IMPROVING ECOLOGICAL MODELING PRACTICES

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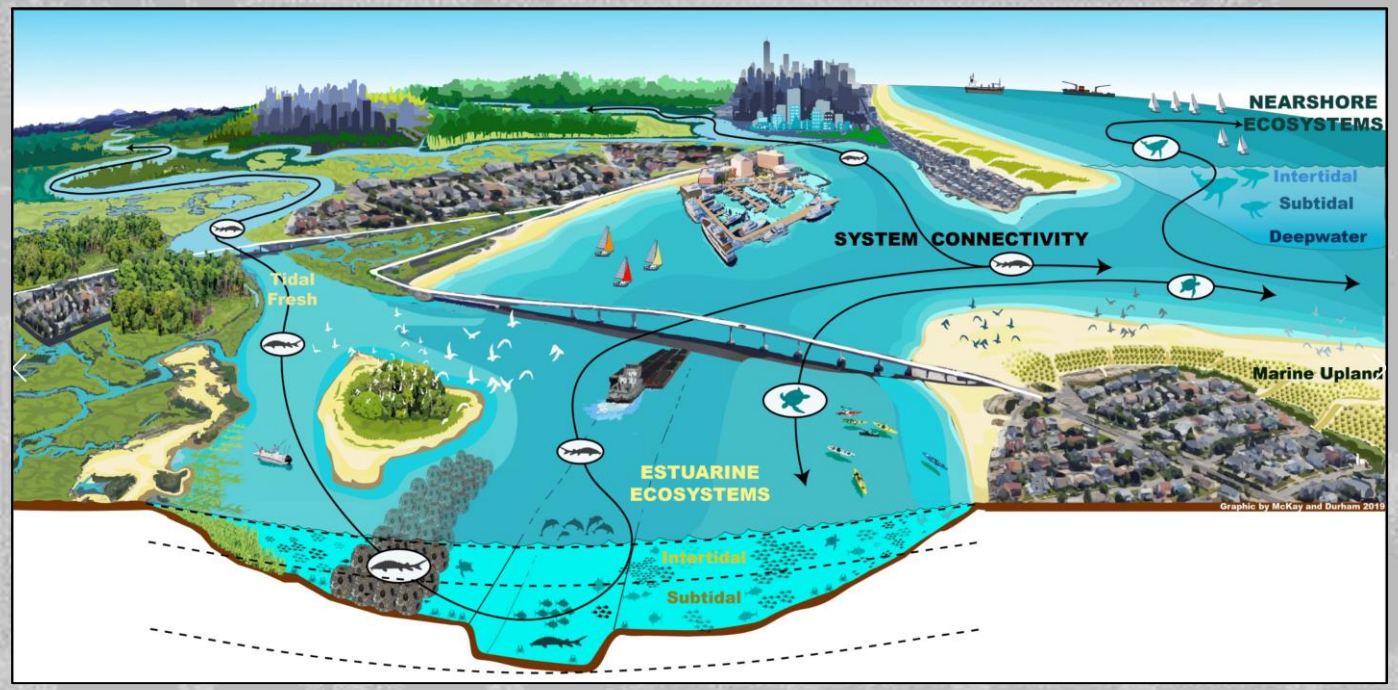
Ecosystem Restoration PCX

20 Feb 2020

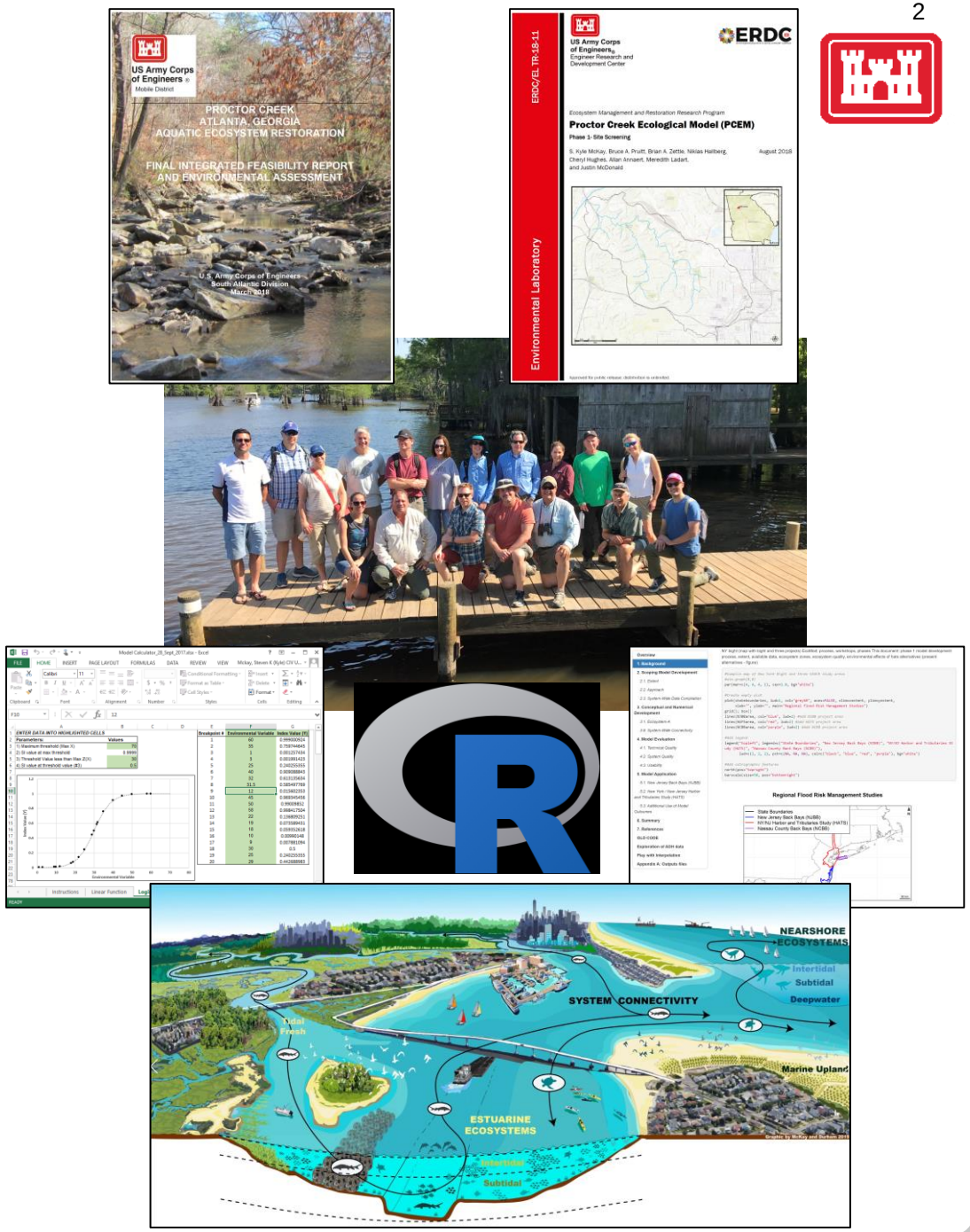


U.S.ARMY

US Army Corps of Engineers®

OVERVIEW

- Ecological models and SMART Planning
  - Model development and certification is not mutually exclusive from planning timelines!
- Mediated model development
  - Model building with friends!
- Tools for rapid model development and application
  - We've got a model for that (maybe)!
- Case study
  - Environmental effects of large-scale, coastal storm risk management studies in New York and New Jersey



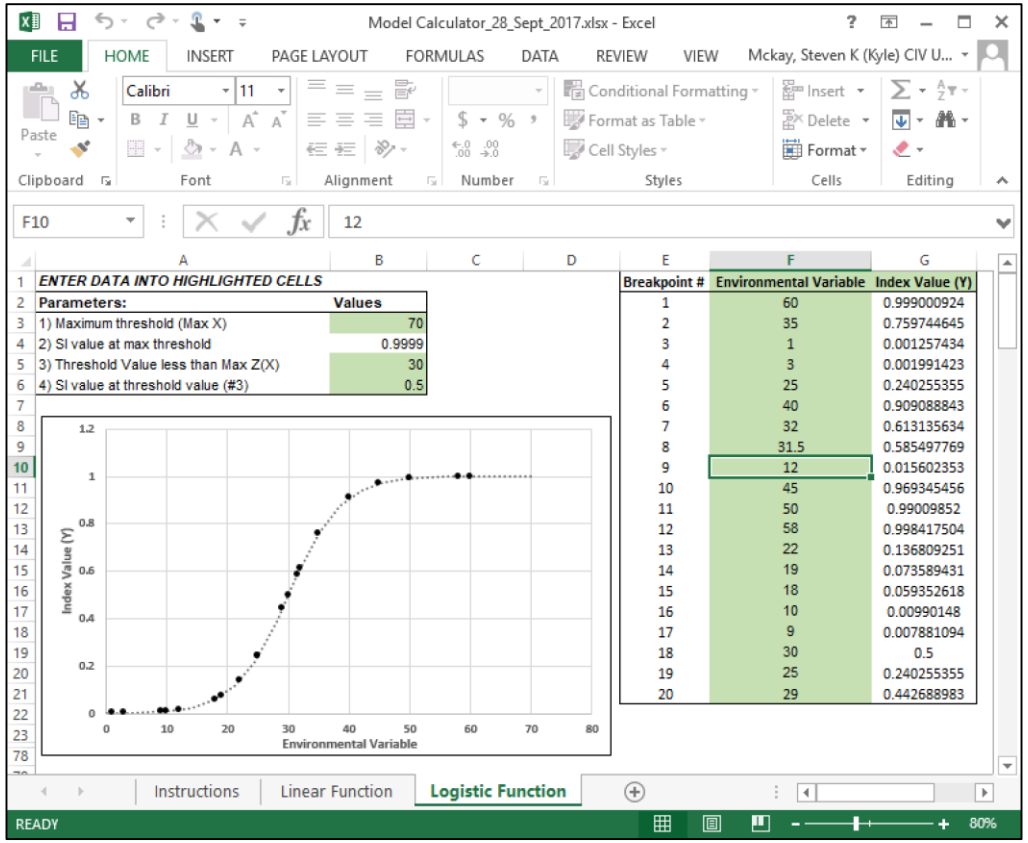
ARE YOU A “MODELER”?

- Yes, definitely!
- Maybe-ish
- No way

ECOLOGICAL MODELS AND SMART PLANNING

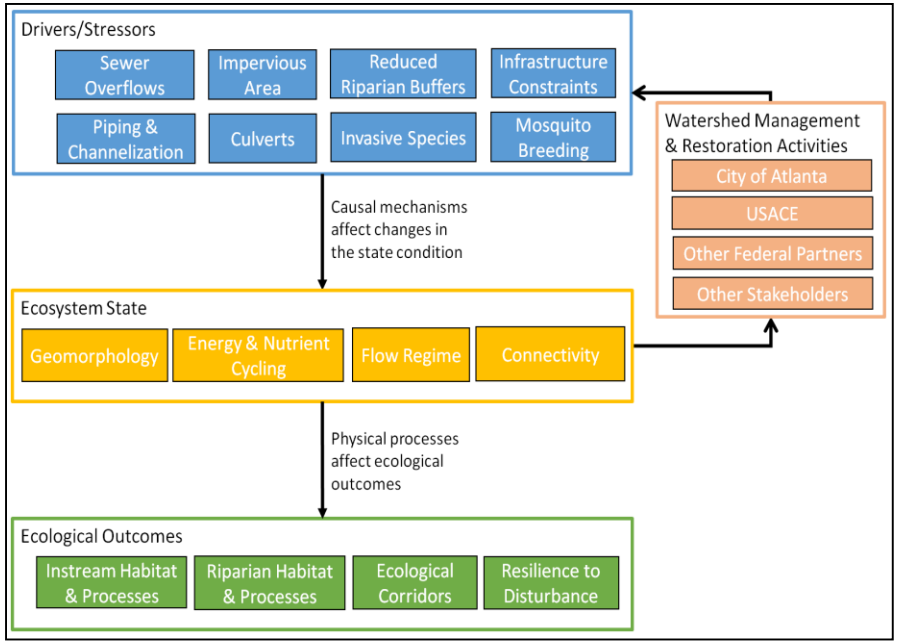
McKay S.K., Richards N., and Swannack T. 2019. Aligning ecological model development with restoration project planning. *ERDC EMRRP-SR-89*. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

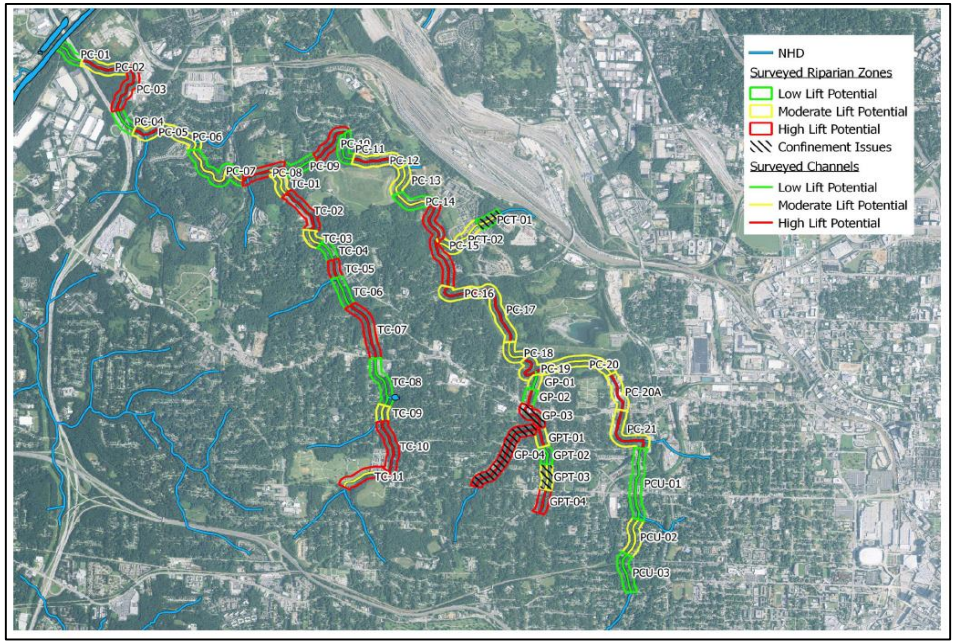
AN ECOLOGICAL MODEL IS USED TO REPRESENT A SYSTEM FOR A PURPOSE



UNDERSTANDING THE SYSTEM, INFORMING PLAN FORMULATION, AND IDENTIFICATION OF KEY UNCERTAINTIES IS CRITICAL.

