Ecological Risk Assessment in the United States

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Purpose of this presentation,

- Describe current approaches to ecological risk assessment in the United States
- Identify several key issues for advancing ecological risk assessment
- Suggest an environmental context for ecological risk management

A formal definition of risk...

$$R = \sum_{k} C_k(A_k) \sum_{i} \sum_{j} P(A_k \setminus E_{ji} \cap S_i) P(E_{ji} \setminus S_i) P(S_i)$$

where,

C_k = consequences of adverse affect k

A_k = adverse affect k

$P(A_k ¥ E_{ji} \cap S_i)$ = probability of A_k given exposure j and stressor i

$P(E_{ji} ¥ S_i)$ = probability of exposure j given stressor i

$P(S_i)$ = probability of stressor i

Consider a simple model of risk

$$\text{Risk} = F\{x_i, p_i, s_i\}$$

x_i = what is at risk

p_i = probability of x_i

s_i = consequences of x_i

Kaplan and Garrick (1981)

Defining “ecological risk”

an *ecological risk* is the conditional probability of a specified ecological event occurring, along with an evaluation of its consequences...

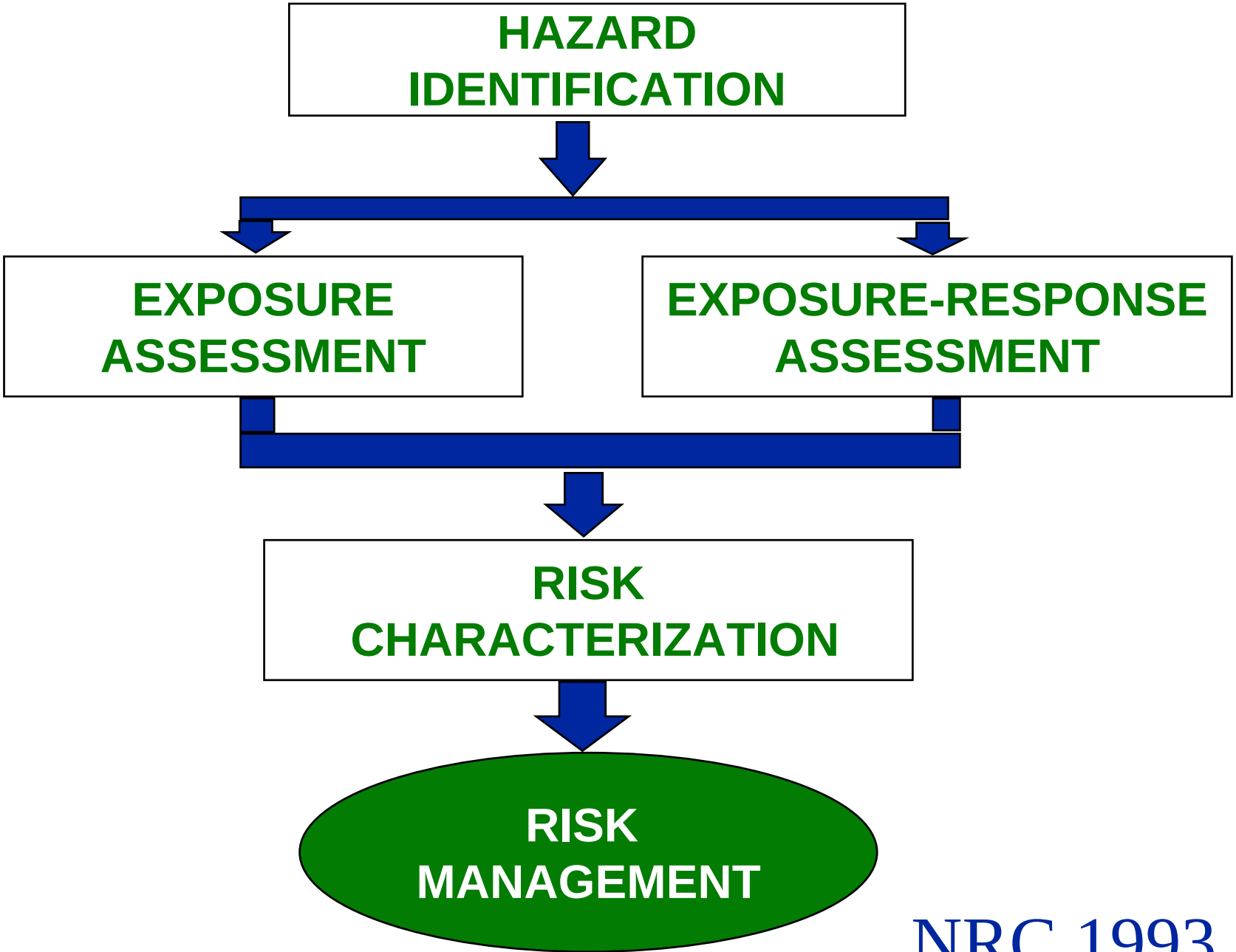
Adverse ecological event might include,

- Local extinction
- Population change
- Community structure
- Growth and reproduction
- Individual loss

- Physiological process (e.g., photosynthesis)
- Energy flow
- Nutrient cycling
- Ecosystem stability

National Research Council

Committee on Risk Assessment Methods


HAZARD IDENTIFICATION
EXPOSURE ASSESSMENT
EXPOSURE-RESPONSE ASSESSMENT
RISK CHARACTERIZATION
RISK MANAGEMENT

NRC 1993

Water Environment Research Foundation (WERF)

Risk Assessment Methods

A Sequential or “Tiered” Approach

- Tier 1: Screening-level assessment
- Tier 2: Detailed assessment using existing data and information
- Tier 3: Detailed assessment involving new data

Each “tier” consists of

- Problem definition
- Source characterization
- Exposure assessment
- Ecological receptor characterization

- Ecological effects characterization
- Risk characterization
- Risk management

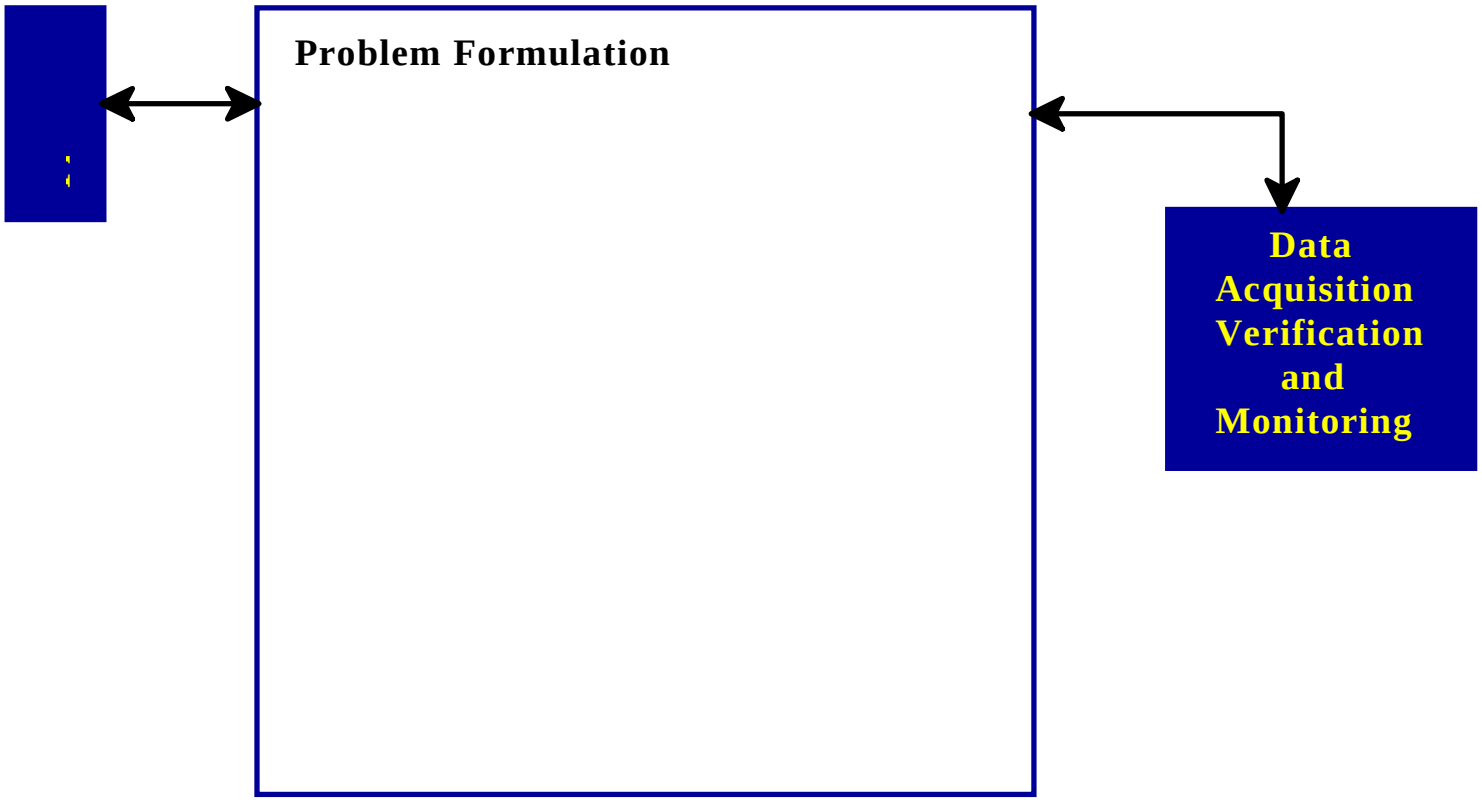
Other frameworks and approaches

- American Society for Testing and Materials Comittee E.47
- OECD
- The Netherlands
- Environment Canada

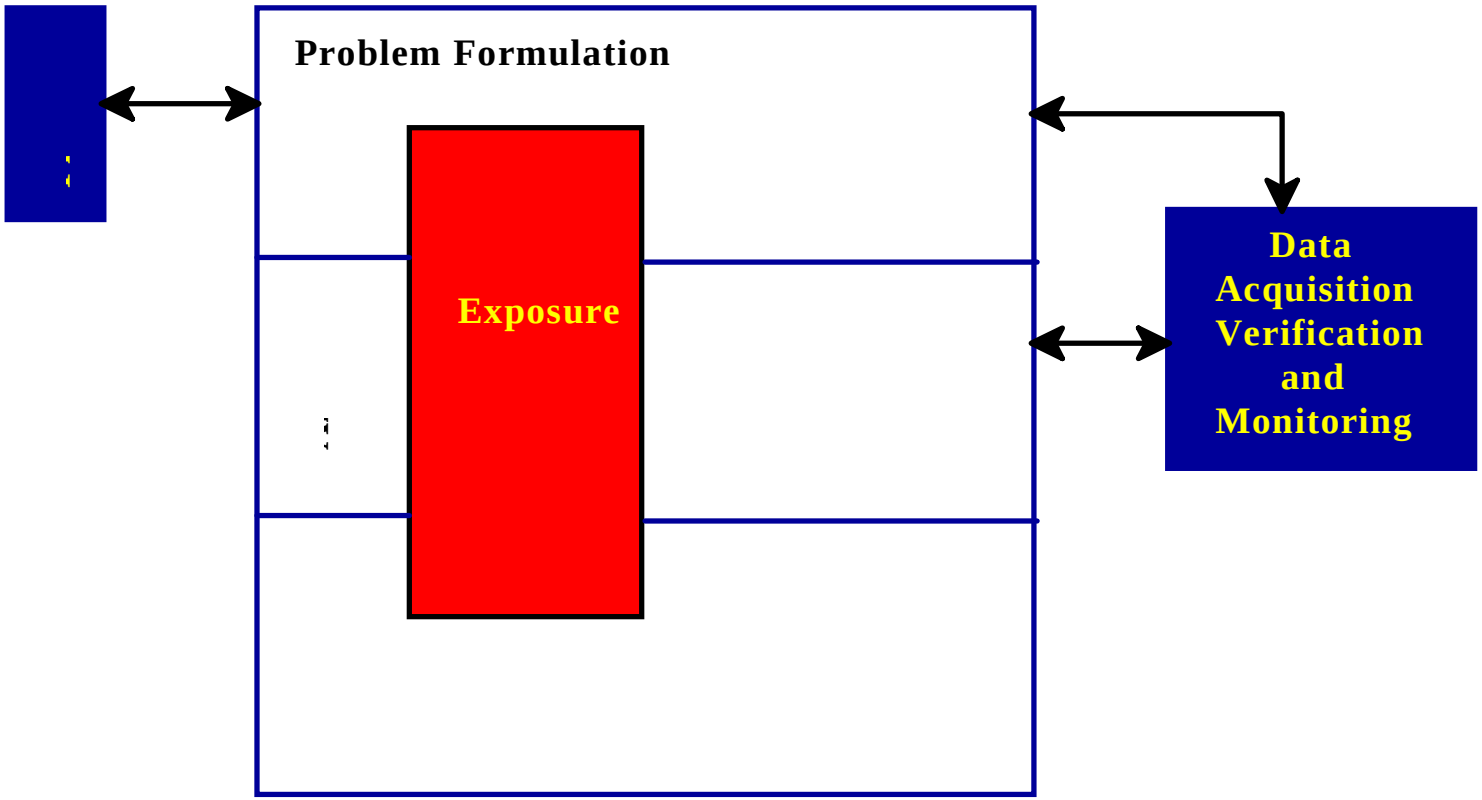
U.S. Environmental Protection Agency (USEPA)

