

A photograph of two people in a traditional wooden boat on a river. One person is standing and using a long pole to maneuver the boat, while the other is seated. A large, dark net is draped over the side of the boat. The background shows lush green trees and a clear blue sky.

ENVIRONMENTAL MONITORING CONCEPTS AND APPLICATIONS



Course Learning Objectives

At the end of this course you should be able to:

- Discuss the role of environmental monitoring in environmental impact assessment (EIA) and follow-up
- Describe available monitoring and modeling tools for use in identifying and assessing environmental impacts in the aquatic environment
- Plan a monitoring program for an example development project in the Mekong River Basin

Lesson Learning Goals

At the end of this lesson you should be able to:

- Discuss the application of monitoring in identifying and quantifying environmental impacts
- Differentiate among monitoring program types
- Describe the objectives of a baseline monitoring program in support of an EIA
- Explain the different tools applied in undertaking an environmental effects monitoring program

Environmental Monitoring Defined

- 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

Monitoring Program Objectives

- Document **baseline** conditions
- Review the **accuracy** of impact predictions
- Review activities and/or **mitigation measures**
- Monitor **compliance** with agreed conditions
- Identify **trends** in impacts
- Assess the **effectiveness** of environmental protection measures and management regulations

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

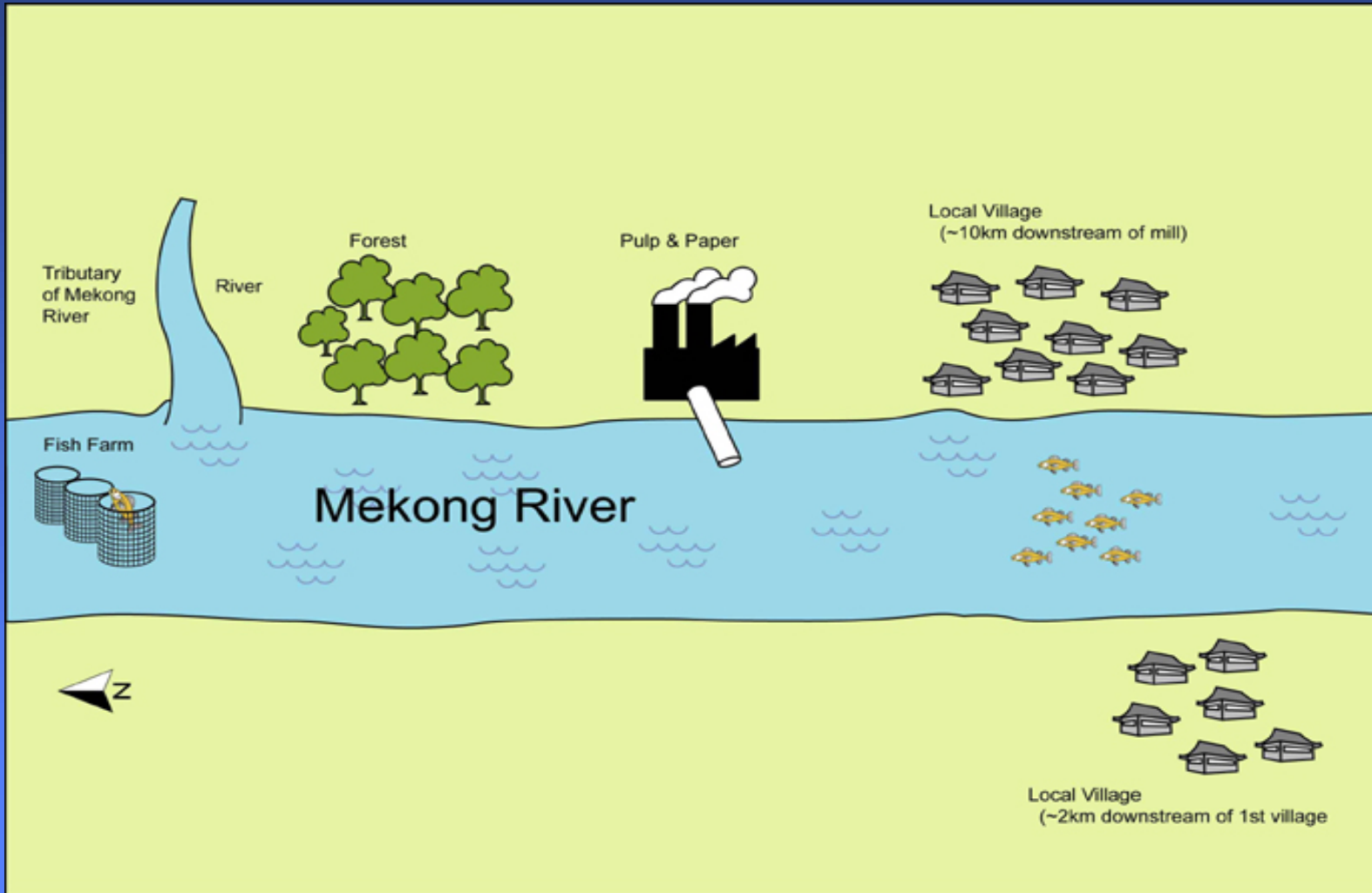
Purpose of Compliance and Environmental Effects Monitoring

