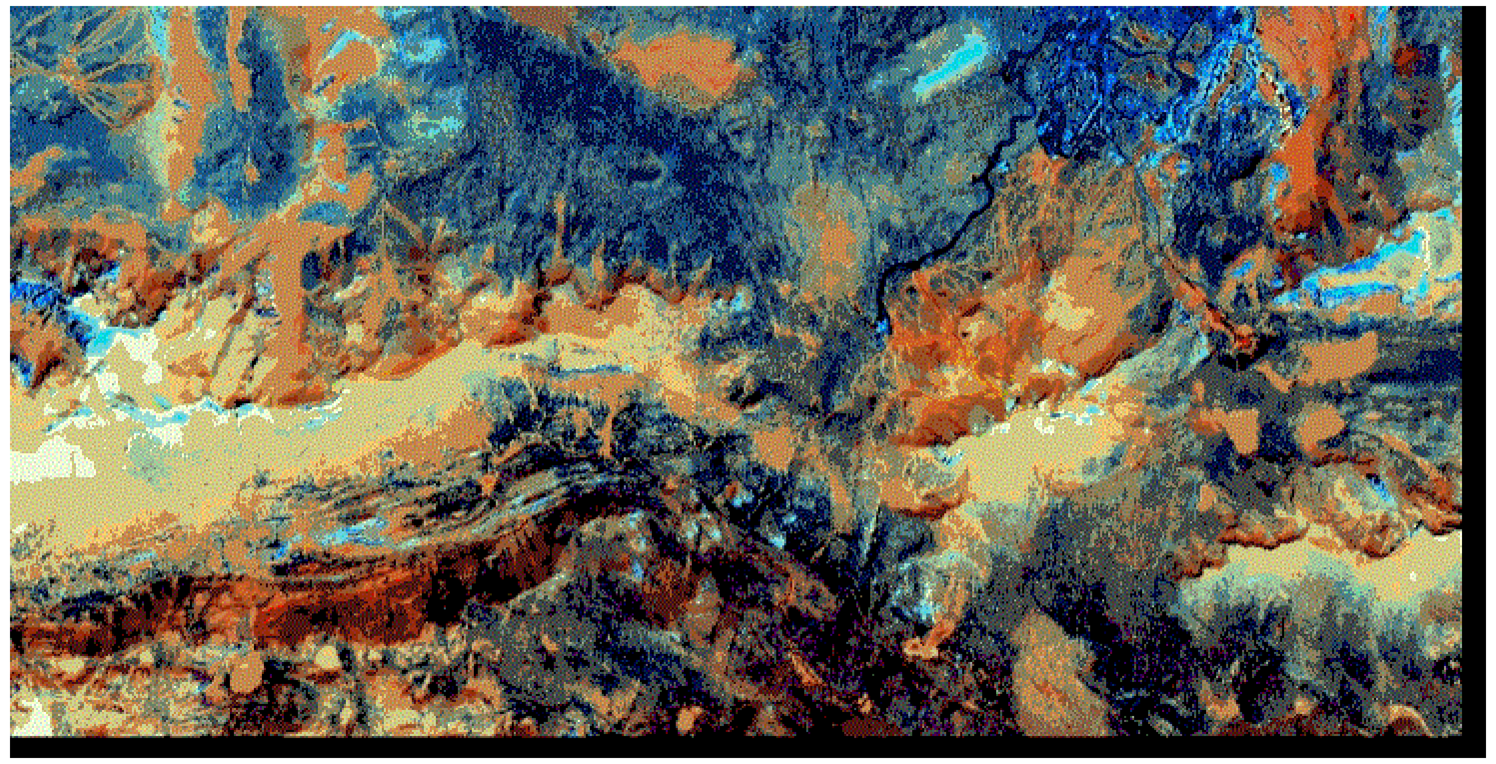
models

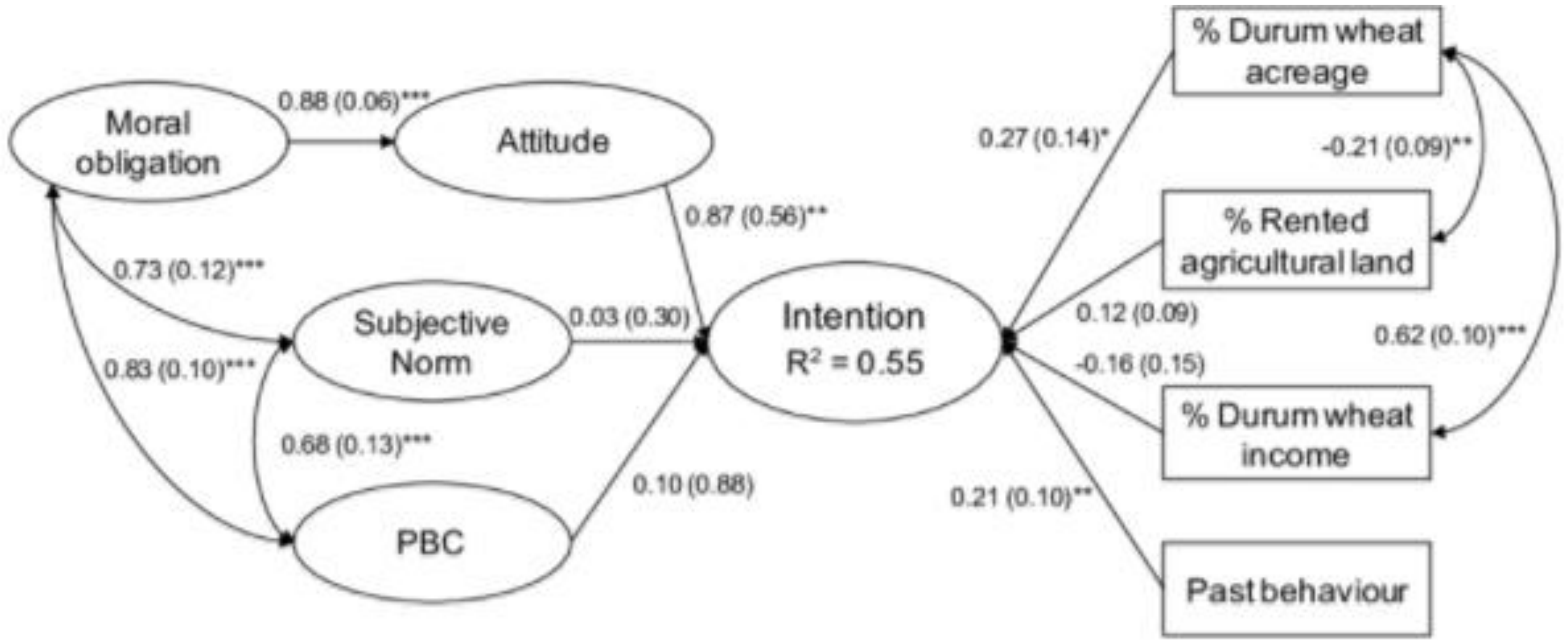
A simple approach to complex problems

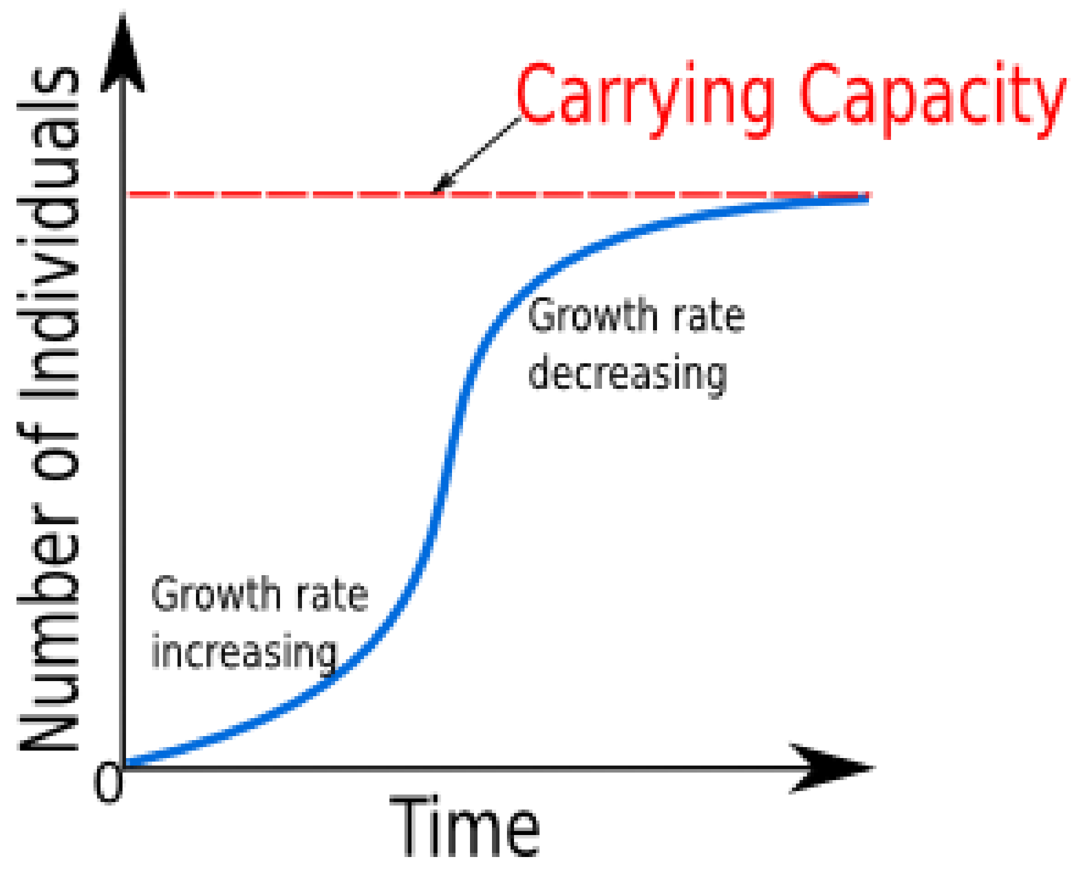
Overview

- Intro to systems thinking
- What is a "model"?
- General notes on modeling
- Types of models
- Overview of the "modeling process

$$
\begin{aligned}
f'(3) &= \lim_{h\to 0}\frac{(3+h)^2-3^2}{h} \\
&= \lim_{h\to 0}\frac{9+6h+h^2-9}{h} \\
&= \lim_{h\to 0}\frac{6h+h^2}{h} \\
&= \lim_{h\to 0}(6+h) \\
&= 6
\end{aligned}
$$





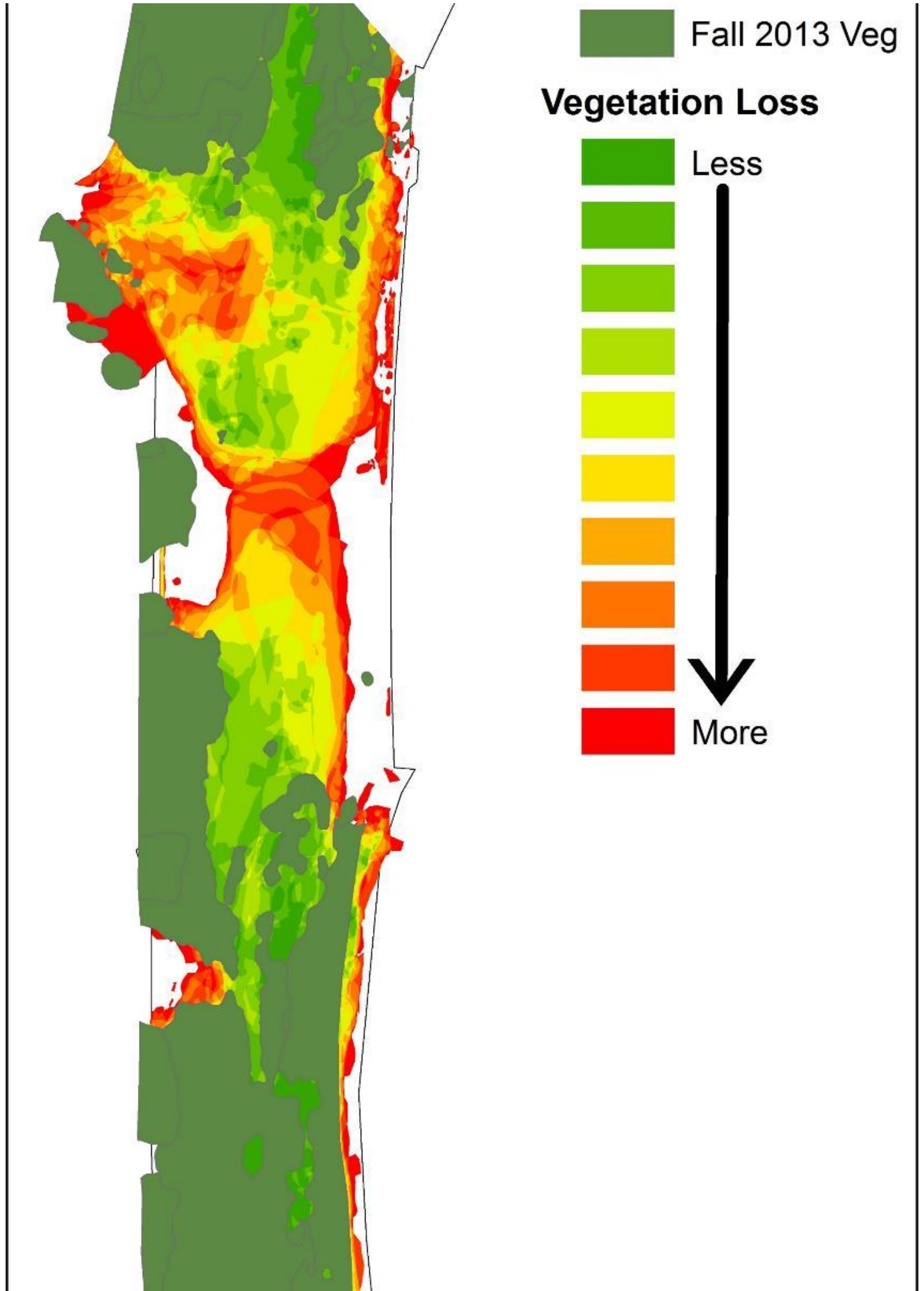


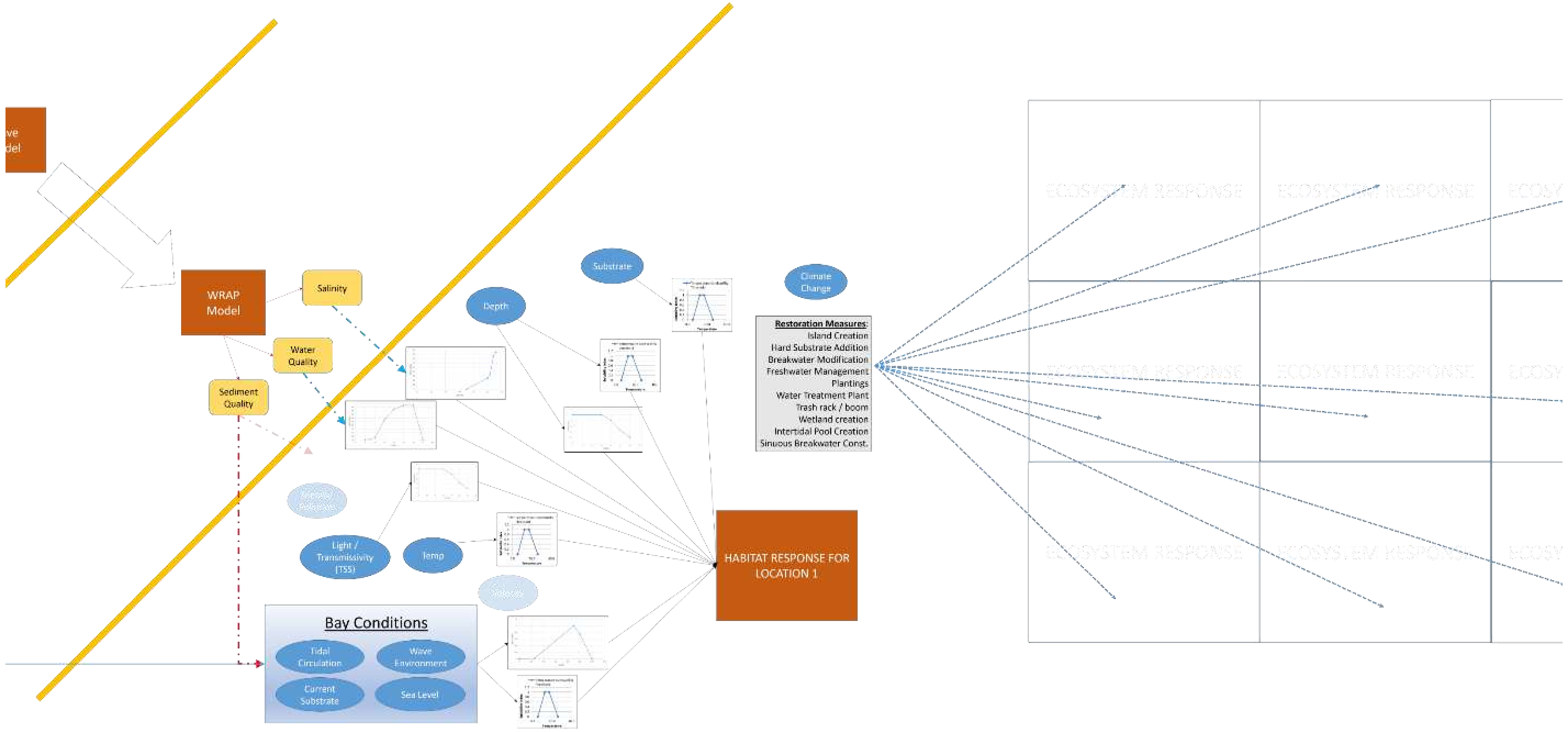
Systems

A system consists of a particular set of objects that interact in space and time. Systems are organized collections of interrelated physical components characterized by a boundary and functional unity.

