Analysis of Optimal Dredging Cycles for Navigation Projects

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Innovative Technologies for a
Resilient Marine Transportation System
June 25, 2014
Washington, D.C.

US Army Corps of Engineers
BUILDING STRONG®

Limited O&M Funding

• **Fiscal constraints force the Corps to make difficult decisions concerning allocation of limited Operations and Maintenance (O&M) funds**

• **We investigate how to optimize limited resources to maximize value to the nation --- in this case measured by tonnage disrupted by shoaling**

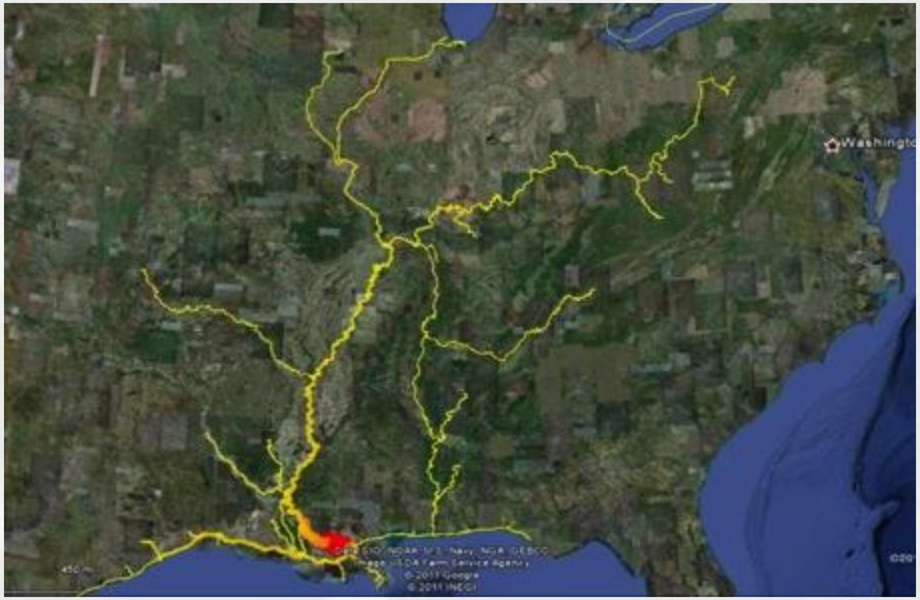
Waterborne Commerce Data

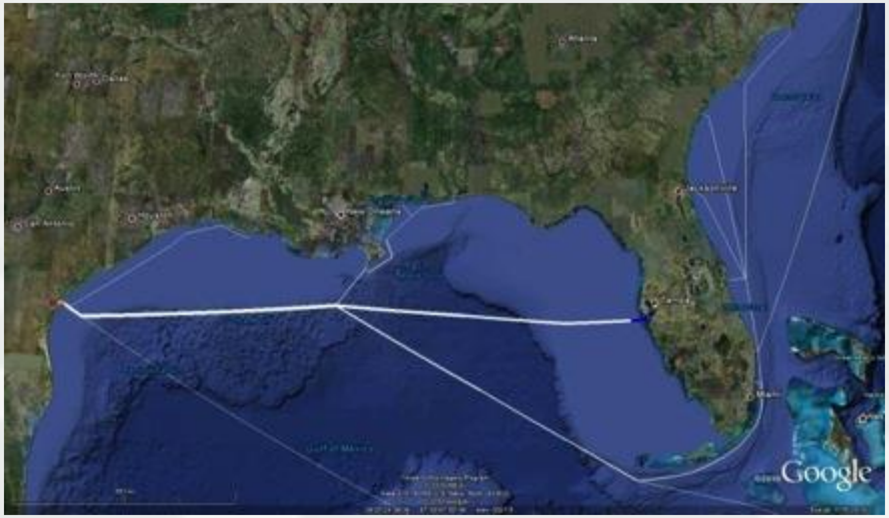
- The Corps' Waterborne Commerce Statistics Center (WCSC) collects and collates data from several sources concerning commercial use of US waterways.
  - ▸ Dock-level, origin-to-destination routing (Corps-use-only)
  - ▸ Includes tons, commodity types, vessel counts, drafts

- Channel Portfolio Tool (CPT: https://www.cpt.usace.army.mil) provides means of querying this large database and analyzing waterway network flow patterns. Now available to all federal employees.

