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To: BES, DSL, ODEQ, and Ross Island stakeholders
From: Desiree Tullos *DDT*

Subject: Results of Alternatives Analysis for Solutions to Harmful Algal Bloom at Ross Island Lagoon

Summary and Objective

The Harmful Algal Bloom (HAB) in the Ross Island lagoon (RIL) is unique due to its occurrence in river, and solutions to the HAB are complicated by environmental, regulatory, and logistical constraints. OSU faculty and students have been supporting stakeholders in identifying potential solutions for addressing the HAB, including hosting a design charrette, synthesizing current knowledge about the system, conducting informational interviews with key stakeholders, reviewing literature on HABs, and developing hydraulic models of proposed solutions to examine their feasibility and effectiveness. Students evaluated a wide range of potential solutions, ranging from hydraulic modifications to microbial solutions (e.g. flocculents, mechanical aeration, nanobubbles, ultrasonic pontoons, barley straw floats).

The objective of this memo is to summarize the key findings of the alternatives analysis and summarize recommendations for further discussion and inquiry. Supporting documents are provided in a link at the end of this memo.

Key findings and Recommendations

The Harmful Algal Bloom (HAB) at Ross Island Lagoon (RIL) is fundamentally a hydraulics problem. While nutrient availability, light, temperature, and other environmental variables contribute to HAB severity, cyanobacteria cannot outcompete other phytoplankton without the presence of stagnant, stratified water in the lagoon.

For example, at low tide during base flow (August), the lagoon has a surface area of 149 acres and a volume of 9574 acre-ft. Currently, the only flow into the lagoon is from tidal pulsing, which is as high as ~ -1500 ft^3/s in August, but the modeled velocity range is only <0.1 ft/s due to the large depth. This means that the retention time (Vol/discharge) in the lagoon is very long and demonstrates why the lagoon is so effective at growing cyanobacteria.

However, there are also environmental and management factors that are likely contributing to the HAB. Reducing these contributing factors is likely to suppress the bloom to some extent, though the effectiveness of reducing the different factors is difficult to estimate.

Recommendations

1) A short-term solution (e.g. aeration mixing) could be implemented soon to prevent the bloom from getting worse. These solutions are relatively inexpensive, but must be repeated regularly, may not completely eliminate the bloom, and can have some unintended environmental consequences that require careful design. Of the options listed, aeration mixing is likely to be most effective, but also most costly (~$200,000 capital costs, ~$80,000 annually O&M). Alum or Phoslock is inexpensive (~$80,000 per application) and is likely to be effective at suppressing the bloom by making phosphorus unavailable. However, it can produce adverse environmental impacts (Huser and Futter 2016) and new aquatic life criteria are currently being established in Oregon (USEPA 2019) that will make this solution infeasible. In addition, it is not clear what the key source of P is in the lagoon (See Data to Inform Management below), repeat applications of alum are required, effectiveness of these treatments is site specific (Spears et al. 2016). Alternately, flocculants can be used to sink cyanobacteria within a season, but are not effective at preventing future blooms and the regulatory pathways and effectiveness of this technique are not clear. Thus, the short-term solution is probably the path of least resistance and easiest to implement, but it requires a strategy and commitment to execute and pay for the treatments over the long term and to address other management actions that may be contributing to the bloom.
2) A long-term solution will require reconfiguring the lagoon to introduce flows that mixing the lagoon and flushes biomass out. Our results suggest that the design of the re-configured lagoon will require both:
    a) flows from the river on the southern/upstream portion of the lagoon during spring runoff, as well as
    b) expanding the lagoon entrance at the Holgate Channel to promote tidal pumping during the summer months when runoff is low.
    c) Some reasonable assurance that contaminated material placed in the lagoon is adequately capped and armored. It should be recognized that the contaminated material may be dispersed across the south end of the island (ODEQ, personal communication) and extend beyond the mapped CAD cells. Significant

experience with dredging and capping in the Lower Willamette can inform the permitting and design to stabilize that material.