System behavior is intrinsically difficult to model due to the dependencies, competitions, feedback loops, indirect/direct relationships, or other interactions

Ecosystem: Complex of ecological communities and their environment, forming a functional whole in nature (Patten & Jørgensen, 1995)





Definition of models

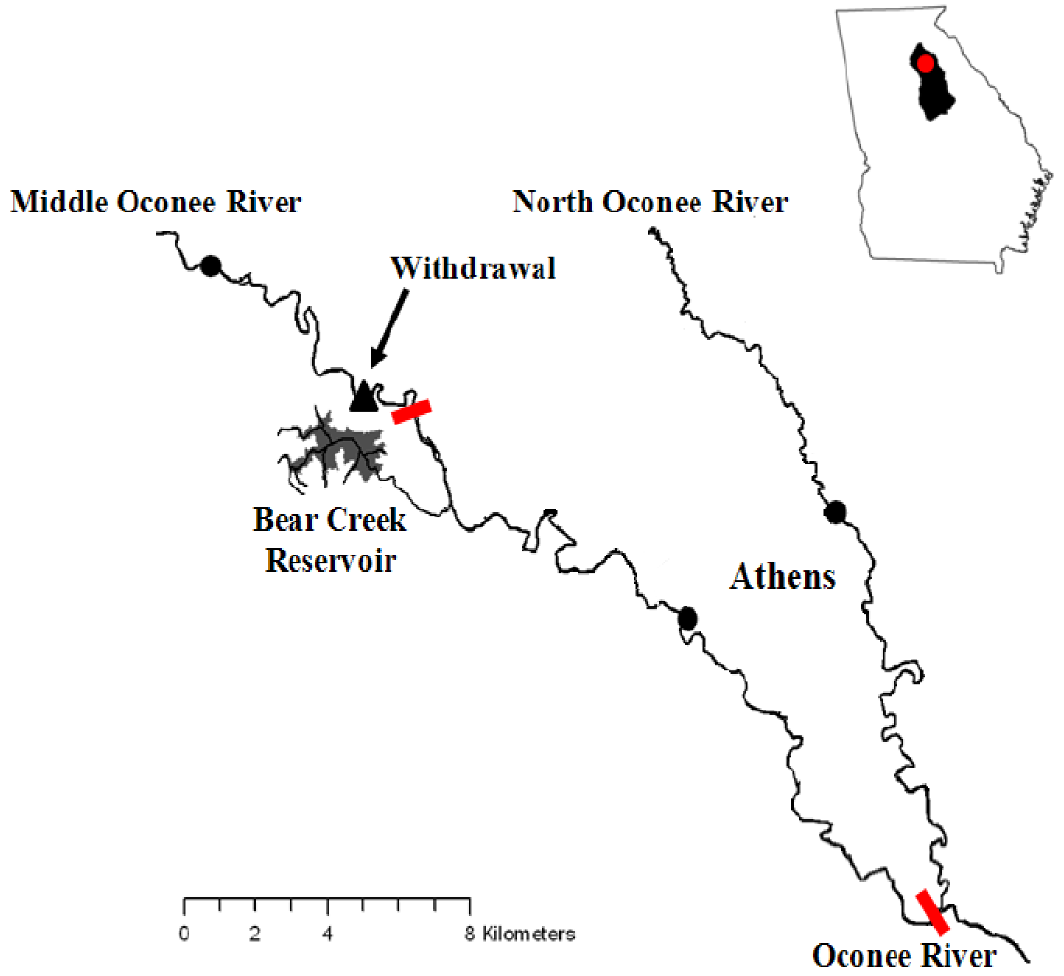
You are a modeler.

- Commonly used in the nerd world: “abstractions of reality”
- Model certification definition (EC-1105-2-412):
  - “a representation of a system for a purpose”
  - “a way to represent a system for the purposes of reproducing, simplifying, analyzing, or understanding it”
- How would your tell your family what a model is?

Definition of model for this class

Conceptual **and** numerical representation of environmental and ecological system

SIDE NOTE: **not** software applicable to any situation



Ecological modeling

Represents environment based on point of view of model builders

- Ecosystems are inherently complex, interdependent systems
- Ecology is a question-driven discipline
- Models are developed ad-hoc (project-by-project) with little reuse
  - Each system reacts differently to stimuli
  - Multiple approaches for a single problem
  - Trade-offs: detail, scale, expense
- Models for monitoring **must be** adaptable

Ecological Modeling Approaches

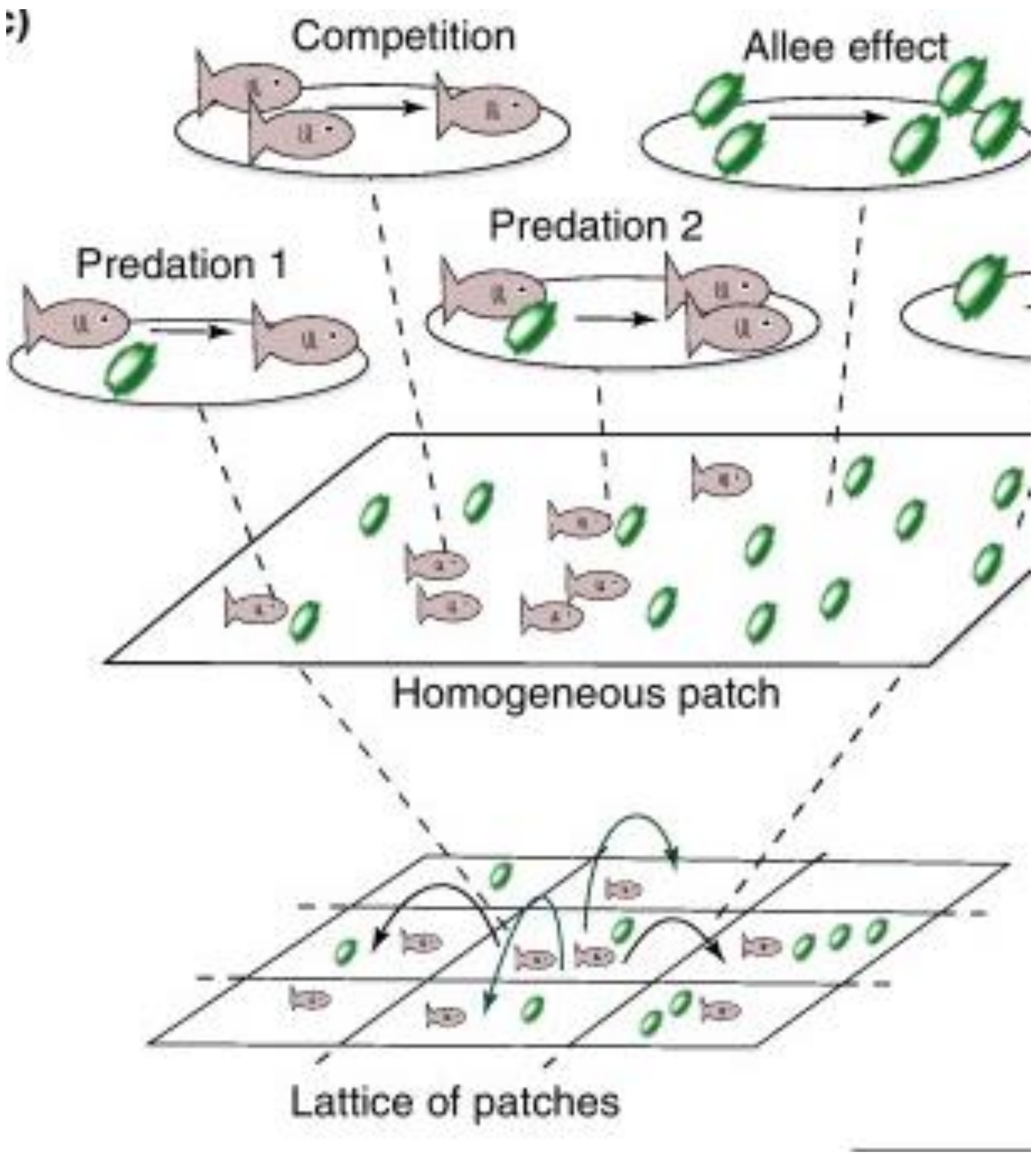
Ecological Question	Example Modeling Approaches
Where might species *X* be found after 5 years?	Habitat suitability index (HSI), GIS-based regression
How will climate change affect system *X*?	Individual (agent) , HSI modeling
Will species *X* persist in region *Y* with habitat fragmentation?	GIS, Metapopulation, Agent-based
How rapidly will species *X* invade area *Y*?	Agent-based ,GIS, System dynamics
How will disease *X* spread through species *Y*?	Demographic, Agent-based, GIS
How will pollutant *M* affect species *X*?	Biochemical model, statistical analysis of experimental data
How much timber can be harvested	Forest growth model
How can we control pest species *X*?	HSI, Agent-based, System dynamics

Engineering v. Ecological Models (Part 1)

	Engineering Models	Ecological Models
Primary Basis	Physics Chemistry (water quality)	Physics Chemistry Biology INTERACTIONS THEREOF
First principles?	Sometimes (e.g., Laws of Motion)	Rare / Never (Often do not exist)
Knowledge of dynamics	High	Low
Model Confidence	High	Low
Science/Art	90/10	25/75

Engineering v. Ecological Models (Part 2)

Engineering Models	Ecological Models
Models are well developed and reusable	Most models are single-use
New application uses old models	New application uses new models
A small set of models is sufficient	A toolbox containing a dozen modeling approaches is required
The model components are well understood	Most ecological systems are poorly understood
Models are used for prediction	Models are used for exploration and education
Models are heavily science-based	Models rely on local expertise



Why do we develop models?

Models!

To increase understanding

To organize thinking

To forecast future conditions

To inform decision-making

Provide a platform for critical thinking

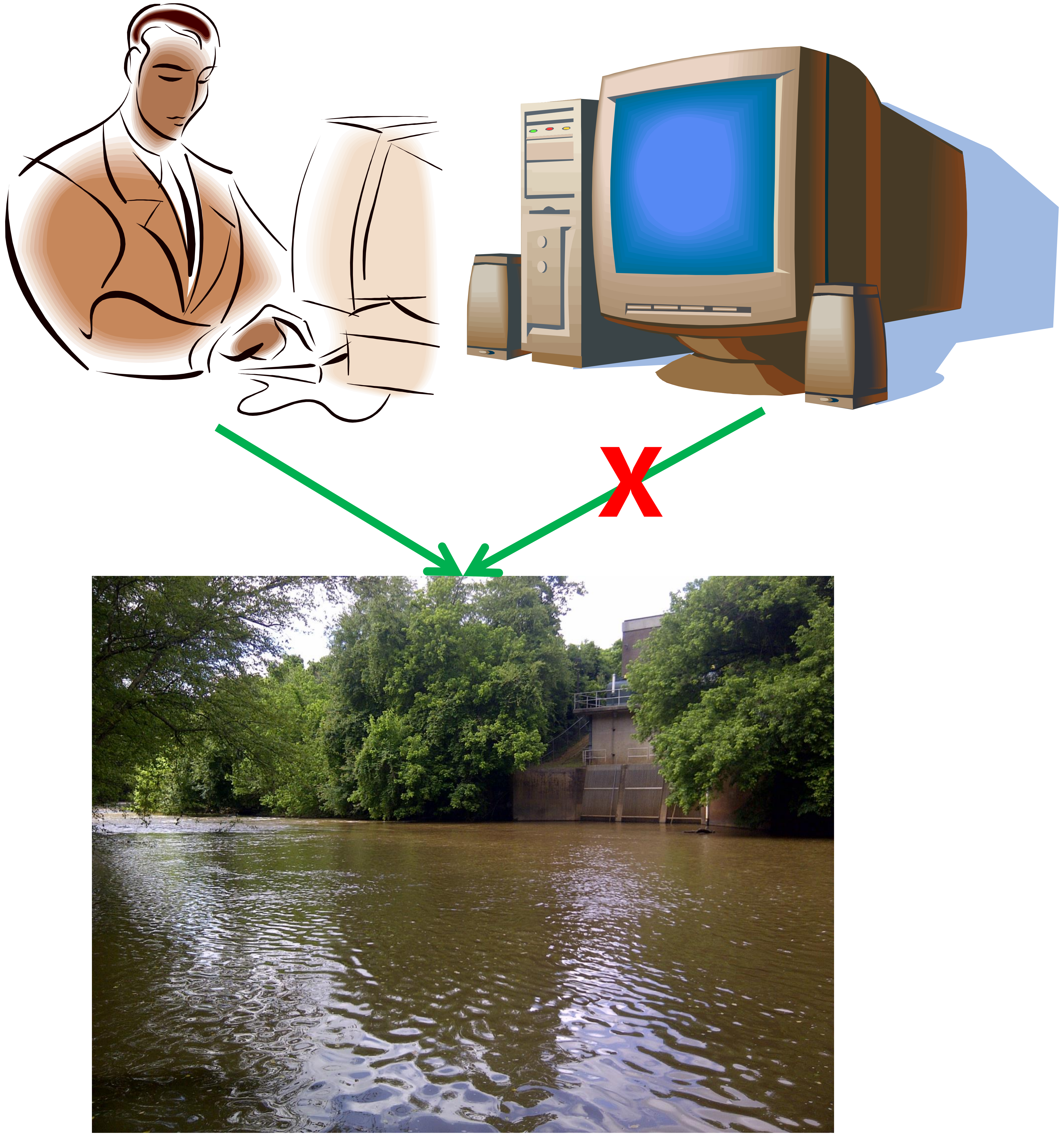
Models are never

Answers or Decisions

People make decisions. Models inform people.

Reality

Inherently a model is an abstraction of reality.



A few thoughts to consider at 10,000 feet before beginning…

Think About	Ask Yourself
Purpose / Objectives	Why are you developing a model (understanding, forecasting, informing, etc.)? What are you trying to accomplish with a model? What question is being asked of the model? What is the model simulating?
Fidelity	What level of accuracy is required (exact v. relative comparison)?
Space	Where is the model targeting? What spatial resolution is of interest (none, order of magnitude)?
Time	Is the model simulating time? How long and detailed (order of magnitude)?
The Big Picture	Are the prior four categories commensurate?

When are models (in)appropriate?

Models might help	Don’t waste your time
•I don’t understand my system! •Examining future trends •Playing out scenarios •Quantifying trade-offs between alternatives •Communicating with stakeholder or decision-makers	•I want to predict EXACTLY what is going to happen •I want “the answer” •Determining value judgments •Replacing critical thinking

Common misconceptions

A model cannot be built with incomplete understanding.

Managers make decisions with incomplete information all the time! This should be an added incentive for model-building as a statement of current best understanding.

A model must be as detailed and realistic as possible.

If models are constructed as ‘purposeful representations of reality’, then design the leanest model possible. Identify the variables that make the system behave and join them in the most simple of formal structures. **Parsimony is key (i.e., Einstein’s aphorism…as simple as possible, but no simpler)**!

Starfield et al. (1997)

Types of Models

Table 1. Description of model types often used for modeling environmental benefits.

