Preliminary Evaluation Feasibility of Aeration for Reducing the Chesapeake Bay Dead Zone

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Here's the Basic Idea

- Do what you oughta, add O2 to water
- Do this by pumping air into the dead zone
- The O2 will dissolve into the water as the bubbles rise
- Tide will disperse the O2 North/South
- East/West pipes will disperse O2 E/W
- Figure out if it's feasible to add enough O2 to offset the imbalance between respiration and natural aeration

Here's NOT the Basic Idea

- Use bubbles to break up the pyncnocline
  - Thus increase natural aeration
- Choose a method for pumping air
- Choose an energy source
- Use pure O2
- Design a system (yet)
- Promote an agenda (yet)

Objections

- Too much air required
- Too much energy to pump air to the bottom
- Very high cost
- No way to get that much O_2 into the water – bubbles rise too fast
- STAC review of wind power said 1000 barges with 11,000 turbines
- Fixing the symptoms, not the problem

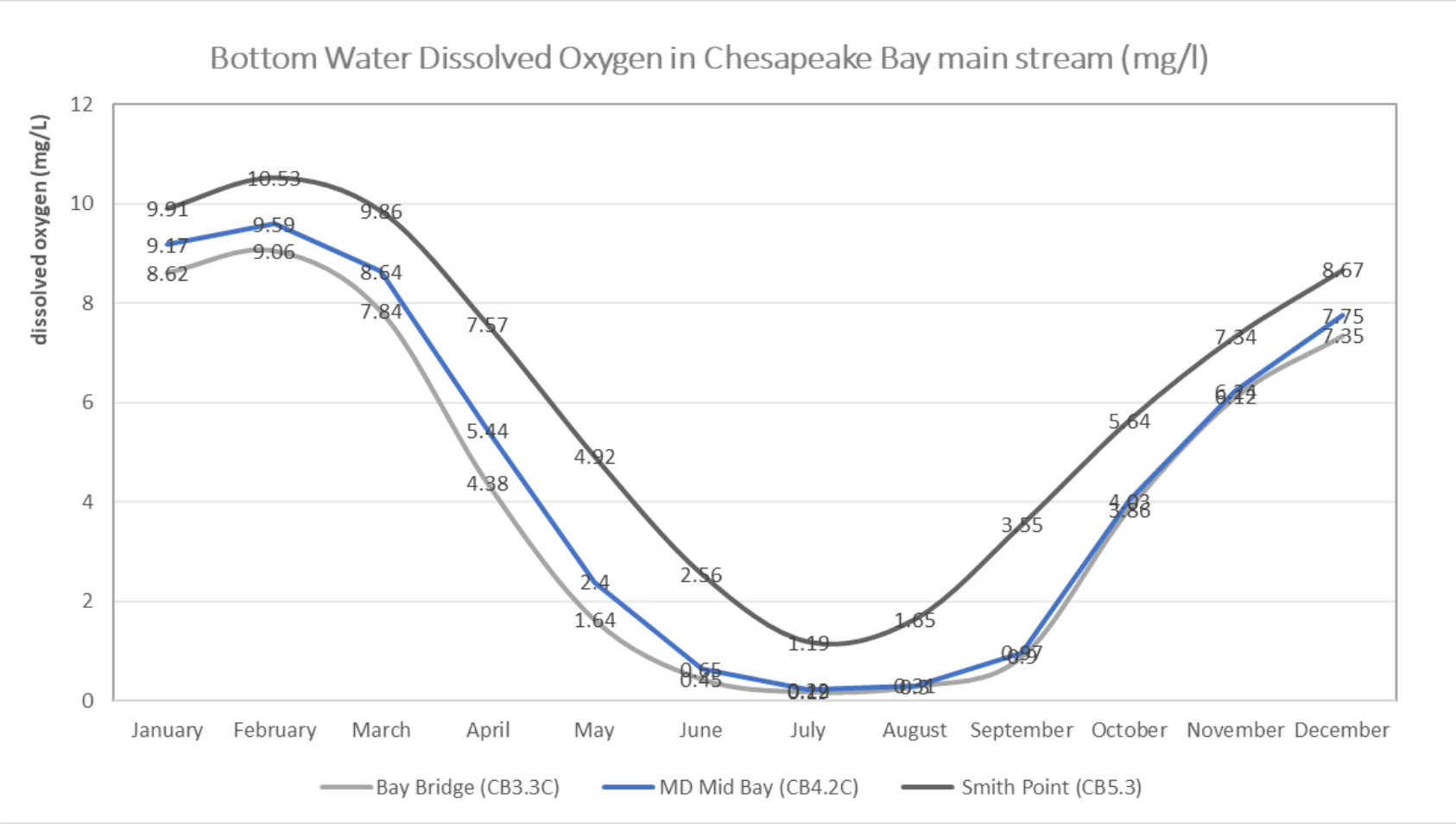
BOE Calculations

- What size pipes?
- What size pumps?
- How much energy?
- What's it gonna cost?
- It all starts with "How much air?"

Data! Data! Who Got the Data?

- BOD levels
- Respiration levels
- Aeration rates
- Sediment O_2 demand rates
- Can I get this stuff from the models?
- What a mess! I'll never get this done!
- There is a real need for additional monitoring compared to other estuaries, particularly continuous monitoring

