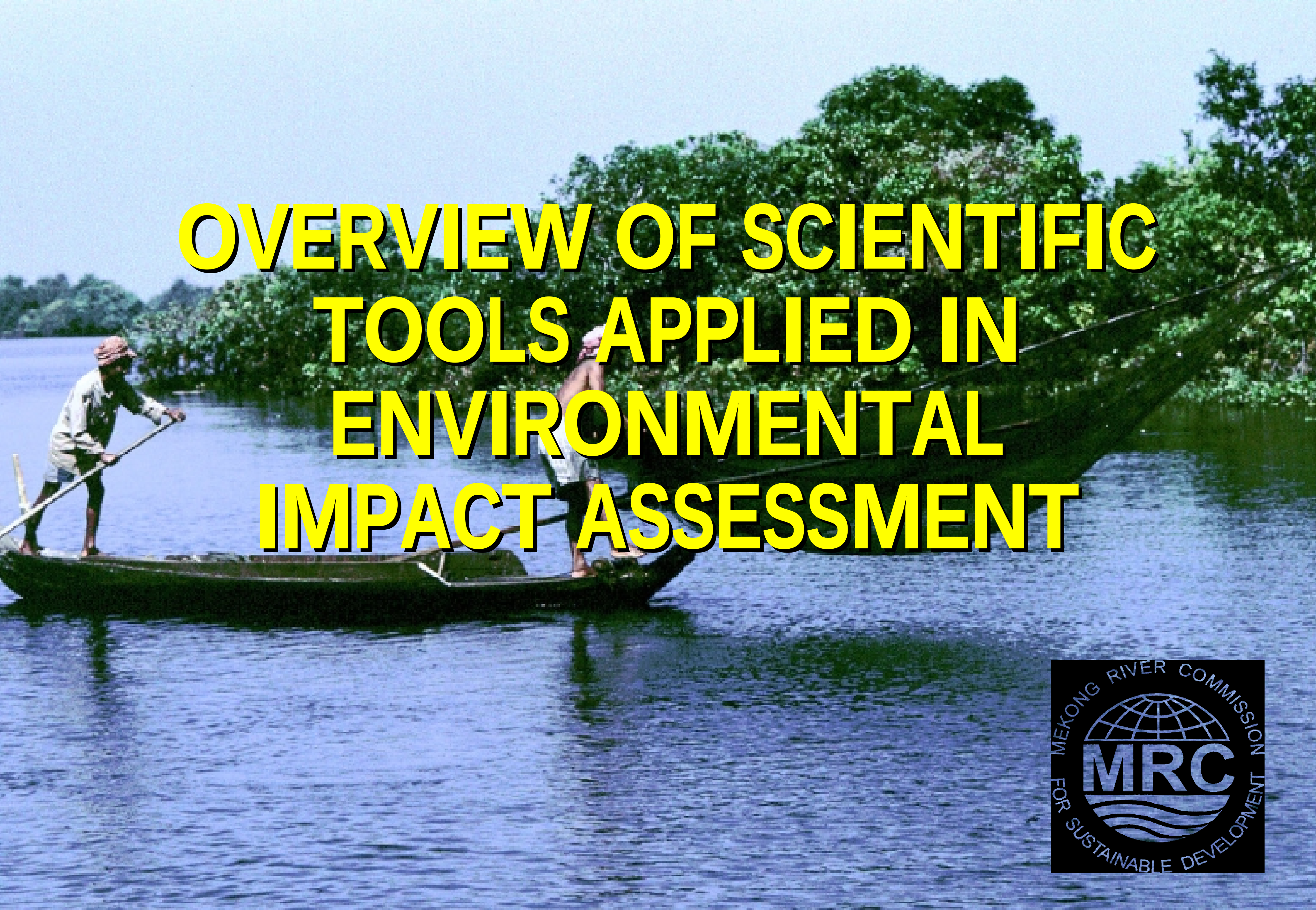
OVERVIEW OF SCIENTIFIC TOOLS APPLIED IN ENVIRONMENTAL IMPACT ASSESSMENT



MEKONG RIVER COMMISSION
MRC
FOR SUSTAINABLE DEVELOPMENT

Application of Science in EIA

- This seminar reviews the evolving science tools of environmental monitoring, ecological risk assessment, and environmental modeling
- These tools are increasingly being applied in an effort to improve the predictive capability of environmental impact assessment (EIA) in anticipating and responding proactively to potential adverse impacts of development activities

Environmental Monitoring

- Environmental monitoring is undertaken to assess the health of ecosystems and detect improvements or degradation in environmental quality
- In the context of EIA, monitoring provides an understanding of pre-development conditions and feedback on the actual environmental impacts of a development project or activity and the effectiveness of mitigation measures applied

Benefits of Monitoring

- Monitoring combined with enforcement ensures proper functioning of environmental protection measures prescribed for development projects or activities
- Monitoring allows the early identification of potentially significant effects (i.e., early trends which could become serious)
- Through assuring compliance in a cost-effective manner, monitoring contributes to optimize the economic-cum-environmental development benefits