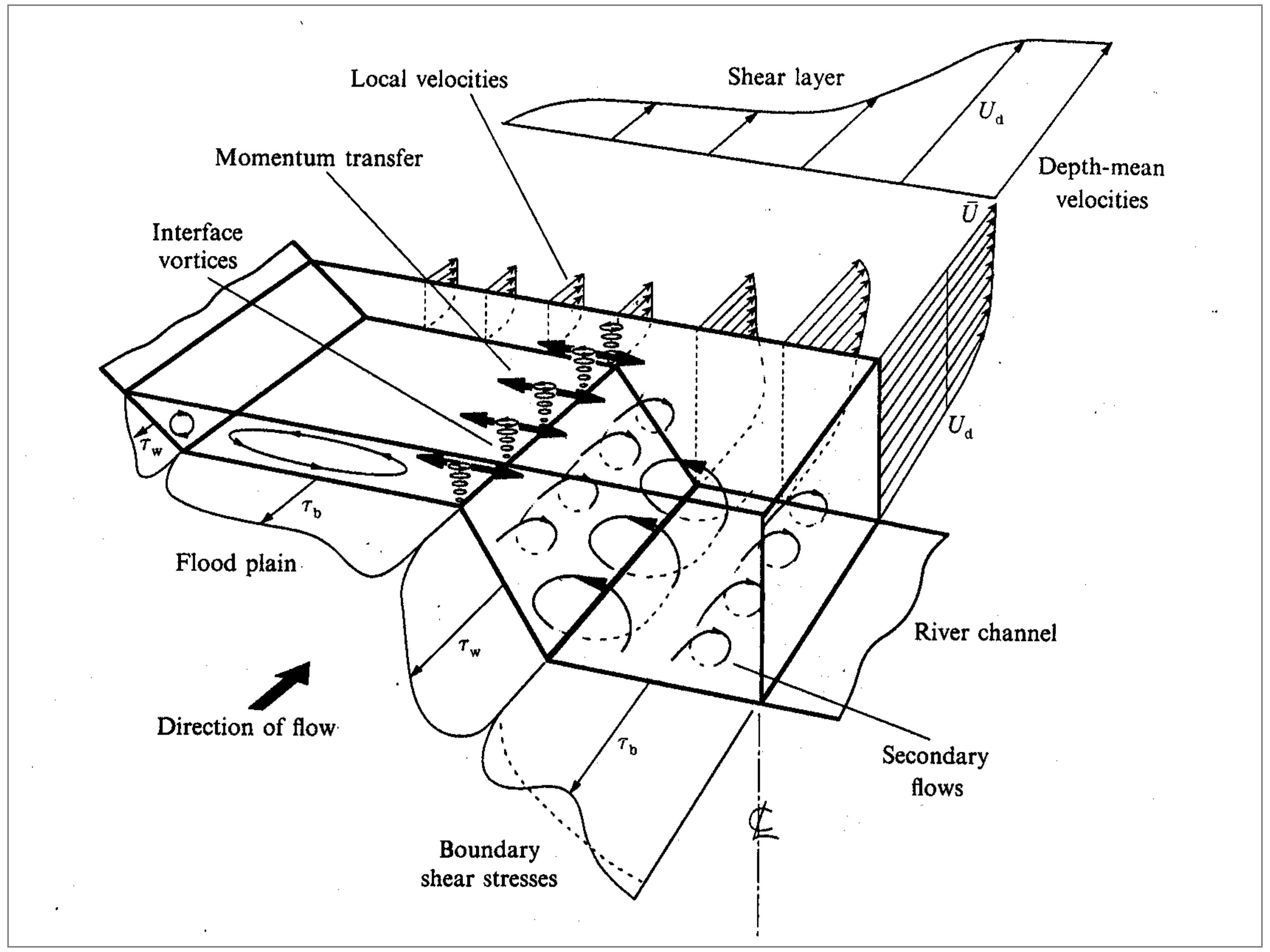
Model	General Use	Example
Analytical	Systems where solution to closed form equations represent system	Population growth, Lotka-Volterra models
Conceptual	Diagramming relationships among components, organizing information, determining data needs	CEMCAT (see Fischenich 2008, for more examples)
Index	Determining habitat quality across a landscape, relates species presence to environmental variables	HSI, HGM
Simulation	Modeling dynamics of complex systems that have multiple factors interacting across scales, often have spatial components	Agent-based models, ADH-CASM, ELAM, ICM, system dynamic models
Statistical	Analysis of datasets to determine distributional properties of the data	ANOVA, goodness-of-fit, regression, t-test,
Spatial	Projects where particular spatial attributes are important can be incorporated into simulation models	GIS, EDYS

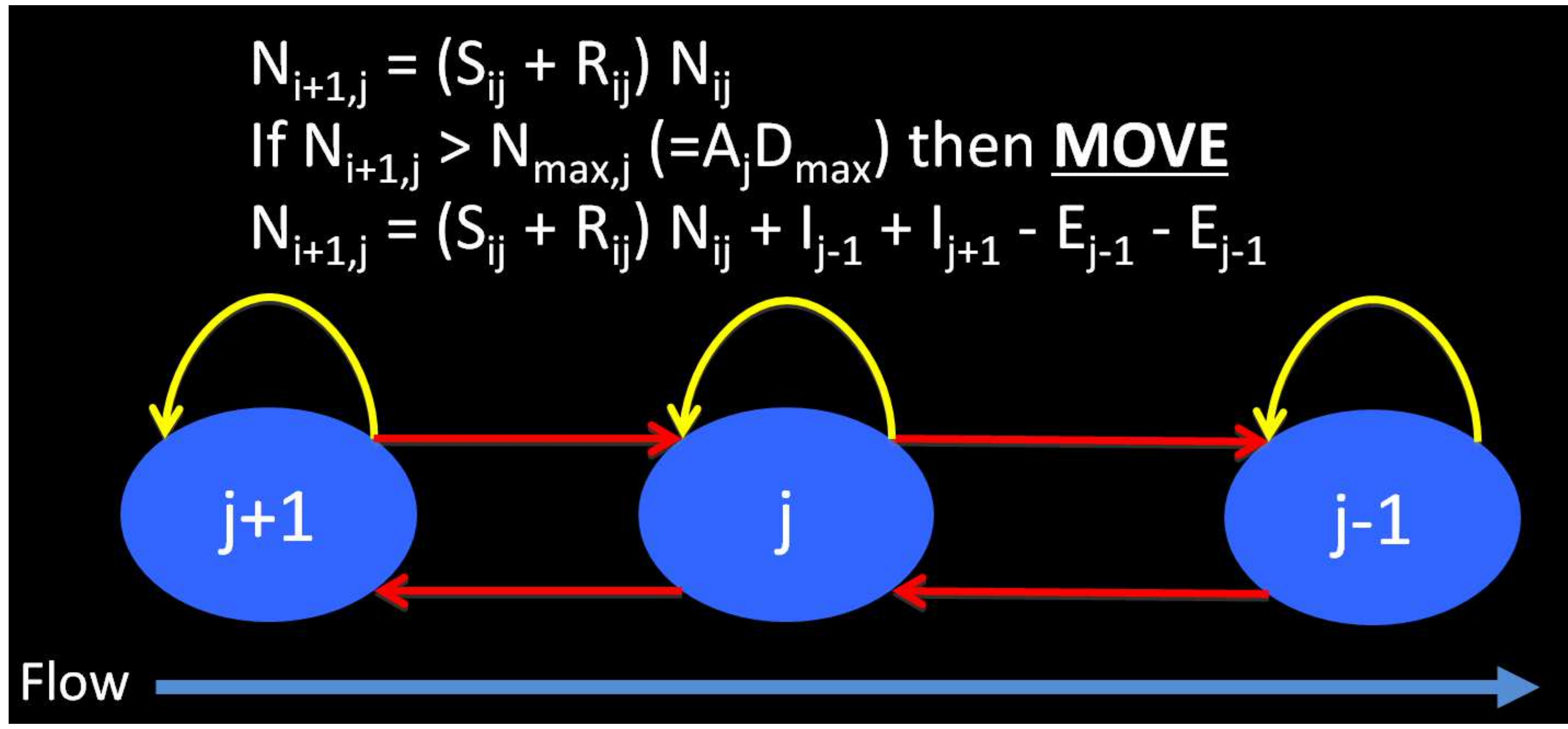
Analytical Models

Solution of closed form equations representing the system

$$\begin{bmatrix} n_0 \\ n_1 \\ \vdots \\ n_{\omega-1} \end{bmatrix}_{t+1} = \begin{bmatrix} f_0 & f_1 & f_2 & f_3 & \dots & f_{\omega-1} \\ s_0 & 0 & 0 & 0 & \dots & 0 \\ 0 & s_1 & 0 & 0 & \dots & 0 \\ 0 & 0 & s_2 & 0 & \dots & 0 \\ 0 & 0 & 0 & \ddots & \dots & 0 \\ 0 & 0 & 0 & \dots & s_{\omega-2} & 0 \end{bmatrix} \begin{bmatrix} n_0 \\ n_1 \\ \vdots \\ n_{\omega-1} \end{bmatrix}_{t}$$

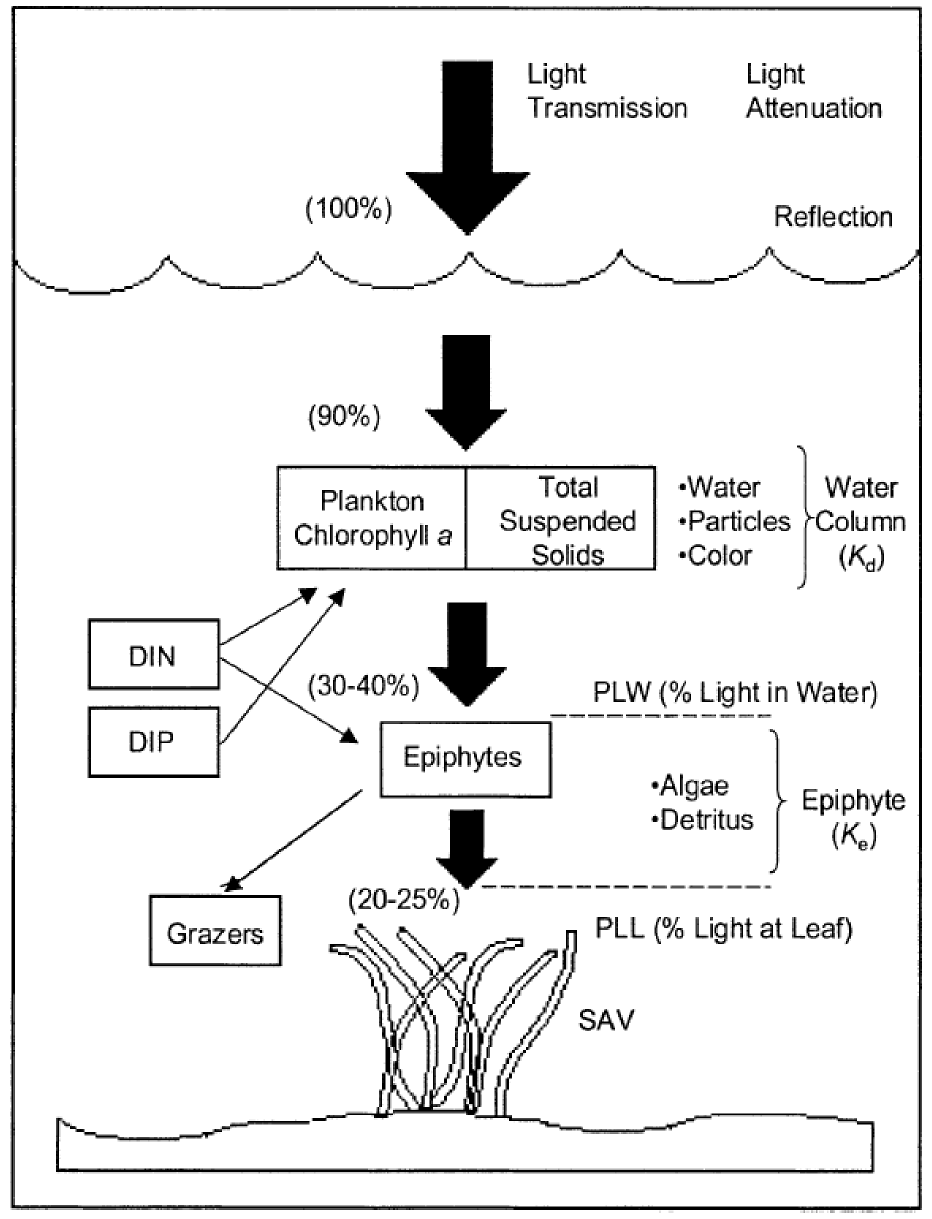
$$\rho g H S_0 + \frac{\partial}{\partial z}\left(\rho\lambda\sqrt{\frac{f}{8}}H^2 U_d \frac{\partial U_d}{\partial z}\right) - \rho {U_d}^2 \frac{f}{8}\sqrt{1+{S_{0z}}^2} = \Gamma$$

