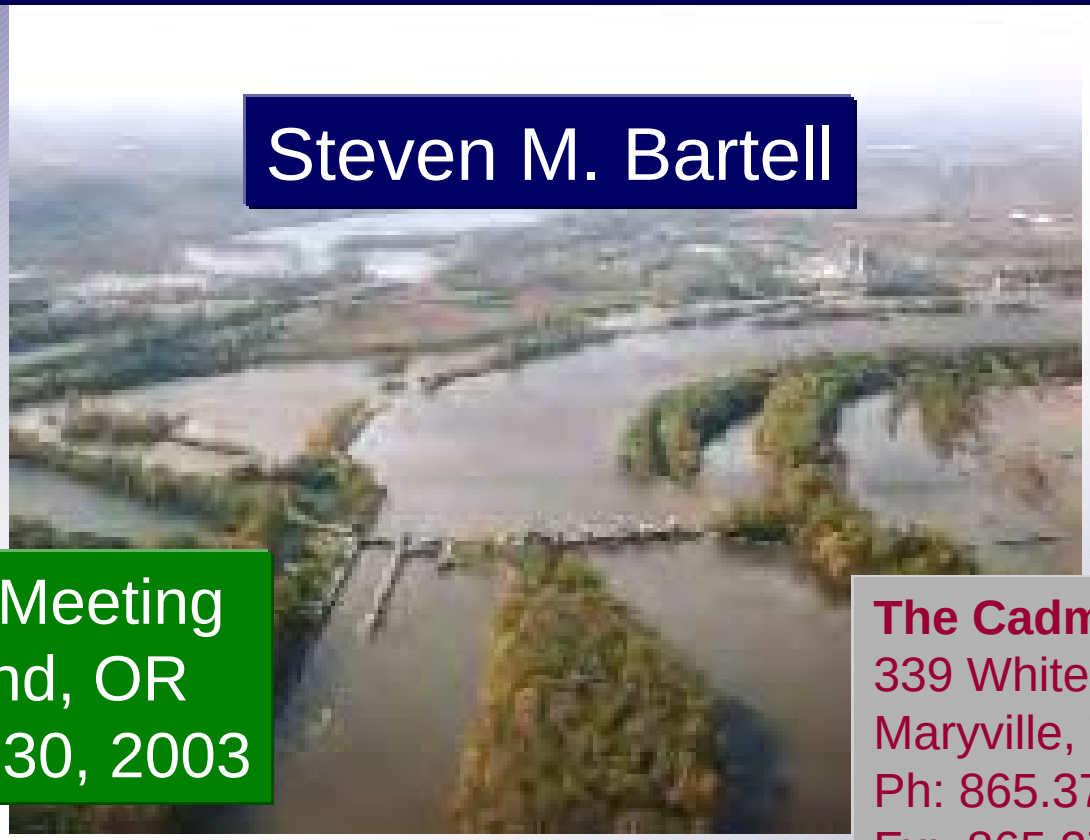
# Ecological Risks Imposed by Commercial Traffic on the Upper Mississippi River



Steven M. Bartell

PIANC Meeting
Portland, OR
October 30, 2003

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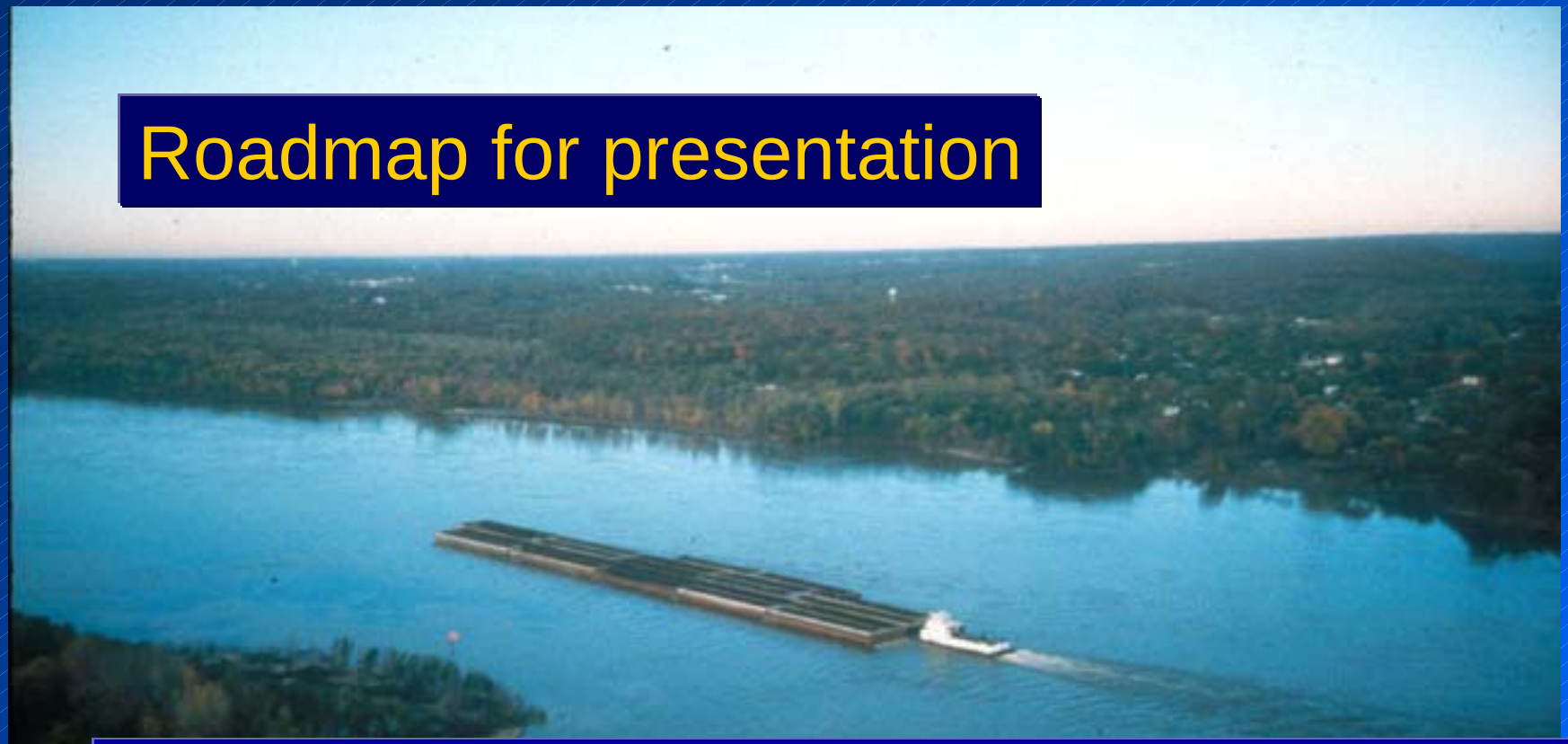
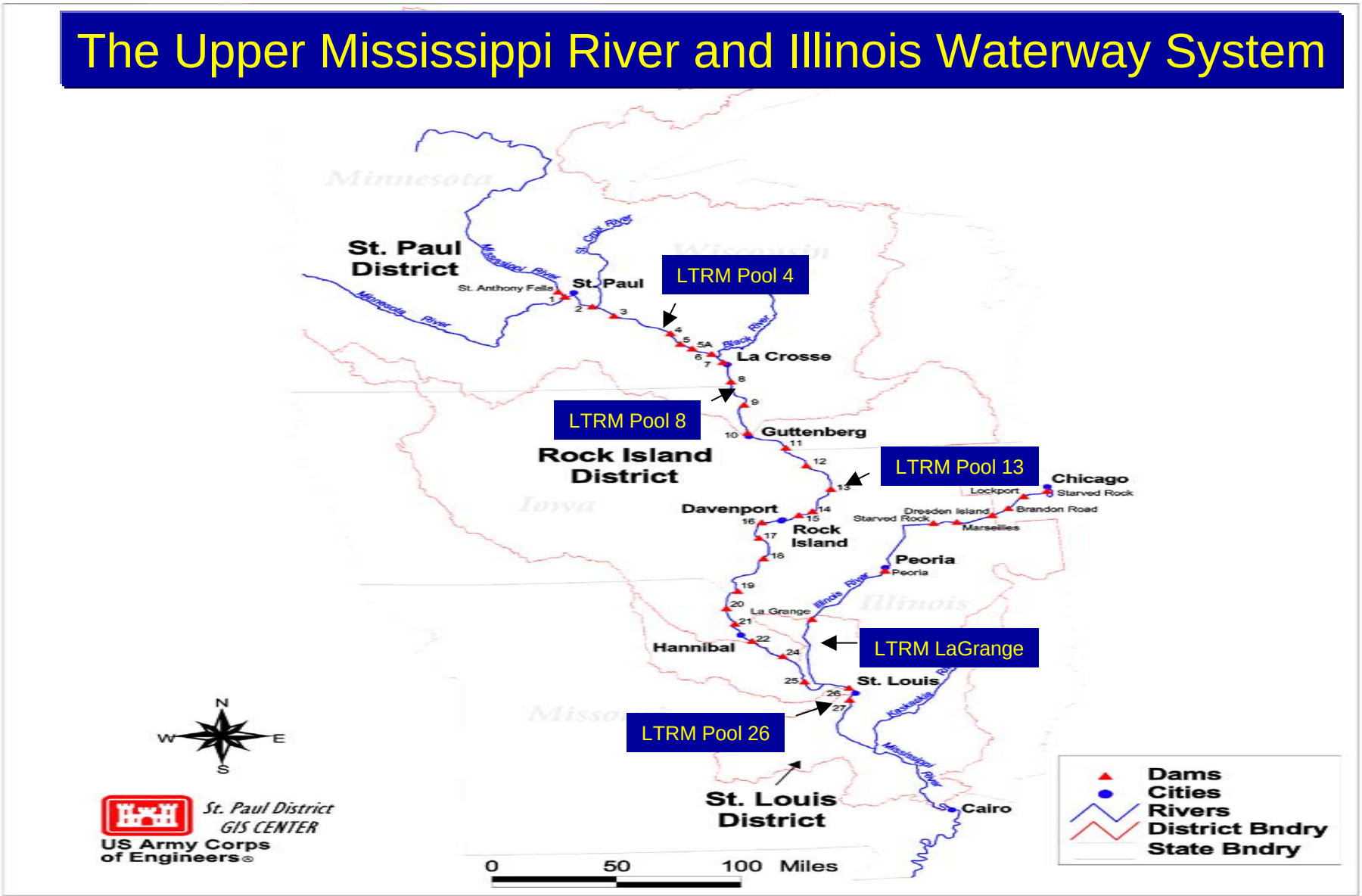
# Roadmap for presentation