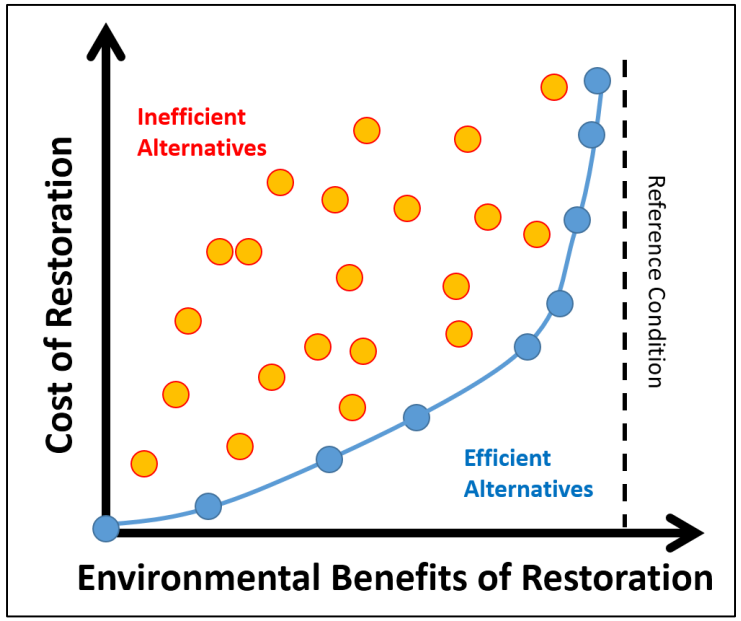
Alternatives Milestone

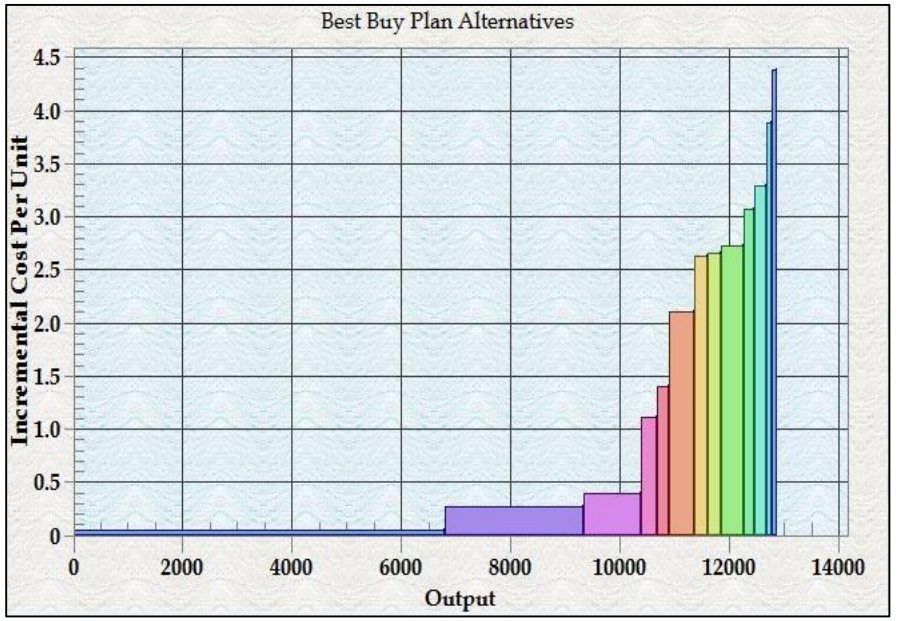




MODELS HAVE A ROLE IN FORECASTING, BENEFIT ANALYSIS, SCENARIO ANALYSIS, AND DECISION-MAKING

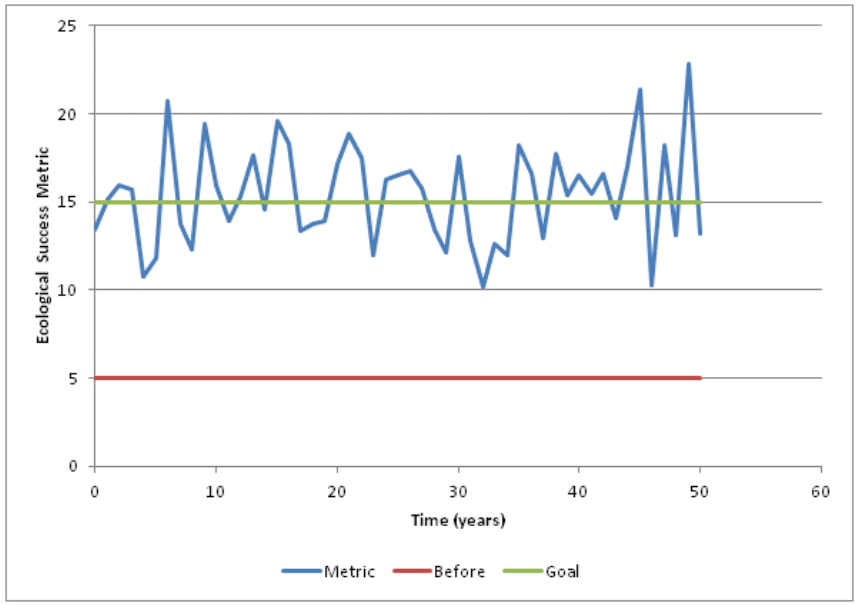
TSP Milestone

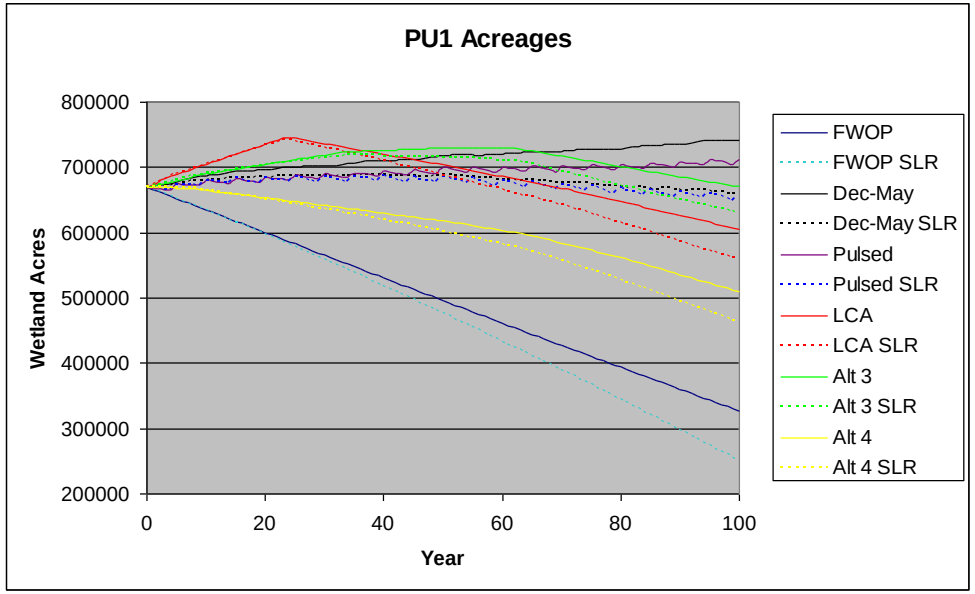




SENSITIVITY OF DECISIONS TO UNCERTAINTY, FEASIBILITY LEVEL DESIGN, AND ADAPTIVE MANAGEMENT & MONITORING BENEFIT FROM ECOLOGICAL MODELS.

Agency Decision Milestone



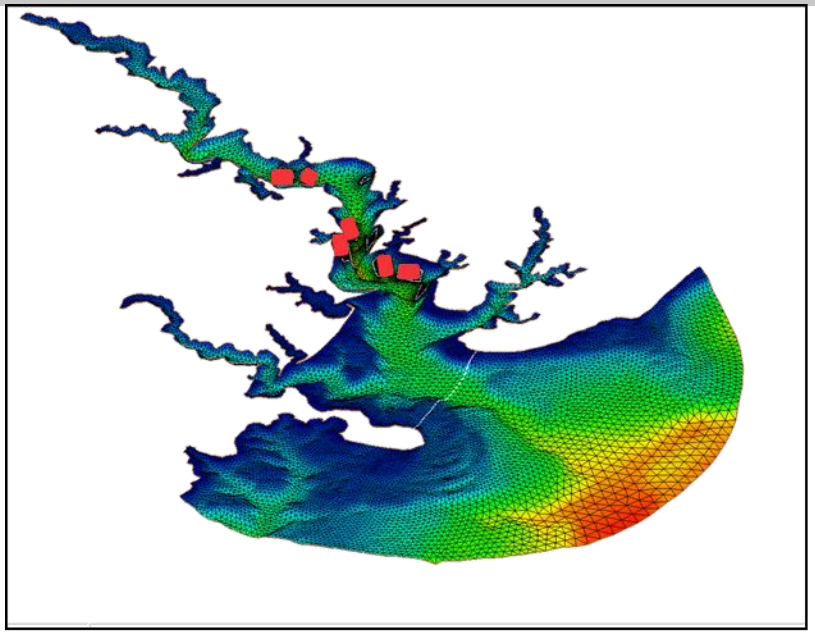


ECOLOGICAL MODEL DEVELOPMENT AND CERTIFICATION IS POSSIBLE IN DECISION-MAKING TIMEFRAMES.

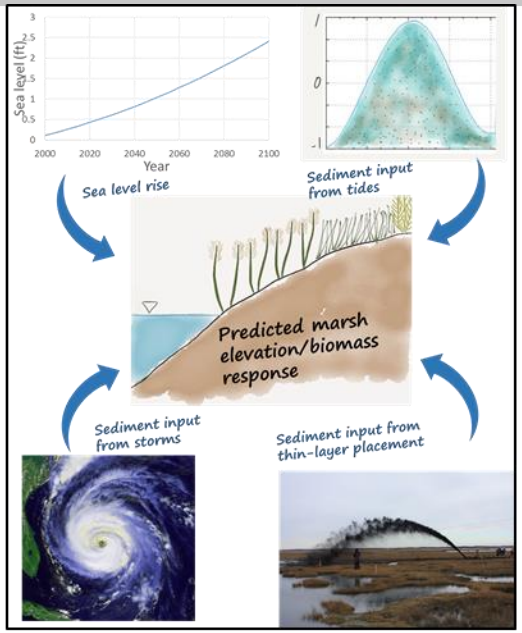
- **Advancing the state of ecological model development in the Corps.**
  - *Expertise* - Ecological model training
  - *Technology* - Statistical and programming platforms
  - *Best practices* - Guidelines for all phases of model development
- **Efficient and effective model certification**
  - Average = 3 to 6 months, $15-20k total
  - Delegated approval
  - Best Practices
  - Experience!
- **Understanding and best use of model complexity and decision-making.**

BUILDING EXPERTISE AND APPLYING BEST PRACTICES

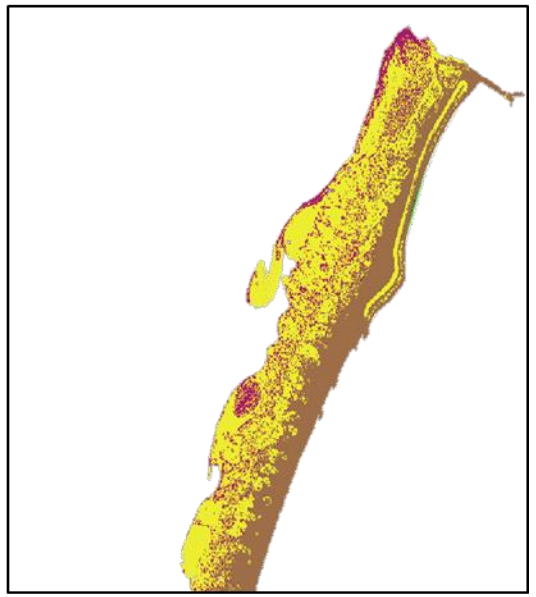
Herman B., McKay S.K., Altman S., Richards N.S., Reif M., Piercy C.D., and Swannack T.M. 2019. Unpacking the black box: Demystifying ecological models through interactive workshops and hands-on learning. *Frontiers in Environmental Science*, 7, 122. doi: 10.3389/fenvs.2019.00122.