Purpose of Baseline Monitoring

- To gather information about a receiving environment which is potentially at risk from a proposed development project or activity
- To identify valued ecosystem components (VEC) in the receiving environment and assess potential threats to these components
- Information gathered on existing conditions provides a baseline for subsequently assessing post-development changes

Baseline Monitoring Objectives

- Baseline monitoring is generally undertaken before a development activity or project is allowed to proceed in order to:
  - establish existing environmental conditions
  - provide background data for future comparisons
- Baseline monitoring typically examines the physical, chemical and biological variables in an ecosystem

Monitoring Variables - Water Chemistry

- Water chemistry can provide a good measure of the soluble contaminants in an aquatic system
- Monitoring parameters include:
  - pH and nutrients
  - total suspended solids (TSS) and conductivity
  - hardness and metals

Monitoring Variables - Sediment Chemistry

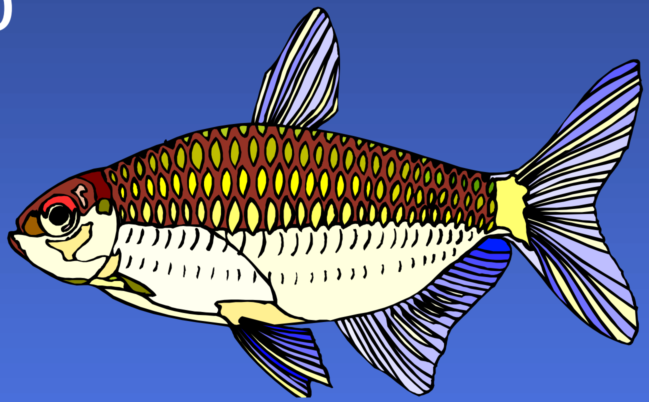
- Analysis of sediment chemistry can help determine the proportion of a particular contaminant that may be available for uptake by aquatic organisms
- Sediment analysis parameters include:
  - moisture content
  - grain size and total organic carbon (TOC)
  - nutrients and metals

Monitoring Variables - Benthic Invertebrate Community

- Benthic invertebrates often form the base of the aquatic food chain; alterations to the benthic community can impact fish and other aquatic life
- Benthic invertebrates are excellent indicators of overall aquatic environmental health

Monitoring Variables - Fisheries Resources

- Fish are generally sensitive to contamination and reflect environmental effects at many levels



- Sampling should include determination of the species and abundance of fish populations present, as well as their migration patterns

Purpose of Compliance and Environmental Effects Monitoring

- Recognize environmental changes (i.e., from baseline conditions) and analyze causes
- Measure adverse impacts and compare with impacts predicted in the EIA
- Evaluate and improve mitigation measures
- Detect short-term and long-term trends to assess the protectiveness of existing standards
- Improve practices and procedures for environmental assessment

Compliance Monitoring Objectives

- Industries are typically required to undertake compliance monitoring on an ongoing basis (e.g., monthly and/or quarterly) to demonstrate that they continue to meet permit requirements which were part of their EIA approval
- Compliance monitoring programs usually are limited to routine chemical analysis of effluent discharges and periodic conduct of toxicity tests

Environmental Effects Monitoring Program Objectives

- EEM programs are intended to look for longer-term changes in environmental quality
- EEM programs are generally industry-specific (e.g., pulp and paper, metal mines) and are designed to determine whether unexpected adverse impacts are occurring
- EEM results indicate whether existing industry regulations are sufficiently protective or whether more stringent regulations are needed

Monitoring Strategy?

- **Haphazard:** place stations anywhere
- **Judgement:** place in specific locations
- **Probability:** place randomly for statistical reasons
- **Systematic:** place evenly over area of concern

Monitoring Study Design Types

- Spatial or Control-Impact (CI)
  - Potential impact area compared to one or more reference (control) areas
- Temporal or Before-After (BA)
  - Potential impact area compared before and after event of interest (e.g., effluent discharge)
- Spatial-temporal or Before-After-Control-Impact (BACI)
  - Combines BA and CI designs; most powerful

Measurement Variables

Considerations in selecting variables include:

- Relevance
- Consideration of indirect effects and factors affecting bioavailability and/or response
- Sensitivity and response time
- Variability
- Practical issues

Water Column Chemistry

Function

- measure of contamination
- can include modifiers (e.g., salinity, pH)
- can include measures of enrichment (C,N,P)

Comments

- extensive database on toxicity/risk of effects for comparison
- preferred medium for soluble contaminants
- variable temporally (requires high frequency of measurement)

Sediment Chemistry

Function	Comments
➔ measure of contamination	➔ some data on toxicity/risk of effects, but less reliable than for water
➔ can include modifiers (e.g., AVS, TOC, grain size)	➔ preferred medium for less soluble contaminants
➔ can include measures of enrichment (C,N,P)	➔ integrates contamination over time (requires low measurement frequency)

Tissue Chemistry

Function

- measures exposure (for the organism)
- measure of contamination (for higher level organisms such as humans)

Comments

- limited data available on toxicity/risk of effects
- tissue concentrations typically drive effects
- necessary for assessing risks to humans
- tissue integrates exposure
- low frequency of measurement

