hydraulic solution, where lack of controls may be unable to detect potential failure within the structure (Table A9). The second highest RPN of 21 comes from the third alternative of “No Action”, where there is no implementation of a solution and the progression of failure has already been observed as HABs continue to exist in the lagoon. The calculation of this ranking provides a semi-quantitative screening to better support complete assessments when solutions are fully developed in the design phase. Thus, this analysis should not be considered a ‘catch-all’ for anything that may go wrong, but rather a tool to consider the critical processes behind each alternative. Due to the nature of the hydraulic solution, which has more design components than the non-hydraulic solution, it appears that the risk is higher. However, estimation of each solution’s effectiveness (especially long-term) may bring more weight into evaluation of these alternatives.

Data Gaps/Questions

Although alternatives have been evaluated and presented here, there are several knowledge gaps and questions that should be addressed as this project is transferred to the next step. A critical component of concern is the exact location and layout of the buried CAD cells. Moving forward, it’s imperative to survey the CAD cells to ensure an acceptable buffer for any solution. Case studies of other large culverts used to connect water bodies of similar water surface elevations would be helpful, to verify performance suggested by the hydraulic model. Case studies of burying akinites to prevent harmful algal blooms would also be helpful to verify the performance of non-hydraulic alternative. The non-hydraulic alternative is not in many articles, but when it is mentioned, burial is often associated with sediment resuspension and removal; therefore making it difficult to isolate whether the results are based off of the colony burial or a combination of the other alternatives. In the same vein, understating the spatial and temporal extent of the HABs would be advantageous for the non-hydraulic solution so that the application of soil is applied in the right place at the right time.

Recommendation

After the evaluation of each alternative, it is the recommendation of Group 7 to pursue the hydraulic solution to final design. A 12 ft diameter, 300 ft long corrugated steel culvert installed through the southwest berm would cost approximately $14,354,247.25. The cost for this alternative is twice the initial price of the non-hydraulic situation; however, because the non-hydraulic alternative may require frequent reapplication, the cost of that solution would quickly eclipse the 14 million dollars. Although the hydraulic solution bears the highest risk priority number, it should be noted that the introduction of flows into the reservoir represents a single implementation, long-term effort to remove HABs from Ross Island. The increased mixing of this solution will continuously address the core cause of algal blooms, even at low flows. In addition, the implementation of a culvert only impacts 0.04% of shallow water habitat in comparison to the 2.63% that would be temporarily impacted with burial. The uncertain future of Ross Island associated with No Action is an incentive to pursue a long-lasting, effective solution.

Appendices

Exhibit A: Aerial Maps

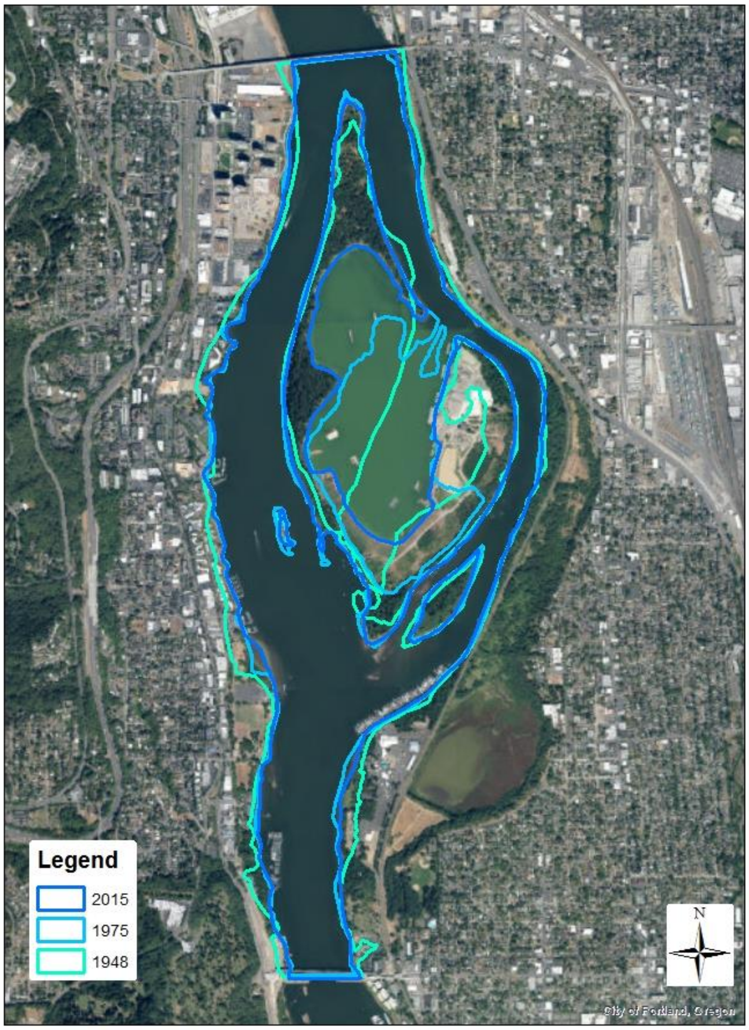

Figure A1. Map of channel and lagoon boundaries over time. Background photo is from 2015.

Table A1. Changes to lagoon surface area, width of the lagoon entrance, and width of upstream channel from 1948 - 2015

Channel Metric	1948	1975	2015
surface area (open water) of lagoon	812,215 m^2	1,073,000 m^2	1,209,000 m^2
width of lagoon entrance (adjacent to Holgate channel)	315 m	150 m	215 m
channel width at Sellwood Bridge	560 m	520 m	520 m

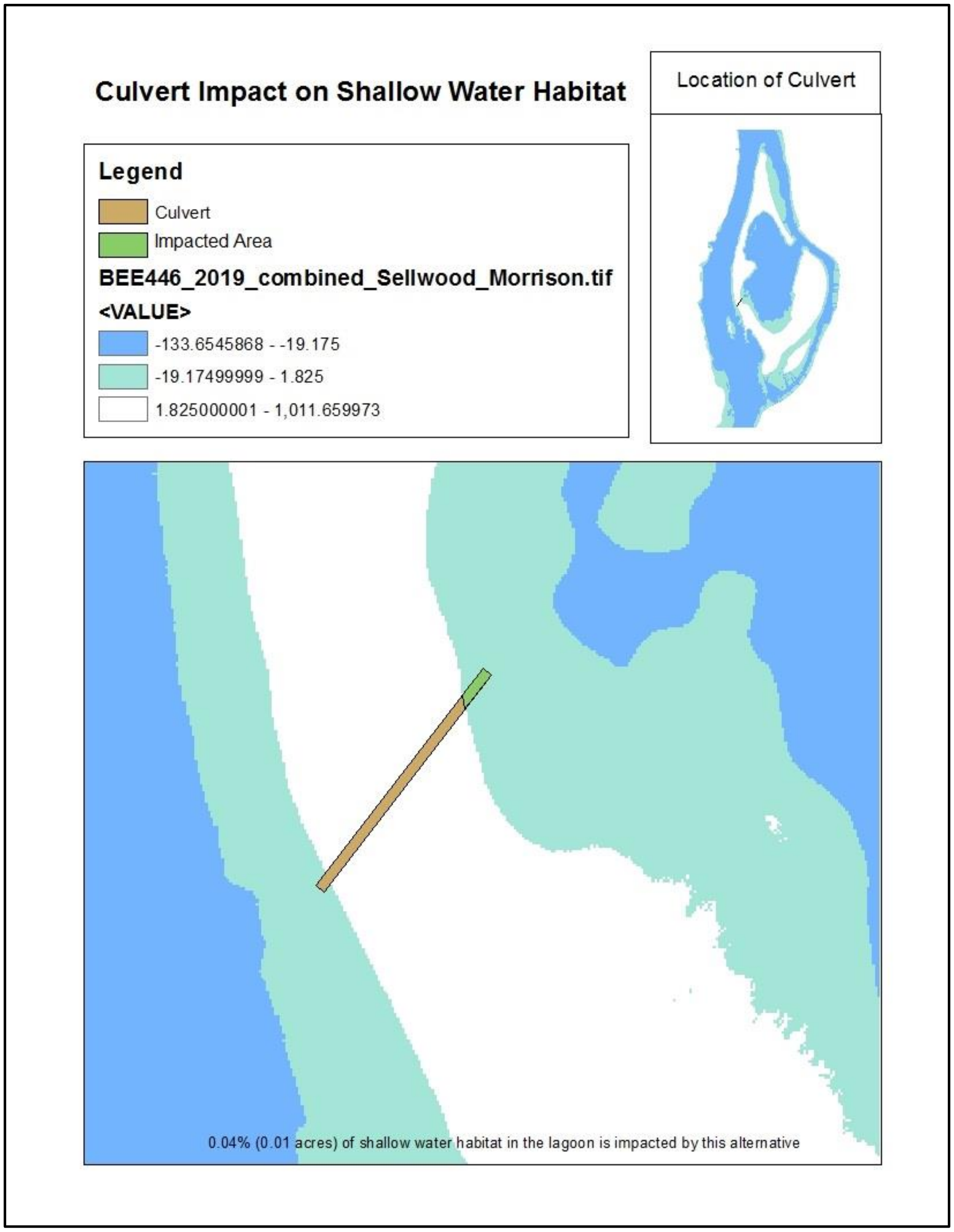

Figure A2. Impacts to shallow water habitat: hydraulic alternative

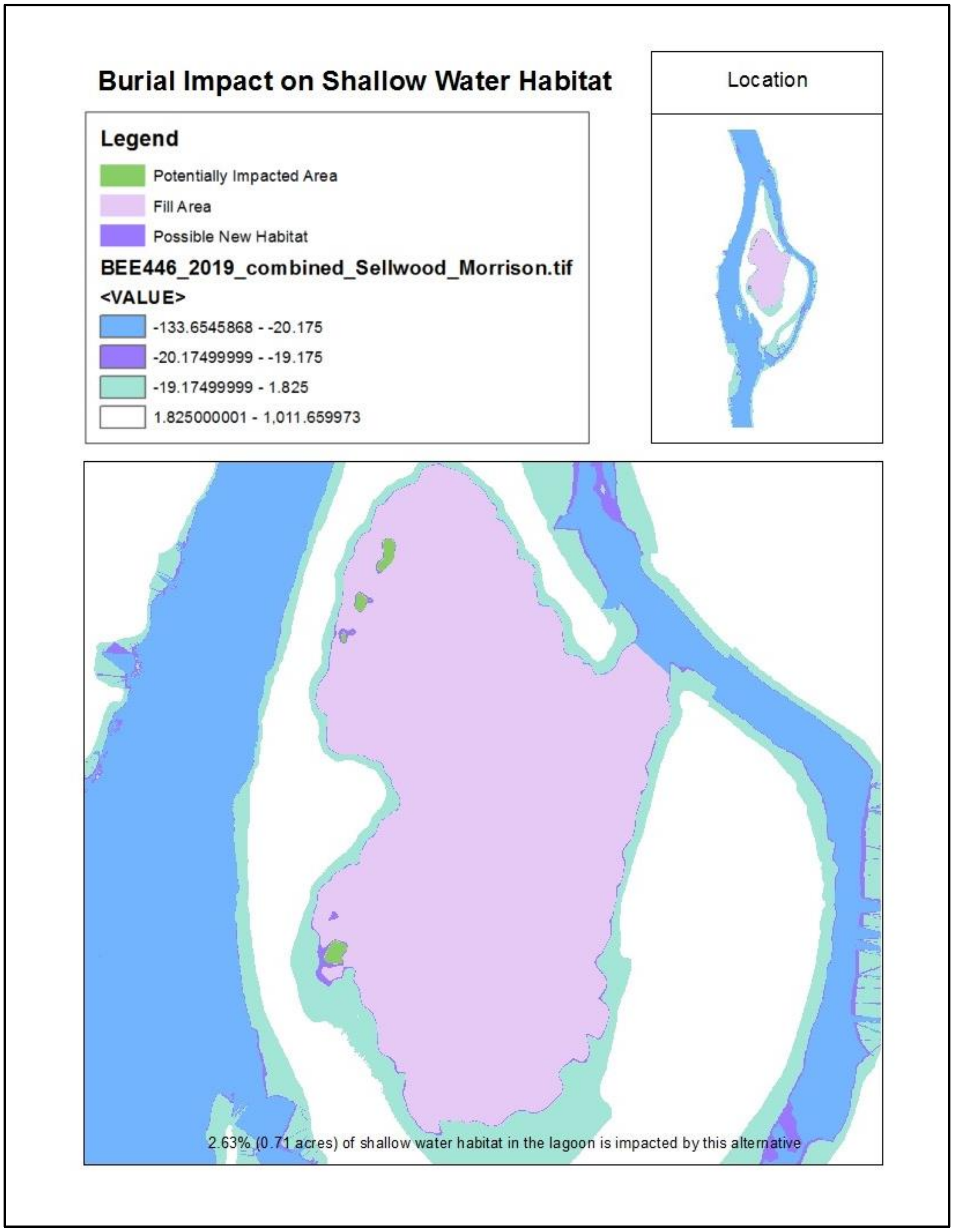

Figure A3. Impacts to shallow water habitat: non-hydraulic alternative.

