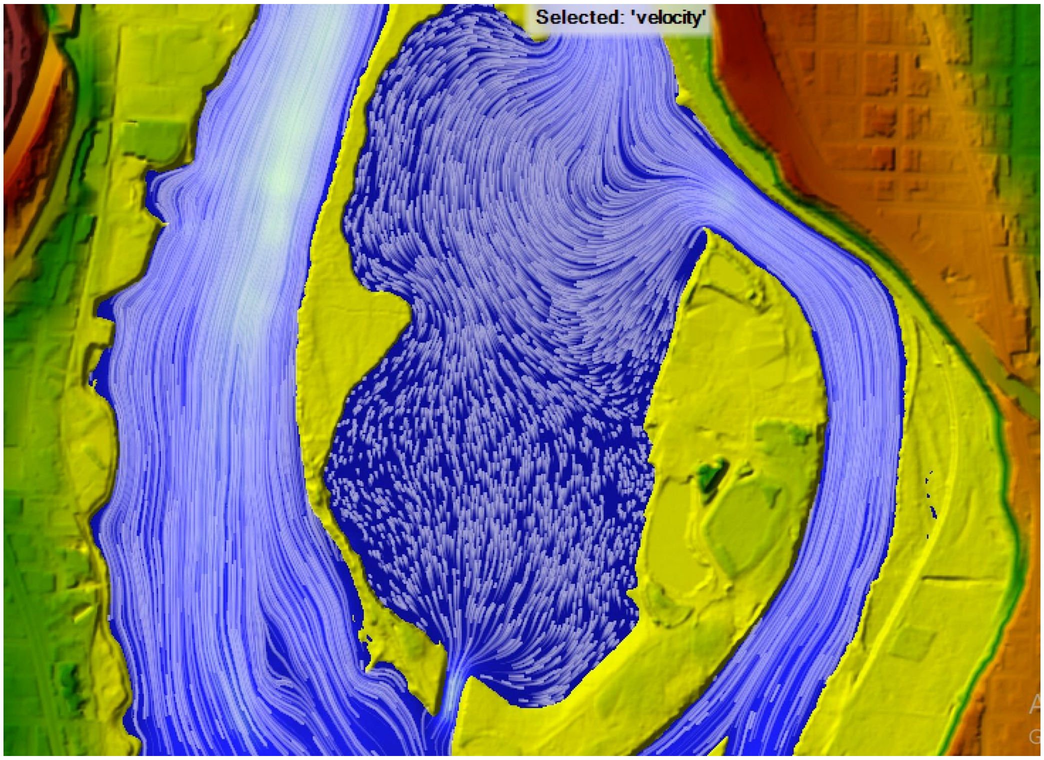
# Ross Island Lagoon Harmful Algal Bloom Final Report

***Design Team 1***

June 14th, 2019



## Objectives

Algal blooms result from excess growth of cyanobacteria in stratified, slow-moving waters. They reduce dissolved oxygen in the water and can be toxic to aquatic life. The mechanisms that contribute to harmful algal blooms (HABs) include high temperatures, a stratified water column, and excess nutrient loading. Ross Island is an anthropogenically modified land mass in the Lower Willamette River, upstream of downtown Portland, OR. Decades of terrain modification by the Army Corps of Engineers and Ross Island Sand and Gravel have contributed to recurring HABs in the lagoon within this island. Originally two islands, an embankment was constructed on the upstream end with imported material, burying contaminated sediment in contained aquatic disposal (CAD) cells. The objective of this report is to analyze three alternative solutions to decrease the formation and severity of HABs at this site. The primary constraints of this project are to fit into the current reclamation plan, to maintain or increase shallow water habitat, and to leave the CAD cells undisturbed.

## Introduction

Numerous factors influence the formation and persistence of HABs, which may lead to hypoxia and toxin release (Herman, 2017). The difficulty for water body management is to understand the complex interactions between physical, chemical, and biological conditions as well as the potential bloom-forming organisms present in the water system (US Army Corps, 2016). Human-caused eutrophication leading to hypoxia often occurs in waters with a “susceptible physical structure” (National Science and Technology Council, 2016). This is defined by a vertical density gradient, or stratification that separates well-oxygenated surface water (e.g., epilimnion) from the sediment and bottom water (e.g., hypolimnion). This is driven by temperature, increasing in summer months. In the case of Ross Island, the mechanism which has lead to stratification is the modified hydraulic flow through the lagoon that was separated from the main river in 1926-1927 by the U.S. Army Corps of Engineers. The addition of an earthen berm connected two previously separated islands, obstructing mainstem flows and resulting in almost completely stagnant water in the lagoon. Decades of gravel mining operations have also greatly changed the bathymetry of the lagoon, further exacerbating stratification and deepening of the lagoon while aiding in nutrient availability for cyanobacteria.

## Site Specifications

Ross Island and the Ross Island Lagoon cover 450 acres (170 acres area + 280 acres lagoon) in the Willamette River. The island and lagoon sit in the north reach of the lower Willamette river. There are two eagle nests on the island that require a 400 foot buffer zone in all directions (US

Army Corps, 2016). Another concern are five contained aquatic disposal (CAD) cells located at approximately -20 ft elevation relative to the Ross Island datum (NAVD88 + 4.96 ft).

## Hydraulic Conditions

Ross Island lagoon is characterized by slow moving, stagnant waters. The velocity at the entrance of the lagoon ranged from approximately 0 ft/s to 0.08 ft/s at the lagoon entrance during typical spring flows (March 26-28th). Within the lagoon, velocities range from 0 ft/s to 0.005 ft/s during the same time frame. While slight variation in velocities are observed throughout the year, as temperatures increase in spring and discharge decreases, stratification becomes more likely. With stratification being a leading cause of HAB formation, spring is the targeted time for introducing flows into the lagoon.

The hydrograph is also influenced by a strong tidal signal from the confluence of the Willamette and the Columbia River downstream from the site. This is captured in the velocity time series at the entrance to the lagoon in Figure 1 in Appendix A. Velocity across the profile increases during high tide as water enters the lagoon. During the summer, this effect is more pronounced; the Holgate Channel actually reverses direction and accumulates in the lagoon during high tide (Figure 2 in Appendix A). The momentum of the river is strong enough in winter flows to overcome the tidal backwater. The lack of significant flow in and out of the lagoon has resulted in temperature stratification, one of the leading causes of algal blooms. Temperatures range from approximately 8 °C at the bottom of the lagoon to 19 °C at the water surface. The stratification of the lagoon is visible in Figure 3 in Appendix A.

## Methods

The first proposed hydraulic alternative is comprised of a 50-ft wide channel that conveys water through the southwest embankment of the island (Figures 4 & 5). The channel will be armoured with 3-ft diameter boulders to protect from erosion and scour. This alternative is intended to capture some of the flow from the mainstem at the upstream end of the island. HAB formation would be discouraged by increasing velocity, displacing stagnant water, and disrupting stratification. The channel was modeled with two methods: a box culvert inline structure created within HEC-RAS, and a modified terrain file created in ArcMap.

The second hydraulic alternative builds on the first by including the southwest channel and also by widening the northeast entrance of the lagoon (Figures 6 & 7). The removal of this embankment is proposed to encourage mixing throughout the north end of the lagoon. This also reduces obstruction of flow out of the lagoon as it enters through the channel.

The primary evaluation metric for both hydraulic alternatives is the Richardson number, which can be used to quantify the extent of stratification and the mixing depth. The velocity profiles used in these calculations were drawn manually in HEC-RAS (Figure 8). A Richardson number calculation is necessary due to fundamental uncertainty inherent to using a 2D model. 2D models in HEC-RAS do not accurately calculate velocities across depth, so velocities in the lagoon are underestimated by the model. Despite large reductions in the Richardson number compared to the existing conditions, both alternatives remain above the critical Richardson number that ensures mixing (0.25). Calculations for each scenario are shown in Appendix D. Richardson number and mixing depth are reported downstream of the proposed channel and at the entrance of the lagoon. Mixing depth assumes the critical Richardson number and determines the depth at which HABs are not expected to form.