- 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

Hypothetical Pulp and Paper Mill Example

- A proposed expansion of a pulp and paper mill located on the Mekong River is presented as an example to illustrate the basic components of environmental monitoring programs
- The example focuses on EIA-related baseline monitoring and EEM programs which should be undertaken in the aquatic receiving environment
- Additional monitoring of the terrestrial environment and air quality may also be required as part of the EIA

Pulp and Paper Mill Location



Background Information

- The Mekong River supports diverse and important resident fish populations which are a major food source for local villagers
- Flow rates in the river in the vicinity of the mill vary seasonally
- Mill effluent discharged to the river contains fibrous particles, high pH, and moderately high dioxin concentrations
- The water that flows past the mill is rich in nutrients from a fish farm located approximately 2 km upstream

Potential Impacts

Impacts from the mill expansion might include:

→ Forests

- » deforestation and habitat loss
- » soil erosion
- » disturbances in soil nutrient and organic matter balances
- » development of monoculture plantation if a portion of the mill site is reforested

Potential Impacts (Cont'd)

→ Air quality

- » increased air emissions (greenhouse gases)
- » particles and dust
- » noise and odor
- » ozone depletion



Potential Impacts (Cont'd)

→ Freshwater ecosystems

- » effluent discharges: high levels of BOD, suspended solids
- » altered or degraded fish habitat
- » solid and hazardous waste
- » toxicity of effluent: from dioxin, sulphate, chlorinated organic compounds



Baseline Monitoring

- Baseline monitoring is generally undertaken before a development activity or project (e.g., the proposed mill expansion) 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

Study Design

- The study design for baseline monitoring of the aquatic receiving environment to be completed in support of the proposed mill expansion should involve two key tasks:
 - » Identify appropriate monitoring stations
 - » Select appropriate monitoring variables

Selection of Sampling Stations

→ Reference sites

- » located upstream from the mill and used to provide data on natural environmental conditions

→ Impact sites

- » located within the effluent plume; data can be compared to post-expansion effluent pollutant concentrations

Sampling Stations

- **R1:** a reference site located upstream of the mill on a tributary of the Mekong River
- **R2:** a reference site located on the Mekong River, upstream of the mill and downstream of the fish farm
- **NF:** a near-field site located 30 m from the discharge site
- **FF:** a far-field site, located 250 m downstream of the effluent discharge

Recommended Sampling Stations



Monitoring Variables

Common baseline monitoring variables are:

- Water chemistry
- Sediment chemistry
- Benthic invertebrate community
- Fisheries resources

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

Sediment Chemistry

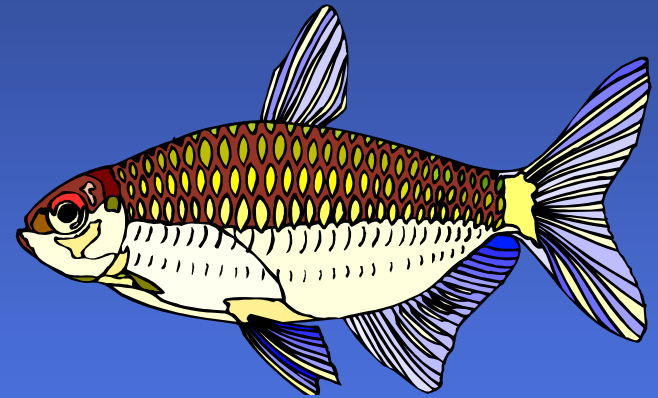
- Analysis of sediment chemistry can help determine the proportion of a particular contaminant that may be available for uptake by aquatic organisms
- Sediment analysis parameters include:
 - » moisture content
 - » grain size and total organic carbon (TOC)
 - » nutrients and metals

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

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



Compliance Monitoring

- Industries such as the pulp and paper mill 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