Exhibit B: Boundary conditions

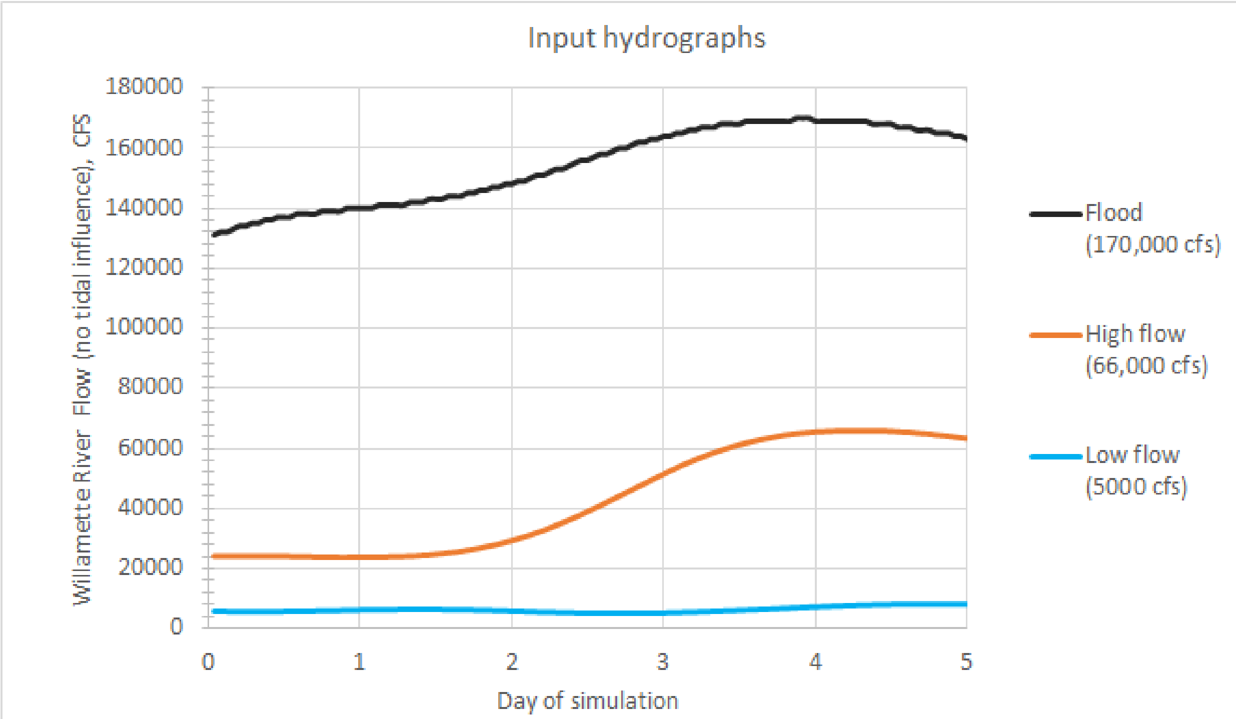

Figure A4. Inflow hydrographs

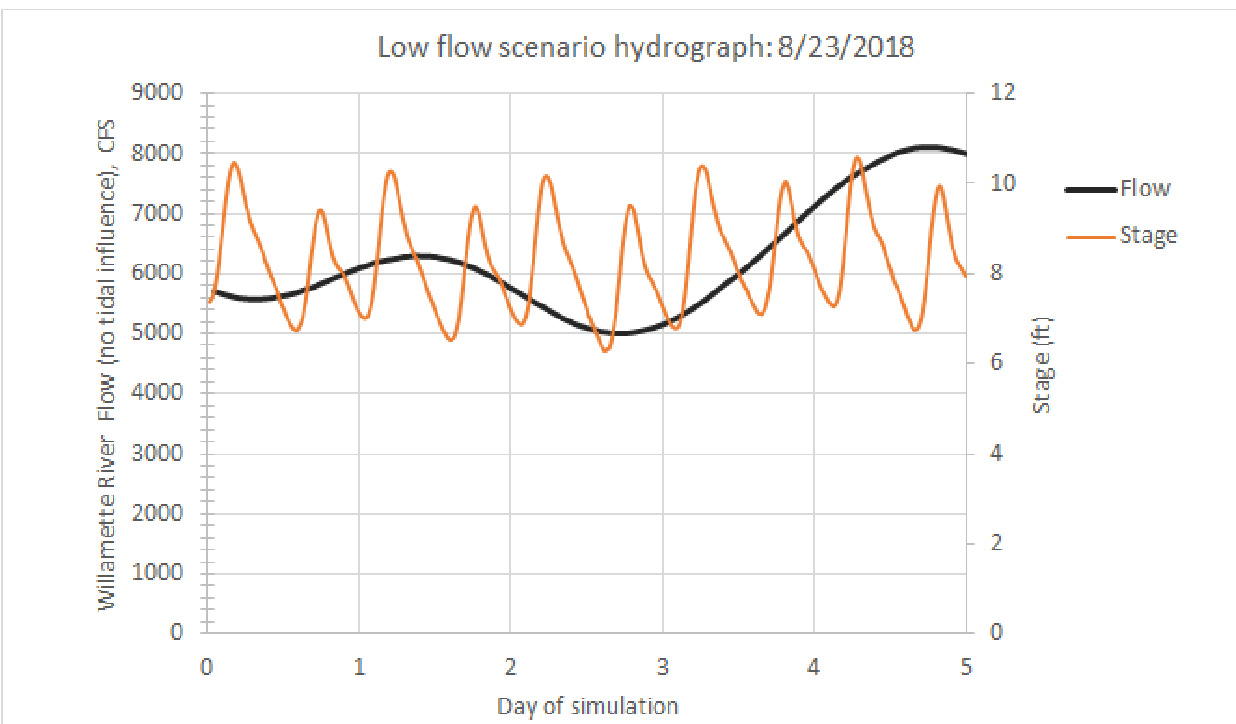

Figure A5. Stage time series at low flow

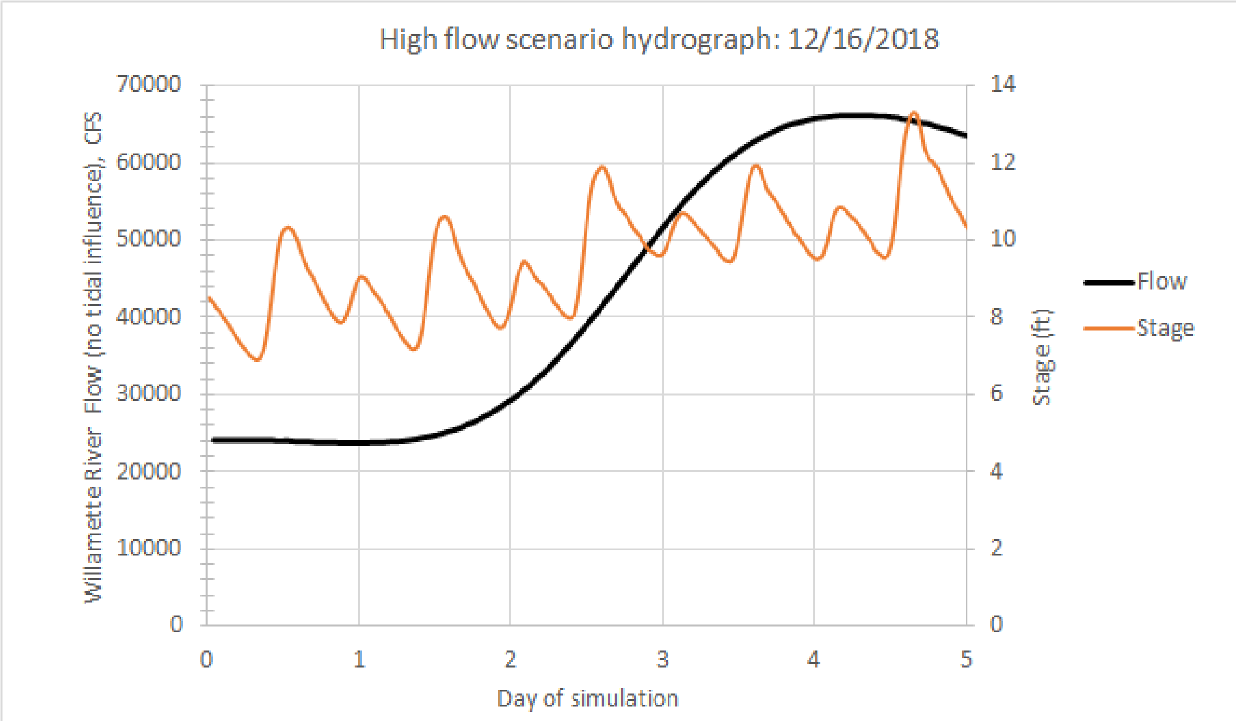

Figure A6. Stage time series at high flow

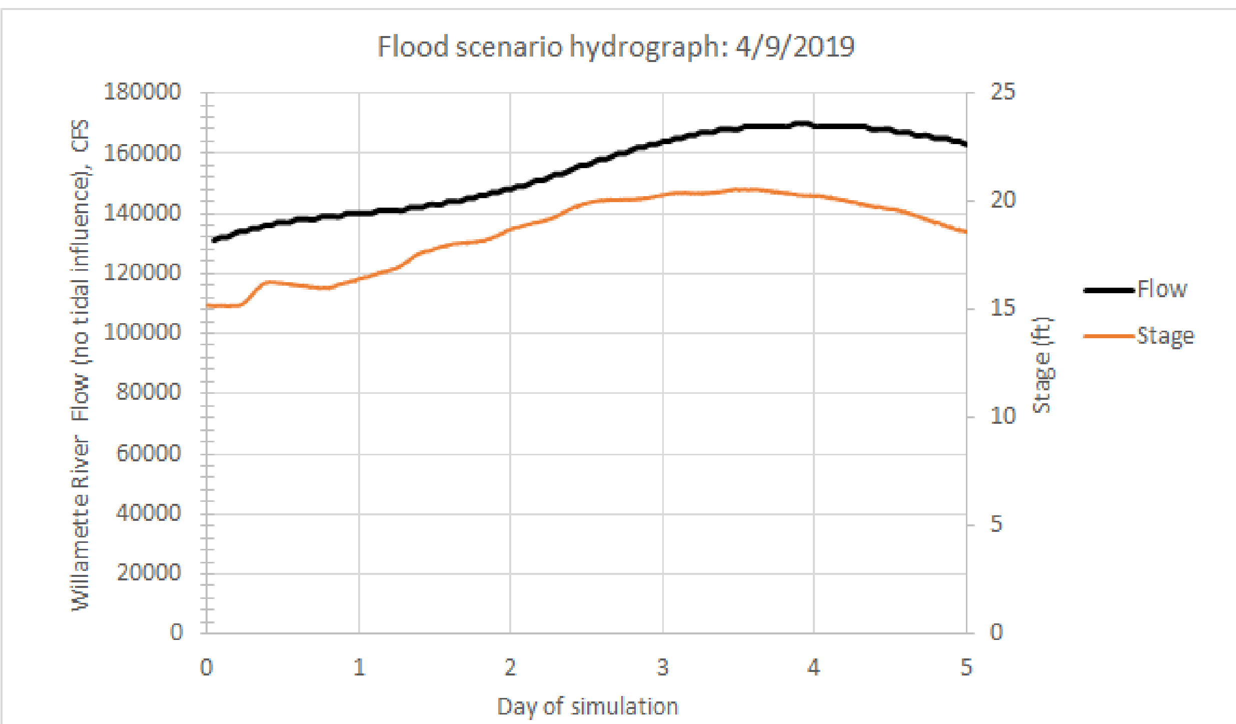

