GEER 2017
Greater Everglades Ecosystem Restoration
*Advancing Science, Restoring the Everglades*

# Application of the comprehensive aquatic system model (CASM-4D) in support of ecosystem restoration

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# Purpose

- Describe the CASM
- Introduce the SAND model
- Present SAND-CASM integration to address ecosystem restoration

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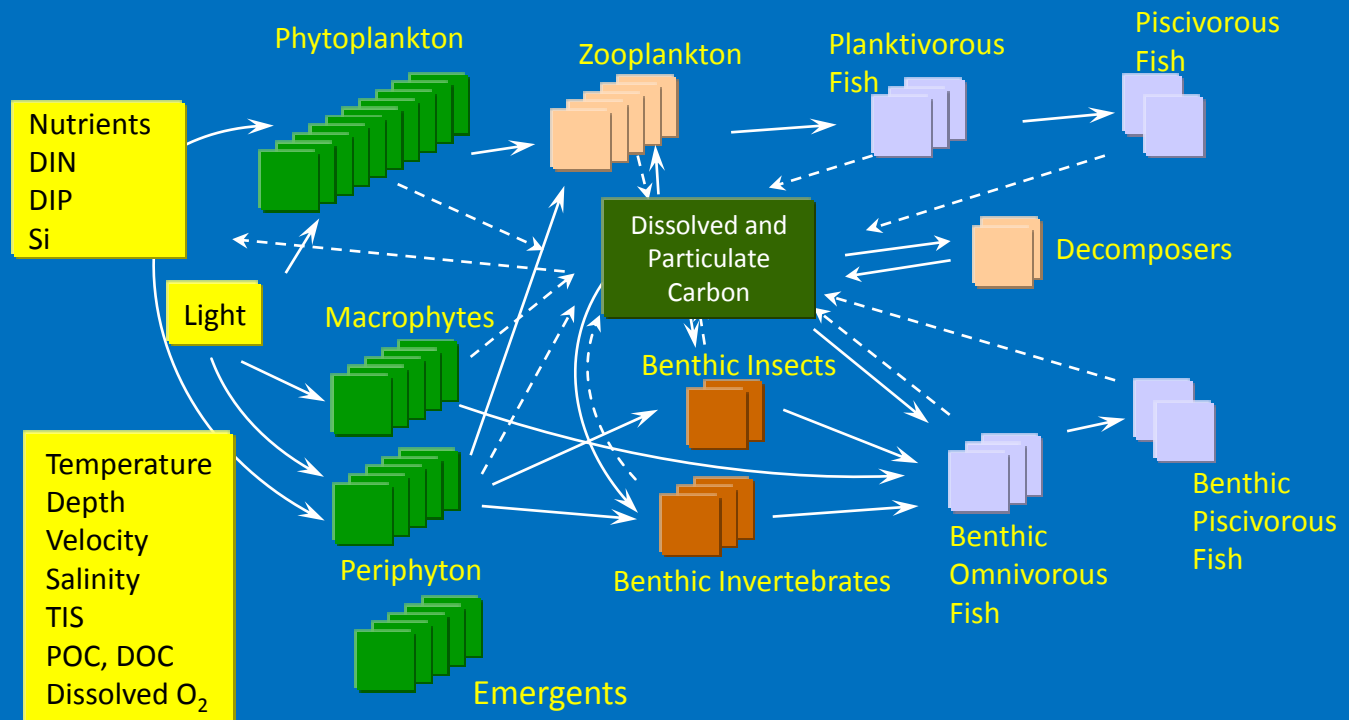
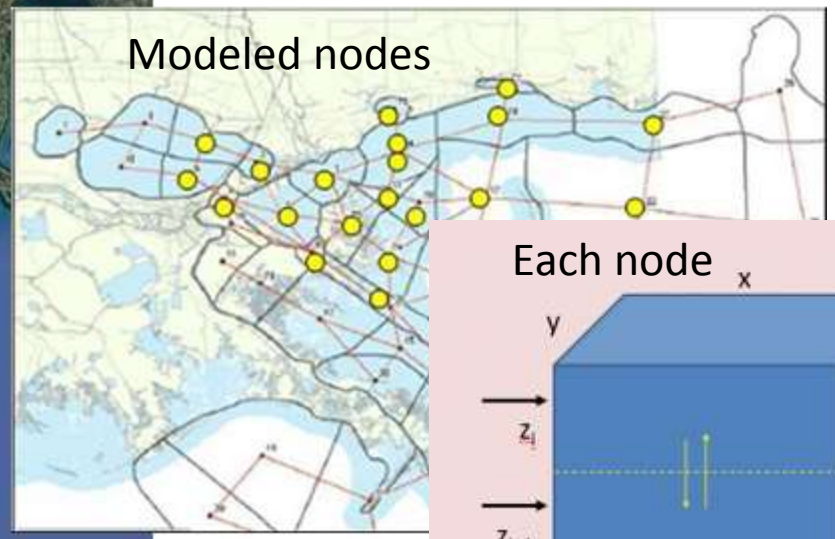
Craig Fischenich
Bobby McComas
ERDC, Vicksburg, MS for
SAND modeling

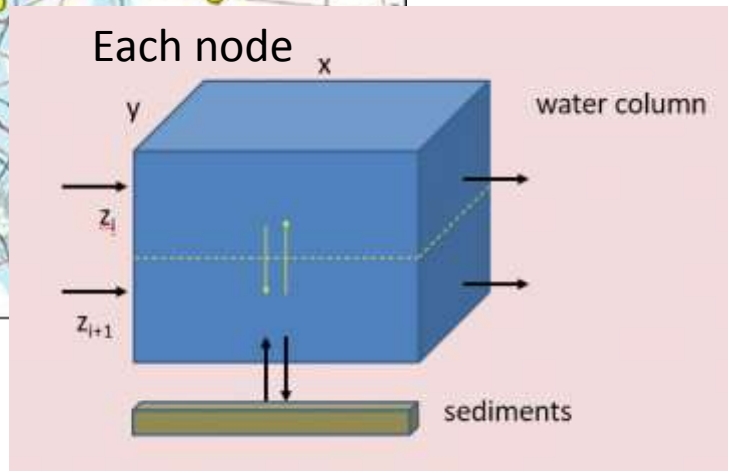
# Comprehensive Aquatic Systems Model – CASM-4D

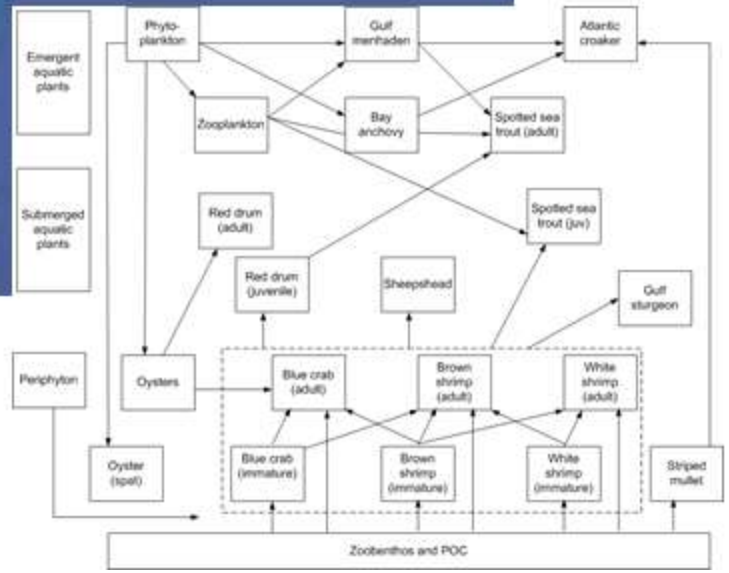



What is the CASM? How does it work?

