Alternatives for Addressing the Ross Island HAB

Prepared for Ross Island Stakeholders

Date: June 14th, 2019

Objective

To reduce or cease the formation of harmful algal blooms (HABs) at Ross Island, in Portland, OR by evaluating two alternatives: the effects of a culvert through the south entrance of the island and the effects of disrupting microbial growth through injection of nanobubbles into the lagoon. A third "no action" option was also evaluated.

Methods

Hydraulic Model

A two-dimensional unsteady model was made to understand the flow, depth, and stratification at Ross Island in Portland, OR. The model was created using the US Army Corps of Engineers' Hydrologic Engineering Center's River Analysis System 5.0.6 (HEC-RAS) and raster data of Ross Island. The model was created based on a tutorial made by Lars Larson and Grace Spann as part of the River Engineering course (BEE 446) at Oregon State University.

Boundary conditions upstream and downstream of Ross Island were selected to constrain the model. Boundary locations were chosen as perpendicular to river flow and at relatively uniform channel sections. USGS data from site 14211720 at the Willamette River was used to create the model. Upstream boundary conditions were based on flow data from March 26th-28th, 2019. Downstream boundary conditions were based on gage height data corrected to the NAVD88 datum from March 26th-28th, 2019. A theta implicit weighting factor ensures model stability through the implicit solution of the St. Venant equations (Goodell, 2009). A weighting factor of 0.6 was chosen because it did not cause numerical instability. The Courant number, the tradeoff between computation interval and resolution and model run time, was set for a maximum of 1 and a minimum of 0.45 to optimize run time and accuracy.

The culverts were created by creating a breakline through the north and south ends of the island and perpendicularly aligning the culvert centerline. The culvert design was iterated manually by changing the size and invert elevation of the culvert to achieve positive velocity inside the culvert. Exit velocities were determined by plotting a velocity time series at a node just outside of the culvert exit point. Velocity was averaged over the time series.

To evaluate the effects of flow across multiple depths to address stratification, Richardson numbers were used. Richardson numbers were found by assuming a mixing depth of 10 m for all flow conditions (low, high, flood, existing, and calibration flow) along with Equation 1. Mixing depths were found by assuming the minimum Richardson number needed to disrupt stratification in the zone of interest of 0.25 and using Equation 5.

Alternatives Analysis Calculations

Standard guidelines for the design of urban stormwater systems (ASCE, 2006) was referenced to identify project components and procedures for the hydraulic solution of using culverts in the lagoon. Specific costs for each of these components were estimated using RS Means (Building Design & Construction, 2010). To identify the components required for the non-hydraulic solution using nanobubbles, Peter Moeller PhD, who is a lead researcher in the Harmful Algal Bloom Monitoring and Reference Branch at NOAA, and Moleaer Inc. were referenced. Once components were identified, their cost was also estimated through direct contact with both aforementioned parties.

Acres of impacted habitat were estimated for the hydraulic solution in ArcGIS using data from HEC-RAS for dimensions of the culverts and placement since the "no action" and microbial alternatives are not predicted to result in a change in habitat (see Figure 11, Appendix). Only 0.02 acres of shallow water habitat would be affected by the installation based on the assumption that a 20-foot buffer around the outlet would be impacted by the introduction of a culvert. Shallow water habitat was classified as an area of water where the depth is +1 to -20 based on the Ross Island Datum. The pre-existing shallow water habitat was calculated to be 27.35 acres (see Figure 10, Appendix). This means that installing the culverts would result in a 0.07% loss in habitat.

A review of literature was conducted to identify the habitat needs and limiting factors for ESA listed and other species that occur in the Lower Willamette. The project impacts were compared to habitat needs and limiting factors were summarized in a table (with references) to identify how the project benefits each aquatic organism (Appendix A1.3 Table 3).

Criteria	**No Action**	**Culverts (Hydraulic)**	**Nanobubbles (Microbial)**
Capital Cost	$0	$13,246,301.40	$5,438,925.00
O&M	$0	$102,312.00	$167,700.00
Habitat Loss/Creation	143 acres of Lagoon	+0 acres -0.02 acres	+0 acres -0 acres
Species Benefitted	Harmful Algae	Salmon, Steelhead, lamprey, amphibians	Steelhead, Lamprey, Sturgeon, Amphibians

Failure Modes and Effects Analysis

A PFMA Analysis template was used to break down each alternative into a functional tree that identified key process steps (see Figures 12-14, Appendix). For each process step, a potential failure mode and the impact of that failure was identified. The severity of the impact of that failure was then rated from 1-5 (one being the least severe), potential causes of failure were identified and the likelihood of occurrence were rated from 1-7 (one being the least likely), and a control option to address or mitigate the failure was identified and the likelihood of detection was rated from 1-5 (one being the lowest). For each process these three numbers (severity, likelihood, detection) were multiplied together to give a Risk Priority Number (RPN) for each process to identify which process posed the largest risk, and which alternative posed the largest cumulative risk of failure.

Existing Hydraulic Conditions in Lagoon

Ross Island lagoon is unique in that it is tidally influenced. Existing depth and velocity maps around Ross Island are shown by Figures 4 and 5 in the Appendix. The depth and velocity profiles across the lagoon entrance show how depth influences velocity (Figures 6, 7, Appendix). At deeper portions of the channel, the velocity is smaller. This is due to the relationships present in the continuity equation. Tides greatly impact flow in the lagoon. Depth and velocity time series indicate the variations in channel behavior at the lagoon entrance due to tidal influences. Depth varies approximately 1-2 ft with the changing tides (Figure 8).