- Allows systems-based approaches to analyze benefit over entire route, not just at single location

MTS Freight Flows



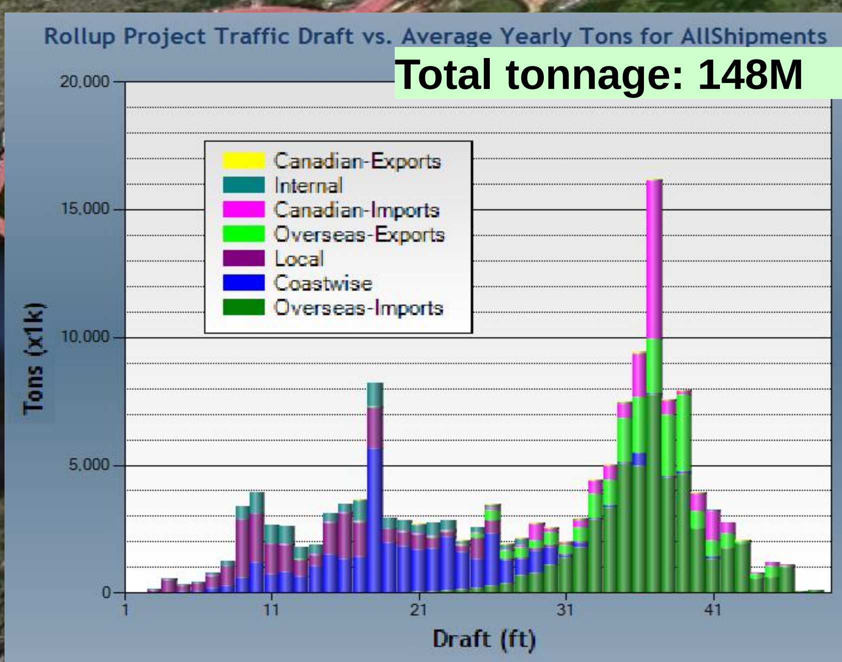


The O-D flows within the WCSC data allow the Corps to evaluate navigation project interdependencies.

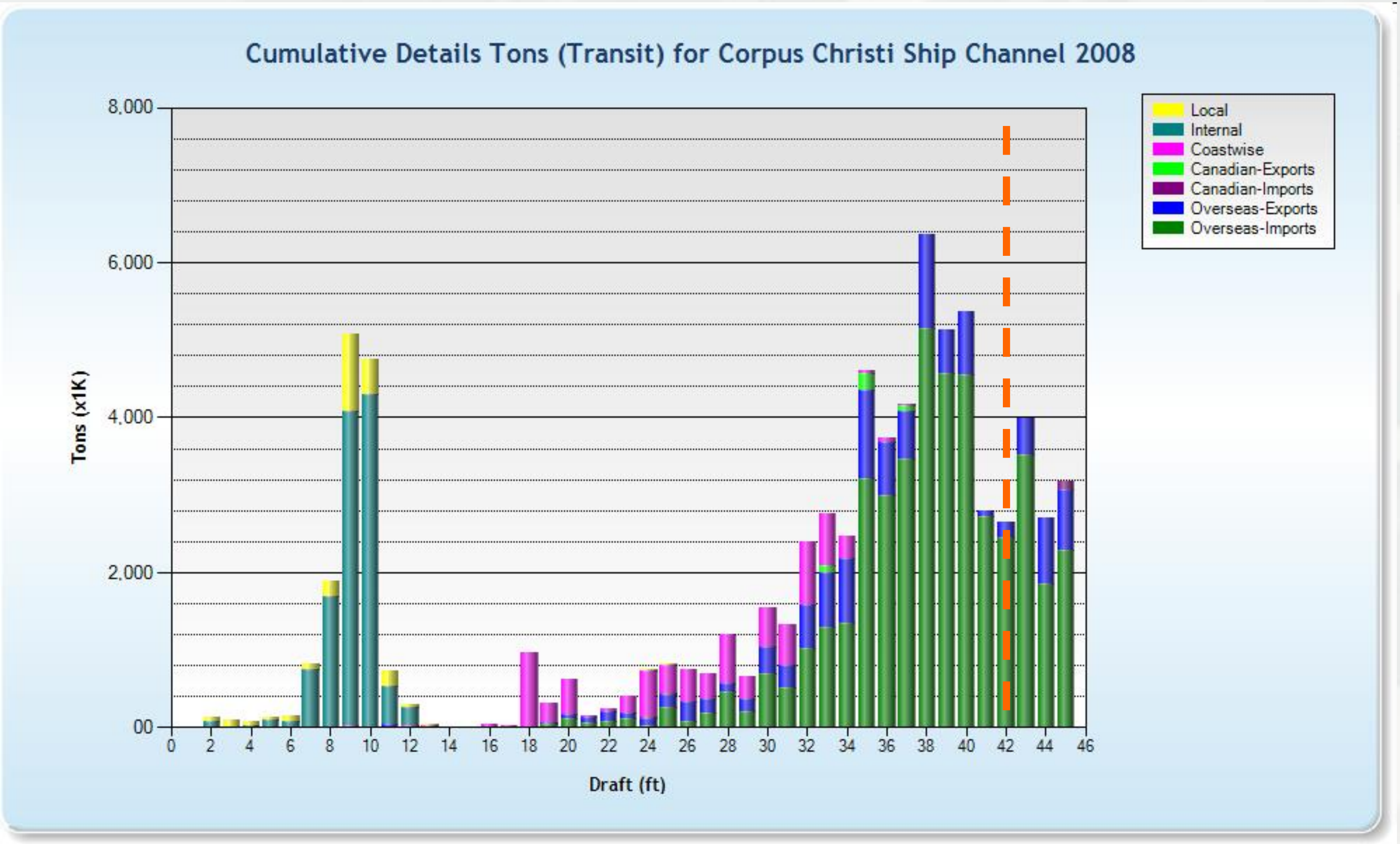
Evaluate entire route, not just one port

Navigation Projects and Transportation Systems

New York Harbor: budgeted as separate navigation projects… yet functions as a navigation system.