# Coastal Louisiana example

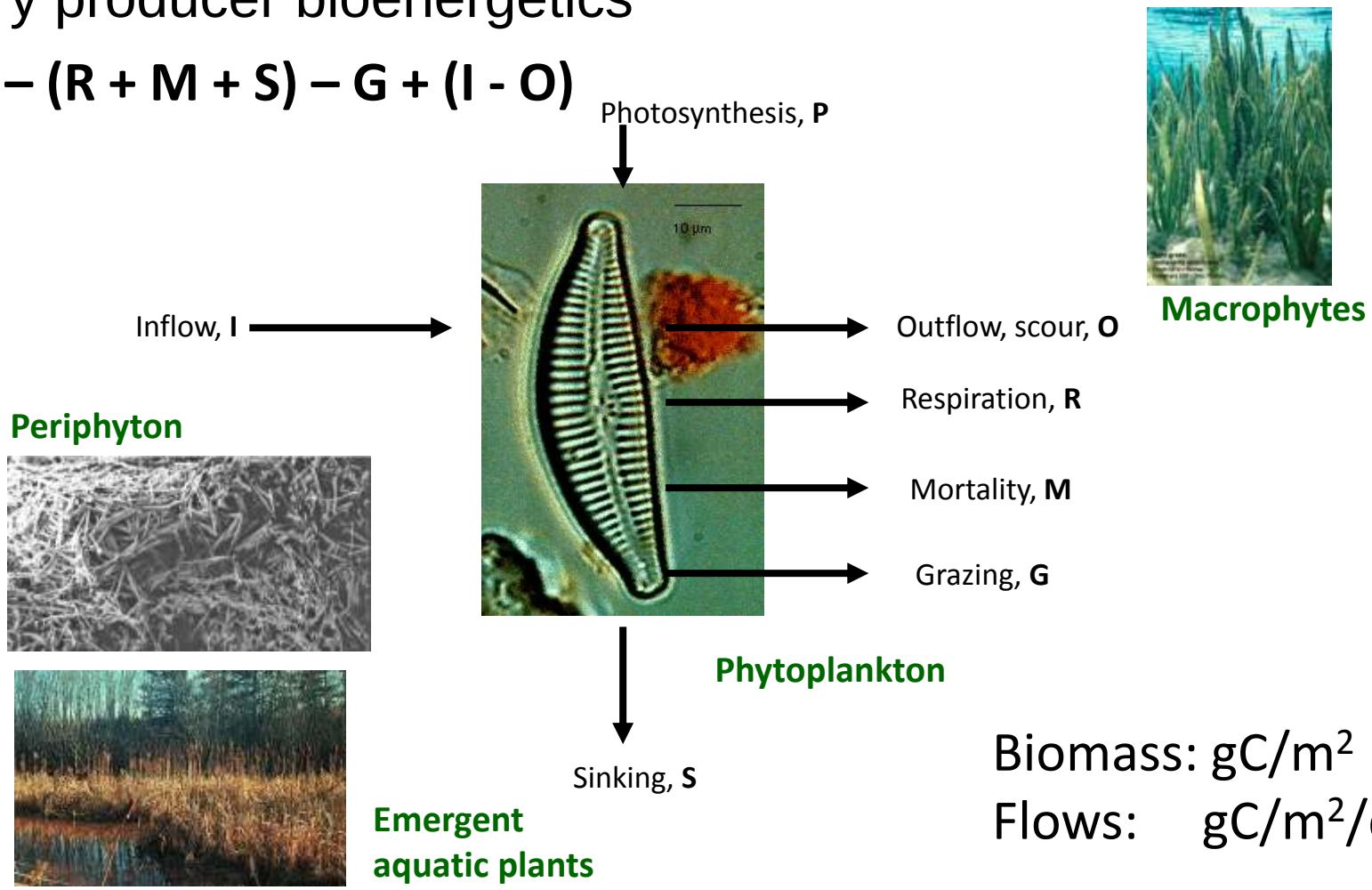




Food web is embedded in each layer of each node

# Modeling aquatic plant populations

## Primary producer bioenergetics

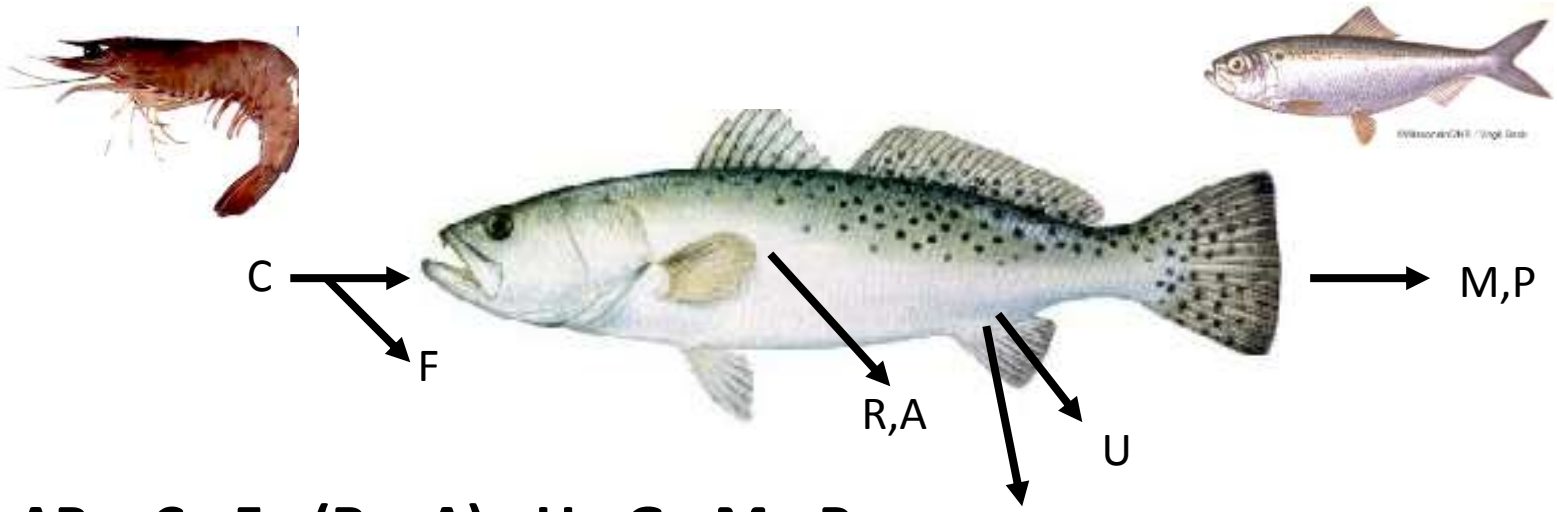
$$\Delta B = P - (R + M + S) - G + (I - O)$$