- Briefly describe the Navigation Study
- Outline the process of ecological risk assessment (ERA)
- Describe the application of ERA to the Study
- Present some preliminary results
- Discuss the ERA in relation to adaptive environmental management

# The Upper Mississippi River and Illinois Waterway System




LTRM – Long Term Resource Monitoring (USGS)

# Revised Tow Cost Model Traffic Forecasts

Alternative 1: Without-project

Alternative 2: Congestion fees

Alternative 4: Moorings (Locks 12, 14, 18, 20, 22, 24, LaGrange) and switchboats (Locks 20-25)

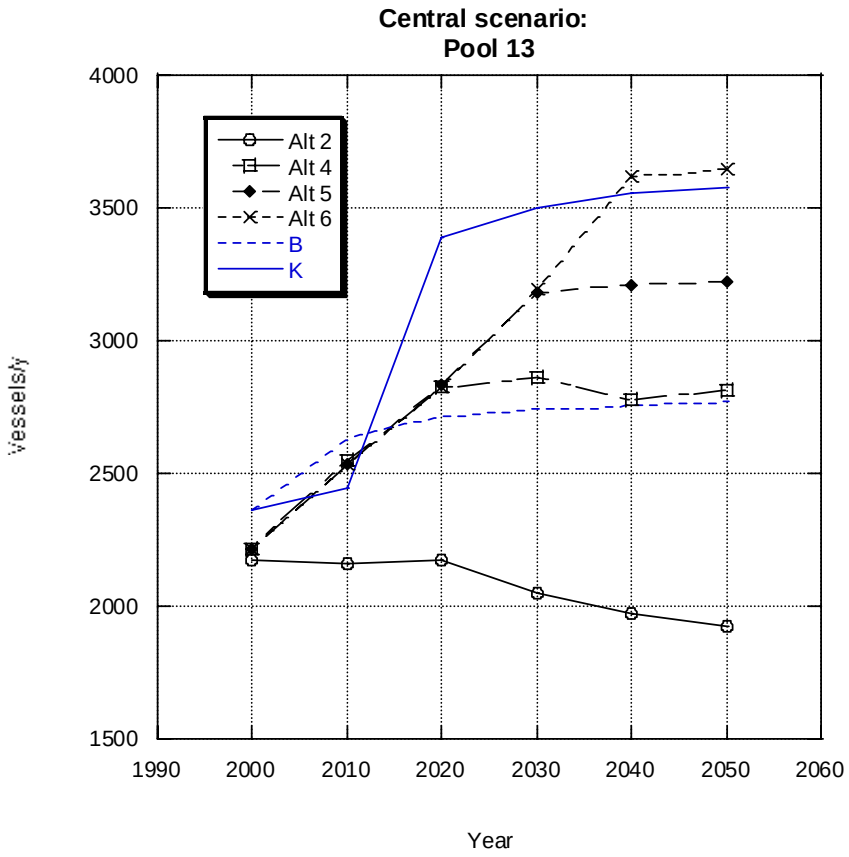
Alternative 5: Moorings (Locks 12, 14, 18, 24, LaGrange), lock extensions (Locks 20-25), switchboats (Peoria, LaGrange)

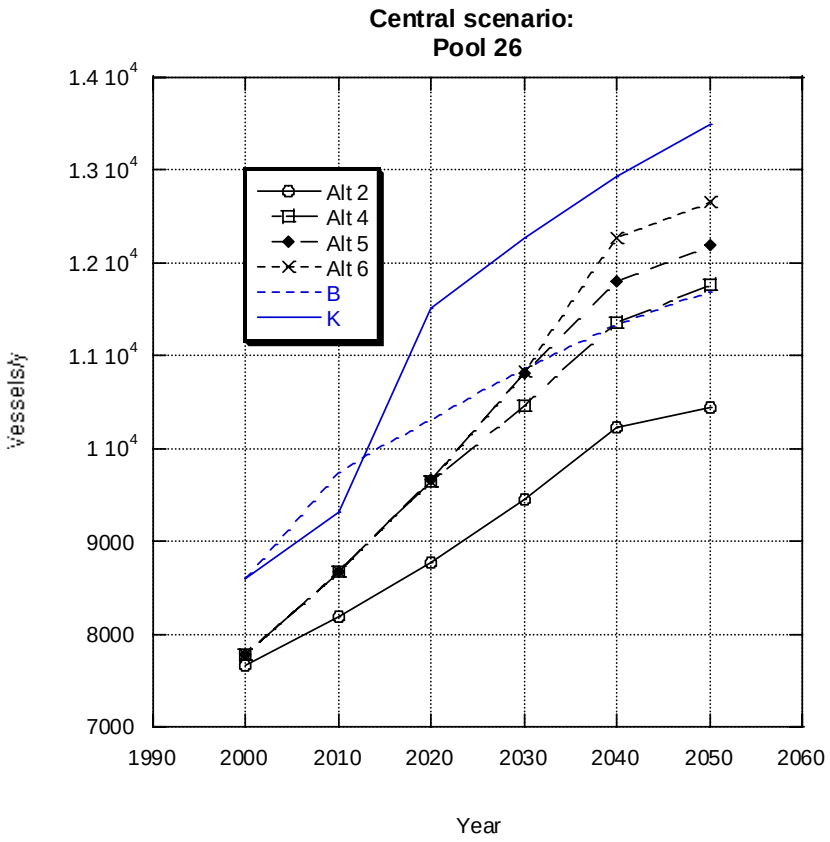
Alternative 6: Switchboats (Locks 11-13), moorings (Locks 12, 14, 18, 24), lock extensions (Locks 14-18), and new locks (Locks 20-25)

Note: Five scenarios within each TCM Alternative based on economic assumptions

Pool 13

Pool 26




TCM Alternatives 2, 4, 5, 6 (Trend Pools)

# A Simple Model of Risk

A *risk* is the <u>probability</u> that an undesired event will occur, along with some evaluation of its consequences (e.g., loss of life, repair costs, environmental impacts)....

$$\text{Risk} \sim f\{x_1, p_1, c_1\}$$

where,

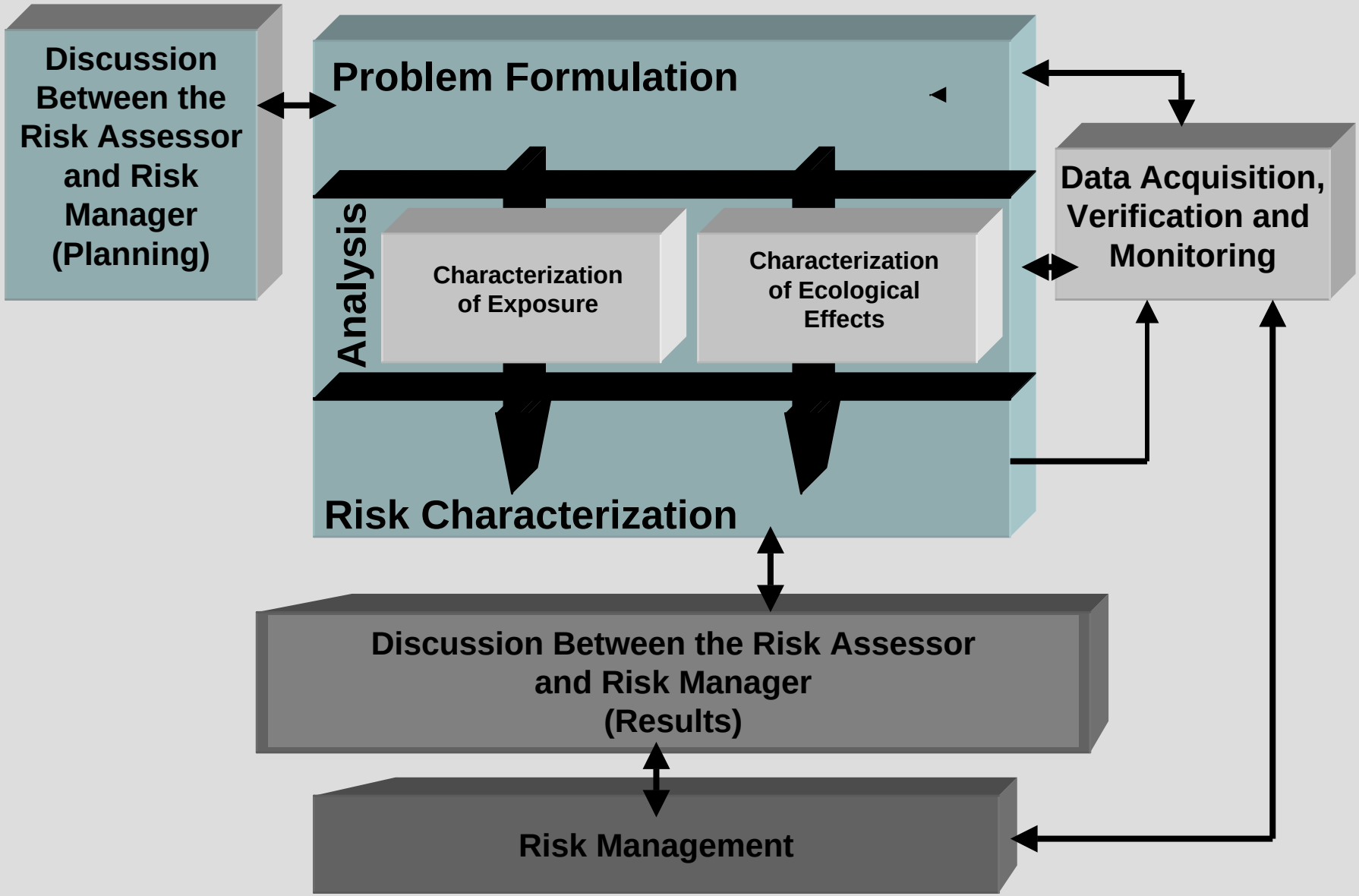
$x_1$ identifies an event of concern (What can go wrong?)

$p_1$ estimates the probability of $x_1$ (How likely is it?

$c_1$ evaluates the consequences of $x_1$ (So what?)