3) Some data assimilation or collection and hydrodynamic modeling would be valuable, as described below, to determine the feasibility and effectiveness of some solutions. For example, the pH and P of the soils in the lagoon would be useful data, as would the concentrations of N and P in the fill material placed in the lagoon to identify if the existing or placed soils act as a source of nutrients. Additionally, detailed 3D modeling of the lagoon hydraulics is needed to provide confident estimates of the mixing depths and sediment transport under hydraulic design alternatives.
4) Revisiting the long-range expectation and trajectory for RIL is likely to help prioritize activities in the lagoon. Strategic thinking from a focus group of experts is needed to avoid solutions that fix short-term problems but create longer term and potentially irreversible problems in a dynamic system. A working group with the greatest likelihood of success would be comprised of collaborative individuals with deep expertise in hydraulics and modeling of rivers, microbiology of cyanobacteria, water quality, aquatic habitat for target species, and regulatory authority and flexibility of the agencies. Lagoon landowners should also participate in the working group. Both governance and technical issues should be addressed. The working group should be funded to support participation of experts from within and outside of the regulating agencies. Some questions that may aid visioning about the lagoon include:
    a) Is the current reclamation plan still the right vision? Is the additional habitat created by additional fill going to contribute meaningful uplift in the ecosystem, and/or how may the filling material and conditions contribute to the HAB?
    b) Does the nexus with the Portland Harbor Superfund site inhibit a long-term solution at RIL? Is the placement of materials in the lagoon with the expectation that they never leave a reasonable assumption? What is the risk of further constraining the lagoon into its current configuration without any flexibility for changing hydrology, regulations, ecosystem conditions, lagoon land ownership, and/or societal values? Can and should these two projects be decoupled by eliminating RIL as a disposal site for lightly contaminated materials?

<u>Scientific and engineering uncertainties</u>

1) There are a number of emerging technologies that were considered, but the effectiveness and permitting pathways for these technologies are unclear. Some of these technologies include ultrasonic platforms, dissolved air flotation and harvest, cavitation treatments, and nanobubblers. These approaches would require a champion within the agencies and community who are willing to be adaptive and innovative in experimenting with these emerging technologies, which should be supported with

strategic monitoring to evaluate their effectiveness and potential for unintended consequences for other organisms.

2) After extensive review of the literature and discussion with global leaders on the topic, it has become clear that it is difficult to define the minimum mixing depth that will completely eliminate the bloom, or how to estimate the effectiveness of partial mixing. Mixing provides three mechanisms for reducing the bloom, and each of these mechanisms suggests a different design, as indicated in the bullet below each mechanism.
    a) *Starve Them: Reduce competitive advantage of buoyancy.* Eliminates the competitive advantage that cyanobacteria have over other/eukaryotic phytoplankton in vertical migrating up to the euphotic zone by producing turbulent flow within the lagoon. Essentially, this strategy involves stirring the water in some portion of the lagoon such that the cyanobacteria are not effectively able to photosynthesize in the euphotic zone.
        i) Velocities required to mix entire euphotic zone (>5m, based on Stuart Dreyer's PAR data) and/or epilimnion (~11m, based on temp profile from USGS, Kurt Carpenter)
    b) *Flush Them: Dilution flushing.* This process involves complete flushing of the water and cyanobacteria biomass out of the lagoon faster than they can reproduce. This mechanism relies on completely replacing the water in the lagoon that contains the bacteria.
        i) If the cells grows at the same rate as the dilution (i.e. flushing) rate, the biomass will be in steady state. If the dilution rate is higher than the growth rate, the cells will wash out, which should effectively suppress the bloom.
        ii) A dilution/flushing rate for the lagoon is calculated as discharge/volume. For the current condition, the dilution rate at the peak tide in August is 1500/ 417,053,710 $ft^3 = 4*10^{-6}$, which is 6 orders of magnitude lower than the growth rate.
        iii) For flushing rates to be greater than the growth rates for the cyanobacteria (0.58-0.93 day-1; Lurling et al. 2012),
            (1) Full depth: discharge into the lagoon needs to be nearly $4(10^8)$ ft3/s to flush the full depth. Since this discharge doesn't exist anywhere in the world, this indicates that flushing the entire lagoon depth is not feasible.
            (2) Upper 10m: Complete flushing the upper 10m of the lagoon at the dilution rate, a volume of ~ 6163 ac-ft, would require a discharge of $2.5(10^8)$ cfs for the current configuration and velocities, which is still not remotely feasible.