How Much O_2 is Needed?



Observations

- DO decline takes months – there is a reservoir of O_2
- The decline is about 3mg/l/MONTH
- That's THE ANSWER!! Net of everything
- That might be manageable
- Not so fast, don't know what's happening in the critical late summer period – but the big bloom is late spring.

O_2 Dispersion is a 1D Problem

- Bubbles rise – vertical dispersion is not an issue
- In the Bay, tides move water N/S
  - Tidal excursion is ~3-5km
  - N/S dispersion is not a big issue
- One E/W lateral will likely serve ~5km of Bay
- Laterals will solve the 1D E/W dispersion problem

How Much Air Is Needed? 10x More Air than O2

- Tiny bubbles – what's the dissolution rate?
  - 10% in STPs
  - Deep Bay is not N_2 saturated, and dissolving gas keeps bubbles from expanding as they rise and thus limits the rate of rise
- ~50% of O_2 in bubble dissolves below the pyncnocline
  - Dirty bubble formula, numerically integrated
  - .5 x .2 = 10% of pumped air dissolves as O_2 N_2 dissolves as well

Cost Estimation Assumptions

- 1.5 mi^3 of anoxic volume
- 5 mg/l/month O_2 for anoxic volume
- 60’ depth (compress to 3 atm for energy calcs)
- 50% energy efficiency for O_2 delivery
- 90 days operation/yr.
- 16 pumping stations

Several Numbers:

1. $1,982.6 M: State and Federal partners invested in Watershed restoration in fiscal year 2017 [1];

2. $47 M: directed to help meet the goals of the Chesapeake Bay Total Maximum Daily Load by CBP Funds[1];