Kaplan and Garrick, 1981

# Framework for Ecological Risk Assessment (ERA)




(redrawn from USEPA 1998)

# Navigation Study Ecological Risk Assessment

**Ecological stressors**
- Commercial vessels
  - physical forces
  - sediment suspension

**Exposure analysis**
- Vessels/day
  - entrainment volumes
  - wake waves
  - shear stresses

**Ecological effects**
- Fish
  - entrainment mortality
  - spawning habitat
- Submerged aquatic plants
  - physical damage
  - plant growth, reproduction
- Unionid mussels
  - growth and reproduction

**Risk characterization**
- Direct measures
  - impacts on adult fish
- Ecological models
  - NavLEM, NavFSH
  - NavSAV
  - NavMSL

Larval Entrainment Model

File Options

**Select from the following options or use menu to make selections:**

**Conduct a New Simulation.**

**View or Plot Results from an Earlier Simualtion.**

# NavLEM

- Conditional entrainment mortality model
- Population-level extrapolations
  - Equivalent Adults Lost
  - Recruitment Forgone
  - Production Forgone

**Welcome to the Larval Entrainment Model**

U.S. Army Corps of Engineers
Rock Island District

THE CADMUS GROUP, INC.

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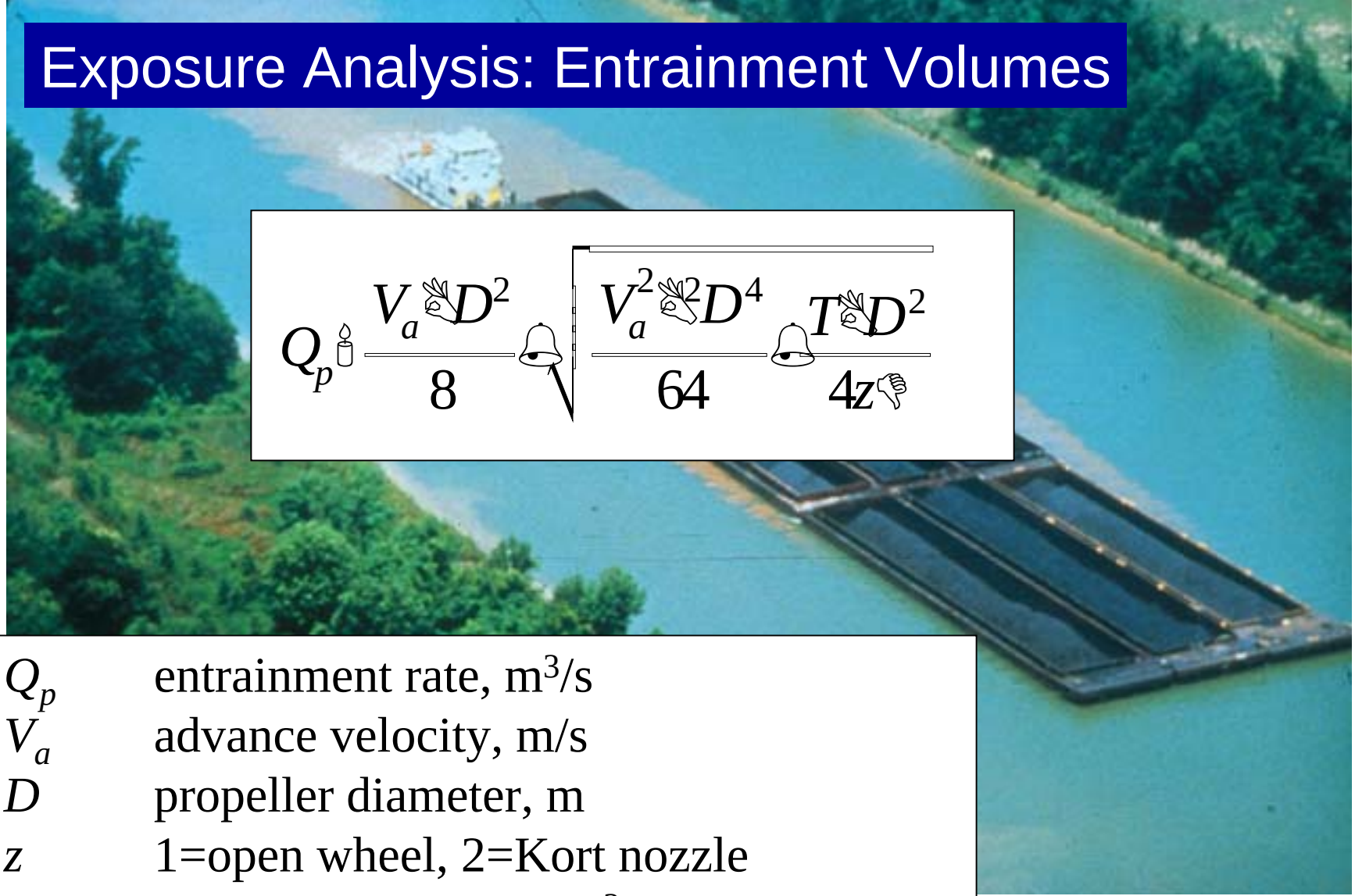
# Exposure Analysis: Entrainment Volumes

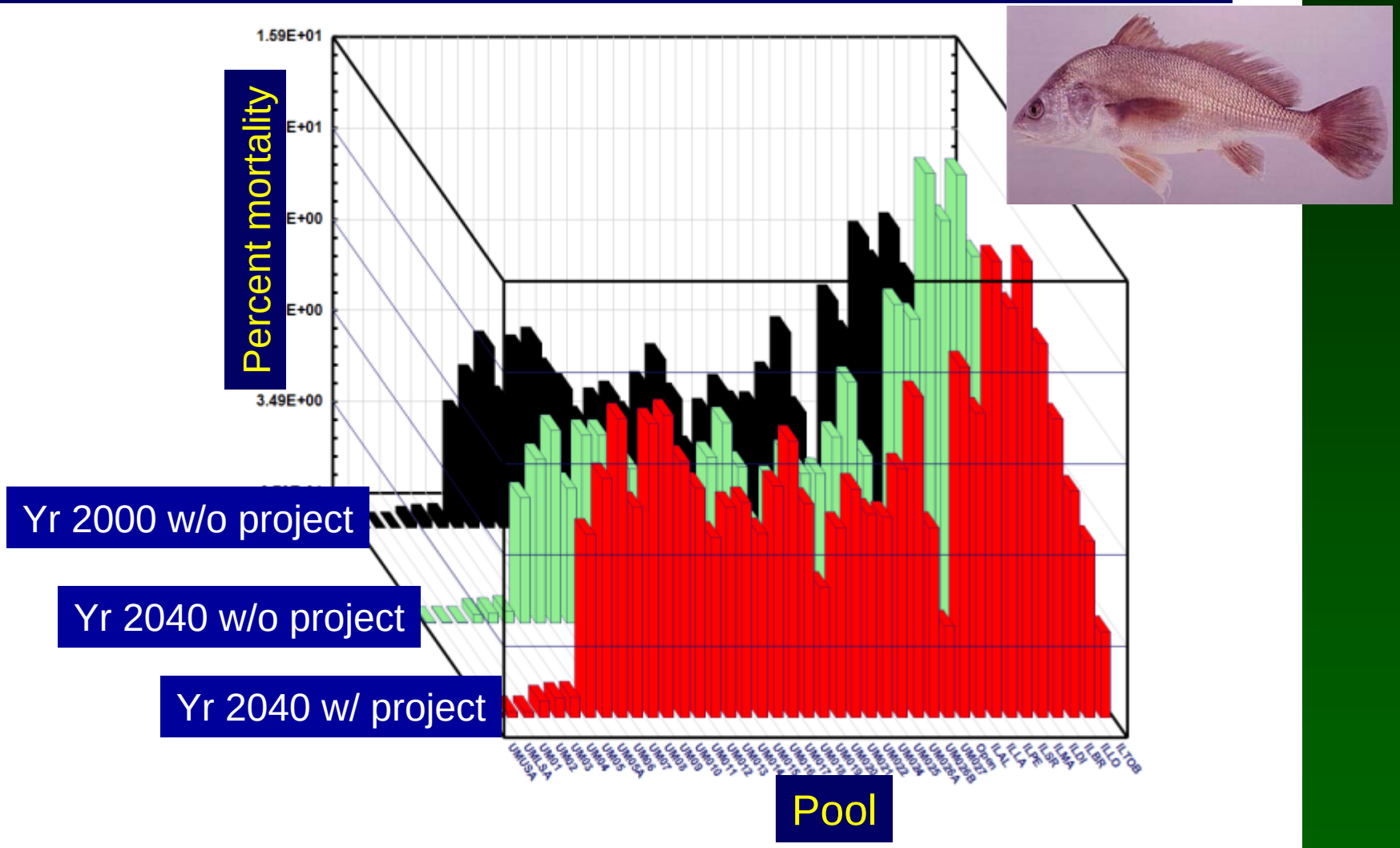


$$Q_p = \frac{V_a \pi D^2}{8} \sqrt{\frac{V_a^2 \pi^2 D^4}{64} + \frac{T \pi D^2}{4 z \rho}}$$

| | |
|---|---|
| $Q_p$ | entrainment rate, $m^3/s$ |
| $V_a$ | advance velocity, m/s |
| $D$ | propeller diameter, m |
| $z$ | 1=open wheel, 2=Kort nozzle |
| $\rho$ | density of water, $kg/m^3$ |
| $T$ | 1/2 of applied horsepower (Toutant eqs.) |

Blaauw and van der Kaa (1978)