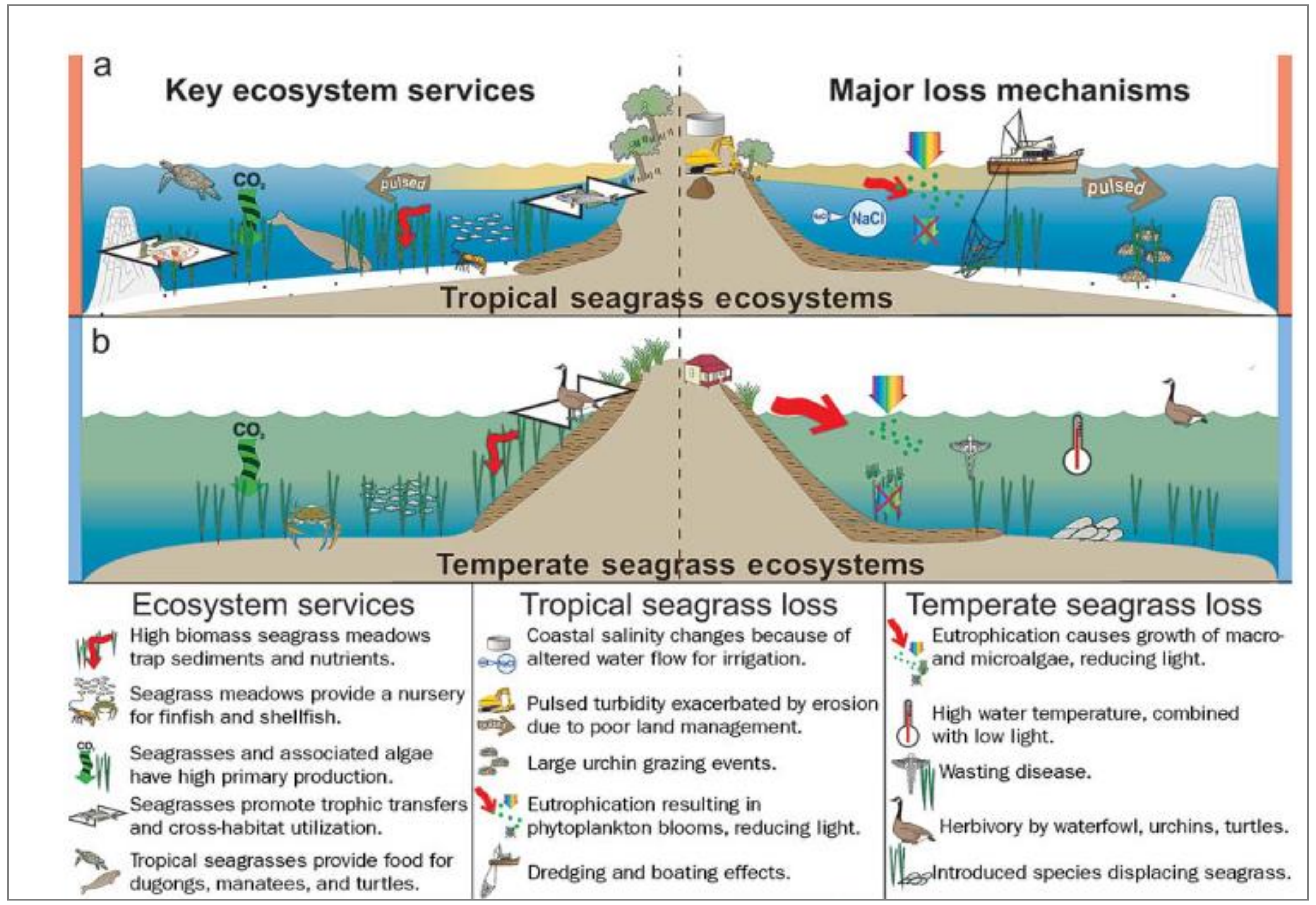


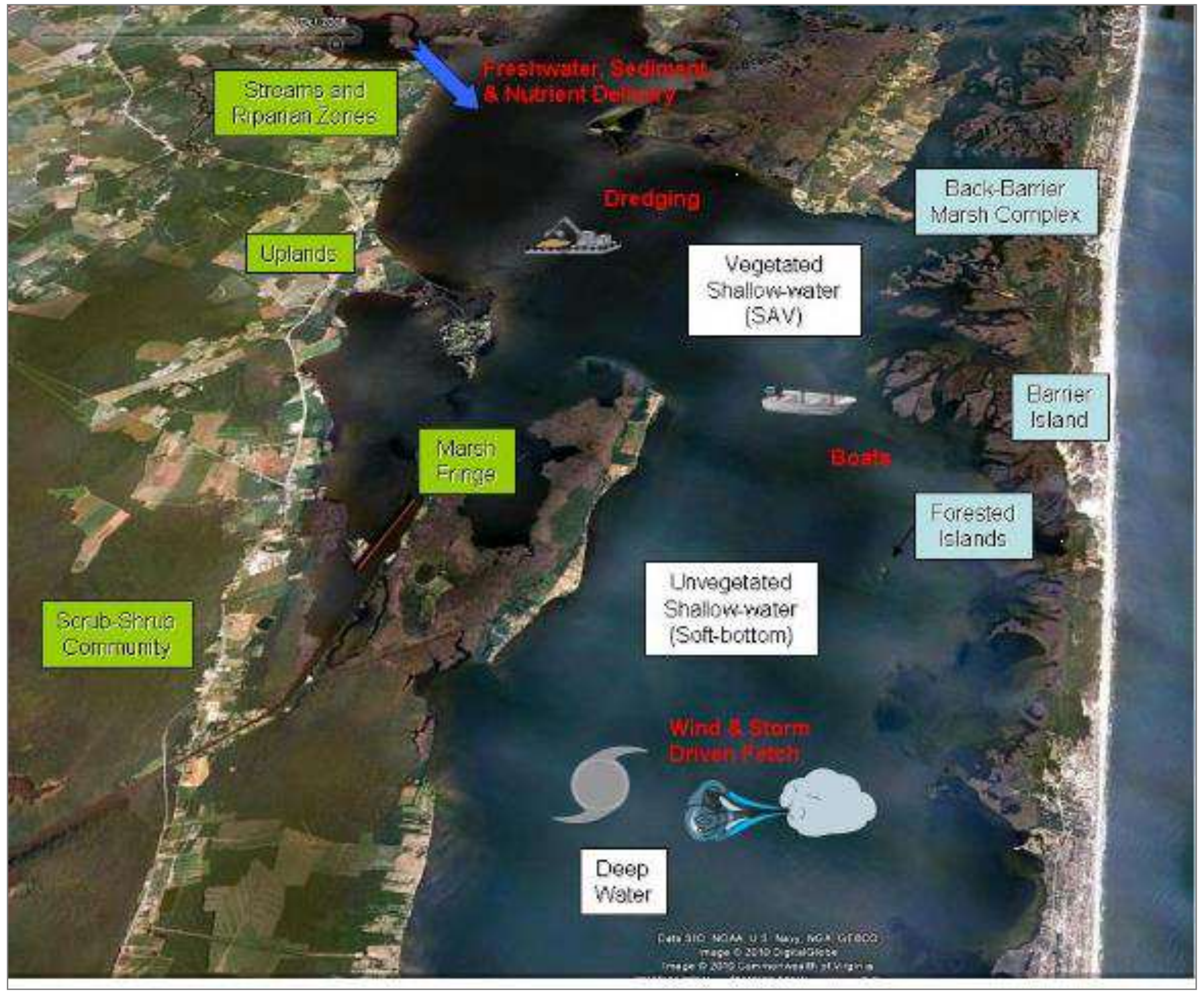


Conceptual Models

Diagramming relationships among components, organizing information, determining data needs, framework for critical thinking







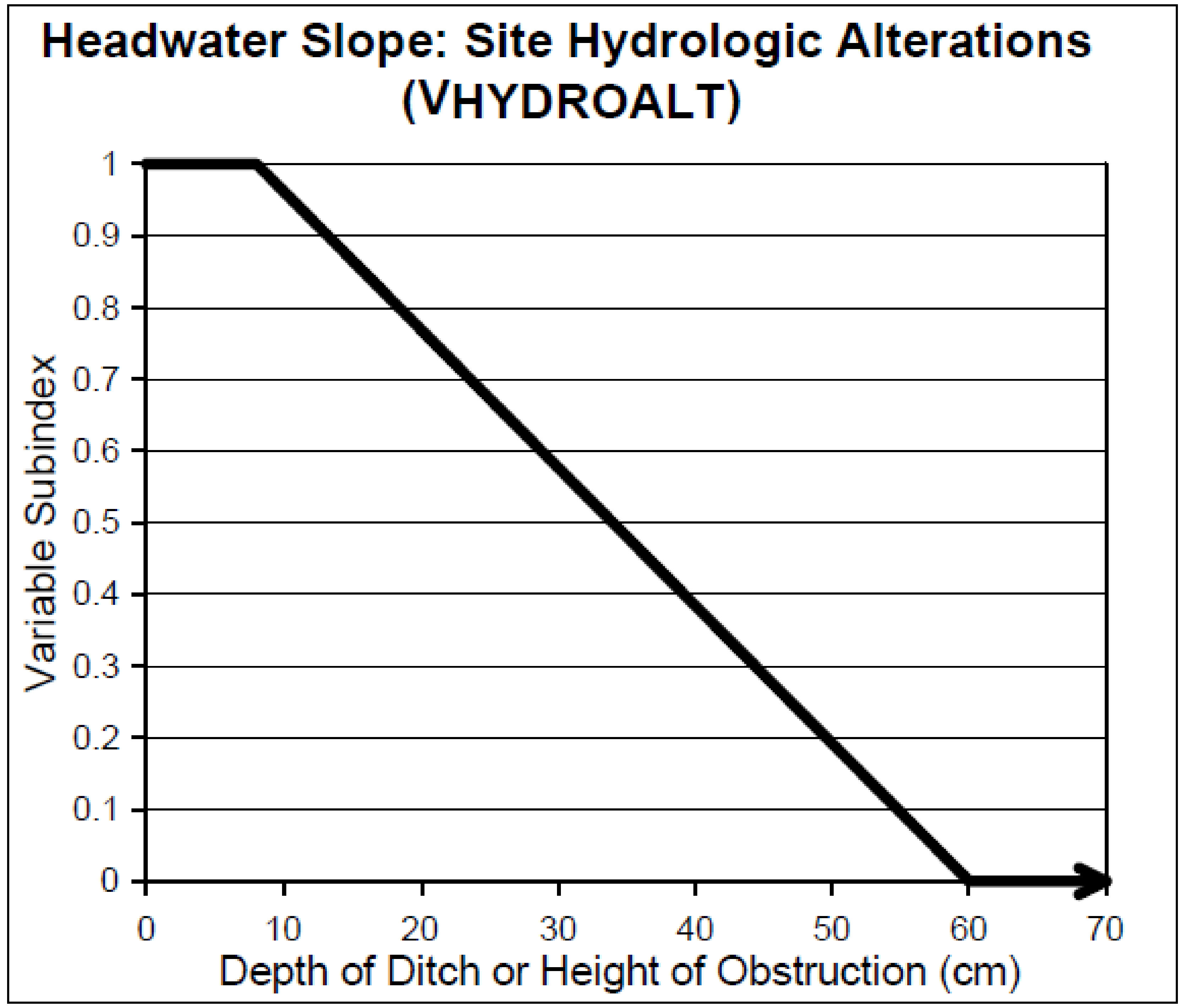
Index models

Determining ecosystem quality relative to environmental variables

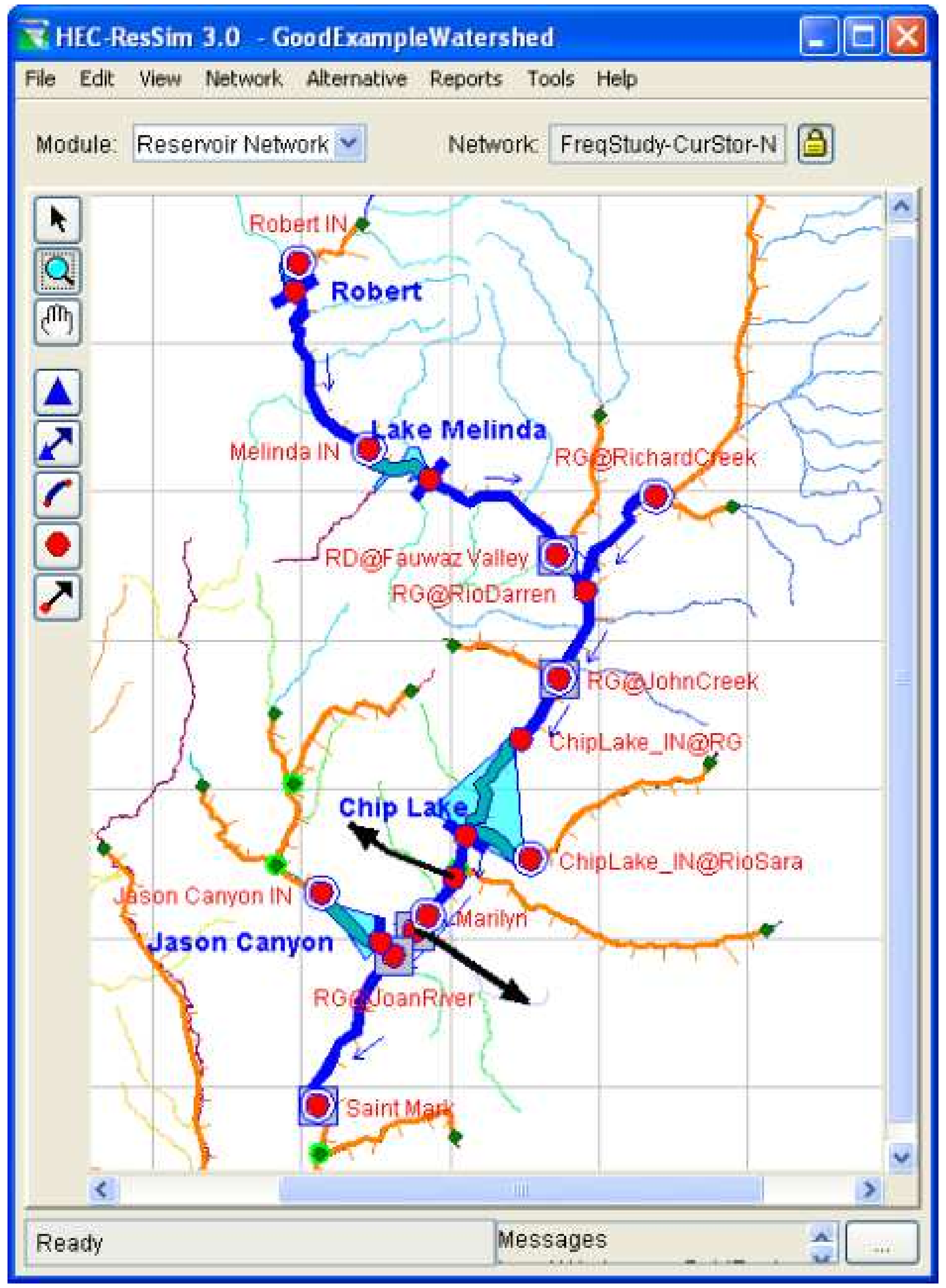
Quantity * Quality

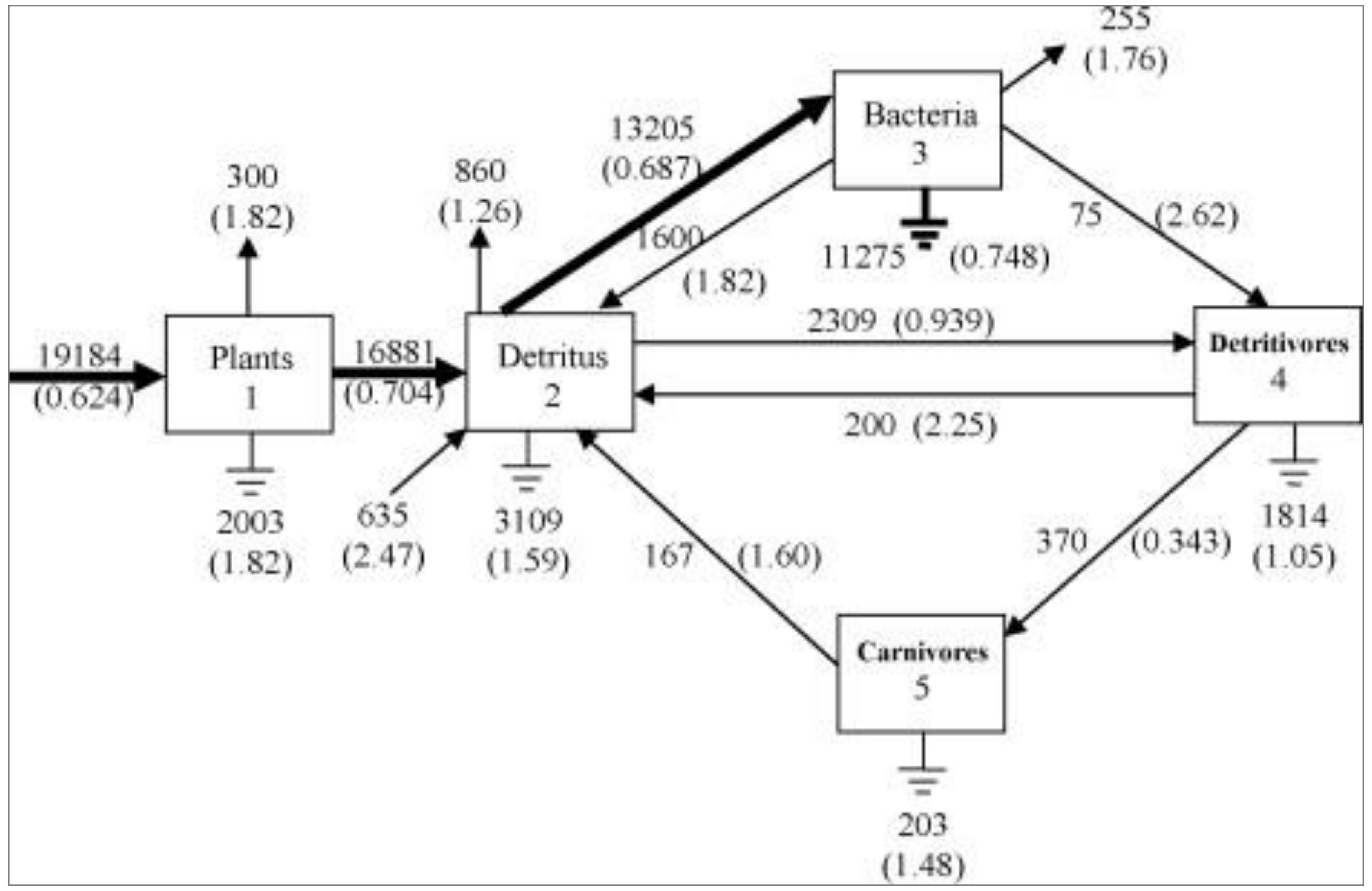
Quality for what?