Proposed Guidelines for
Ecological Risk Assessment

1996



Ecological risk assessment framework (USEPA 1992, 1996)



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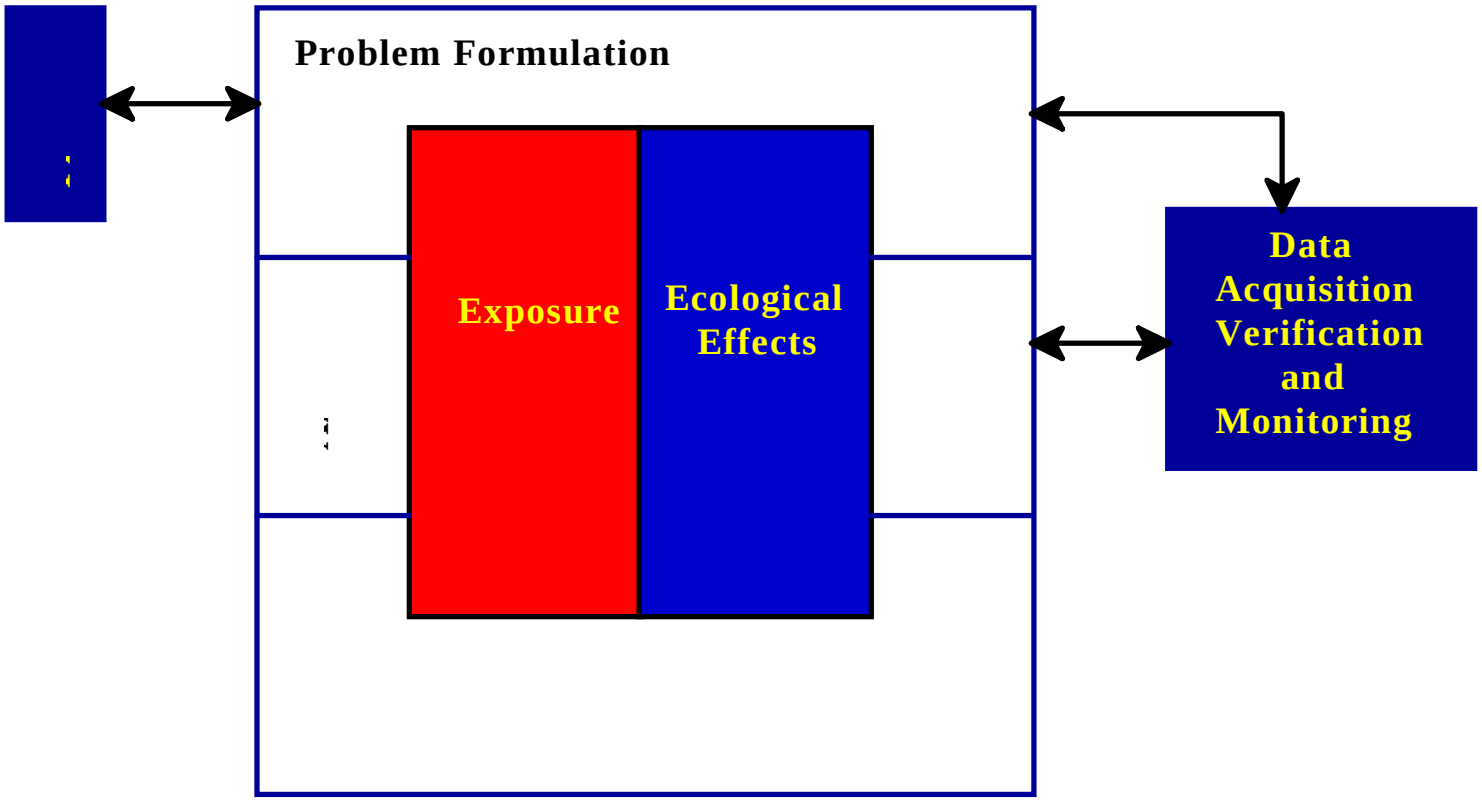
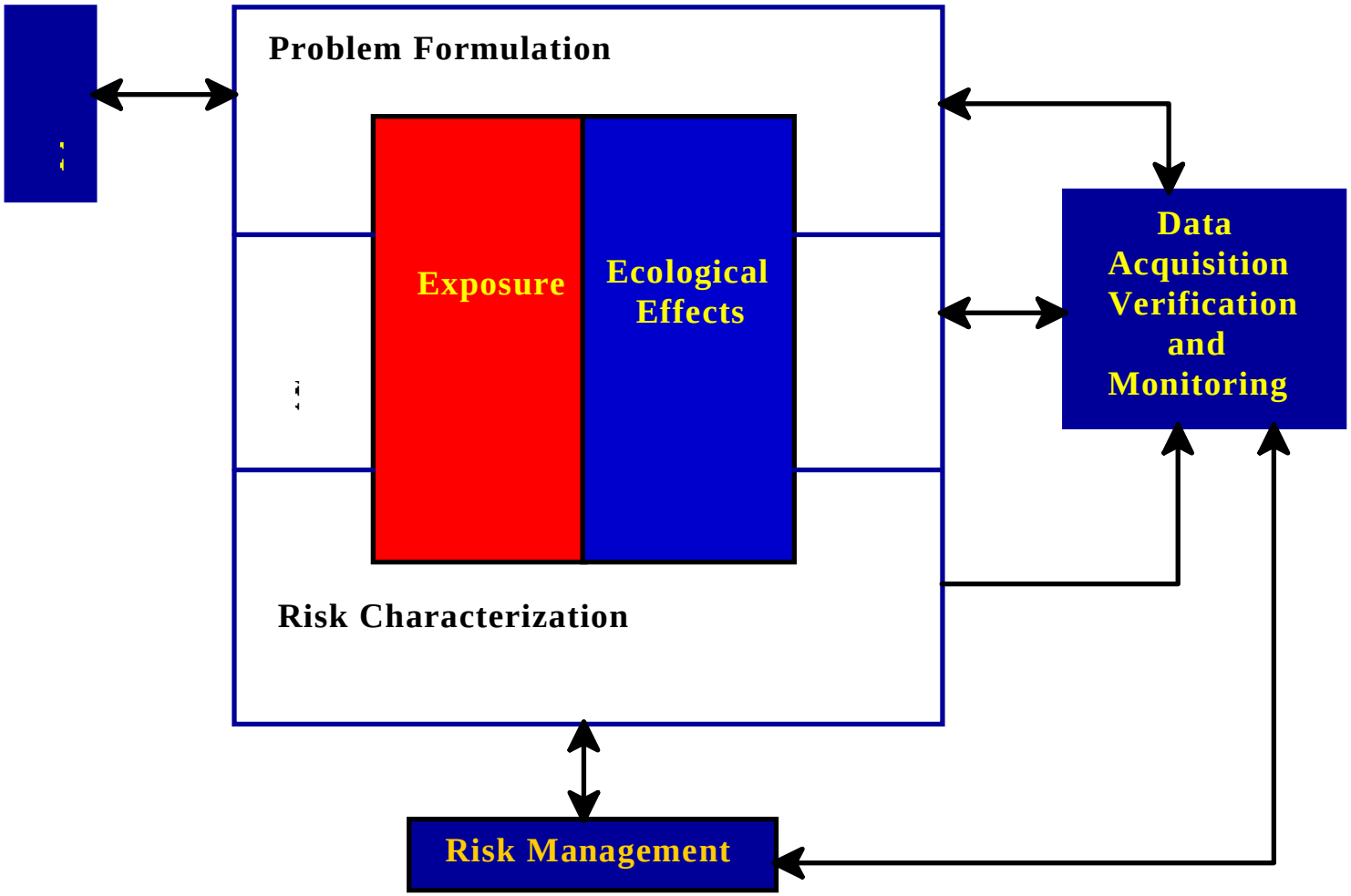
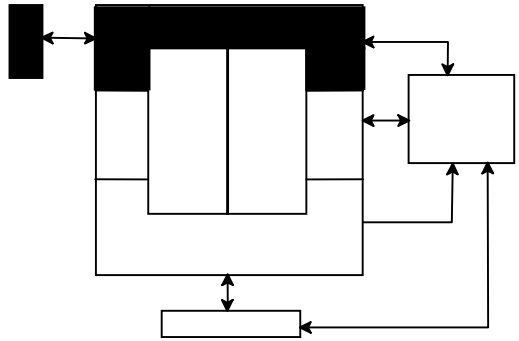


Ecological risk assessment framework (USEPA 1992, 1996)



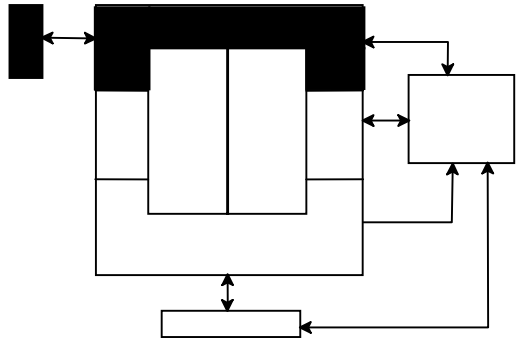
Ecological risk assessment framework (USEPA 1992, 1996)

Problem Formulation



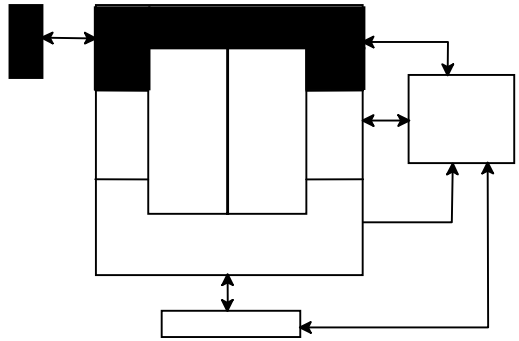
- Integrate available information
- Select what to protect
- Construct a conceptual model
- Develop a plan for analysis

Integrate available information



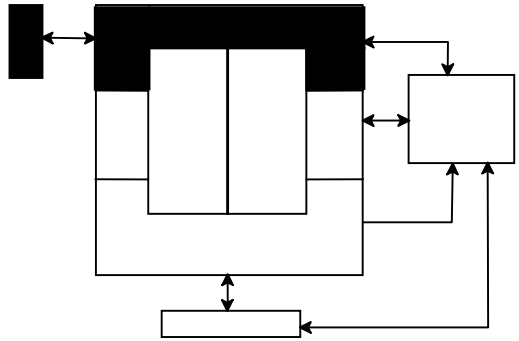
- Foundation of problem formulation
- Stressors, exposure, effects, ecosystems
- Influenced by reason for the assessment
- Scoping process

Selecting what to protect



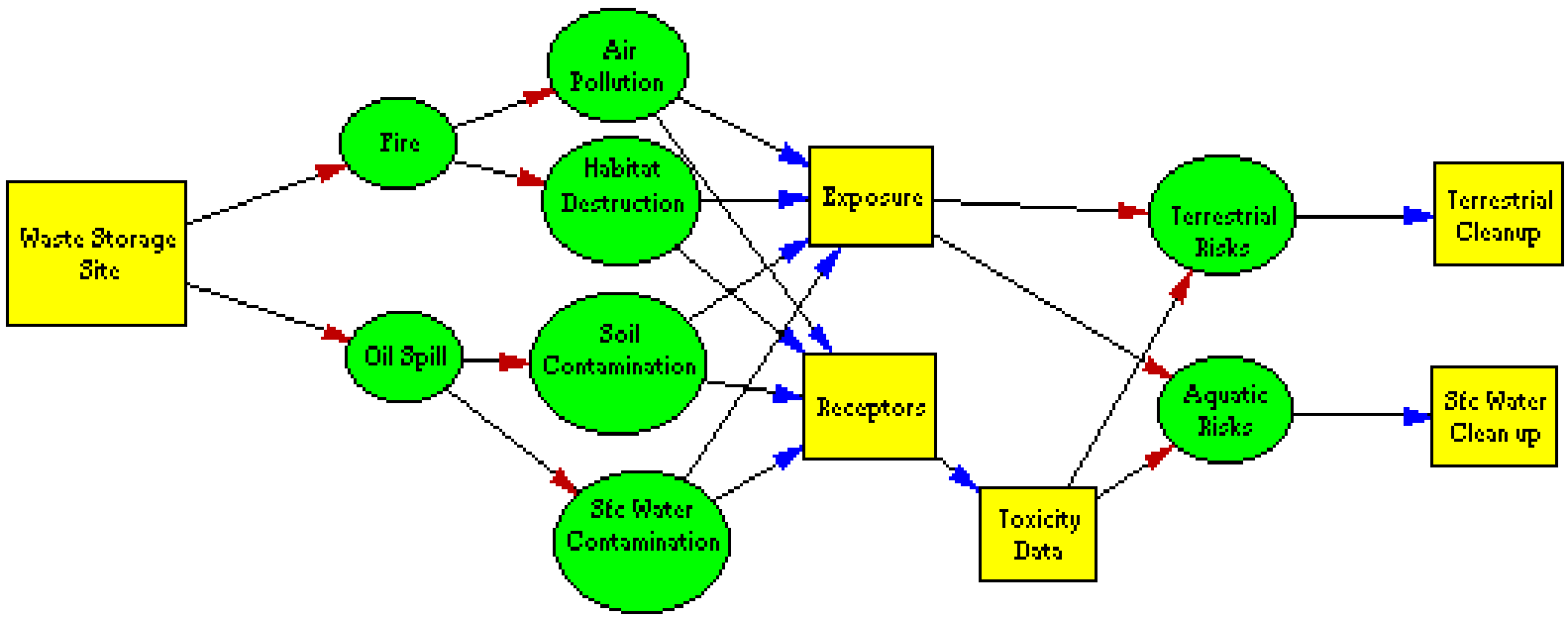
- Ecological relevance
- Sensitive or susceptible to stressor(s)
- Likelihood of exposure
- Relevance to risk management