Details of Alternatives

Culverts

The final culvert design would consist of a south and north culvert (Figure 1). The final culvert on the south end was a concrete box culvert with a 100 ft span and 20 ft rise with an upstream invert elevation of -11ft and downstream invert elevation of 11.5ft (Figure 2, Appendix). The length of the culvert was 374.8 ft and had an assumed Mannings' n for concrete of 0.015. The northern culvert was made of the same materials and dimensions but was 550.9 ft in length (Figure 3, Appendix). The southern culvert velocities and Richardson numbers are presented in tables 4 and 5 in the Appendix. The highest velocity achieved at the exit of the culvert was 0.21 ft/s (0.06 m/s) during April flood flows which resulted in a Richardson number of 31 at a depth of 10 m (Equation 2). During late August when the HAB is a concern, the maximum velocity achieved at the exit point was 0.02 ft/s. This resulted in a Richardson number of 3405 with a depth of 10 m. This number is not near the minimum needed Richardson number of 0.25 to achieve mixing in the lagoon. However, it is better than the existing lagoon without a culvert which has a Richardson number of 67267 at a depth of 10 m. The minimum velocity in the lagoon to achieve a Richardson number of 0.25 would be 2.2 ft/s which does not even exist in the main channel and is not subject to HABs (Equation 4). This suggests that larger Richardson numbers may still be adequate to provide enough mixing in the lagoon for destratification. However, the range of satisfactory Richardson numbers remains unknown. In addition, for April flood flows with an assumed Richardson number of 0.25, the calculated mixing depth was only 9.58 cm, which is not close to the desired 10 m mixing depth (Equation 6). These calculations represent the best case scenario and assumes even mixing across the lagoon from the culvert exit point. Uneven mixing may occur.

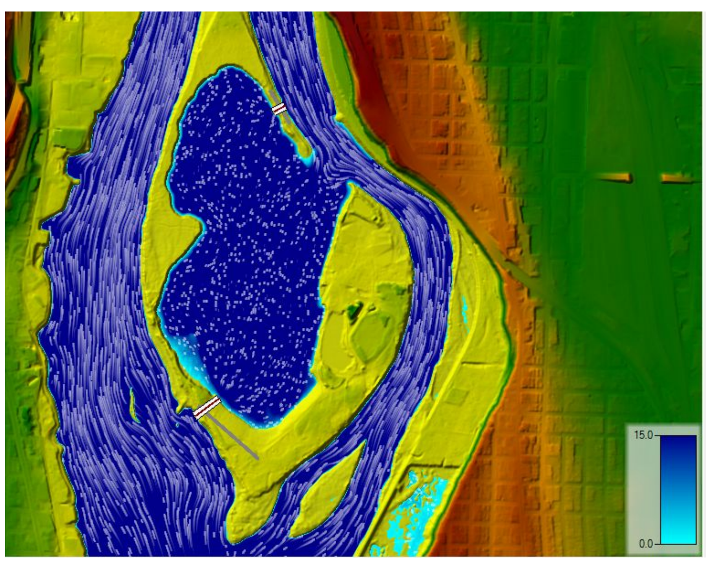

Figure 1: Altered landscape of Ross Island with a north and south culvert. Flow enters from the southern culvert (lower white rectangle with red centerline) and exits through the lagoon entrance and north culvert (upper white marking with red centerline).

The Ross Island Datum (RID) was used as a reference point for determining areas of shallow water habitat. Shallow water habitat was defined to be +1 to -20 of the RID. The RID was inputted into ArcGIS, along with the terrain data and coordinates and dimensions of the culverts, to create Figure 11 (see Appendix). This figure shows the shallow water habitat, 0.02 acres, affected by the culvert installation. The acreage of affected habitat would not be visible at the map scale, so all of the shallow water habitat was included in Figure 10. A buffer zone of 20 feet at the entry and exit points adjacent to the lagoon were used to calculate final estimates for habitat loss. No shallow water habitat loss was calculated for the north culvert. It is possible that more habitat at the south culvert would be lost if a buffer of more than 20 feet was selected.

Nanobubbles

Nanobubbles are comprised of both oxygen and ozone. As the bubbles implode, they form hydroxyl radicals which cause the algae to lose cell membrane integrity and damage the protein and DNA. Nanobubbles are created with an onsite ozone generator and are pumped into the lake several feet below the surface. Several successful field scale tests have already been conducted on lakes and ponds similar in size to the Ross Island lagoon. Algal cysts are destroyed by the nanobubbles, but retreatments would have to occur due to the continual presence of algae entering the lagoon from upstream. In addition, nanobubbles are non-selective about the DNA and proteins they damage and therefore beneficial diatoms can be harmed by this technology. However, no ill effect has been seen on aquatic life such as fish and plant species.

It was not estimated that the microbial solution would result in habitat loss. Without further knowledge about the placement or number of the generators, no map was created to show this. However, they would either be placed along the side of the lagoon, resulting in a minimal footprint, or a generator would be stationed on a boat that could reach all surface waters of the lagoon.

Alternative Analysis

Practicable, Logistics, & Existing Technology

Practicability, Logistics, & Existing Technology of each proposed solution were evaluated based on the criteria found in Preparing an Alternatives Analysis (Fort Worth District, 2014).
These criteria include cost, existing technology, and logistics. Cost were evaluated to ensure that the overall scope/cost of the project is not unreasonably expensive. Existing technology were evaluated to assess the limitations of current technology while also incorporating the most effective/least-invasive construction methods available. Logistics were evaluated to ensure that the means to incorporate these solutions are readily available or reasonably attainable.

The hydraulic solution using culverts is a readily available option, as culverts are used far and wide in various aspects of water management and water treatment. Installing a culvert on the north and south end of the lagoon is being proposed as a solution in hopes that they will cause sufficient mixing or destratification to deter the occurrence of a HAB. The installation of these two culverts in the Ross Island Lagoon was modeled in HEC-RAS to attempt to determine their capability to induce mixing. After achieving a functional model of these two culverts in the Ross Island lagoon, the results for this hydraulic solution were inconclusive in their ability to cause sufficient mixing. As a result of these inconclusive results, it was determined that the installation of culverts at the north and south ends of the lagoon does not meet the project criteria or achieve the overall project purpose.

The microbial solution of using nanobubble generators to control or prevent HAB in the Ross Island lagoon is a readily available option. This solution has various case studies that demonstrate its capabilities to reduce and eliminate algae in ponds and lakes. From speaking directly with a producer of nanobubble generators, Moleaer Inc., these units produce optimum results in still water with high retention times. Such conditions are consistently present in the Ross Island lagoon. The nanobubble generators are also a very scalable option. The evaluation of this microbial solution determined that it meets the project criteria as well as achieves the overall project purpose.

Failure Modes Analysis

The PFMA identified six possible modes of failure for the Nanobubble Technology treatment option, each of these processes had an RPN score of 8 or less, with an average score of 5 and a total treatment RPN of 30. The hydraulic solution generated four possible modes of failure with RPN scores that ranges from 10-24, with an average score of 18.25 and a total treatment RPN of 74.