Physical Variables

Function

- ➔ can be stressors (e.g., suspended sediments or deposited solids)
- ➔ can be modifiers (e.g., temperature, sediment grain size)

Comments

- ➔ limited data available on risk of physical alterations
- ➔ useful for data analysis and interpretation
- ➔ low cost
- ➔ variable measurement frequent required

Biological Variables

Function	Comments
➔ direct measurements of effects in the real world (i.e., not relying on literature data or laboratory data)	➔ confounding factors can make results interpretation difficult ➔ high cost ➔ low measurement frequency

Benthic Invertebrates

Function

- measurement of population or community level effects
- benthos important as fish prey

Comments

- long history in monitoring
- response scale appropriate for point sources
- responds to enrichment or contamination
- high cost; low frequency

Fish

Function

- measure affects at many levels (community, population, organism, tissue, cellular)
- important socially

Comments

- long history in monitoring
- scale may be too broad depending on species of concern
- generally sensitive to enrichment, contaminants and physical alteration
- high cost; low frequency

Toxicological Variables

Function	Comments
➔ direct measurement of contaminant-related effects (i.e., toxicity)	➔ effects measurements under controlled conditions ➔ standard methods ➔ integrate modifying effects ➔ exposure may be unrealistic ➔ high cost ➔ measurement frequency: low (sediments); high (water)

Questions Answered with Toxicity Tests

- Is the material toxic? at lethal or sublethal levels?
- What compounds are most toxic, and under what conditions?
- Which organisms, endpoints are most sensitive?

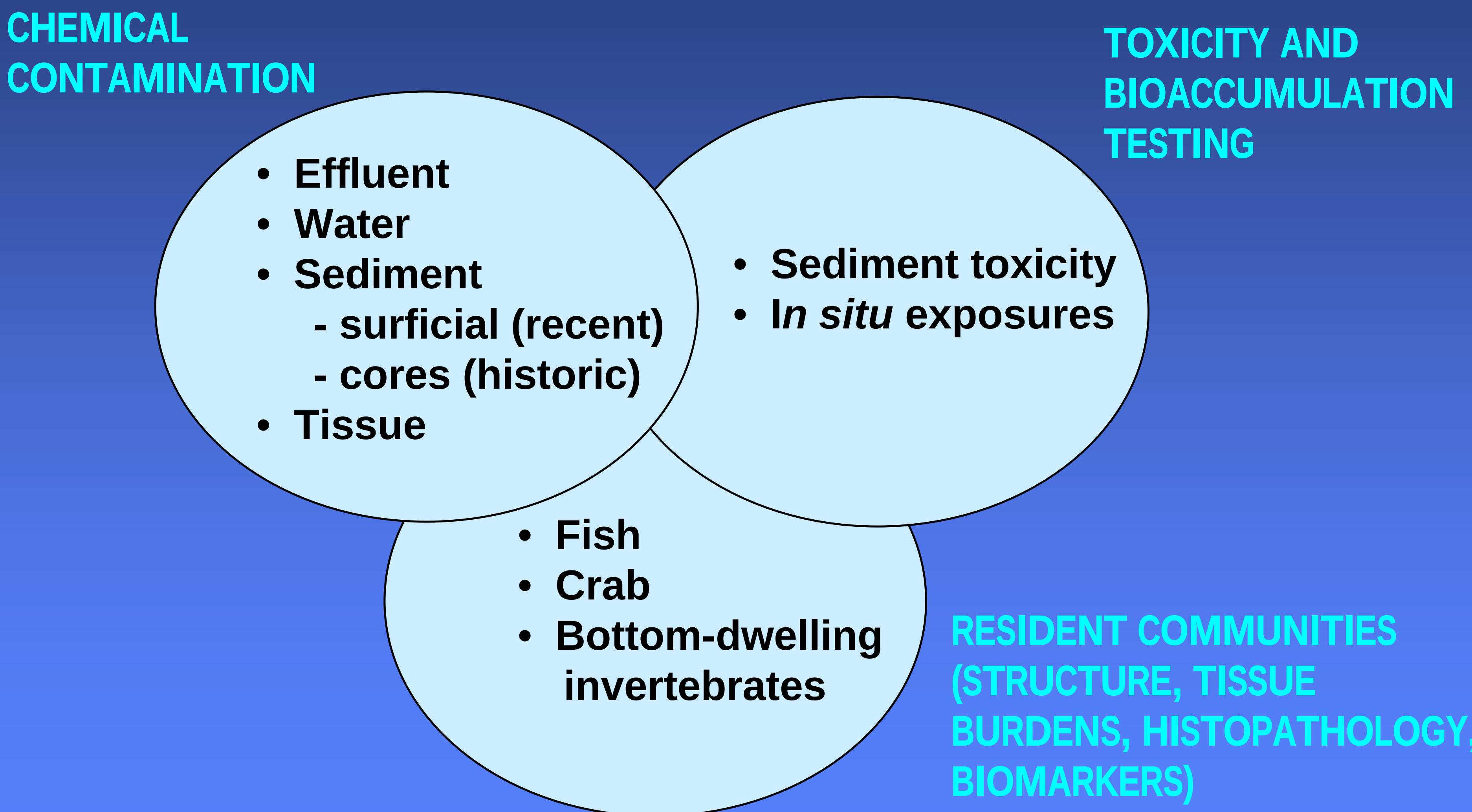
Questions Answered with Toxicity Tests (Cont'd)

- Are measured chemicals bioavailable and do they induce effects?
- Comparison of toxicity between locations?
- Changes in toxicity over time or with cleanup?
- Regulatory standard (e.g., criteria or permit) met?