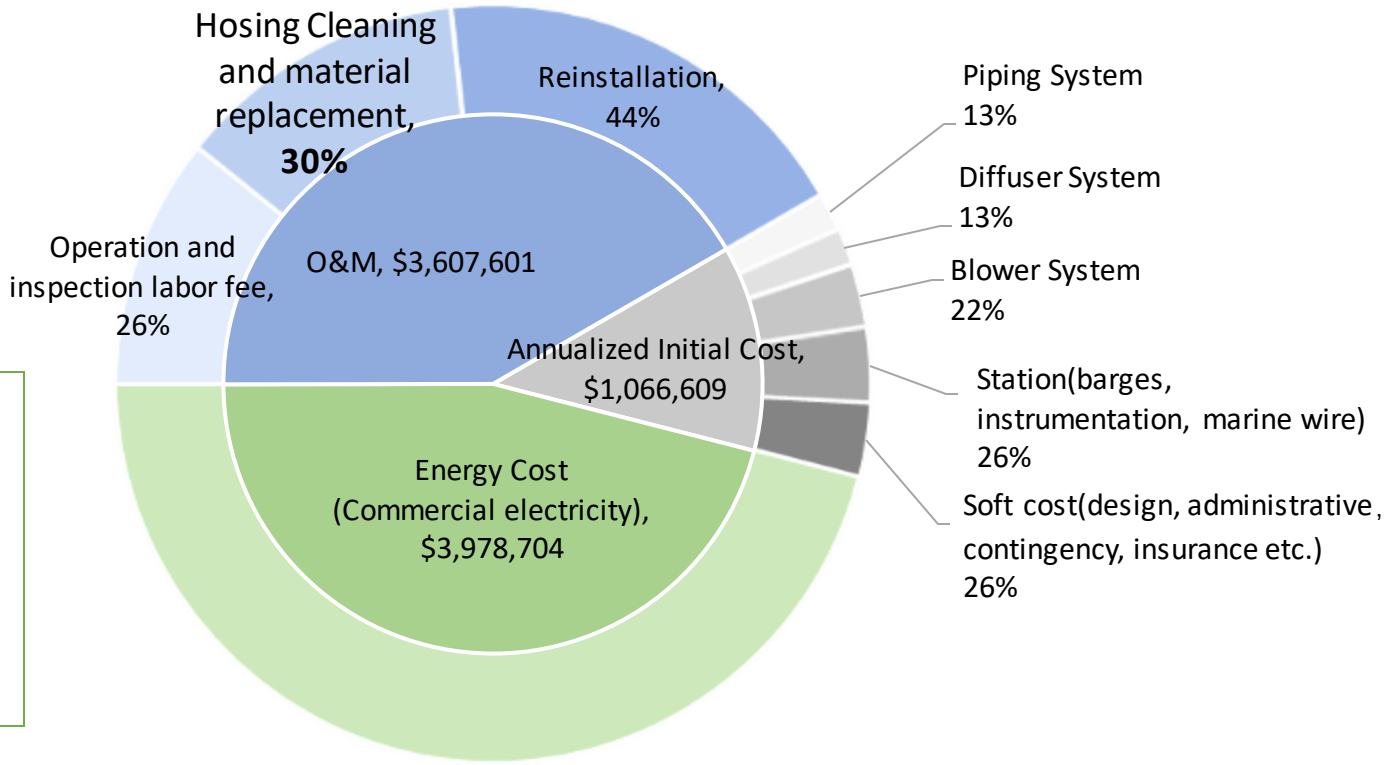
3. According to EPA officials, it may take a significant number of years for changes to occur in water quality after implementation of TMDLs[2];

4. $80 M: Welfare effect (equivalent to 80 Millions dollars) with 25% increase of DO levels across the region[3];

Reference:

1. www.chesapeakeprogress.com/funding;
2. https://www.epa.gov/tmdl/impaired-waters-restoration-process-recovery;
3. *Massey, D. M., S. C. Newbold, and B. Gentner. 2006. Valuing water quality changes using a bioeconomic model of a coastal recreational fishery. Journal of Environmental Economics and Management 52: 482–500.*

Engineering Cost Analysis:



Total Annual Cost:

$8,652,914

On the order of **0.5%** of current combined Federal and State Bay Program expenditures on an annual basis (4)

Reference:

1. Boyle, William C. (1990). *Fine pore aeration for wastewater treatment*. Park Ridge, N.J., U.S.A: Noyes Data Corp;
2. W. Harris, Roy & John, Jr, Cullinane, M & Sun, Paul. (1982). *Process Design and Cost Estimating Algorithms for the Computer Assisted Procedure for Design and Evaluation of Wastewater Treatment Systems (CAPDET)*. 1706. ;
3. Web Price;
4. www.chesapeakeprogress.com/funding