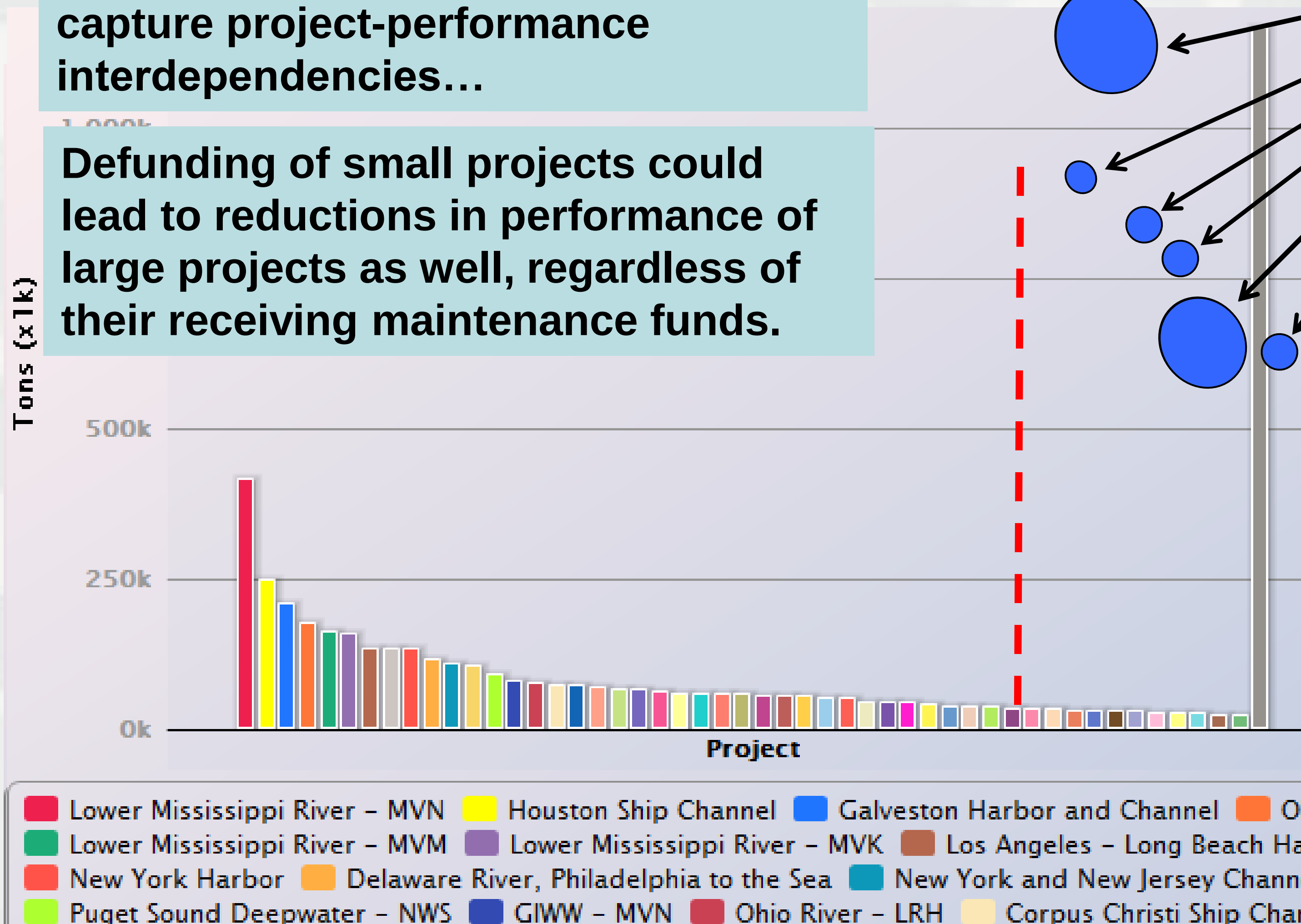
Focus on Shoal-vulnerable Cargo

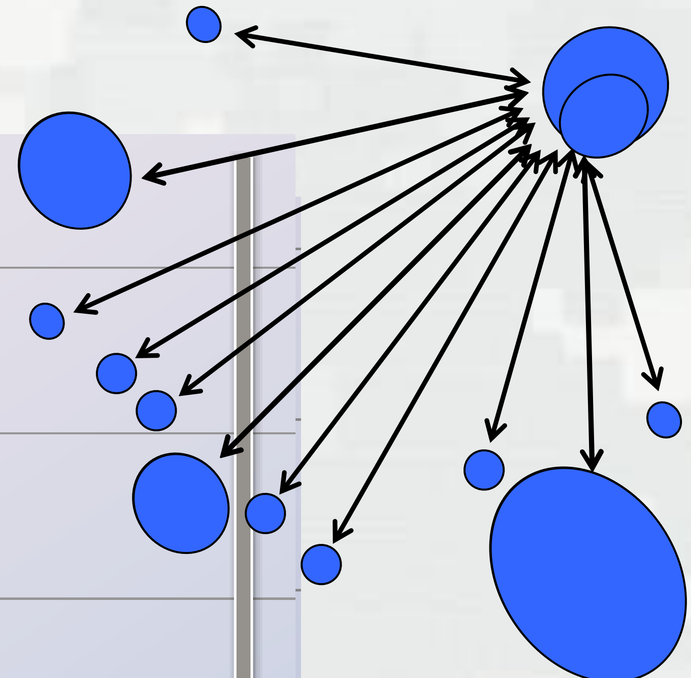


Project View versus System View

Rank-ordered project evaluation with cut-off line for funding often does not capture project-performance interdependencies…

Defunding of small projects could lead to reductions in performance of large projects as well, regardless of their receiving maintenance funds.





Mixed-Integer Program

$$Max \quad \sum_{i}\sum_{j<i} b_{ij} x_{ij} \qquad (1.0)$$

$$s.t.$$

$$x_{ij} \le d_k, \qquad \forall i,j: i<j, \text{ and } k \in S(i,j) \qquad (1.1)$$

$$\sum_{k} d_k \le x_{ij} + \left|S(i,j)\right| - 1 \qquad \forall i,j: i<j, \text{ and } k \in S(i,j) \qquad (1.2)$$

$$\sum_{i} d_i c_i \le B \qquad \forall i,j: i<j \qquad (1.3)$$

$$d, binary \;\; for\ all\ i\ ; \quad x_{ij} \ge 0, \text{ for all } i, j. \qquad (1.4)$$

x_{ij} = Objective function variable, which is 1 when both port *i* and *j* and all the other intermediate ports along the route connecting *i* to *j* are dredged for the improved benefits; 0, otherwise, where $i \neq j$
d_i = Binary decision variable, which is 1 when port *i* is selected to dredge; 0, otherwise
b_{ij} = The maximum increase in the direct capacity between *i* and *j* by dredging both port *i* and *j*
c_j= The cost for dredging port *j*
B= The total amount of budget available for dredging projects for a planning period.
S(i,j)= Set of all projects that are necessary to realize the benefit of b_{ij}. $\{i,j\} \in S(i,j)$. For example, if a flow from i to j goes through port i,k,m,j, S={i,k,m,j}.

New Formulation

- Multiple Depths

4 Dredging Options

4 Shoaling Options

11 Total Depths

New Formulation

- Multiple Depths
- Multiple Costs

Cost to dredge 1-4 Feet

Mob/Demob Costs included

New Formulation

- Multiple Depths
- Multiple Costs
- Multiple Tonnages

Entire path must be dredged

Tonnage passes at "shallowest" point on path

New Formulation

- Multiple Depths
- Multiple Costs
- Multiple Tonnages
- Multi-Year

The end state (depth at each port) of a simulation is the starting point for the next year

(20 year simulation)