Future Work

For the nanobubble technology, pilot studies could be performed at Ross Island lagoon with special attention as to how the nanobubbles impact the aquatic life there. For the culvert, it is uncertain how culvert will affect the CAD cells due to the limitations of a 2D model. More studies regarding how velocity may dissipate with depth in the lagoon should be conducted.

Recommendation

Based on an RPN analysis of the two alternatives, the Nanobubble Technology treatment option has a less likelihood of catastrophic failure, and represents a more attractive option. Due to concerns regarding the culvert's ability to mix the lagoon during August flows, it is recommended that the Ross Island Stakeholders move forwards with the microbial option of nanobubble injection.

References

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Appendix

A1.1 Table 1: Breakdown of the cost of the hydraulic solution using culverts.

Equipment	Quantity	Cost	Source
Excavator	36,558.15 Cubic yards	**$5,552,947.00**	RS Means
Concrete Box Culvert	2 [167.3’(L) x 100’(W) x 20’(H)]	**$1,776,056.80**	RS Means
RipRap	18” Min. Thickness (74,356 sq. yds)	**$5,891,551.60**	RS Means
Mobilization	2-20 ton Capacity	**$25,746.00**	RS Means
O&M	Erosion correction, Debris removal, Reinforcement.	**$102,312.00/year**	Drainage Maintenance (2015)

A1.2 Table 2: Breakdown of the cost of the non-hydraulic solution using nanobubbles.

Equipment	Quantity	Cost	Source
Moleaer Optimus Nanobubble Generator	100 (200 gpm) ($54,357.00/each)	**$5,435,700.00**	Moleaer Inc.
Labor/Install	3 hours/unit	**$3,225.00**	Moleaer Inc.
O&M	3hrs/week/unit	**$167,700/year**	Moleaer Inc.
1-year Warranty	100	**$0.00**	Moleaer Inc.

A1.3 Table 3: The project impacts were compared to habitat needs and limiting factors as summarized to identify how the project benefits each aquatic organisms.

Organism	**Habitat Needs**	**Limiting Factors**	**Project Benefits**	**Source**
Steelhead	>24cm pool depth 40-91 cm/s Velocity 0.6-10.2 cm Substrate (Fines <20%) 4-10 C Temperature	Rearing Habitat	HAB removal will allow food sources to rebound in the lagoon & improve water quality.	(USBR 2012)
Trout	.15-10 cm Substrate (<20% Fines) 12-18 C Temperature 1-2m pool depth	Fines	HAB removal will allow food sources to rebound in the lagoon & improve water quality.	(Adams et al. 2008)
Salmon	9-13 C Temperature >18 cm pool depth 30 - 91 cm/s Velocity 1.3 - 10.2 cm Substrate	Suitable Habitat	HAB removal will allow food sources to rebound in the lagoon & improve water quality.	(Bjornn & Reiser 1991)
Lamprey	Similar to Salmon	Water Quality	HAB removal will allow food sources to rebound in the lagoon & improve water quality.	(USFWS)

A1.4 Table 4: Richardson numbers calculated for each flow condition assuming a depth of 10m and using Equation 1

Flow Condition	Velocity (ft/s)	Velocity (m/s)	Assumed Depth of 10 m	RI
August - Low Flow	0.02	0.01	10	3405
March - Calibration Flow	0.09	0.03	10	168
December - High Flow	0.16	0.05	10	53
April - Flood Flow	0.21	0.06	10	31
Exisiting Conditions	0.0045	0.00	10	67267

A1.5 Table 5: Mixing depths calculated using Equation 5 and assuming a Richardson value of 0.25

Flow Condition	Velocity (ft/s)	Velocity (m/s)	Assuming RI of 0.25	Mixing Depth (m)	Mixing Depth (cm)
August - Low Flow	0.02	0.01	0.25	0.001	0.09
March - Calibration Flow	0.09	0.03	0.25	0.018	1.76
December - High Flow	0.16	0.05	0.25	0.056	5.56
April - Flood Flow	0.21	0.06	0.25	0.096	9.58
Exisiting Conditions	0.0045	0.00	0.25	0.000	0.00

A1.6 Table 6: Potential failure modes analysis for the microbial solution

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	Resp.
	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?	Who is responsible for making sure the actions are completed?
Nanobubble Technology	Oxygen generator	Inability to produce oxygen molecules for mixing.	Algae will persist	1	power failure; mechanical failure	2	preventative maintenance; surge protector; backup power source	2	4	replace it when needed; regular inspections	NBOT Operator, Treatment Manager
	Ozone generator	Inability to produce ozone molecules for mixing	Algae will persist	1	power failure; mechanical failure	2	preventative maintenance; surge protector; backup power source	2	4	replace it when needed; regular inspections	NBOT Operator, Treatment Manager
	Mixer failure	Inability to properly mix ozone and oxygen to the desired concentrations	The mixture may not be optimized to the treatment location	1	power failure; mechanical failure	2	preventative maintenance; surge protector; backup power source	2	4	replace it when needed; regular inspections	NBOT Operator, Treatment Manager
	Pump failure	Pump is unable to disperse oxygen and ozone molecules into the water	Algae will persist	2	power failure; mechanical failure	2	preventative maintenance; surge protector; backup power source	2	8	replace it when needed; regular inspections	NBOT Operator, Treatment Manager
	Natural disasters	Power failure or the unit is destroyed due to a natural disaster	Algae will persist	1	naturally	2	protective housing; management plan	3	6	follow through with management plan	Treatment Manager
	Power failure	Power is unable to be suplied to the unit, and none of components function	Algae will persist	1	lightning strike; city power failure	2	backup power source; periodic inspections	2	4	backup power source regularly inspected	Treatment Manager

A1.7 Table 7: Potential failure modes analysis for the hydraulic solution

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	Resp.
	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?	Who is responsible for making sure the actions are completed?
Culvert	Concrete Channel	cracking and seepage, which leads to erosion	Erosion of island; loss of wetland; CAD cells exposed; structural failure of channel	4	inadequate design; subsidence; aging infrastructure	3	design reviews; regular monitoring; factors of safety	2	24	follow through with management plan	Engineering Manager, RISG, COP
	Intake Gate	buckling of gate arms; failure of connections; inadvertantly 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	follow through with management plan	Engineering Manager, RISG, COP
	Outflow	Outflow velocity is such that it causes scour	Erosion of island; loss of wetland; CAD cells exposed; structural failure of channel	4	Inadequate design; high flood event	3	design reviews; factors of safety for rip-rap, regular monitoring	2	24	follow through with management plan	Engineering Manager, RISG, COP
	Natural Disaster	Failure of the artificial structure due to an earthquake	Soil liquefaction, loss of part or all of the structure, permanent channel formation	5	Cascadia Subduction Zone Event	2	Design reviews, factors of safety for structural stability	1	10	Ensuring that the concrete channel is reinforced to address normal shifts in soil, and is able to withstand expected earthquakes caused by the Cascadia Subduction Zone	RISG, COP, State of Oregon