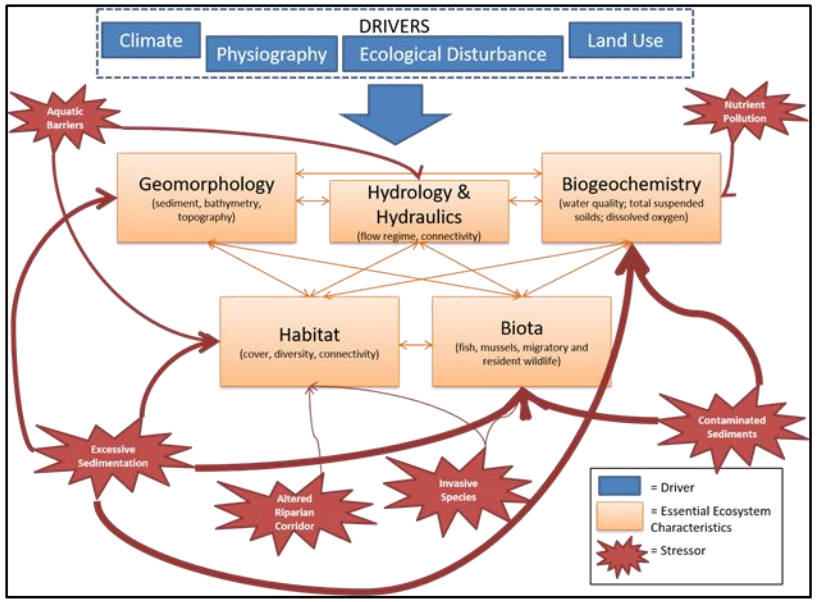
Oyster modeling: USACE-NAN & ERDC



Beneficial use:
USACE-NAP & ERDC



NNBF and EGS: ERDC



ER Project: USACE-MVS & ERDC

ER Project: USACE-SPL & ERDC

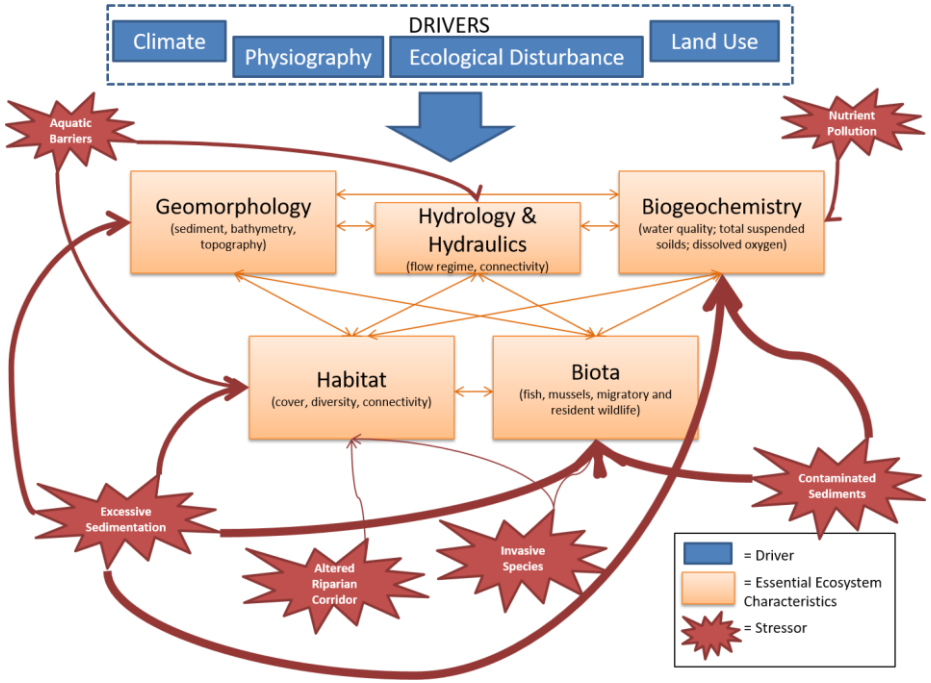
COLLABORATIVE MODEL DEVELOPMENT

- Model development, application, and certification can overwhelm project teams
- Coupling ERDC tech and District expertise reduces model development time while introducing new tech
- Developed a short course (1.5 days) to work through models
  - USACE and agency partners can attend
  - Series of lectures and labs on good modeling practice in USACE
  - Hands-on, problem-specific curriculum for a district to work through from concept to application
  - Model development is interactive and in real-time
  - *Best of both worlds*
- Our objectives are to:
  - Empower district-led modeling through ERDC tools and collaboration
  - Increase stakeholder buy-in through transparent, scientifically defensible model development.
  - Create a collaborative modeling culture.

COLLABORATIVE MODEL DEVELOPMENT

Collaborative modeling streamlines project life cycle by:

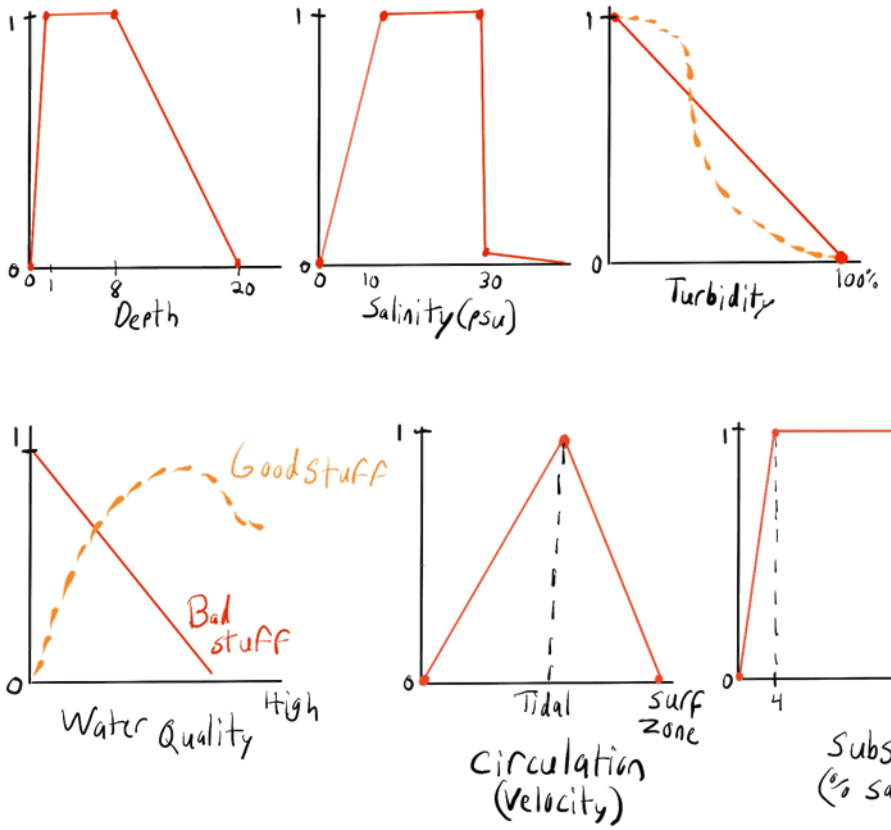
1. being a natural mechanism to facilitate interagency interactions and buy-in,
2. providing a framework for documentation and transparency,
3. reducing risk by providing more details upon which to base decisions, and
4. introducing emerging ERDC tools and models for project planning and operations while introducing ERDC to district needs and issues

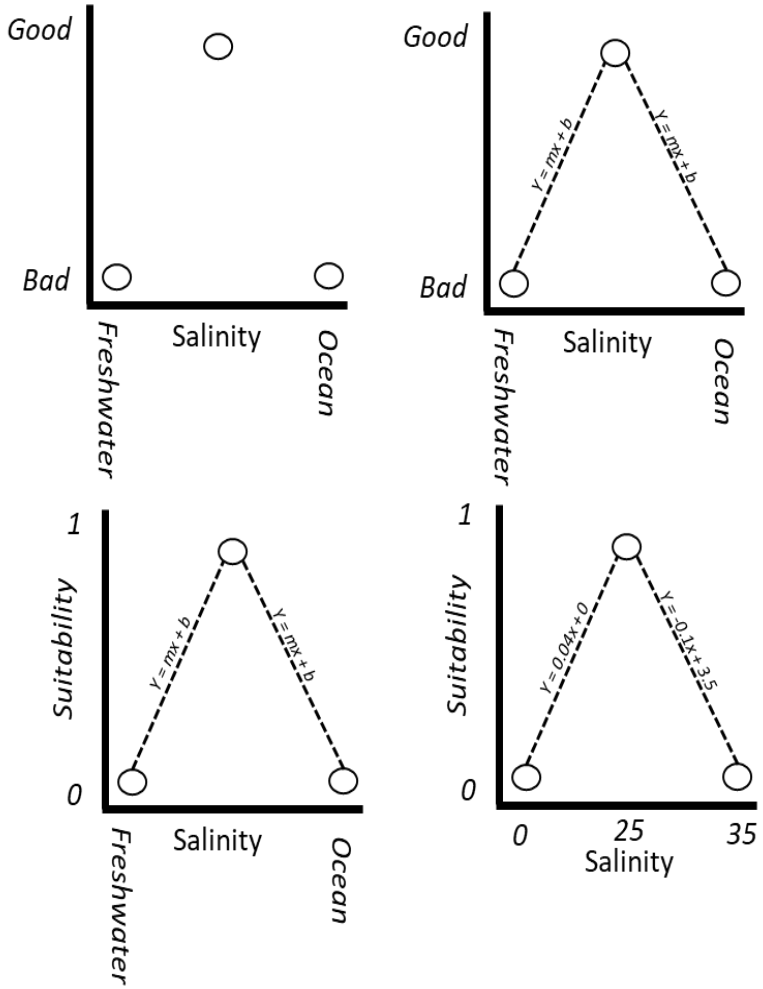


BIGGEST CHALLENGE IN MODEL DEVELOPMENT

The Math

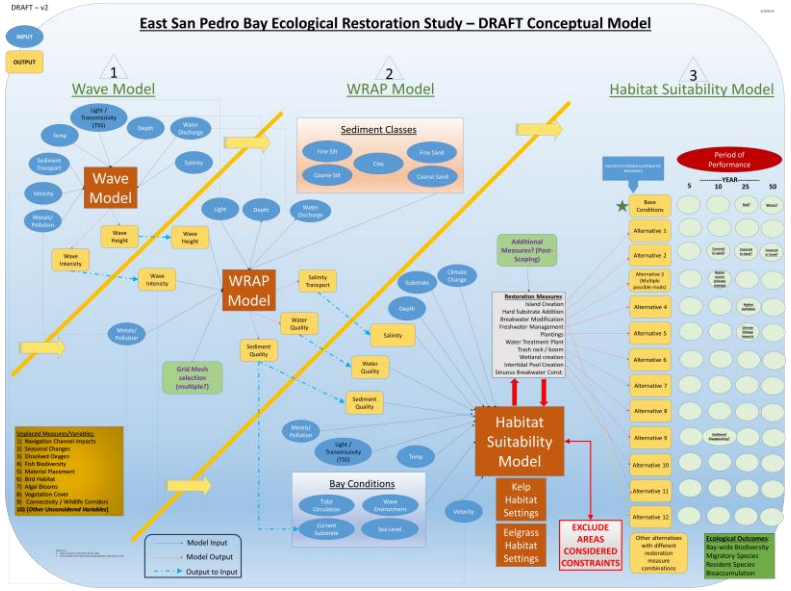
Modeling is viewed as a complex task that can only be completed by engineers & mathematicians

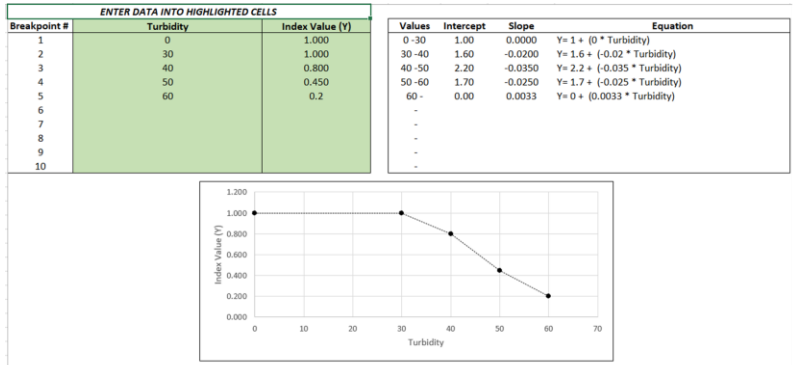




TOOLKIT FOR INTERACTIVE MODELING (TAM)

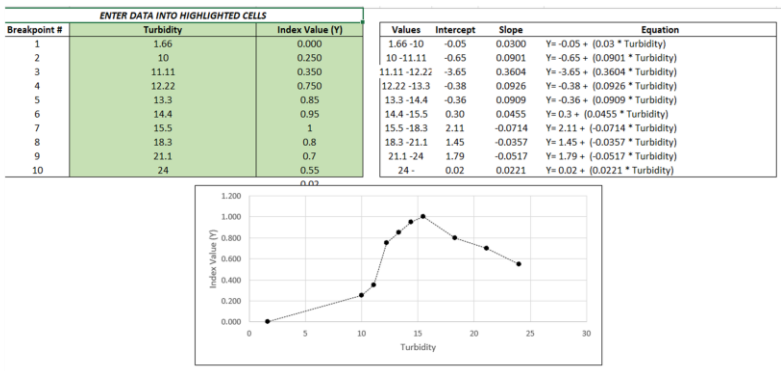
- Facilitated modeling develops model in real time (certified for national use)
- Increases transparency by demystifying modeling
- Catalyzes PDT, so they can focus on integrating relevant input data and models
- Increases critical thinking





ENTER DATA INTO HIGHLIGHTED CELLS		
Breakpoint #	Turbidity	Index Value (Y)
1	0	1.000
2	30	1.000
3	40	0.800
4	50	0.450
5	60	0.2
6		
7		
8		
9		
10		

Values	Intercept	Slope	Equation
0 -30	1.00	0.0000	Y= 1 + (0 * Turbidity)
30 -40	1.60	-0.0200	Y= 1.6 + (-0.02 * Turbidity)
40 -50	2.20	-0.0350	Y= 2.2 + (-0.035 * Turbidity)
50 -60	1.70	-0.0250	Y= 1.7 + (-0.025 * Turbidity)
60 -	0.00	0.0033	Y= 0 + (0.0033 * Turbidity)



ENTER DATA INTO HIGHLIGHTED CELLS		
Breakpoint #	Turbidity	Index Value (Y)
1	1.66	0.000
2	10	0.250
3	11.11	0.350
4	12.22	0.750
5	13.3	0.85
6	14.4	0.95
7	15.5	1
8	18.3	0.8
9	21.1	0.7
10	24	0.55

Values	Intercept	Slope	Equation
1.66 -10	-0.05	0.0300	Y= -0.05 + (0.03 * Turbidity)
10 -11.11	-0.65	0.0901	Y= -0.65 + (0.0901 * Turbidity)
11.11 -12.22	-3.65	0.3604	Y= -3.65 + (0.3604 * Turbidity)
12.22 -13.3	-0.38	0.0926	Y= -0.38 + (0.0926 * Turbidity)
13.3 -14.4	-0.36	0.0909	Y= -0.36 + (0.0909 * Turbidity)
14.4 -15.5	0.30	0.0455	Y= 0.3 + (0.0455 * Turbidity)
15.5 -18.3	2.11	-0.0714	Y= 2.11 + (-0.0714 * Turbidity)
18.3 -21.1	1.45	-0.0357	Y= 1.45 + (-0.0357 * Turbidity)
21.1 -24	1.79	-0.0517	Y= 1.79 + (-0.0517 * Turbidity)
24 -	0.02	0.0221	Y= 0.02 + (0.0221 * Turbidity)

Carrillo C.C., McKay S.K., and Swannack T. *Forthcoming*. Ecological model development: Toolkit for interActive Modeling (TAM). *ERDC TR-EMRRP*.