# Percent entrainment mortality for freshwater drum for TCM Alternative 6



## Forecast #2: Alternative K - Incremental Increase in EAL for Year 2040

| | | Mississippi River | | | | | Illinois Waterway | | |
|---|---|---|---|---|---|---|---|---|---|
| | Species | USA-3 | 4-8 | 9-15 | 16-27 | Open River | Lower | Middle | Upper |
| 1 | Blue Sucker | 0 | 0 | 0 | 4 | 2 | 0 | 0 | 0 |
| 2 | Smallmouth Bass | 2 | 6 | 20 | 41 | 15 | 1 | 1 | 1 |
| 3 | Northern Pike | 83 | 283 | 663 | 86 | 31 | 9 | 6 | 1 |
| 4 | Bigmouth Buffalo | 7 | 7 | 75 | 206 | 9 | 3 | 3 | 1 |
| 5 | Smallmouth Buffalo | 21 | 21 | 235 | 649 | 28 | 9 | 10 | 3 |
| 6 | Largemouth Bass | 2 | 161 | 520 | 1,054 | 361 | 31 | 35 | 1 |
| 7 | Sturgeon | 11 | 162 | 558 | 1,214 | 558 | 37 | 46 | 0 |
| 8 | Paddlefish | 38 | 176 | 589 | 1,264 | 429 | 39 | 19 | 0 |
| 9 | Walleye | 359 | 561 | 1,139 | 2,153 | 35 | 5 | 5 | 2 |
| 10 | Blue Catfish | 0 | 0 | 751 | 2,583 | 16 | 0 | 0 | 0 |
| 11 | Goldeye | 16 | 90 | 883 | 2,830 | 191 | 25 | 25 | 0 |
| 12 | Flathead Catfish | 86 | 667 | 2,183 | 4,393 | 53 | 52 | 59 | 22 |
| 13 | River Carpsucker | 10 | 23 | 887 | 6,021 | 395 | 176 | 177 | 59 |
| 14 | Mooneye | 13 | 41 | 1,638 | 6,661 | 258 | 67 | 32 | 0 |
| 15 | Sauger | 271 | 333 | 7,733 | 7,860 | 201 | 28 | 28 | 9 |
| 16 | Bluegill | 5 | 114 | 1,151 | 9,055 | 6 | 200 | 204 | 74 |
| 17 | Shorthead Redhorse | 19 | 38 | 4,688 | 9,362 | 77 | 90 | 90 | 30 |
| 18 | Channel Catfish | 345 | 907 | 6,674 | 31,820 | 195 | 267 | 295 | 106 |
| 19 | Crappie | 914 | 1,350 | 7,128 | 32,580 | 51 | 805 | 824 | 261 |
| 20 | Freshwater Drum | 306 | 546 | 13,580 | 39,230 | 163 | 375 | 379 | 131 |
| 21 | White Bass | 1,438 | 4,653 | 24,840 | 40,080 | 78 | 314 | 323 | 56 |
| 22 | Spotted Sucker | 635 | 667 | 47,760 | 47,190 | 1,364 | 1,309 | 1,350 | 0 |
| | TOTALS | 4,582 | 10,808 | 123,695 | 246,336 | 4,513 | 3,843 | 3,912 | 756 |
| | Percent of River | 1.2 | 2.8 | 32.1 | 63.9 | 1.2 | 45.2 | 46.0 | 8.9 |
| Total Mississippi River = | | 385,420 | | Impact Index (EAL) | | | Total IWW = | | 8,511 |
| Total UMR-IWW = | | 393,931 | | | 1000 to 5000 | | | | |
| | % Miss = | 97.8 | | | 5000 to 15,000 | | | % IWW = | 2.2 |
| | | | | | >15,000 | | | | |

# Equivalent adults lost for year 2040 traffic

| Scenario | TCM Alternative 2 | 4 | 5 | 6 | |
|---|---|---|---|---|---|
| Least favorable | N/A | 120 | 436 | 979 | (UMR) |
| | | 4 | 72 | 1,895 | (IWW) |
| Less favorable | N/A | 34,386 | 87,560 | 92,981 | |
| | | 374 | 1,462 | 3,681 | |
| Central | N/A | 38,320 | 95,693 | 161,880 | |
| | | 183 | 1,362 | 5,352 | |
| Favorable | N/A | 39,969 | 105,035 | 185,382 | |
| | | 330 | 1,470 | 5,516 | |
| Most favorable | N/A | 64,973 | 183,856 | 274,231 | |
| | | 242 | 1,163 | 5,671 | |

N/A: Without-project traffic scenarios > Alternative 2 scenarios

# Characterize effects on fish spawning habitat for selected TCM Alternatives

Black Crappie Spawning Index (SI)

NavFSH

Baseline: $SI_b = (V1 \times V2 \times V3 \times V4)^{1/4}$

Modified by Tow Passage: $SI_m = SI_b \times V5 \times V6$

V1 = Structure
V2 = Ambient Current (ft/s)
V3 = Water Depth (ft)
V4 = Substrate Size (mm)
V5 = Scour Disturbance Modifier (inches)
V6 = Velocity Disturbance Modifier (ft/s)

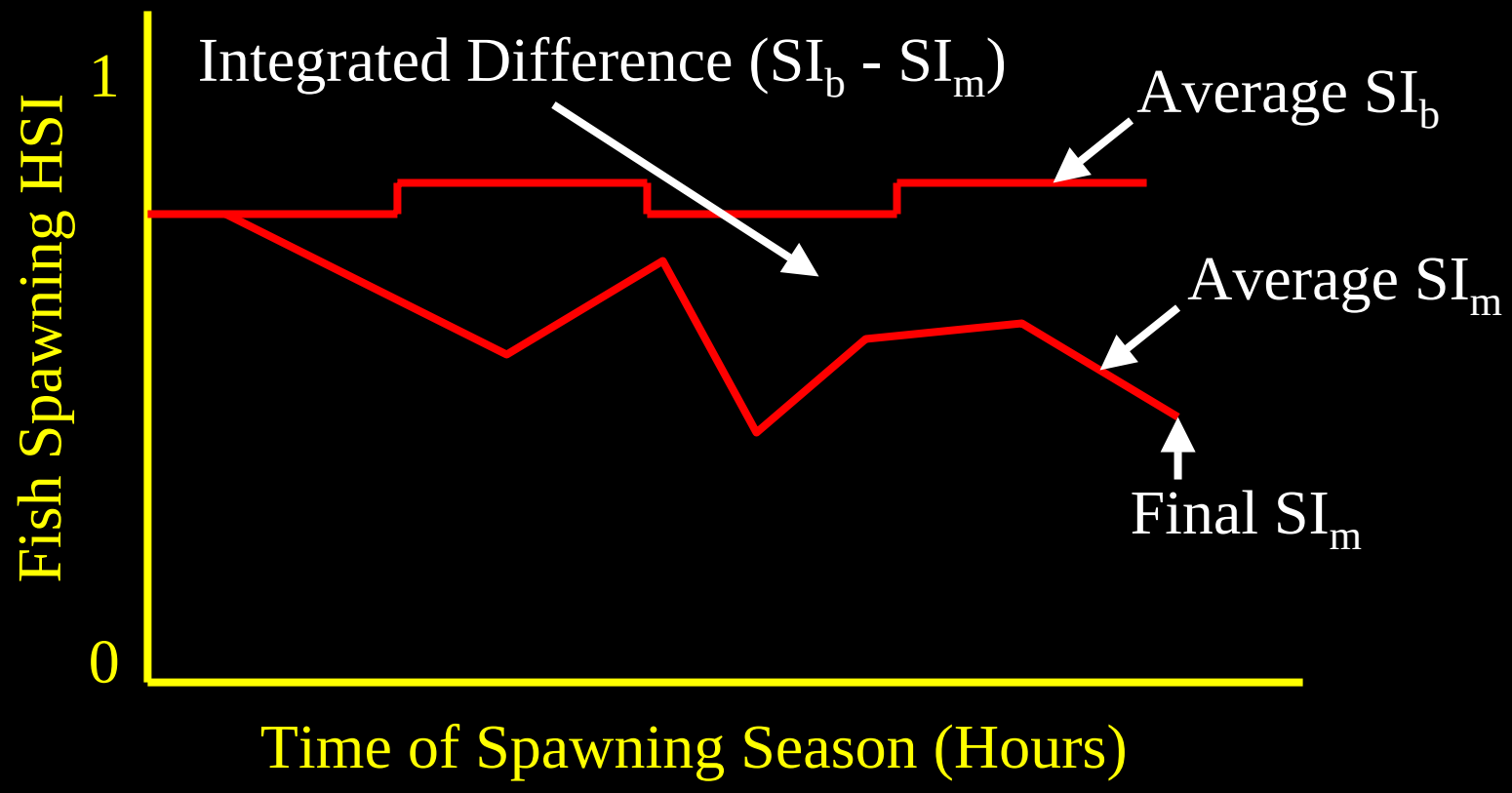
**Navigation Stressors**

- Current velocity
- Bed shear stress

| Fish Species | HSI Model Developed | Physical Forces* | | | |
|---|---|---|---|---|---|
| | | Water Level Fluctuation | Scour Depth | Tow Velocity | Substrate Size |
| Lake Sturgeon | x | | | | x |
| Paddlefish | x | | | x | x |
| Northern Pike | | | | | |
| Emerald Shiner | x | | | x | |
| Bullhead Minnow | | | | | |
| Bigmouth Buffalo | x | | | x | x |
| Channel Catfish | | | | | |
| Largemouth Bass | x | x | | x | x |
| Spotted Bass | x | | | x | x |
| Black Crappie | x | | x | x | x |
| Sauger | x | | x | x | x |
| Walleye | x | x | | x | x |
| Freshwater Drum | x | | | x | |

*Includes ambient water depth and current velocity

# For Each Scenario:
# GIS Cell, species, year, percentile




Average % Impact = $(SI_b - SI_m / SI_b) \times 100$

Plant Growth: Impact of Commercial Traffic on UMIRS

# Welcome to the Simulation Model for the Growth of Submersed Aquatic Vegetation

NavSAV

**Select Vegetation for Simulation**

*Vallisneria americana*

*Potamogeton pectinatus*

**Input Method**

Plant Process Parameters
- ○ Through User-Defined Excel File
- ○ Through Defualt Excel File
- ◉ Through Model-Default Values

Functionally Defined Parameters
- ◉ Through Default Excel File
- ○ Through User-Defined Excel File

Environmental Parameters
- ◉ Through Excel Files
- ○ Through ASCII Files

Click Here to Start

U.S. Army Corps of Engineers
Rock Island District

US Army Corps of Engineers
Vicksburg District ERDC/EL

*Vallisneria americana*

*Potamogeton pectinatus*

Contact Information:
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The model was adapted from the original FORTRAN version (Best and Boyd, 2001; see full reference in the Help file).