Biomass: $gC/m^2$

Flows: $gC/m^2/d$

# Modeling fish and invertebrate populations




**$\Delta B = C - F - (R + A) - U - G - M - P$**

Biomass: $gC/m^2$

Flows: $gC/m^2/d$

# Environmental inputs define habitat quality and distribution

## Habitat quality effects on population-specific modeled growth

Producer habitat modifier

$H_{mod} = F(h_{salinity}, h_{depth}, h_{velocity})$

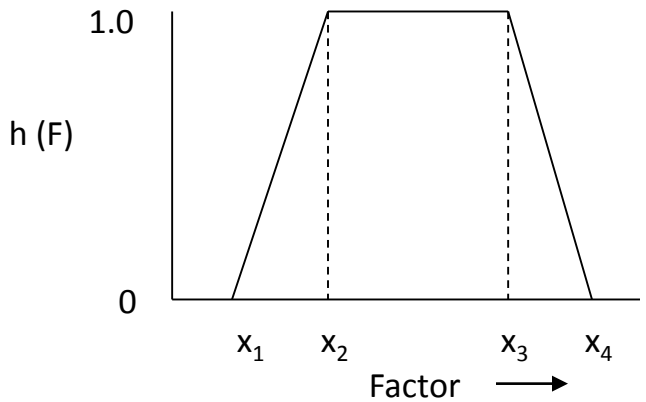
Consumer habitat modifier

$H_{mod} = F(h_{DO}, h_{depth}, h_{salinity}, h_{velocity})$

For each species, node, and time step:

$dB/dt = r\, H_{mod}\, B$,

where, r is the overall growth rate determined by the bioenergetics

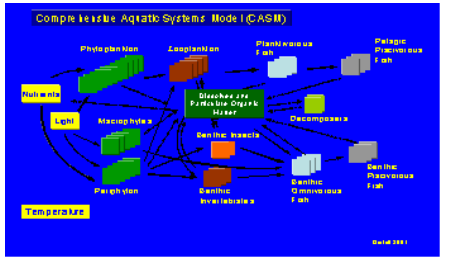



$x_1$ = lower threshold

$x_2$-$x_3$ = optimal range

$x_4$ = upper threshold

# CASM-4D Outputs




**Biological/Ecological**

Daily values of population biomass ($gC/m^2$)