Figures

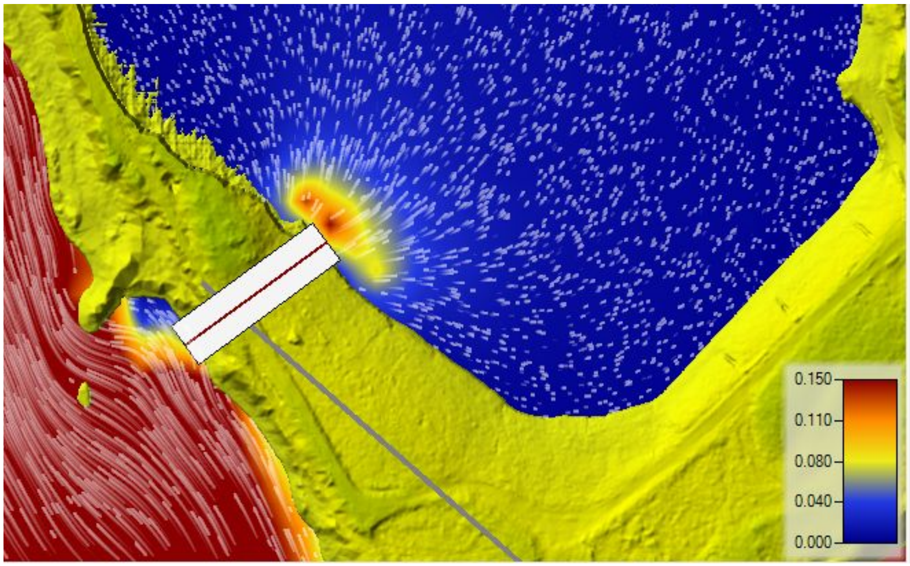

Figure 2: South culvert transporting flow from the main channel (left) to the lagoon (right). Colored bar scale represents velocity in (ft/s).

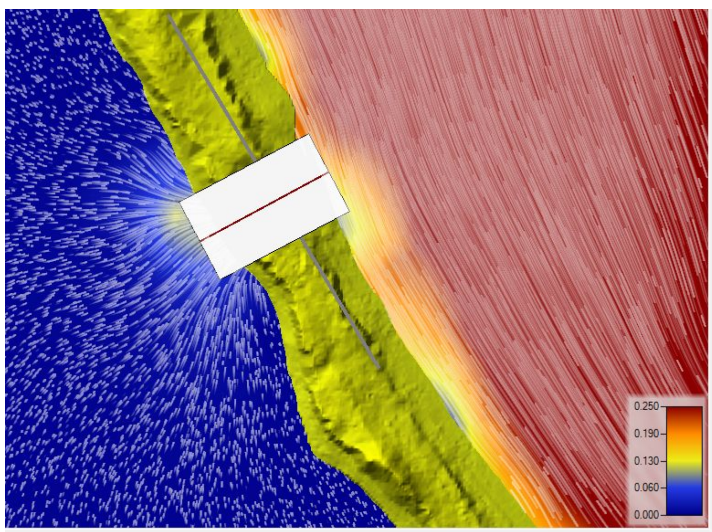

Figure 3: North culvert transporting flow to the main channel (right) from the lagoon (right). Colored bar scale represents velocity in (ft/s).

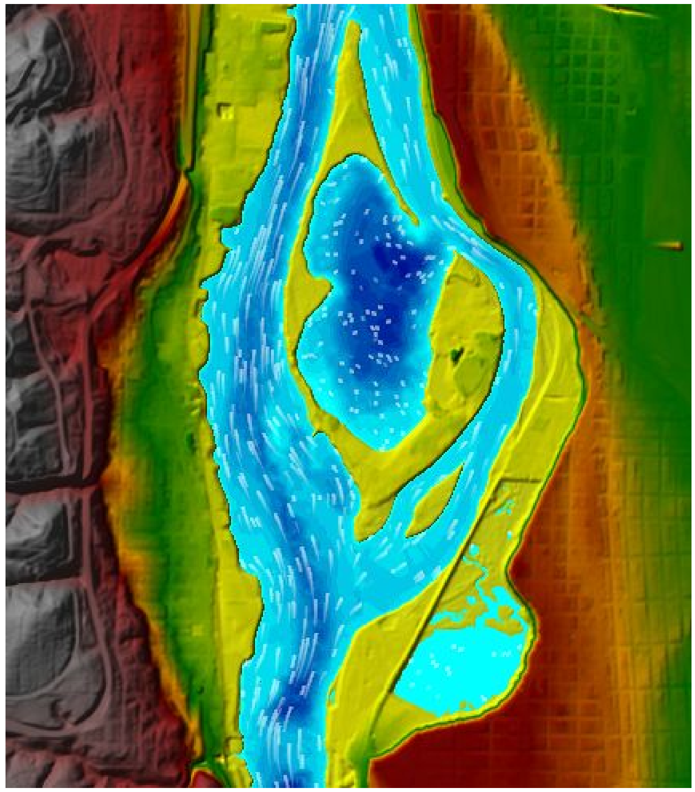

Figure 4: Depth map of Ross Island lagoon. Green, yellow, and red gradients represent landform elevation changes. Blue represents water. White lines represent particle flow.