- EEM programs are intended to look for longer-term changes in environmental quality as a result of the mill effluent discharge
- 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

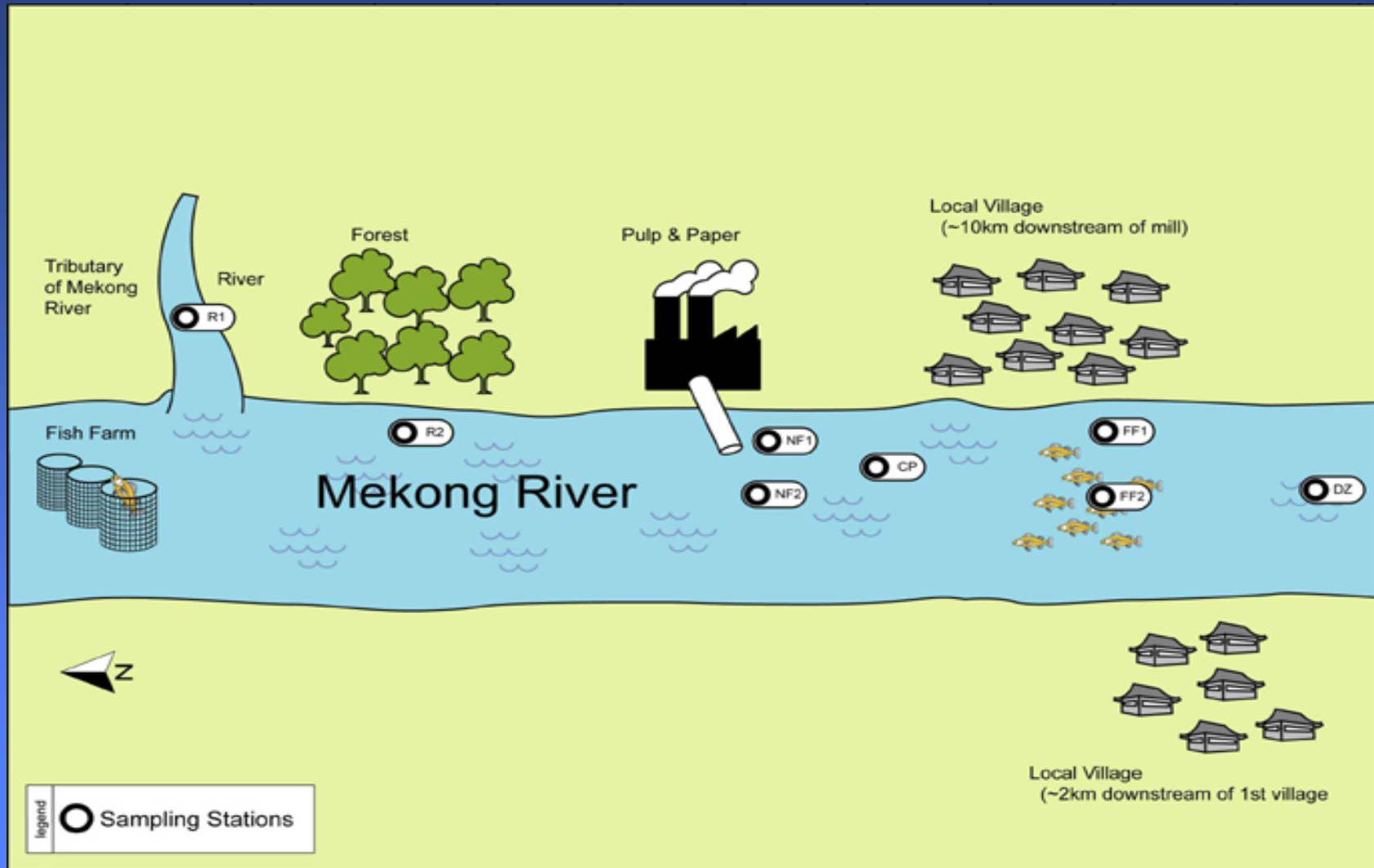
- Spatial or Control-Impact (CI)
 - » Potential impact area compared to one or more reference (control) areas
- Temporal or Before-After (BA)
 - » Potential impact area compared before and after event of interest (e.g., effluent discharge)
- Spatial-temporal or Before-After-Control-Impact (BACI)
 - »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

Sampling Program Design

Critical steps in finalizing a study design include:

- Selection of sampling locations
- Selecting sampling times and frequency
- Selecting appropriate level of replication
- Selection of measurement variables