Bottom-up Initial Cost Estimation:

Category	Cost, $	Note
Material Cost	**5,325,108**	
1. Piping System	960,640	
• Downpipe		D=1.5 feet, price for per meter, aluminum transmission pipe for distributed diffusers, average 6km for each station market price
• Airflow transmission pipe		
2. Diffusers System	922,658	
• Diffusers		D=3.5'', price $/ ft, 0-50 cfm, cost of diffusers, the below-water air piping
• Anchoring		20% of piping system
3. Blowers System	1,565,238	
• Blowers		Capacity @ B45 scfm, sourcing from Madison, WI, 7/scfm
• Air infiltration system		$3000 for 27500scfm blower
4. Station Construction	1,876,571	
• Instrumentation & Control		Auto-control system, 30% of blower
• Used Barge		Draft= 15 ft, deck length 25 ft, http://www.maritimesales.com/ETT10.htm
• Marine Wire		Cost per meter, low voltage
Mobilization, Insurance	**426,009**	8% of material cost
Contigency	**213,004**	4% of material cost
Design & Engineering	**894,618**	15% of construction cost
Legal & Administrative	**298,206**	5% of construction cost

Total Initial Cost	7,156,945
Equivalent Annual Cost[1]	1,066,609

1. Assumption: interested rate: 8%; Operation duration: 10 years.

Energy Cost Estimation:

❖ **Table 1- Energy Demand**

Name	Value	Demand
Air needed	8.19E+09	l/day
Work Required	9.95E+11	J/day
Energy Needed (50% efficiency)	5.53E+05	kWh/day

❖ **Table 2- Energy Options**

	1. Commercial electricity	2. Solar generation	3. Source From Marine
Strategy	• Connected by marine wires	• Connected by marine wires; • 2256 KW solar panels with $1.95/W[1] can cover full demand considering renewable energy incentives.	• Wave with average height 1.5 ft and period 4s is likely to produce an integrated volumetric air flow of about 1E+09 liter per day with 5 barges.
Levelized cost	$0.08 /Kwh $5.4 E-03/ml Air	$0.092 /Kwh $6.2 E-03/ml Air	(Unfinished, Need check!)
Co-benefits		- Green Energy; - Likely to be more cost-effective in 2-3 years.	- Green Energy; - Reduce wave impact on navigation and bank erosion.

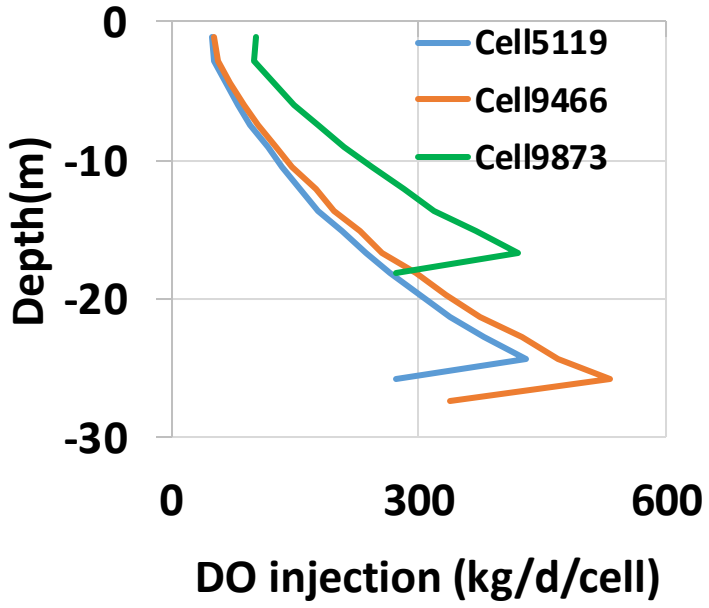
1. Fu, Ran, Feldman, David J., Margolis, Robert M., Woodhouse, Michael A., & Ardani, Kristen B. *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017*. United States. doi:10.2172/1390776.