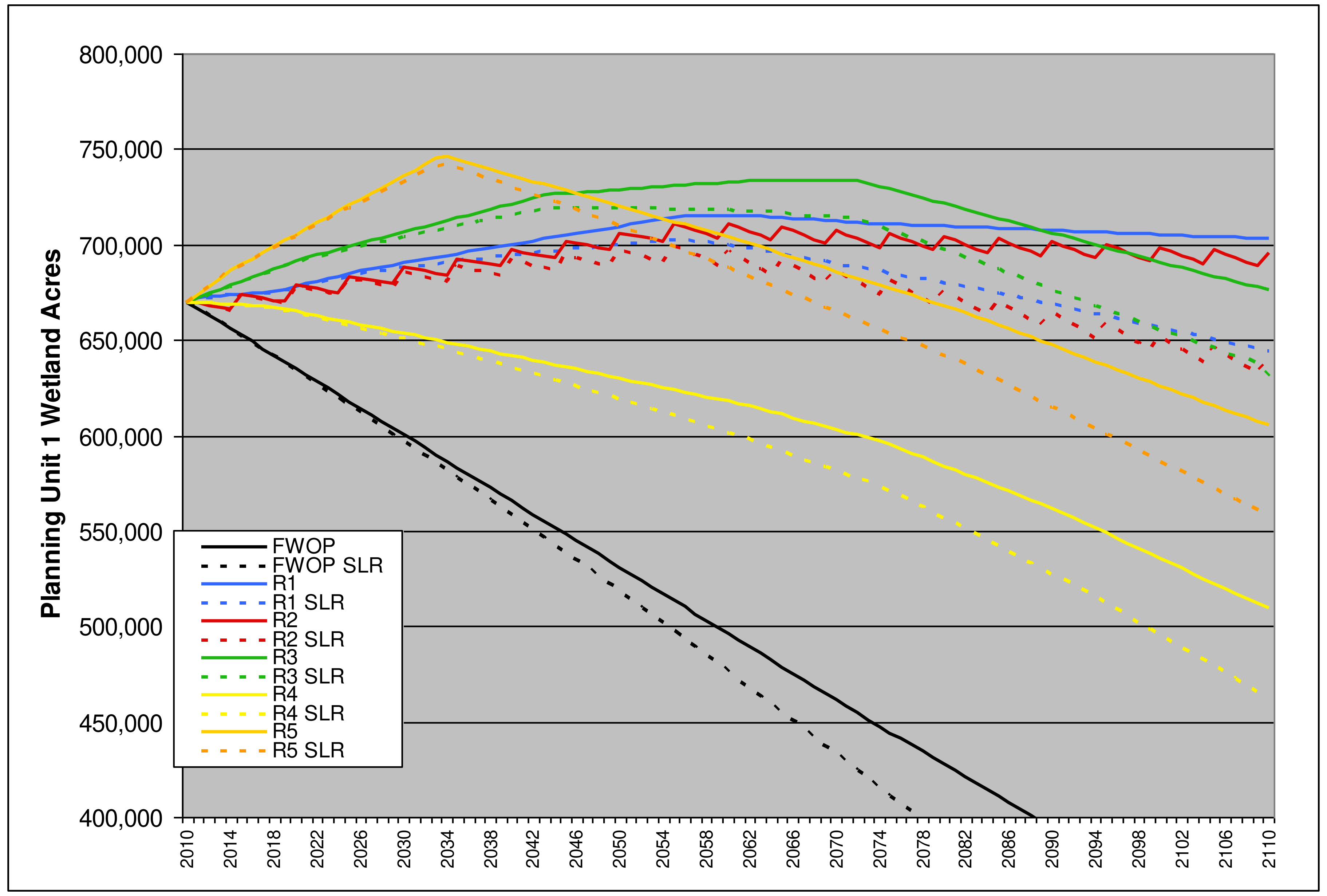
- Species – HSI
- Community – HSI
- Function – HGM



$$FCI = \sqrt{Hydro * \left(\frac{Catch + Upuse + Big3 + Tden}{4}\right)}$$



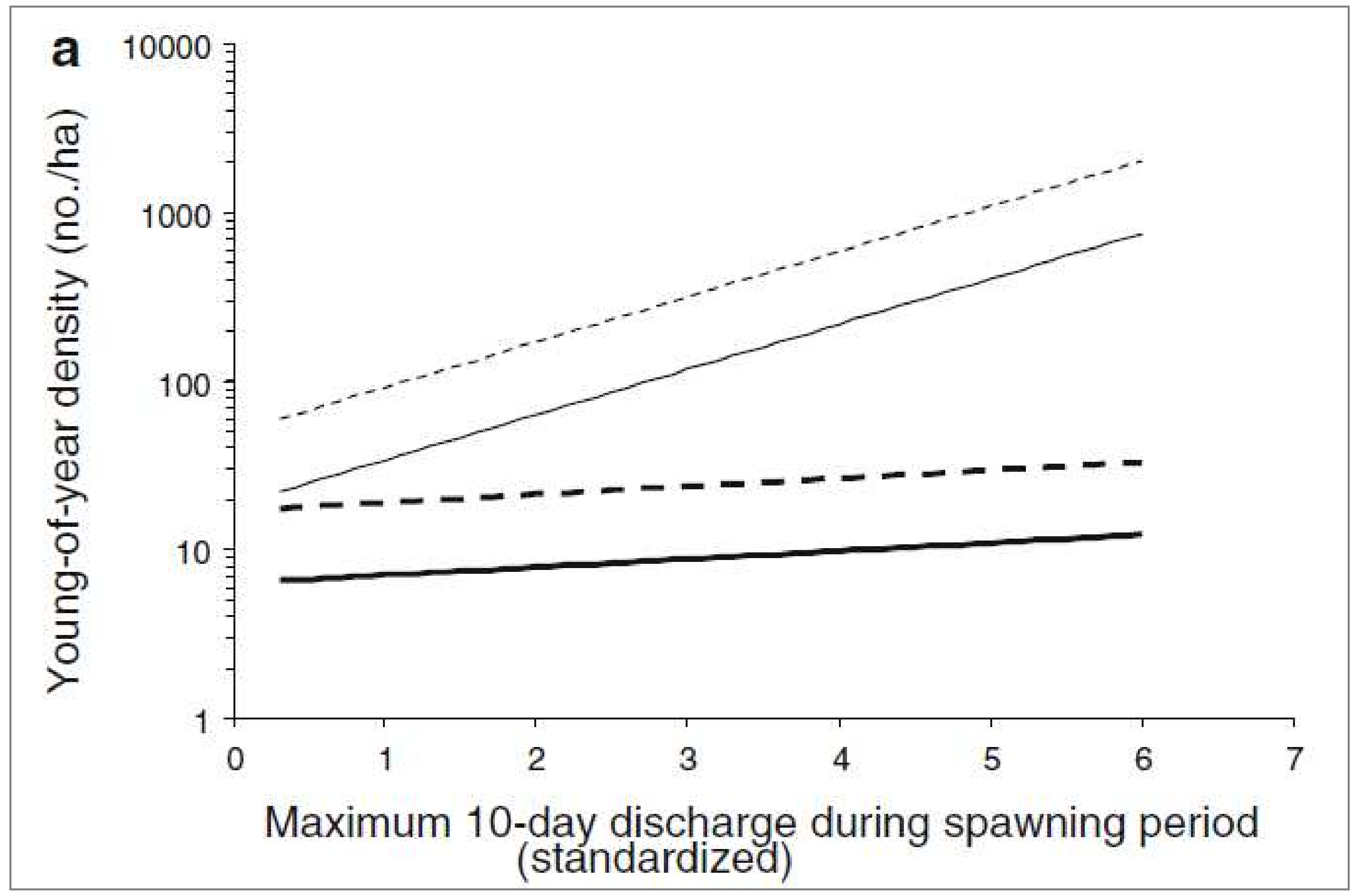


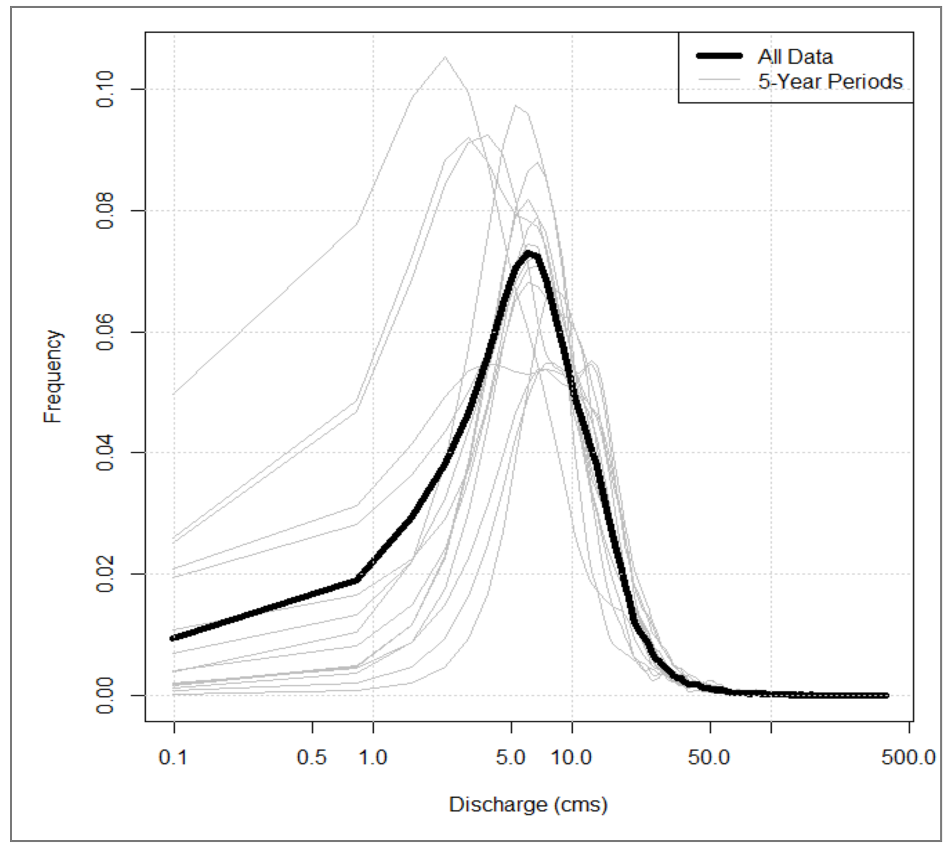


Simulation models

Statistical Models

Analysis of datasets to determine distributional properties of the data





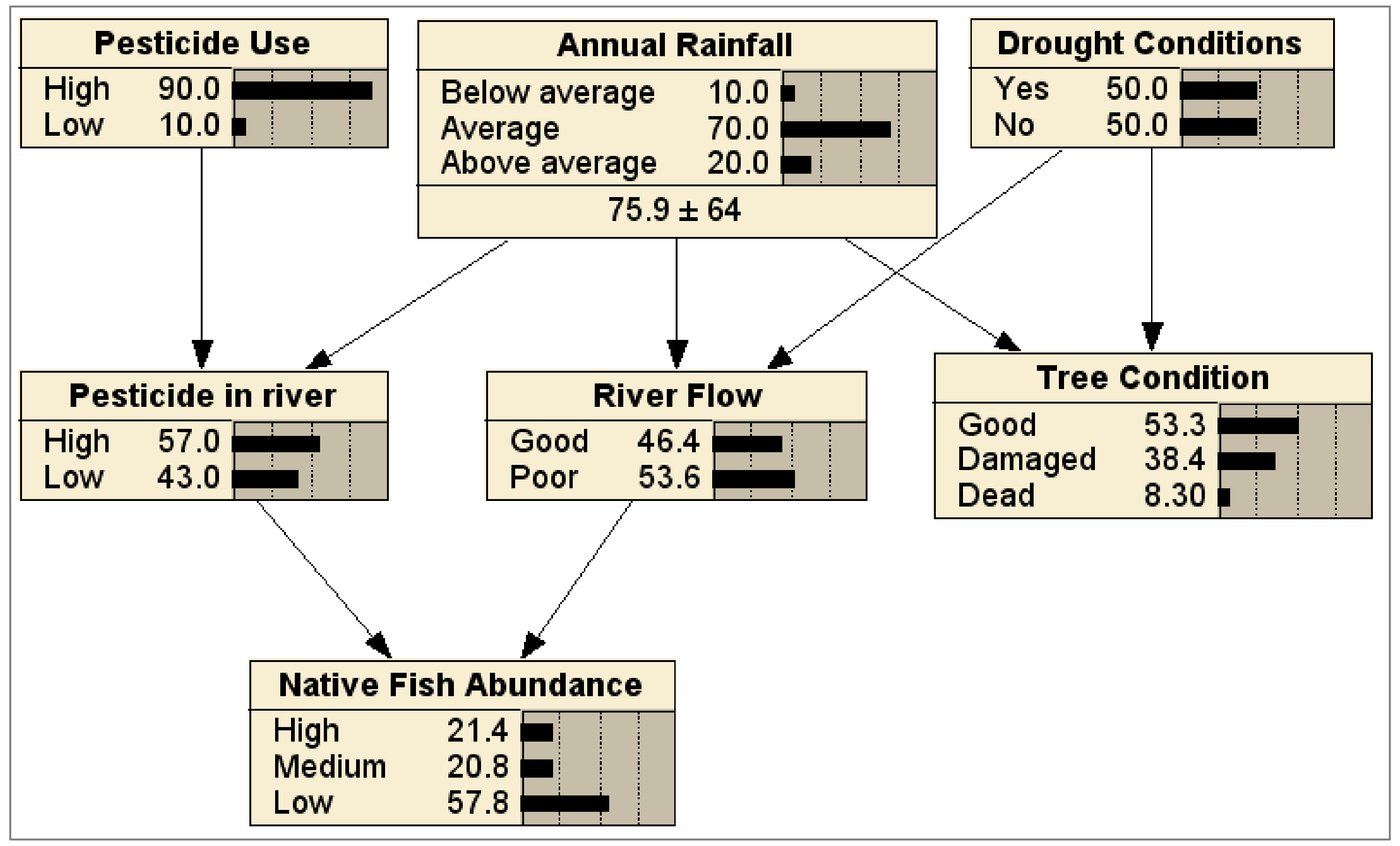
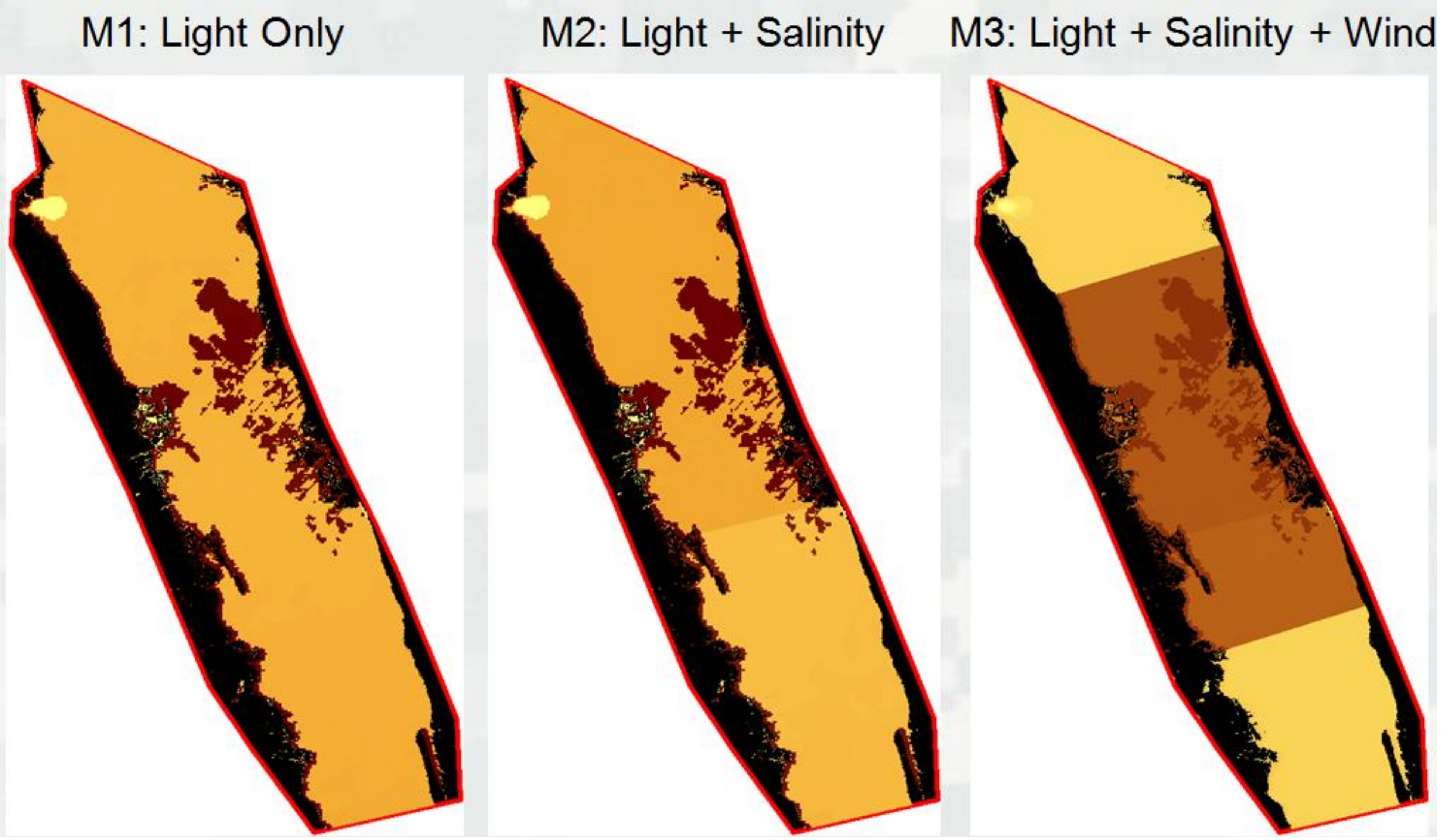
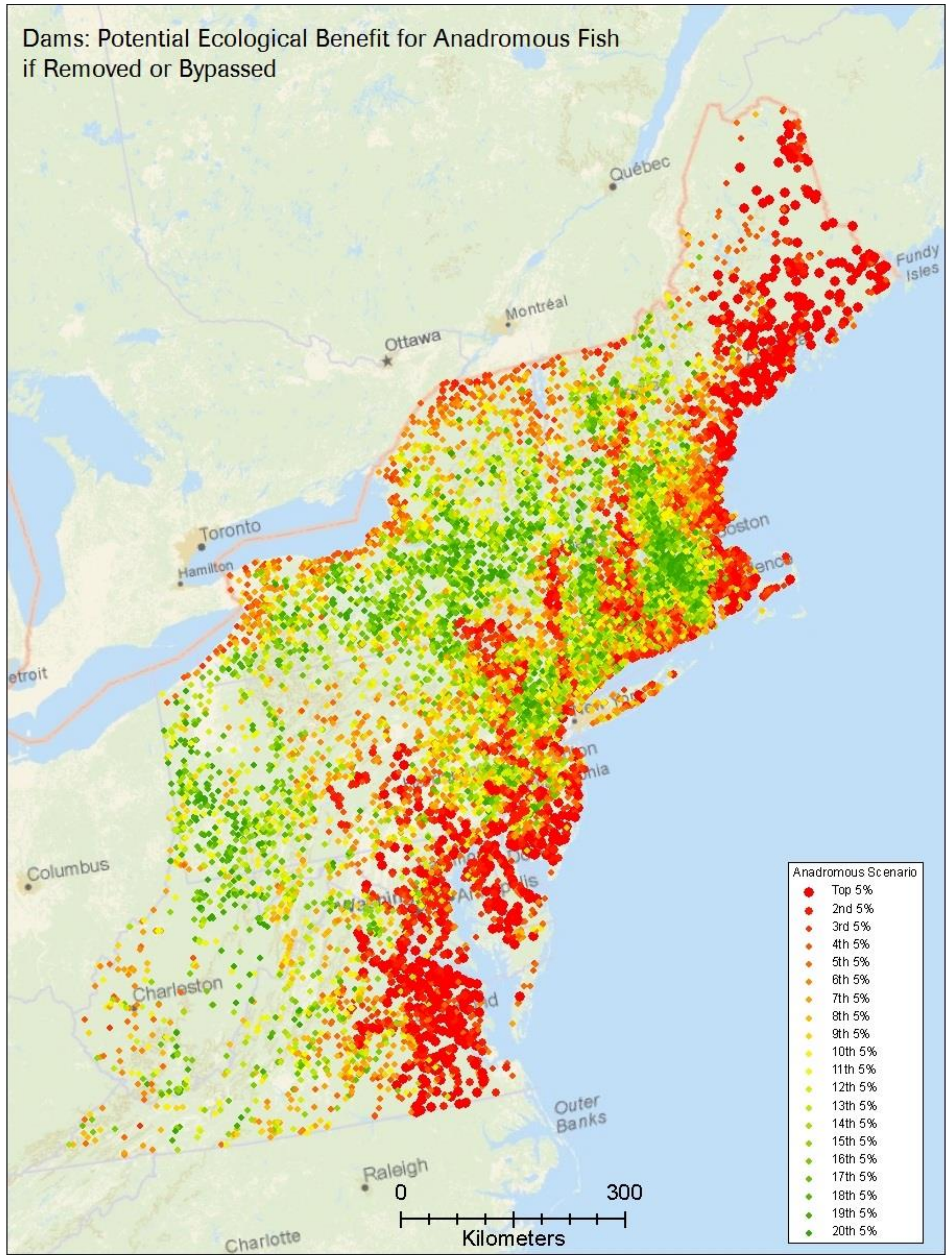