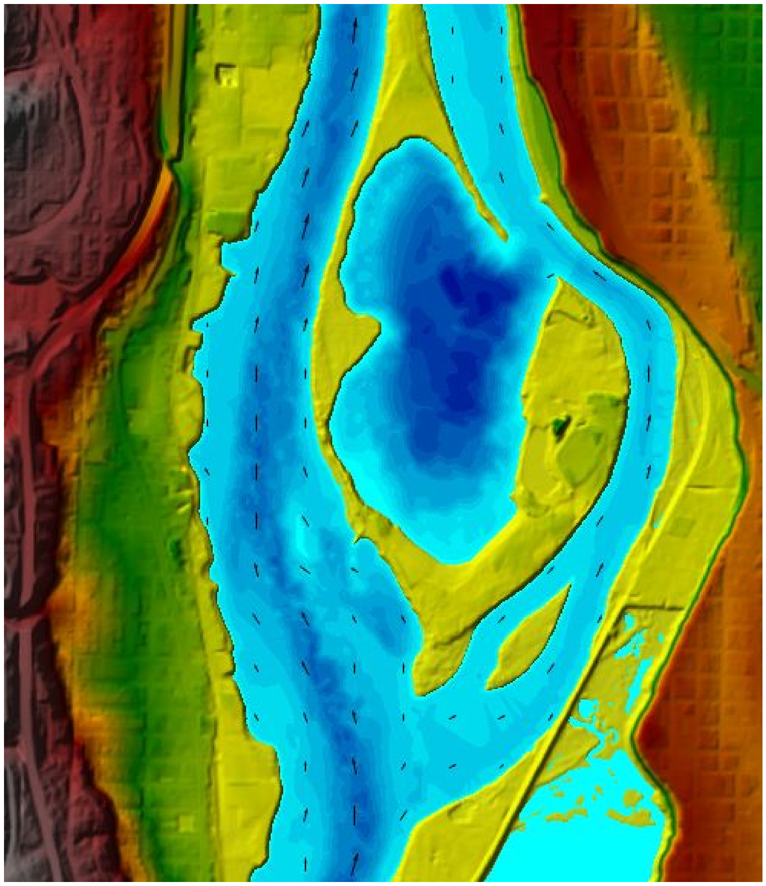

Figure 5: Velocity vectors around the Ross Island lagoon. Longer velocity vectors indicate faster flow.

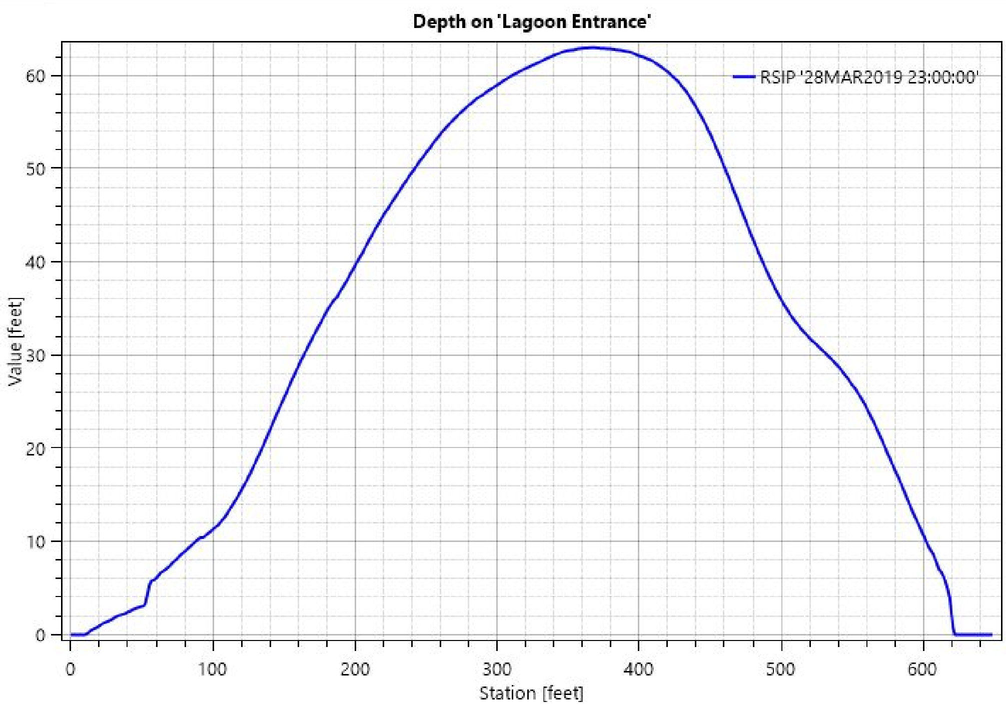

Figure 6: Depth profile of the Ross Island lagoon entrance at Holgate Channel, in Portland,OR.

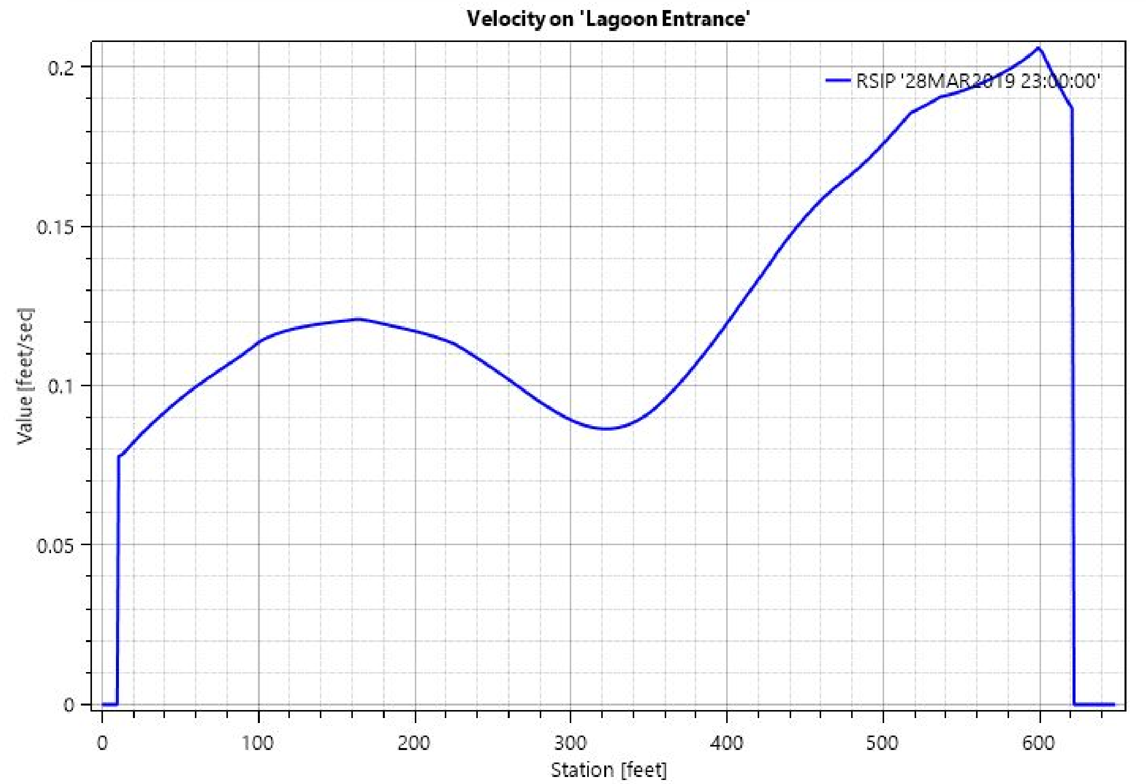

Figure 7: Velocity profile of the Ross Island lagoon entrance at Holgate Channel, in Portland,OR.