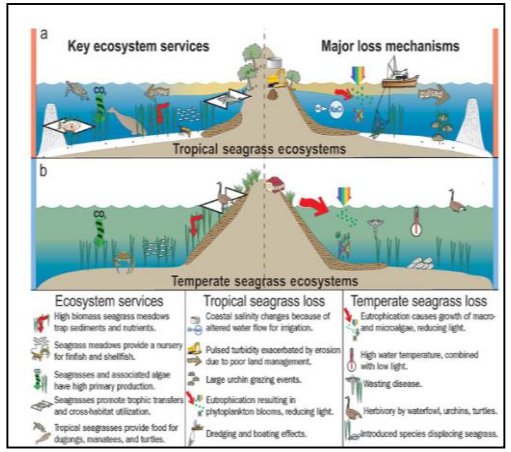
TECHNOLOGY TO FACILITATE MODEL DEVELOPMENT

DIVERSE ECOLOGICAL MODELING TOOLS

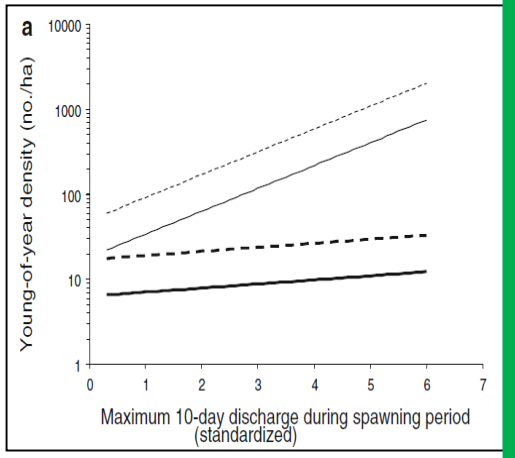
Approach

Outcome

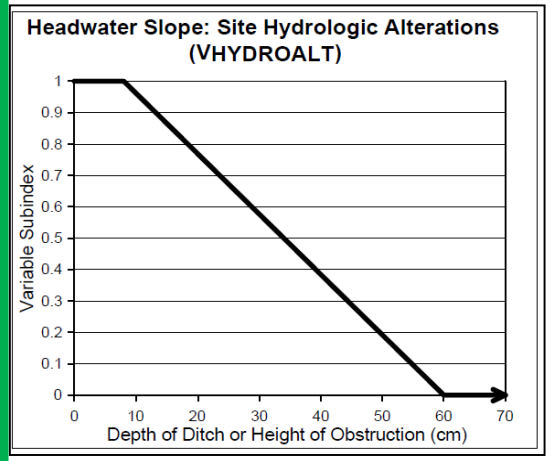
Conceptual



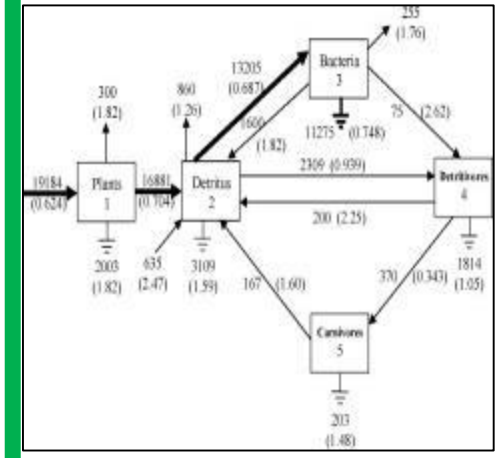
Statistical



Index-based



Mass Balance



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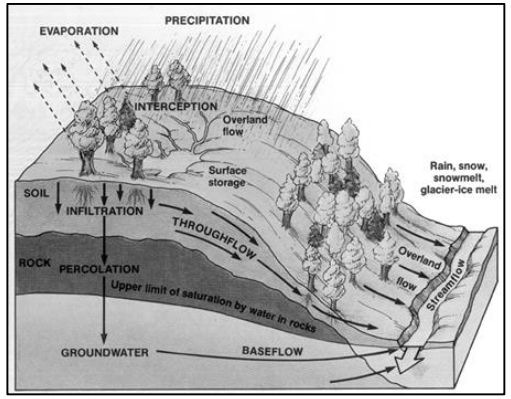
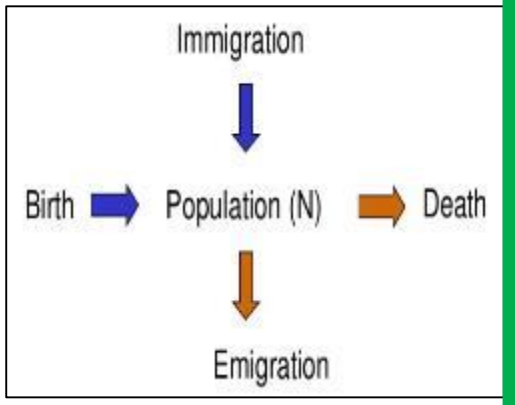
Physical

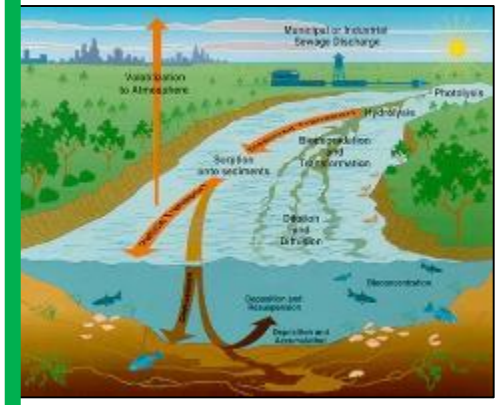


Population



Habitat

Ecosystem



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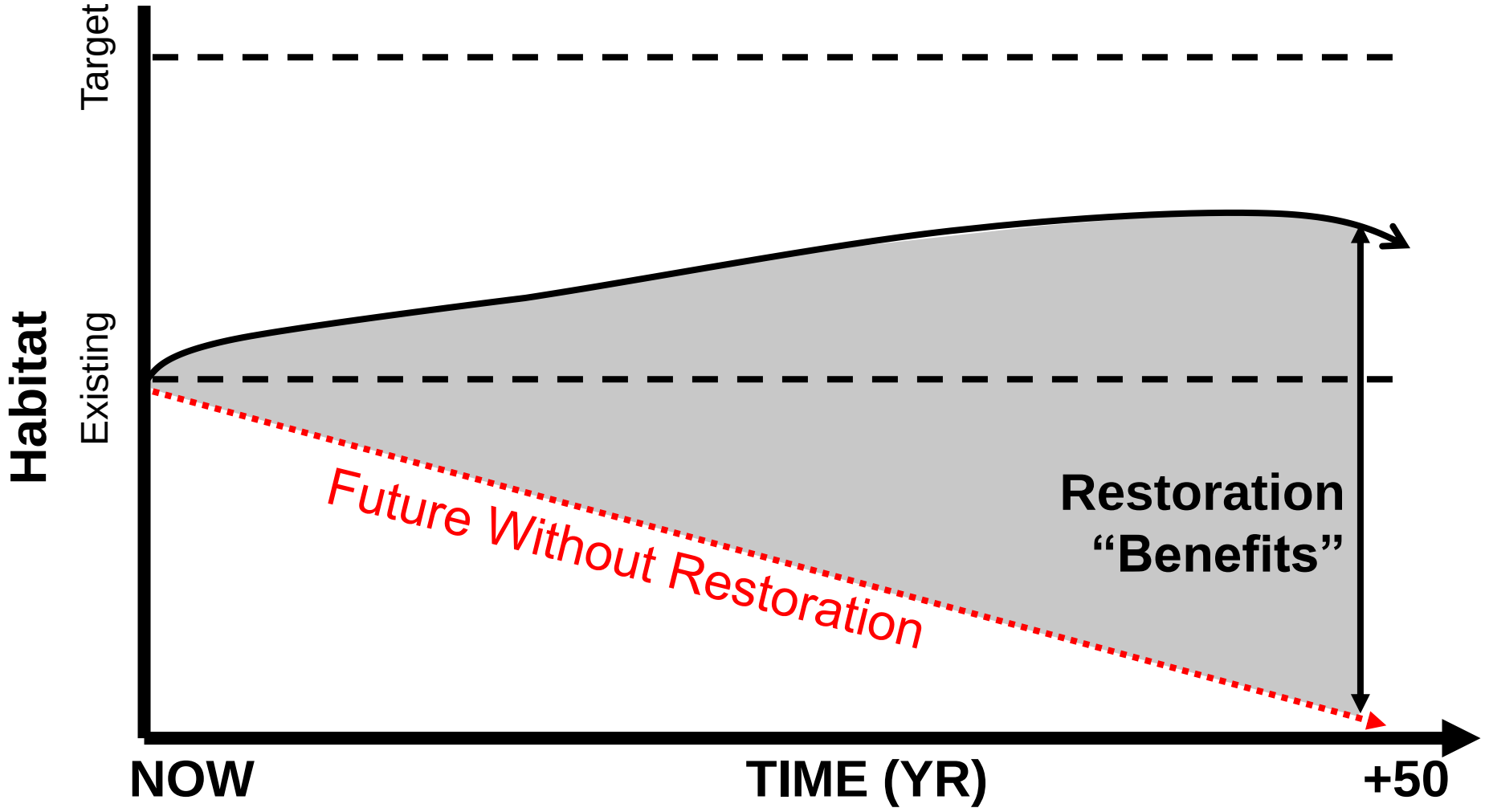
HABITAT MODELS IN THEORY



HABITAT MODELS IN PRACTICE

HSI BLUEGILL MODEL WORKSHEET INSTRUCTIONS:					
Riverine	1. Please Choose Riverine or Lacustrine from the box at left				
	2. Enter Data Values below which are highlighed green				
Enter Condition:		FWOP (216 acres)	Enter Year:	0	
Variable	Habitat	Description	DATA	HSI	Comments
V1	R	% Pool Area	53.4%	0.89	
V2	R and L	% Cover (logs & brush)	10.9%	0.64	
V3	R and L	% Cover (vegetation)	14.3%	0.95	
V4	L	% Littoral Area			
V5	L	Avg. Total Dissolved Solids (TDS) (in ppm)			
V6	R and L	Avg. Turbidity (ppm)	64	0.93	
V7	R and L	pH Range	A	1.00	
V8	R and L	Min. Dissolved Oxygen (DO) - Summer	A	1.00	
V9	R and L	Salinity (ppt)	-1	nf	
V10	R and L	Max. Midsummer Temp. (Adult) (C)	29.1	0.30	
V11	R and L	Avg. Water Temp. (Spawning) (C)	22.4	1.00	
V12	R and L	Max. Early Summer Temp. (Fry) (C)	24.2	0.94	
V13	R and L	Max. Midsummer Temp. (Juvenile) (C)	29.8	0.99	
V14	R	Avg. Current Velocity (cm/s)	5.01	1.00	
V15	R	Avg. Current Velocity (Spawning) (cm/s)	5.59	1.00	
V16	R	Avg. Current Velocity (Fry) (cm/s)	5.59	0.61	
V17	R	Avg. Current Velocity (Juvenile) (cm/s)	6.8	0.79	
V18	R	Stream Gradient (m/km)	0.1	1.00	
V19	L	Reservoir Drawdown during spawning (m)			
V20	R and L	Substrate Composition	B	0.70	
		Food (Cf)		0.81	
		Cover (Cc)		0.79	
		Water Quality (Cwq)		0.87	
		Reproduction (Cr)		0.89	
		Other (Cot)		0.90	
		Summer HSI		0.86	
WITH WINTER HSI MODIFICATIONS					
Variable		Description			
Va	R and L	% of Backwater > 4 Feet in Depth	0.9%	0.21	
Vb	R and L	Min. Dissolved Oxygen (DO) - Winter	B	0.70	
Vc	R and L	Water Temperature (C)	1.4	0.57	
Vd	R and L	Current Velocity (cm/s)	1.4	0.24	
		Winter Cover (Cw-c)		0.21	
		Winter Water Quality (Cw-wq)		0.66	
		Winter Other (Cw-ot)		0.24	
		Winter HSI		0.39	
		Overall HSI with Winter Modifications		0.39	

Ad hoc spreadsheet models for:

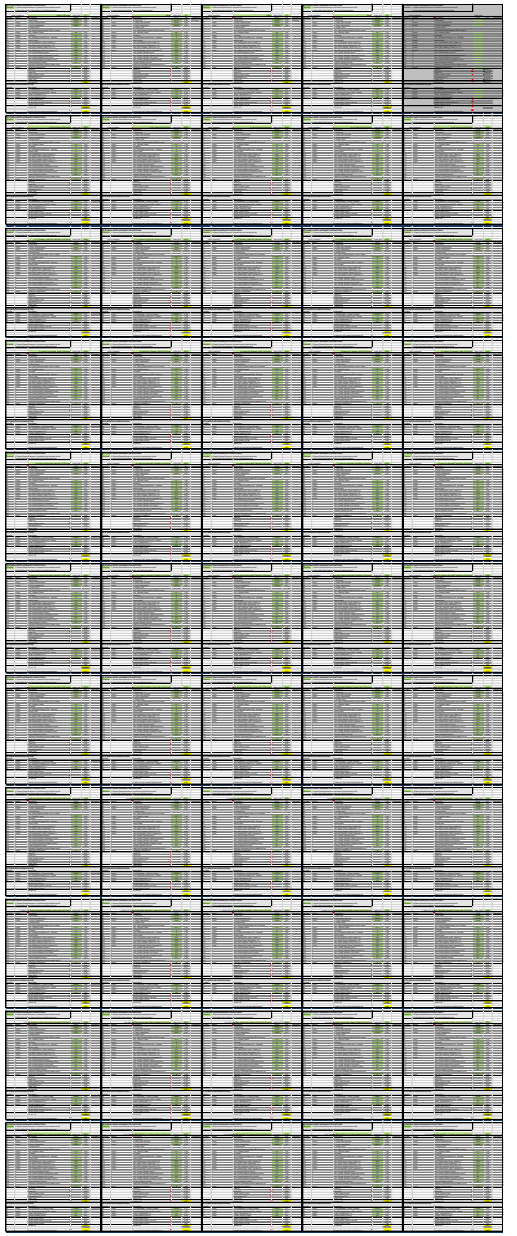
- a single taxa
- one location
- one restoration alternative
- one point in time

NO PROBLEM!