Table 3 Model selection criterion for the top ten Pradel reverse time, tag-recapture models of mussel survival (*Phi*), capture probability (*p*) and recruitment (*f*)

Model	−2Log *L*	*K*	Δ AIC_c	w_i
Phi(Maximum 10-day summer discharge), *p*(Discharge during sampling, species) *f*(Median summer discharge lag 2)	4574.1	8	0.000	0.071
Phi(Maximum 10-day summer discharge), *p*(Discharge during sampling, species) *f*(Maximum 10-day summer discharge lag 2)	4574.1	8	0.007	0.070
Phi(Maximum 10-day summer discharge), *p*(Discharge during sampling, species) *f*(Minimum 10-day spring discharge lag 2)	4574.1	8	0.056	0.069
Phi(Maximum 10-day summer discharge), *p*(Discharge during sampling, species) *f*(Minimum 10-day summer discharge lag 2)	4574.1	8	0.065	0.068
Phi(Maximum 10-day summer discharge), *p*(Discharge during sampling, species) f(Median spring discharge lag 2)	4574.2	8	0.120	0.067
Phi(Maximum 10-day summer discharge), *p*(Discharge during sampling, species) *f*(Maximum 10-day spring discharge lag 2)	4574.3	8	0.204	0.064
Phi(Median summer discharge), *p*(Discharge during sampling, species) *f*(Median spring discharge lag 2)	4574.9	8	0.848	0.046
Phi(Median summer discharge), *p*(Discharge during sampling, species) *f*(Maximum 10-day spring discharge lag 2)	4575.0	8	0.896	0.045
Phi(Median summer discharge), *p*(Discharge during sampling, species) *f*(Minimum 10-day spring discharge lag 2)	4575.0	8	0.897	0.045
Phi(Median summer discharge), *p*(Discharge during sampling, species) *f*(Maximum 10-day summer discharge lag 2)	4575.0	8	0.988	0.043





Spatial Models

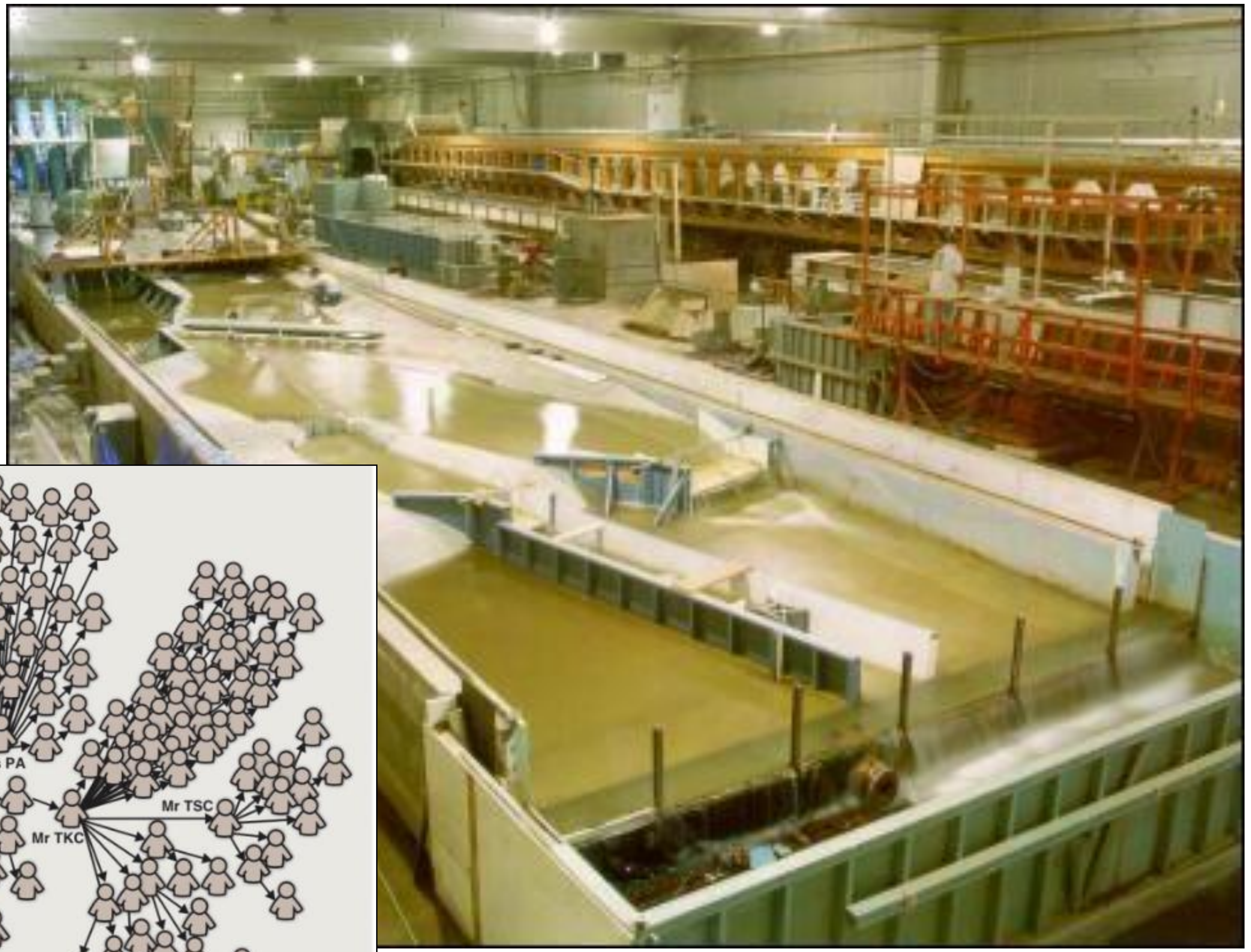
Combination of spatial attributes often coupled with simulation