Pulp Mill Sampling Stations



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

- measure of contamination
- can include modifiers (e.g., AVS, TOC, grain size)
- can include measures of enrichment (C,N,P)

Comments

- some data on toxicity/risk of effects, but less reliable than for water
- preferred medium for less soluble contaminants
- 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

- direct measurements of effects in the real world (i.e., not relying on literature data or laboratory data)

Comments

- 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

Benthic Community in Sediments

Healthy Sediment Community



Impacted Sediment Community



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

- direct measurement of contaminant-related effects (i.e., toxicity)

Comments

- effects measurements under controlled conditions
- standard methods
- integrate modifying effects
- exposure may be unrealistic
- high cost
- measurement frequency: low (sediments); high (water)

Features of Toxicity Testing

- One of the basic tools of aquatic toxicology
- Based on an experimental model (e.g., uses controls, replicates)
- Consists of two components:
 - » a receptor (aquatic organism)
 - » a stressor (chemical or anthropogenic substance)

Features of Toxicity Testing (Cont'd)

- Involves exposure of the receptor to the stressor under controlled conditions
- Used to evaluate the concentration of a substance and the duration of exposure required to produce the effect

Testable Questions

- Is discharge impacting the receiving environment?
- If so, what is (are) the impact(s)?
- If so, what is the spatial extent of the impact(s)?
- What is the environmental significance of any observed impact(s)?
- Can any impacts be attributed to specific contaminants?