Ad hoc spreadsheet models for:

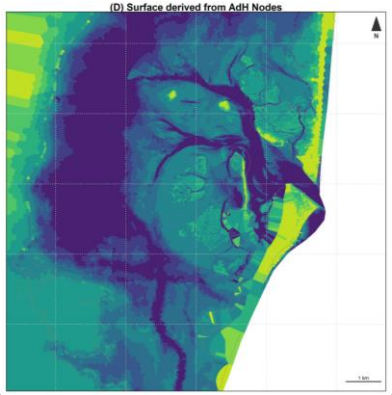
- a single taxa
- one location
- multiple restoration alternatives
- multiple points in time

WELL…



WHY BUILD AN R PACKAGE?

Problem for Restoration Practitioners	Why an R package would help
Lots of habitat models with complex structure	Compile existing USFWS habitat models in one place
Ad hoc spreadsheet models commonly contain errors	Error-checking and code review are part of package approval (and certification)
Spreadsheet models are not widely available	R packages are publicly available (and free)
Habitat is spatially distributed	R has loads of geospatial functions
Spreadsheets many have limited visualization capability	Functions can be developed for high-end, rapid data viz
Habitat analysis are often separate from decision tools and require sequential analyses in multiple platforms	One-stop-shopping for integrated habitat and decision modeling
Some practitioners may not be comfortable with code-based modeling	R packages can be accessed through user-friendly web applications
Model documentation can be laborious	Connectivity to real-time model documentation through Rmarkdown



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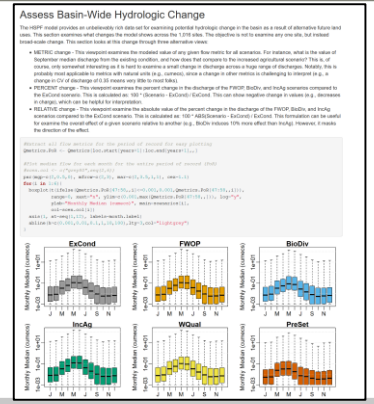


ECOREST R PACKAGE: HABITAT DATA

- Compiled 100+ habitat suitability models from USFWS (with 500+ sub-models)
- All models and metadata loaded into the package
- Generic data structure for user-defined models

pl.area.avg.summer.flow.pct	pl.area.avg.summer.flow.SIV	cov.pls.litt.area.summer.pct	cov.pls.litt.area.summer.SIV	cov.aq.veg.pct	cov.aq.veg.SIV
0	0	0	0.2	0	0
60	1	20	1.0	15	1
100	1	60	1.0	30	1
NA	NA	100	0.2	100	0
NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA

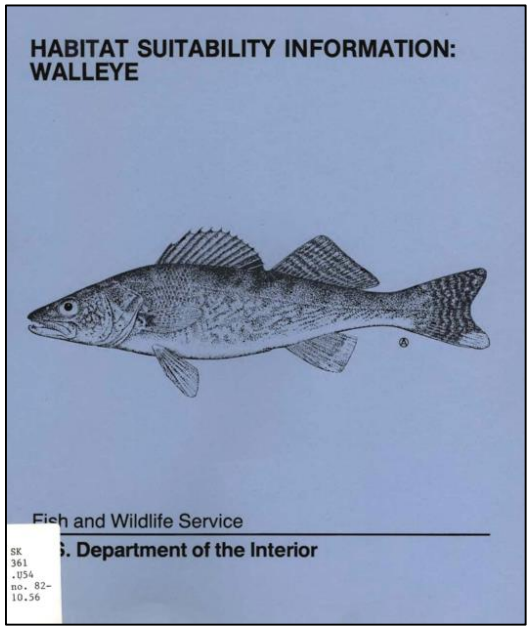
model	submodel	species	geography	ecosystem	documentation	note	HSI.equation
bluegillRiv	RIVERINE Food Component	Lepomis machrochirus	Wherever bluegills occur in North America	Fish Passage, Fresh Wetland, Lake, Large River, Stream	Stuber, RJ, G Gebhart and OE Maughan. 1982. Habitat Suitability Index Models: Bluegill. USFWS Report FWS/OBS-82/10.8. 26pp.		ifelse (CWQ | CR <=0.4, min(CF, CC, CWQ, CR), (CF*CC*(CWQ^2)*CR)^(1/5))
bluegillLac	LACUSTRINE Food Component	Lepomis machrochirus	Wherever bluegills occur in North America	Fish Passage, Fresh Wetland, Lake, Large River, Stream	Stuber, RJ, G Gebhart and OE Maughan. 1982. Habitat Suitability Index Models: Bluegill. USFWS Report FWS/OBS-82/10.8. 26pp.	drop SVI19 in natural lake	ifelse (CWQ | CR <=0.4, min(CF, CC, CWQ, CR), (CF*CC*(CWQ^2)*CR)^(1/5))

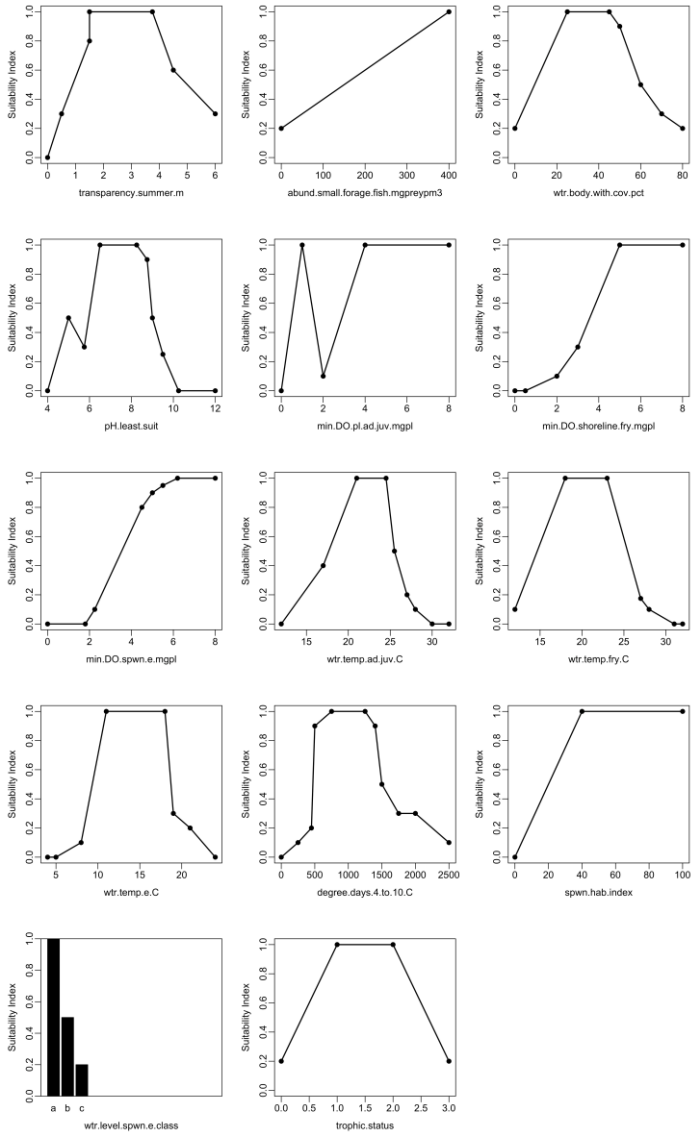
McKay S.K. and Hernández-Abrams D.D. *Forthcoming*. ecorest: An R Package for conducting analyses to inform restoration decision making. *R Vignette*.

ECOREST R PACKAGE: HABITAT MODELING

Key Functions:

- View habitat suitability index curves
- Compute suitability relative to multiple variables
- Compute overall patch quality by combining variables via:
  - USFWS equations
  - Arithmetic mean
  - Weighted arithmetic mean
  - Geometric mean
  - Minimum
- Compute habitat units





EcoRest HSI

Select model

Walleye Riv

Waleye Lac

Calculate SI

Calculate SI

Calculate HSI

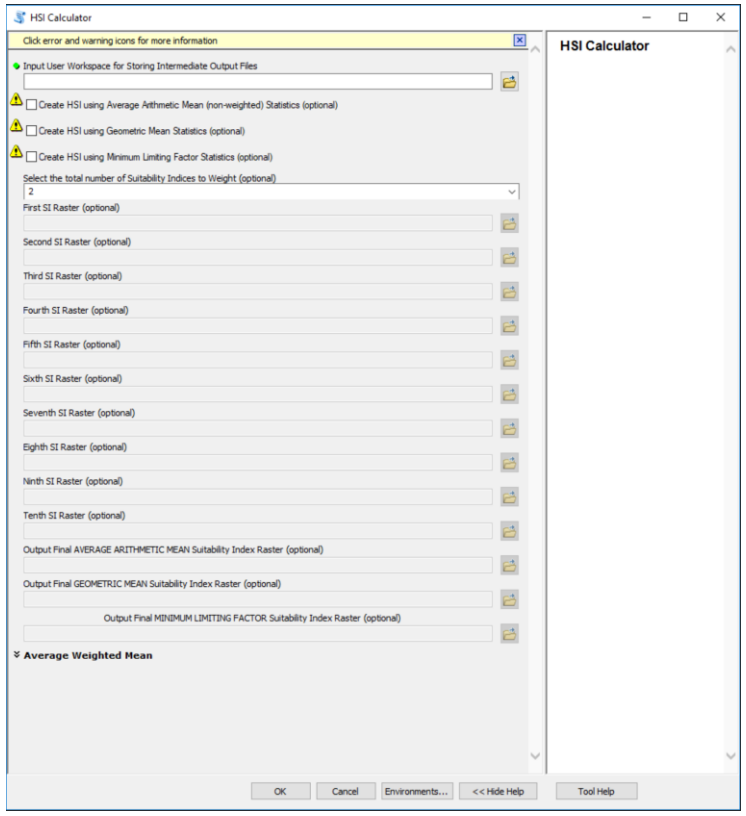
Calculate HU

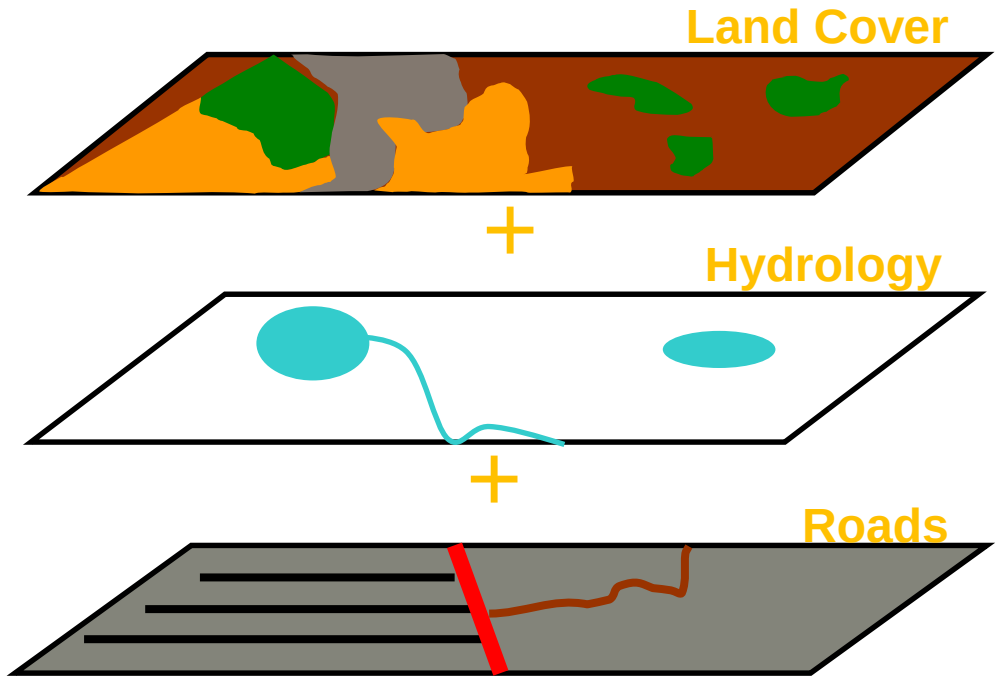
Alternative	Time	SIV1	SIV2	SIV3	SIV4	SIV5	SIV6	SIV7	SIV8	SIV9	SIV10	SIV11	SIV12	SIV13	SIV14	Quality	Quantity	Habitat Units
FWOP	0	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
FWOP	1	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
FWOP	10	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
FWOP	20	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
FWOP	30	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
FWOP	40	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
FWOP	50	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
BankProtection	0	0.24	0.30	0.232	1	1	1	1	0.5	1	0.3	0.908	0.250	1	1	0.238	1.5	0.357
BankProtection	1	0.24	0.38	0.680	1	1	1	1	0.5	1	0.3	0.908	0.775	1	1	0.300	1.5	0.450
BankProtection	10	0.24	0.42	0.680	1	1	1	1	0.5	1	0.3	0.908	0.775	1	1	0.300	1.5	0.450
BankProtection	20	0.24	0.42	0.680	1	1	1	1	0.5	1	0.3	0.908	0.775	1	1	0.300	1.5	0.450
BankProtection	30	0.24	0.42	0.680	1	1	1	1	0.5	1	0.3	0.908	0.775	1	1	0.300	1.5	0.450
BankProtection	40	0.24	0.42	0.680	1	1	1	1	0.5	1	0.3	0.908	0.775	1	1	0.300	1.5	0.450
BankProtection	50	0.24	0.42	0.680	1	1	1	1	0.5	1	0.3	0.908	0.775	1	1	0.300	1.5	0.450

SO YOU DON'T WANT TO USE R? NO PROBLEM!