Conceptual model

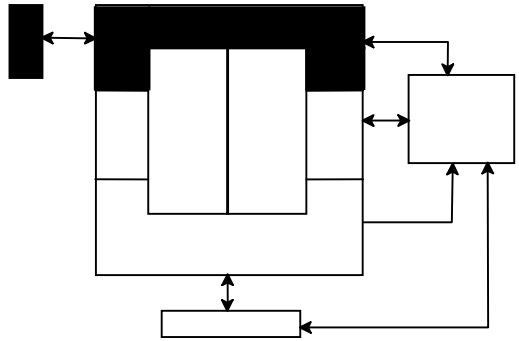


- Blueprint for the entire assessment
- Two principal products:
  - Set of risk hypotheses
  - Diagram illustrating the conceptual model

Hazardous Waste Storage Sites

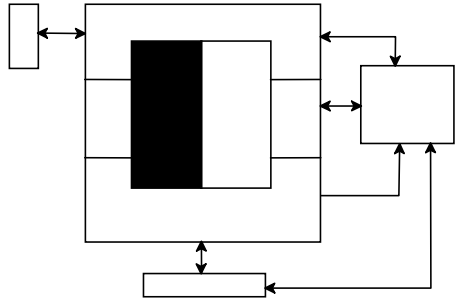


Plan for analysis



- Final stage of problem formulation
- Detail the methods for analysis phase
- Synopsis of measures to evaluate risk hypotheses
- Anticipate uncertainties, their impacts
- Entering results into decision-making

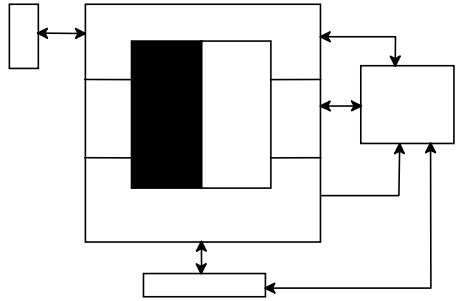
Exposure Analysis



- Source of the stressor(s)
- Scale and distribution of the stressor
- Pathways of exposure

Product: Exposure Profile

Exposure Profile



- Identify receptors
- Describe relevant pathways
- Frequency, intensity, extent, duration
- Address variability

The profile synthesizes above information in a report or model....

Deer Exposure to Mercury

$$E = \frac{(C_w \cdot I_w) + (C_s I_v \cdot B_v + C_s \cdot I_s) \cdot H}{B_w}$$

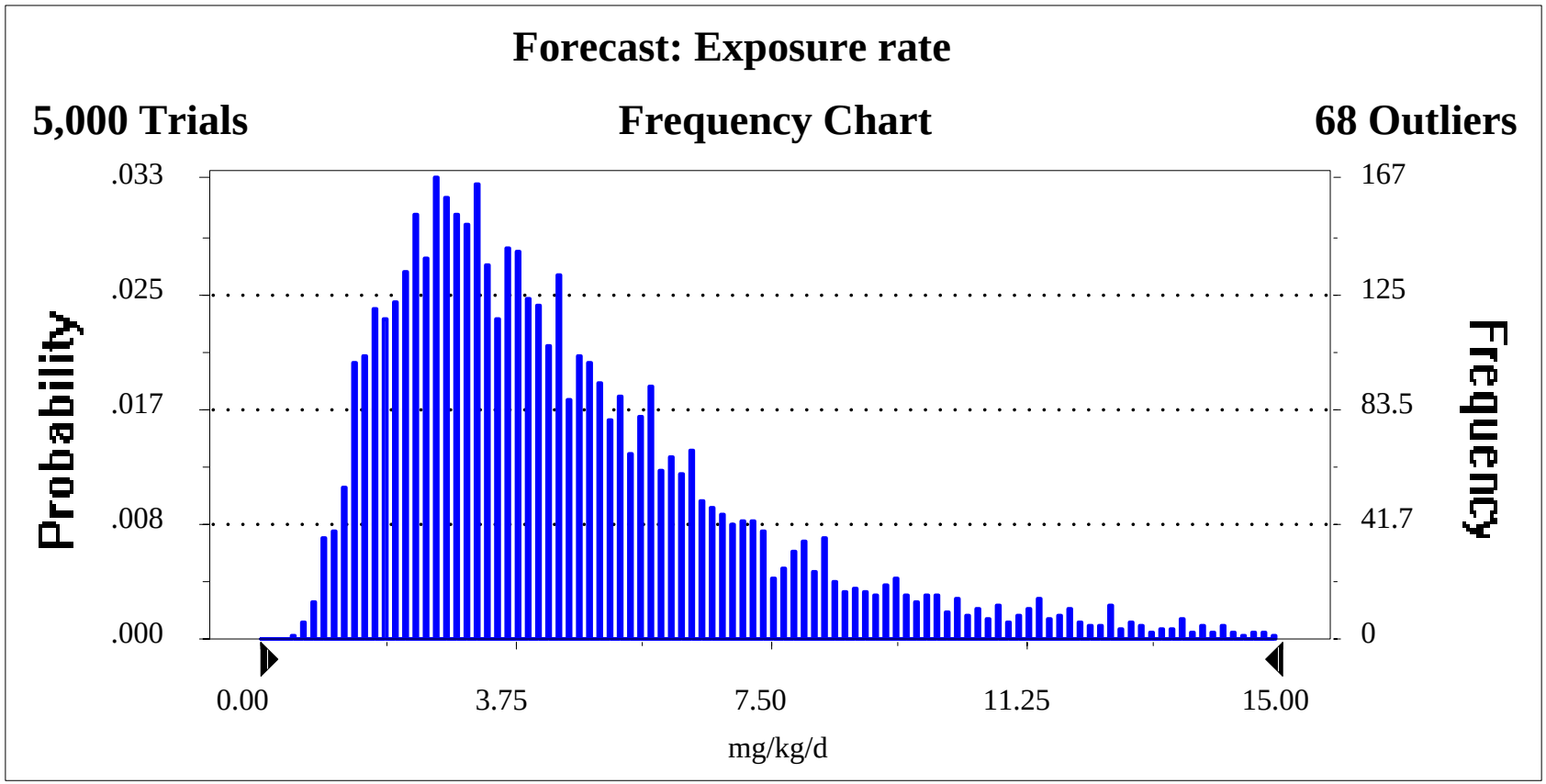
Model parameter values

Accumulation pathways for deer

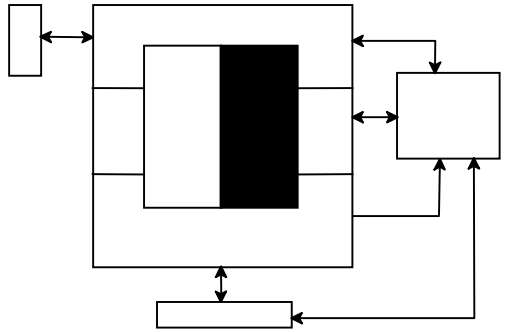
Model Parameter	Units	Value
Cw, concentration of chemical in water	(mg/kg)	0.10
Iw, water ingestion rate for deer	(L/d)	1.10
Cs, concentration of chemical in soil	(mg/kg)	1.20
Iv, rate of ingestion of vegetation	(kg/d)	1.60
Bv, soil-to-plant transfer factor	(unitless)	200
Is, incidental soil ingestion	(kg/d)	0.02
H, ratio of home range area to site area	(unitless)	0.50
BW, body weight of deer	(kg)	45.40

Total Exposure to Deer

Parameter	Units	Value
E, total exposure to deer	(mg/kg/d)	2.96
B, toxicity benchmark : mercury LD50	(mg/kg/d)	17.80
Quotient = E/B	(unitless)	0.17


Forecast: Exposure rate
5,000 Trials
Frequency Chart
68 Outliers
Probability
.033
.025
.017
.008
.000
167
125
83.5
41.7
0
Frequency
0.00
3.75
7.50
11.25
15.00
mg/kg/d

Effects Analysis



- Stressor-response analysis
- Establish cause and effect relationships
- Linking measures to assessment endpoints

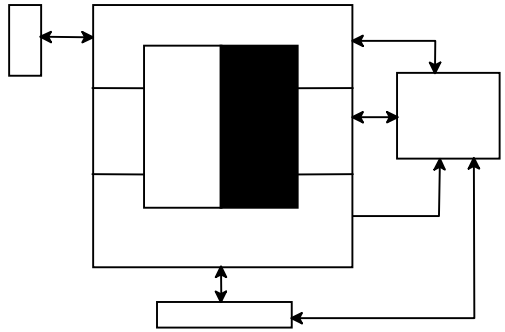
Product: Stressor-response profile

Adverse ecological event might include,

- Local extinction
- Population change
- Community structure
- Growth and reproduction
- Individual loss

- Physiological process (e.g., photosynthesis)
- Energy flow
- Nutrient cycling
- Ecosystem stability

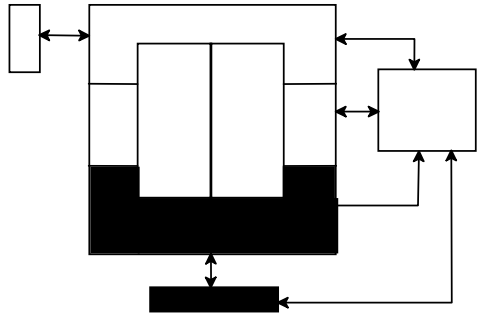
Stressor-response profile



- Identify effects of concern
- Establish causal linkage to stressor
- Estimate severity of effects in relation to intensity of exposure
- Characterize uncertainties

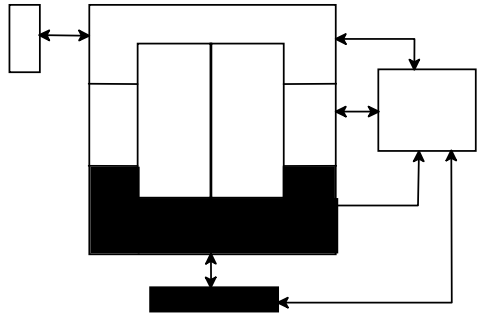
Profile may be a report or model...