The third alternative calls for the implementation of 20 floating, solar-powered aeration compressors. These compressors inject air into the water causing turbulent mixing between the deep, cool water of the hypolimnion and the warm, surface epilimnion. Mixing of the water column circulates cyanobacteria below their optimal photic and temperature zone preventing formation and persistence of blooms. Figure 9 in Appendix B provides a visual representation of the solar panels in the lagoon. Each system is capable of displacing 14 cubic feet per minute, and can treat up to 9 acres (Living Water Aeration, 2019). The system will operate from April to September when flows are lowest and stratification is most likely to promote growth of HAB’s (Cong, 2011). This alternative poses no threat to the subsurface CAD cells, and would not promote erosion or changes in hydraulics from the existing conditions. Additionally, aeration would increase the concentration of dissolved oxygen providing a wide array of benefits to aquatic life.

## Alternatives Analysis

### Economic Analysis

Total cost for the open channel is estimated to be $850,000 with $500 yearly operations and maintenance (O&M). The total cost for the widened lagoon entrance is $1,440,000 with $500 annual O&M. These costs assume the open channel is lined with riprap and not concrete, and includes excavation, dewatering, staging and labor costs for both hydraulic alternatives. The solar aerators capital cost is $181,000 with an annual O&M cost of $70,800 (Hale, 2018).The capital cost accounts for materials, structural components and labor. The solar aerator annual O&M costs include set-up, take-down, monitoring, and associated labor. All costs were estimated using RSMeans data and manufacturer price quotes and are reported in Table 1, 2 and 3 in Appendix C.

### Habitat Impact and Benefit to Species

The first alternative does not provide foreseen species benefits. The second alternative would create additional shallow water habitat in the site. In total, 4.2 acres of shallow water habitat would be added to the northeast corner of the lagoon. The proposed excavation in the northeast draws the elevation down to -20 ft relative to Ross Island datum; therefore, shallow water habitat is being created. To accomplish this, 110 acre-feet of material would have to be removed from the northeast entrance. This material would be relocated to the western bank to increase bank stability. Figure 10 in Appendix B shows the areas of habitat creation and modification of the embankments. The third alternative would also lead to overall benefits to the site. Stratification disruption from the aerators should decrease the severity of the HABs, which improves conditions for chinook, steelhead, sturgeon, and other ESA-listed species.

Juvenile chinook, steelhead, and sturgeon are expected to benefit from the second alternative due to the implementation of more shallow water habitat and increased access to the lagoon. Increased flow and mixing of the lagoon is expected to decrease the severity of the HABs which will likely decrease fish die-off caused by hypoxic conditions. Species benefits for each alternative are outlined in Table 4 in Appendix C.

Construction in a river always comes with many unknowns and unforeseeable impacts. Bed scour and erosion are always possible when rerouting flow or moving material. The open-channel could fail due to mis-calculations or construction errors. Flood flows are also variable and could impact any alternative to a known degree. Additionally, the existing habitats will either be removed or disturbed when the northeast entrance is excavated. There will be a removal of woody habitat on the island and most of the shallow water habitat surrounding the northeast embankment will undergo similar disturbances.

Aerators could impact the aquatic life in an unforeseeable way due to their noise/disturbance. The aerators may also pose a risk to the human recreation in the area. Vandalism risk is present to an unknown extent. Storage of the aerators may also impact the area depending on the method of storage.

## Failure Modes Analysis

A failure modes analysis was conducted following the Federal Emergency Management Agency's (FEMA) template serving as a guide. A comprehensive spreadsheet using this template can be found in Appendix C under Table 5. Additionally, to better conceptualize the possible components of each project prone to failure, key component trees were developed for each of the three alternatives (Appendix C). Using the existing risk priority number (RPN) framework developed by FEMA, the outcomes of the appended analysis indicate that the first hydraulic solution has the lowest total risk involved due to the simplicity of the project compared to the other two alternatives. This recommendation is proposed with the strong caveat that sufficient armoring against scour under a wide range of flows is essential to prevent disturbance of the CAD cells.

Based on the HEC-RAS models for the two hydraulic alternatives, there was no observed impact on base flood elevation (BFE). This model suggests compliance with the "no-rise" permitting required for a project of this nature. Using these flood data, predictions were made about the magnitude of forces these structures would have to withstand, resulting in low and moderate risk of failure for the first and second hydraulic solution, respectively. The solar aerators have negligible risk of failure due to flood events as they will only be deployed during warm, low flow months, and will not impact BFE.

## Outcomes and Recommendation

A comparison of the Richardson number was completed for the existing conditions and the first and second hydraulic alternatives. Table 6 in Appendix D displays the Richardson number and mixing depth for different scenarios. This analysis showed that widening the entrance is an important component in promoting mixing of the lagoon. During the peak of the 2019 April flood event, the second hydraulic alternative produced a Richardson number at the entrance of the lagoon that was less than half that of the initial conditions and the first alternative. As a result, the mixing depth of the second alternative was approximately 18 feet, while the first alternative and initial conditions produced a depth of approximately 7 feet. At the entrance of the channel on the lagoon side, the Richardson numbers and mixing depths were within two feet of each other for the first and second alternative.

The Richardson numbers and mixing depths near the channel outfall were also similar in March flows for the first and second alternative. However, the second alternative was approximately twice as effective as the existing conditions and first alternative at the entrance of the lagoon. The existing conditions and first alternative showed very similar results for August flows at the entrance of the lagoon with the second alternative being the least effective. The decreased effectiveness of the second alternative in August could be a result of increased tidal pumping into the lagoon intersecting with flows leaving the lagoon. At the channel outfall, the first alternative was the only scenario that resulted in any mixing. Notably, for each alternative and location, the mixing depth was never more than one foot for August.

Although the most cost-effective, and posing the fewest risks to erosion of CAD cells, the lack of literature and examples of large scale projects using hydraulic aerators poses great uncertainty in the effectiveness of the third alternative (Herman, 2017). Another concern is that a turbulence-driven turnover event would allow potentially nutrient-rich water from lower levels to reach the upper water column favorable to HAB species (Chong, 2011). Before moving forward with floating solar aerators, a need for pilot studies under similar conditions to the Ross Island lagoon would be needed before implementing them in a project of this scale.

The analyses described above indicate that the second hydraulic alternative is the most effective long term solution. The Richardson number and the effective mixing depth indicate that the second hydraulic alternative would have a moderate effectiveness, and the existing conditions and first alternative would have low levels of effectiveness. The solar aerators have the potential to be effective, however, their constant maintenance requirements make it less realistic in the long term.

## Discussion

While this analysis indicates that the second hydraulic alternative could be effective in controlling HABs in Ross Island lagoon, further investigation of each alternative is suggested due to limitations in this analysis. 2D HEC-RAS assumes uniform velocity throughout the water column. This assumption is not representative of hydraulic processes and leads to underestimation of velocities. Furthermore, comparison between the model results relies on the location of each velocity profile line, and differences in profile line location between models could inaccurately represent the relative effectiveness. Results from each model were taken from a single point in time to enable comparison between alternatives. However, unsteady flow and the tidal influence are best represented by a time series. Another significant uncertainty is how shallow mixing would impact formation of HABs.

While aeration has proven to be effective at reducing HAB's in reservoirs and ponds, one of the major disadvantages is the feasibility of implementation over a large area (Cong, 2011). Few studies have addressed using aeration at a scale greater than a dozen acres to help reduce stratification (Herman, 2017). While floating solar panel systems are increasing in popularity for commercial aquaculture and power generation in countries such as Japan and China, there are few examples of similar projects in the U.S to build from.

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# Appendices

## Appendix A

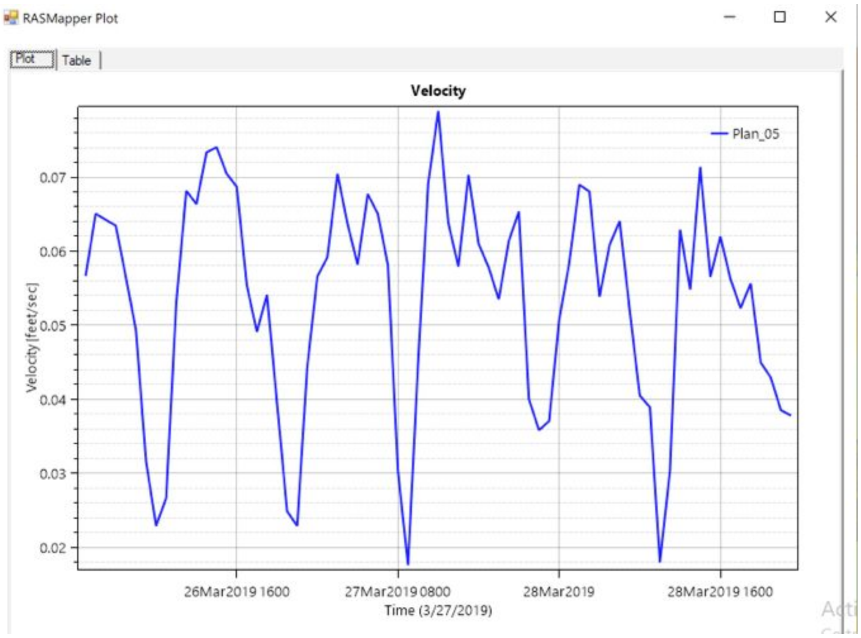


Figure 1: Velocity time series at the Holgate Channel entrance showing tidal influence.