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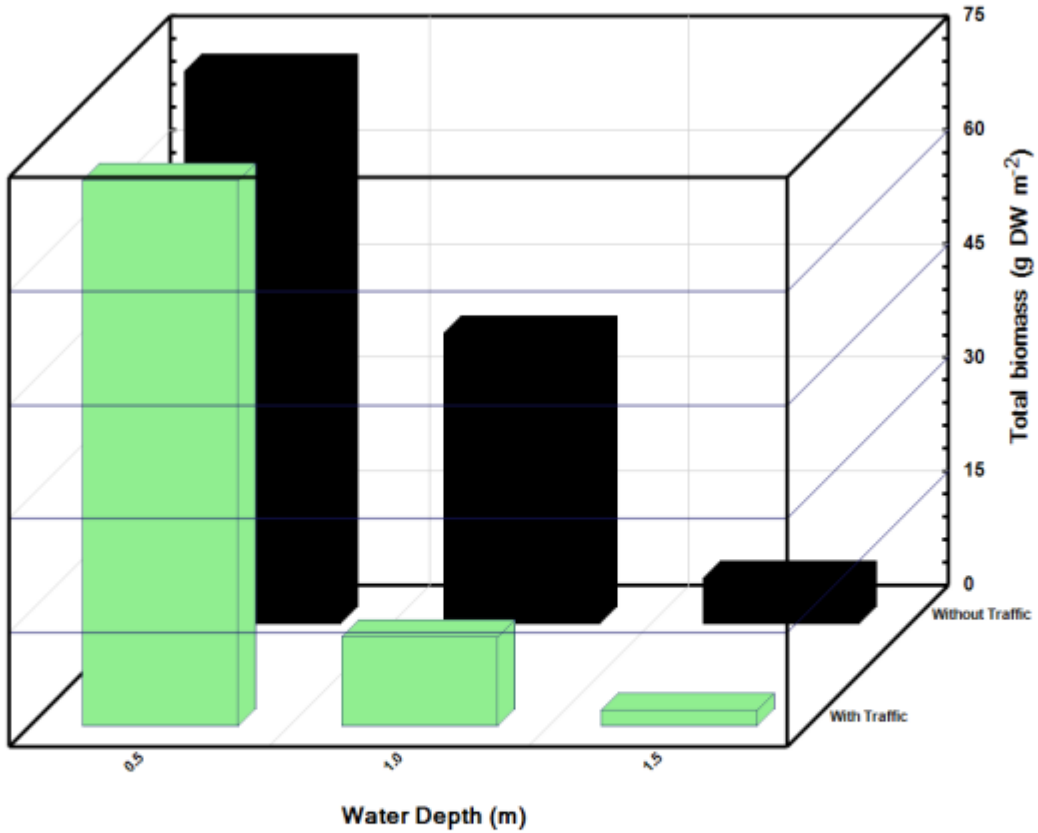
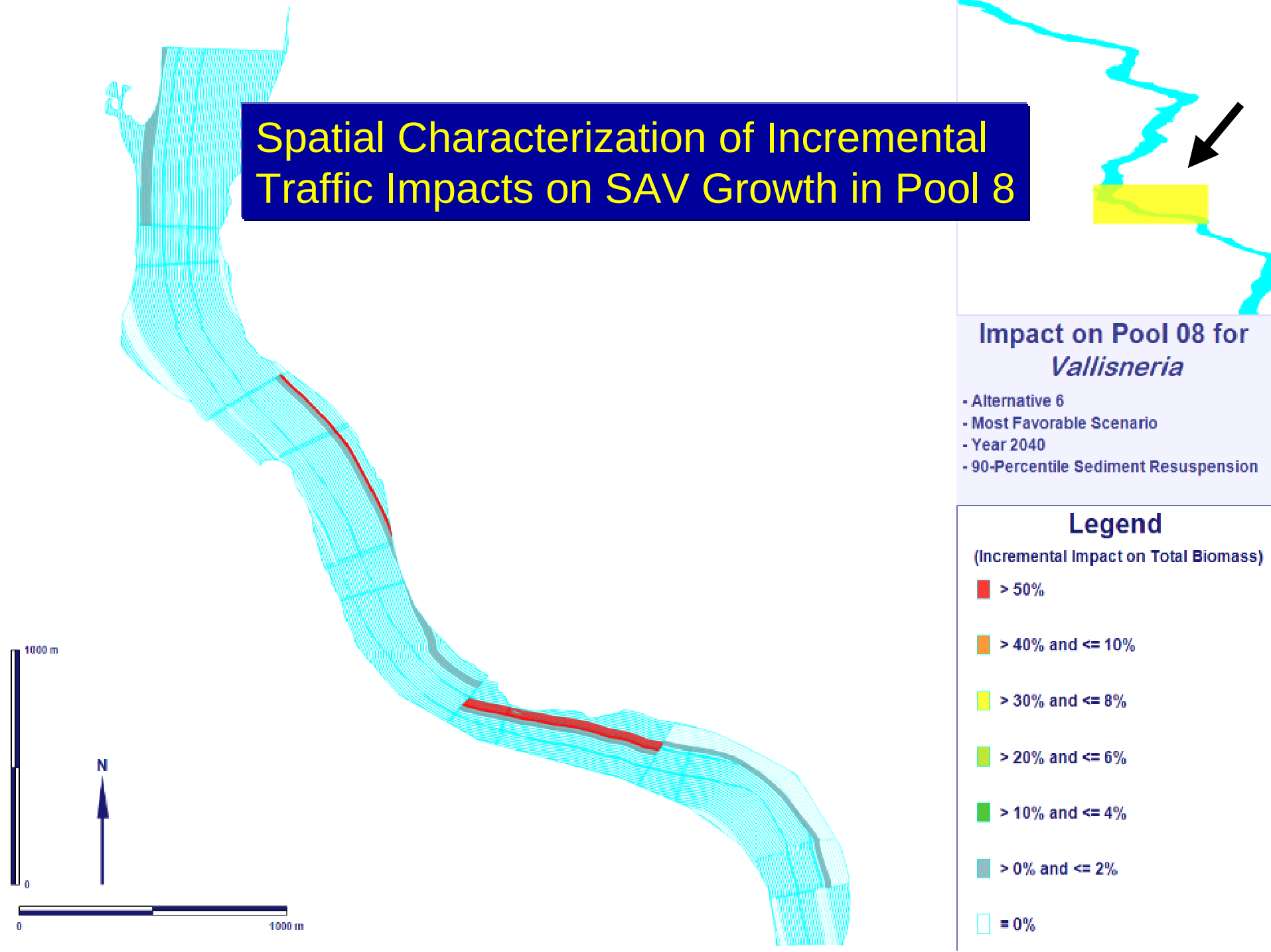
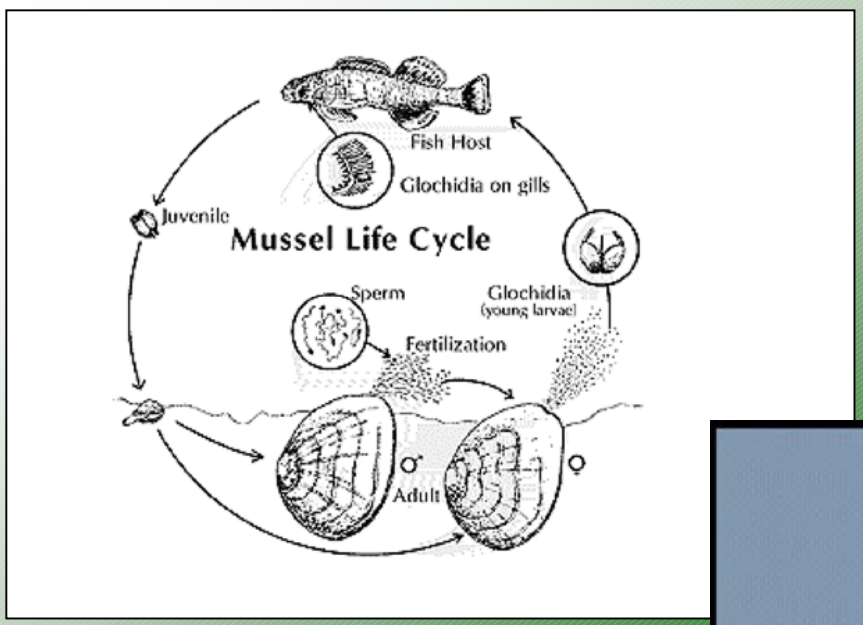
Maximum Total Biomass of Vallisneria With and Without Year 2000 Traffic in UMR Pool 04 and 90 Percentile Sediment Resuspension for Favorable Scenario



# Spatial Characterization of Incremental Traffic Impacts on SAV Growth in Pool 8






## Navigation Stressor

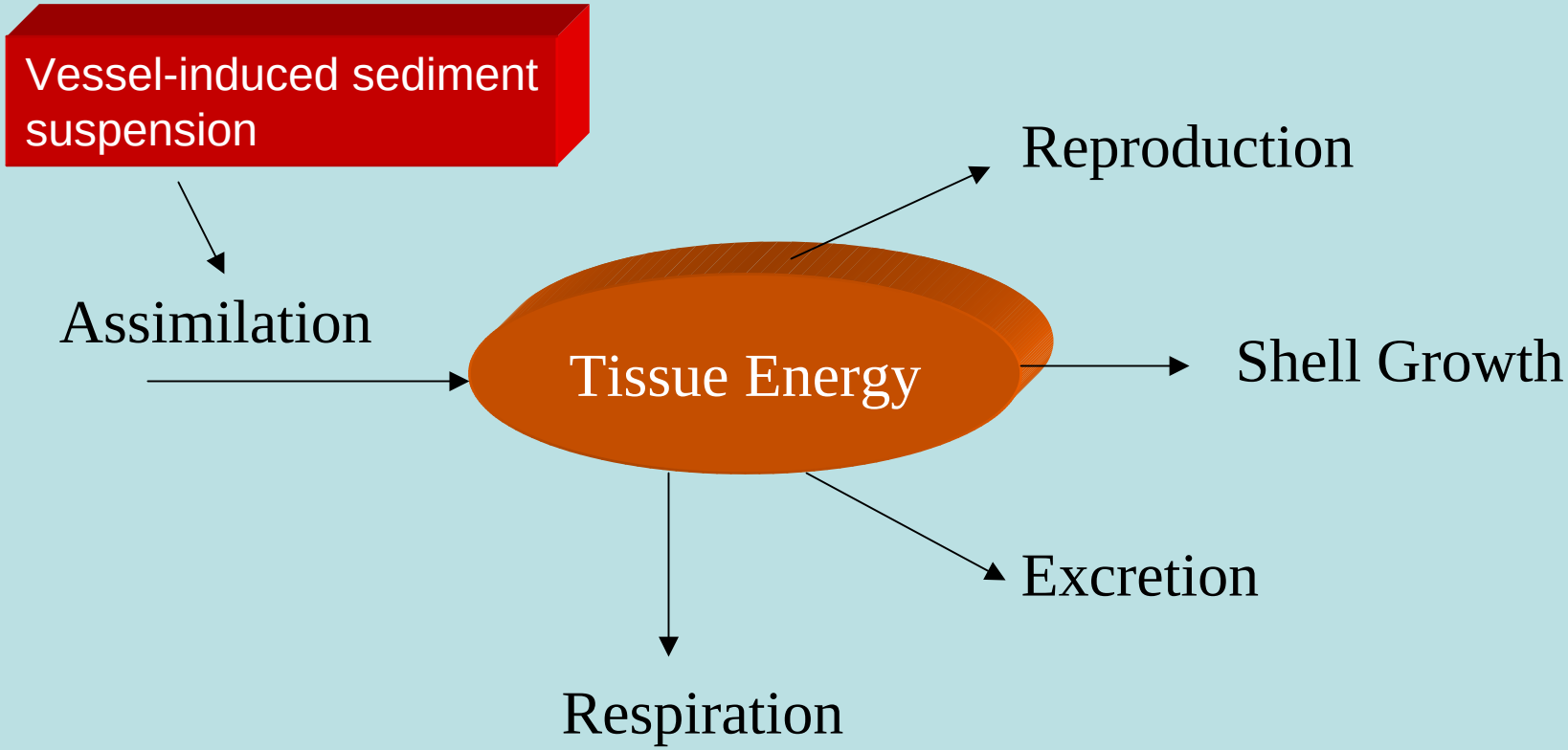
- Sediment suspension

## Assessment endpoints

- growth
- reproduction

Threeridge mussel (*Amblema plicata*)