Figure A7. Stage time series at flood flows

Exhibit C: HEC-RAS model

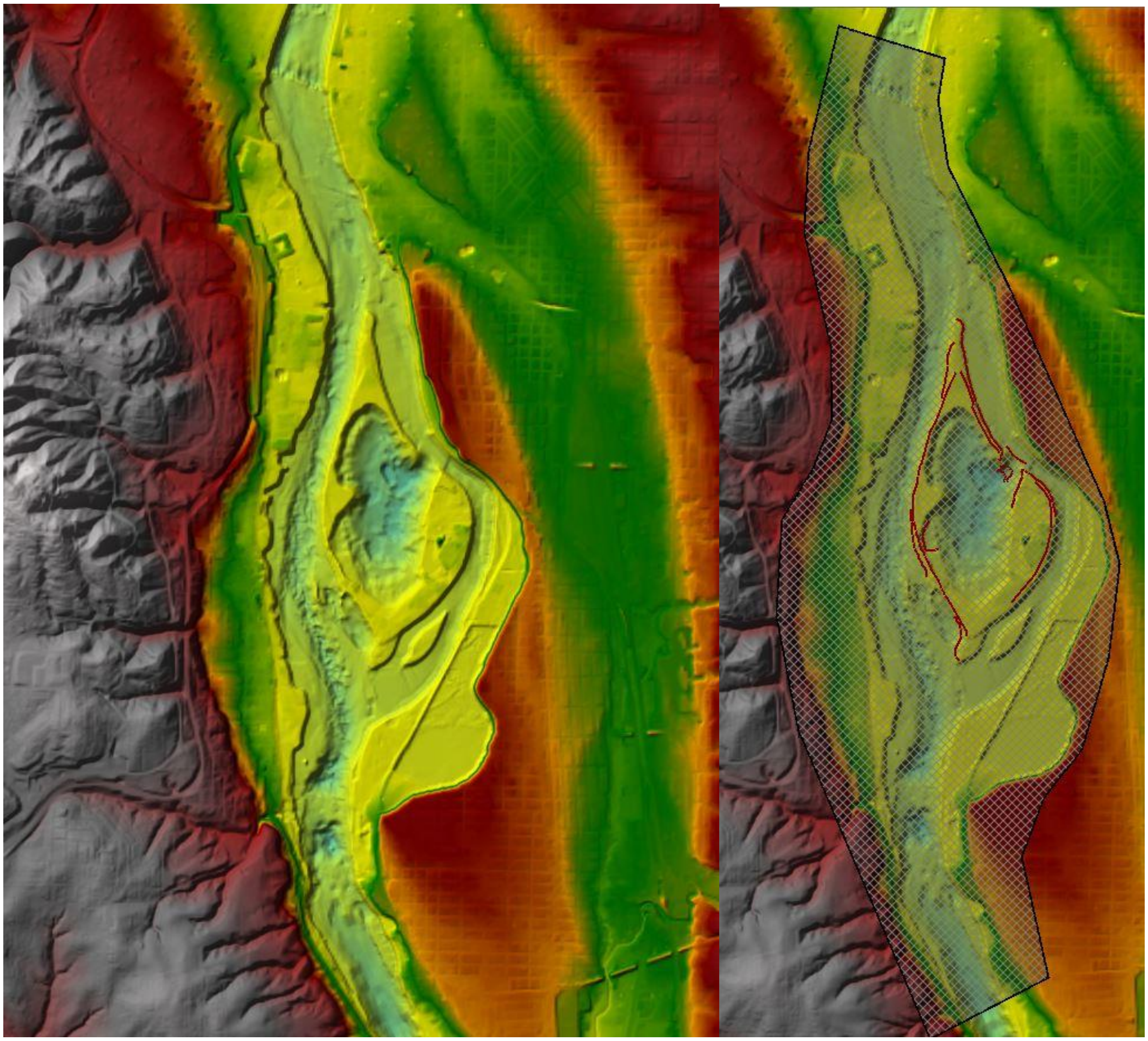

Figure A8. Terrain and model domain

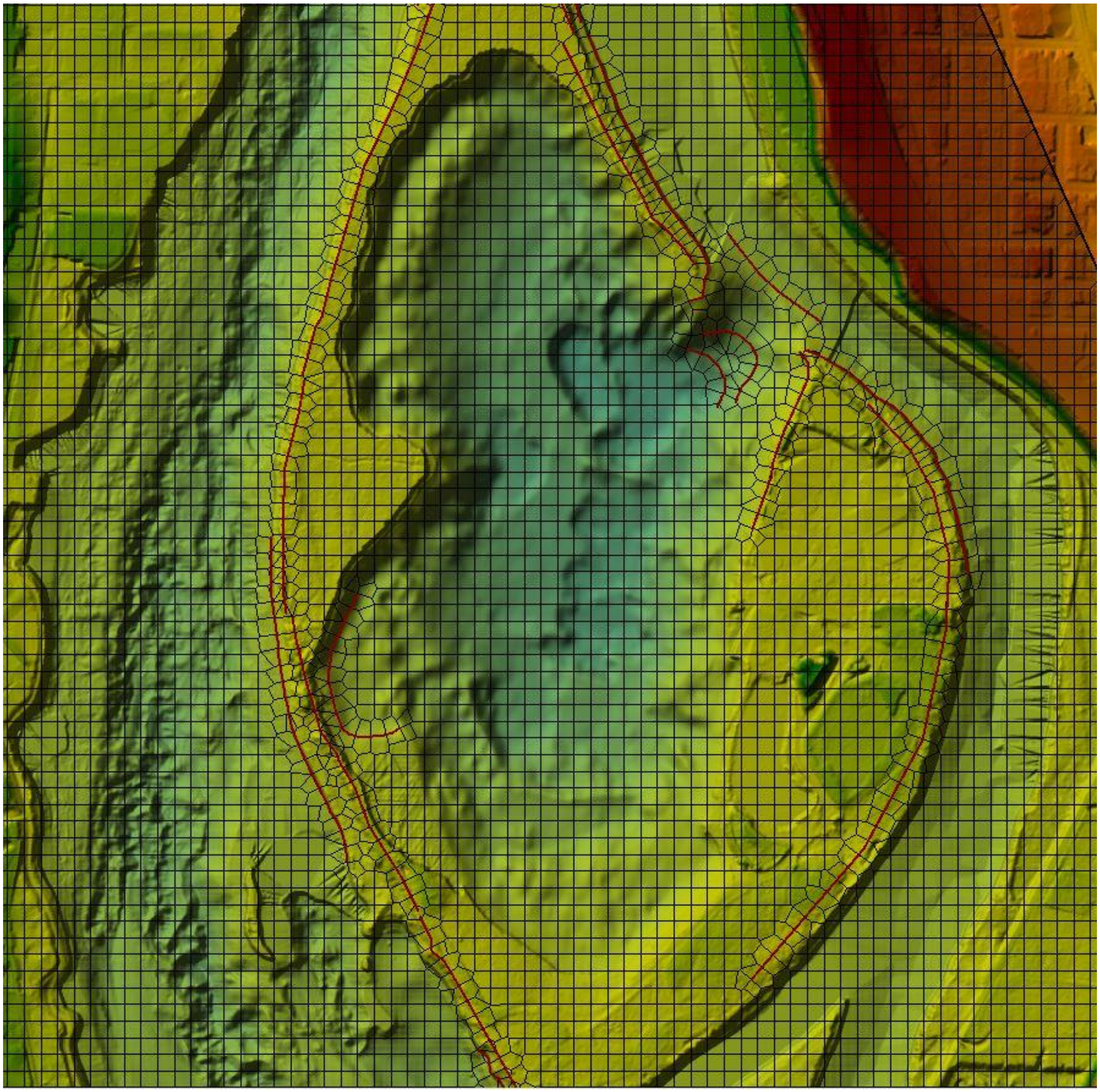

Figure A9. Grid mesh

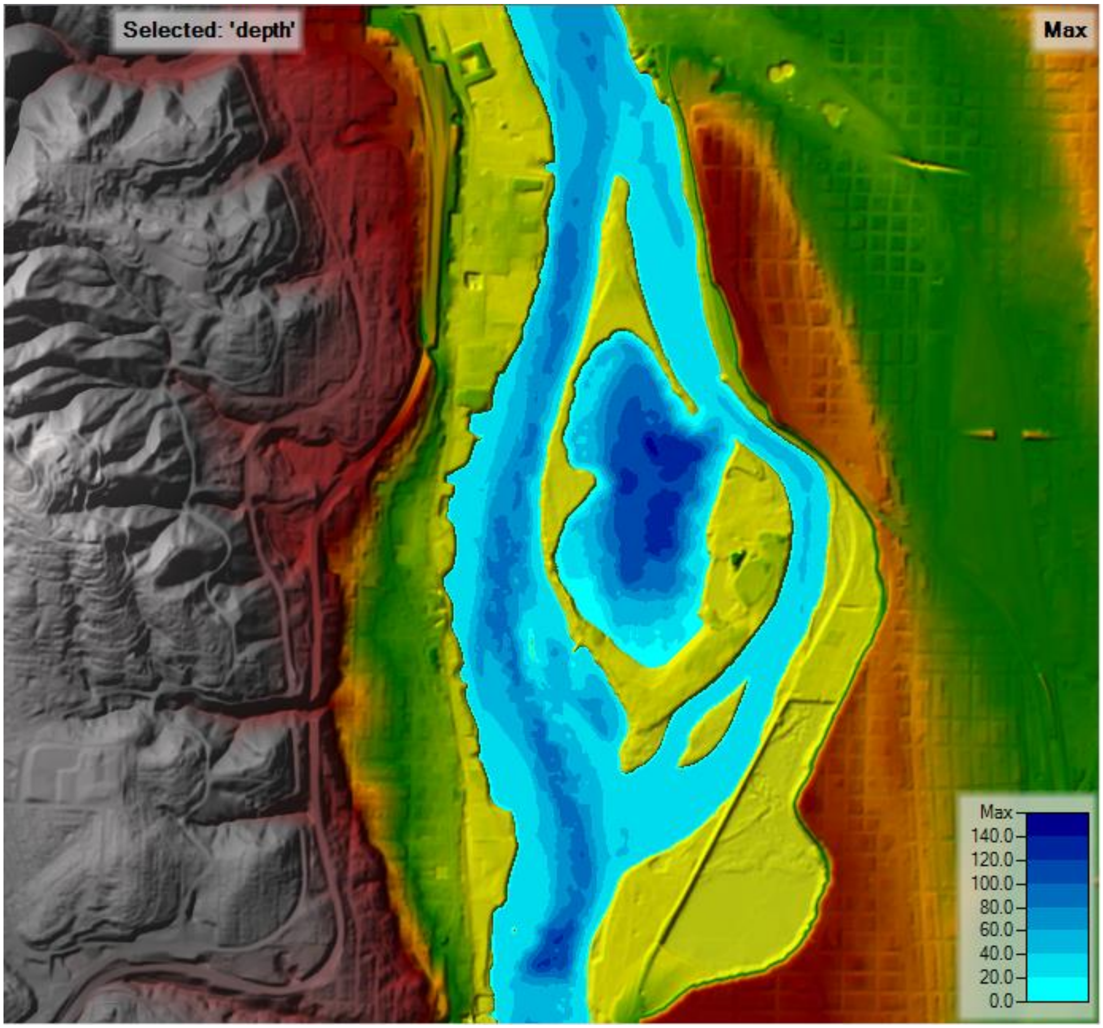

Figure A10. Lagoon depth (ft)