Community diversity

System-level N and P assimilation

Oxygen produced

Carbon sequestration

**Environmental**

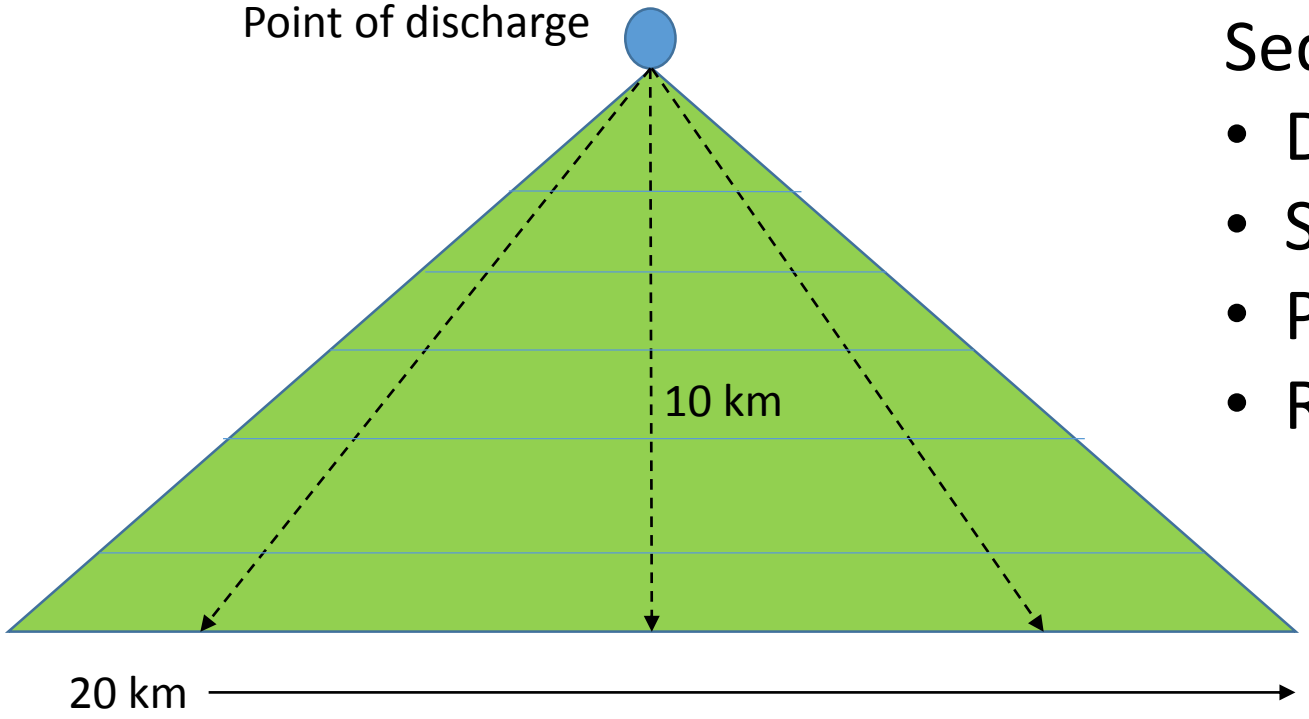
Dissolved oxygen

DIN, DIP, Si, TIS, POC, DOC

**Ecological Risks**

Population, community, ecosystem effects

# SAND V3: Sediment And Nutrient Diversion Model - Planform

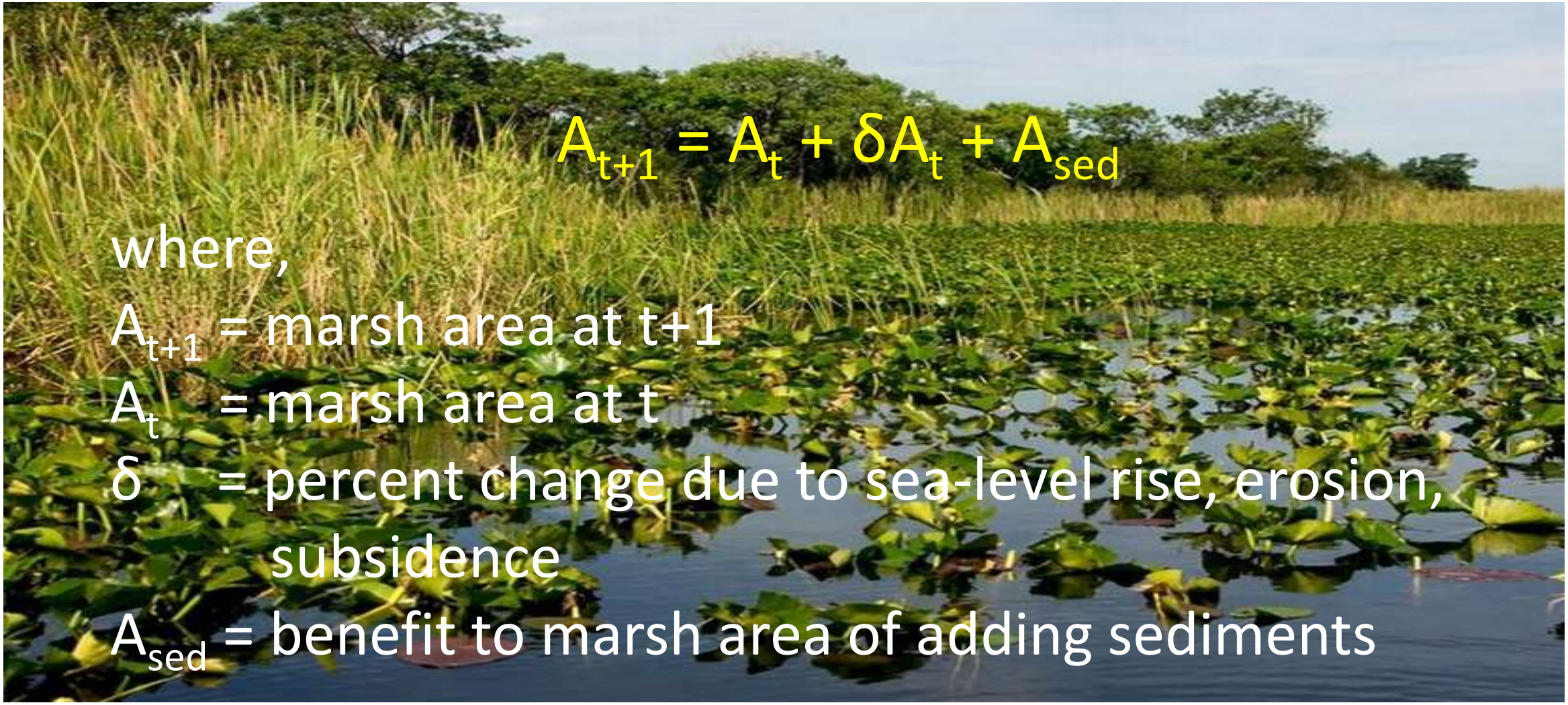



Sediment accumulation

- Discharge, velocity
- Suspended sediment concentrations
- Particle size
- Roughness