Risk Characterization



- Estimating risks
- Describing risks
- Reporting risks

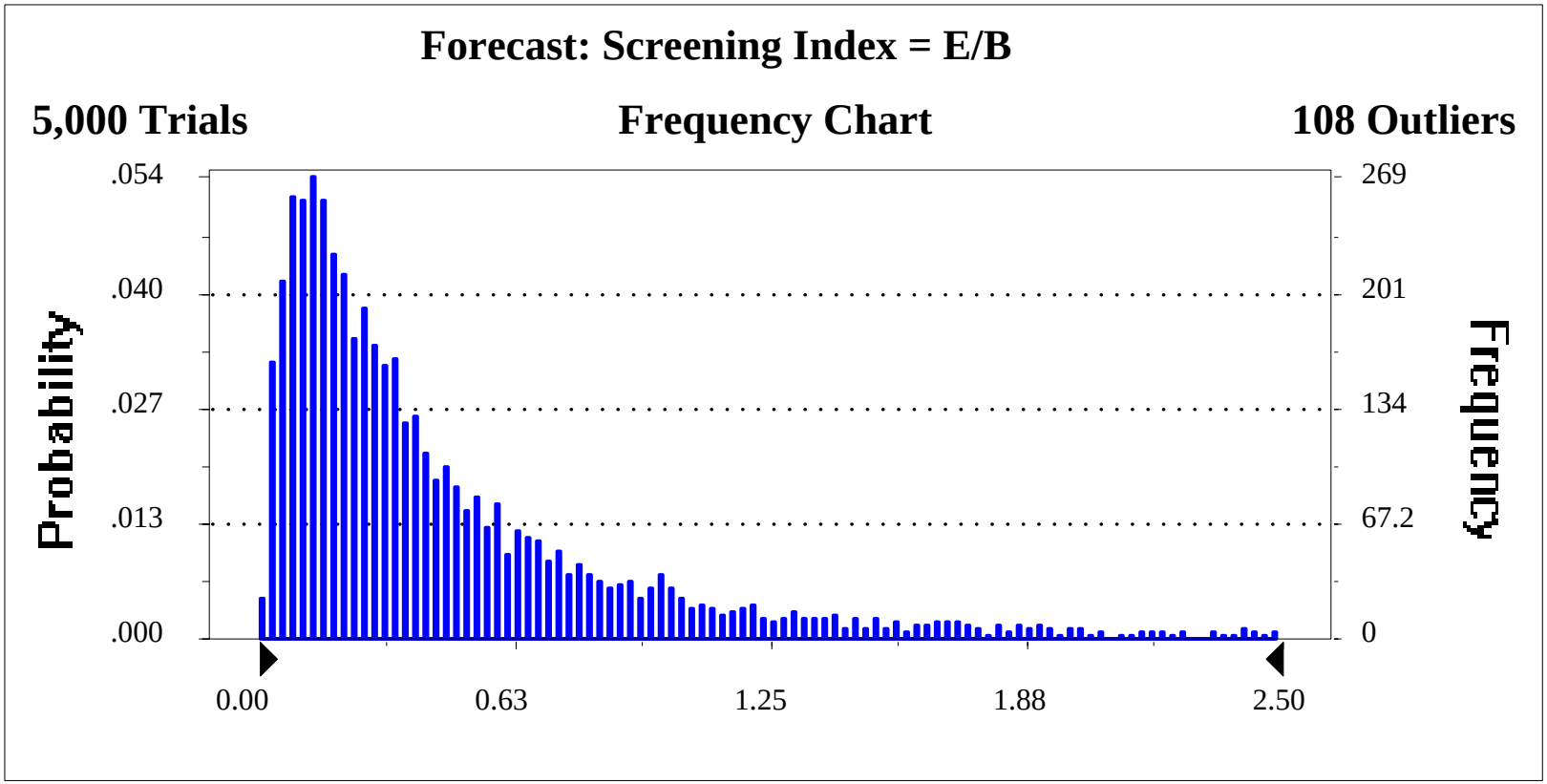
Estimating risks



- Qualitative estimates
- Single-value estimates
- Entire stress-response relationships
- Address variability in exposure and/or effects

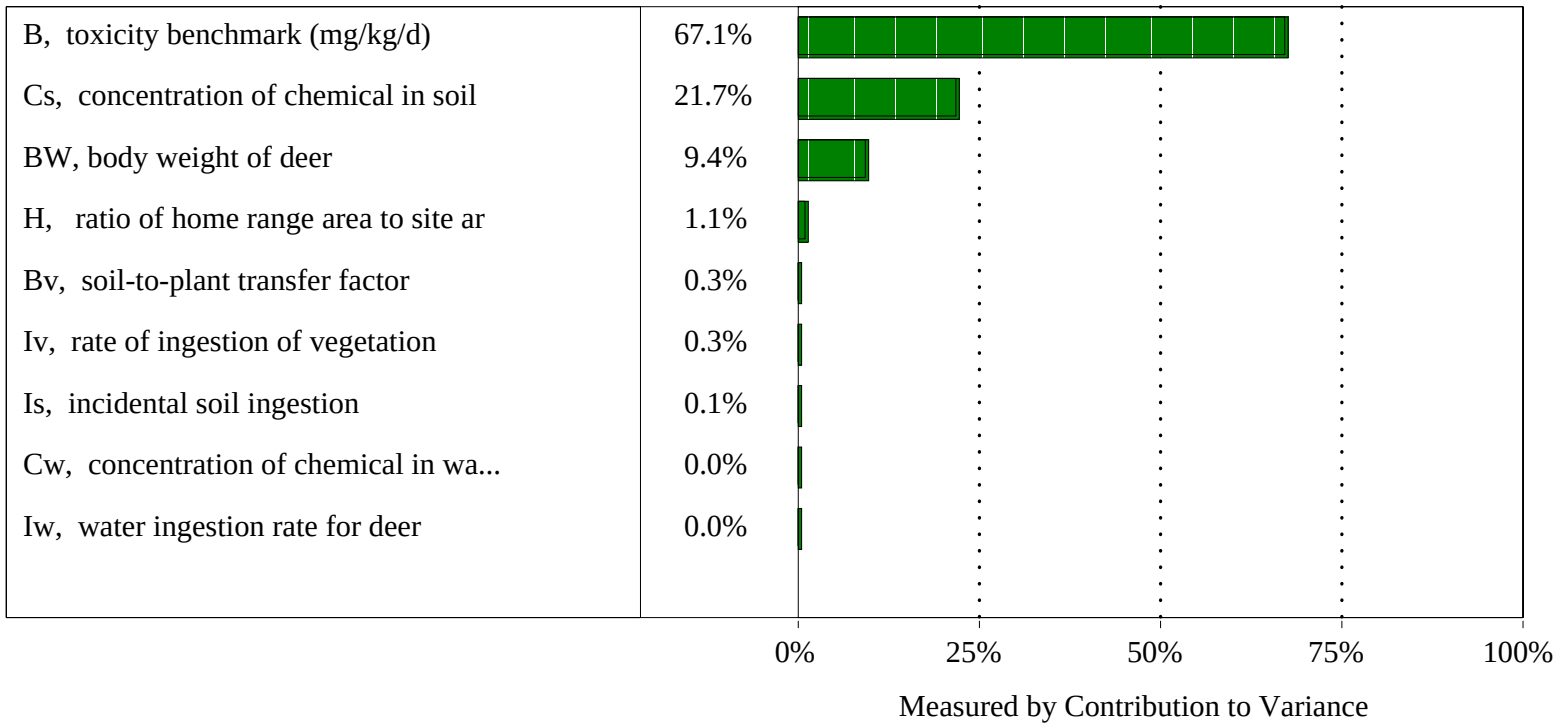
Total Exposure to Deer

Parameter	Units	Value
E, total exposure to deer	(mg/kg/d)	2.96
B, toxicity benchmark : mercury LD50	(mg/kg/d)	17.80
Quotient = E/B	(unitless)	0.17


Forecast: Screening Index = E/B
5,000 Trials
Frequency Chart
108 Outliers
Probability
Frequency
.054
.040
.027
.013
.000
269
201
134
67.2
0
0.00
0.63
1.25
1.88
2.50

Sensitivity Chart

Target Forecast: Screening Index = E/B

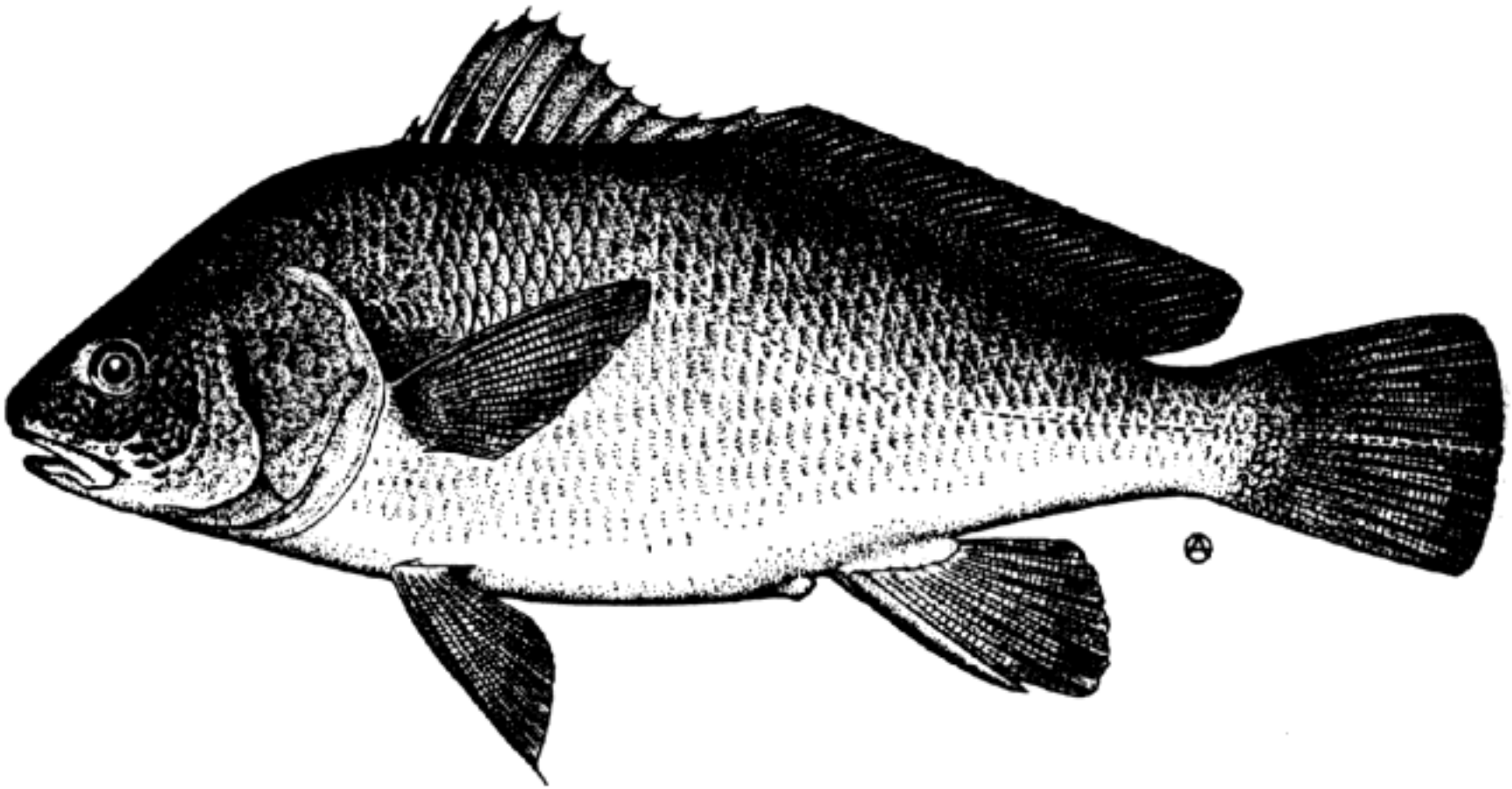


Population models

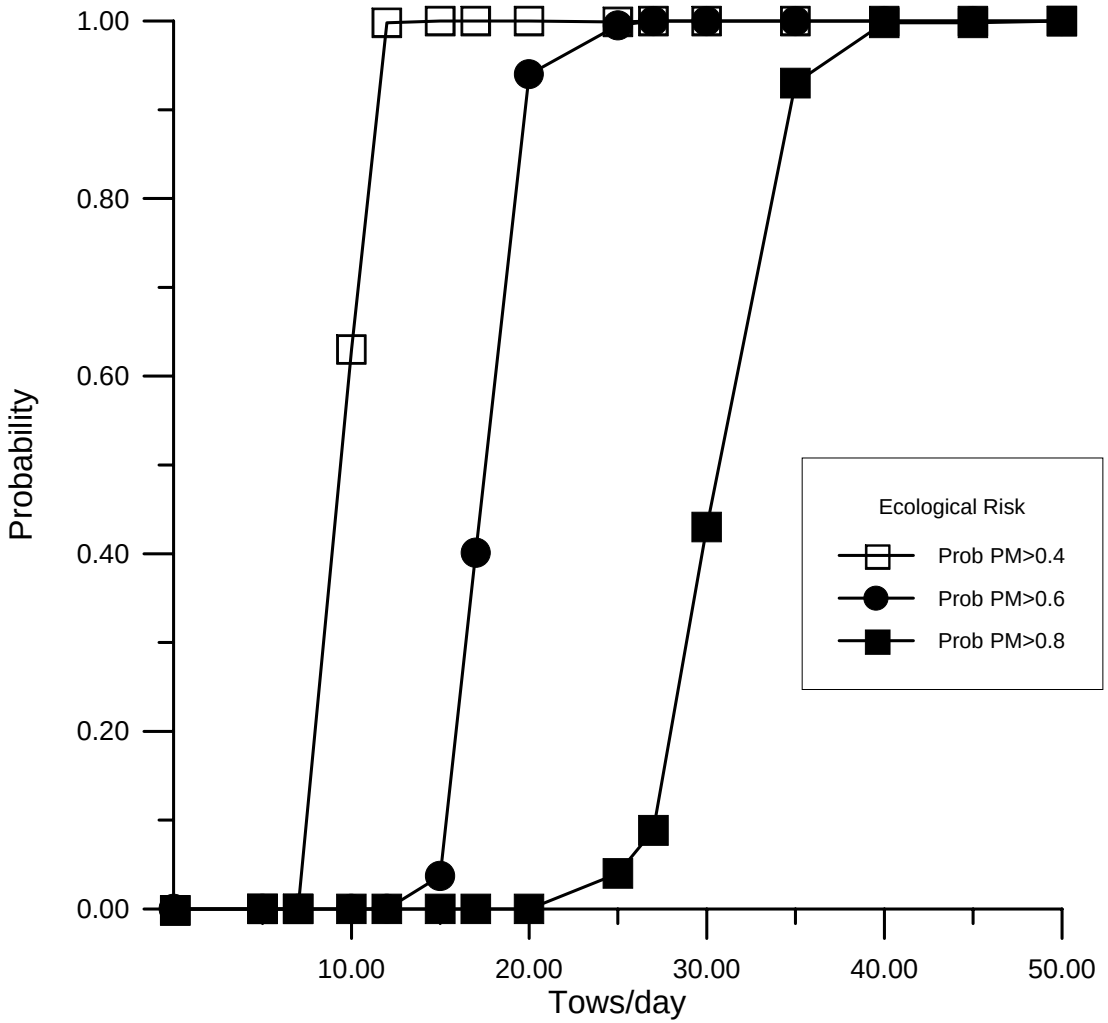
- Structured population models
- Demographics
- Bioenergetics
- Collections of modeled individuals