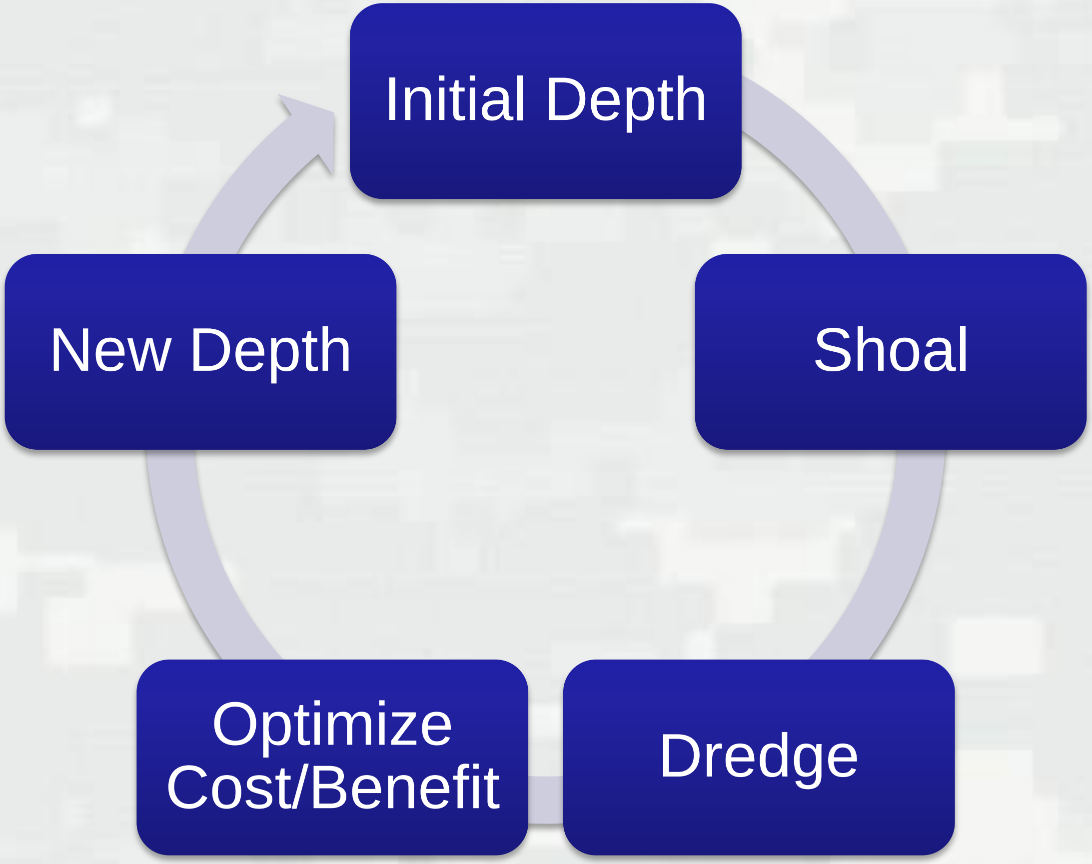
New Formulation

- Multiple Depths
- Multiple Costs
- Multiple Tonnages
- Multi-Year
- Shoaling

At the start of each "year", each channel shoals at a rate dependent on:

- Current Depth
- Previous Year Dredging

Basic Algorithm



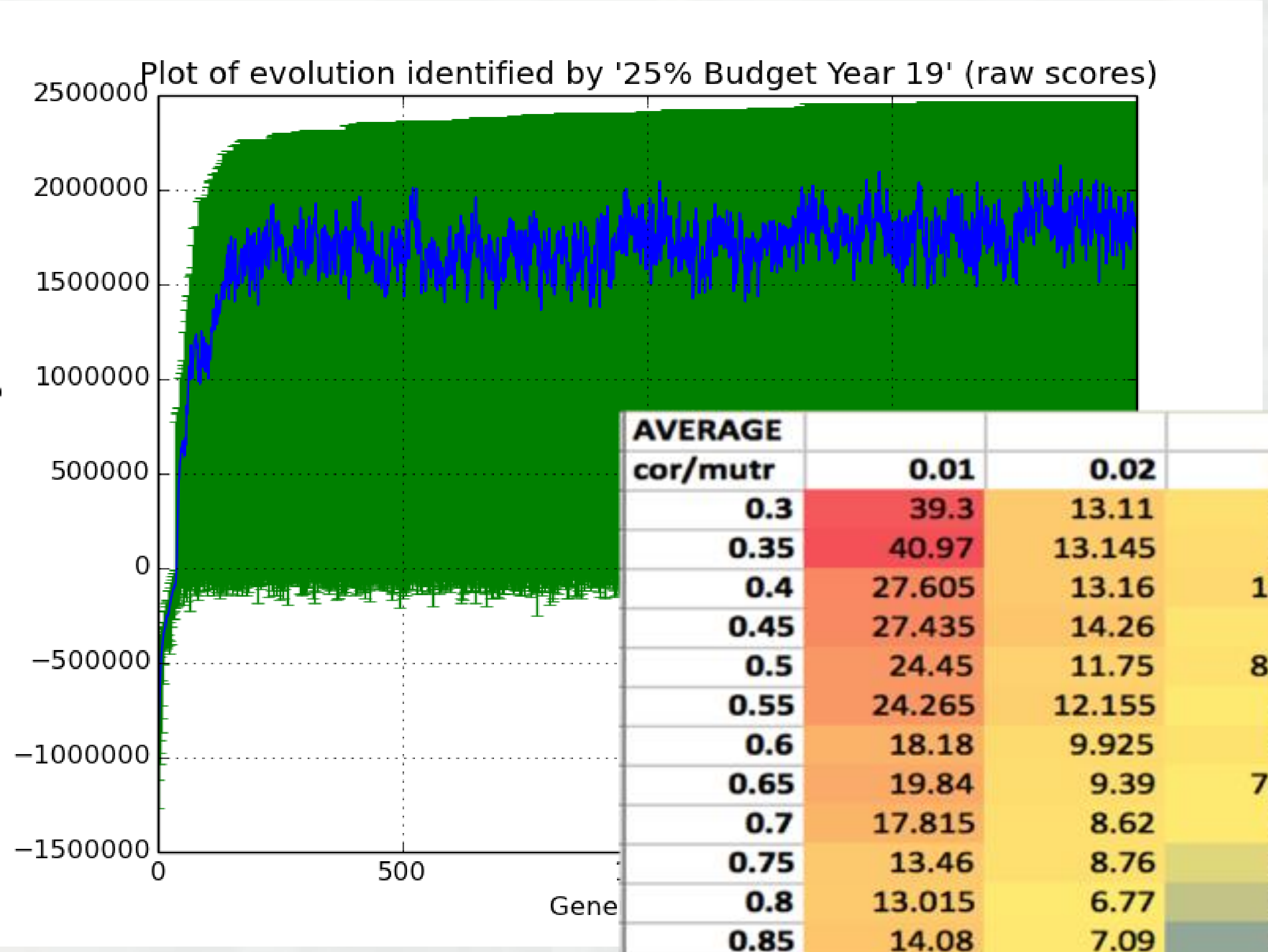
Solving the System

- Use Genetic Algorithm (pyevolve) to optimize dredging decision
- For a system with 783 unique ports and 39,418 routes, it takes ~ 20-40 minutes to optimize one “year”
- 10^{11} possibilities *each year!*