- Different tools for different user communities!
- All tools build from the USFWS habitat data set

- ArcGIS Toolbox
- Raster data focused
- POC: Christina Saltus

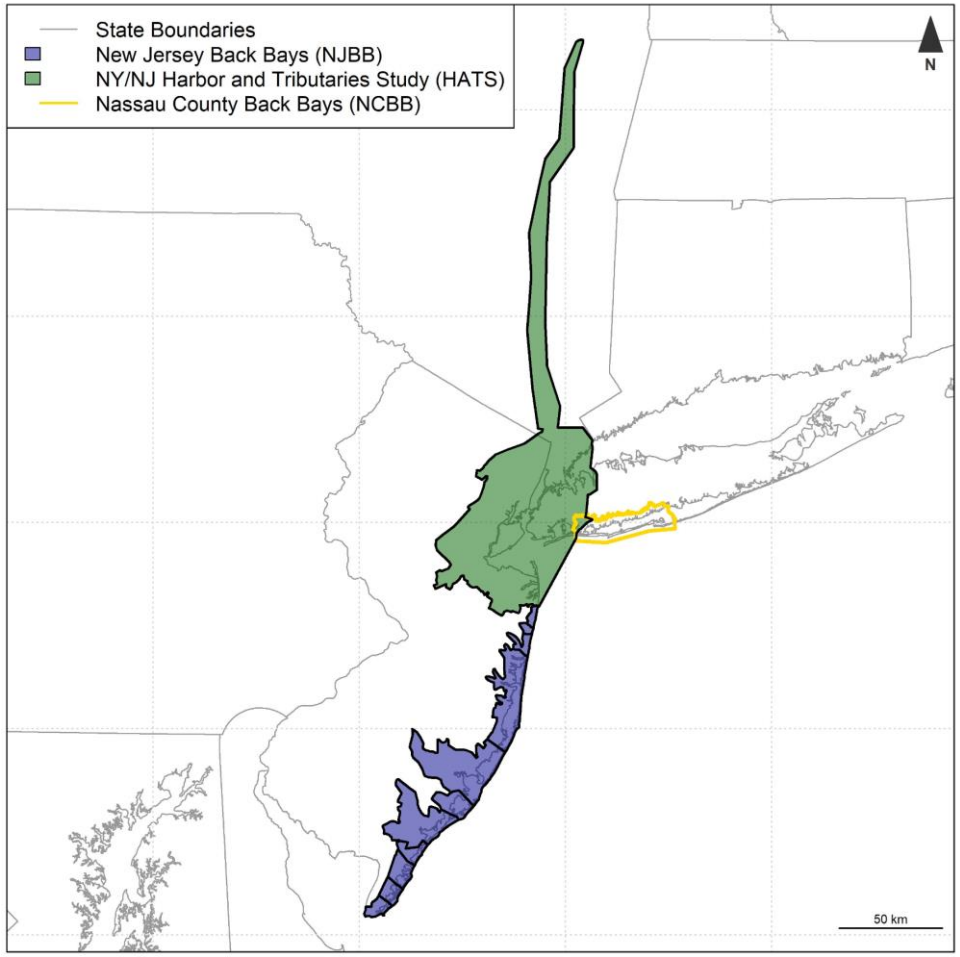




CASE STUDY:
NEW YORK BIGHT ECOLOGICAL MODEL

WHY BUILD A MODEL?

Regional Coastal Storm Risk Management (CSRM) Studies

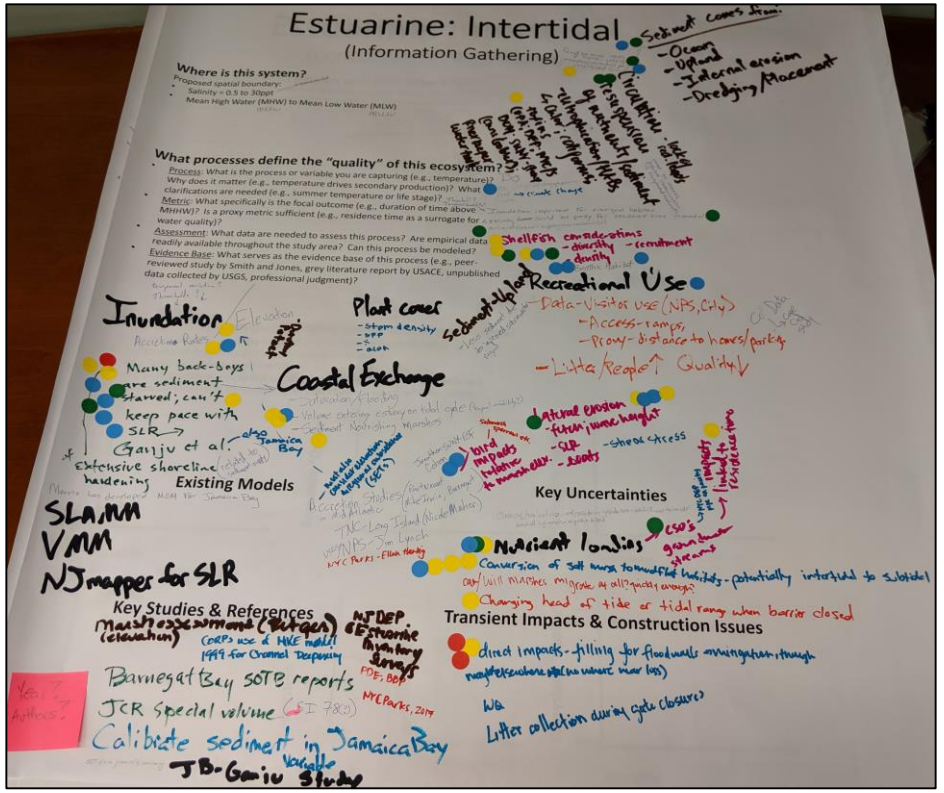


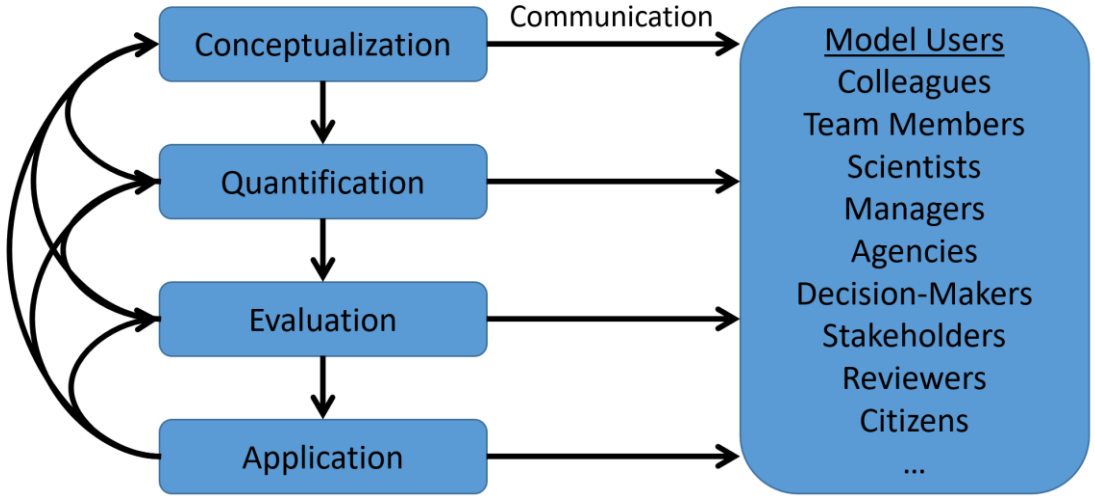
Compliance with the National Environmental Policy Act (NEPA)

MODEL DEVELOPMENT PROCESS

A series of workshops to iteratively develop models with research and synthesis between meetings.

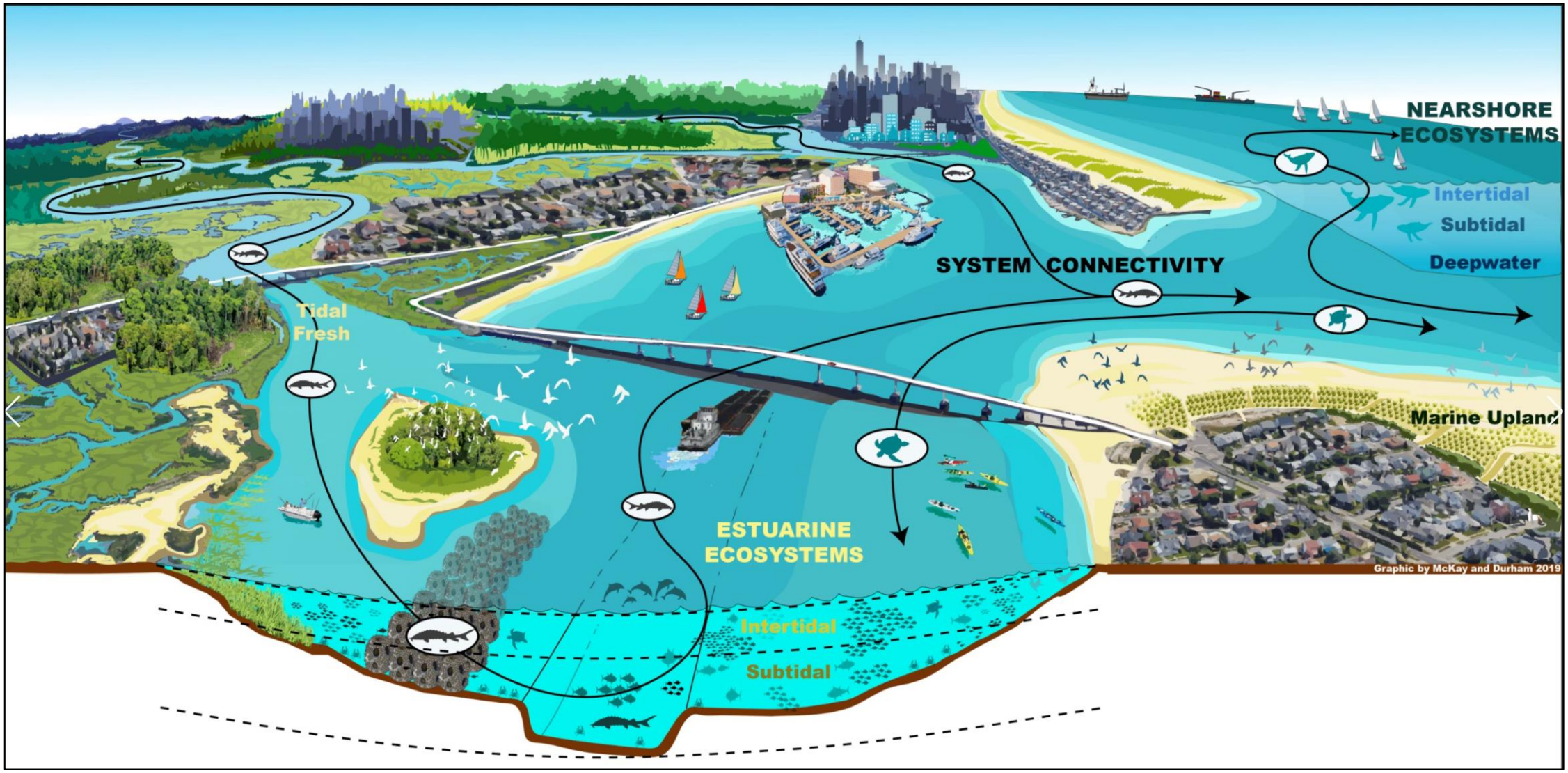
- Preliminary workshop with Philadelphia District (Jan 2019)
- USACE workshop with two Districts (Mar 2019)
- Interagency conceptual modeling workshop (Jun 2019)
- Interagency numerical modeling update (Nov 2019)
- Phase-1 Model application to NJBB (Feb 2019)
- …





Ecological Model Development Process
(Herman et al. 2019)

MODEL CONCEPTUALIZATION

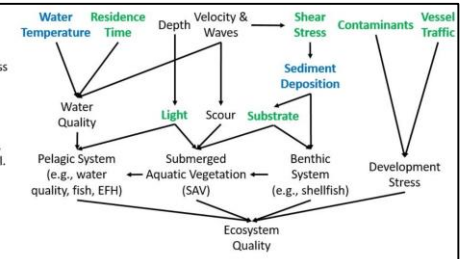


MODEL QUANTIFICATION

Conceptual Models
("How the system works")

Key data, models, studies, and resources

- USFWS HEP models: red drum (Buckley 1984), great blue heron (Short and Cooper 1985), black duck (PAM-HEP), silverside (PAM-HEP 1985)
- Other habitat suitability models: oyster (Swannack et al. 2014), seagrass (Koch 2001, Short et al. 2002, Kemp et al. 2004, Shafer et al. 2016)
- Harbor mitigation functional assessment littoral model (USACE 2000)
- Residence time, flushing, and water quality studies (Defne and Ganju 2015, Rynne et al. 2016, Defne et al. 2017, NYC DEP 2018)
- Regional studies of Barnegat Bay (JCR 2017), water quality (HDR 2018), Jamaica Bay (Fischbach et al. 2018), indices of biotic integrity (Ren et al. 2017, Llanso 2002), etc.