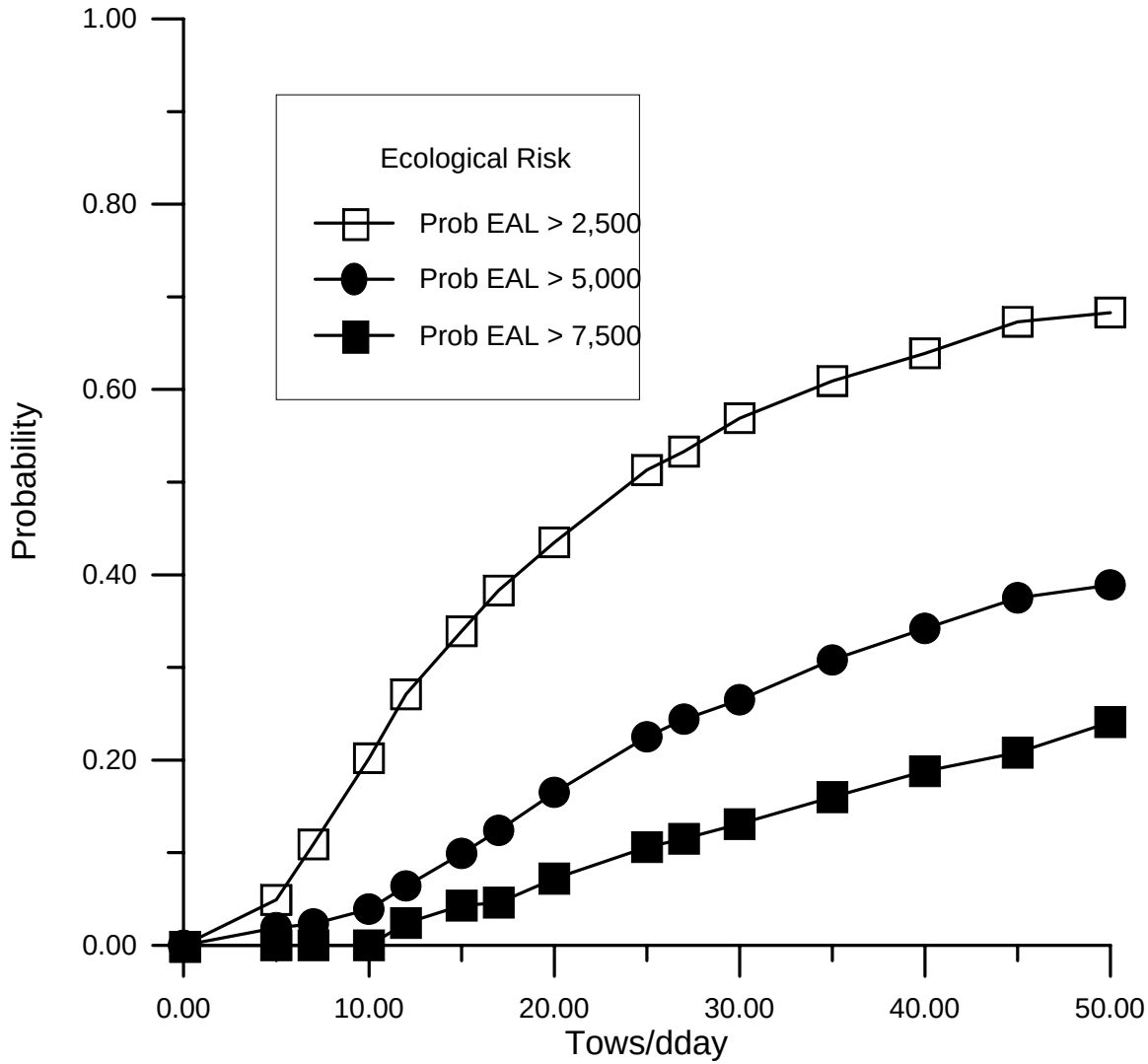
FRESHWATER DRUM

Aplodinotus grunniens Rafinesque



Freshwater Drum: Proportional Mortality Risk vs Tows/day




Ecological Risk
Prob EAL > 2,500
Prob EAL > 5,000
Prob EAL > 7,500
Probability
1.00
0.80
0.60
0.40
0.20
0.00
0.00
10.00
20.00
30.00
40.00
50.00
Tows/dday

Community models

- Empirical models
  - diversity indices (alpha, beta)
  - biotic integrity (Karr)
  - multivariate analyses (e.g., Landis)
- Gradient models
- Community assembly models (Post)

Ecosystem models

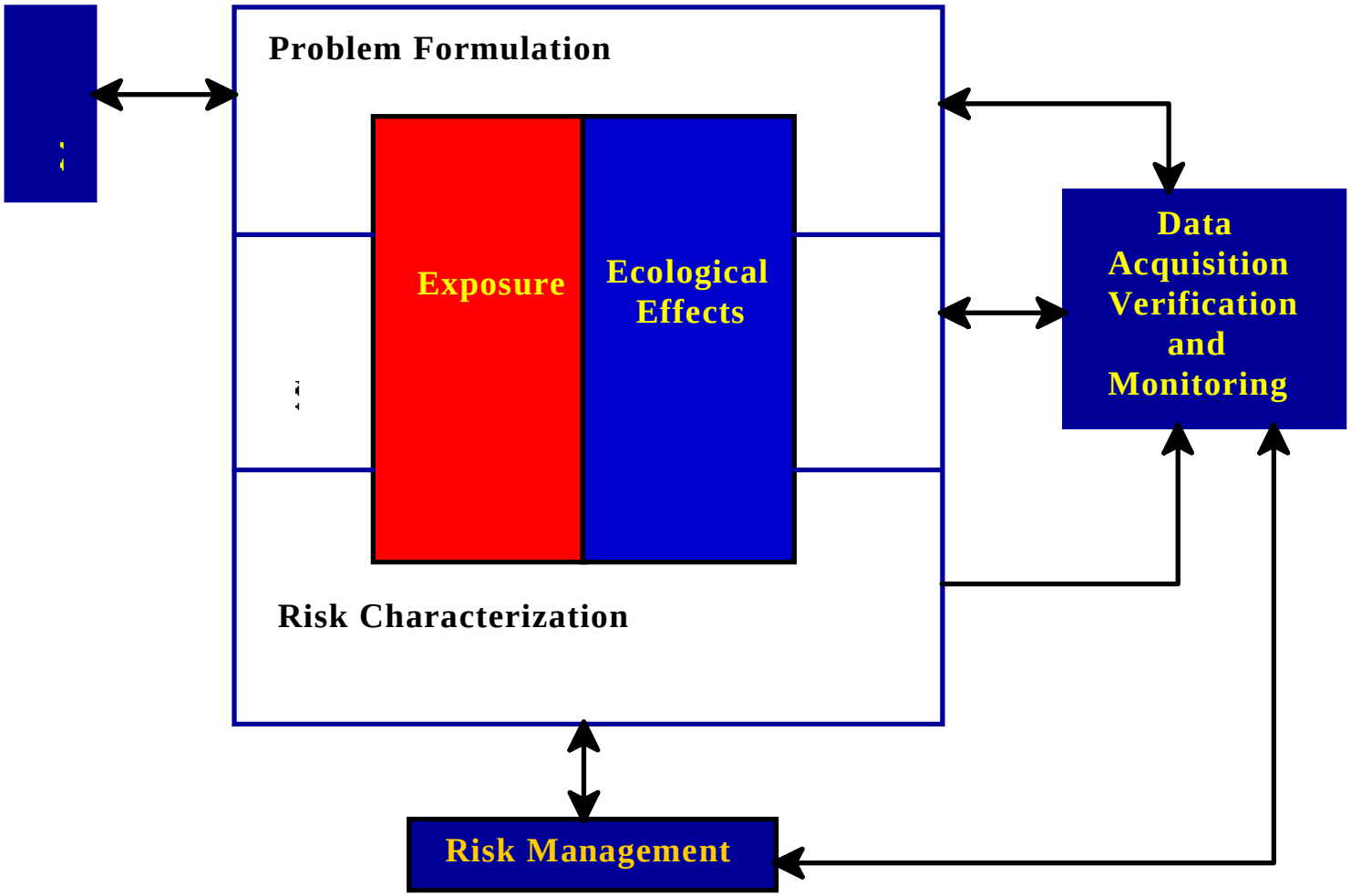
- Emphasize biotic-abiotic interactions in defining x_i's
- Explicit representation of detailed system structure and function
- Dynamic in space and time
- Scale, aggregation, parameter estimation
- Accuracy, precision

Examples of ecosystem models for risk assessment

- AQUATOX
- LERAM
- SWACOM, CASM, IFEM
- Other models (Suter and Bartell 1993)

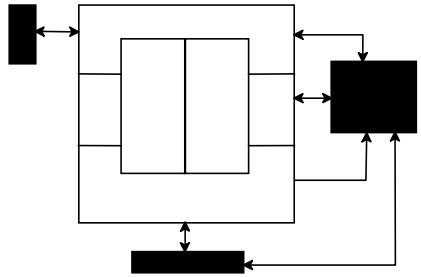
Landscape and larger scale models

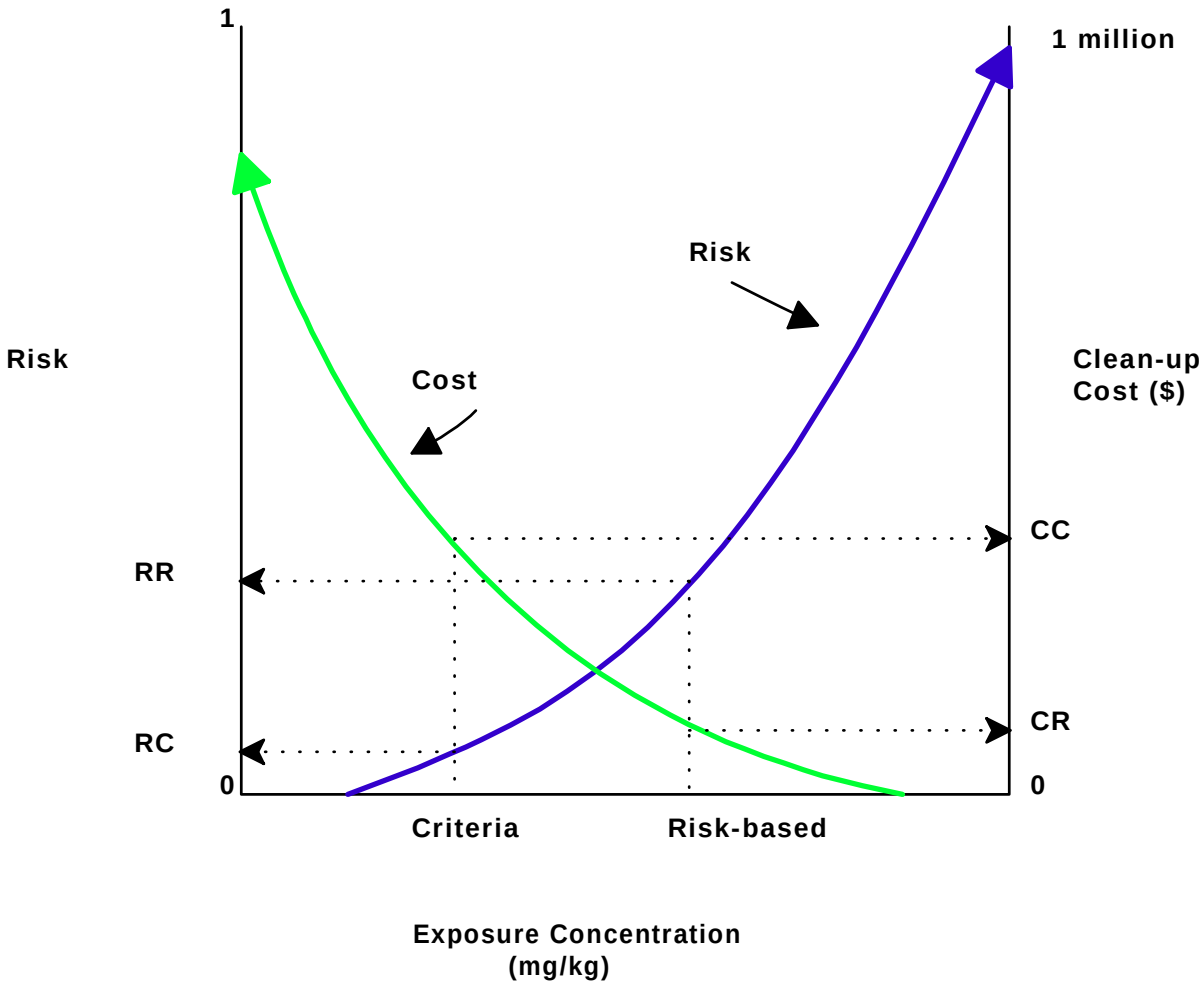
- Characterize pattern on the landscape
  - Land use patterns
  - Indices: dominance, contagion, fractals
- Understand processes that determine pattern
  - Hydrology, geochemistry
  - Vegetation (ecology, dynamics)
  - Human activities