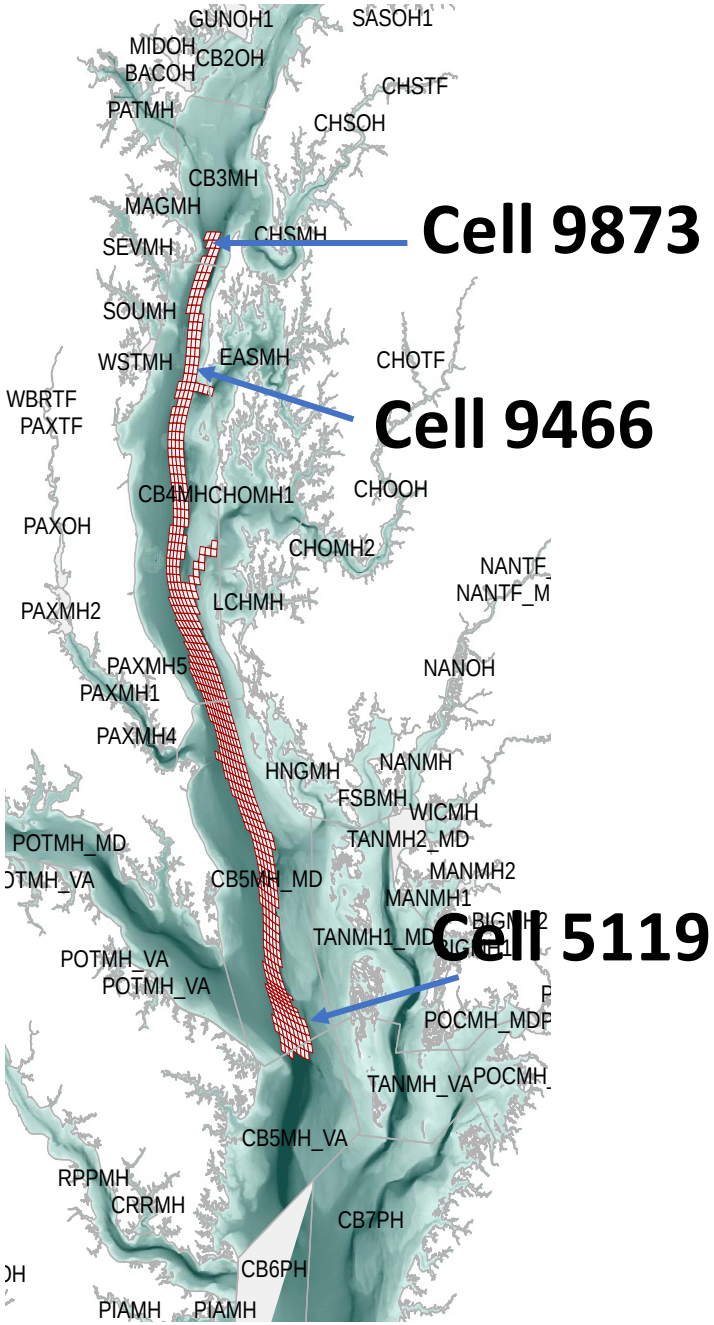
But, Will It Work??

- Testing with CBWQSTM
- Adding O_2 to model
  - Vertical distribution of O_2 injection per calculations from dirty bubble formula
  - Assume uniform distribution of O_2 injection in all model columns > 50' deep between Smith Point and Bay Bridge in main channel
  - Total O_2 addition consistent with cost estimate