Exhibit D: Culvert

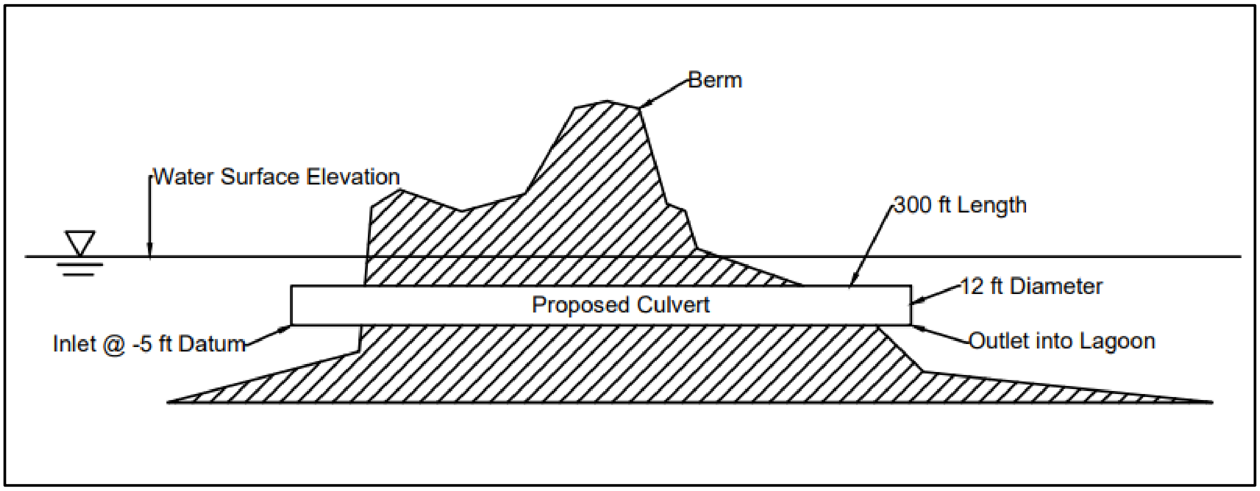

Figure A11. Culvert Schematic: Planar View

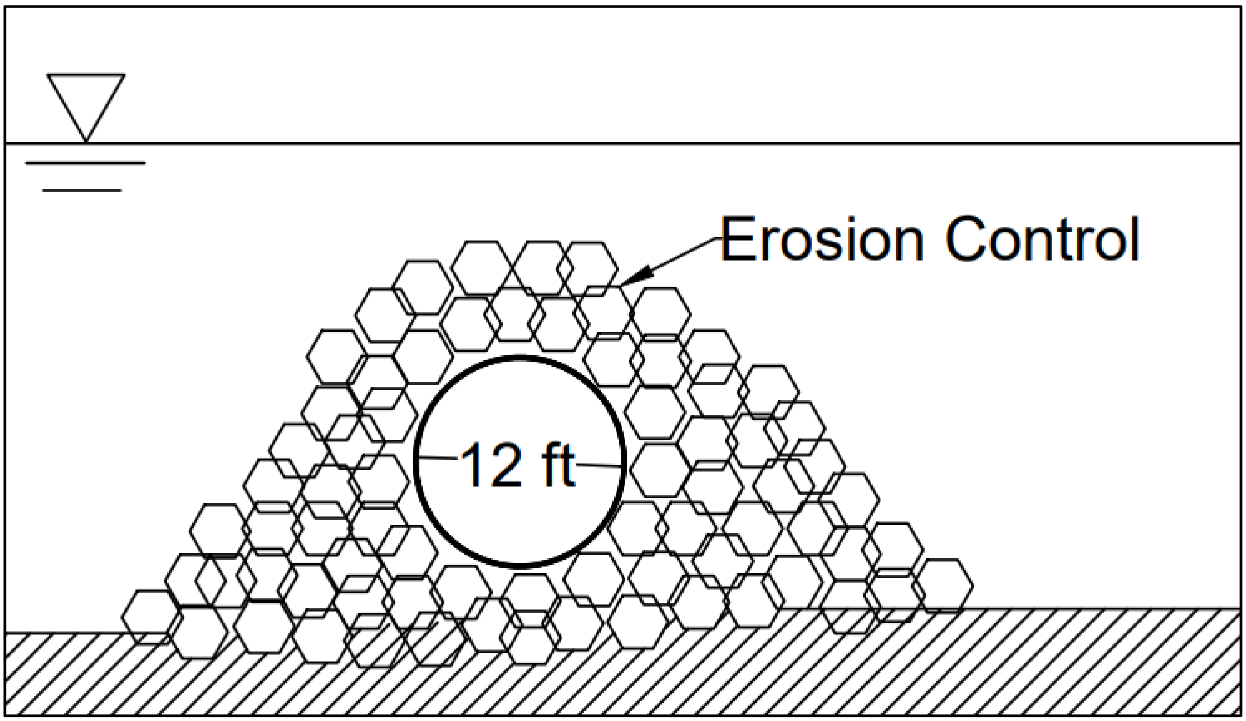

Figure A12. Culvert Schematic: Section View

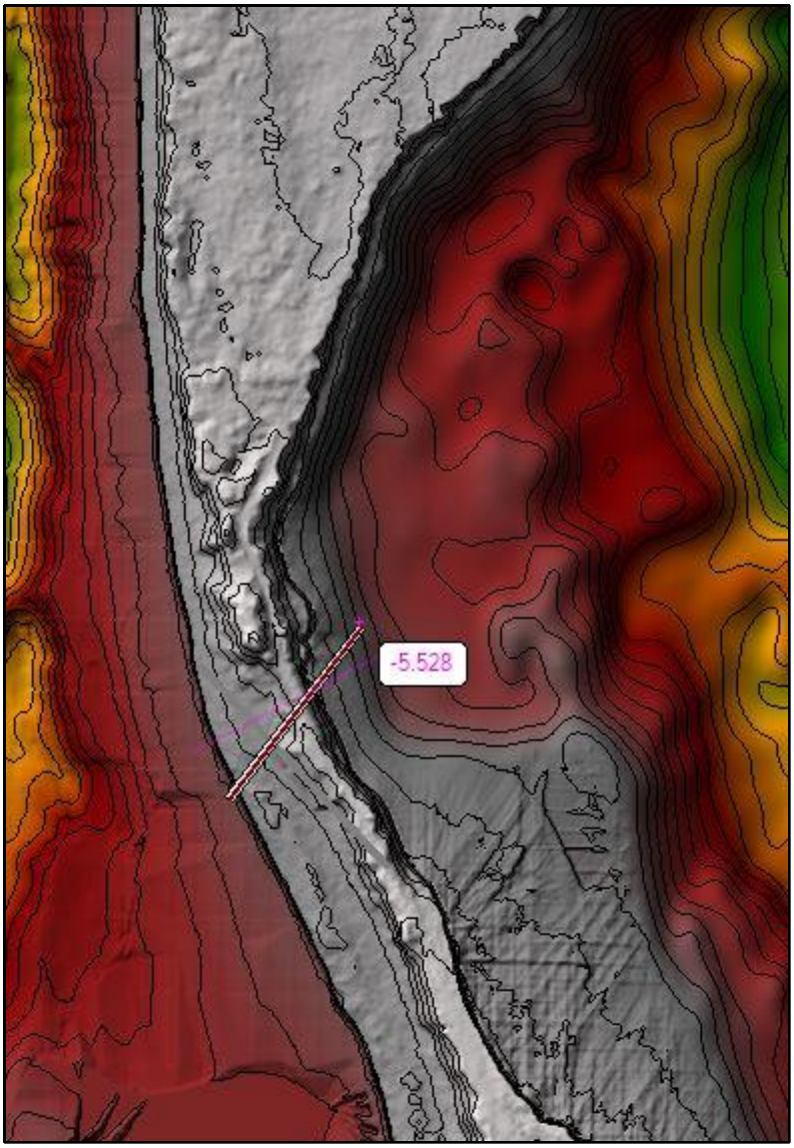

Figure A13. Culvert terrain

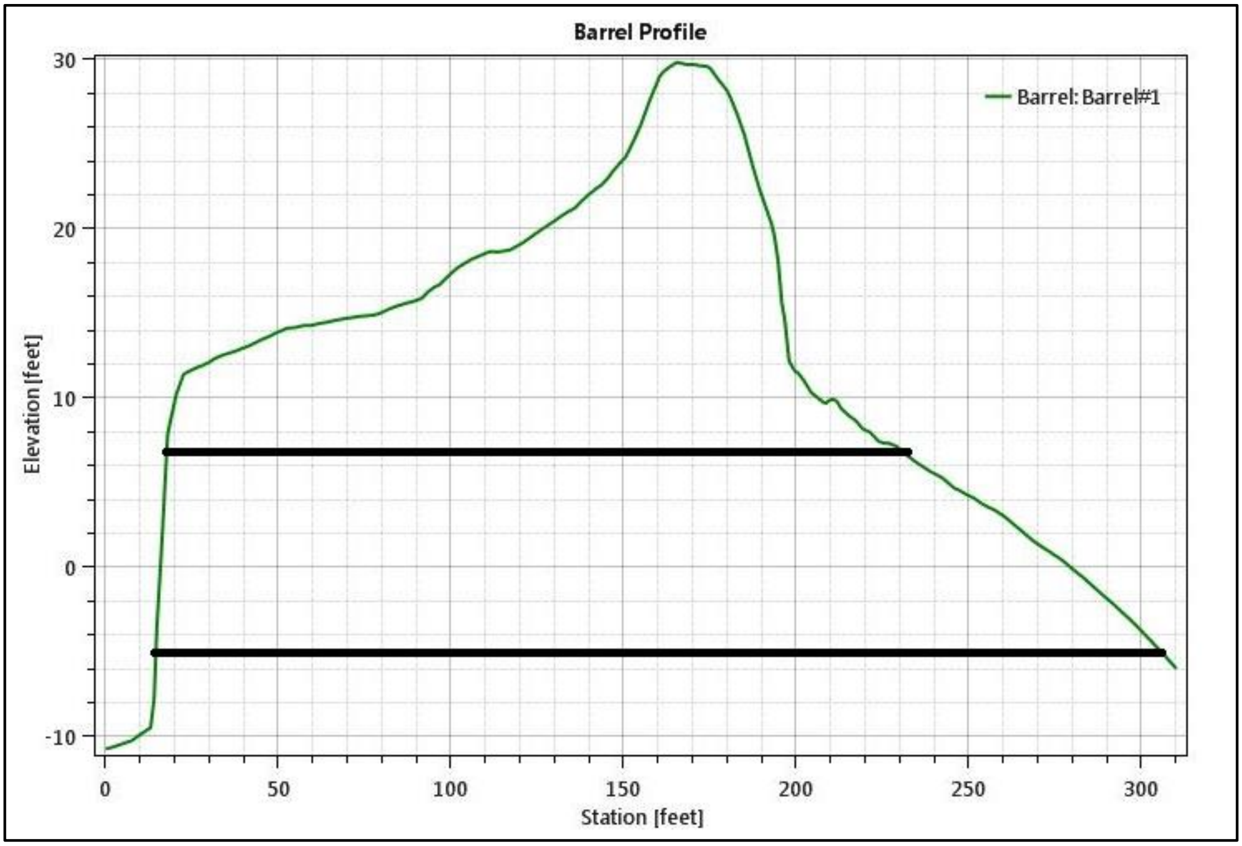

Figure A14. Culvert Section Elevations

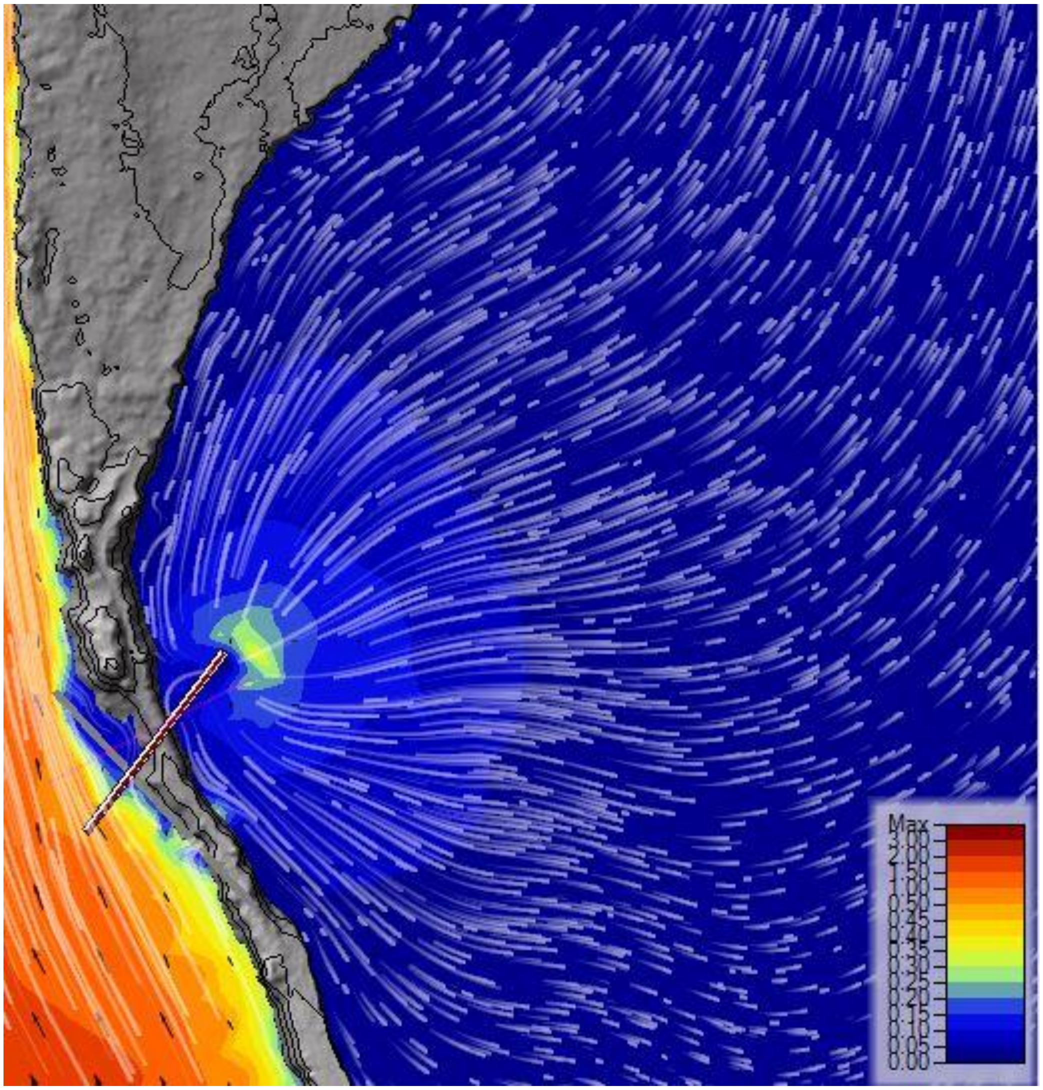

Figure A15. Culvert Performance Example

Exhibit E: HEC-RAS results

Baseline scenarios

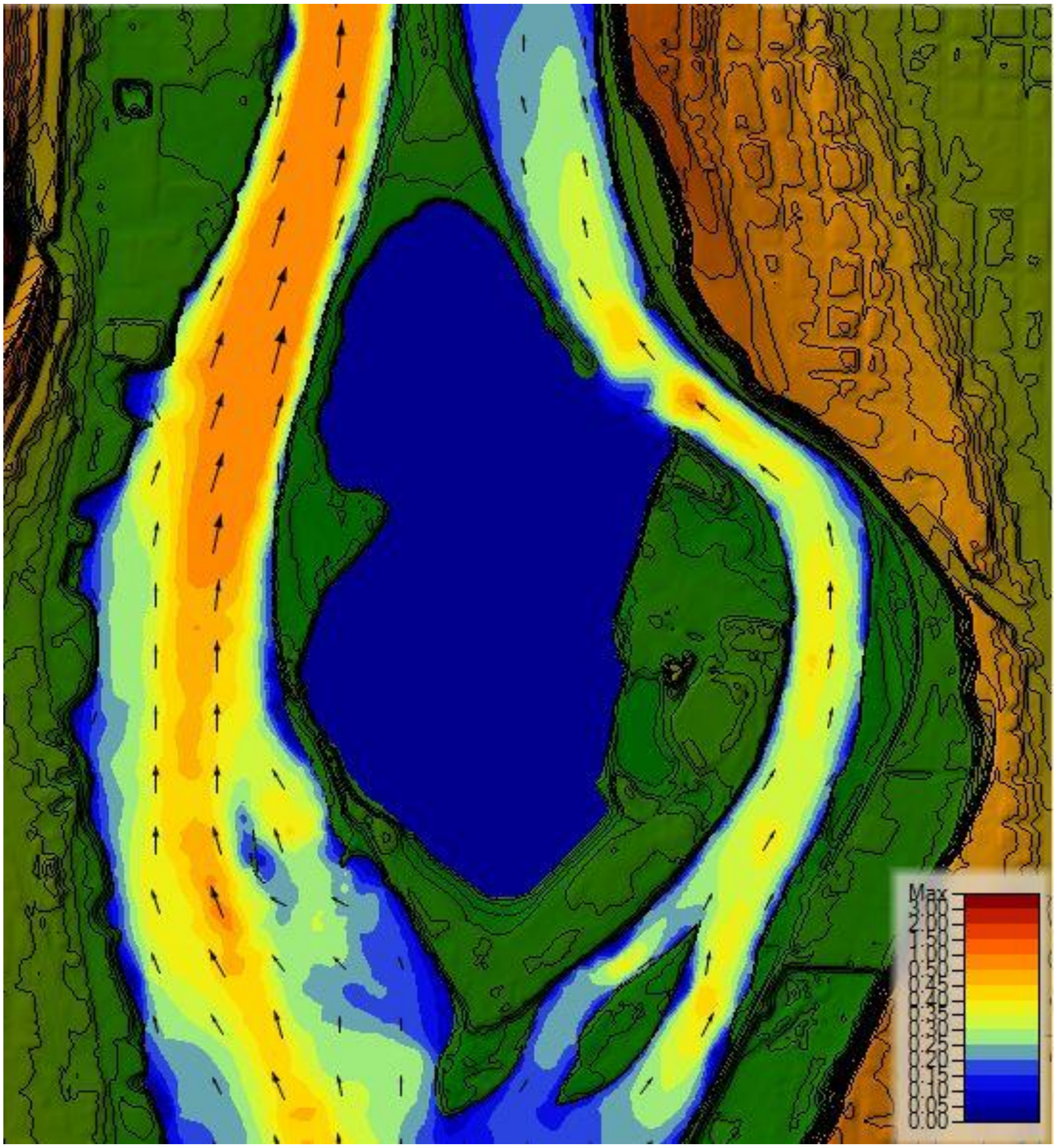

Figure A16. Baseline conditions

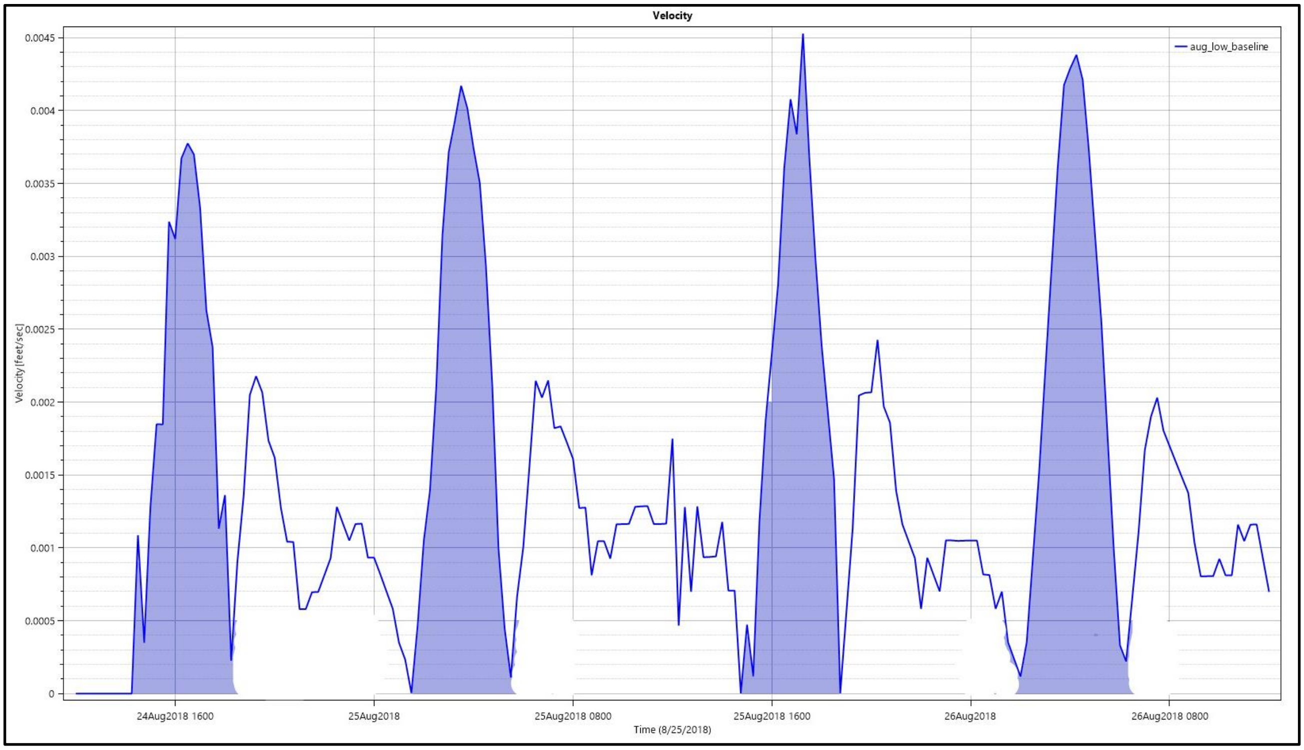

Figure A17. Baseline results - tidal pulsing, lagoon velocities

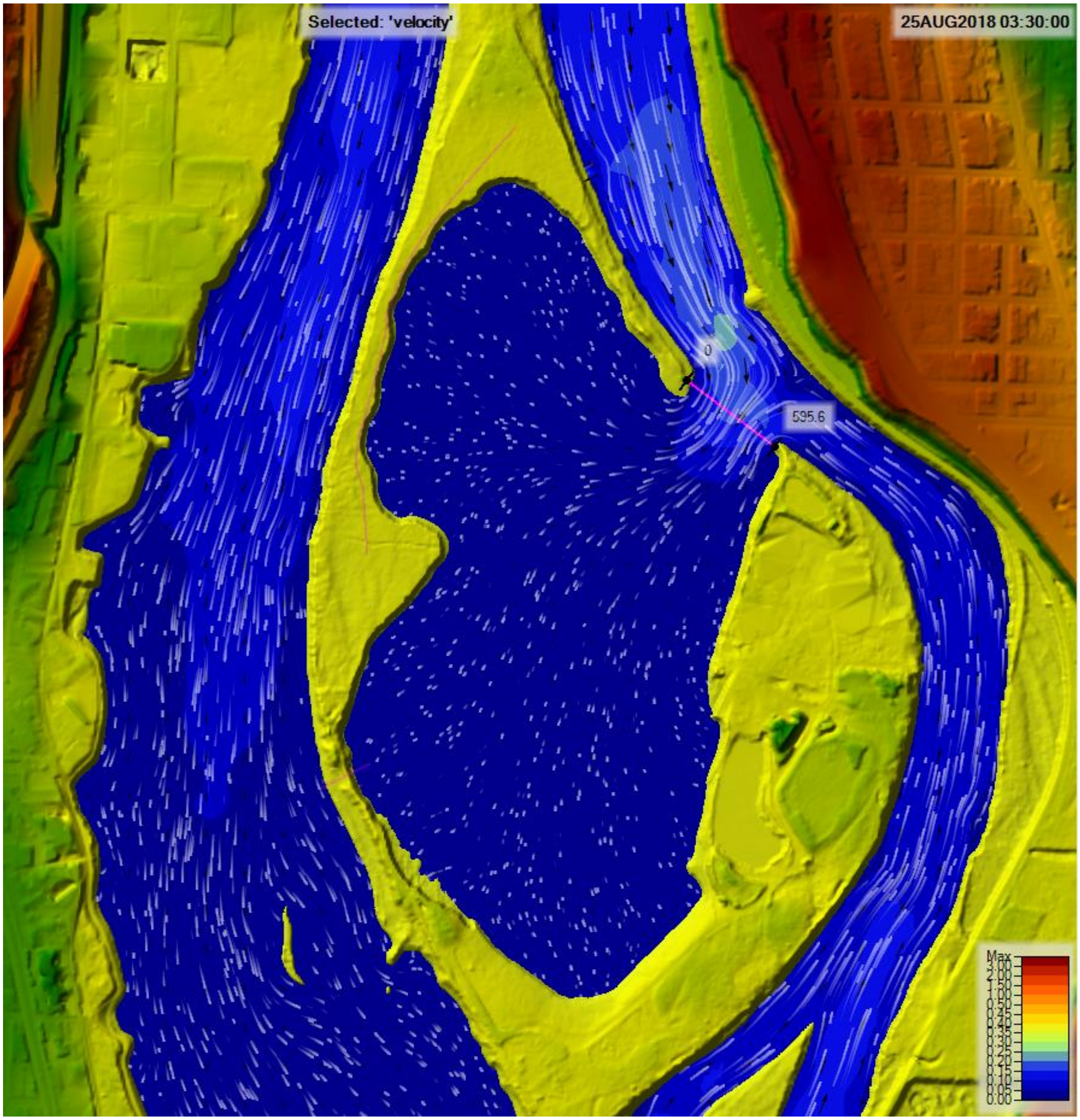

Figure A18. Baseline results - tidal pulsing, high tide

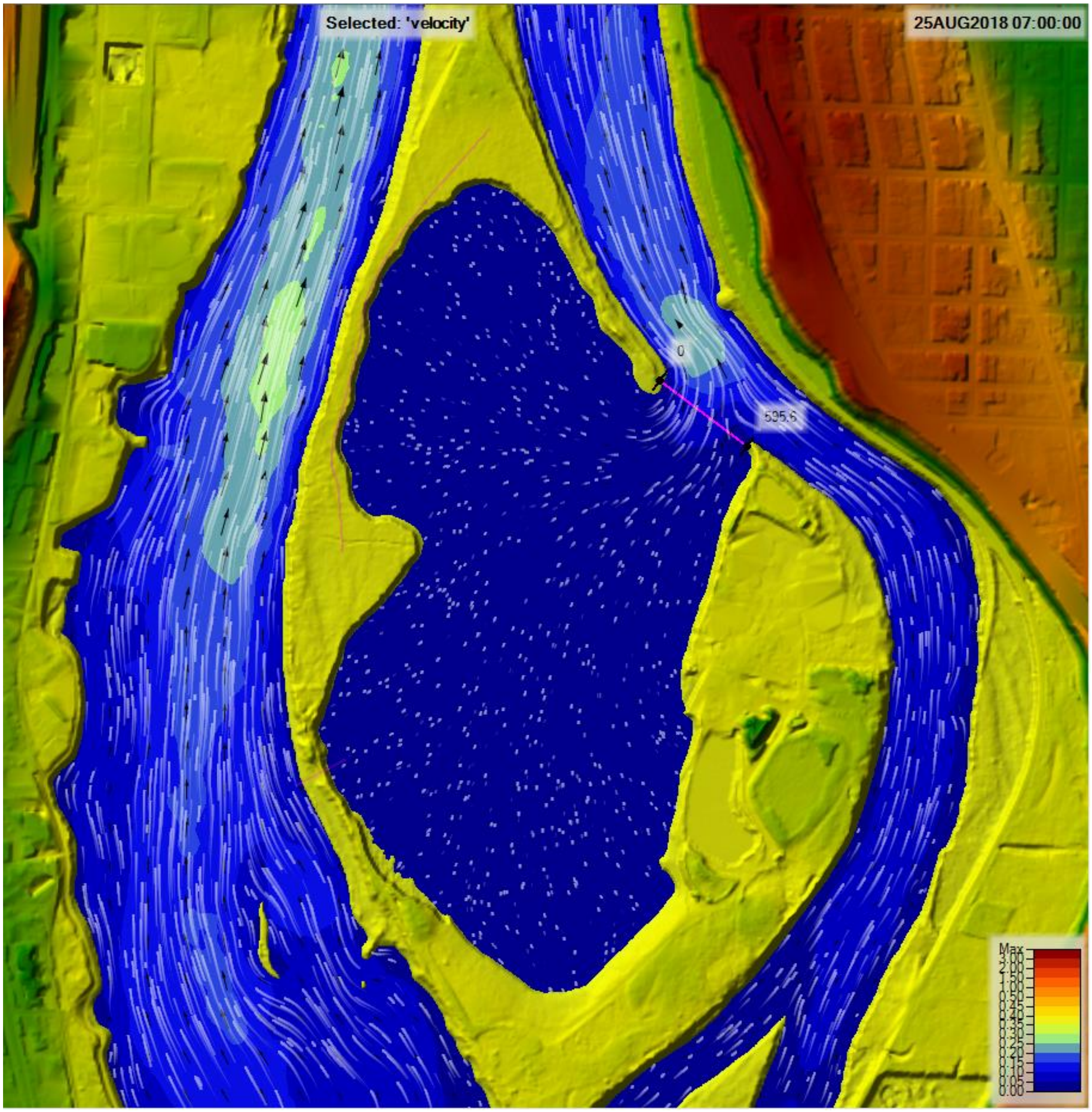

Figure A19. Baseline results - tidal pulsing, low tide

Culvert scenarios

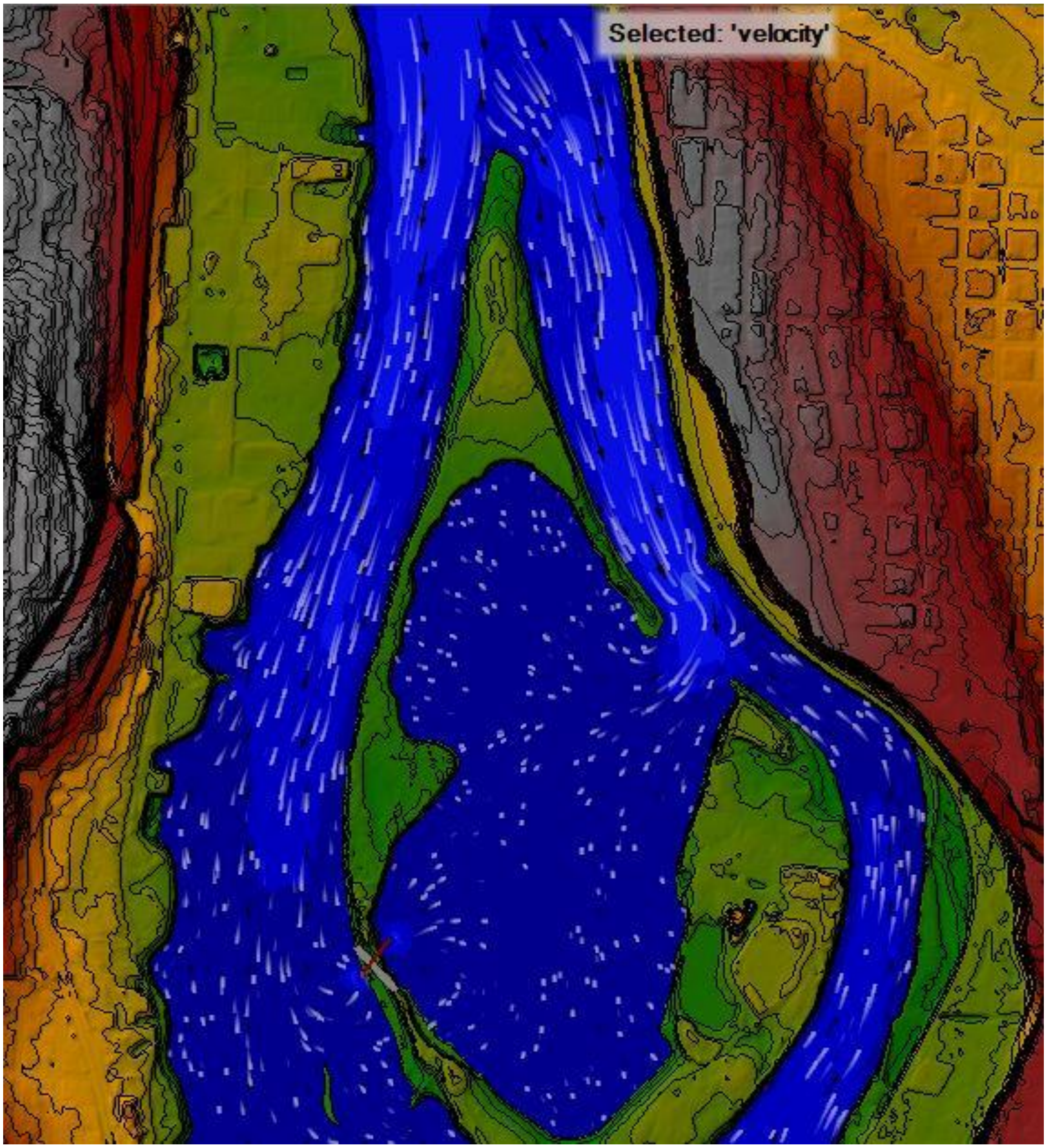

Figure A20. Low flow