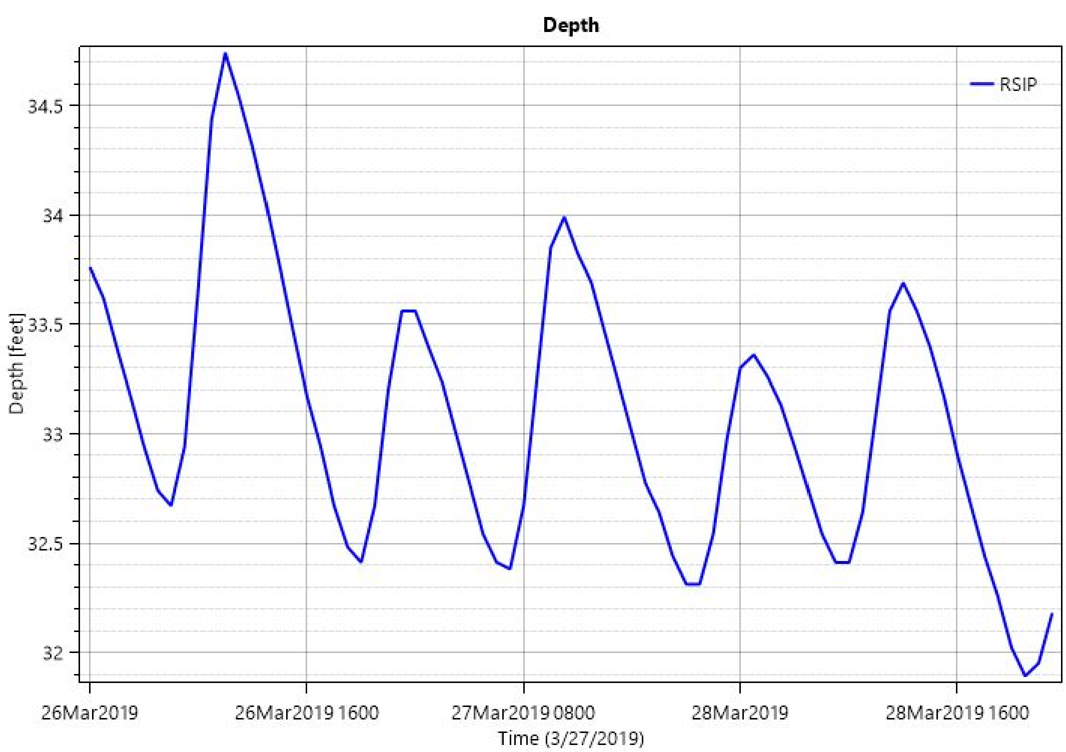

Figure 8: Depth time series of the Ross Island lagoon entrance at Holgate Channel, in Portland,OR.

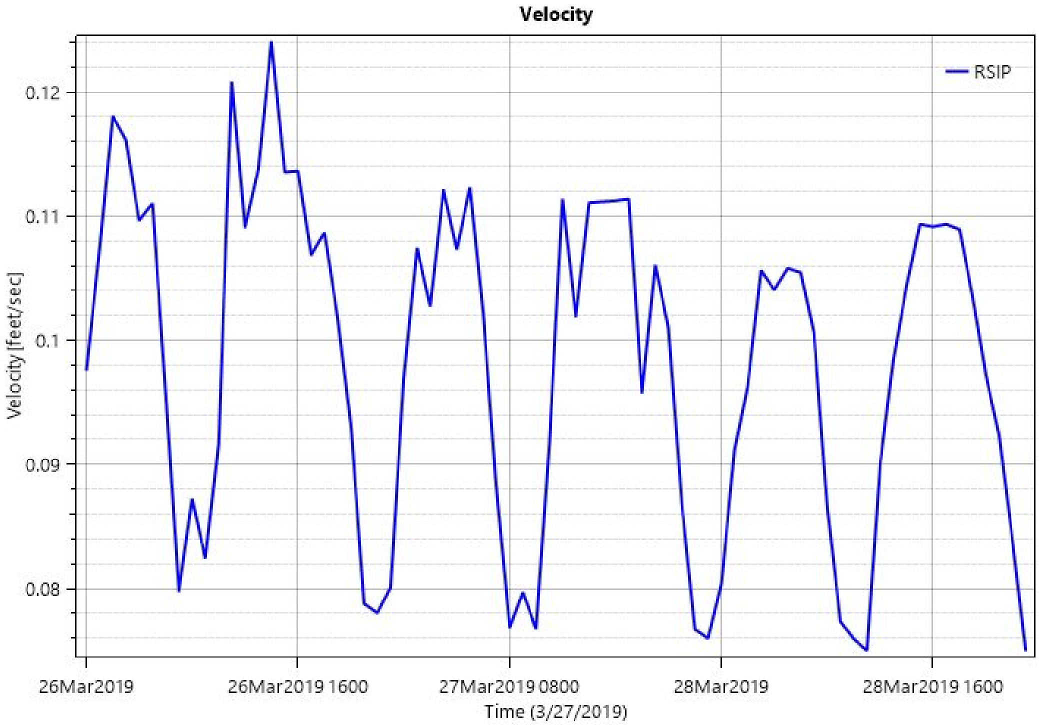

Figure 9: Velocity time series of the Ross Island lagoon entrance at Holgate Channel, in Portland,OR. Note the velocity oscillates due to tidal influences.