# Characterize effects of commercial navigation on unionid mussel growth and reproduction.




# NavMSL - Unionid Mussel Bioenergetics Model

# Assimilation:

$$A = K_a \cdot W_t^{ba} \cdot a \cdot C \cdot p(t) \cdot f_a(T) \cdot k_a$$

| | |
|---|---|
| $K_a$ | filtration rate at 20 $^0$C, mL/g/h |
| ba | weight dependence of filtration |
| a | assimilation efficiency |
| C | food concentration, g/mL |
| $f_a(T)$ | temperature dependence of filtration |
| p(t) | active filtration (0,1) time |
| $k_a$ | converts assimilated food to energy, 20 kJ/g |

# Pool 13 Average Effects – Alternative K

| Average Tissue Dry Weight (g), Shell Dry Weight (g), Total Dry Weight (g) and Cumulative Reproductive Effort (kJ) for Mussels in for Mussels in all Beds in Pool 13 During Years With and Without Project for Alternative K | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tissue Dry Weight (g) | | | Shell Dry Weight (g) | | | Total Dry Weight (g) | | | Reproductive Effort (kJ) | | |
| 2010 | W/O | With | Diff. | W/O | With | Diff. | W/O | With | Diff. | W/O | With | Diff. |
| 10% | 3.07 | 3.07 | 0.00 | 79.45 | 79.45 | 0.00 | 82.52 | 82.52 | 0.00 | 4.11 | 4.11 | 0.00 |
| 50% | 3.00 | 3.00 | 0.00 | 77.77 | 77.77 | 0.00 | 80.77 | 80.77 | 0.00 | 3.92 | 3.92 | 0.00 |
| 90% | 2.84 | 2.84 | 0.00 | 73.94 | 73.94 | 0.00 | 76.78 | 76.78 | 0.00 | 3.56 | 3.56 | 0.00 |
| 2020 | | | | | | | | | | | | |
| 10% | 3.07 | 3.07 | 0.00 | 79.45 | 79.44 | 0.01 | 82.52 | 82.51 | 0.01 | 4.11 | 4.11 | 0.00 |
| 50% | 2.99 | 2.97 | 0.02 | 77.60 | 77.12 | 0.47 | 80.59 | 80.10 | 0.49 | 3.91 | 3.86 | 0.05 |
| 90% | 2.81 | 2.74 | 0.07 | 73.38 | 71.67 | 1.71 | 76.19 | 74.41 | 1.78 | 3.53 | 3.41 | 0.12 |
| 2030 | | | | | | | | | | | | |
| 10% | 3.07 | 3.07 | 0.00 | 79.44 | 79.45 | 0.00 | 82.51 | 82.52 | -0.01 | 4.11 | 4.11 | 0.00 |
| 50% | 2.99 | 2.97 | 0.02 | 77.64 | 77.09 | 0.55 | 80.63 | 80.06 | 0.57 | 3.91 | 3.84 | 0.07 |
| 90% | 2.83 | 2.73 | 0.11 | 73.78 | 71.17 | 2.61 | 76.62 | 73.89 | 2.72 | 3.57 | 3.40 | 0.17 |
| 2040 | | | | | | | | | | | | |
| 10% | 1.84 | 1.84 | 0.00 | 47.64 | 47.65 | -0.01 | 49.48 | 49.49 | -0.01 | 2.46 | 2.46 | 0.00 |
| 50% | 3.00 | 2.98 | 0.02 | 77.79 | 77.29 | 0.51 | 80.79 | 80.26 | 0.53 | 3.92 | 3.84 | 0.08 |
| 90% | 2.84 | 2.71 | 0.13 | 74.05 | 70.92 | 3.13 | 76.89 | 73.63 | 3.26 | 3.58 | 3.39 | 0.19 |
| 2050 | | | | | | | | | | | | |
| 10% | 1.84 | 1.84 | 0.00 | 47.67 | 47.66 | 0.01 | 49.52 | 49.51 | 0.01 | 2.46 | 2.46 | 0.00 |
| 50% | 2.99 | 2.97 | 0.02 | 77.68 | 77.20 | 0.48 | 80.68 | 80.17 | 0.51 | 3.91 | 3.83 | 0.08 |
| 90% | 2.84 | 2.70 | 0.14 | 74.00 | 70.57 | 3.43 | 76.84 | 73.27 | 3.57 | 3.56 | 3.37 | 0.19 |

# A Simple Model of Risk

A *risk* is the <u>probability</u> that an undesired event will occur, along with some evaluation of its consequences (e.g., loss of life, repair costs, environmental impacts)....

$$\text{Risk} \sim f\{x_1, p_1, c_1\}$$

where,

$x_1$ identifies an event of concern (What can go wrong?)

$p_1$ estimates the probability of $x_1$ (How likely is it?

$c_1$ evaluates the consequences of $x_1$ (So what?)

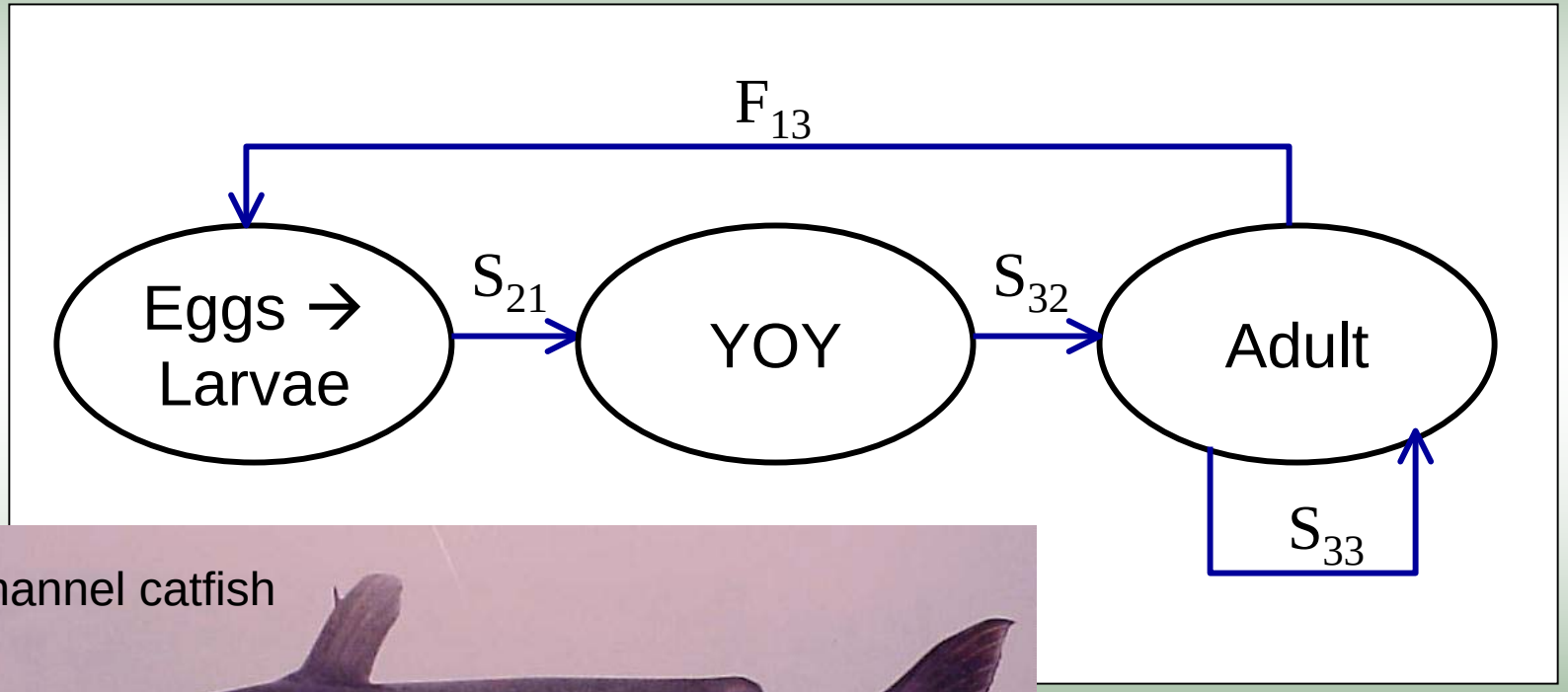
Note: Most assessments will address multiple endpoints, e.g., several $x_i$'s

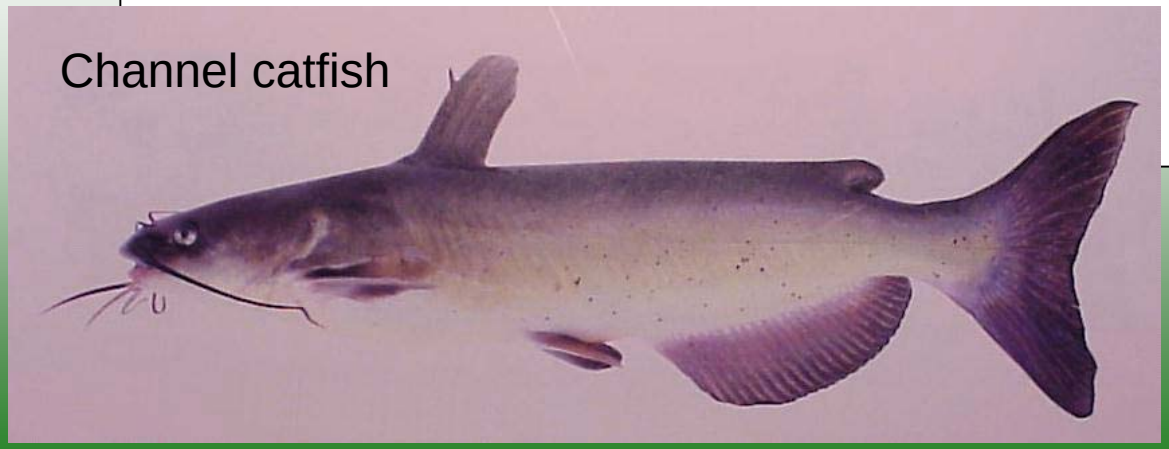
Kaplan and Garrick, 1981
*Risk Analysis*, Vol. 1