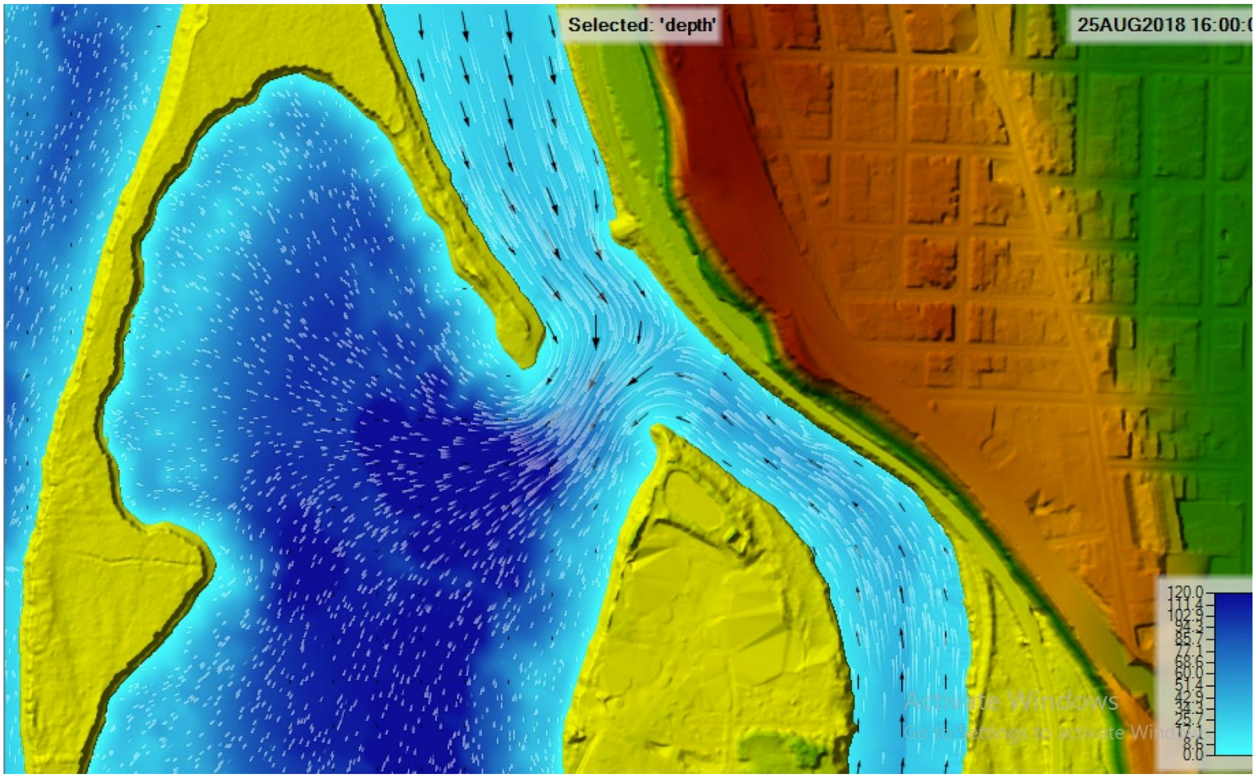


Figure 2: Holgate Channel reversal during high tide under low summer flows (25 August 2018)

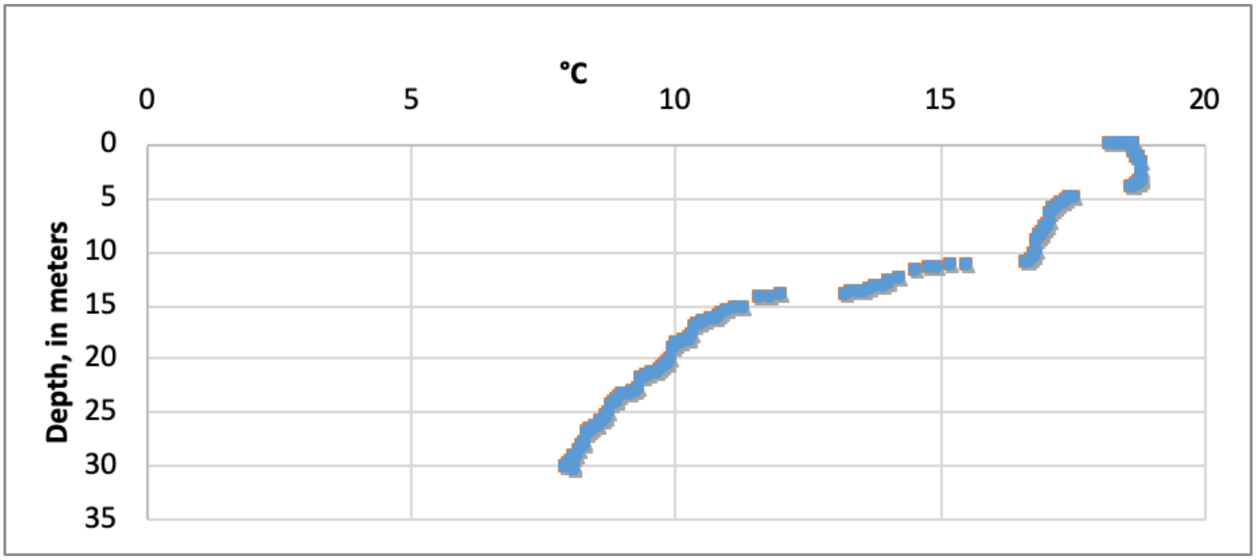


Figure 3. Temperature profile of Ross Island lagoon on June 05, 2018 at 13:38pm (Source: Kurt Carpenter, USGS)