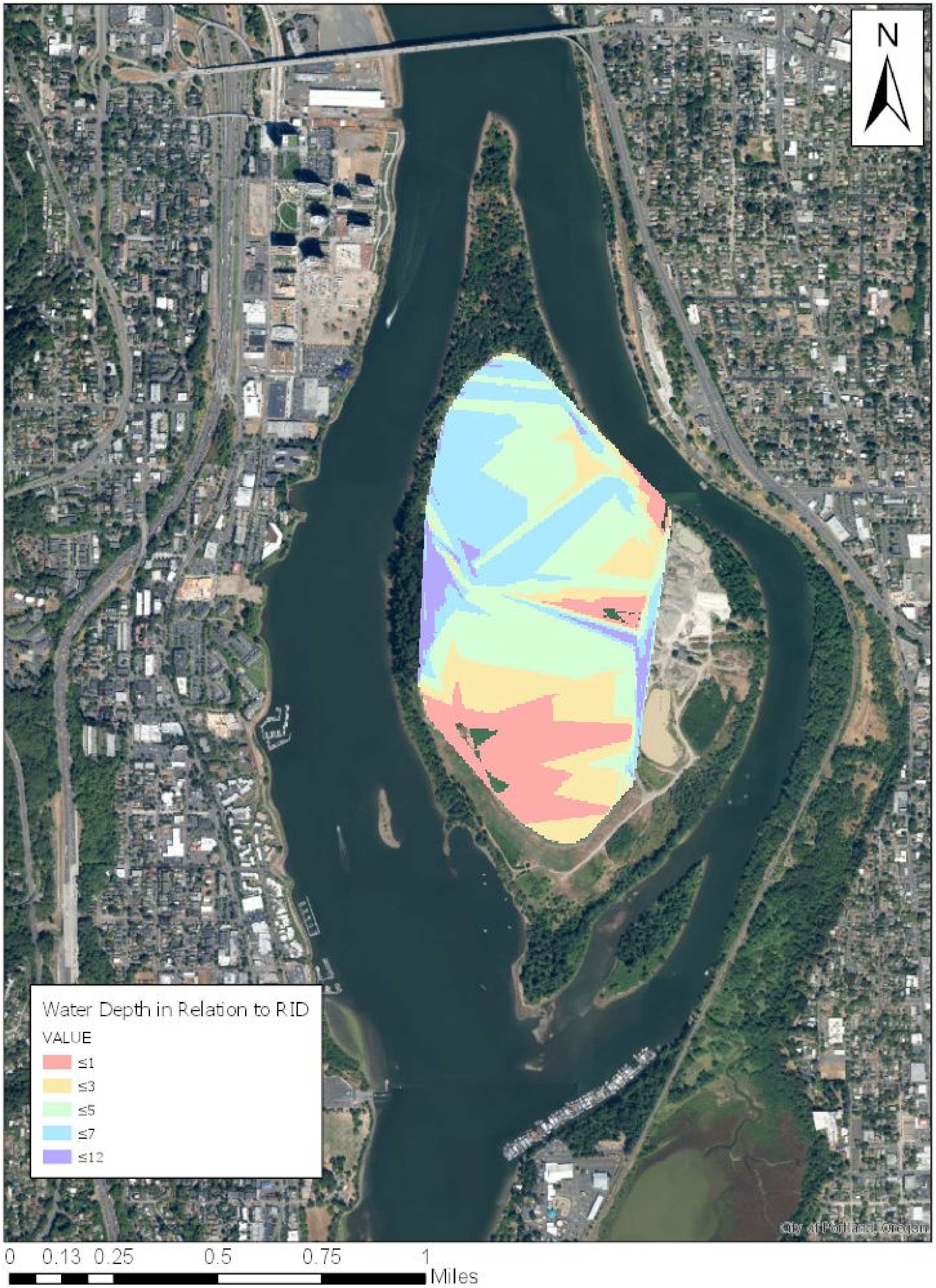

Figure 10: Water Depths in Relation to the Ross Island Datum (RID)