Genetic Algorithm (GA)

- No sense of a traditional "downhill" for an optimizer to follow
- Must explore the space "randomly"
- GA allows us to "efficiently" explore space
  - ▶ Main constraint is time

GA Parameters



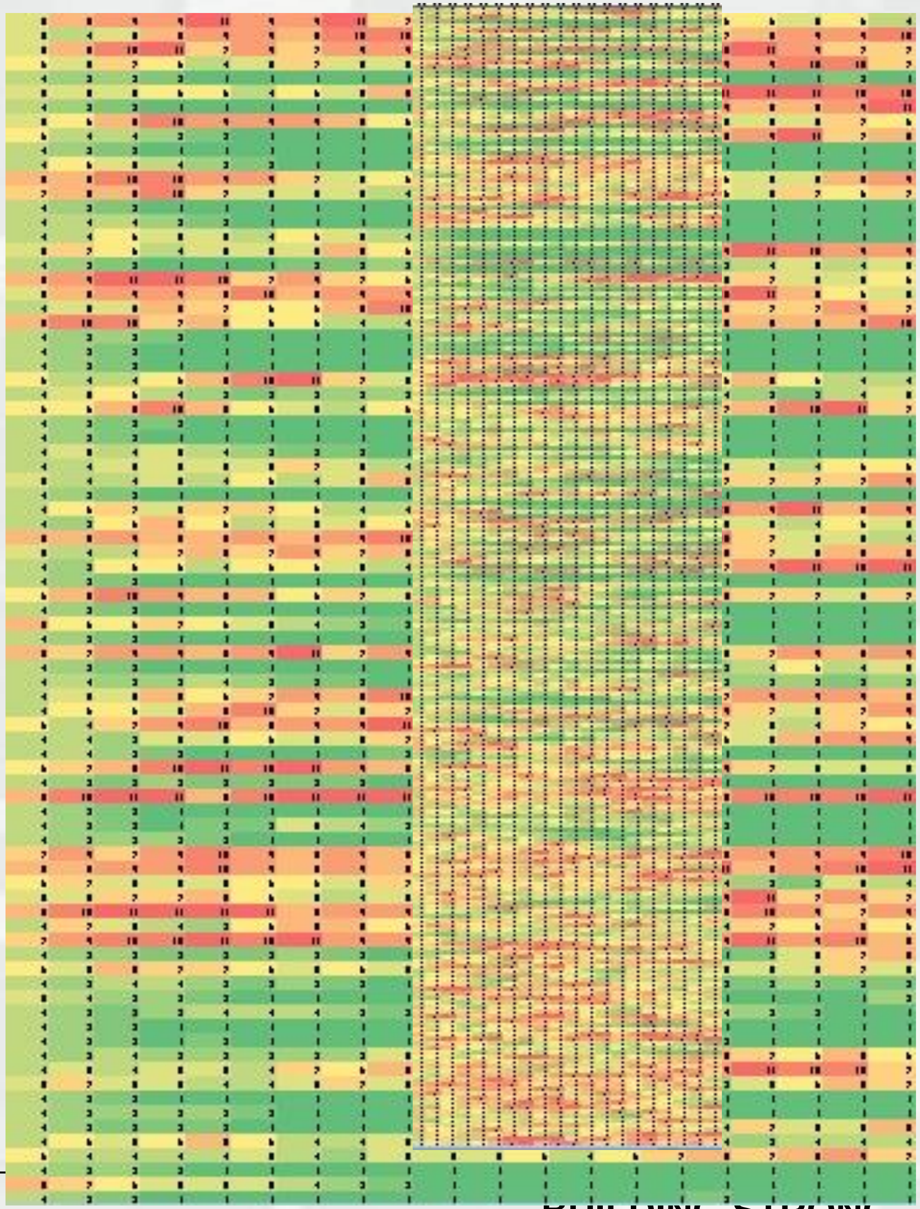
AVERAGE					
cor/mutr	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**
0.3	39.3	13.11	8.64	6.18	6.315
0.35	40.97	13.145	9.66	6.68	5.94
0.4	27.605	13.16	10.06	7.735	5.15
0.45	27.435	14.26	8	6.415	5.4
0.5	24.45	11.75	8.595	5.755	4.325
0.55	24.265	12.155	6.89	5.885	5.125
0.6	18.18	9.925	8.25	5.27	4.705
0.65	19.84	9.39	7.025	5.75	4.71
0.7	17.815	8.62	6.83	5.785	4.245
0.75	13.46	8.76	6.23	5.495	4.14
0.8	13.015	6.77	5.69	3.96	3.88
0.85	14.08	7.09	4.81	4.595	3.86
0.9	8.85	7.17	4.83	4.06	4.09
0.95	8.475	5.51	4.545	3.835	3.305
1	9.435	5.095	3.895	3.21	3.2

Model Output

Over 20 budget years, GA identifies solutions that balance:

- maintaining some projects fully
- allowing others to mostly shoal in
- Cyclical maintenance strategies, with dredging only every few years

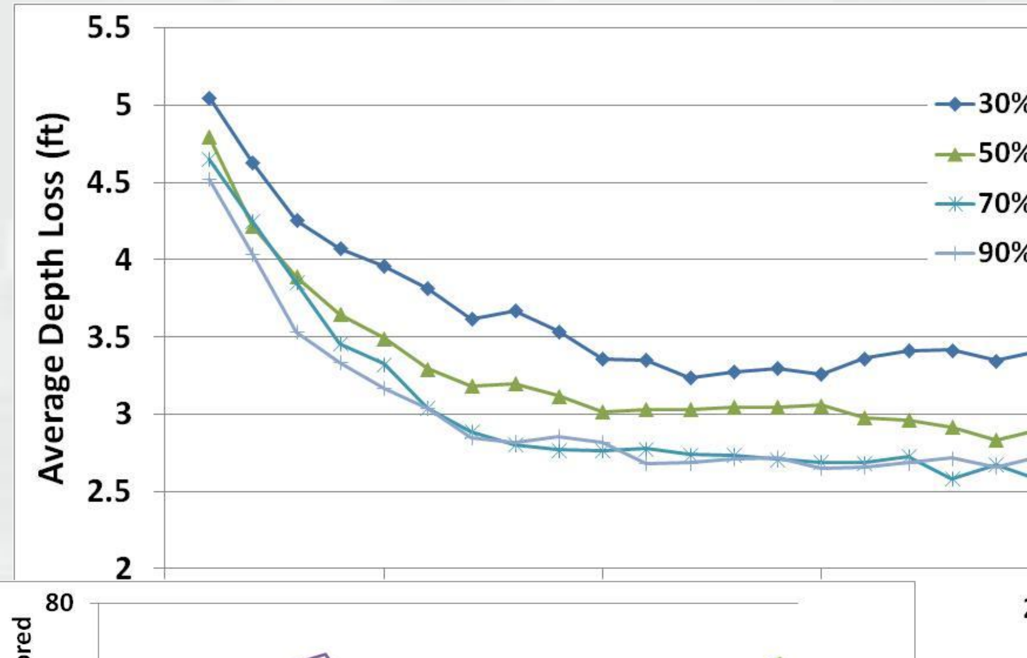
GA shows preference for projects with higher heuristic scores, e.g. dredging costs/tonnage



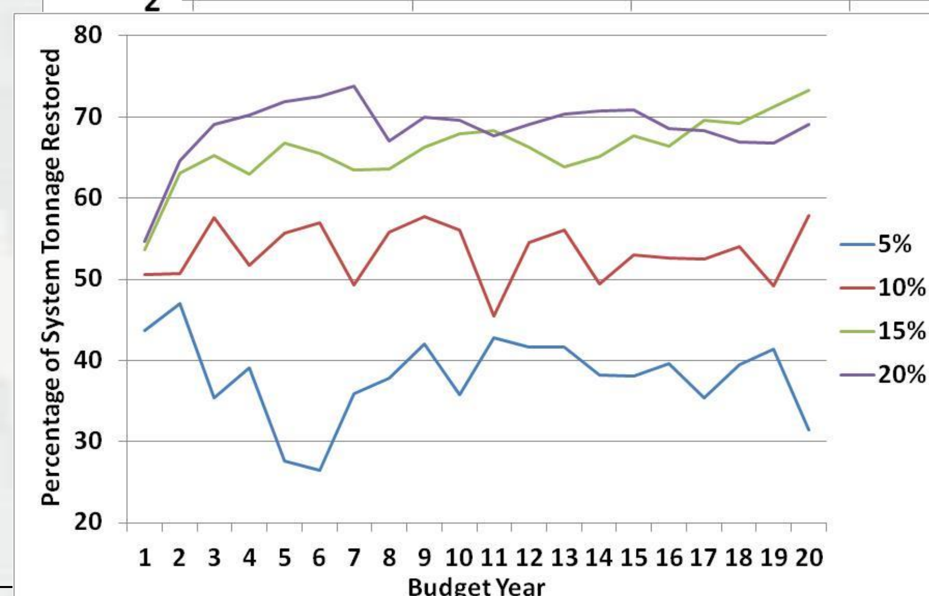
Model Output

Simulated 20 budget years:

- Various proxies for overall system performance (e.g. avg. loss of depth) show improvement through time, depending on the budget constraint.