Example has 50 spatial  zones across the model domain

# SAND V3: Sediment And Nutrient Diversion Model



$$A_{t+1} = A_t + \delta A_t + A_{sed}$$

where,

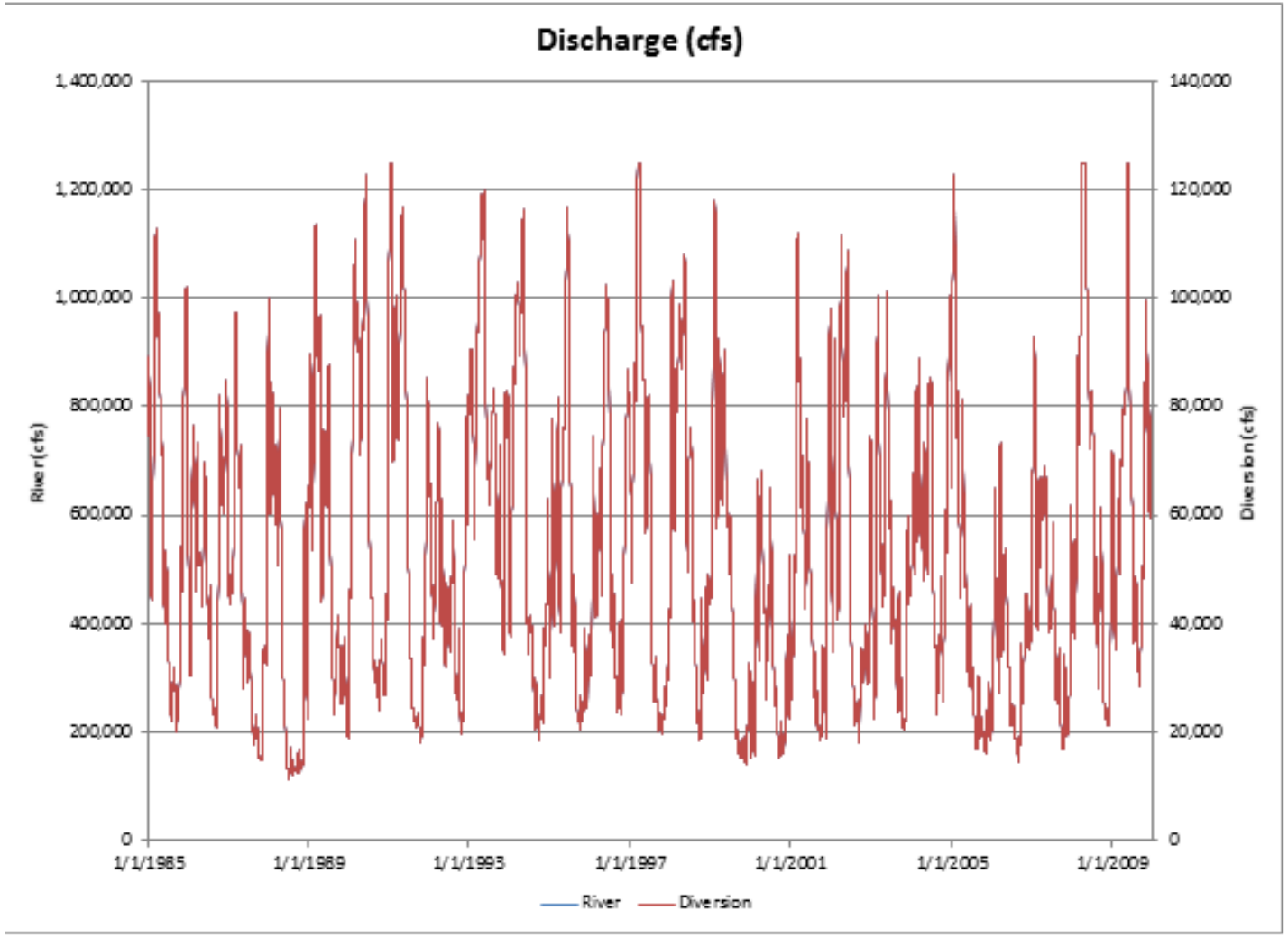
$A_{t+1}$ = marsh area at t+1

$A_t$ = marsh area at t

$\delta$ = percent change due to sea-level rise, erosion, subsidence

$A_{sed}$ = benefit to marsh area of adding sediments

# Example SAND input river discharge – 25 y



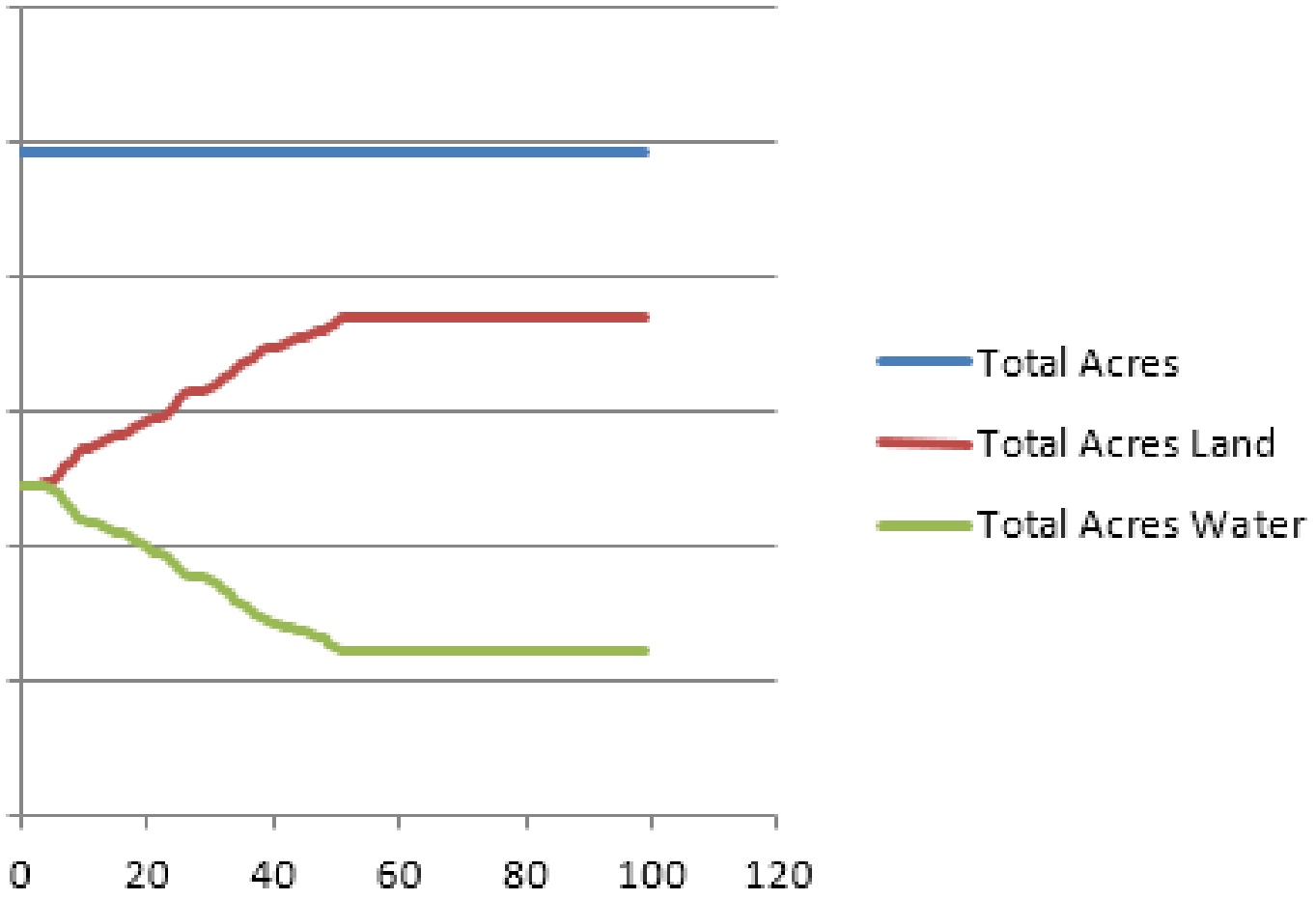

- Daily discharge
- Suspended sediment load
- Nutrient concentration

# SAND annual sediment deposition (feet) – selected zones

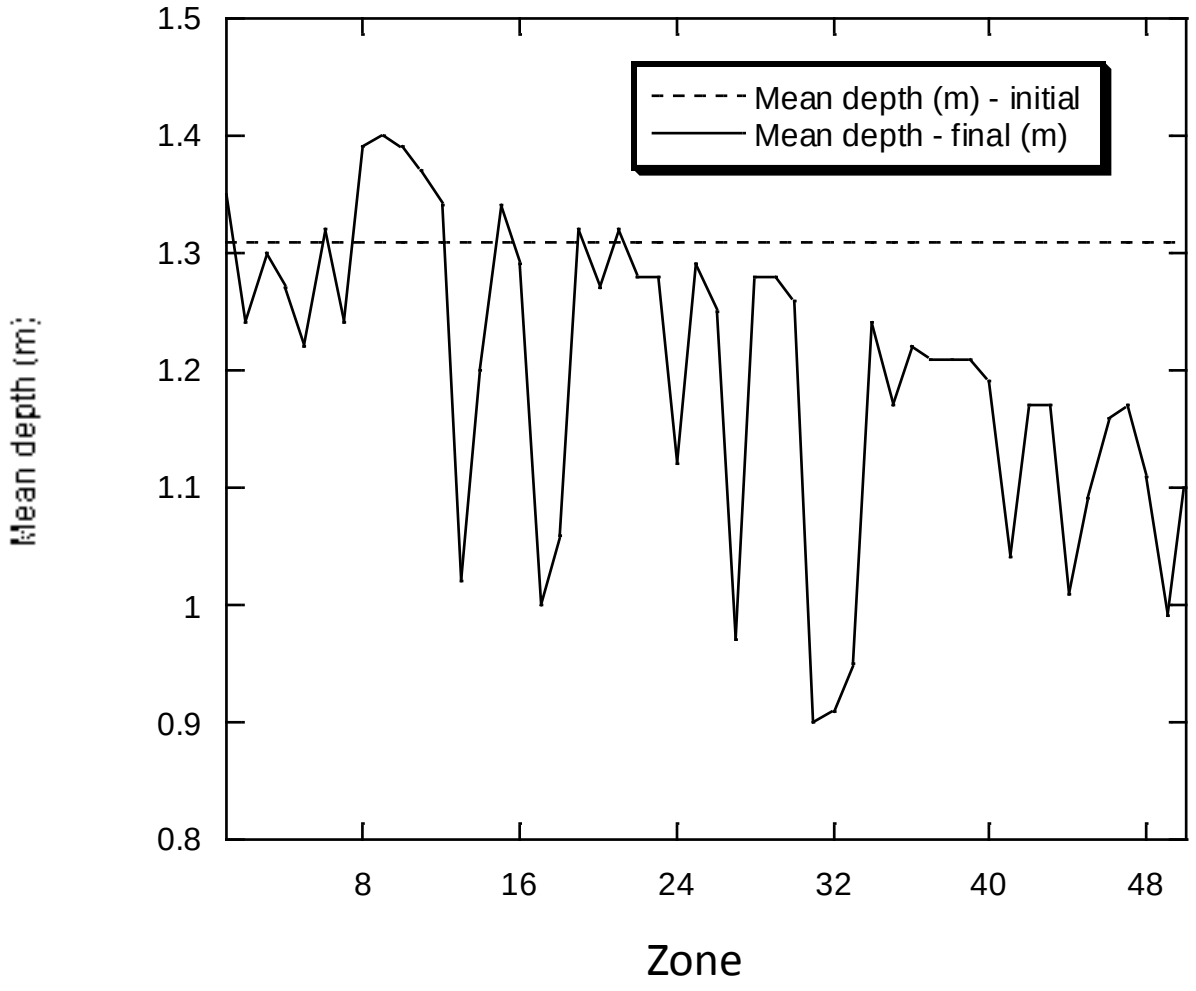
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 | Zone 8 | Zone 9 | Zone 10 | Zone 11 | Zone 12 | Zone 13 | Zone 14 | Zone 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year 1 | 0.6728 | 1.0143 | 0.9810 | 0.7435 | 0.6027 | 0.5103 | 0.4455 | 0.3980 | 0.3621 | 0.3342 | 0.3120 | 0.2938 | 0.2787 | 0.2661 | 0.2553 |
| Year 2 | 0.5879 | 0.9237 | 0.7651 | 0.5800 | 0.4705 | 0.3612 | 0.3164 | 0.2839 | 0.2595 | 0.2408 | 0.2259 | 0.2140 | 0.2043 | 0.1961 | 0.1889 |
| Year 3 | 0.4583 | 0.6596 | 0.5901 | 0.4051 | 0.3289 | 0.2784 | 0.2439 | 0.2188 | 0.2000 | 0.1853 | 0.1589 | 0.1506 | 0.1435 | 0.1371 | 0.1314 |
| Year 4 | 0.3970 | 0.5917 | 0.5935 | 0.4598 | 0.3322 | 0.2815 | 0.2452 | 0.2193 | 0.1995 | 0.1839 | 0.1713 | 0.1612 | 0.1529 | 0.1459 | 0.1400 |
| Year 5 | 0.5721 | 0.9673 | 1.0813 | 0.8635 | 0.6983 | 0.5247 | 0.4569 | 0.4068 | 0.3674 | 0.3380 | 0.3147 | 0.2960 | 0.2804 | 0.2673 | 0.2559 |
| Year 6 | 0.5838 | 0.0000 | 0.0000 | 1.0997 | 0.8141 | 0.6834 | 0.5933 | 0.4710 | 0.4264 | 0.3914 | 0.3634 | 0.3410 | 0.3210 | 0.3055 | 0.2920 |