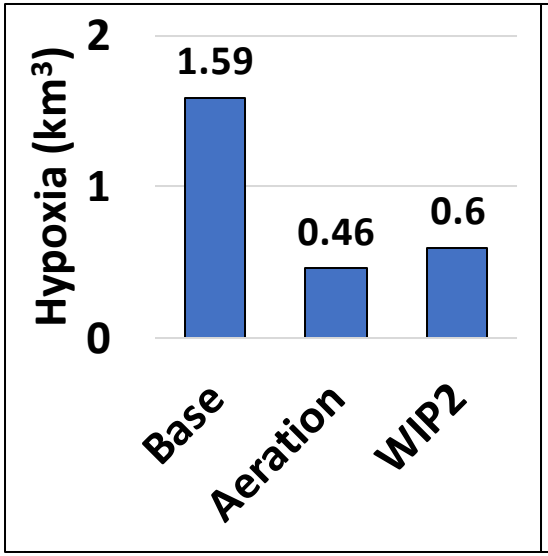
Simulation and comparison

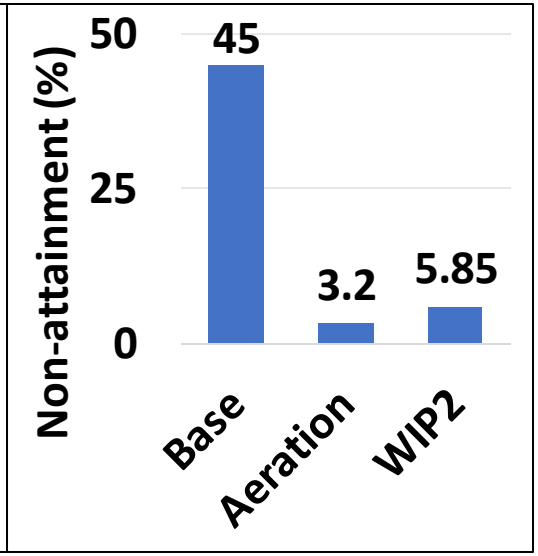
- **Aeration – Base + O2 addition, Apr. 1 – Sep. 30.**
- **585 surface cells receive DO injection in the water column, 8481 cells in total.**
- **3 millions pounds of DO per day and 539 million pounds per year.**
- **Base – Calibration 1991-2000.**
- **WIP2 – Nutrient reduction of Watershed Implementation Plan Phase II.**