Why Use Integrative Assessment?

- Lack of knowledge of cause and effect information to describe environmental quality
- When neither observation nor experimentation alone can be used to describe environmental quality
- Evaluate system at various levels of biological organization
- Test hypothesis that a specific development is not having environmental effects

Integrative Assessment Example



Integrative Assessment Response Patterns

Chemical Contamination	Toxicity	Community Alteration
+	+	+
-	-	-
+	-	-
-	+	-
-	-	+
+	+	-
-	+	+
+	-	+

Interpreting Monitoring Results

- Comparison of chemistry results with water quality and/or effluent standards can help determine which of the potential stressors are present in levels high enough to harm aquatic life
- Toxicity testing results using both 100% effluent and receiving water concentrations provide additional, but not conclusive evidence, concerning likely adverse impacts in the receiving environment

Interpreting Monitoring Results (Cont'd)

- Results of benthic communities studies or sampling of fish populations (e.g., tissue contaminant concentrations, changes in growth and/or reproduction) can collaborate chemistry and toxicity testing results
- Weight of evidence approach supports scientifically-defensible conclusions on development-related impacts occurring in the receiving environment

Water Quality Standards

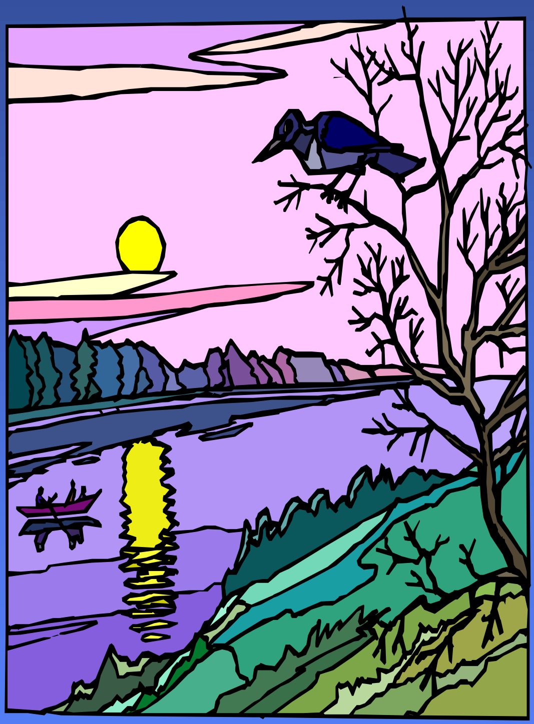
- The contaminant concentrations found in effluent and/or receiving water samples can be compared to the water quality standards of Thailand or Vietnam, or to international standards
- Water quality standards are numerical limits set for a variety of chemical and biological pollutants in order to protect surface water quality

Effluent Standards

- Effluent standards pertain to the quality of the discharge water itself
- They do not establish an overall level of pollutant loading for a given water body
  - unless effluent standards are periodically reviewed and updated to reflect the needs of a receiving aquatic ecosystem, they can be ineffective in protecting the ecosystem

Stream Standards

- Stream standards refer to the quality of the receiving water downstream from the origin of the wastewater discharge
- Generally, a detailed stream analysis is required to determine the level of wastewater treatment required to maintain the health of the ecosystem