| Year 7 | 0.5862 | 0.0000 | 0.0000 | 0.0000 | 1.0758 | 0.8876 | 0.6755 | 0.5976 | 0.5391 | 0.4927 | 0.4094 | 0.3833 | 0.3613 | 0.3429 | 0.3274 |
| Year 8 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4186 | 0.3560 | 0.2799 | 0.2532 | 0.2332 | 0.2172 | 0.2051 | 0.1952 | 0.1871 | 0.1644 |
| Year 9 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.9285 | 0.8057 | 0.6363 | 0.5805 | 0.5355 | 0.5003 | 0.4710 | 0.4467 | 0.4263 |
| Year 10 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4648 | 0.4147 | 0.3821 | 0.3166 | 0.2983 | 0.2830 | 0.2699 |
| Year 11 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3537 | 0.3208 | 0.2972 | 0.2798 | 0.2369 | 0.2262 |
| Year 12 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3673 | 0.3319 | 0.3119 | 0.2953 | 0.2520 |
| Year 13 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.4163 | 0.3804 | 0.3582 | 0.3393 |
| Year 14 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3775 | 0.3463 | 0.3276 |
| Year 15 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3925 | 0.3585 | 0.2567 |
| Year 16 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1790 | 0.1632 | 0.0000 |
| Year 17 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3826 | 0.0000 | 0.0000 |
| Year 18 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Year 19 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Year 20 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Year 21 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Year 22 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

- Depends upon discharge, velocity, particle size, bathymetry, and sediment consolidation
- Value of zero means maximum amount of land-building achieved for the zone