## Appendix B

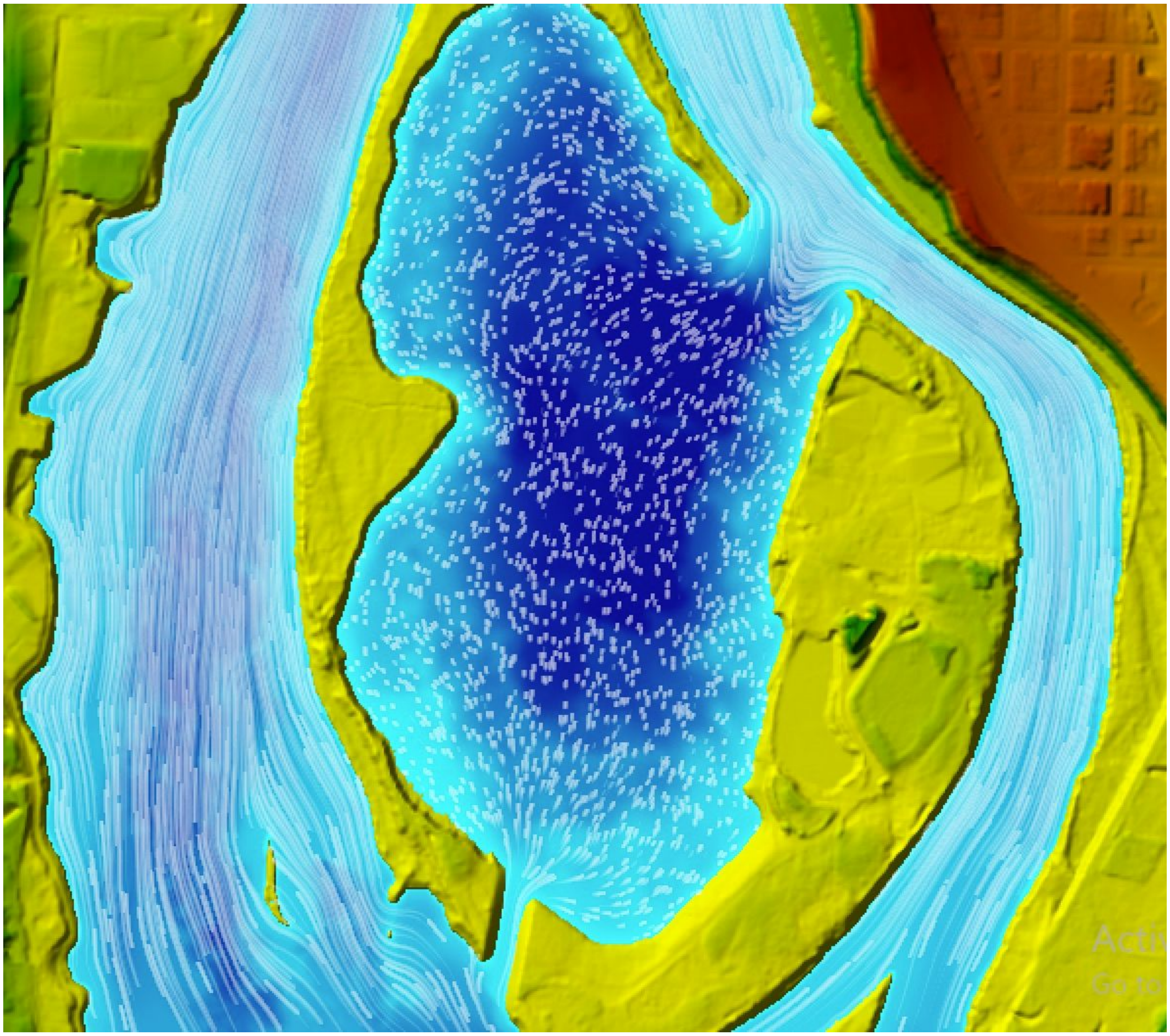


Figure 4: Hydraulic alternative 1

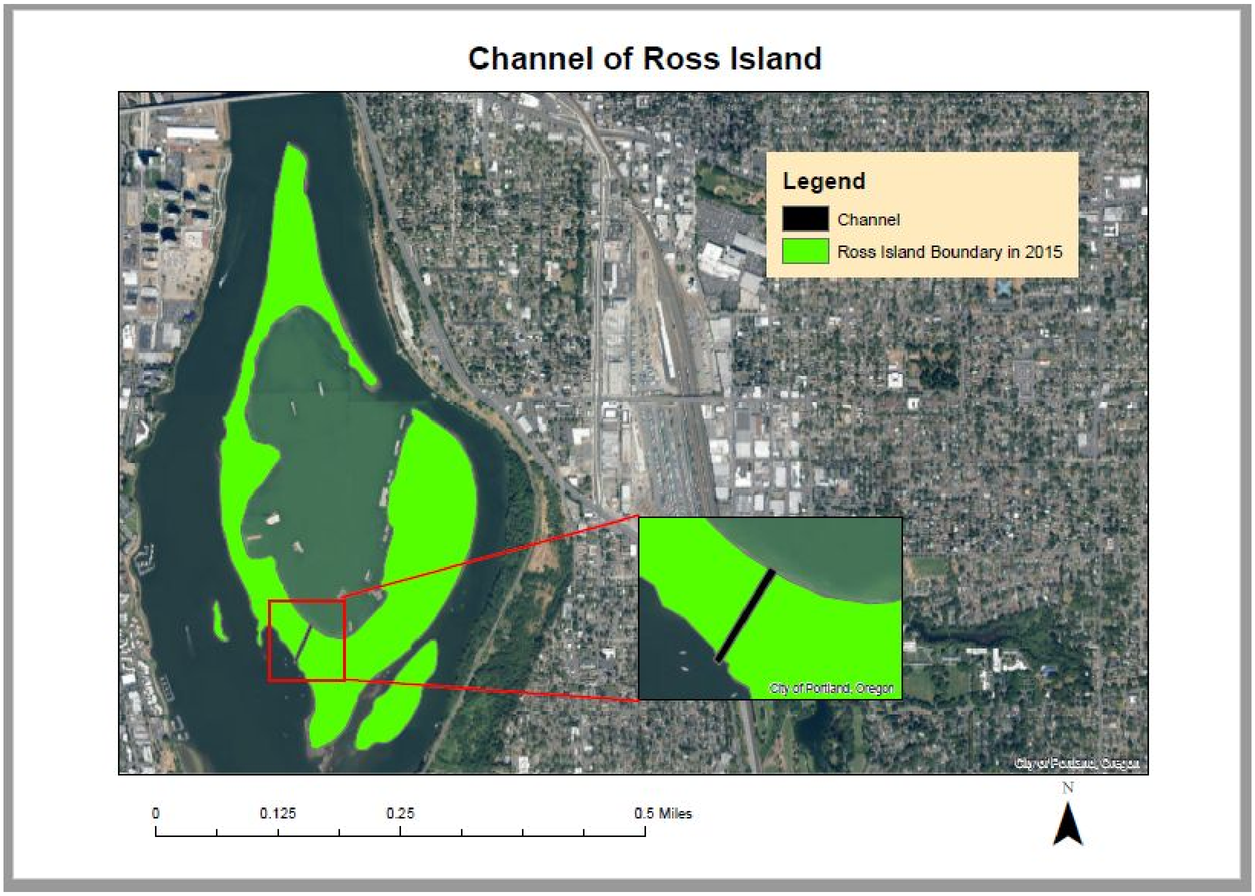


Figure 5: Map view of hydraulic alternative 1

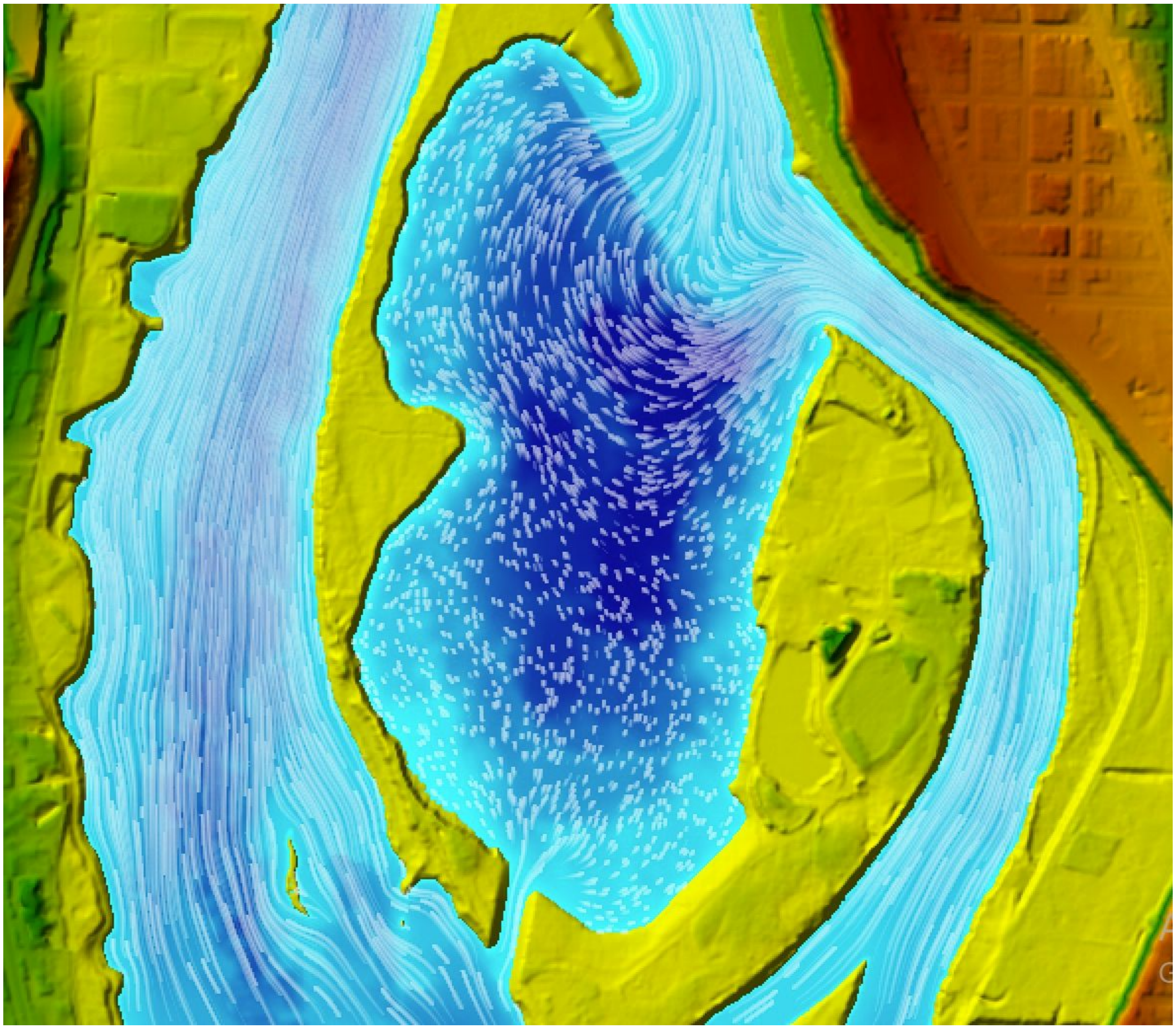


Figure 6: Hydraulic alternative 2

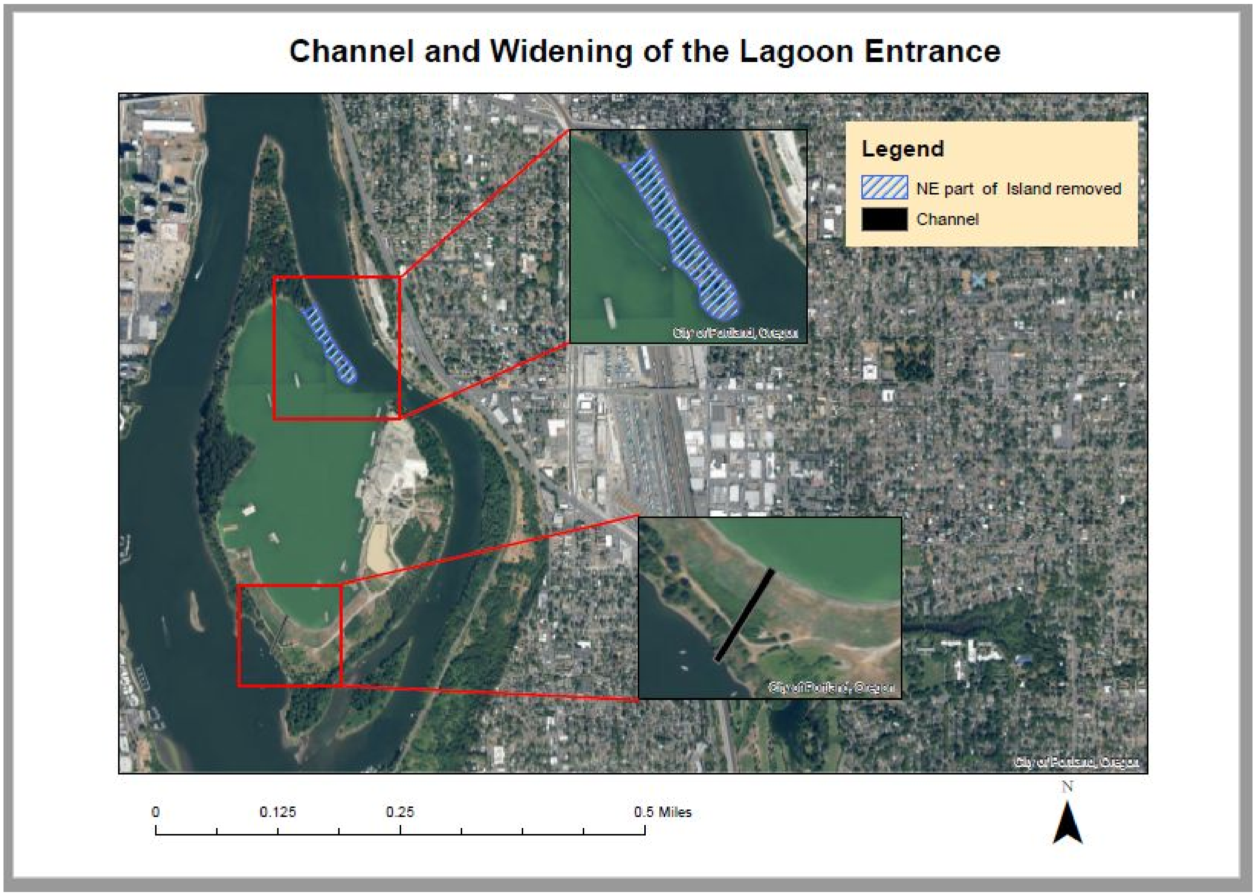


Figure 7: Map view of hydraulic alternative 2

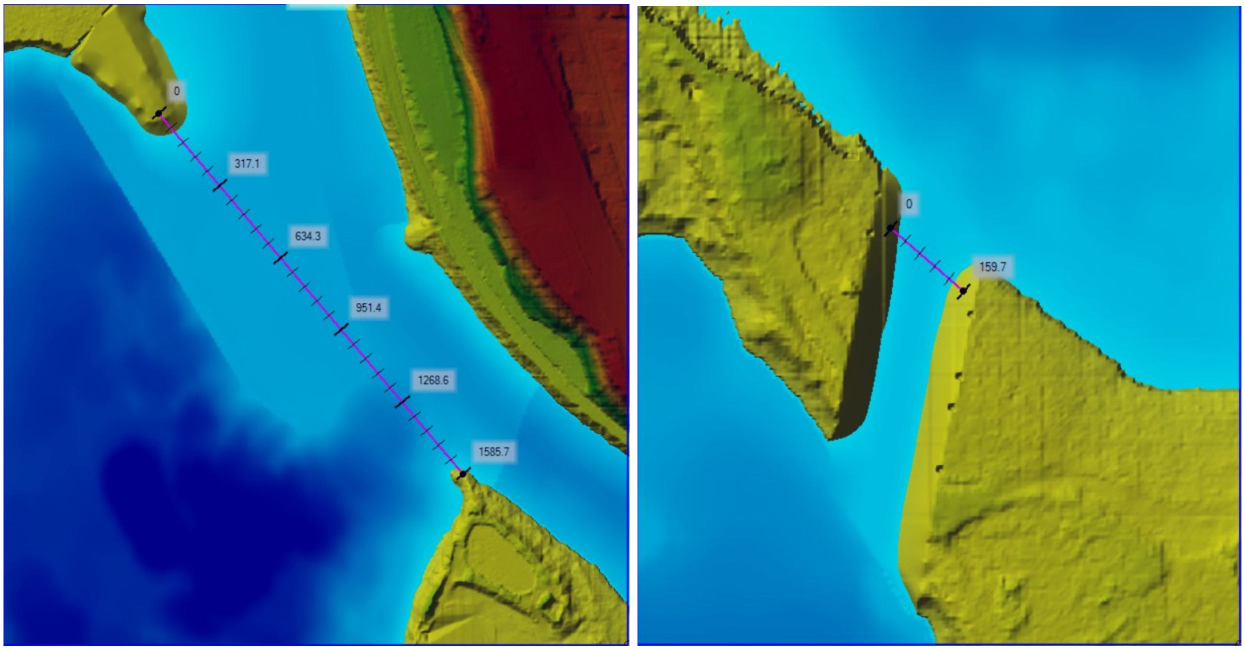


Figure 8: Profile line locations for Richardson numbers and mixing depth

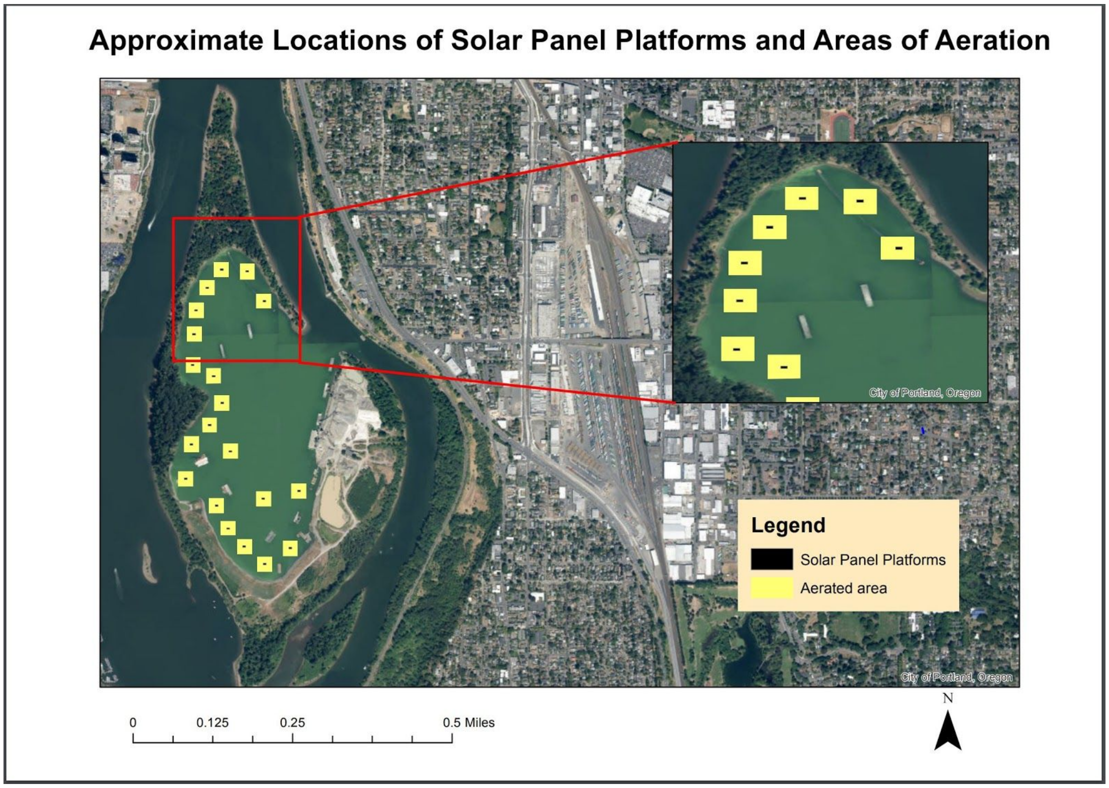


Figure 9: Approximate spread of solar panel platforms in Ross Island and their associated aerated areas

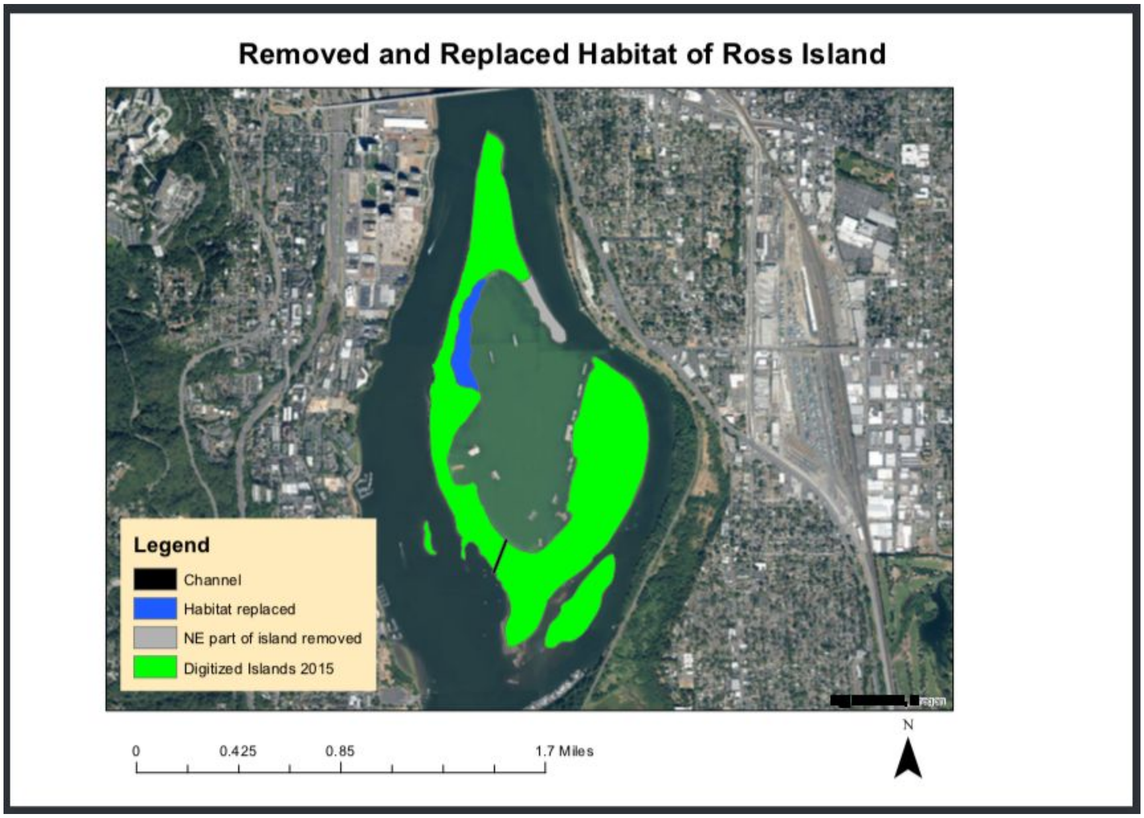