Concluding Thoughts

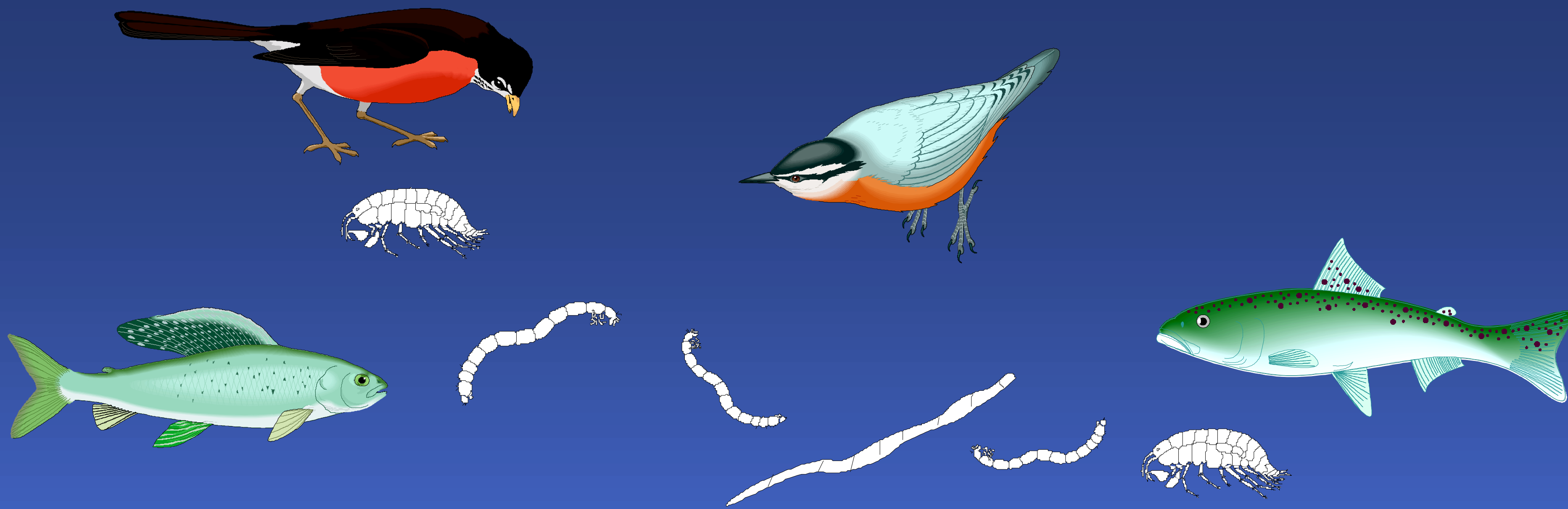
Important points to remember are:

- Well-designed monitoring programs can provide important feedback on the actual environment impacts of development projects
- Baseline monitoring is essential to provide a understanding of existing environmental conditions and VEC at risk
- Follow-up monitoring programs assess the effectiveness of project-specific mitigative measures and the overall protectiveness of environmental protection regulations

What is Ecological Risk Assessment?

Definition:

A tool that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors



RISK = Magnitude of Adverse Ecological Effects X Probability of Adverse Ecological Effects

Temperature Change

Cu

PCBs

Hg

Habitat Loss

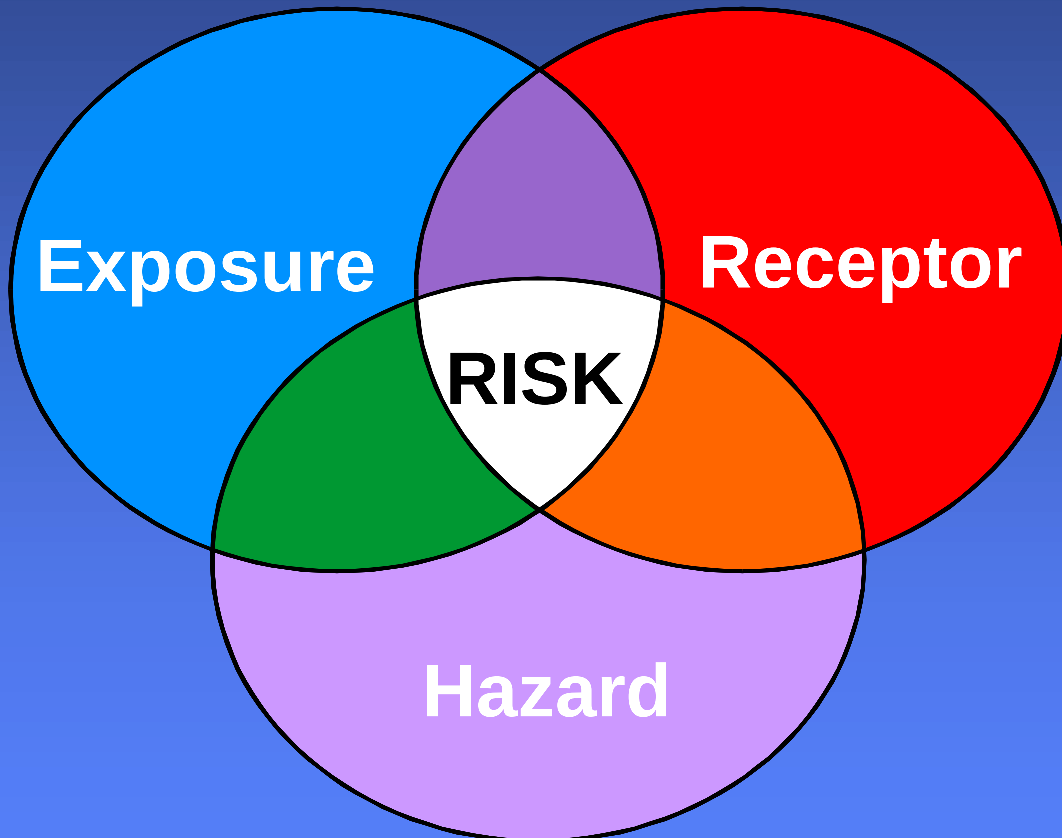
DDT

What Constitutes Risk?