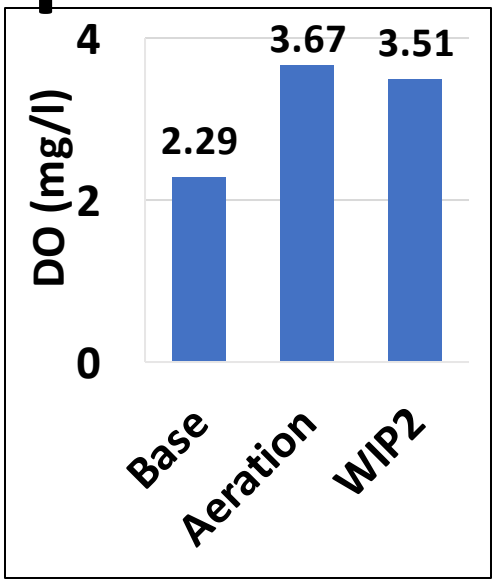


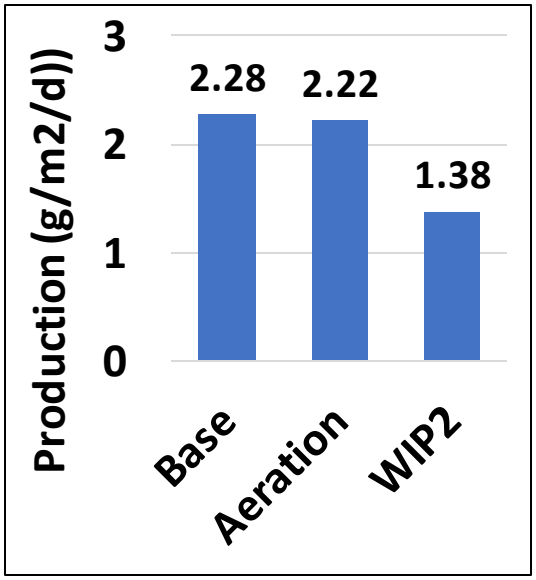


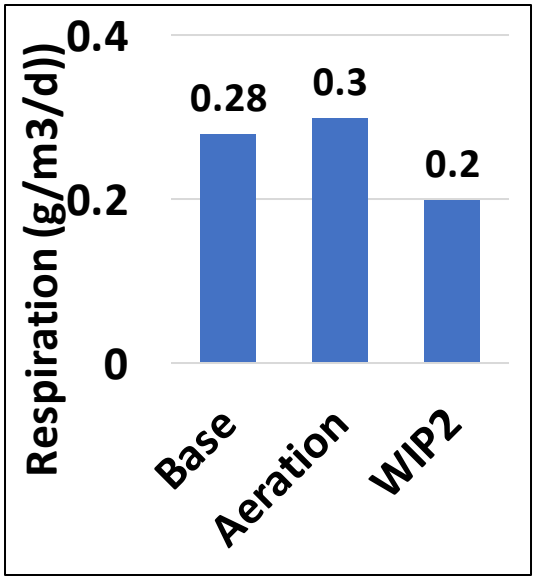
Comparison of water quality variables in CB4 deep channel Apr-Sep