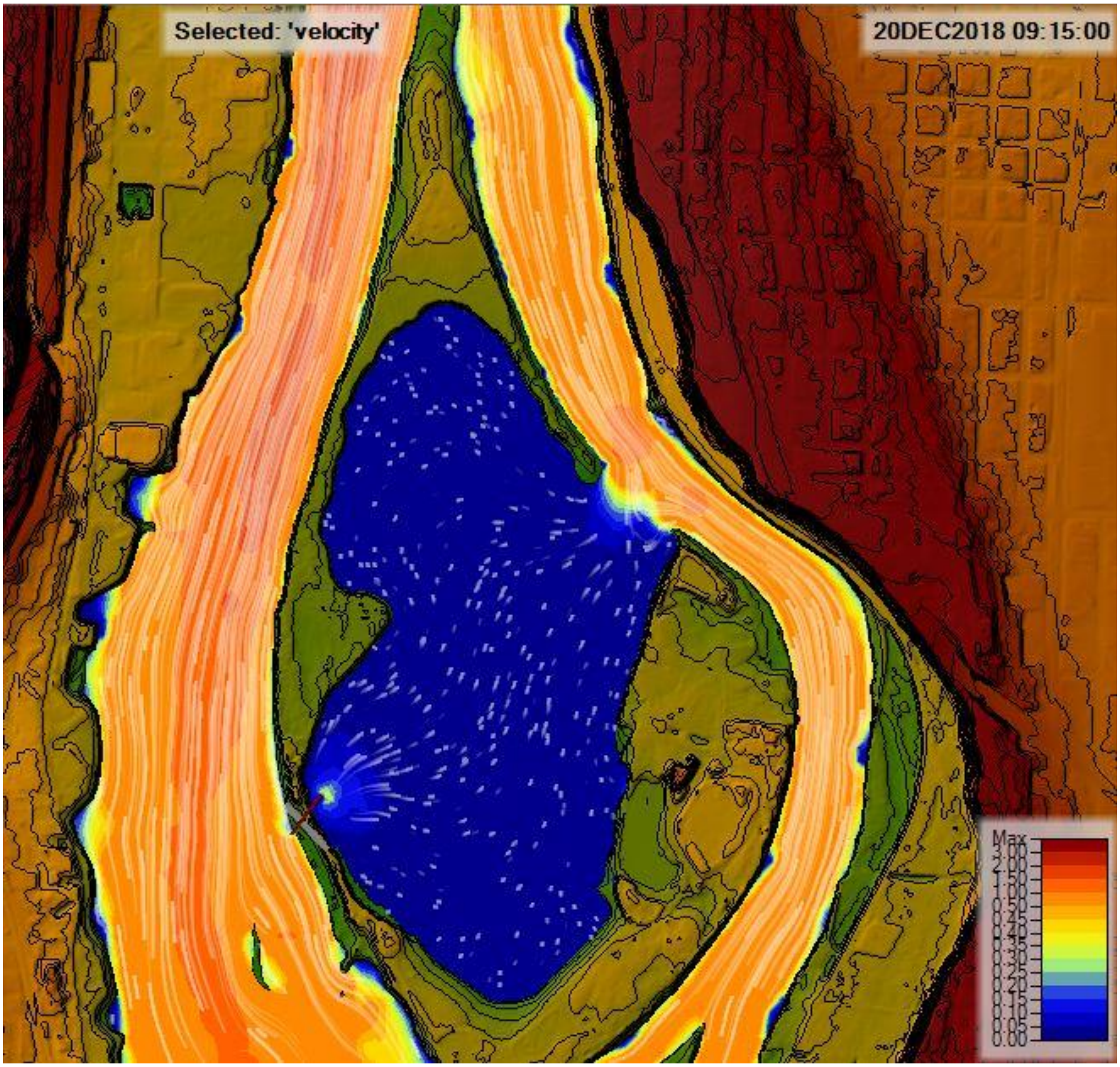

Figure A21. High flow

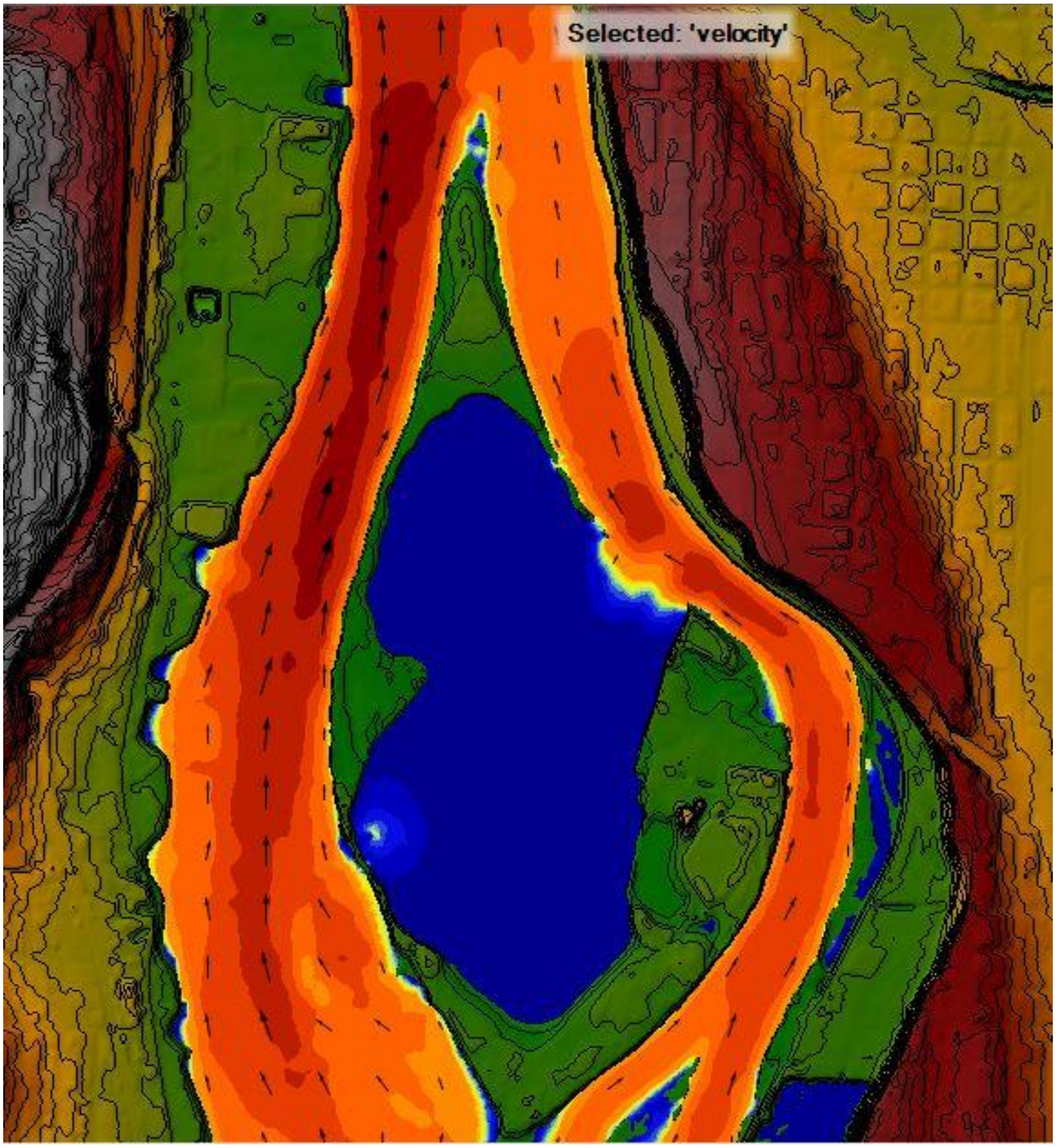

Figure A22. Flood flow

Figure 2. Temperature profile of Ross Island lagoon on June 05, 2018 at 13:38pm (Source: Kurt Carpenter, USGS)

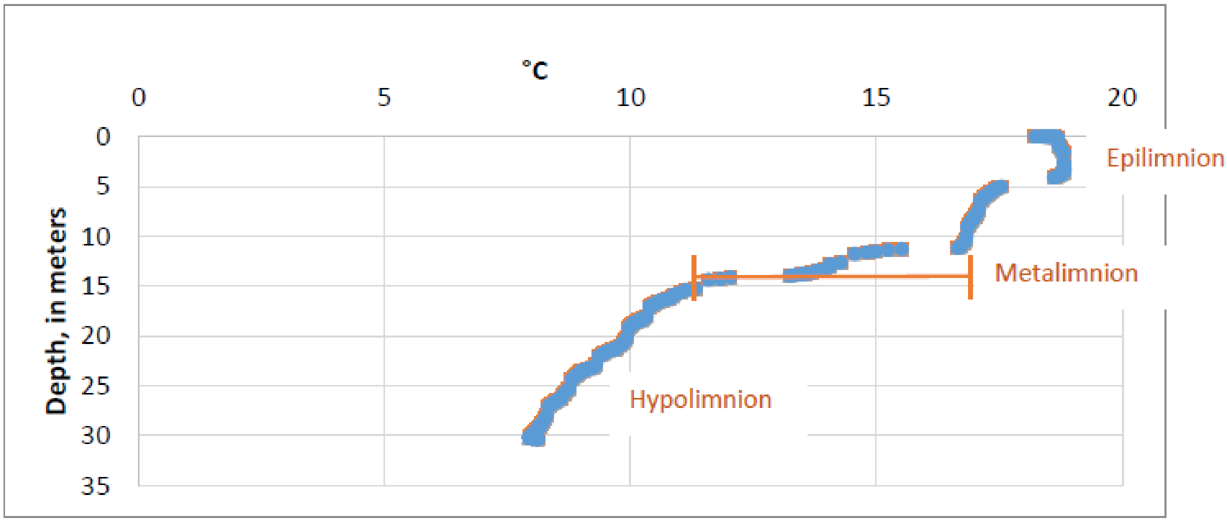

Figure A23. Temperature gradient in Ross Island Lagoon.

Table A2. Results

			Baseline conditions				Culvert alternative			
			Velocity(ft/s)		Richardson number		Velocity(ft/s)		Richardson number	
Scenario	Flow (cfs)	Date	Lagoon inlet	Lagoon @ culvert	Lagoon inlet	Lagoon @ culvert	Lagoon inlet	Lagoon @ culvert	Lagoon inlet	Lagoon @ culvert
Low flow	5000	25-Aug-18	0.16	0.006	45	31955	0.11	0.17	95.07	39.81
High flow	66000	20-Dec-18	0.43	0.004	6.2	71899	0.43	0.42	6.22	6.52
Flood	170000	13-Apr-19	1.2	0.0015	0.80	511282	1.13	0.38	0.90	7.97

Exhibit F: Cost Analysis

Hydraulic Alternative

Table A3. Labor:

Component Name	ID	Component Description	Unit	Price ($/unit)	Quantity	Cost