Figure 10: Shallow water habitat creation and modification areas

**Appendix C**

Table 1: Hydraulic alternatives capital and operations and maintenance costs

| | Open Channel | | Widened Entrance | |
|---|---|---|---|---|
| | Construction Cost | Labor Cost | Construction Cost | Labor Cost |
| **Excavation** | $119,700 | $72,000 | $190,000 | $160,000 |
| **Cofferdam** | $18,000 | $8,000 | - | |
| **Sheet Piles** | - | | $600,000 | $90,000 |
| **Riprap** | $550,000 | $67,000 | $360,000 | $20,000 |
| **Staging** | - | $20,000 | - | $20,000 |
| **Annual Monitoring** | - | $500 | - | $500 |
| **Total:** | **$687,700** | **$167,500** | **$1,150,000** | **$290,500** |

Table 2: Capital cost of solar panel aerators

| | **Cost** |
|---|---|
| **Solar Panels, Pumps, Aerators, & Tubing** | $74,000 |
| **Pontoons & Supporting Structures** | $100,000 |
| **Construction Labor** | $7,200 |
| **Total Capital Cost:** | **$181,000** |

Table 3: Operation and maintenance costs for solar panel aerators

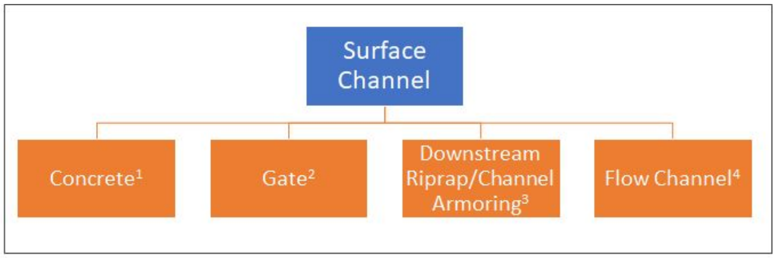
| | **Cost** |
|---|---|
| **Deployment/Removal** | $4,479 |
| **Labor** | $29,985 |
| **End of Season Maintenance** | $5,987 |
| **Summer On-call Monitoring** | $29,948 |
| **General Monitoring** | $400 |
| **Total Annual O&M Cost:** | **$70,800** |

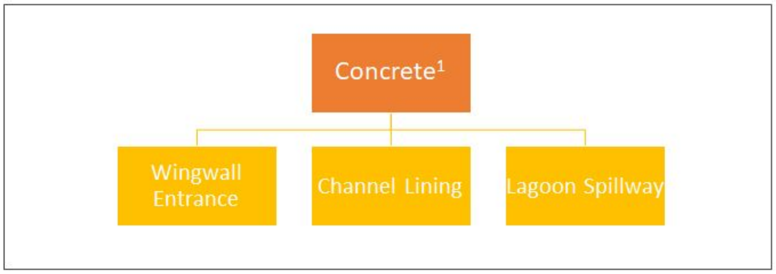
Table 4: Species benefits and habitat requirements