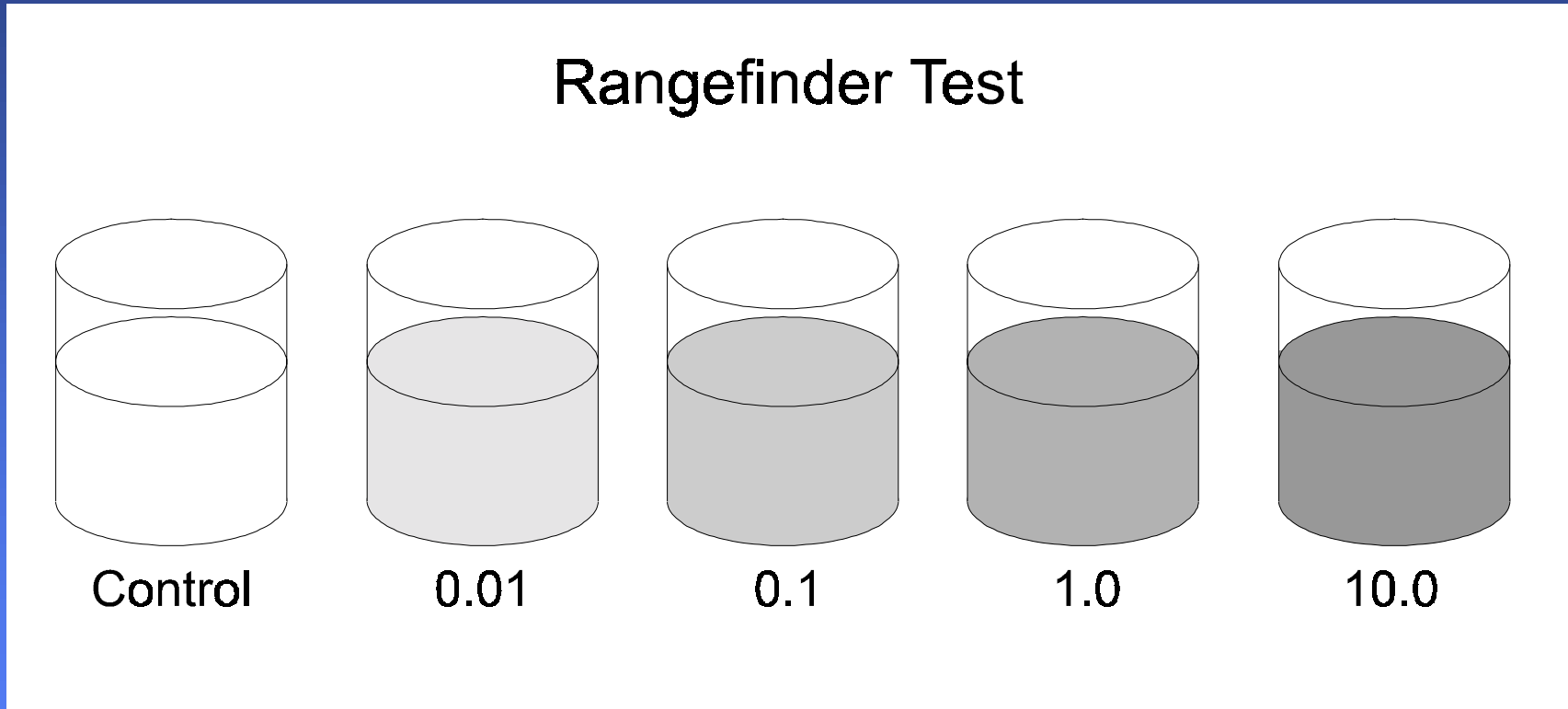
Questions Answered with Toxicity Tests

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

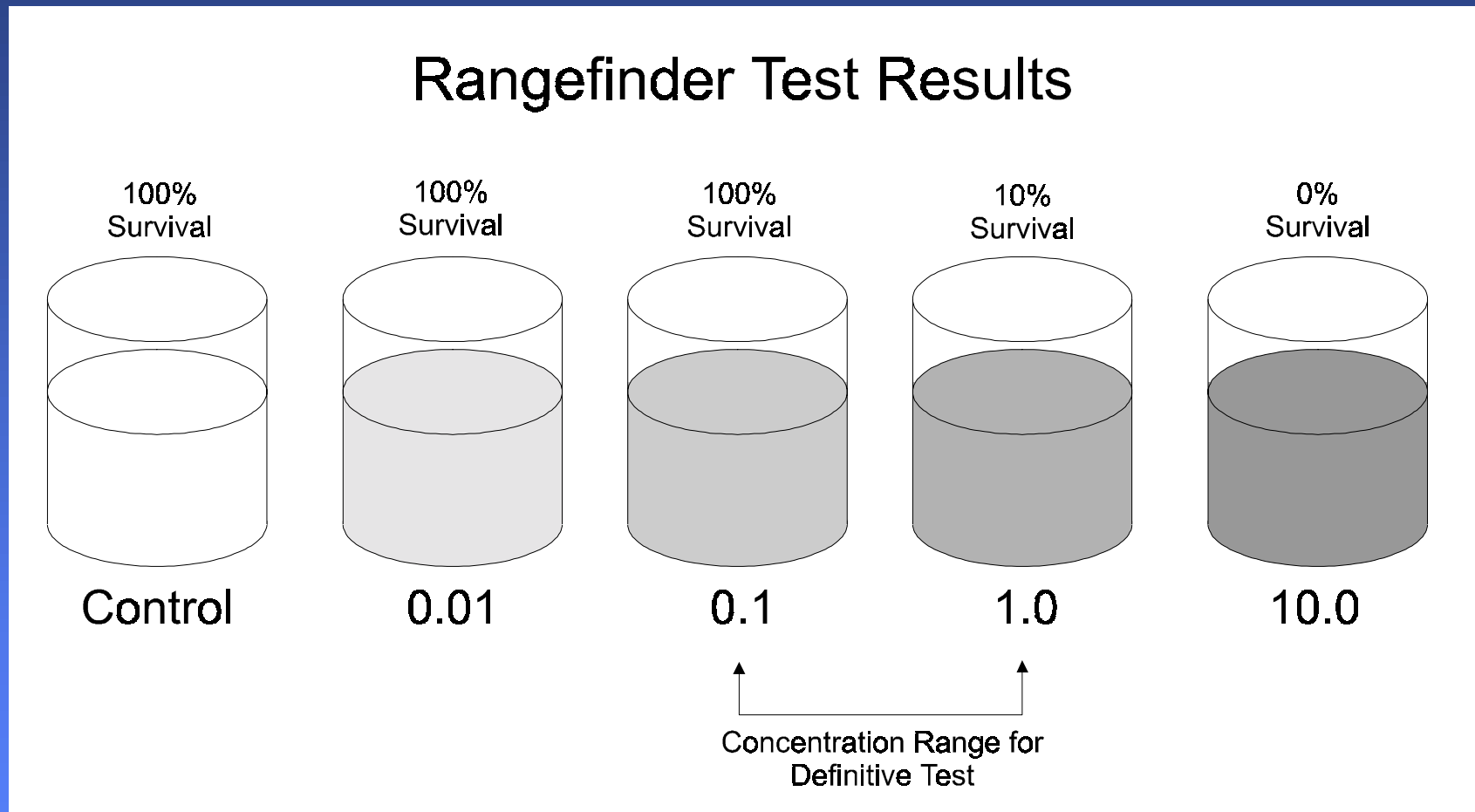
Questions Answered with Toxicity Tests (Cont'd)

- 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?