# Fish Demographic Modeling Approach:

- Describes population as three life stages
  - Eggs/larvae, YOY, adults
- Population changes as function of survival and reproduction for each stage
- Larval entrainment added as additional mortality term, S’
- Projects population changes on yearly time scale for 50 years (i.e., 2000 – 2050)

# Demographic Model for Fish Population Growth



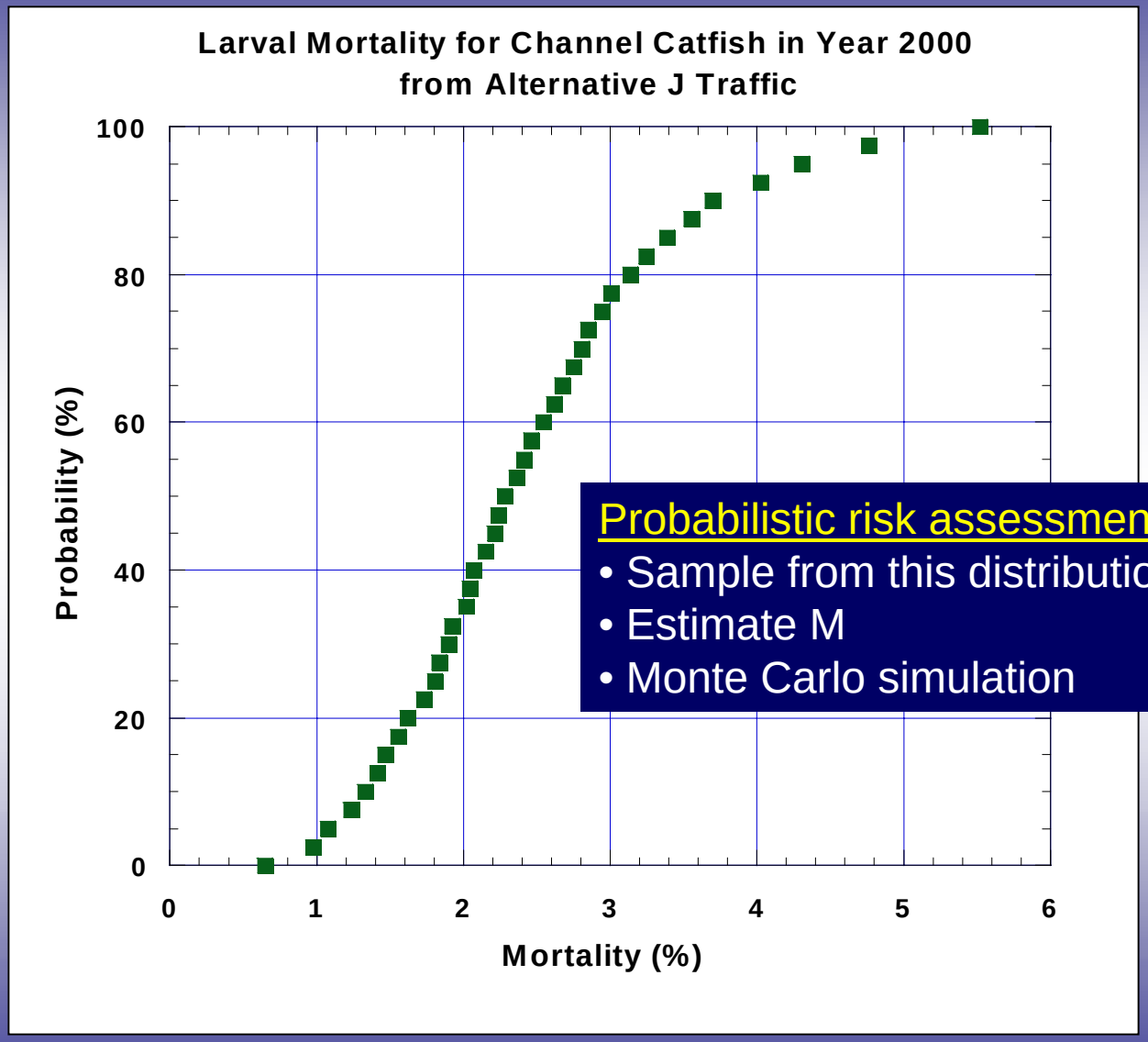
# Demographic Model for Fish Population Growth

$$\begin{bmatrix} 0 & 0 & F_{13} \\ S_{21} + S' & 0 & 0 \\ 0 & S_{32} & S_{33} \end{bmatrix} \times \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}_t = \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}_{t+1}$$

where, $S' = - S_{21} M$

S’ = Navigation Induced Survivorship
M = Navigation Induced Larval Mortality

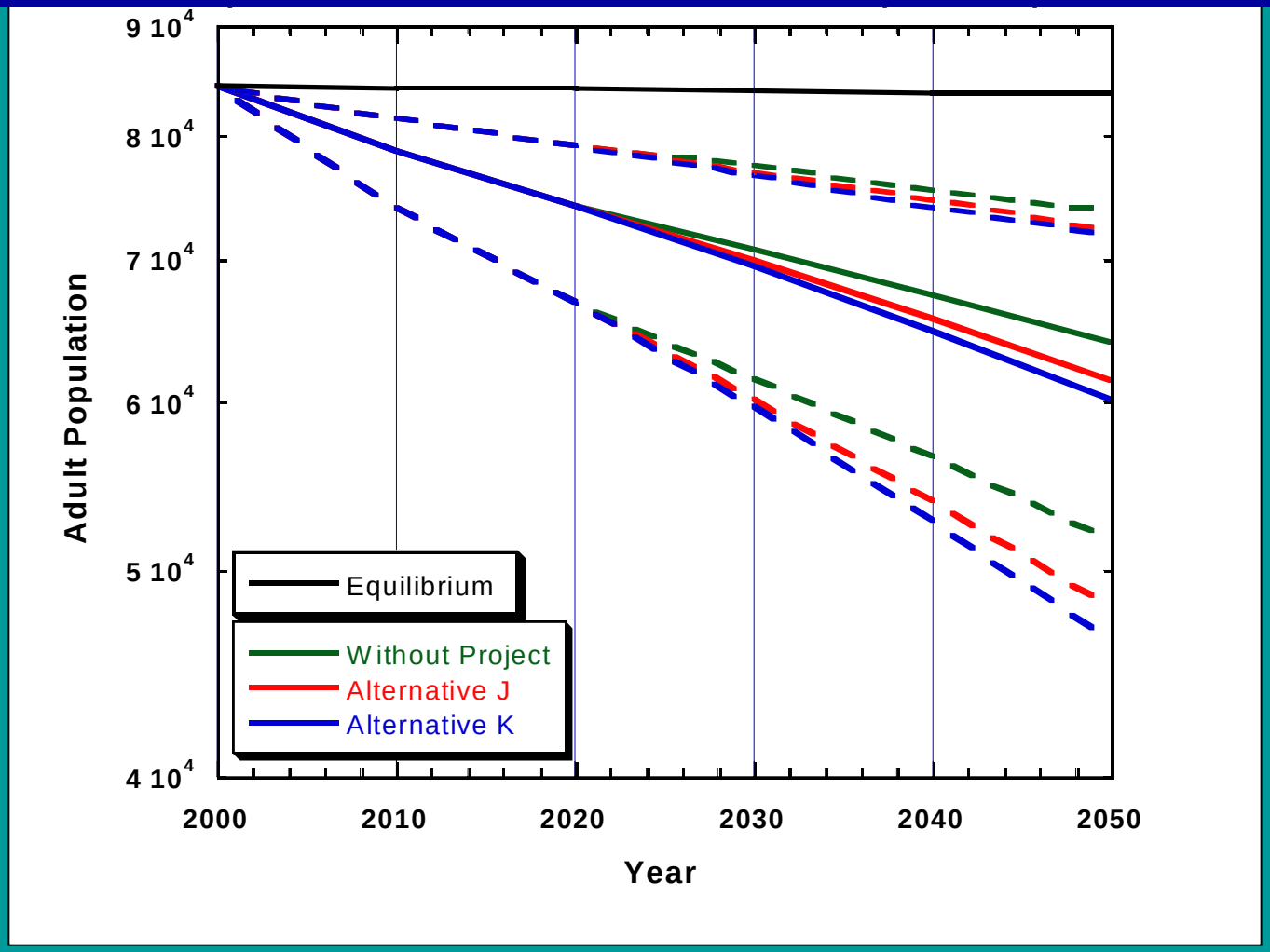
# Distribution of percent larval mortality