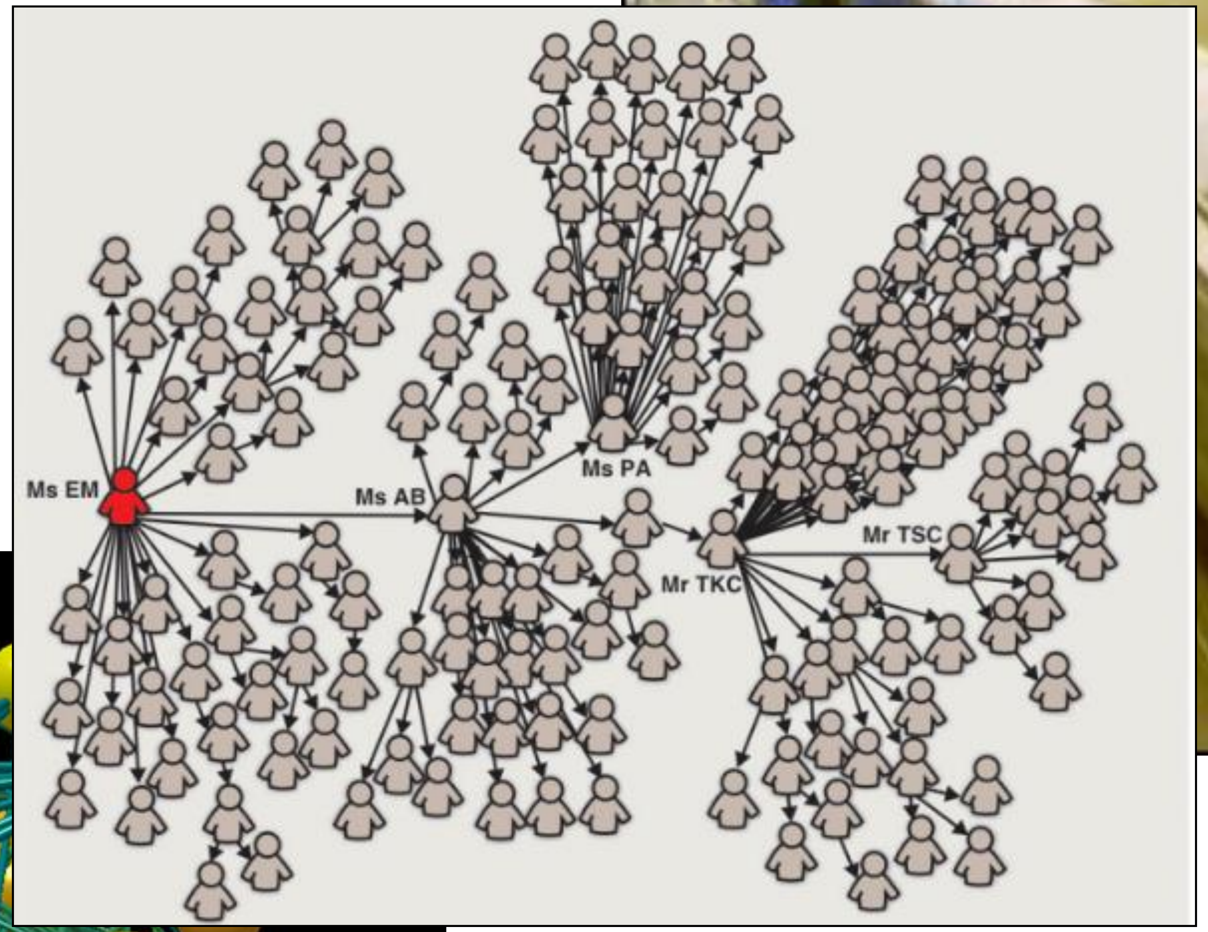
Other Notable Model Types

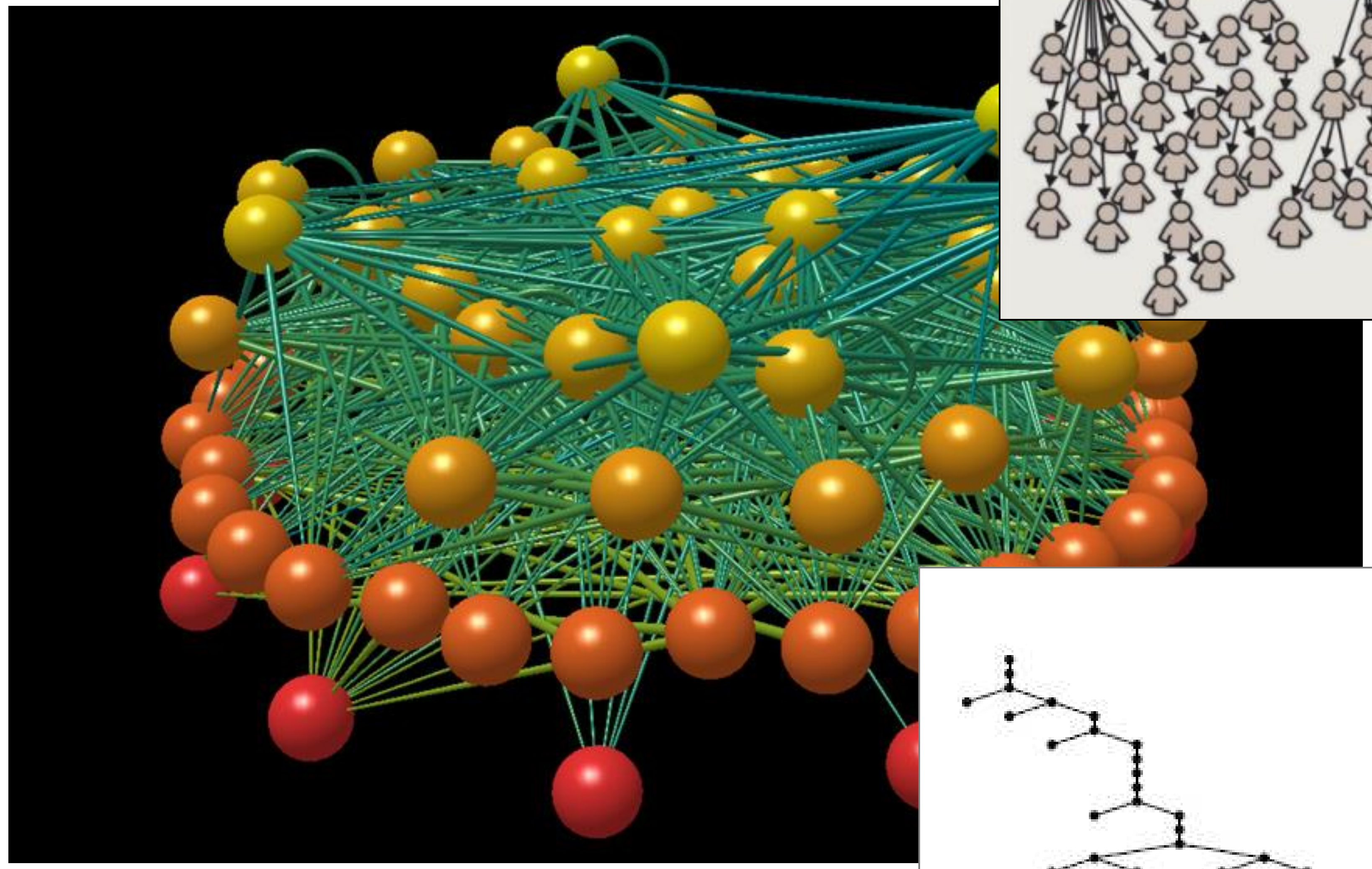
Physical

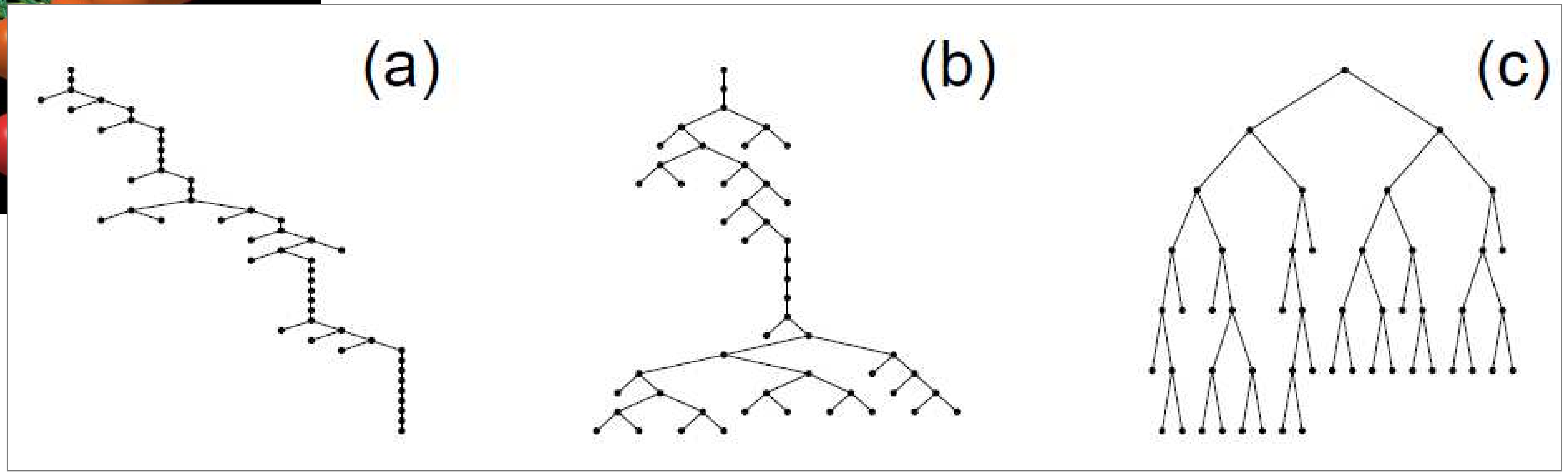
Systems

Networks

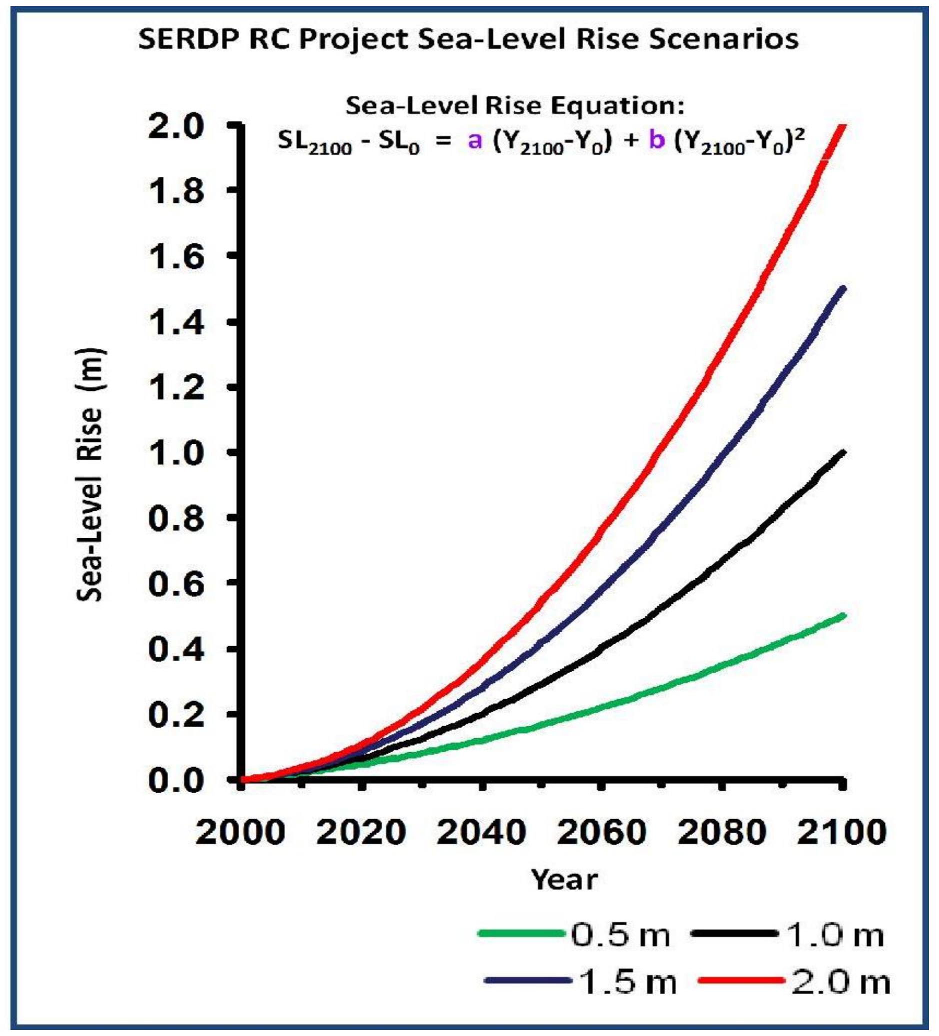


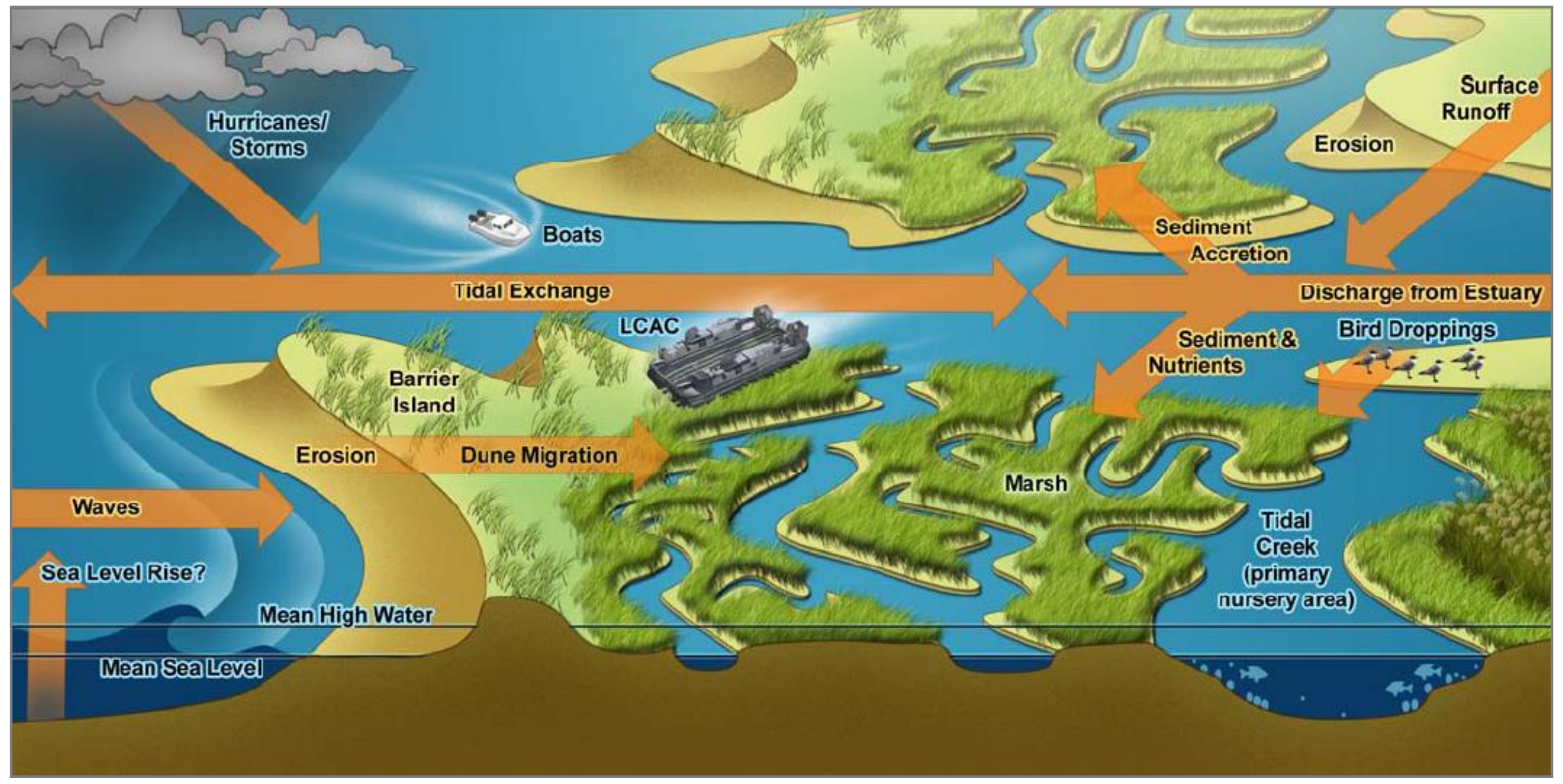


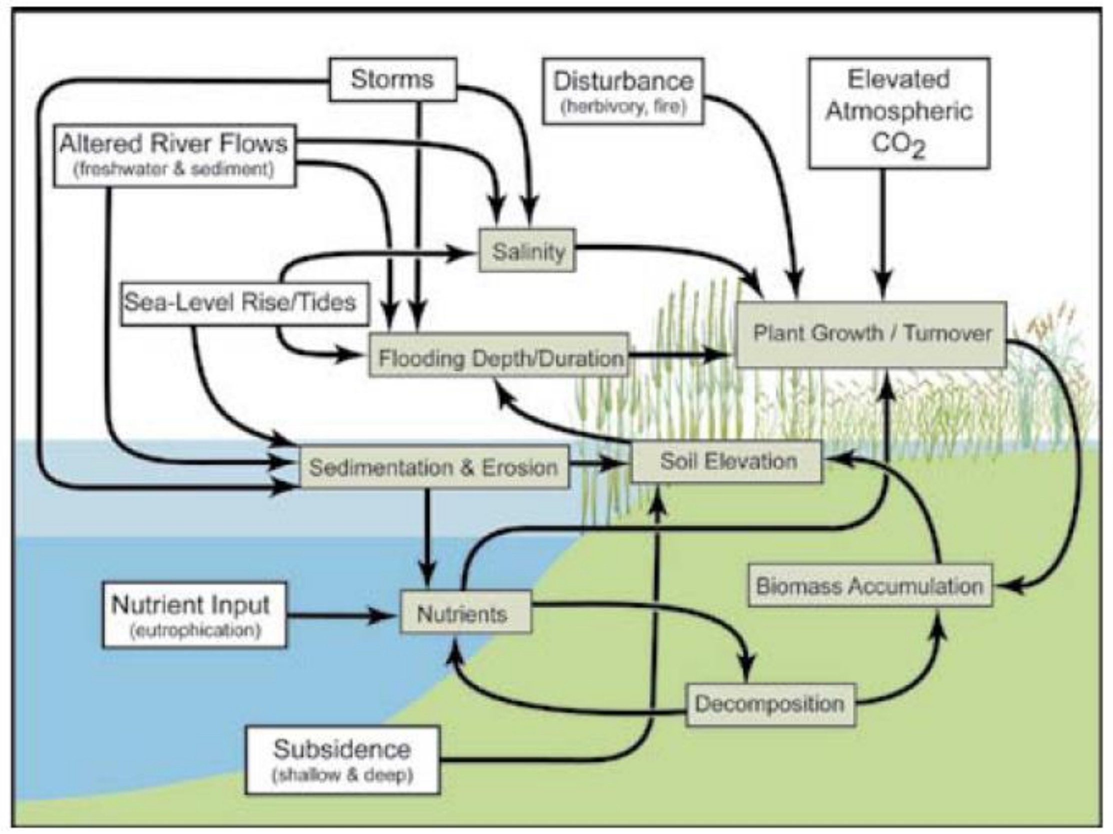


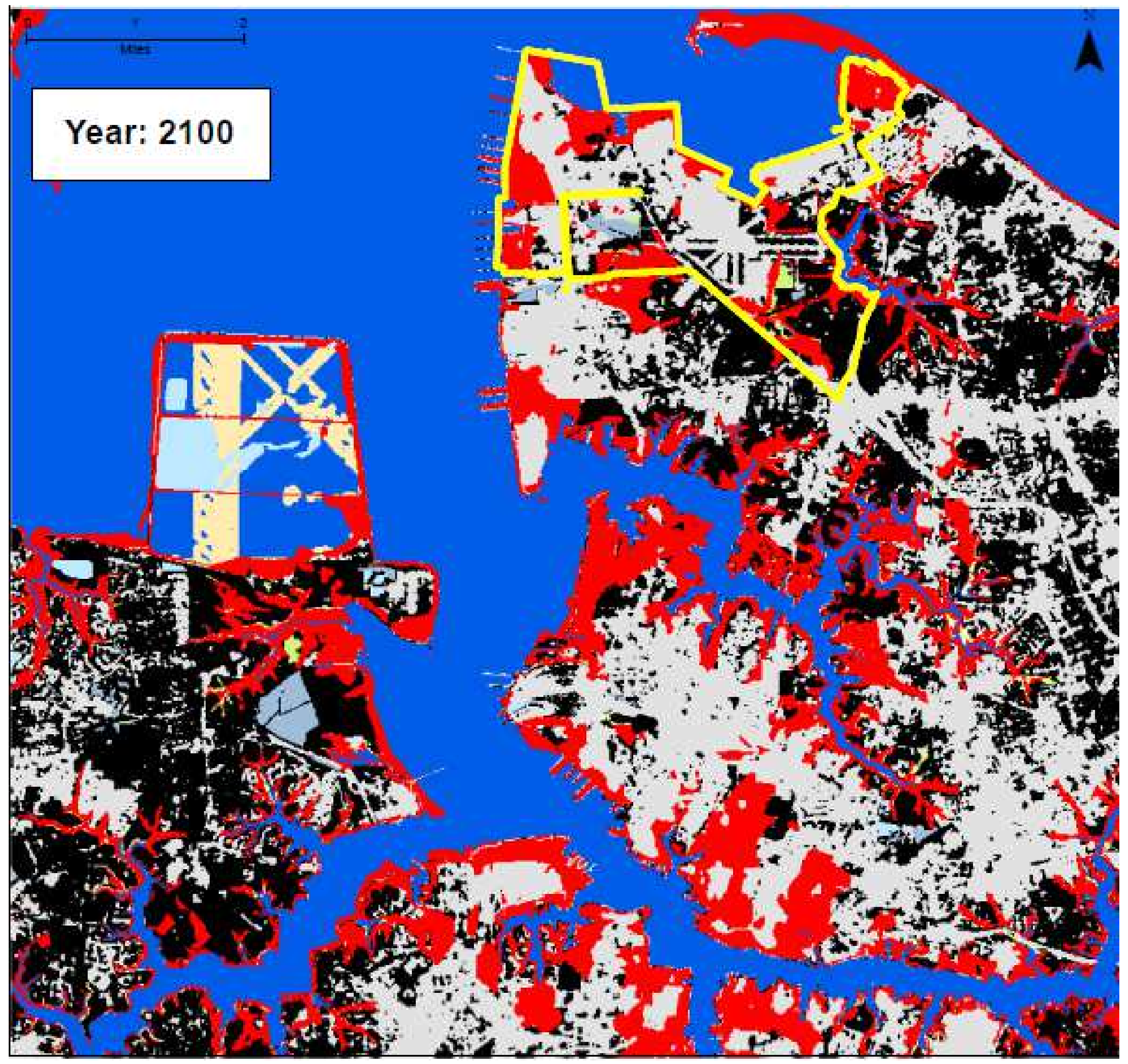


Integrated Modeling









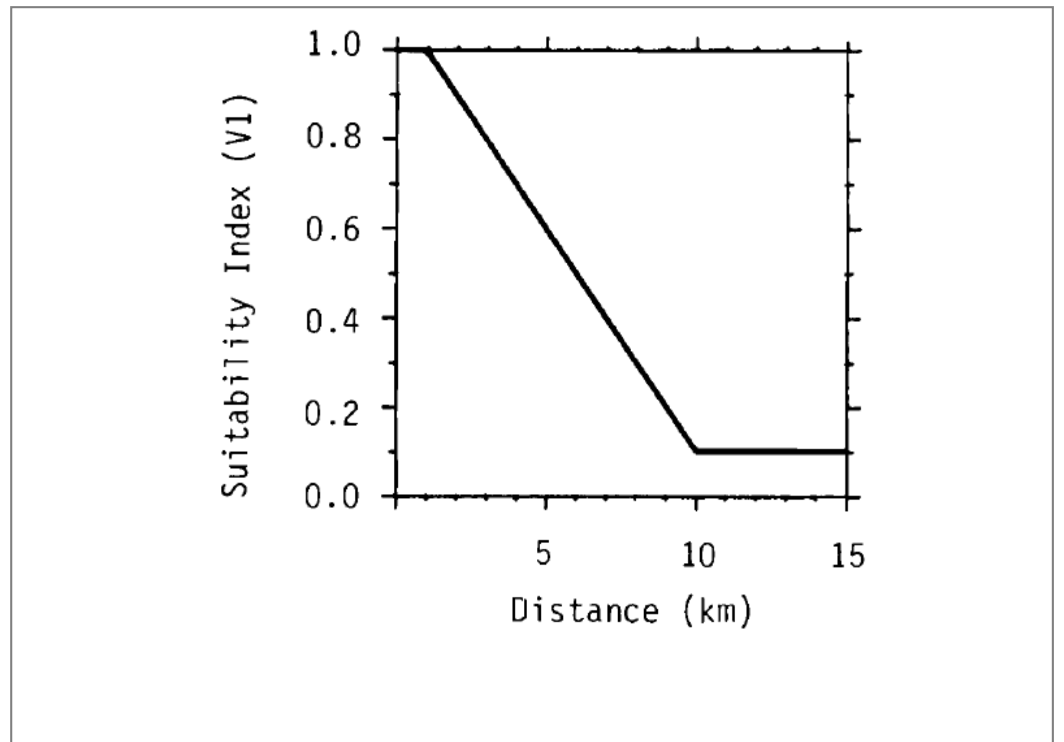
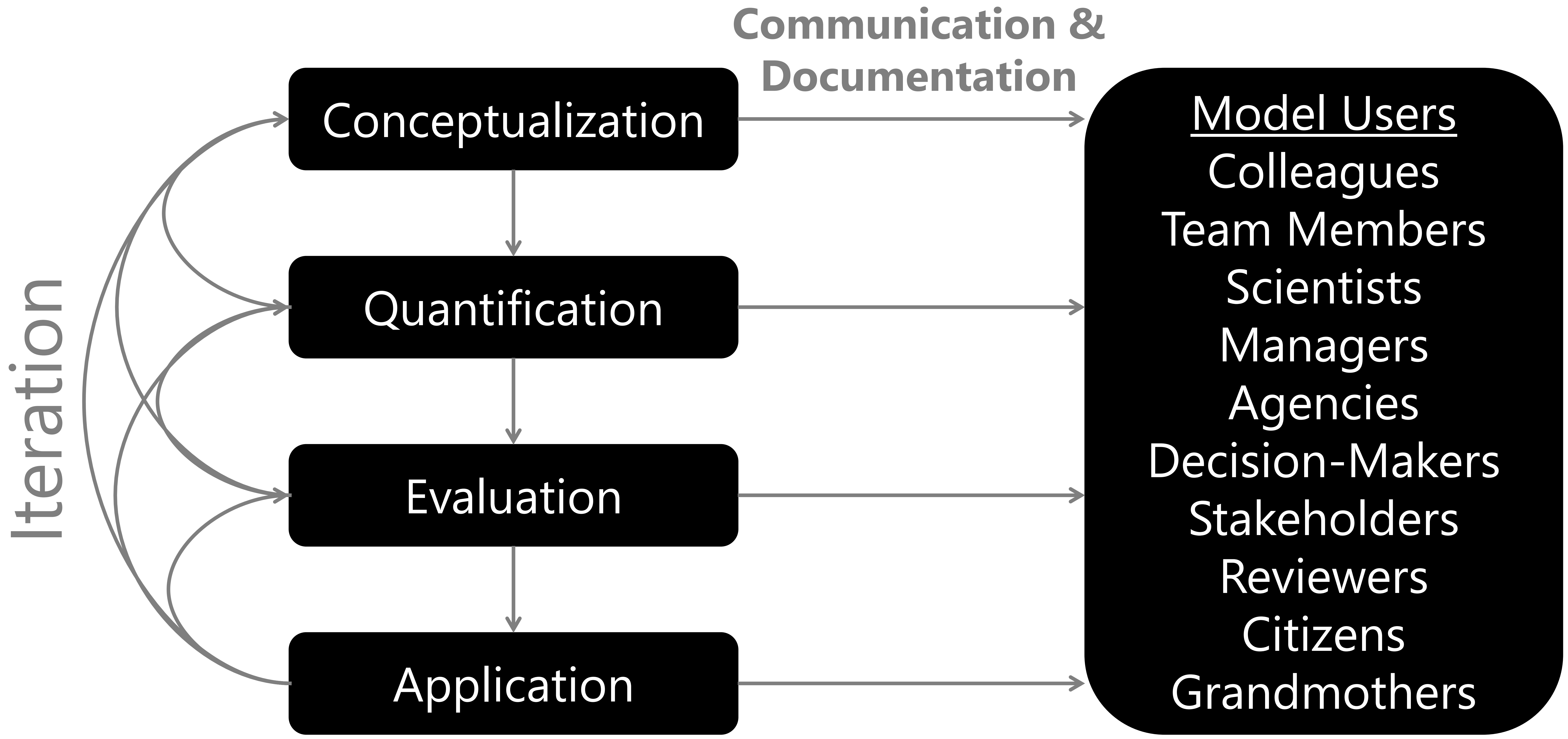


Figure 2. Distance between foraging areas and heronry sites modifies SI values.

The Modeling Process

Ecological Model Development



Key attributes for model development teams

- Creativity
- Flexibility
- Quiet
- Determination
- Humility
- Constructive criticism
- Listening to local experts!

Dr. Kyle McKay, modeling

Develop, refine, collaborate, iterate!

Covered throughout this course, but worth emphasizing

Developing good modeling practices is the key

- Don’t rely on good models; be a good modeler
- Communication and documentation are underemphasized, but overly important

The value of a “strawman” or alpha-version

Key warnings:

- Beware of plots without data points…
- Beware of anyone claiming their ecological model is predicting exactly what the future will look like
- Beware of an ecological model that is “well-behaved” (ecosystems are noisy, stochastic systems, not linear trajectories)

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Take-away Points:

- Models cannot cure all that ails you.
- Models can serve as useful tools.
- Many types (and combinations) of models exist.
- Model development is iterative, but these loops can be rapid!
  - Iteration helps avoid the pitfalls.

References for Further Reading

Grant W.E. and Swannack T.M. 2008. Ecological modeling: A common-sense approach to theory and practice. Malden, MA: Blackwell Publishing.

Schmolke A., Thorbek P., DeAngelis D.L., and Grimm V. 2010. Ecological models supporting environmental decision making: A strategy for the future. Trends in Ecology and Evolution, 25: 479-486.

Swannack T.M., Fischenich J.C., and Tazik D.J. 2012. Ecological Modeling Guide for Ecosystem Restoration and Management. ERDC/EL TR-12-18, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

McKay S.K. and Pruitt B.A. 2012. An Approach for Developing Regional Environmental Benefits Models. EMRRP-EBA-14, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Model Certification

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Policy and Guidance

- Present – EC 1105-2-412
  - PB 2013-02 – Continued EC 1105-2-412
  - PGN Update to include model certification and process
  - New guidance to align with principles of SMART Planning

- Model Cert SOP
  - Includes details of the certification process
  - Also being updated in near future

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314-1000

EC 1105-2-412

CECW-CP

Circular
No. 1105-2-412

31 March 2011

EXPIRES 31 March 2013
Planning
ASSURING QUALITY OF PLANNING MODELS

1. Purpose. This circular establishes the process and the requirements for assuring the quality of planning models.

2. Applicability. This circular applies to all USACE elements, Major Subordinate Commands (MSCs), and district commands having Civil Works responsibility. This guidance applies to planning models as defined in Paragraph 5 of this Circular.

3. References.

a. The Information Quality Act, Public Law No. 106-554.

b. Engineer Regulation 1105-2-100, Planning Guidance Notebook, April 2000.

c. Engineering and Construction Bulletin 2007-6: Model Certification Issues for Engineering Software in Planning Studies.

d. U.S. Army Corps of Engineers, Report of the Planning Models Improvement Task Force, September 2003.

e. Office of Management and Budget, Final Information Quality Bulletin for Peer Review, Federal Register Vol. 70, No. 10, January 14, 2005, pp 2664-2677.

4. Background.

a. The Corps of Engineers Planning Models Improvement Program (PMIP) was established in 2003 to assess the state of planning models in the Corps and to make recommendations to assure that high quality methods and tools are available to enable informed decisions on investments in the Nation's water resources infrastructure and natural environment. The main objective of the PMIP is to carry out "a process to review, improve and validate analytical tools and models for U.S. Army Corps of Engineers (USACE) Civil Works business programs." In carrying out this initiative, a PMIP Task Force was established to examine planning model issues, assess the state of planning models in the Corps, and develop recommendations on improvements to planning models and related analytical tools. The PMIP Task Force collected the views of Corps leaders and recognized technical experts, and conducted investigations and

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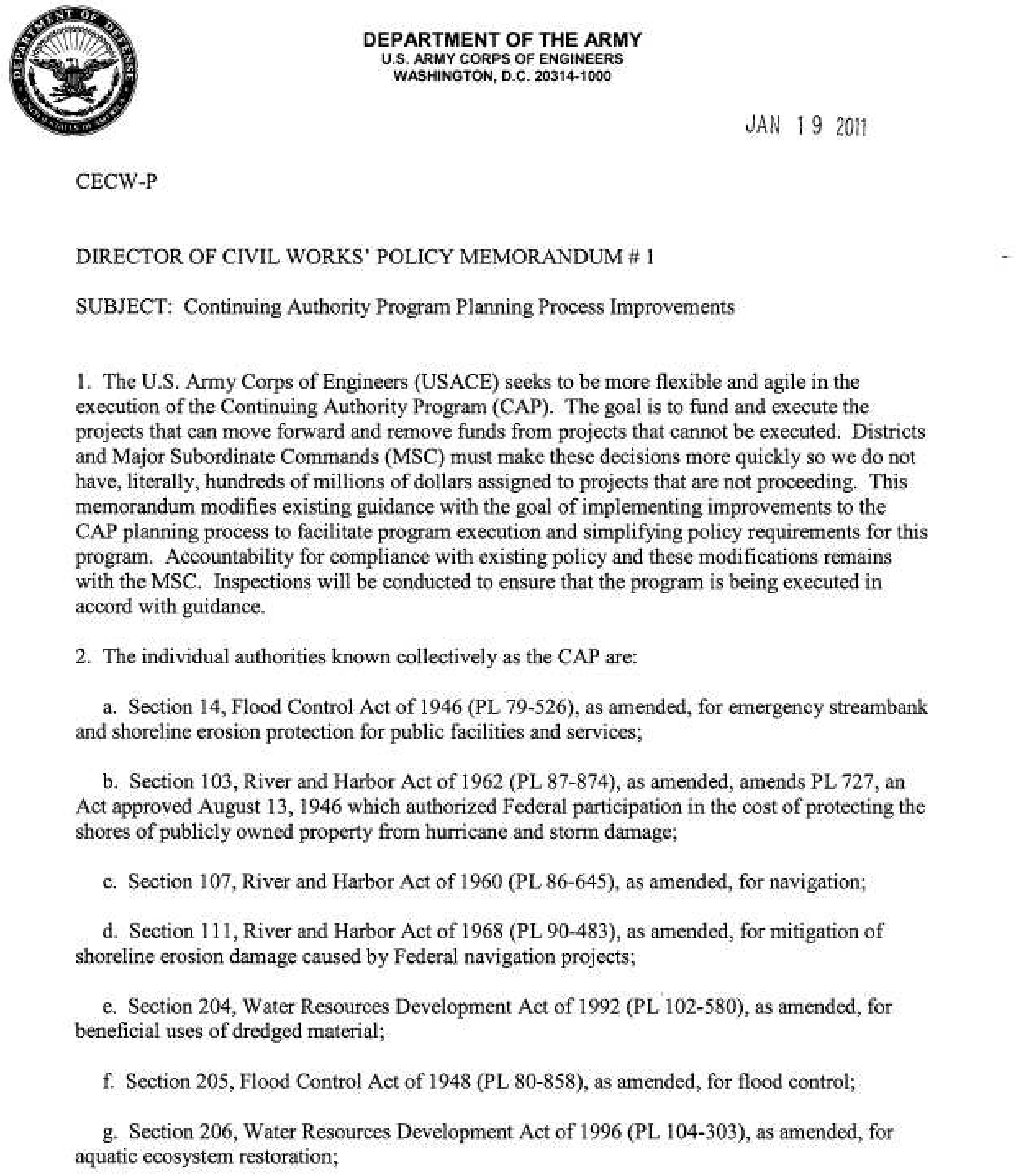
Policy and Guidance

- Continuing Authorities Program Planning Process Memo – Jan 2011
  - Approval of planning models not required
  - MSC responsible for assuring quality of models