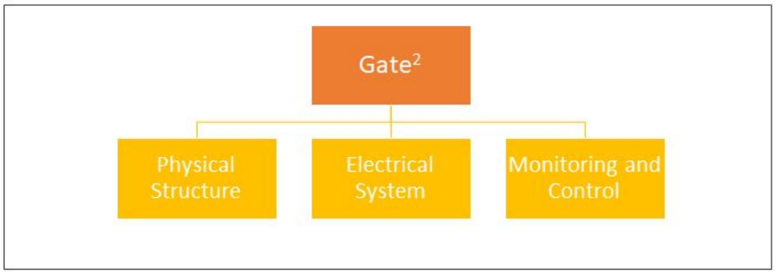
| Alternative | Species Benefitted | Habitat Needs | Project Benefits |
|---|---|---|---|
| **Hydraulic Alternatives:** Concrete Open-Channel & Lagoon Entrance Widening | Lamprey | - Low velocity<br>- Fine substrates<br>- Low turbidity | Decreased HABs will restore ideal areas for junelines to burrow but not increase turbidity too much |
| | Steelhead | - Cold water<br>- Safe spawning area | Displaced material will be moved to the western side of the lagoon to build up shallow water habitat. Increased flow to the lagoon will introduce colder waters. |
| | Chinook | | |
| | Sturgeon | | |
| **Non-Hydraulic Alternative**: Solar Aeration | Mussels | - High water quality<br>- Increased DO | Reduced HABs due to aeration will improve water quality |
| | Lamprey | - Low velocity<br>- Fine substrates<br>- Low turbidity<br>- Increased DO | Aeration will not add velocity or turbidity to areas lamprey will be and will not disrupt fine sediment habitat on the river bed. |
| | Steelhead | - Safe spawning areas<br>- Increased DO | Aeration will increase water quality and not disrupt any existing ideal spawning habitat. |
| | Chinook | | |
| | Sturgeon | | |