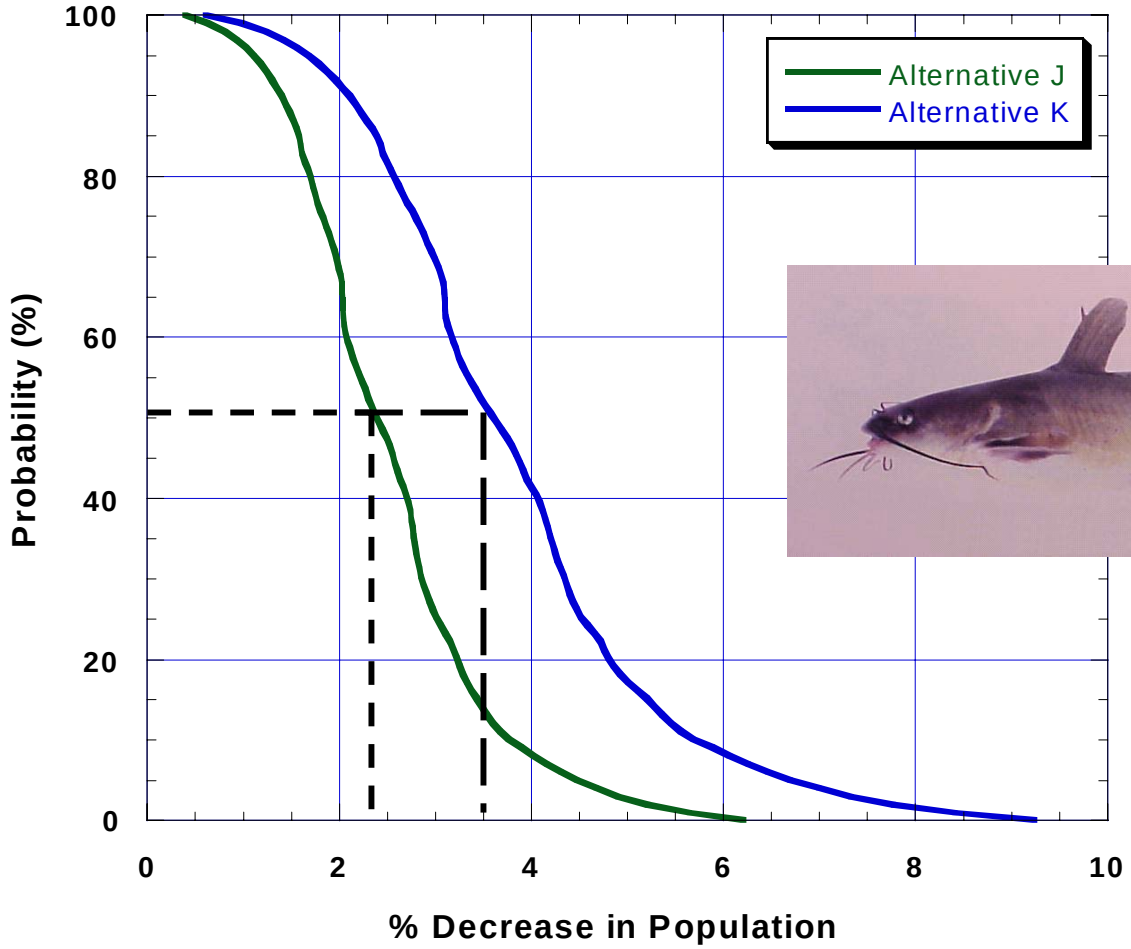

Probabilistic risk assessment

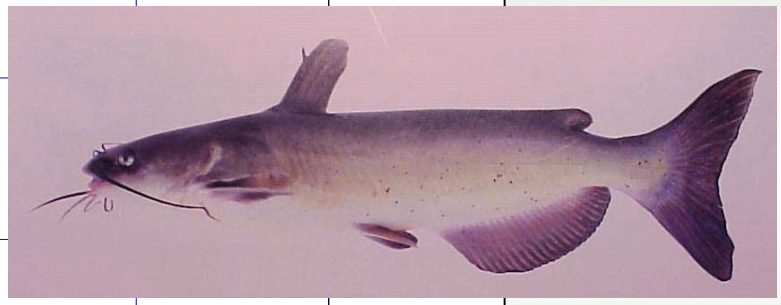
- Sample from this distribution
- Estimate M
- Monte Carlo simulation

# Traffic Impacts on Adult Channel Catfish Population Size for LTRM Pool 13: Alternatives J and K

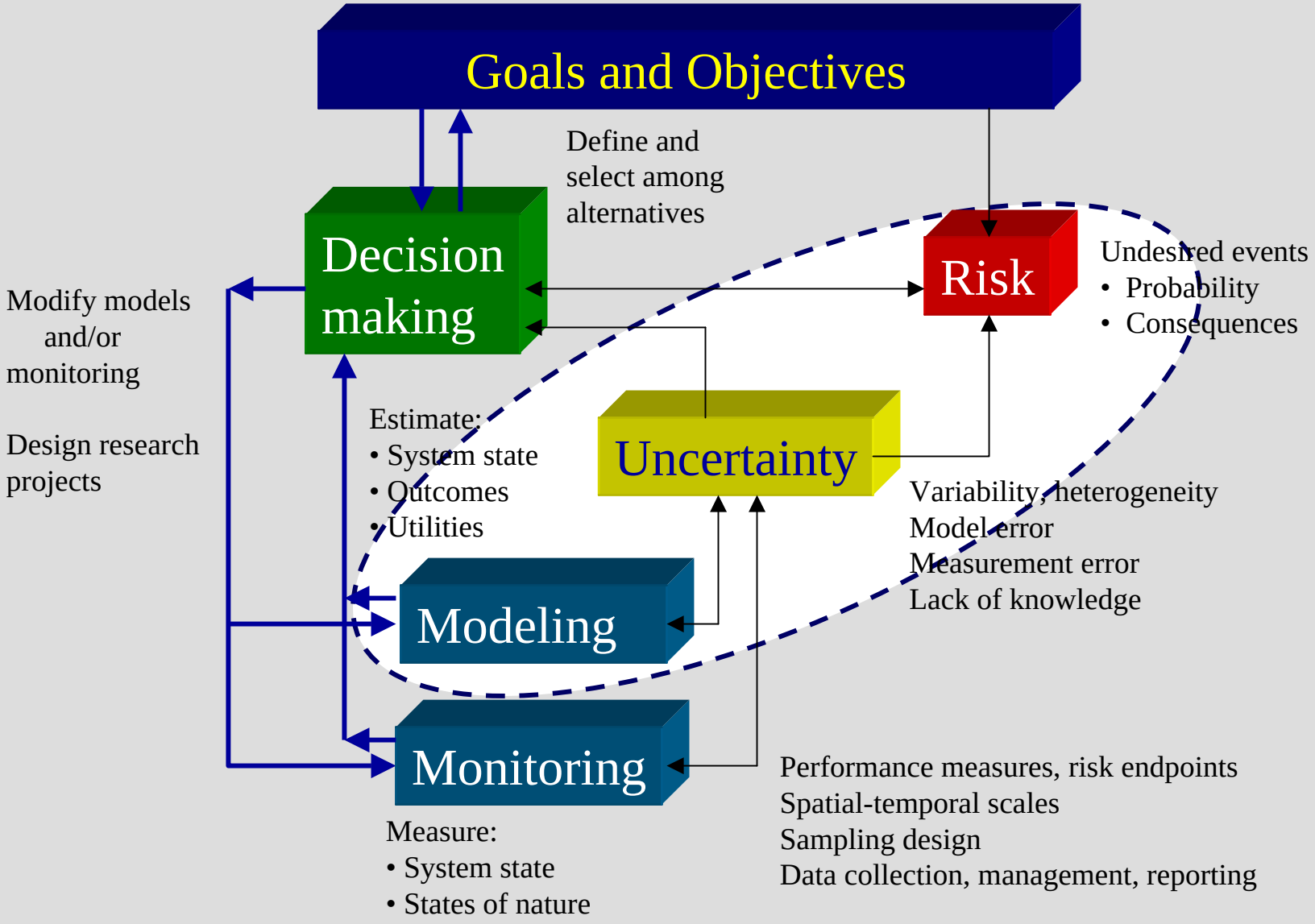


# Risk of Population Decreases for Traffic Alternatives J and K – Year 2040

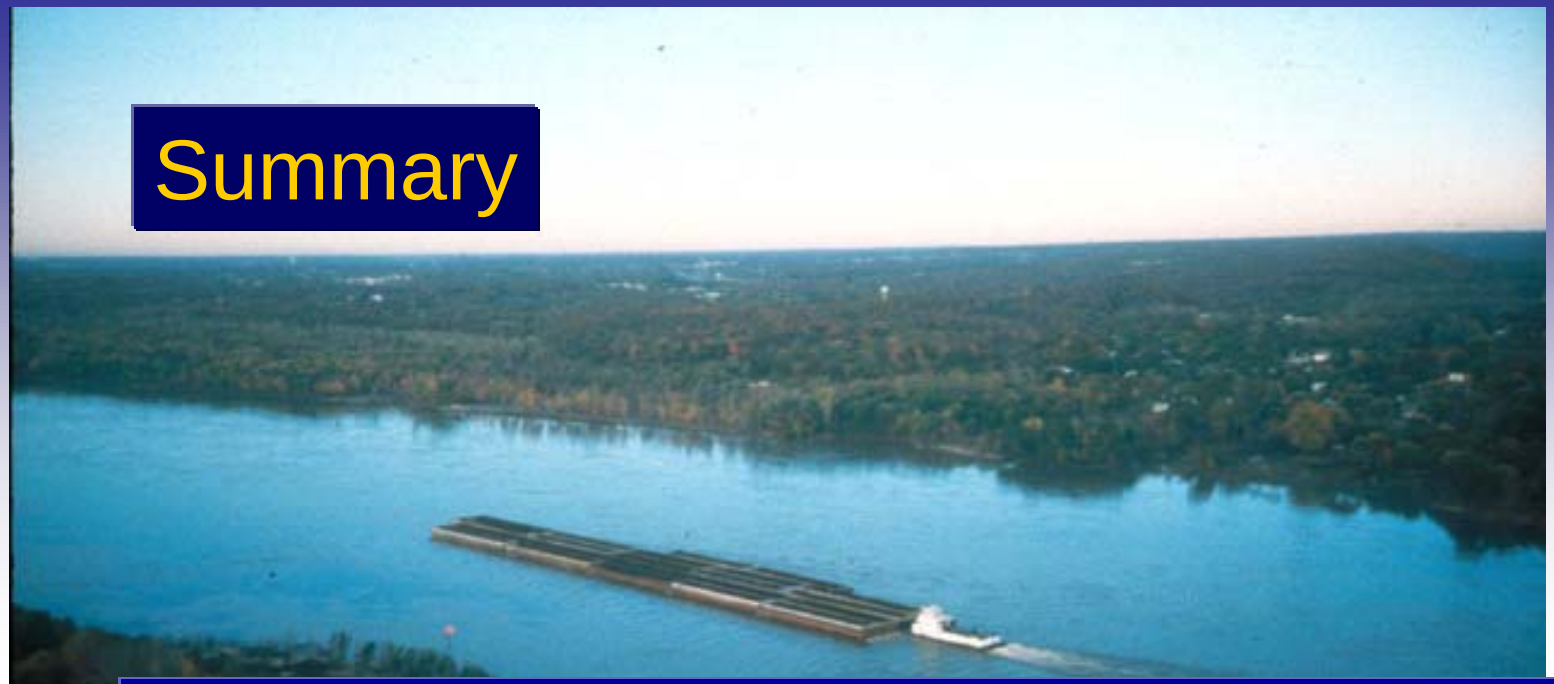


# Adaptive Management and Decision Framework




# Conceptual Model for Risk-based Decision Making



# Summary

- The ERA framework usefully applies in assessing risks posed by commercial navigation on the UMRS
- The Navigation Study ERA relies extensively on the implementation of ecological models
- The models suggest different magnitudes of risk for fish, SAV, and unionid mussels
- The results of an ERA can feed effectively into a risk-based framework for adaptive environmental management