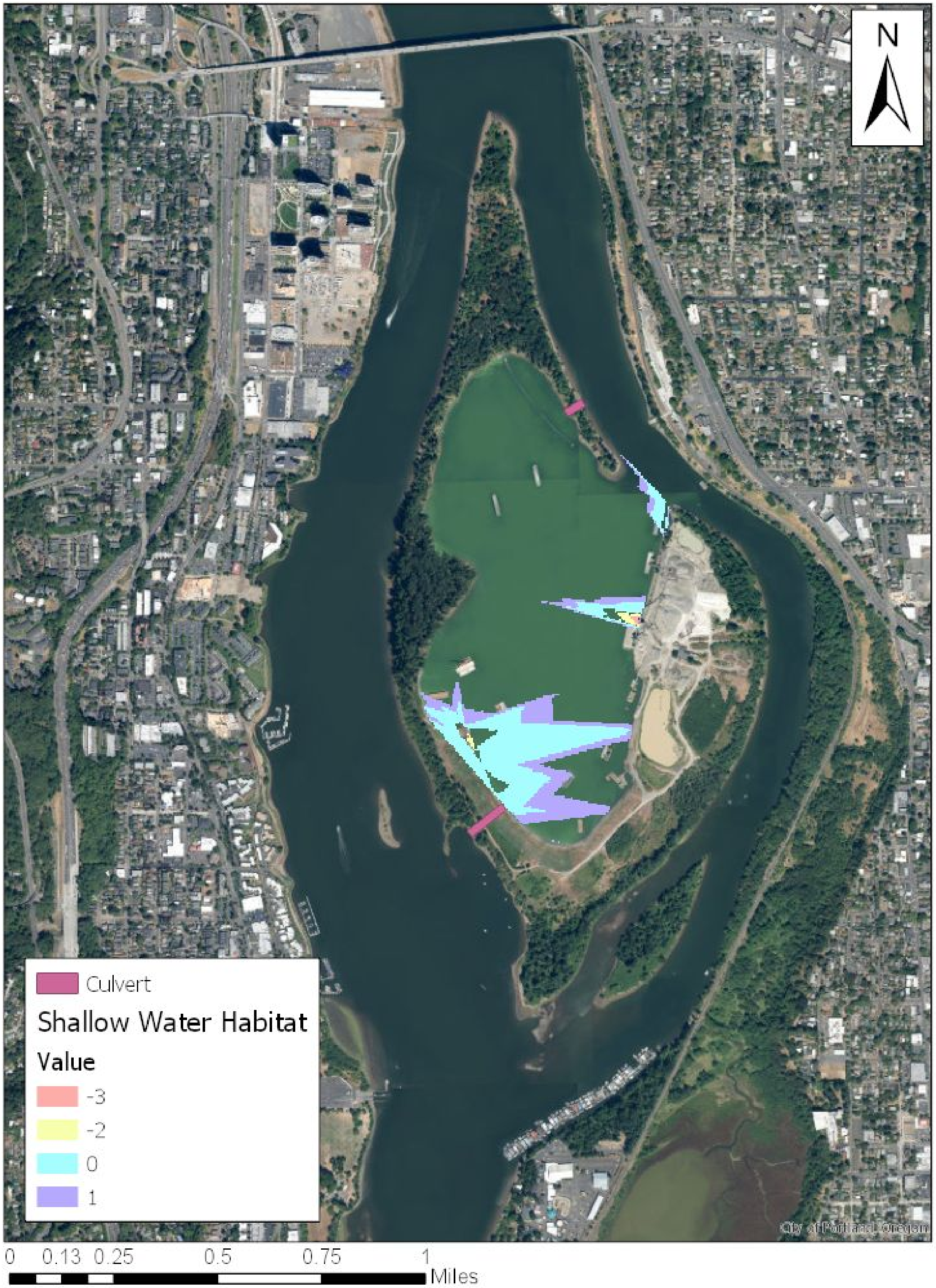

Figure 11: Hydraulic Solution with the Shallow Water Habitat in Ross Island

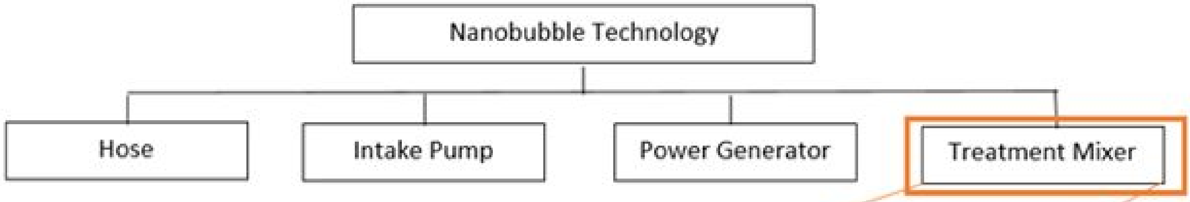

Figure 12. Nanobubble Technology Functional Tree

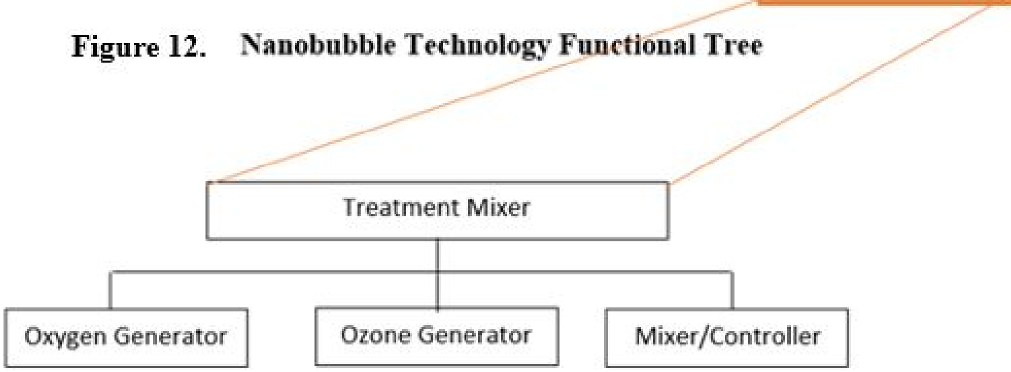

Figure 13. Treatment Mixer Functional Tree

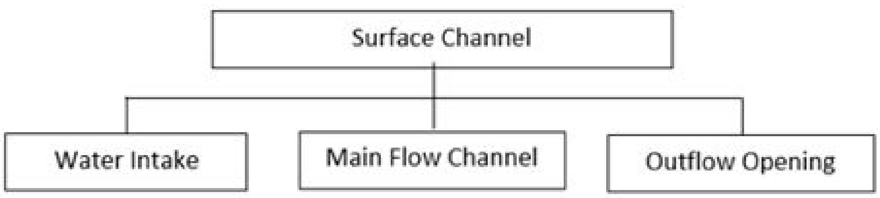

Figure 14. Surface Channel Functional Tree

Equations

Nomenclature

Variable	Symbol	Units
Density	ρ	$\frac{kg}{m^3}$
Depth	y	m
Gravity	g	$\frac{m}{s^2}$
Richardson Number	Ri	-
Velocity	u	$\frac{m}{s}$

1. Richardson’s number general equation

$$Ri = \frac{\left(\frac{g}{\rho}\right)\left(\frac{\partial \rho}{\partial y}\right)}{\left(\frac{\partial u}{\partial y}\right)^2}$$

2. Example calculation of Richardson number

$$Ri = \frac{\left(\frac{9.81\,\frac{m}{s^2}}{1000\,\frac{kg}{m^3}}\right)\left(\frac{998.46 - 999.55\,\frac{kg}{m^3}}{10m}\right)}{\left(\frac{0.06\,\frac{m}{s}}{10m}\right)^2}$$

$$Ri = 31$$

3. Richardson equation rearranged for velocity

$$\partial u^2 = \frac{\left(\frac{g}{\rho}\right)\left(\frac{\partial \rho}{\partial y}\right)(\partial y)^2}{Ri}$$

4. Calculation of velocity needed for mixing at 10m

$$\partial u^2 = \frac{\left(\dfrac{9.81\,\dfrac{m}{s^2}}{1000\,\dfrac{kg}{m^3}}\right)\left(\dfrac{998.46 - 999.55\,\dfrac{kg}{m^3}}{10m}\right)(10^2)}{0.25}$$

$$u = \frac{0.66m}{s} = 2.2\,\frac{ft}{s}$$

5. Richardson equation rearranged for mixing depth

$$\partial y = \frac{\left(\dfrac{\rho}{g}\right)(\partial u)^2(Ri)}{\partial \rho}$$

6. Example of mixing depth calculation assuming Ri = 0.25

$$y = \frac{\left(\dfrac{1000\,\dfrac{kg}{m^3}}{9.81\,\dfrac{m}{s^2}}\right)\left(0.06\,\dfrac{m}{s}\right)^2(0.25)}{998.46 - 999.55\,\dfrac{kg}{m^3}}$$

$$y = 0.096\ m$$