Landscape and Site Development Engineer	0800	Engineer to survey the project area and oversee project development.	Percentage	4.5	2	$18,442.85
Structural Engineer	1200	Engineer to oversee project and ensure the culvert is built properly/ensure stability of structure and banks.	Percentage	1.75	2	$7,172.22
Field Engineer	0100	Engineer(s) to assist the landscape and structural engineers.	Hour	$44.56	10	$445.58
Engineer	0210	Engineer(s) to plan out the project and calculate parameters.	Hour	$58.30	10	$583.00
Project Manager	0180	Labors that require management; which could be a crew supervisor or time managers.	Hour	$95.29	30	$2,858.55
General Labor	0231	Workers to construct and maintain the	Hour	$23.08	424	$9,785.92

		culvert.				
Specialized Labor	0235	Laborer with a specialized skill set (biologists in this case)	Hour	$109.94	71	$7,805.74

Table A4. Equipment and Mobilization:

Component Name	ID	Component Description	Unit	Price ($/unit)	Quantity	Cost
40-ton Crane	0300	Crane that will place the steel culvert pipe into the excavated trench. (Labor and Equipment)	Hour	$263.29	4	$1,053.15
Crane Driver	1700	Driver to haul the crane to the project site.	Hour	$21.58	4	$86.33
12-Foot Steel Grating (Circular)	0300	Grating that will serve as a screen for the Culverts (Labor and Equipment).	lb	$5.82	100	$582.00
12-foot diameter, 10-gauge, helical corrugated steel pipe culvert		The culvert described for this hydraulic alternative.	Ft	$420	300	$126,000.00
Truck, Dump, 12 Cubic Yards	1215	To hold the excavated material.	Hour	$97.19	226	$21,964.94
50-ton towed trailer	1600	Towed Trailer that will haul equipment to the site (Labor and Equipment).	Hour	$360.45	10	$3,604.54
Excavator for bulk bank measure, sandy clay and loam	5500	Excavator to create a trench for the Steel Culvert; 350 cubic yard per hour capacity (Labor and Equipment).	Cubic Yard	$1.32	22,280	$29,409.60