(3) Thus we do not know what flushing depth, if any, would produce a dilution rate that would exceed the growth rate.

c) *Explode Them: Collapsing gas vesicles.* The gas vesicles that allow cyanobacteria to migrate vertically are sensitive to pressure and will rupture when they are mixed down to increasing pressures. Microcystis requires the greatest mixing depth of around 10m to achieve a pressure of ~150kPa (Stuart Dreyer 2019).

Based on these mechanisms, we were able to identify one design (Figure 1) that would mix the euphotic zone based on PAR during some times of the year, but not a solution adequately mixed the lagoon in August or that suppressed stratification or mix deep enough to collapse gas vesicles. While the details of this specific design did not achieve adequate mixing even for PAR during August, modifications (i.e. deepening, widening) of the southwest channel are expected to be effective, pending constraints on encroachments on CAD cells and/or wetlands. The exceptional volume of the lagoon makes it difficult to achieve a mixing of ~ 10m, which is likely to be most effective by achieving the mechanisms of mixing the entire epilimnion and collapsing gas vesicles.

Thus, it is not clear that the design, based on introducing river flow on the southern end and expanding tidal pumping by widening the existing lagoon entrance, will be effective at fully suppressing the bloom. There is scientific uncertainty in exactly what depths or velocities are needed to suppress the bloom, as well as modeling uncertainty regarding the actual mixing depths and flushing velocities for the examined alternatives. Alternate configurations (e.g. a wider channel on the upstream end near CAD #5) could be examined to increase mixing depths or lagoon velocities, though a 3D model should be used to finalize designs and conservative engineering of armoring to maintain the CAD cells will be needed.

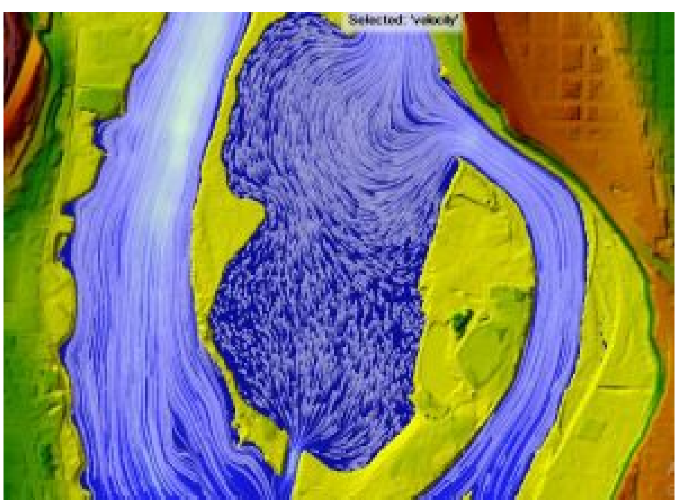

Figure 1. Model simulation of modifications needed to increase mixing into the lagoon, requiring both an upstream conveyance for introducing river flows during winter and a widening of the Holgate entrance to enhance tidal pumping. Modifications include a surface conveyance along the southwest corner, adjacent to CAD cell #5, and an expansion of the lagoon entrance along the Holgate channel. While this example only mixes the surface to a depth of ~0.5ft in August, it mixes the lagoon up to ~ 18' during the spring (based on April

flows), which is expected to suppress but not fully eliminate the bloom. A final design would need to establish the best dimensions for both entrances to minimize wetland impacts and risk to CAD cells, while maximizing the late summer velocities into the lagoon.