Transient impacts and construction issues

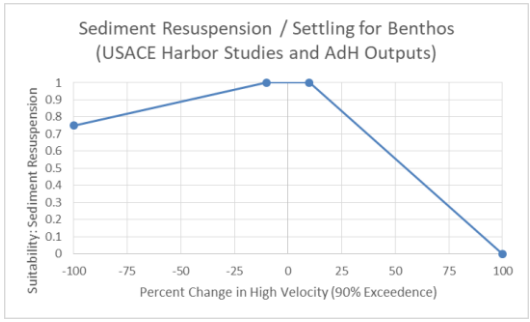
- Environmental windows for winter flounder
- Construction noise and vibration
- Construction disturbance and sediment release

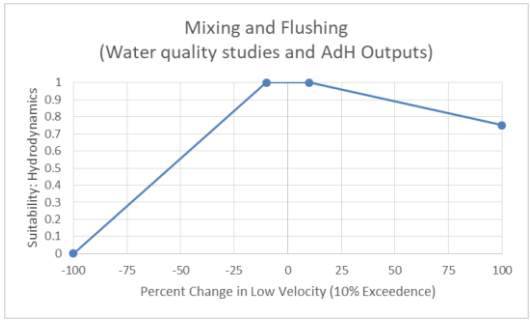
Critical uncertainties and data gaps

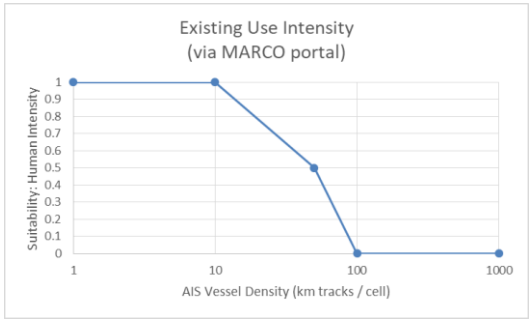
- Water quality processes
- Relative composition of habitat types (e.g., SAV, oyster, open water)

Process	Metric	Assessment	Evidence Base	In NYBEM?
What is the process or variable being captured? Why does it matter?	*What metrics, measurable outcomes, or proxies exist for this process?*	*What data are needed to assess this process (e.g., empirical observation, remote sensing, model outputs)?*	*What evidence supports this process (e.g., studies, data, judgment)?*	*Will the variable(s) be included in NYBEM?*
Substrate suitability for SAV	Substrate grain sizes	AdH initial sediment input (currently static, but future application could be dynamic with time)	Short et al. (2002) compile general seagrass substrate suitability criteria, which we assume to be generally "good" for estuarine subtidal systems.	Phase 1 (static input) Phase 2 (dynamic)
Growth of submerged aquatic vegetation and associated ecological benefits	Percent of light transmitted through water (PLW)	Estimate of light penetration at median depth based on Kemp et al. (2004)	Light is well-acknowledged as a crucial limiting factor for SAV (Short et al. 2002, Kemp et al. 2004), albeit alongside many other variables (Koch 2001)	Phase 1 (depth only) Phase 2 (light model may include other variables)
Change in hydrodynamics altering sedimentation processes	Percent change in median shear stress from FWOP	AdH Output	Deposition and burial are important processes for benthic and SAV communities. However, scour is equally important. As such, percent deviation from the FWOP is used as a proxy for both directions of change.	Phase 1
General assessment of "stressors" from development of the coastal zone	Presence of known contaminants within 100m Vessel traffic	Data being compiled by USACE consultants via EPA National Priorities List sites Automatic Identification System (AIS) vessel density data from MARCOS portal	Contaminants are well-acknowledged as a key driver of ecological health regionally Proxy for general use of waterways (Lathrop et al. 2017)	Phase 1 Phase 1
Water quality processes and effects on pelagic community	Resident time (proxy) Temperature Other WQ constituents	AdH outputs and/or Particle Tracking Model AdH (future simulations) Potential assessment via data /models for water quality, plankton dynamics, fisheries, etc.	Well-known water quality proxy with defined methods (e.g., Defne and Ganju 2015, Rynne et al. 2016) Key driver of water quality and nutrient processes, particularly as they relate to CSOs, algal blooms, and hypoxia Direct simulation of focal outcomes (e.g., Defne et al. 2017, HDR 2018)	Phase 1 Phase 2 No

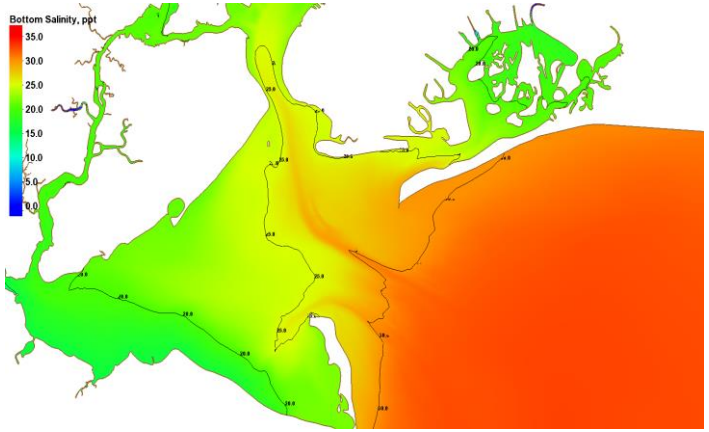
Quantitative Model
("Suitability Index")







Model Application
(parameterized with hydro models and available data)

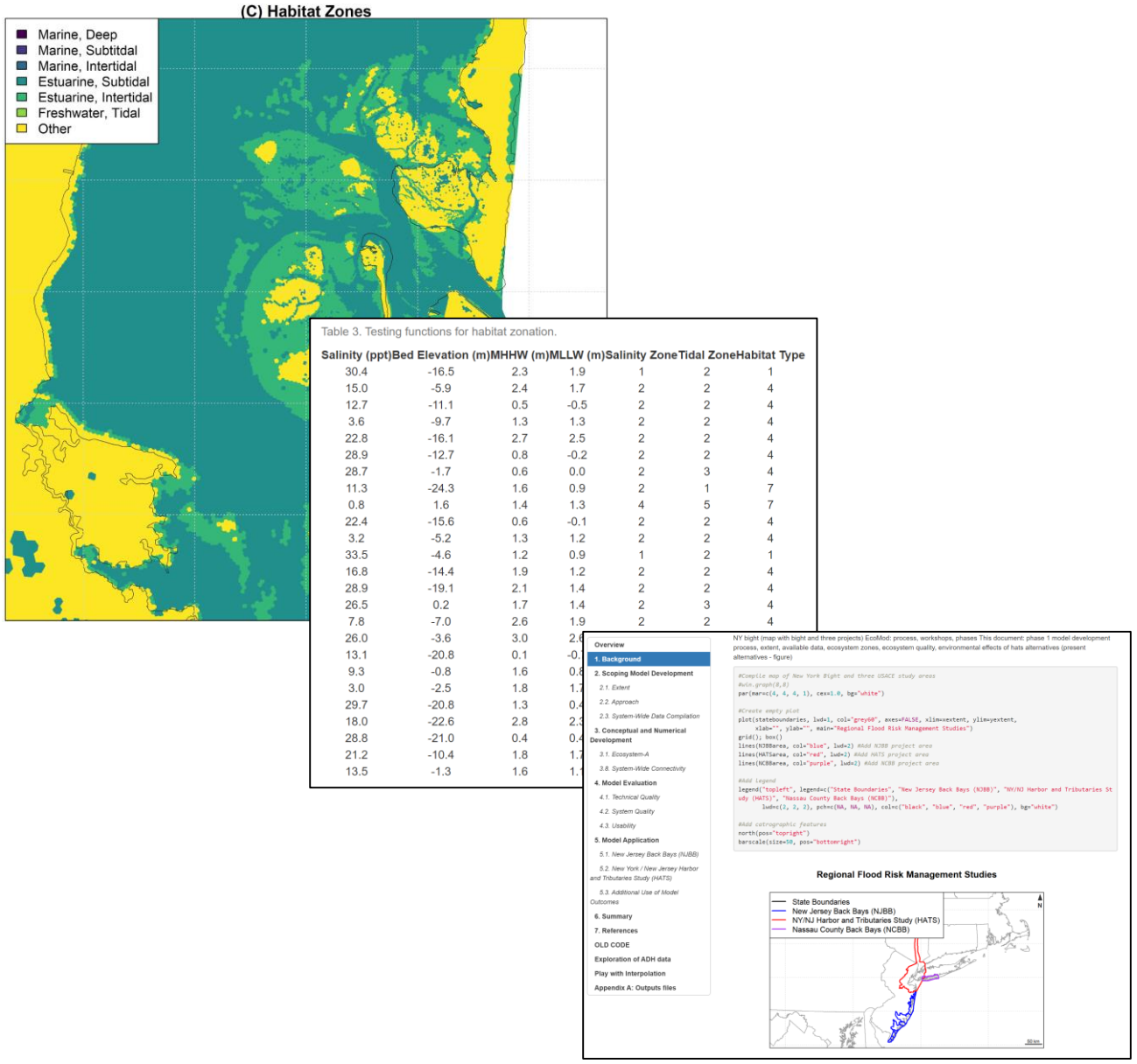


MODEL EVALUATION (UNDERWAY)

- Technical Quality
  - Drawing from existing models and regional literature
  - Agency feedback ***during*** development
  - Comparison with known habitats (e.g., oyster, SAV, National Wetlands Inventory)
  - USACE certification

- System Quality
  - Code-sharing and inspection
  - Testing plan

- Usability
  - Transparent documentation
  - Data and code sharing
  - No GUI planned

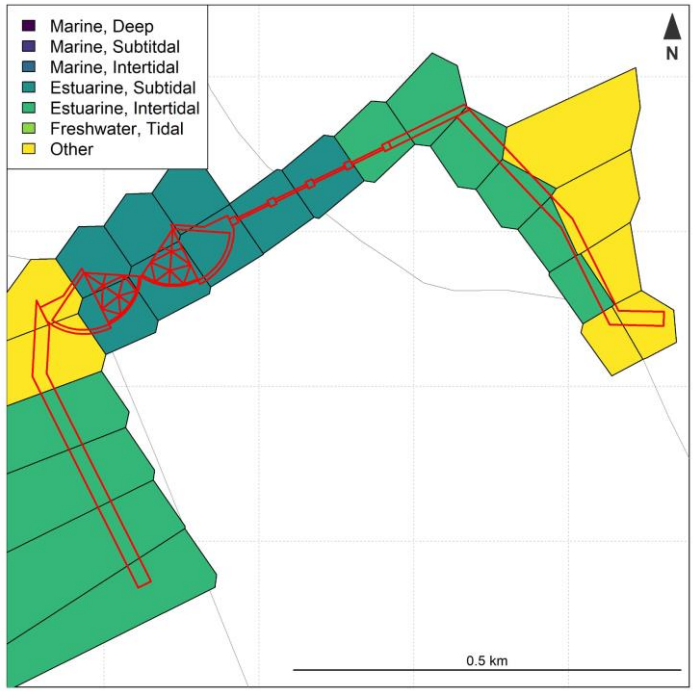


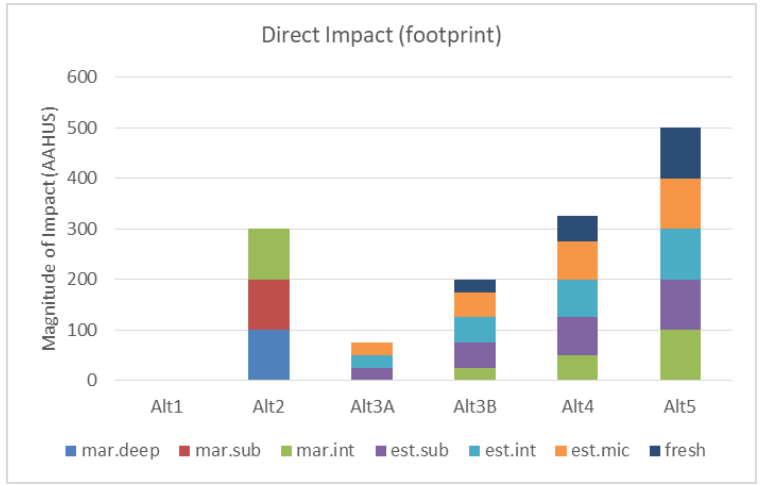
MODEL APPLICATION & COMMUNICATION (UNDERWAY)

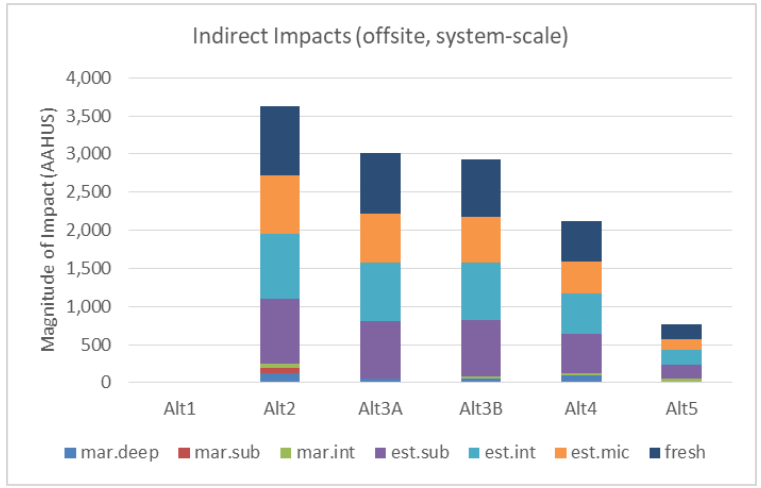
- Application for screening environmental impacts as part of a programmatic EIS (i.e., “tiered” EIS)