A risk does not exist unless two conditions are satisfied:

1. The stressor has the inherent ability to cause one or more adverse effects
2. The stressor co-occurs with or contacts an ecological component long enough and at sufficient intensity to elicit the identified adverse effect

Required Components of Risk



Risk Terminology

- Risk Assessment: The process of determining risk
- Receptor: The organism(s) or ecological resource(s) of interest that might be adversely affected by contact with or exposure to a stressor

Risk Terminology (Cont'd)

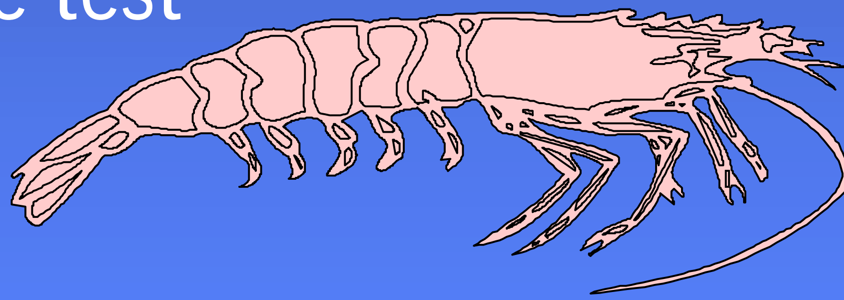
- Stressor:
  - Any physical, chemical or biological entity that can induce an adverse effect
  - Adverse ecological effects encompass a wide range of disturbances ranging from mortality in an individual organisms to a loss of ecosystem function

Risk Terminology (Cont'd)

- Exposure:
  - The process by which a stressor is delivered to a receptor
  - Exposure is a result of the magnitude and form of a stressor in the environment, coupled with the presence of the receptor

ERA – Is It or Isn't It?

1. The 96-h LC50 for juvenile penaeid shrimp exposed to cadmium is 960 g/L Cd. In other words, this concentration of Cd has been shown to kill 50% of the test organisms.



ERA – Is It or Isn't It? (Cont'd)

2. The water level in a mangrove area is predicted to drop as a result of drainage for reclamation activity. The organisms in the area will not be able to survive without access to aquatic habitat. Without risk management intervention, the biodiversity of the area could be severely reduced.

ERA – Is It or Isn’t It? (Cont’d)

3. Elevated levels of pesticide residues have been detected in subsurface soils in a large plot of land on the outskirts of a large city

Components of ERA

1. Problem Formulation
2. Exposure Assessment
3. Effects Assessment
4. Risk Characterization

Problem Formulation

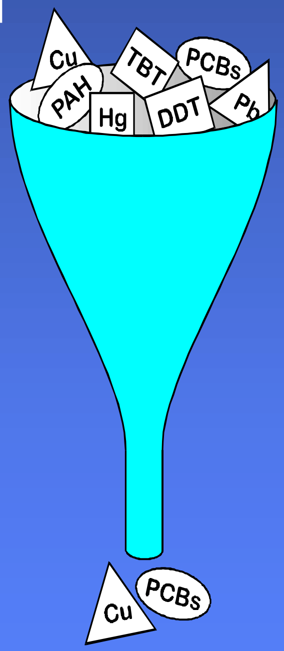
- Identification of potential ecological effects
- Selection of assessment and measurement endpoints
- Development of a conceptual model and risk hypotheses
- Determination of the approach for conducting the assessment

Identify Stressors of Concern

- Stressors:
  - chemical (inorganic or organic substances)
  - physical (extreme conditions or habitat loss)
  - biological (altering biological structure)
- Direct and indirect effects should be considered
- Examine all exposure pathways

Selecting Key Stressors of Concern

- **Objective:** Focus on most relevant stressors
- For example, for contaminants screen concentrations against:
  - natural background levels
  - toxicity-based environmental criteria
  - nutritional requirements (mammals and birds)



Questions to Address in Exposure Assessment

1. What receptors are exposed to the stressor(s)?
2. What are the significant routes of exposure?
3. What are the exposure concentrations?
4. What is the exposure duration?

Questions to Address in Exposure Assessment (Cont'd)

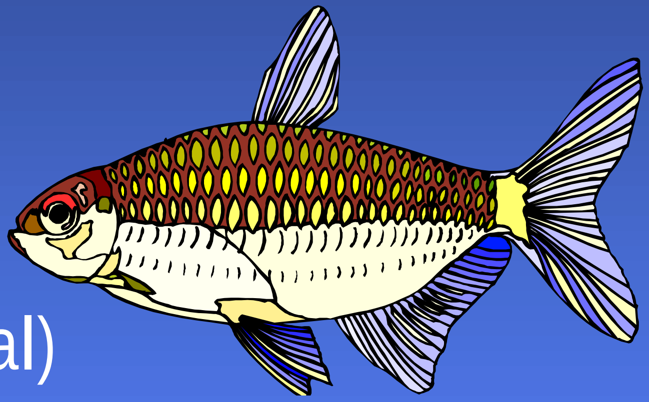
5. What is the frequency of exposure?
6. Are there any seasonal or climatic variations likely to affect exposure?
7. Are there any site-specific geophysical, physical and chemical conditions affecting exposure?