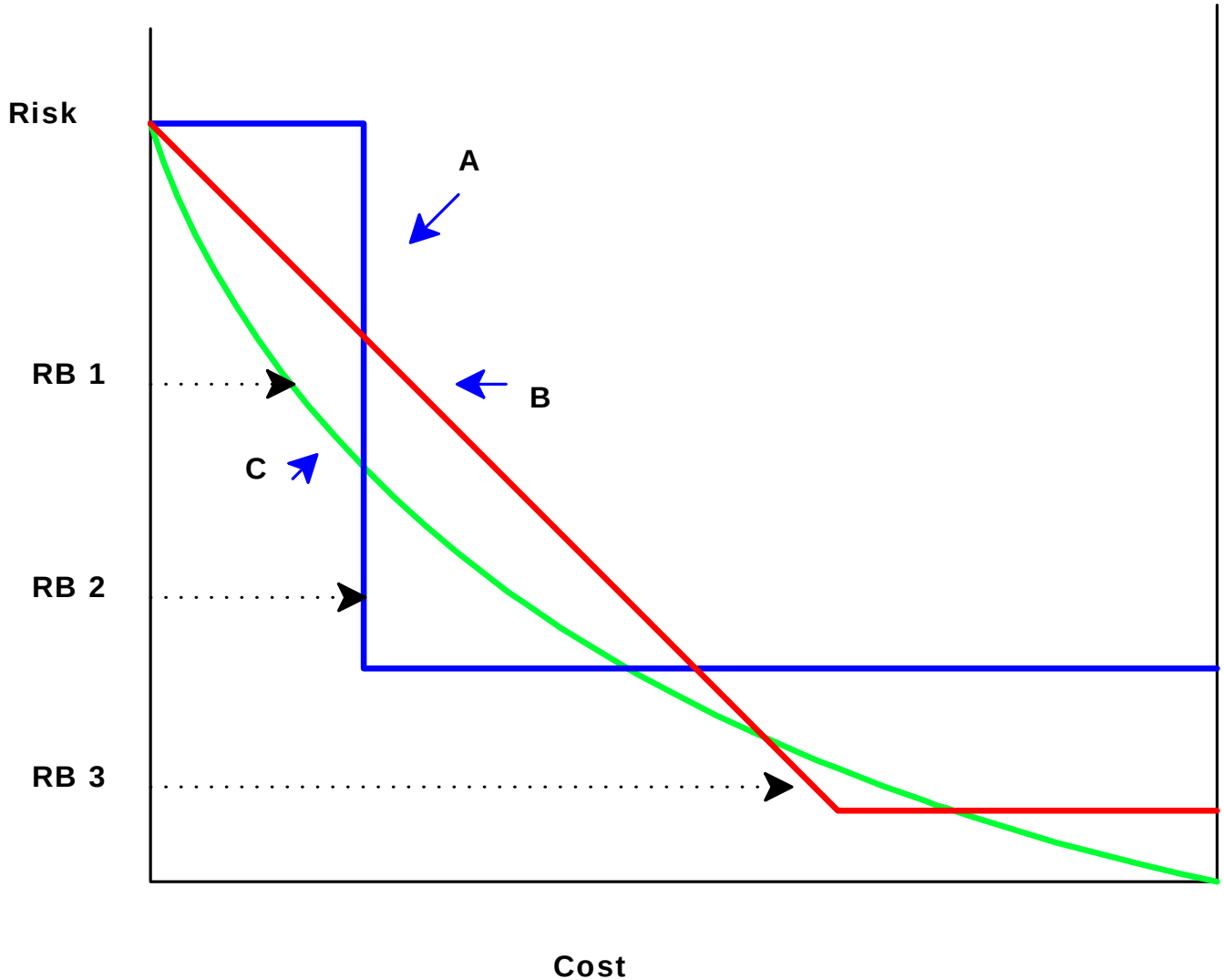
Ecological risk assessment framework (USEPA 1992, 1996)

Risk Planning, Risk Management





Risk-based remediation: costs and decisions

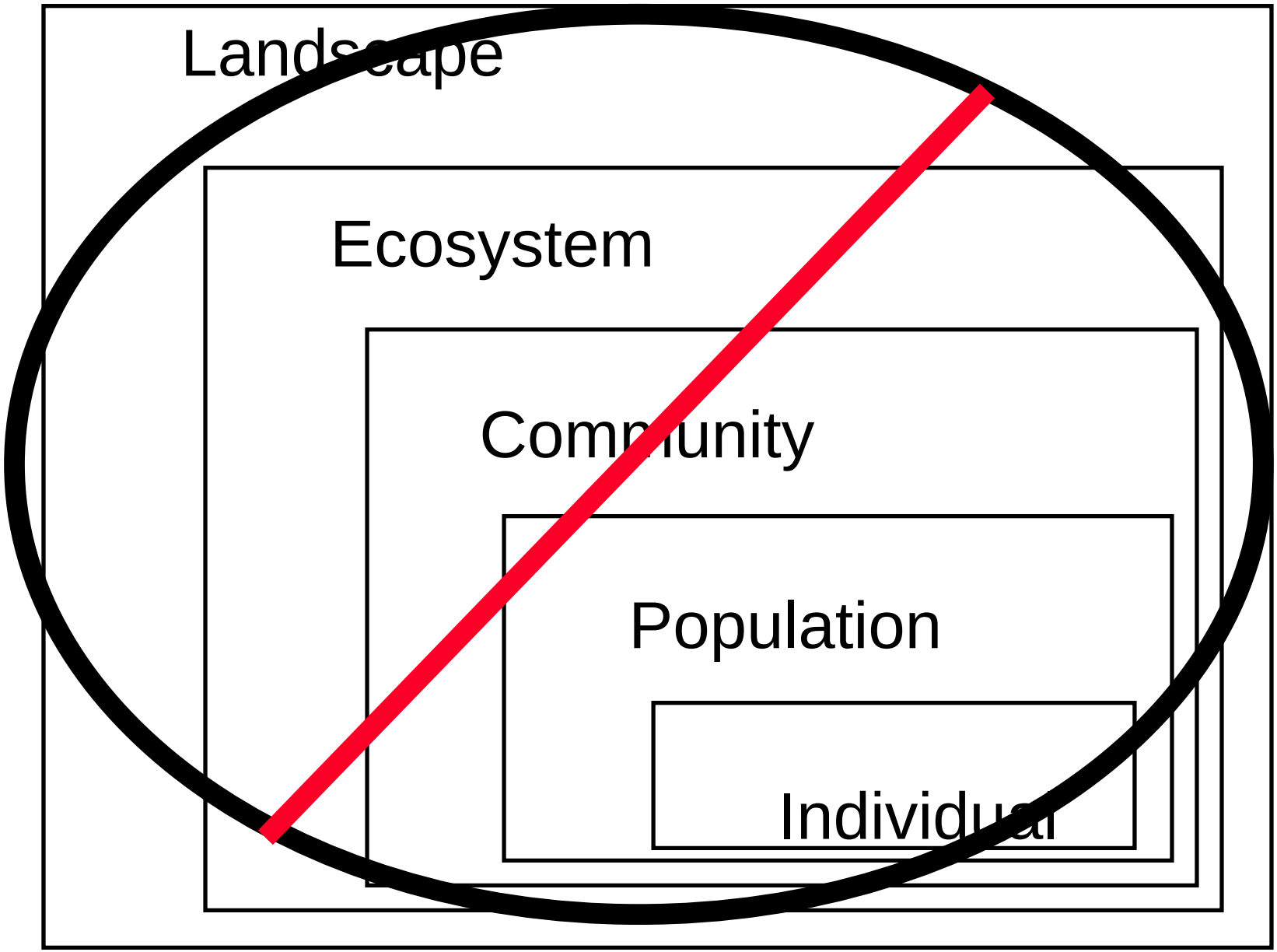


Critical Issues in Advancing Ecological Risk Assessment

Technical and policy issues that need to be successfully addressed in order to advance the process of ecological risk assessment and provide for meaningful risk management....

Several Critical Issues in Ecological Risk Assessment

- Endpoint selection
- Multiple stressors
- Stress-response functions
- Ecological scale and complexity
- Decision criteria and ecological significance


Landscape
Ecosystem
Community
Population
Individual

Fundamental Ecological Views of Nature

- what environment?
- ecological frame of reference
- reference site selection

a key component needed for meaningful assessments...

Three metaphors of nature (Holling 1986)

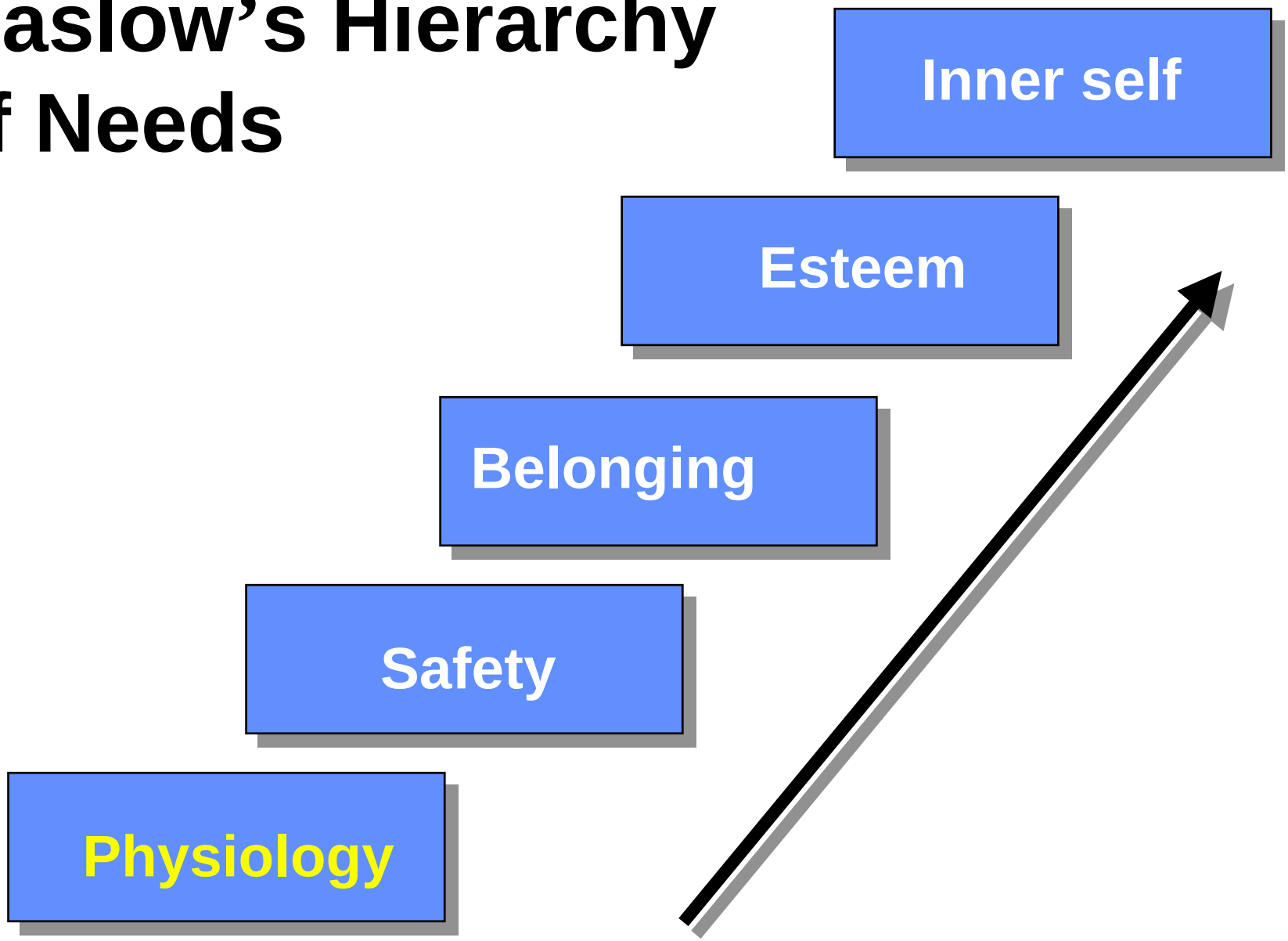
- An environment in equilibrium
- A dynamic environment
- An evolutionary environment