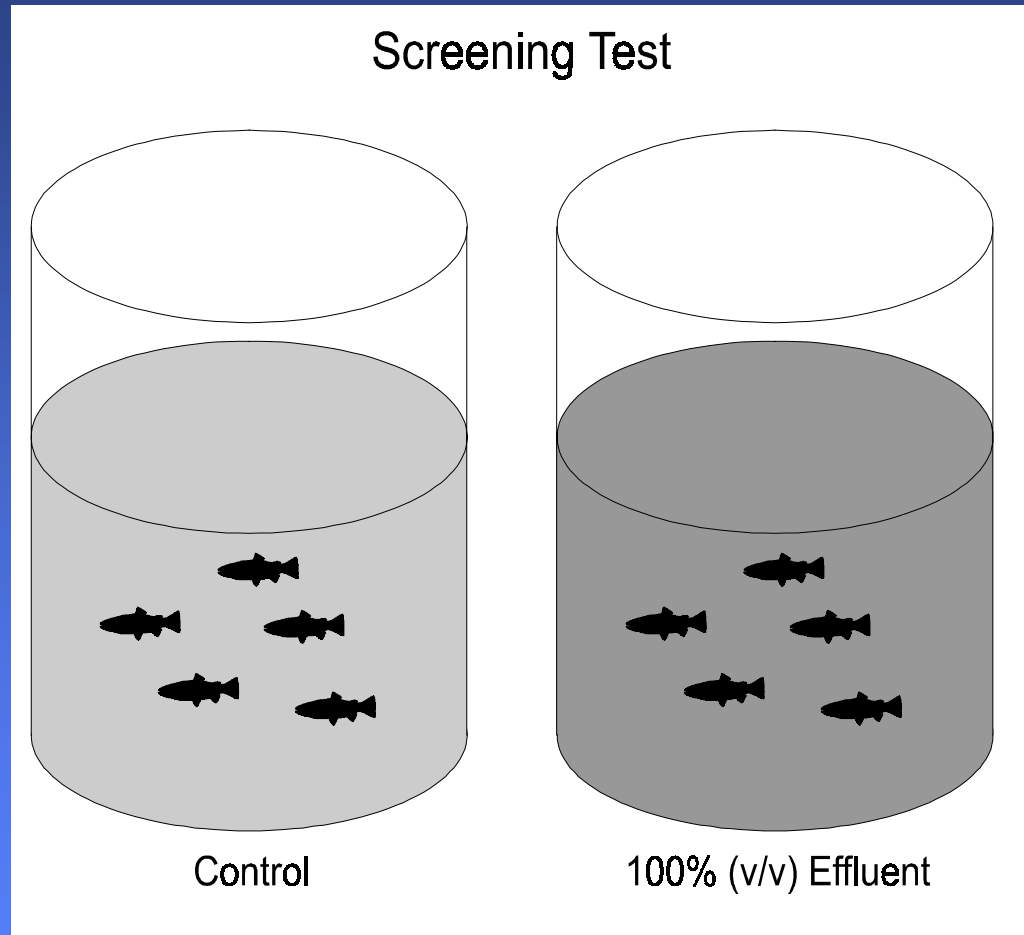
Rangefinder Test



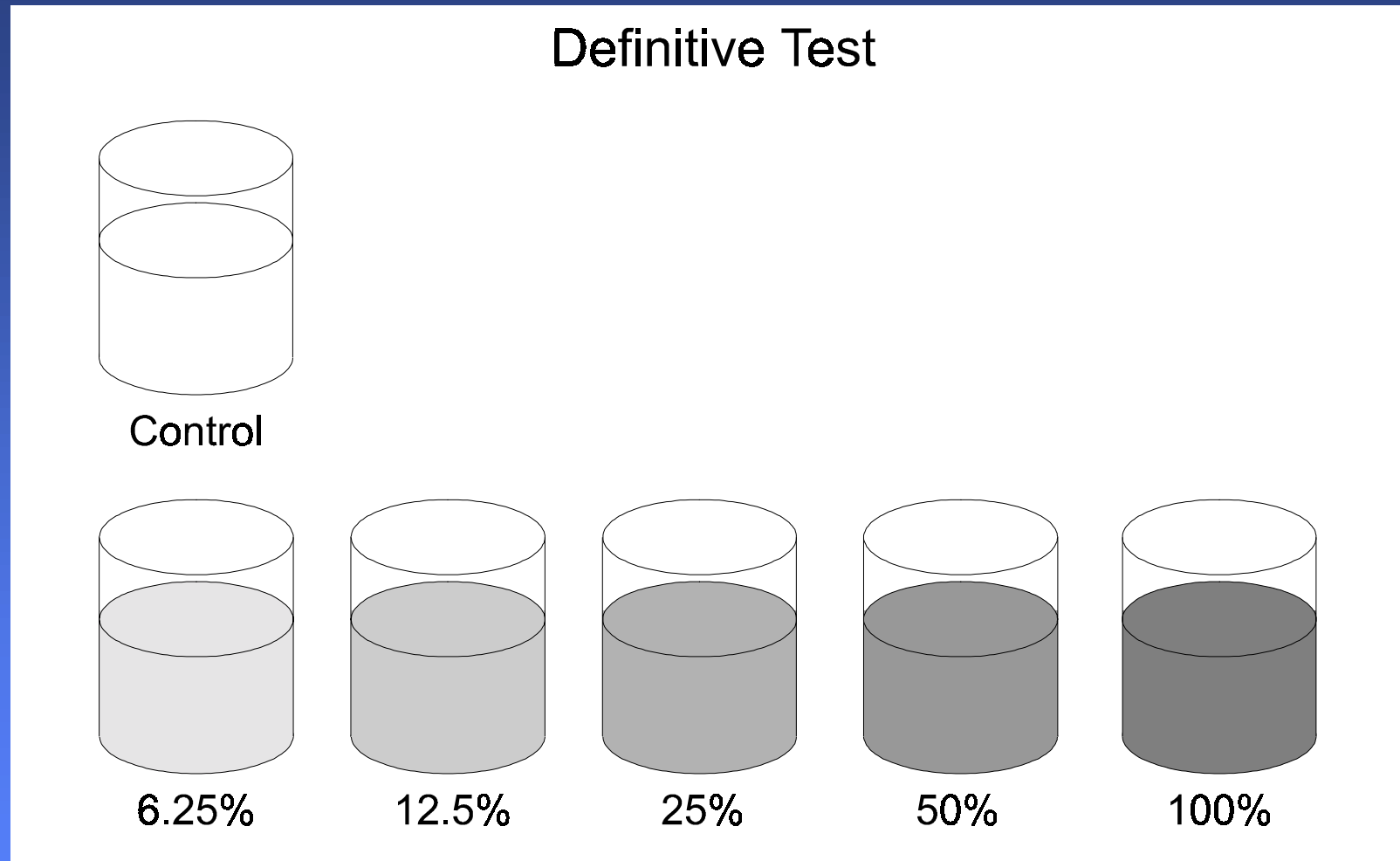
Rangefinder Test Results



Screening Test



Definitive Test



Aquatic Toxicity Test Organisms

- Algae/aquatic plants
- Invertebrates
- Fish

Focus has been on single-species tests, although some microcosm studies have also been conducted

Test Species Selection

- Commercial, recreational, ecological importance
- Geographic distribution
- Availability of sensitive stages
- Ease of culture and tolerance to handling
- Consistent performance
- Sensitivity
- Toxicological database available

Test Battery Approach

Fish early life stage
development test

Inland silverside (*Menidia
beryllina*)

Invertebrate
reproduction test

Echinoderm sperm cell

Plant toxicity test

Champia parvula

Toxicity Testing Statistical Endpoints

Hypothesis Testing:

- LOEC
- NOEC

Point Estimates:

- LC50, EC50
- IC_p

Toxicity Testing

Statistical Endpoints (Cont'd)

Hypothesis Testing: Is there a statistically significant difference between the mean response in the treatment(s) and the mean response in a control or reference sample?

Point Estimate: What toxicant concentration will cause a specific effect on the test population?

Toxicity Testing Statistical Endpoints (Cont'd)

LOEC

- Lowest Observed Effect Concentration
- Lowest concentration of test material that has a statistically significant adverse effect on the test organisms as compared to the control
- also called LOEL, LOAEL, LOAEC

Toxicity Testing Statistical Endpoints (Cont'd)

NOEC

- No Observed Effect Concentration
- Highest concentration of test material that does not have a statistically significant adverse effect on the test organisms as compared to the control
- also called NOEL, NOAEC, NOAEL

Toxicity Testing Statistical Endpoints (Cont'd)

TEC

- Threshold Effect Concentration
- Geometric mean of the NOEC and LOEC values
- also called MATC (Maximum Acceptable Toxicant Concentration) or 'Chronic Value' by US EPA

Toxicity Testing Statistical Endpoints (Cont'd)