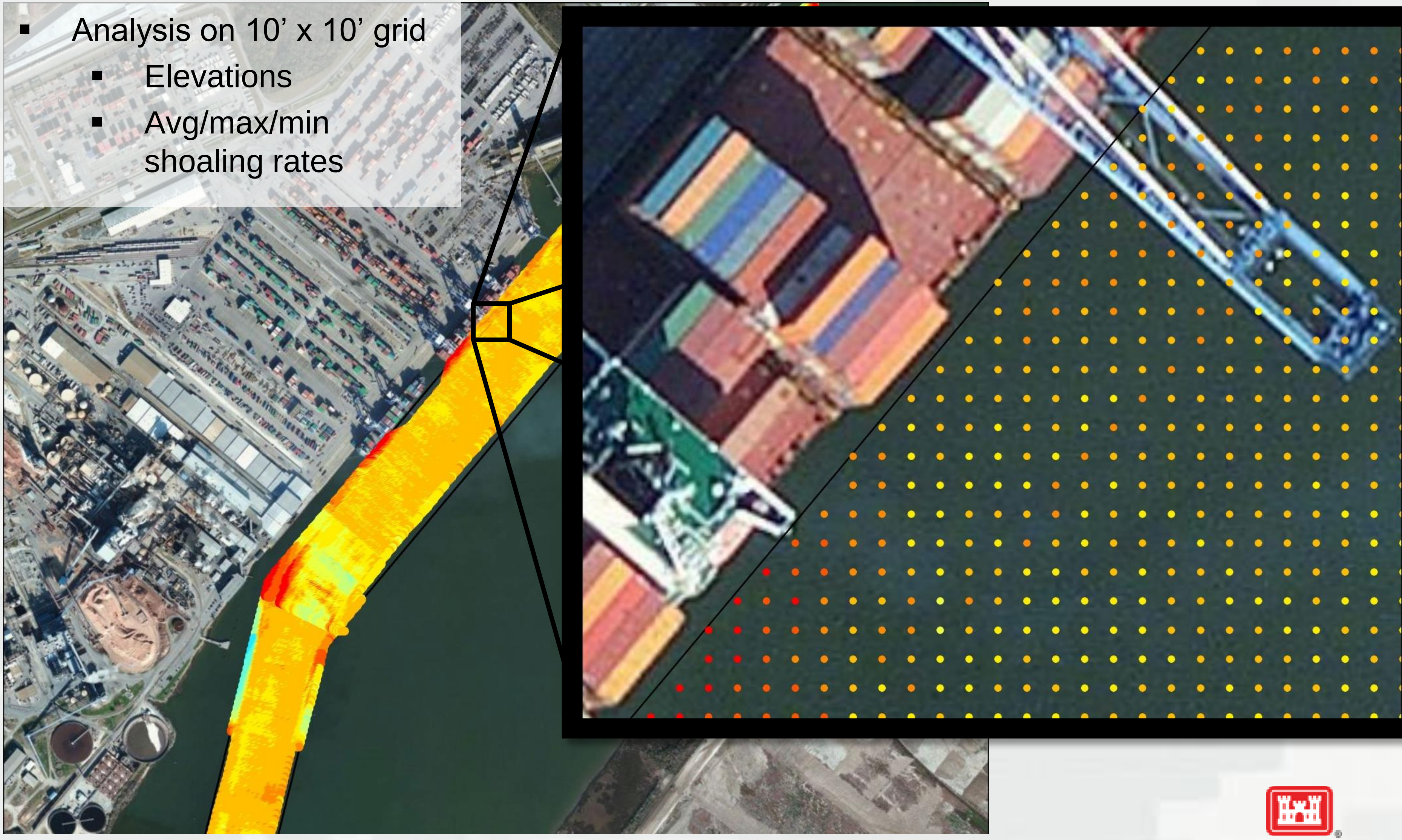


- As shoaling rules are relaxed or tightened, overall performance can change significantly…



Improved Shoal Forecasting

- Analysis on 10’ x 10’ grid
  - Elevations
  - Avg/max/min shoaling rates



Better Shoaling Data
→ Fewer Model Assumptions

		Quantity (CY) at different future times to reach specified depth						
Target Elev, ft (MLLW)	Dredge Cut, ft (MLLW)	Now	6 mos.	12 mos.	18 mos.	24 mos.	30 mos.	36 mos.
-45	-47	171,608	423,772	790,205	1,207,360	1,625,518	1,999,915	2,230,219
-43	-45	65,202	221,973	502,672	850,467	1,203,905	1,517,865	1,697,573
-41	-43	30,921	111,59[illegible]	313,894	606,834	915,851	1,195,519	1,353,134
-39	-41	14,615	52,706	184,026	421,057	691,288	939,472	1,080,938
-37	-39	5,801	26,432	102,175	275,375	509,354	730,962	858,071
-35	-37	1,107	12,820	52,997	169,619	358,176	556,497	672,752
-33	-35	0	5,187	27,232	99,895	236,771	407,405	515,969
-31	-33	0	905	13,695	54,885	146,987	282,359	381,179
-29	-31	0	13	5,812	29,086	85,495	182,608	266,129
-27	-29	0	2	1,271	15,452	45,198	107,254	172,888
-25	-27	0	0	172	7,243	21,502	56,055	99,746
-23	-25	0	0	48	2,312	9,467	24,086	46,945
-21	-23	0	0	7	528	3,256	6,834	15,480
-19	-21	0	0	0	39	317	621	1,630
-17	-19	0	0	0	0	0	0	0

Ongoing Challenges

- Investigate sensitivity to shoaling decisions
- Data integrity (specifically mob/demob costs)
- Compare solutions against heuristics