A Context for Managing Ecological Risks

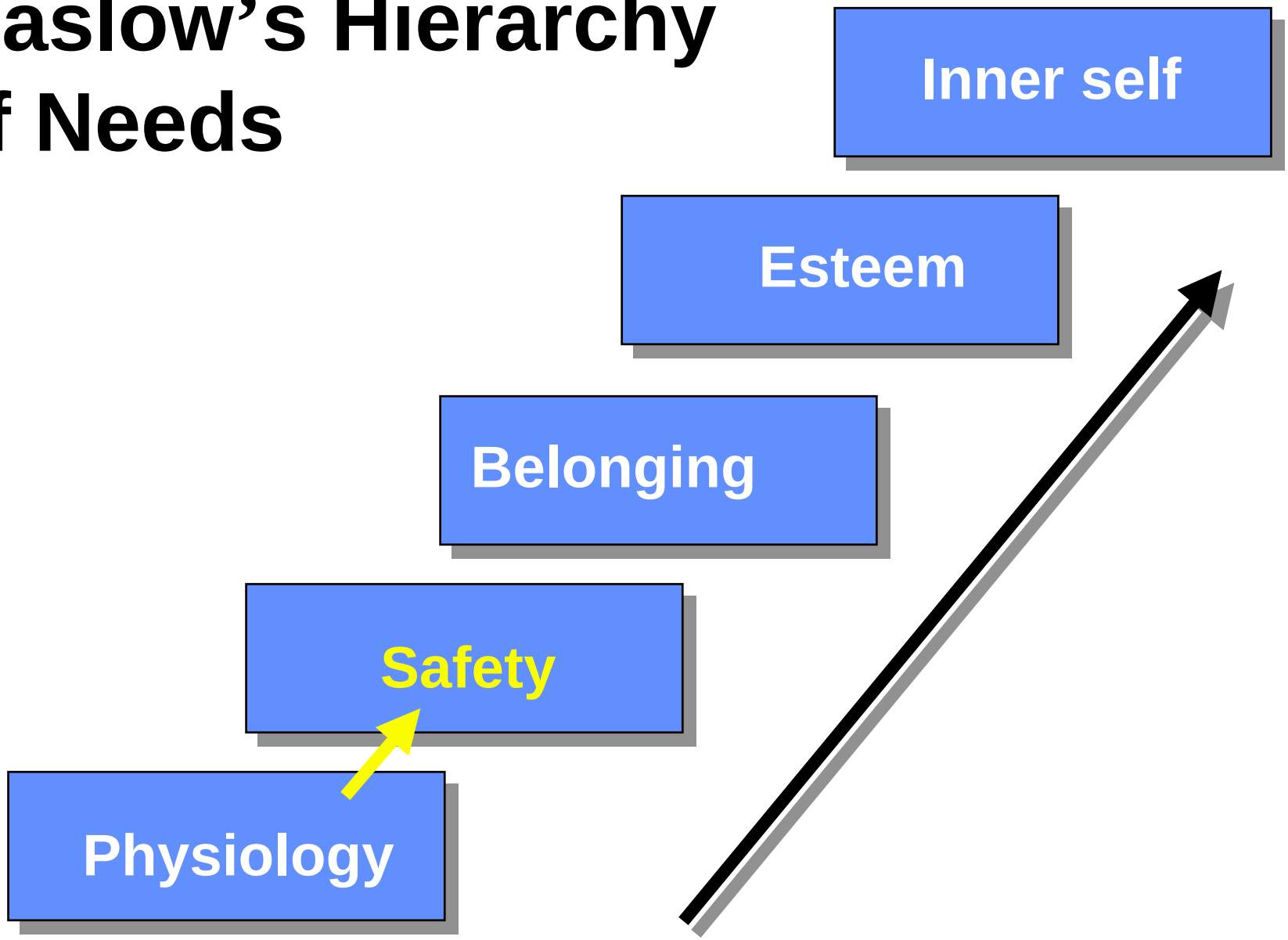
Human demography

- Root cause of environmental problems
- 170 people/minute added to Earth
- 250,000 people/day