EC50

- The concentration of test material that causes a specified effect, either lethal or sublethal, in 50% of the test organisms in a specified exposure time
- The effect and the exposure time must be specified

Toxicity Testing Statistical Endpoints (Cont'd)

LC50

- The median lethal concentration
- The concentration of test material that is estimated to be lethal to 50% of the test organisms in a specified exposure time
- Expressed as a time-dependent value (e.g., 96-h LC50)

Toxicity Testing Statistical Endpoints (Cont'd)

IC_p

- Concentration of test material that causes a specified percentage (p) inhibition in a biological function
- Applies to rate functions (e.g., growth, reproduction) rather than quantal data
- IC₂₅ and IC₅₀ are most common

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

CHEMICAL CONTAMINATION

- Effluent
- Water
- Sediment
 - surficial (recent)
 - cores (historic)
- Tissue

TOXICITY AND BIOACCUMULATION TESTING

- Sediment toxicity
- *In situ* exposures

- Fish
- Crab
- Bottom-dwelling invertebrates

RESIDENT COMMUNITIES (STRUCTURE, TISSUE BURDENS, HISTOPATHOLOGY, BIOMARKERS)

Integrative Assessment Outputs

Component

Information Provided

Information Lacking

Sediment Toxicity

Laboratory responses by organisms exposed to test conditions

- Field responses
- Responses to tests not conducted and organisms not exposed

Sediment Chemistry

Presence and levels of measured chemicals

- Chemical (bio)availability
- Presence and levels of chemicals not measured

Benthic Community Structure

Presence and numbers of taxa and individuals

- Causality [e.g., natural (competition, predation, habitat) versus human-related effects (chemicals causing toxic effects)]

Integrative Assessment Response Patterns

**Chemical
Contamination**

Toxicity

**Community
Alteration**

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Interpreting Monitoring Results

- The primary environmental concern relating to the hypothetical pulp and paper mill is potential impacts to water quality and aquatic biota
- Potential stressors in the effluent include:
 - » changes in biochemical oxygen demand (BOD)
 - » adsorbable organic halogens (AOXs): dioxins
 - » phenols and resins
 - » metals

Interpreting Monitoring Results (Cont'd)

- Comparison of mill effluent chemistry results with environmental quality values (e.g., water quality 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 (i.e., positive response in 2 or more components of an integrative assessment) allows scientifically-defensible conclusions on development-related impacts occurring in the receiving environment

Environmental Quality Values

- Environmental quality values (EQV) are values, or narrative statements, which represent the protective thresholds for particular parameters
- EQVs are derived using scientific information
- EQVs are developed to protect certain, specified resources (e.g., fish in a river receiving environment)
- EQVs provide a benchmark for assessing ambient environmental quality (e.g., water quality)

How are EQVs Derived?

- EQVs are media specific (e.g., water, air)
- VECs and protection goals are established
- Toxicity information is collected from the literature or generated
- Toxicity database is analyzed according to accepted approach
- Uncertainty factors or safety factors are often incorporated into the final value

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

Common Water Quality Standard Parameters

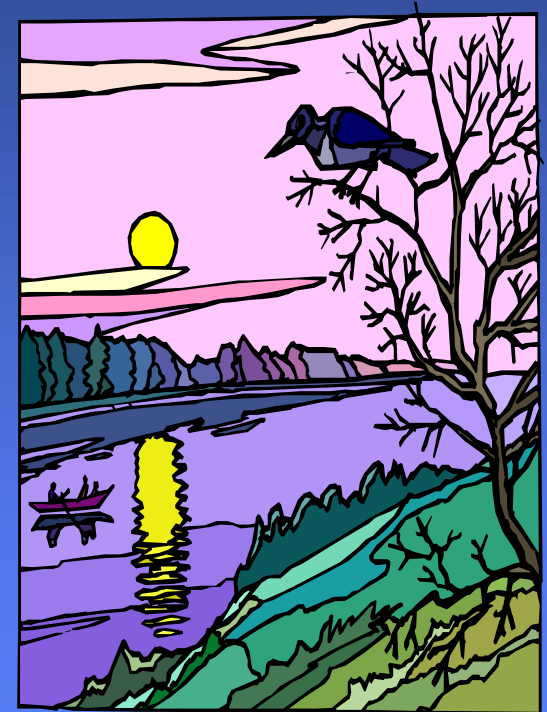
- Dissolved oxygen
- pH and temperature
- Turbidity
- Hardness
- Total dissolved solids, total suspended solids
- Concentrations of specific chemical pollutants or heavy metals

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