<u>Additional modeling</u>

1) One key limitation of our modeling work is that a 2D, depth averaged model was used, which does not represent velocities with depth. 2D modeling was needed due to the lateral variability in the channel. However, by not representing variations over depth, the model spreads momentum in each cell across the entire depth, which is up to 120' in the lagoon. This results in estimates of surface velocities that are lower than the lagoon actually experiences, whereas velocities transition to zero at an unknown depth. We attempted to overcome this limitation of the 2D model by using the Richardson number to estimate the depth at which mixing would occur. The Richardson number is commonly used to identify the depth at which shearing forces from velocity exceed stabilizing forces of density, with a theoretical value of 0.25 reflecting a fully mixed system (Kirillin and Shatwell 2016). There are some important limitations to this approach and a 3D model is warranted if further resolution on the lagoon hydraulics and design details are desired.
2) Any solution that would increase velocities to the lagoon would need to include modeling and potentially armoring to demonstrate that material placed in the lagoon will not be eroded and flushed downstream. Future placement of lightly-contaminated material in RIL should be carefully planned to not further constrain HAB solutions, and will also require further modeling to ensure that the new material is also not mobilized.

<u>Additional Data to Inform Management</u>

a) The use of, and recommendations for more, concrete rubble in the lagoon may be contributing to the HAB. The cement in concrete is known to contribute to elevated pH. Research (Gao et al. 2016) has shown that elevate pH by upregulating gas vesicle protein genes, making them more buoyant. Soil pH data should be collected and/or existing data reviewed to examine if pH modifications could help suppress the bloom.
b) P sources and management
    i) P data collected in 2018 by ODEQ at the Morrison St. bridge indicate that TP levels in the Willamette River are on the order of 0.025-0.067 mg/L. These concentrations indicate the river is not contributing significantly to the dominance of cyanobacteria in the lagoon (Dokulil and Teubner 2000) and suggest that the key source of P is internal recycling from soil P.
    ii) However, TP from the river is probably also not limiting the bacteria during the summer, which need ~ 0.05mg/L TP before growth starts to become limited (Tim Otten, personal communication). In July and August

of 2018, TP concentrations at the USGS gauge were 0.05 and 0.06 mg/L, respectively. Thus, concentrations of TP from the river are low and are probably not the primary source of P, but may be used by the bacteria under some circumstances. For reference, hypertrophic lakes like Taihu Lake in China have around 0.4-1.0 mg/L TP, approximately an order of magnitude higher TP.

iii) It is worth noting that current values are lower than the range (0.03-0.18 mg/L) reported by ODEQ for the 2000-2005 sampling period, suggesting that ambient TP concentrations in the river have been declining over time.

iv) Data on the P concentrations in the lagoon sediments were not available but should be to help determine if alum additions will be beneficial.

v) According to the 401 permit, the material being placed to meet requirements for the reclamation plan are rightfully being tested for N and P, but I was not able to find those data or anyone who knows where those data are stored. Without that information, and given that these materials are being placed during the summer in-water work period (July 01-Oct 01), it is not clear if placed material is contributing to the HAB by fertilizing the lagoon. Those data should be collected and available to ODEQ personnel and be included in annual permits.

In summary, solutions to the HAB at RIL are feasible and needed, applying temporary solutions to suppress the bloom over the short term and adjusting the hydraulics to eliminate the bloom over the long term. However, the leadership and coordination between agencies and the landowners needs to be improved to design, fund, and implement a solution that is effective and sustainable in this changing system.

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Attachments

All documentation of supporting analysis conducted by OSU is available online at:
http://blogs.oregonstate.edu/rivers/ross-island-harmful-algal-bloom/