  - ATR used to ensure models and analyses are:
    - Compliant with Corps policy
    - Theoretically sound
    - Computationally accurate
    - Transparent
    - Described to address limitations and use
    - Documented appropriately



DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
WASHINGTON, D.C. 20314-1000

JAN 19 2011

CECW-P

DIRECTOR OF CIVIL WORKS' POLICY MEMORANDUM # 1

SUBJECT: Continuing Authority Program Planning Process Improvements

1. The U.S. Army Corps of Engineers (USACE) seeks to be more flexible and agile in the execution of the Continuing Authority Program (CAP). The goal is to fund and execute the projects that can move forward and remove funds from projects that cannot be executed. Districts and Major Subordinate Commands (MSC) must make these decisions more quickly so we do not have, literally, hundreds of millions of dollars assigned to projects that are not proceeding. This memorandum modifies existing guidance with the goal of implementing improvements to the CAP planning process to facilitate program execution and simplifying policy requirements for this program. Accountability for compliance with existing policy and these modifications remains with the MSC. Inspections will be conducted to ensure that the program is being executed in accord with guidance.

2. The individual authorities known collectively as the CAP are:

a. Section 14, Flood Control Act of 1946 (PL 79-526), as amended, for emergency streambank and shoreline erosion protection for public facilities and services;

b. Section 103, River and Harbor Act of 1962 (PL 87-874), as amended, amends PL 727, an Act approved August 13, 1946 which authorized Federal participation in the cost of protecting the shores of publicly owned property from hurricane and storm damage;

c. Section 107, River and Harbor Act of 1960 (PL 86-645), as amended, for navigation;

d. Section 111, River and Harbor Act of 1968 (PL 90-483), as amended, for mitigation of shoreline erosion damage caused by Federal navigation projects;

e. Section 204, Water Resources Development Act of 1992 (PL 102-580), as amended, for beneficial uses of dredged material;

f. Section 205, Flood Control Act of 1948 (PL 80-858), as amended, for flood control;

g. Section 206, Water Resources Development Act of 1996 (PL 104-303), as amended, for aquatic ecosystem restoration;

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Definitions

What is “model certification”?

“… a corporate approval that the model is sound and functional.”

What is a planning model?

Models and analytical tools that planners use to define water resources management problems and opportunities, formulate potential alternatives, evaluate potential effects of alternatives, and support decision-making.

Includes all models used for planning, regardless of their scope or source

What is a “certified” planning model?

“… A planning model reviewed and certified by the appropriate Planning Center of Expertise (PCX) in accordance with the criteria and procedures specified in EC 1105-2-412.”

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Certification Criteria

What criteria used by the PCX as basis for certification?

Technical Quality – Contemporary theory, consistent with design objectives, documented, tested

System Quality – Computational integrity, appropriately programmed, verified or stress-tested

Usability – Ease of use, availability of input, transparency, error potential, education of user

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Easier Model Approval

Develop and use Conceptual Models

- Excellent tool to communicate stressors and drivers
- Inform level of detail
- Selection of model

EARLY, EARLY, EARLY Communication with ECO-PCX

- During identification of problems and opportunities
- Selecting models and level of detail necessary
- Selection and review should be in-progress or complete by the Alternatives Milestone
- Preparation of plan for review, testing, and documentation (i.e., Model Review Plan)
- In advance of any kind of internal, external, formal, or informal review

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Easier Model Approval

- Complete model documentation
  - Address model certification criteria including application to planning
  - Documentation of prior model review and testing
    - Reviewers' qualifications,
    - Review charge
    - Comments and responses,
    - Proposed revisions to the model

- Early identification of model review needs facilitates:
  - Review process setup
  - Concurrent review with model development

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Easier Model Approval

Already reviewed model?

- Provide review documentation including:
  - reviewers' qualifications,
  - Review charge
  - comments and responses,
  - proposed revisions to the model.

Don't overlook Quality Control of your spreadsheets to ensure computational correctness and usability.

Early identification of model review needs facilitates:

- Review process setup
- Concurrent review with model development