Exposure Pathways

- Four elements must be present for an exposure pathway to be complete:
  - source or release of the stressor
  - transport to a point of contact
  - contact
  - absorption

Examples of Exposure Pathways

- Fish or other aquatic receptors - route of exposure may be:
  - water (ingestion and dermal)
  - food (ingestion)
  - sediment (ingestion and dermal)



Examples of Exposure Pathways (Cont'd)

- Mammals and birds - route of exposure may be:
  - water (ingestion and dermal)
  - food (ingestion)
  - sediment (incidental ingestion)

Exposure Assessment Results

The end product of the exposure assessment is an estimation of the environmental concentration of each contaminant of concern to which each receptor of concern is exposed

What are Effects?

- Increased enzyme activity
- 20% reduction in fish population
- Accumulation of a contaminant in tissues
- Statistically significant decrease in fecundity
- 50% fish mortality in an acute toxicity test

Which ones are important?

Effects (Hazard) Assessment

- Describes the relationship between the stressor(s) and the receptor(s)
- Is used to link a contaminant to a biological response
- Information sources about effects:
  - Literature
  - Laboratory studies
  - Field studies

Effects Assessment Results

The endpoint of the effects assessment is the highest exposure concentration for each stressor that does not result in unacceptable ecological effects to each receptor

Risk Characterization

- The final phase of the ecological risk assessment
- Estimates the magnitude and probability of effects
- Integrates other risk assessment components (i.e., exposure and effects assessments)

Risk Characterization (Cont'd)

- Risk characterization involves three steps:
  1. Calculation of risk estimate
  2. Description of uncertainty associated with the estimate
  3. Interpretation of the ecological significance of the risk estimate
- Risk characterization can be done on a qualitative or quantitative basis

Uncertainty Analysis

- Uncertainty analysis identifies and quantifies uncertainty
- Major sources of uncertainty:
  - Definition of scope
  - Information and data
  - Natural variability
  - Error

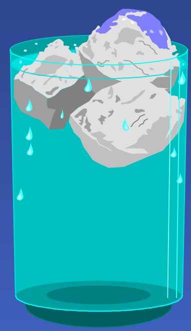
Communication

- Risk assessor presents results to environmental managers (e.g., government agency, industry)
- Liaison reduces chance of results misinterpretation
- Risk assessor works with environmental managers to develop mitigative measures

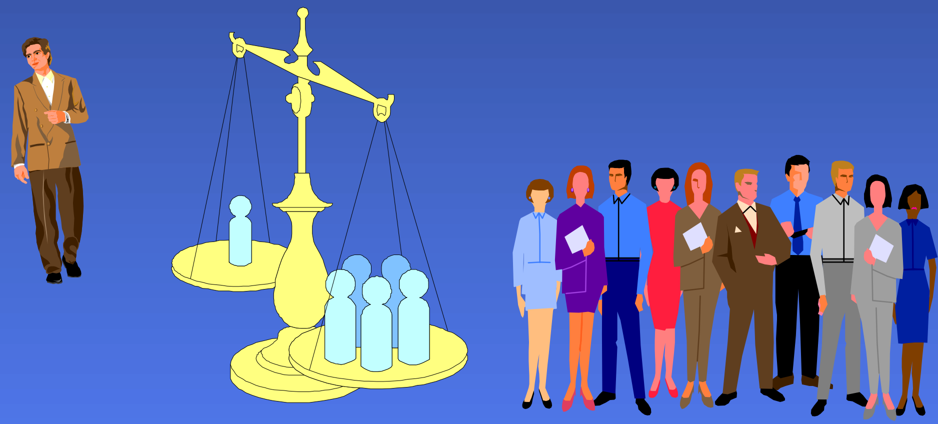
The Decision-Making Process

- ➔ Start with scientific information from the risk assessment
- ➔ Integrate other relevant information
  - » economic constraints
  - » societal concerns
- ➔ Evaluate risk management options
- ➔ Identify most appropriate course of action

Selecting Alternatives



Risk of small amounts of halomethanes being produced from drinking water chlorination OR



Public health risk from pathogenic organisms in non-chlorinated drinking water

Benefits of Using Risk Assessment in Decision Making

- It provides the quantitative basis for comparing and prioritizing risks
- It provides a systematic means of improving the understanding of risks
- It acknowledges inherent uncertainty, making the assessment more credible

Benefits (Cont'd)

- It estimates clear and consistent endpoints
- It provides a means for the parties making environmental decisions to compare the implications of their assumptions and data
- Risk assessment separates the scientific process of estimating the magnitude and probability of effects (risk analysis) from the process of choosing among alternatives and determining acceptability of risks (risk management)

Integrating ERA with EIA

- Regional ERA facilitates environmental planning and management on a regional scale

Environmental Impact Assessment

Goal: To determine impact and analyze alternative options

- ERA quantitatively evaluates risks of EIA related stressors to humans or valued ecological resources

Benefits of Using ERA in EIA

- Provide more focused methods for exploring EIA issues
- Allows evaluation of different mitigation option to manage risks (i.e., risk reduction)
- Explicitly addresses uncertainty
- Regional ERAs can focus the scope of EIA towards sensitive issues (e.g., cumulative impacts)