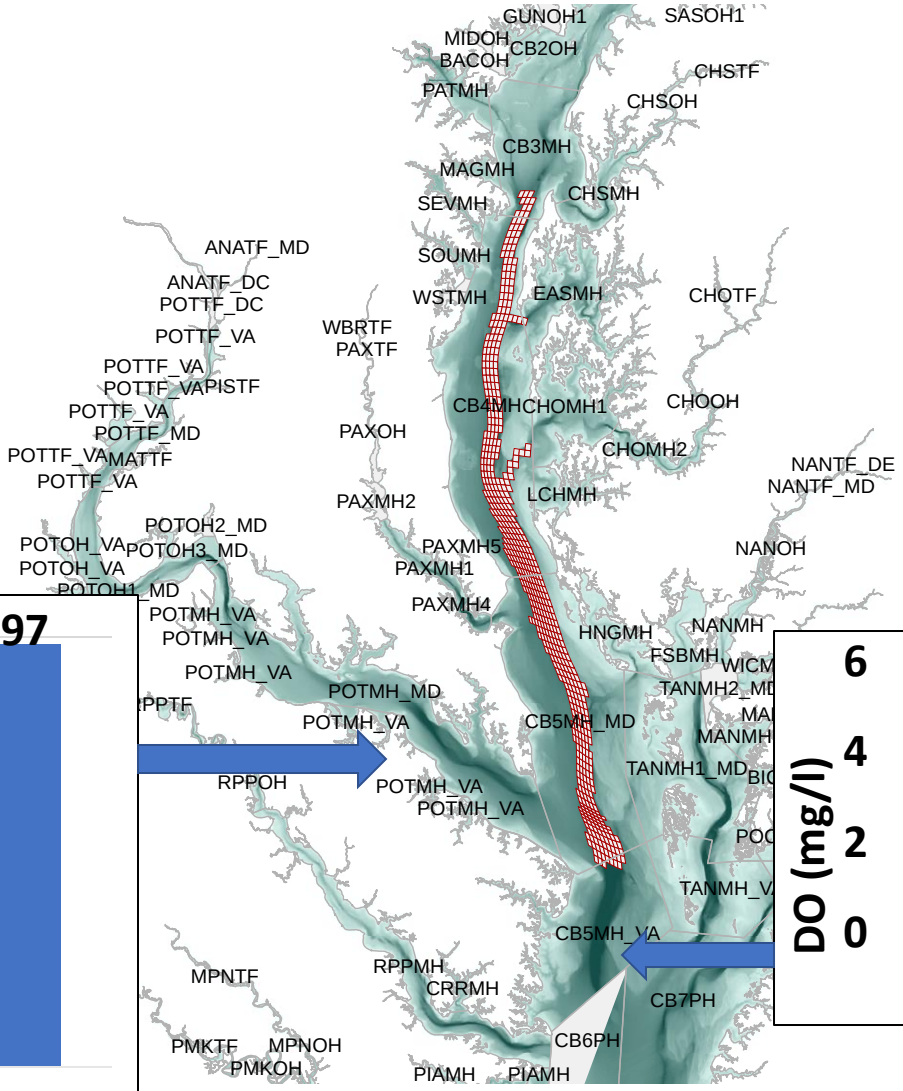




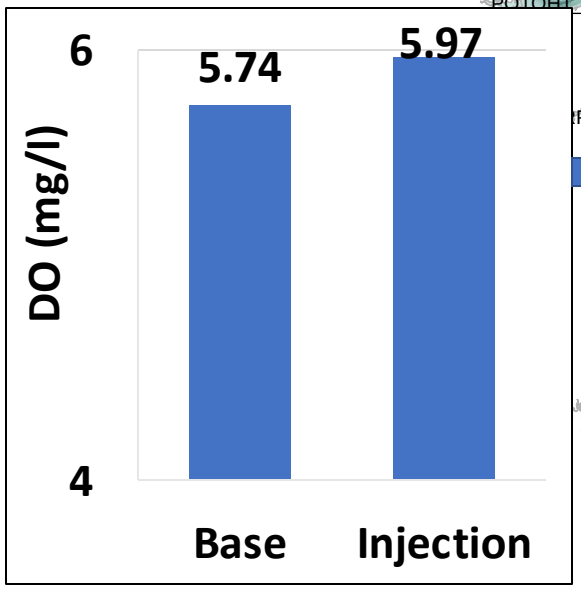




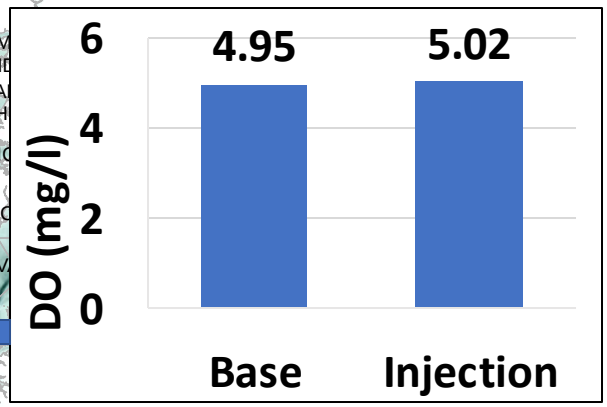
Spill over?



Potomac



VA5MH



Conclusions and Next Steps

- This MIGHT actually provide rapid and substantial reductions in dead zone
  - Model results say DO performance in main channel is comparable to Bay Program – but that's only one parameter
  - Costs seem attractive relative to the problem being addressed
- The model results are model results, not real world – we need experiments
- Costs and performance will depend on design

EXPERIMENTS!!!

- Model runs, model runs, model runs
  - diffuser optimization,
  - O2 distribution,
  - Current loadings, etc.
- Confirm dissolution rates
- Test diffuser designs, particularly for fouling
- Identify other implications e.g.
  - Nutrient cycling
  - N_2 concentration impacts
  - Destratification impacts, etc.
- Use the CBWQSTM to design the physical experiments

Design Challenges

- Location of pump stations – shore or barges
- Power source
  - Grid, waves, wind, solar, combinations
  - Interruptible power, ancillary services
- Navigation impacts and system stability
  - Dredging, anchoring, prop wash, drunks
- Pipe and diffuser materials and anchoring
- O&M
  - Fouling, R&R, Service
- Student competition?

Thank You

Discussion,
Comments and Suggestions?

Animation of Bay Bridge (CB3/CB4) Base Run (Top) – Infusion (Bottom)