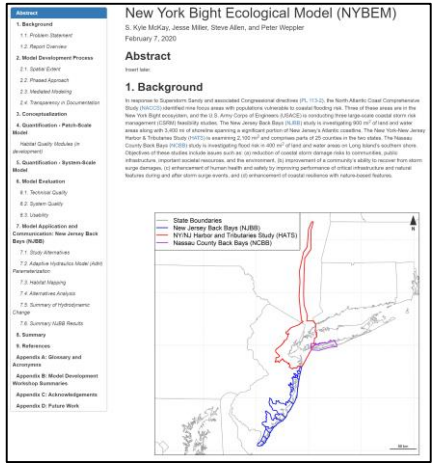
- Primary model outputs:
  - Direct impacts
  - Indirect effects
  - Cumulative, regional effects

- Benefits of process:
  - Agency involvement
  - Transparency
  - Regional gap analysis
  - Custom tools for unique planning challenges





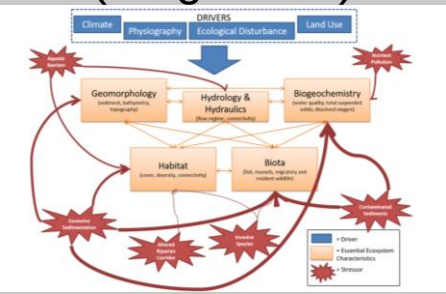




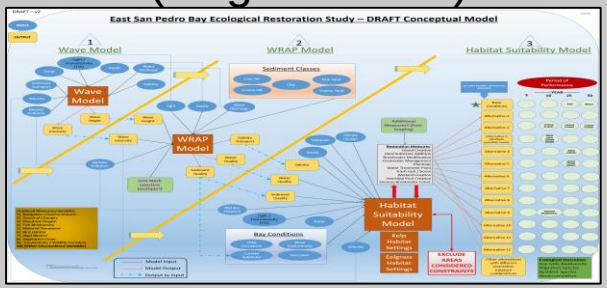
ALL VALUES ARE FICTIONAL AND PURELY REPRESENTATIVE OF THE TYPES OF ANALYTICAL OUTCOMES

TAKE-HOME POINTS

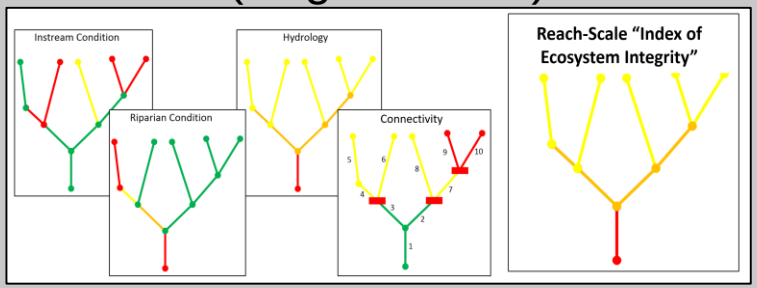
Meramac River (Single Use)



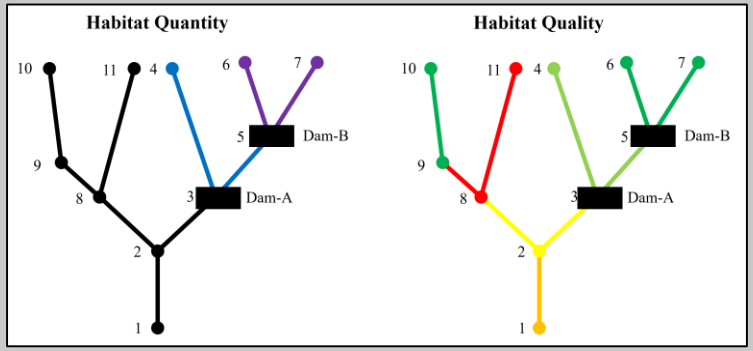
East San Pedro Bay (Regional Use)



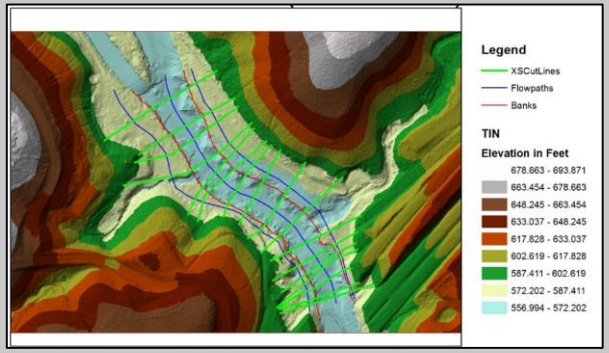
Proctor Creek, Georgia (Regional Use)



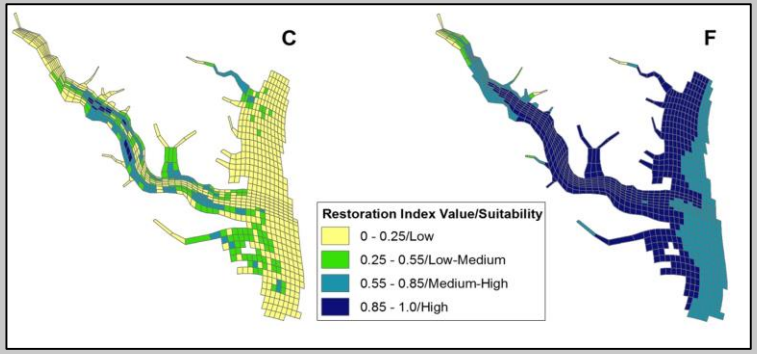
Fish Passage Prioritization (National Use)



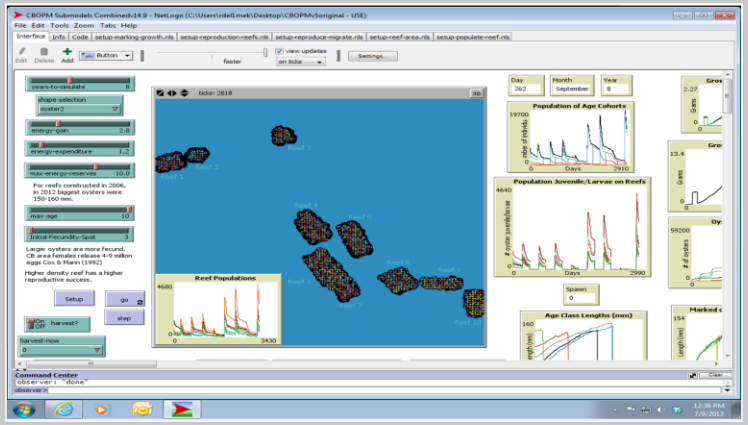
Environmental Flows, Georgia (R&D)



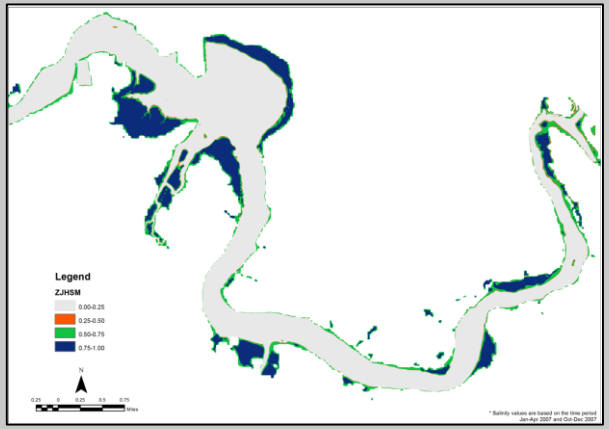
Oyster Habitat Suitability (Gulf and Atlantic Coast)



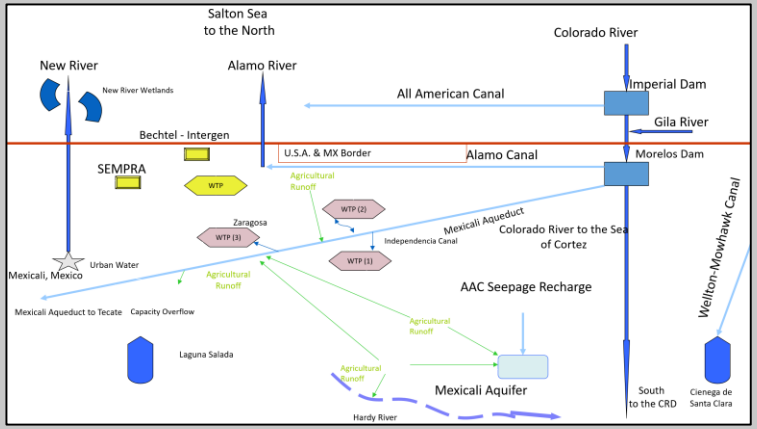
Oyster Population Dynamics, Virginia (R&D)



Invasive seagrass, Oregon (R&D)



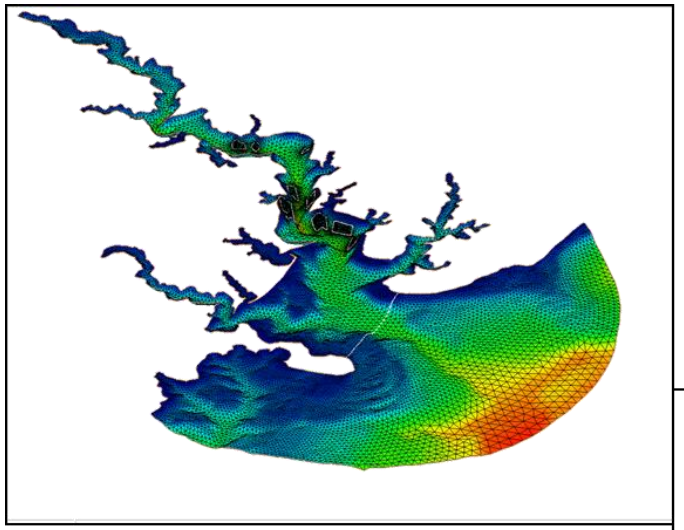
Salton Sea, California (R&D)

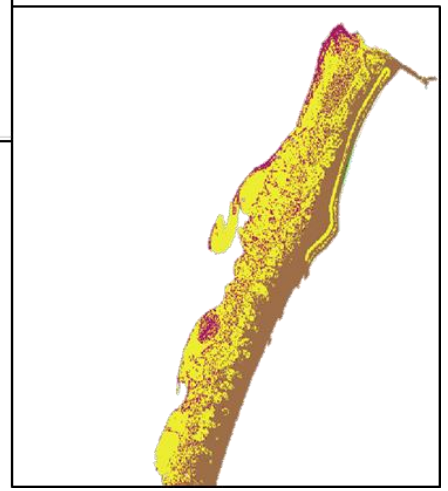


FUTURE DIRECTIONS

- Implementing ERDC technology and models across USACE
- The field of modeling has come a long way, ERDC is actively moving the needle, but there's more to be done

- Developing new tools
  - Multi-platform TAM
  - Model selection tool
  - Interactive spatial toolkits
  - Refining integrated modeling packages
  - Guidance for good modeling practices





WHAT ARE YOUR MAJOR MODELING CHALLENGES? WHAT TOOLS DO YOU NEED?

QUESTIONS AND COMMENTS

Acknowledgements

- Ecosystem Management and Restoration Research Program (EMRRP)
- ERDC Office of Research and Technology Transfer (ORTT)
- Water Operations Technical Support (WOTS) Program
- Multiple District Partners: Mobile, Los Angeles, New England, New York, Philadelphia, St. Louis, Rock Island, St. Paul, Fort Worth, Baltimore, Norfolk, San Francisco,…

Contact information

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- Kyle McKay, Kyle.McKay@usace.army.mil, 917-790-8717
- Todd Swannack, Todd.M.Swannack@usace.army.mil, 601-415-3509

POTENTIALLY USEFUL RESOURCES

- McKay S.K., Richards N., and Swannack T. 2019. Aligning ecological model development with restoration project planning. *ERDC EMRRP-SR-89*. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.
- Toolkit for interActive Modeling (TAM), Certified for National Use.
  - ERDC Technical Note – Ecological model development: Toolkit for interActive Modeling (Forthcoming)
- Habitat Suitability Modeling Tools
  - Library of 500+ USFWS Habitat Suitability Models
  - EcoRest R package + Vignette / User Manual (Spring 2020)
  - EcoRest Shiny App (Summer 2020)
  - ArcGIS Toolbox + User Manual
- Best Practices in Model Development:
  - Herman B., McKay S.K., Altman S., Richards N.S., Reif M., Piercy C.D., and Swannack T.M. 2019. Unpacking the black box: Demystifying ecological models through interactive workshops and hands-on learning. *Frontiers in Environmental Science*, 7, 122.
  - McKay S.K., Kohtio D.M., Scarpa C.A., Tommaso D.M., Weppler P.M., and Baron L.A. 2020. Incorporating multiple lines of evidence in urban stream restoration decision-making. Submitted to *Journal of the American Water Resources Association*.
  - Book Chapter – Encyclopedia of Ecology – Systems ecology
  - Book Chapter – Encyclopedia of Ecology – Model Types: Overview
  - Book Chapter – Encyclopedia of Ecology – Visualization as a tool for ecological analysis
  - ERDC Technical Note – Evaluation of system quality (Summer 2020)
  - ERDC Technical Note – Best practices for coding ecological models (Summer 2020)
  - ERDC Technical Note – Model application using scenario analysis (Spring 2020)
  - ERDC Technical Note – Conceptual modeling for large-scale regional projects (Spring 2020)
- Webinars: Models and SMART Planning (Proctor Creek), environmental flow modeling (Minnesota River), Incorporating secondary objectives to restoration planning (Hudson-Raritan Estuary), Data visualization,…
- Conferences: Ecological Society of America, Society for Freshwater Science, Symposium on Urban Stream Ecology
- Video series on key aspects of the model development process (Summer 2020)
- Facilitated modeling workshops: East San Pedro Bay, Cypress Valley, New York Bight, Swan Island, San Francisco Bay