800 ton, 45-foot wide, 90-foot long barge	0240	Barge that will transport equipment to the project site (Labor and Equipment).	Hour	$129.51	4	$1,053.15

Table A5. Dewatering and Maintenance:

Dewatering Management, Flooding and Dewatering		To dewater the trench as it is excavated (Labor and Equipment).	Acre-foot	$213.59	89	$19,009.51
Power Tool	6180	Power tool that will be used to maintain the culvert pipe (Labor and Equipment).	Square foot	$0.93	11422.83	$10,623.23

Non-Hydraulic Alternative

Table A6. Labor:

Component Name	ID	Component Description	Unit	Price ($/unit)	Quantity	Cost
Extraction Test	0250	Extraction test to observe the cyanobacteria samples in the existing sediment (Labor and Test).	Each	$150	2	$300.00
Field Engineer	0100	Engineer(s) to assist the landscape and structural engineers.	Hour	$44.56	10	$445.58
Engineer	0210	Engineer(s) to plan out the project and calculate parameters.	Hour	$58.30	10	$583.00

Project Manager	0180	Labors that require management; which could be a crew supervisor or time managers.	Hour	$95.29	30	$2,858.55
General Labor	0231	Workers to transport and lay fill and drive boats.	Hour	$23.08	424	$9,785.92
Specialized Labor	0235	Laborer with a specialized skill set (biologists in this case)	Hour	$109.94	71	$7,805.74

Table A7. Equipment and Mobilization:

Component Name	ID	Component Description	Unit	Price ($/unit)	Quantity	Cost
Small work boat, gas, 16-foot, 50 horsepower	3000	Boat(s) that will be used to apply fill to lagoon (Equipment).	Hour	$10.38	30	$311.25
Large work boat, diesel, 48-foot, 200 horsepower	4000	Boat(s) that will be used to apply fill to lagoon (Equipment).	Hour	$297.50	10	$2,975.00
River sand, Portland Sand and Gravel		Material that will be applied to the lagoon (Material).	Cubic Yard	$30	192067.33	$5,762,019.90
3 ½ Cubic Yard Excavator	7340	Excavator that will be used to transfer fill material (Labor and Equipment).	Cubic Yard	$3.99	192067.33	$766,348.65
800 ton, 45-foot wide, 90-foot long barge	0240	Barge that will transport equipment and fill to the project site (Labor and Equipment).	Hour	$129.51	4	$518.05
Truck, Dump, 12 Cubic Yards	1215	To hold the fill material.	Hour	$97.19	100	$9,719.00

Fill Calculation

Table A8. Fill Area and Shallow Water Habitat Area:

Price:	Total Area of Lagoon	Shallow Water Habitat Area	Area where the fill will be applied
$30 per Cubic Yard	702,722 yd^2	129,954 yd^2	576,202 yd^2

$$Volume\ of\ Sediment = Area\ to\ apply\ fill \times \frac{1\ yard}{3\ feet}$$

$$Volume\ of\ Sediment = 576{,}202\ yd^2 \times \frac{1\ yd}{3\ ft}$$

$$Volume\ of\ Sediment = 192{,}067.33\ yd^3$$

Exhibit G: Failure Modes Analysis

Diagrams of Key Design Features

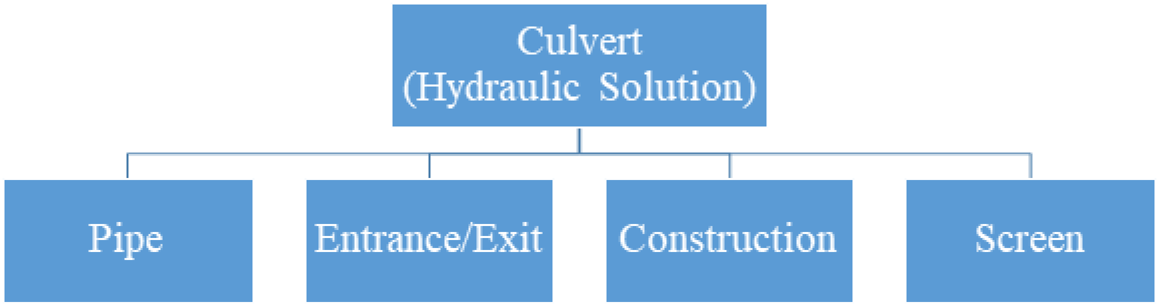

Figure A24. Components of the Hydraulic Solution

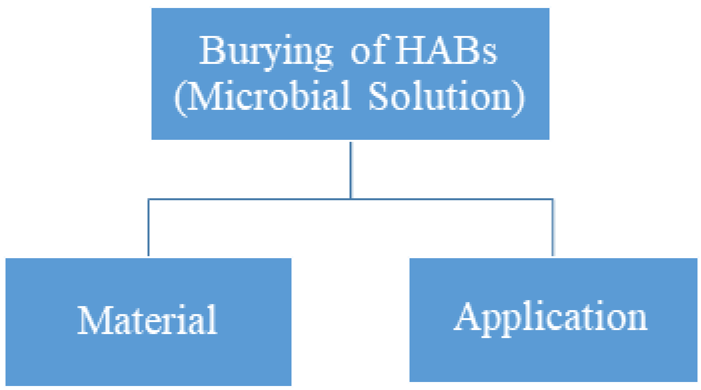

Figure A25. Components of the Non-Hydraulic Solution

Potential Failure Modes Analysis Table

Table A9. Analysis of Each Alternative to Calculate the Risk Priority Number

Alternative	Process Step	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 5)	Potential Causes	LIKELIHOOD (1 - 7)	Current Controls	DETECTION (1 - 5)	RPN (S * L * D)
	What is the process or feature under investigation?	In what ways could the process or feature go wrong?	What is the impact if this failure is not prevented?		What causes the process or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?		
Burial	Material	Introducing invasive species, contamination	Loss native species, impact on wetland area, protected species	2	Improper source	3	Supply/contracting reviews; regular monitoring	1	6
Burial	Application	Wash away, non-uniform, applied inappropriately	Damage downstream infrastructure and biota	3	Malpractice, storm events	2	Clear communication and timing, experience	1	6
Burial	Burial Method	Lack of effectiveness	Continued violation of water quality standards	3	Inadequate design	6	Design reviews	1	18
Conveyance	Pipe	Extreme velocities, corrosion and cracking	Damage the island, CAD cell exposed, floating of pipe, harm wildlife	5	Inadequate design, storm event, aging	2	Regular monitoring	3	30
Conveyance	Entrance/Exit	Erosion, deposition, piping	Scour downstream, CAD cells exposed	5	Lack of maintenance and protection.	3	Regular monitoring and maintenance	1	15
Conveyance	Entrance/Exit	Blockage	No mixing in lagoon, damage to pipe	3	Lack of maintenance and protection, flood debris	5	Regular monitoring and maintenance	1	15
Conveyance	Screen	Break, blockage	Damage to entrance, injury to wildlife, danger to humans	2	Flood debris, aging	2	Regular monitoring and maintenance	1	4
Conveyance	Construction	Expose CAD cells	Exposure to contaminants	5	Malpractice, inadequate site investigation / borings,	3	Investigation and inspection	1	15
Conveyance	Culvert system	Lack of effectiveness	Continued violation of water quality standards	3	Inadequate design	3	Design reviews	1	9
No action	Microbial activity	Continued HABs	Degraded water quality	3	No action	7	Action	1	21
Burial	Material	Introducing invasive species, contamination	Loss native species, impact on wetland area, protected species	2	Improper source	3	Supply/contracting reviews; regular monitoring	1	6
Burial	Application	Wash away, non-uniform, applied inappropriately	Damage downstream infrastructure and biota	3	Malpractice, storm events	2	Clear communication and timing, experience	1	6

Table A10. Species Impacts

Species	Diet	Habitat	Needs	Effect of Culvert	Effect of Fill
Chinook Salmon	-Zooplankton and terrestrial insects for sub-yearlings. As they move downriver they shift from larger midges to trichopterans to daphnia (1)	Need complex habitat and clean gravel for spawning (2)	-Cold and clean water, rich in dissolved oxygen -Cool deep resting holes during the summer(2)	The culvert would benefit this species because it would allow for the lagoon to mix the hot and cold waters and therefore have an overall cooling effect on the water Also, there would now be a flow of water which this species prefers.	This alternative would not benefit this species because it does not create a flow of water in the lagoon; which is a preferable habitat for salmon.
Lower Columbia River Steelhead	-Eat other fish, invertebrates and insects (1)	-Need complex habitat with clean gravel (2)	-Clean, cool, and well-aerated water (1)	The culvert would benefit for the same reason as the Chinook Salmon.	Not benefit for same reason as Chinook Salmon.
Sturgeon	- Benthic feeder or filter feeder	Clean, coarse cobble with a continuous flow of fast water is required for spawning -Juveniles need sands and colder, deep waters; but tend to migrate to areas with a	- Highly migratory fish that need different materials and conditions for different stage in their lifecycle (3)	This alternative could possibly be beneficial to this species as it would introduce a flow into the lagoon. This could intrigue this species and introduce them into an area where food is available and competition would be low.	This alternative would have little to no effect on this species because sturgeon migrate toward larger supplies of food and their prey would take a significant amount of time to

		greater supply of food -Adults prefer sand and gravel as well as shallower waters with slow moving waters (3)			migrate into the new sediment of the lagoon.
Lamprey	-Young lamprey feed on microscopic plants and animals while adults parasitize fish (1)	-Larvae need fine sediments on the river bottom -Fine gravel needed for spawning (2)	-Need low velocities and fine sediments to burrow into during juvenile stages (4) -Temperatures of less than 72 degrees fahrenheit (4)	Beneficial because the culvert would provide low velocities and the total water profile would be cooler as a whole in the lagoon.	Could be beneficial because the lower waters would be cold enough for the lamprey and the fill used would be fine enough.
Amphibians	-Aquatic and terrestrial invertebrates (6)	-Species that require open water need slow-moving areas, logs, and rocks (6)	-Some larvae need the water to be low in temperature and turbidity (6)	Little to no net impact. Possible lower water temperatures in the lagoon would positively impact species, but increased flow would negatively impact species.	Little to no impact. Most of the impact of this alternative would be in the lower depths of the lagoon outside of the range of these species.
Birds	-Species such as Bald Eagle and Osprey feed mainly on fish, but may also feed on	-Osprey nests are often over water. Bald eagles nest in trees and both require	Habitat, especially for foraging. Food, low levels of pollution and pesticides (7)	Beneficial because it is likely to have a positive impact on fish prey species.	No impact because it is unlikely to benefit prey species.

	amphibians, mammals, and large invertebrates (7)	sticks for nesting material (7)			
Coho Salmon	- A wide range of plankton and insects (1)	-Clean Gravel and complex habitat for spawning (2)	-Clean and cold water that is well-aerated (1)	The culvert would benefit for the same reason as the Chinook Salmon.	Not benefit for same reason as Chinook Salmon.
Chum Salmon	- Insects and other invertebrates (1)	Stream Gravel bars with upwelling flow (2)	-Clean and cold water that is fast flowing and aerated (1)	The culvert would benefit for the same reason as the Chinook Salmon.	Not benefit for same reason as Chinook Salmon.

Exhibit J: HEC-RAS model

The HEC-RAS model is uploaded separately. There are 2 geometries and 3 hydrologic scenarios, for 6 total model results.

Exhibit K: References

1. Williams, John E., et al. *Field Guide to Common Fish of the Willamette Valley Floodplain*. Oregon State University, 2014.

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