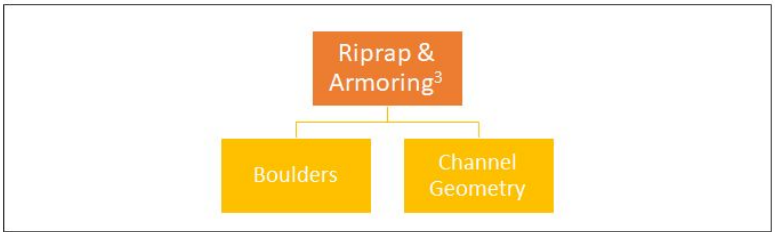
## Potential Failure Modes Analysis

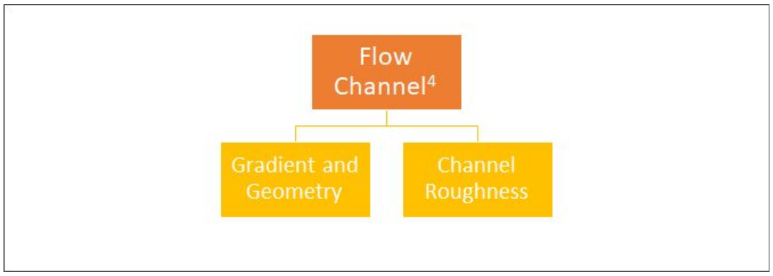
### Alternative 1 Component Tree



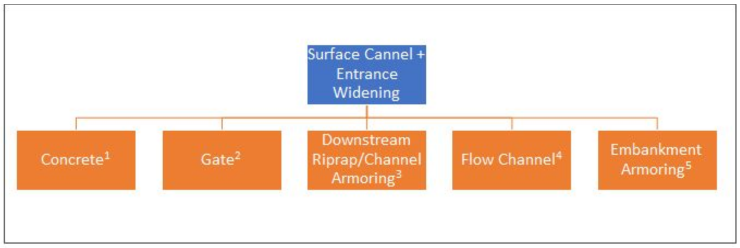


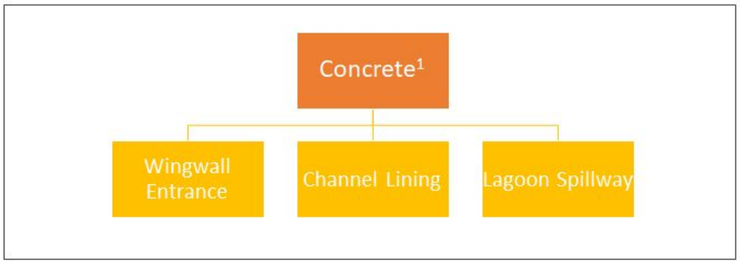


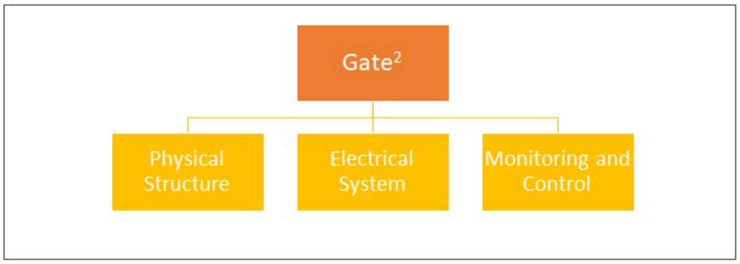


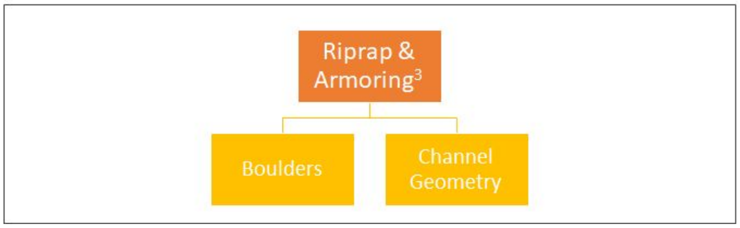


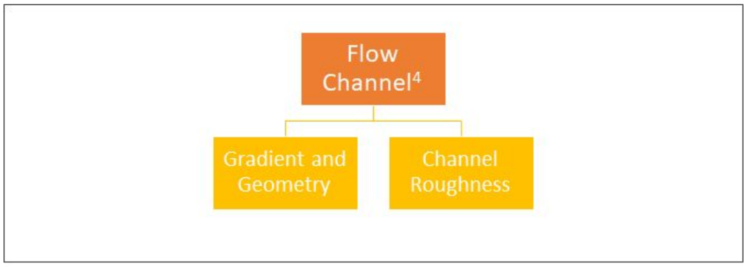
Alternative 2 Component Tree

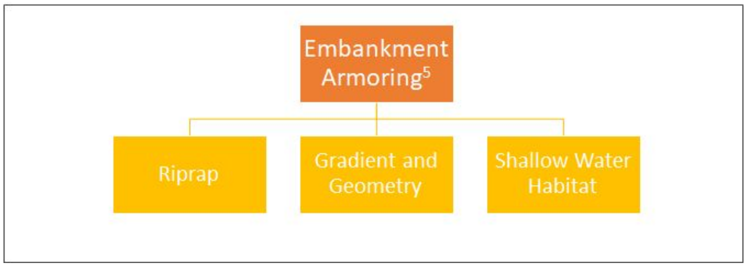












Alternative 3 Component Tree

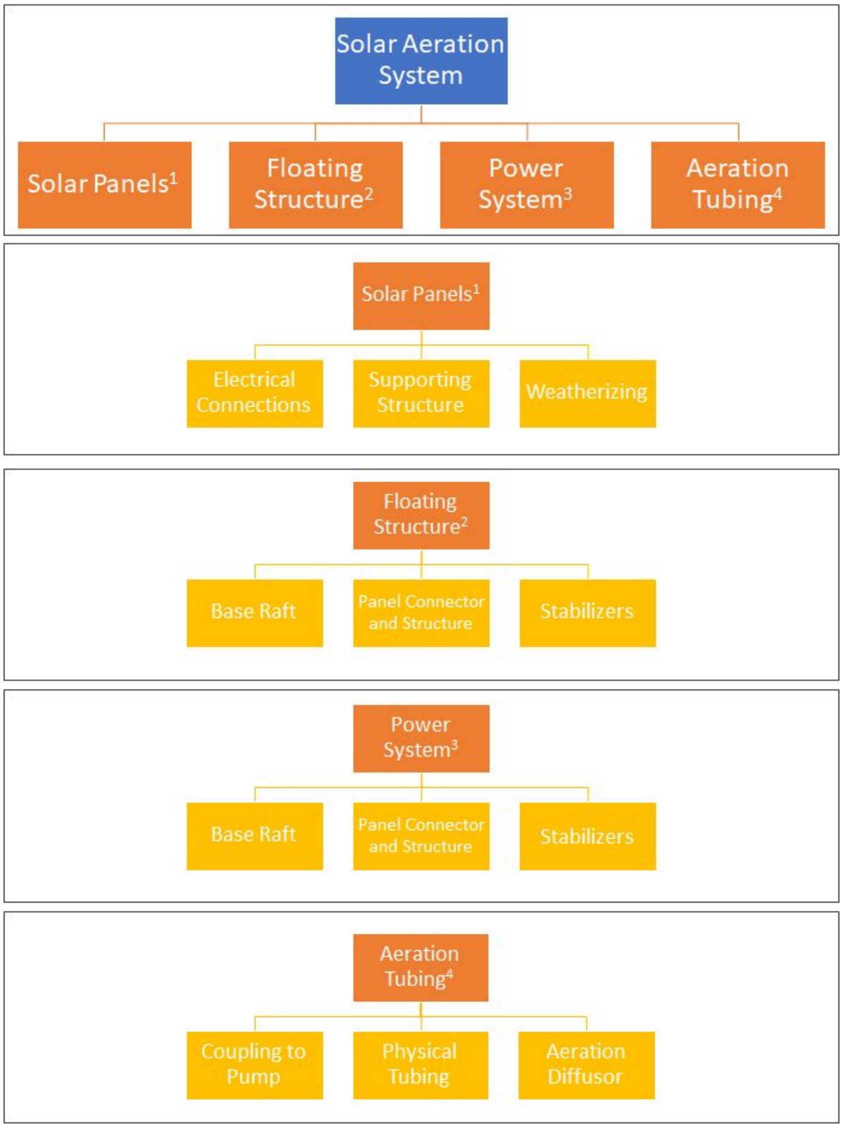


Table 5: FEMA Failure Modes Analysis

| 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) | Action Recommended |
|---|---|---|---|---|---|---|---|---|---|---|
| | 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? | | | What are the recommended actions for reducing the occurrence of the cause or improving detection? |
| 1 | Surface Channel - concrete | Cracking and seepage, which leads to erosion | Erosion of island; CAD cells exposed | 4 | Inadequate design; subsidence; aging infrastructure | 3 | Design reviews; regular monitoring | 1 | 12 | Ensure appropriate factor of safety in construction and visually inspect annually |
| 1 | Surface Channel - gate | Buckling of gate arms; failure of connections; inadvertently left open | Lagoon could capture river; loss of operations for RISG, navigation, habitat, etc. | 5 | Inadequate design; high flood event; aging infrastructure; misuse | 3 | Design reviews; regular monitoring | 1 | 15 | Design with real time monitoring of gate status |
| 1 | Surface Channel- downstream interface | Scour downstream of the channel | CAD cells become exposed overtime, water quality issues | 5 | Bad armoring, knickpoint, erosion, very high flood flows | 3 | Annual inspections of channel | 3 | 45 | Over engineer armoring where channel meets lagoon and inspect channel frequently |
| 1 | Surface Channel - flow stream | Debris blockage of main channel | Erosion of sides of channels, flow meanders across berm | 4 | Failure to maintain channel, channel lining slides into main canal | 2 | Regular visual inspection of surface channel | 2 | 16 | Perform channel cleaning annually and remove obstructions |
| 2 | Solar Aerator- Floating structure | Buckling in bad weather | Costly damage to solar panels and reduced aeration | 4 | Exposure to weather beyond what the structure was designed for | 4 | Floating structure should be designed to withstand poor weather, careful monitoring of weather conditions for preventative action | 4 | 64 | Factor of safety used in construction of raft, removing panels during winter |
| 2 | Solar Aerator- Mechanical pump failure | Aging or overuse of mechanical components leads to failure | Lack of mixing could lead to stratification and formation of HAB's | 3 | Using the pump continuously under conditions beyond what it is designed for and lack of preventative maintenance | 3 | Video feed of lagoon surface to ensure aerators are functioning properly | 3 | 27 | Live video feed will improve deduction of pump failures |
| 2 | Solar Aerator- Aeration tubing | Biofouling causes reduced airflow, potential causing pressure that disconnects tubing | Lack of mixing could lead to stratification and formation of HAB's | 3 | Lack of regular maintenance, not using large enough tubing | 3 | Video feed of lagoon surface to ensure aerators are functioning properly | 4 | 36 | Live video feed will improve deduction of pump failures |
| 2 | Solar Aerator- Panels and structure | Defacement or tampering | Costly damage to solar panels and reduced aeration | 2 | Public access to lagoon can lead to risk of tampering | 5 | Visual inspection would make tempering evident | 3 | 30 | Security cameras and fencing will discourage trespassing |
| 3 | Widening Lagoon Entrance- Armoring (a) | Eroding due to increased boating wake | Remaining berm will erode away, destruction of shallow water habitat | 3 | Boats not abiding by "no wake" zone near lagoon entrance | 3 | Stricter patrol and fines of boaters not recognizing the no wake zone | 3 | 27 | Clear markings indicating no wake zone and regular patrol of area to enforce boaters |
| 3 | Widening Lagoon Entrance- Armoring (b) | Eroding in flood conditions | Remaining berm will erode away, destruction of shallow water habitat | 3 | High Flow events such as Q>100 year event could lead to overtopping of gate and additional erosion near entrance | 3 | Weather forecasting and gate adjustments | 4 | 36 | Proper sizing Riprap using multiple methods under flood conditions |
| 3 | Widening Lagoon Entrance- Armoring (c) | Erosion due to increased flow into lagoon via surface channel | The section of the lagoon entrance that was widened will erode away, destruction of habitat | 4 | Increased flow from surface channel will cause higher flows exiting lagoon, increase potential for erosion | 2 | Surface Channel gate management and proper sizing of Riprap | 3 | 24 | Predictions of flow increase due to surface channel and proper sizing of Riprap |

## Appendix D

Table 6: Calculations for richardson number and mixing depths.

| | | Channel | | Entrance | |
|---|---|---|---|---|---|
| Time | Alternative | Richardson Number | Mixing Depth | Richardson Number | Mixing Depth |
| April 12th | existing conditions | 199822 | 0.000 | 1.09 | 7.516 |
| | 1 | 7.12 | 42.985 | 1.05 | 7.782 |
| | 2 | 0.18 | 44.646 | 0.44 | 18.610 |
| March 27th | existing conditions | 287743 | 0.000 | 23.14 | 0.354 |
| | 1 | 7.12 | 1.152 | 23.35 | 0.351 |
| | 2 | 6.88 | 1.192 | 11.03 | 0.743 |
| August 25th | existing conditions | 127886 | 0.000 | 135.98 | 0.060 |
| | 1 | 309.32 | 0.027 | 145.31 | 0.056 |
| | 2 | 71935 | 0.000 | 264.23 | 0.031 |

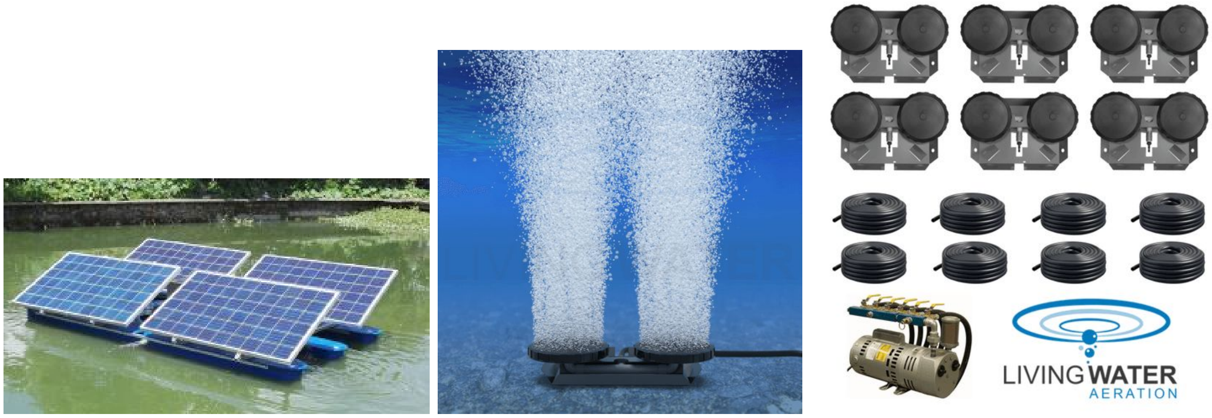


Figure 11. Images from Living Water Aeration showing models of their systems.