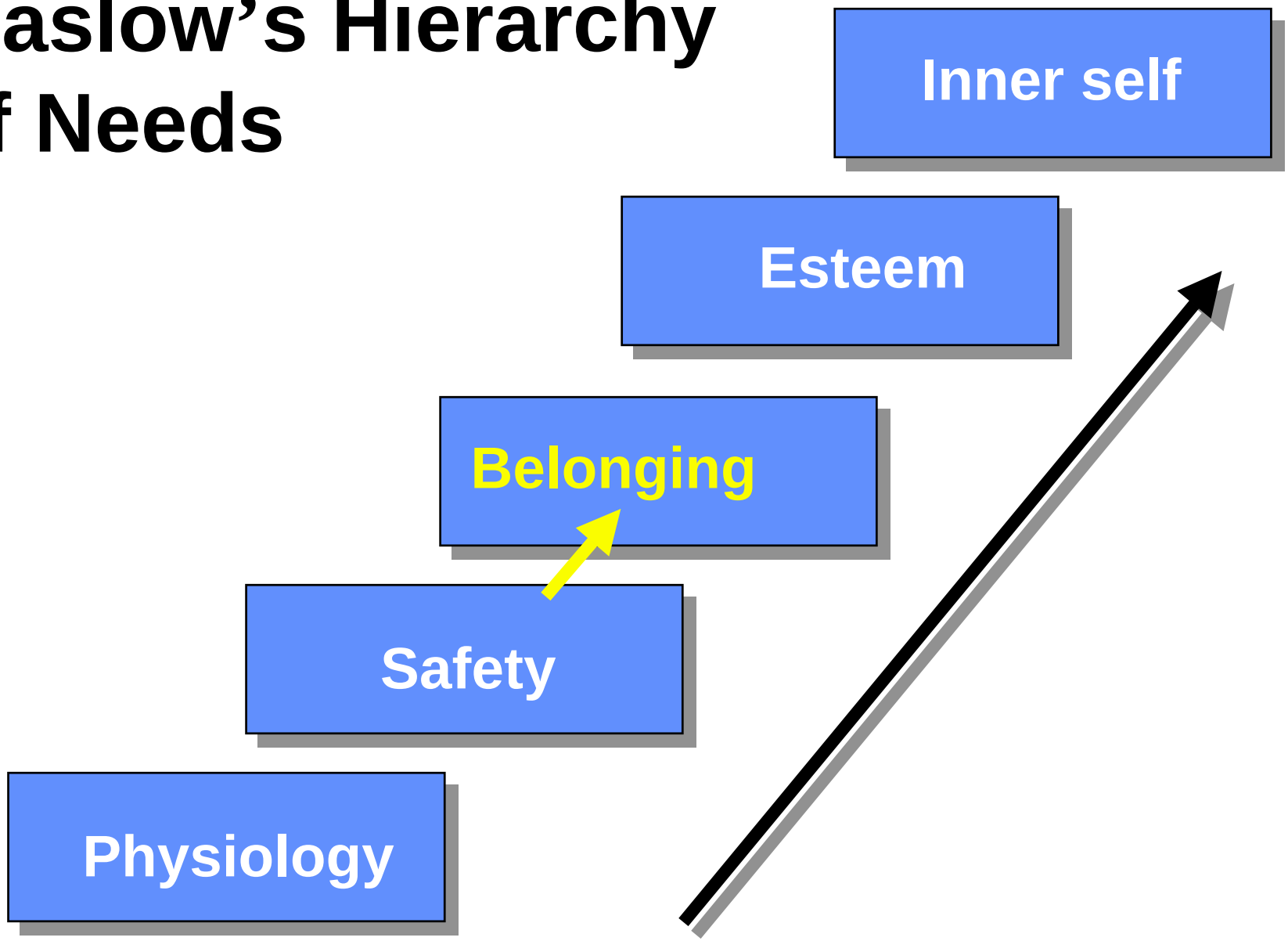
Maslow's Hierarchy of Needs



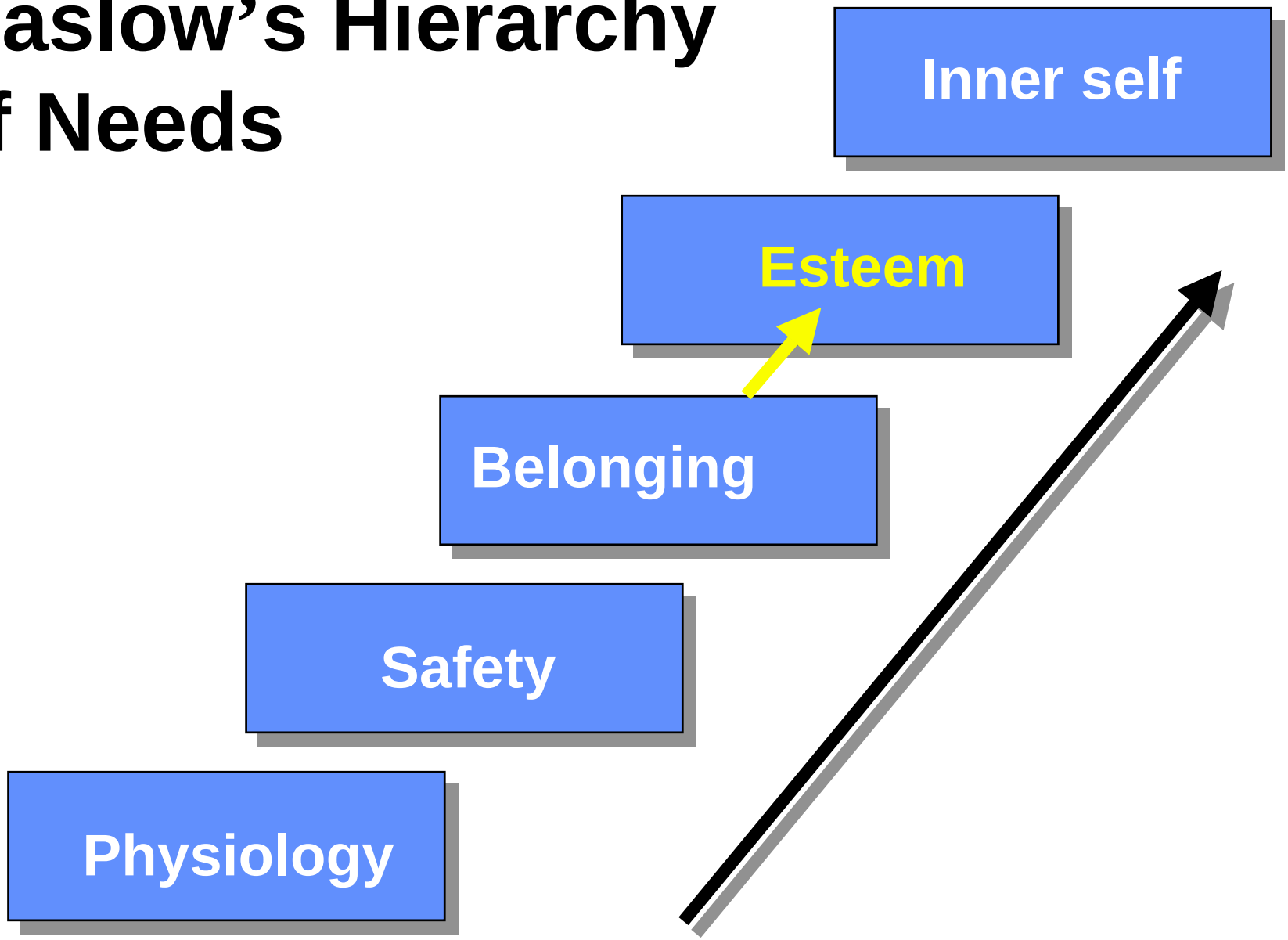
Maslow's Hierarchy of Needs



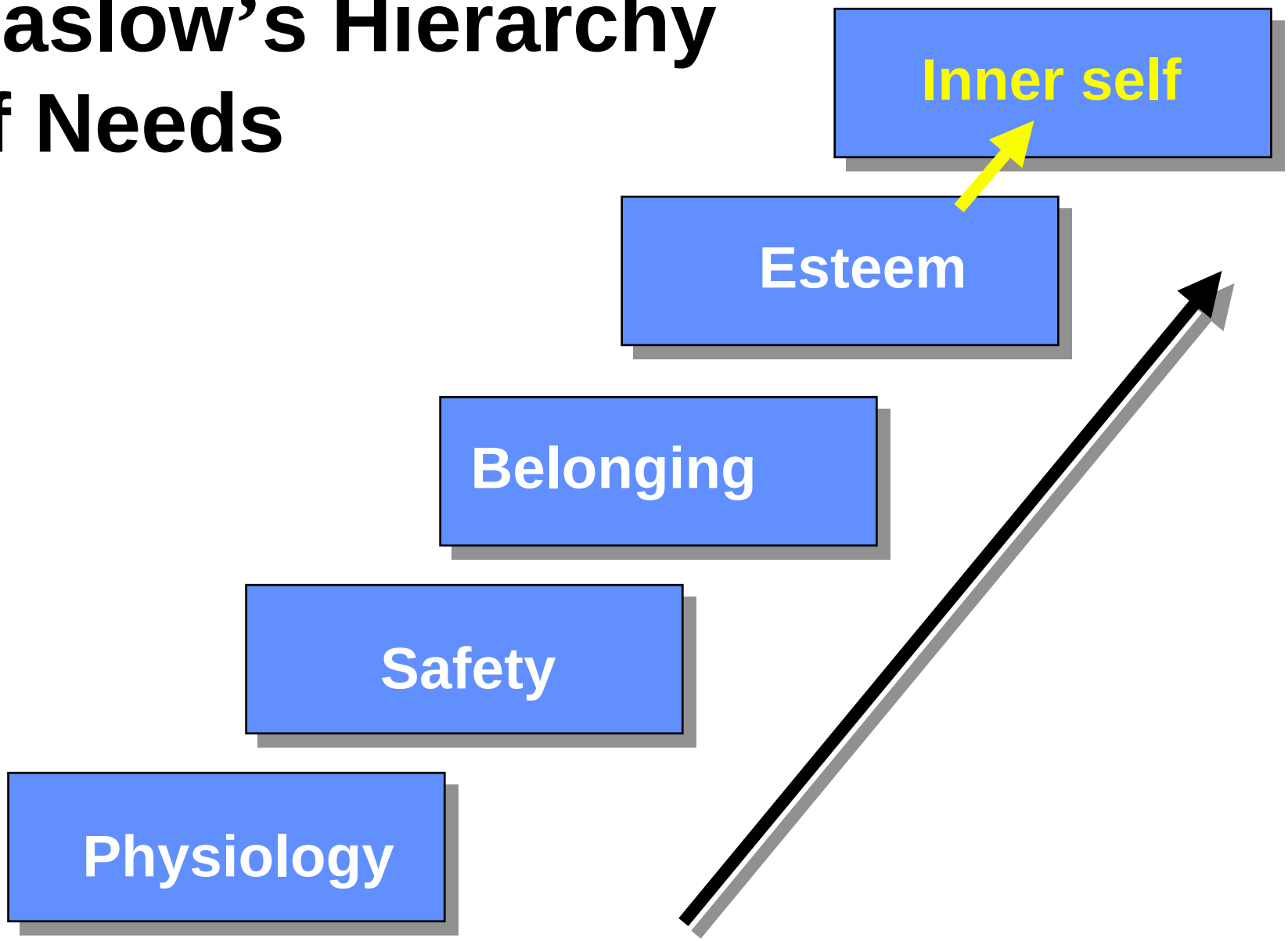
Maslow's Hierarchy of Needs



Maslow's Hierarchy of Needs



Maslow's Hierarchy of Needs



Third law of human ecology

total impact = population x
per capita impact

Hardin (1991)

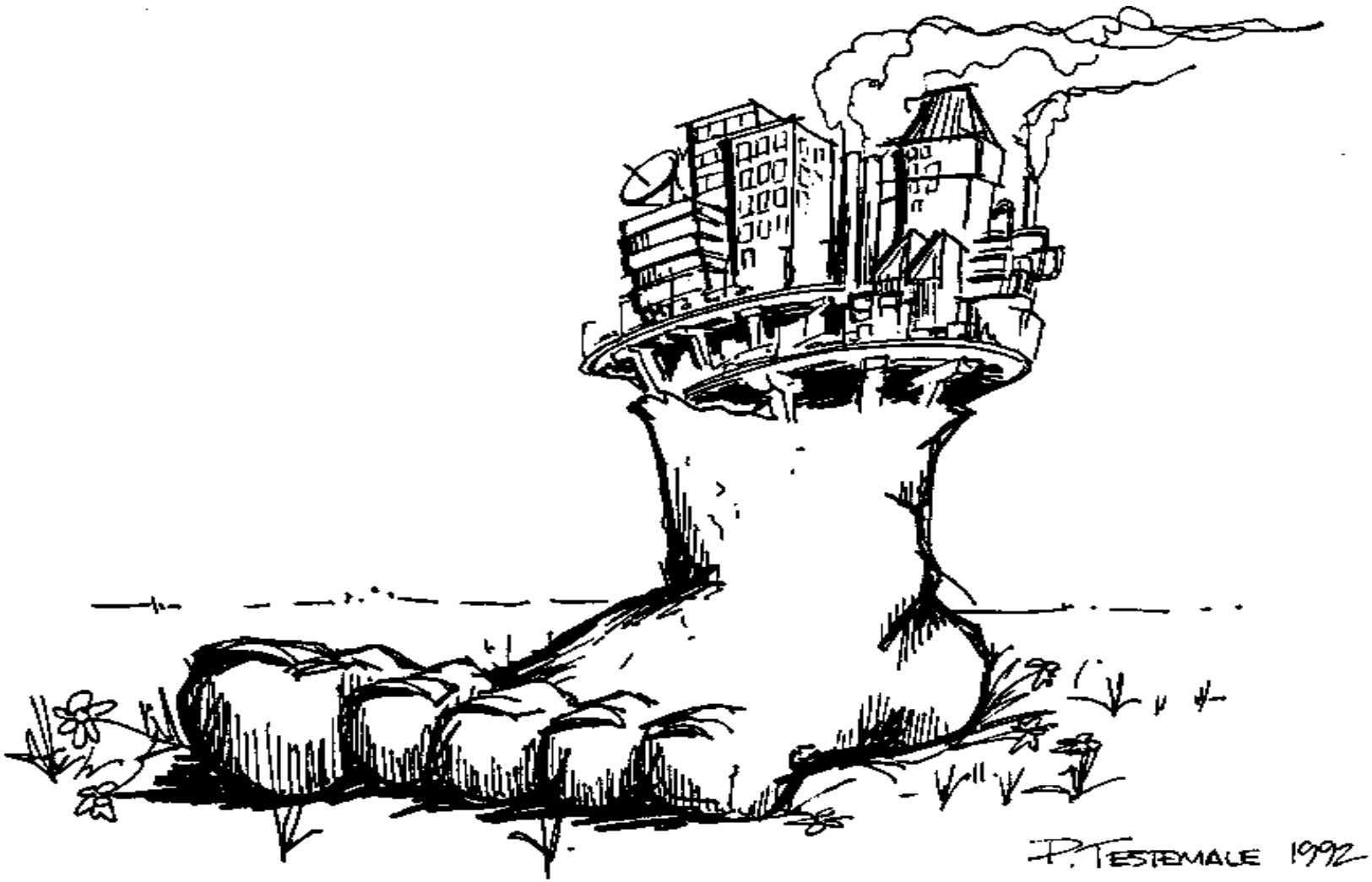
$$I = P \times A \times T$$

P = Population

A = Affluence

T = Technology

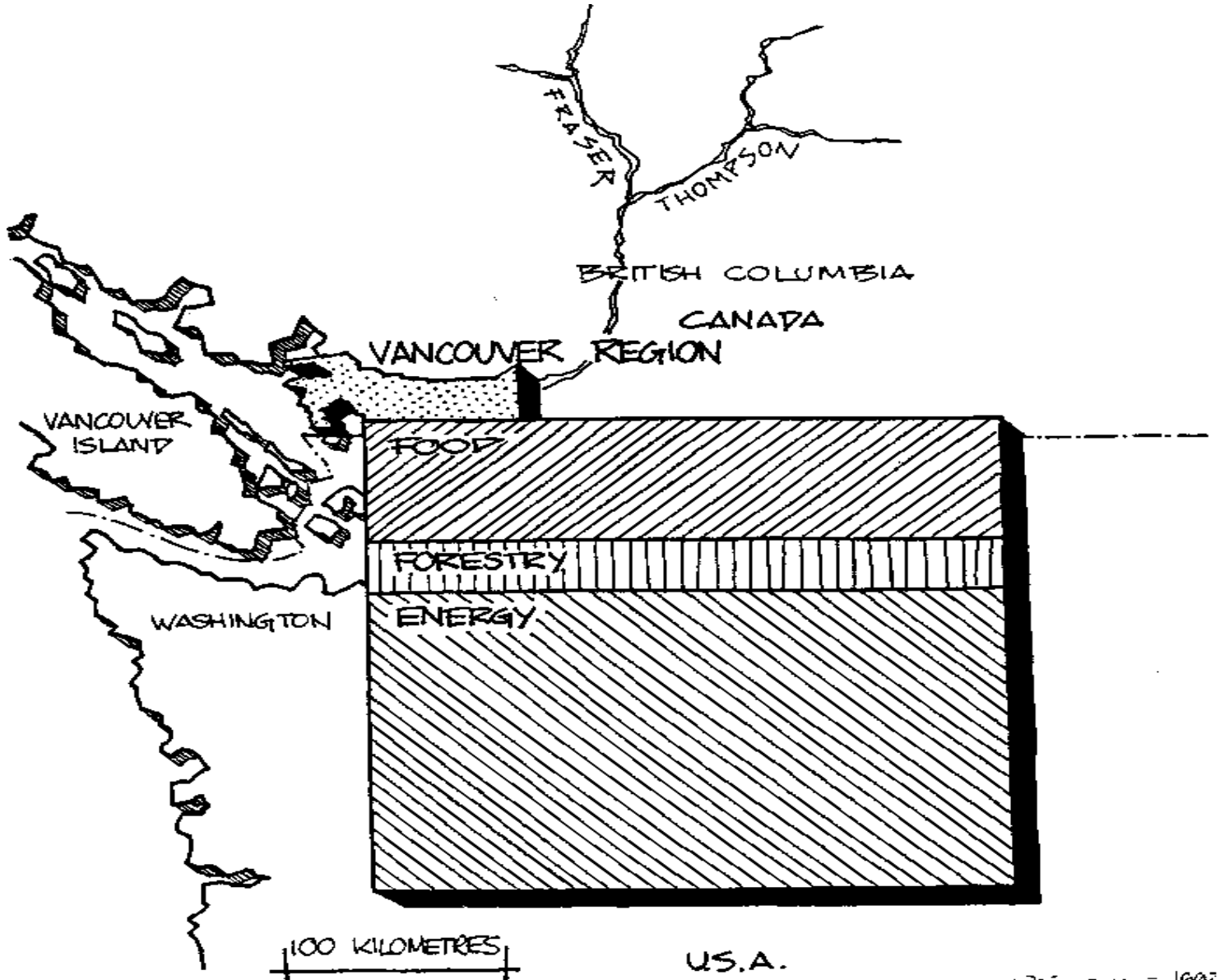
Holdren and Erlich (1974)



The ecological footprints of individual regions are much larger than the land areas they physically occupy.

“ECOLOGICAL FOOTPRINTS”

- Natural capital requirements of human economy
- Total land area required to maintain a given population
- Appropriated carrying capacity


FRASER
THOMPSON
BRITISH COLUMBIA
CANADA
VANCOUVER REGION
VANCOUVER ISLAND
FOOD
FORESTRY
ENERGY
WASHINGTON
100 KILOMETRES
U.S.A.
- P. TESTEMALE 1993

SUSTAINABLE ENVIRONMENTAL MANAGEMENT

A subset of sustainable development

"...improving the quality of human life while living within the carrying capacity of supporting ecosystems."

WORLD CONSERVATION UNION, 1991

Precedence for Planning

- 10Th Century Native Americans
- Laws of the Indies (1573)
- Early English Settlements
- Regional Planning Association of America (1920’s)

Law of the Indies (Spain)

- Settlement Directives ca. 1573
- 148 Separate Ordinances
- Site Selection Referenced to Local Resources
- Main Square With Public Buildings

SUSTAINABLE ENVIRONMENTAL MANAGEMENT

- Stabilizing population
- Sustaining agriculture
- Conserving biological diversity
- Reducing wastes, pollution

... ALL *TOWARD* A STEADY-STATE

In summary,

- Frameworks for assessing ecological risk continue to evolve in the United States
- Essentially parallel efforts with USEPA Framework as the major guideline
- Important technical and policy issues remain to be addressed
- Require a management context for meaningful ecological risk assessment

Thank you very much!