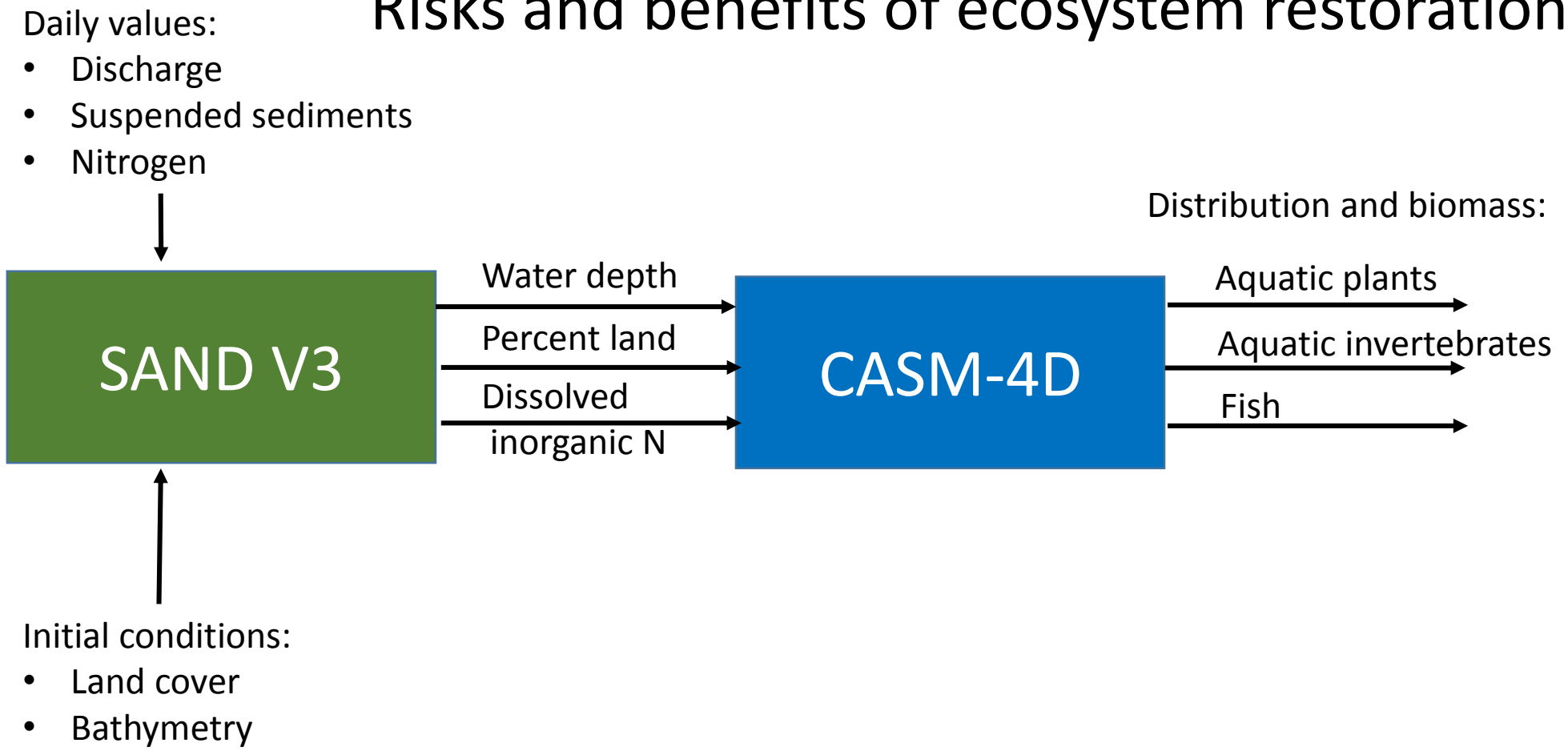
# SAND modeled changes in land cover – entire domain



# SAND modeled changes in mean zone depth – after 25 y

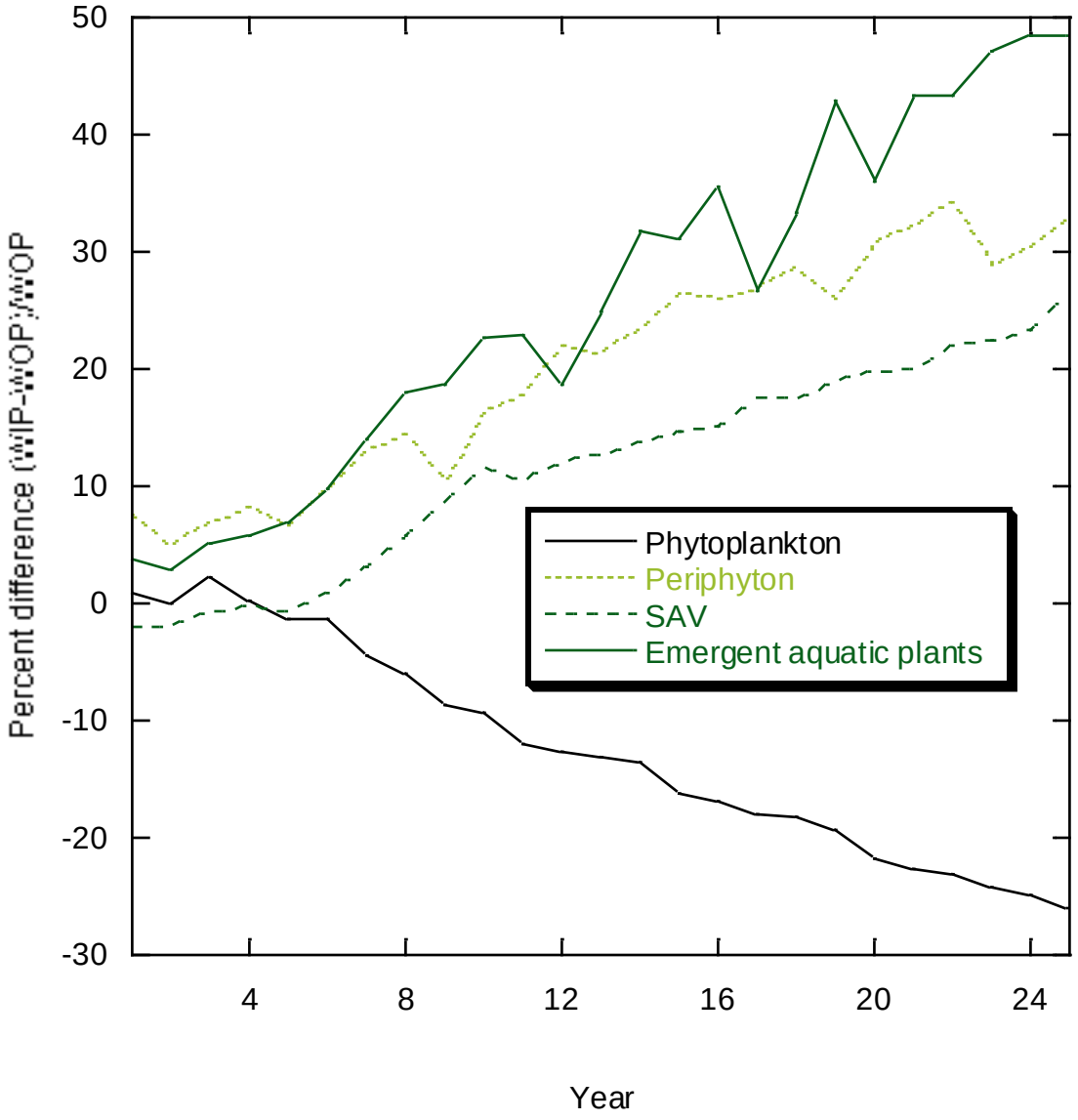


# Risks and benefits of ecosystem restoration




Use an integrated modeling approach to examine ecological implications of sediment management