Concluding Thoughts

Important points to remember are:

- ERA can make an important contribution to EIA by quantifying potential risks to humans and/or valued ecological resources
- Uncertainty is explicitly expressed for purposes of decision making and identifying additional scientific study needs
- Using a risk-based approach to EIA evaluation can guide selection of mitigation measures which will result in the most risk reduction per unit expenditure

Environmental Modeling

- Ecosystem modeling can be used to simulate the response of ecosystems, such as aquatic receiving environments, under varying conditions of disturbance
- Modeling can help explain and predict the effects of human activities on ecosystems (e.g., the fate and pathways of toxic substances discharged by industry)

Environmental Modeling Challenges

- Model development is a difficult task, due to the complexity of natural systems
- A high degree of simplification and a number of assumptions must be built into any model

Just remember...

Environmental Modeling Challenges (Cont'd)

- No model can account for all environmental variables and predict outcomes with 100% accuracy
- BUT, a good model can tell us much more about an ecosystem than we might know based on observation and data collection alone

Types of Environmental Models

- Conceptual models
- Theoretical models
- Empirical models

Conceptual Models

- A conceptual model is a written description and a visual representation of the predicted relationships between ecosystems and the stressors to which they may be exposed, such as biological or chemical pollutants
- Conceptual models represent many relationships and frequently are developed to help determine the ecological risk posed by a pollutant
- These models can be useful in the development of an environmental monitoring program

Theoretical Models

- Theoretical models can be developed when the physical, chemical, and biological processes of an ecosystem and a potential contaminant are well understood
- They require a great deal of observation and data collection in order to calibrate, but they can be very useful for predicting specific relationships, such as how a selected species will react to a known quantity of a chemical

Empirical Models

- Empirical models are generated from the data collected at specific sites over a given period of time
- The relationships identified from the data analysis often are expressed as a mathematical equation
- In general, they can be easier to construct than theoretical models, as they have smaller data requirements

Reservoir Sedimentation Example

- Estimating the effects of potential sediment accumulation in reservoirs is necessary when planning a hydropower project
- Sedimentation of hydropower dam reservoirs commonly occurs much faster than predicted in environmental impact assessments

Reservoir Sedimentation Example (Cont'd)

Reservoir sedimentation often leads to:

- ➔ Reduced storage volume in the reservoir
- ➔ Changes in water quality near the dam
- ➔ Increased flooding upstream of the dam, due to reduced storage capacity of the reservoir
- ➔ Degraded habitat downstream of the dam

Reservoir Sedimentation Example (Cont'd)

- Modeling the sediment load in a reservoir can be accomplished through the use of an empirical model like the following formula:

$$q_t = \sum C_i Q_i \Delta P$$

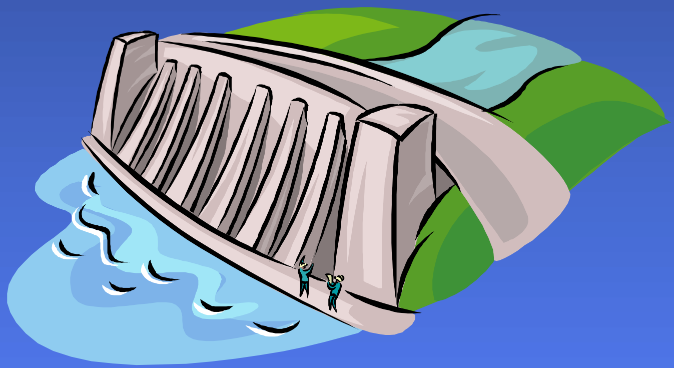
Reservoir Sedimentation Example (Cont'd)

Where:

- q_t = average total sediment load (in weight per unit time)
- C_i = sediment concentration per unit time
- Q_i = average flow duration per unit time
- ΔP = equal divisions of the flow duration curve, which is describes the cumulative distribution of stream run-off passing the dam

Reservoir Sedimentation Example (Cont'd)

- In other words, the model can determine the average sediment load per year



- Modeling the sediment load can be very useful in selecting a method for reducing sediment accumulation

Advantages of Environmental Modeling

- A good model can reveal more about a ecosystem processes and responses than we might otherwise learn through conventional (i.e., limited number) sampling techniques
- Modeling can predict how a ecosystem might behave before any disturbance occurs
- Modeling can be used to simulate different mitigative measures to minimize potential impacts from development activities

Limitations of Environmental Modeling

- A model is not a substitute for actual monitoring and assessment of ecosystems at risk from development activities
- Models are only as good as the information they contain
- A model often makes assumptions about the natural environment that cannot be validated; this inherent uncertainty must be acknowledged when evaluating a model's conclusions

Concluding Thoughts

Important points to remember are:

- Models can serve as powerful tools in understanding ecosystems and potential impacts from development activities
- The complexity of ecosystems and often limited knowledge of natural processes necessitates a high degree of simplification in model development
- Users of model outputs must be aware of the model's limitations!