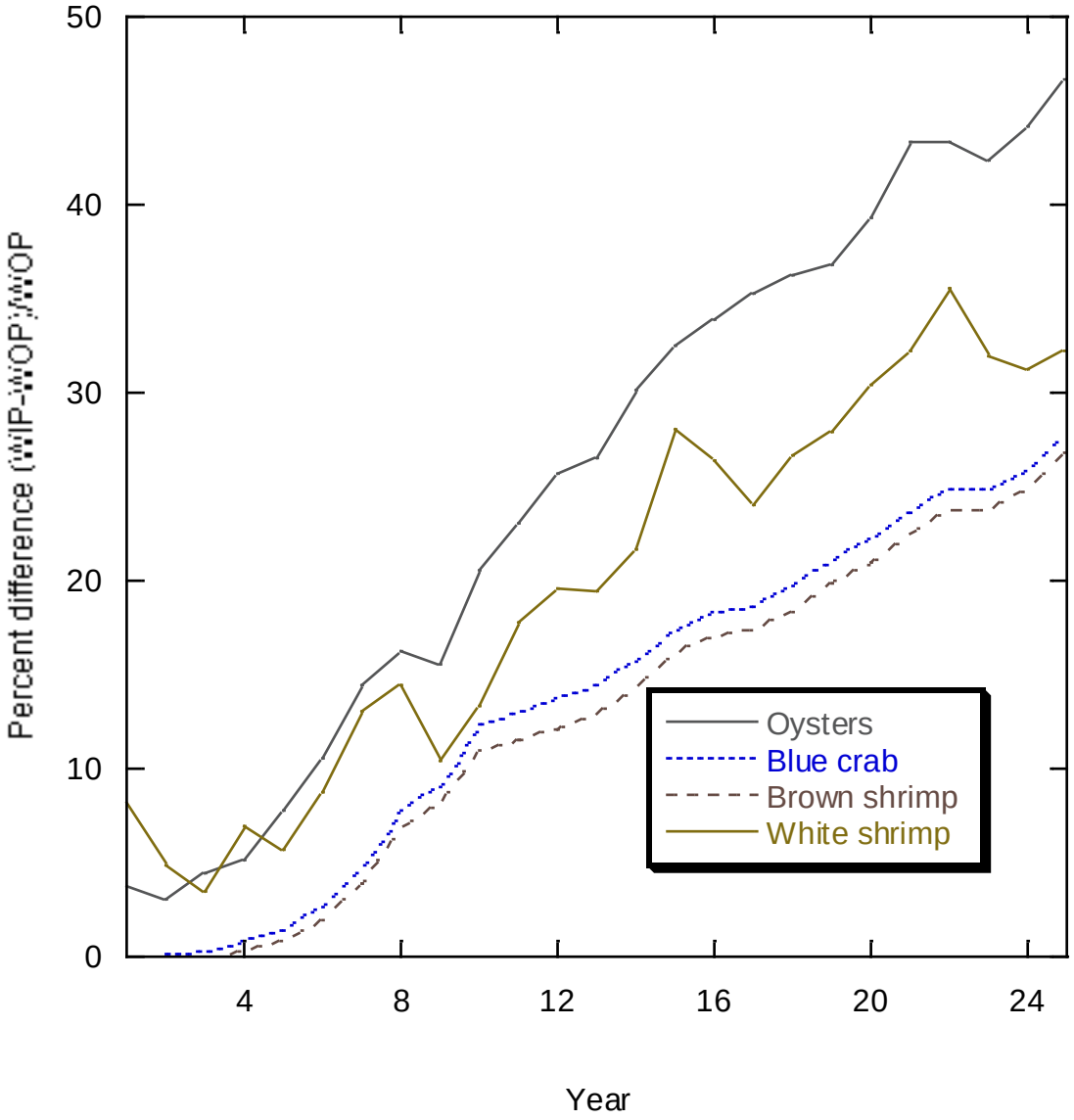
# SAND-CASM modeled changes in aquatic plants – entire domain



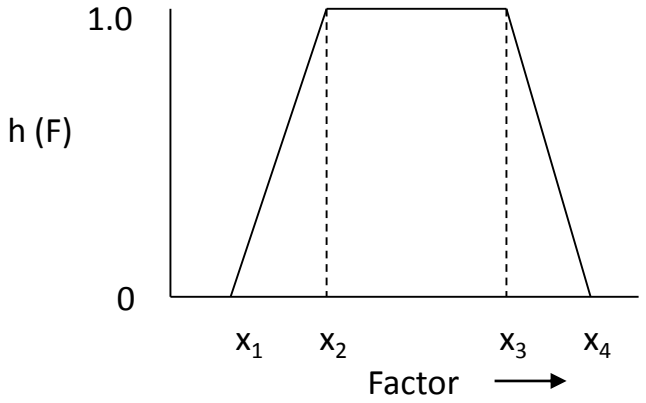

Results reflect

- Population-specific depth preferences
- Population-specific responses to DIN loading
- Overall increase of land-cover, less open water

# SAND-CASM modeled changes in benthic invertebrates – entire domain




- Population-specific depth preferences
- Indirect food web effects ,
  e.g., increased periphyton production




# Relevance to GEER:

- Managed flows
- Beneficial sediment use
- Temperature
- Salinity
- Nutrients (N, P)
- Combined factors


Thank you.

# Governing equations

## Aquatic plants

$$dB_i/B_i dt = [Pm_i \{h(T), f(I), g(N), hmod\}(1-prespi)] - dresp_i\ h(T) - (s_i + m_i) - \sum[h(T)\ B_i\ C_{ij}\ w_{ij}\ a_{ij}\ h_{ij}\ B_i)/(B_i + \sum w_{ij}\ a_{ij}\ h_{ij}\ B_i)]$$

## Fish and invertebrates

$$dB_i/B_i dt = \sum[(Cm_i\ h(T)\ w_{ij}\ a_i\ h_{ij}\ B_j)/(B_i + \sum w_{ij}\ a_{ij}\ h_{ij}\ B_j) - (u_i + f_i + rsda_i)] - r_i\ h(T) - m_i - \sum[(Cm_j\ h(T)\ w_{ij}\ a_{ij}\ h_{ij}\ B_j)/(B_j + \sum w_{ij}\ a_{ij}\ h_{ij}\ B_i)] - sp_i$$

- First-order linear differential equations with nonlinear terms
- One instance of the governing equation for each population
- Equations interrelated by trophic interaction terms

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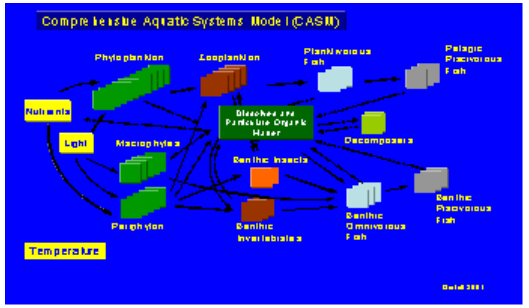
# Integration of CASM-4D with physical models

Hydrodynamic and Hydraulic Model Outputs

- depth
- current velocity
- suspended sediments
- temperature
- salinity

time series of input values

CASM-4D




Scale differences between H&H models and CASM routinely requires some spatial and or temporal averaging…

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