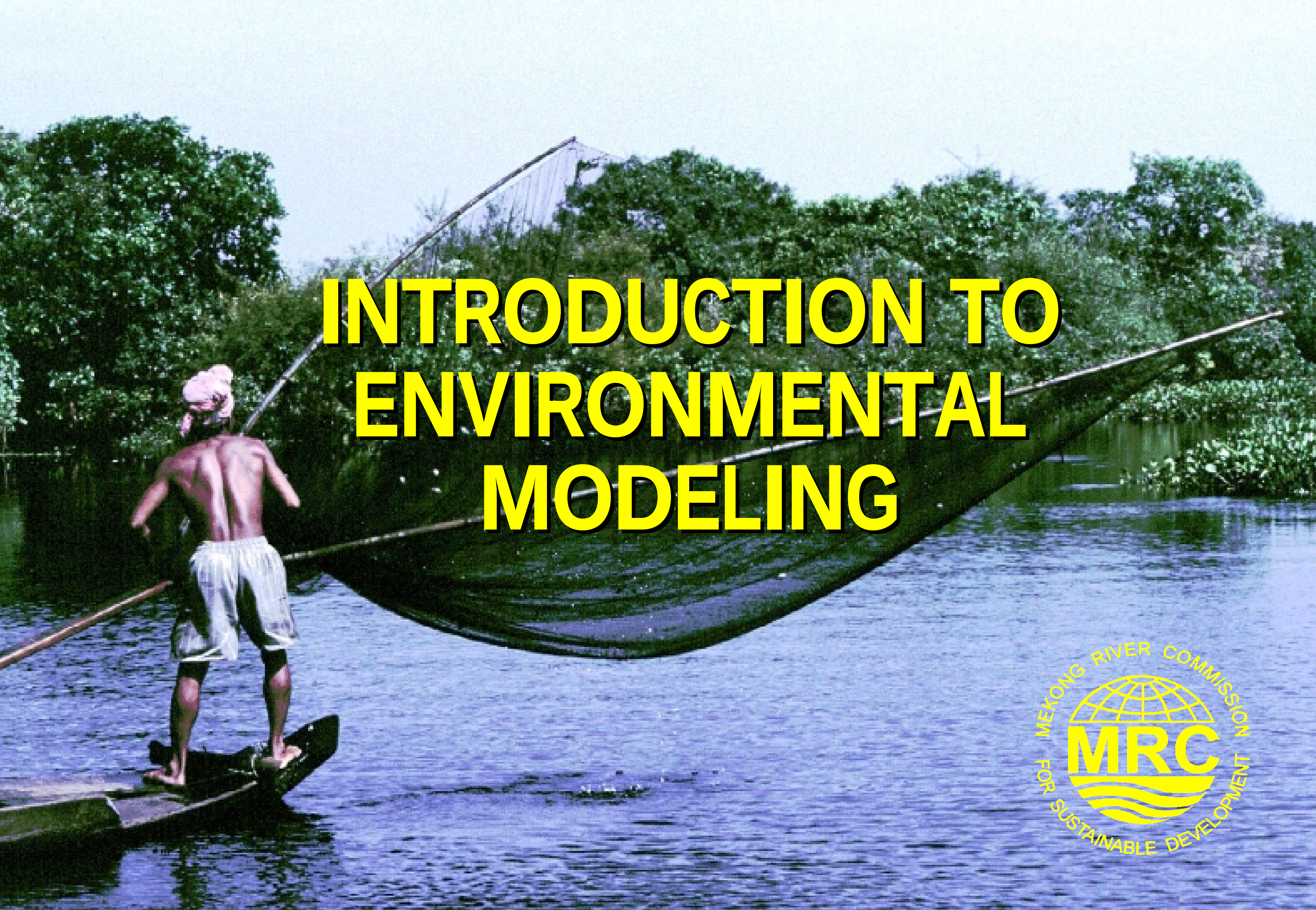

INTRODUCTION TO
ENVIRONMENTAL
MODELING
MEKONG RIVER COMMISSION
MRC
FOR SUSTAINABLE DEVELOPMENT

Lesson Learning Goals

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

- Describe different types of environmental models
- Discuss practical applications of environmental modeling in predicting and assessing potential environmental impacts and in planning development activities
- Identify both advantages and limitations of environmental modeling

Application of 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, examples include:
  - Erosion modeling
  - Reservoir sedimentation models
  - Hydrologic models
  - Chemical fate and transport models

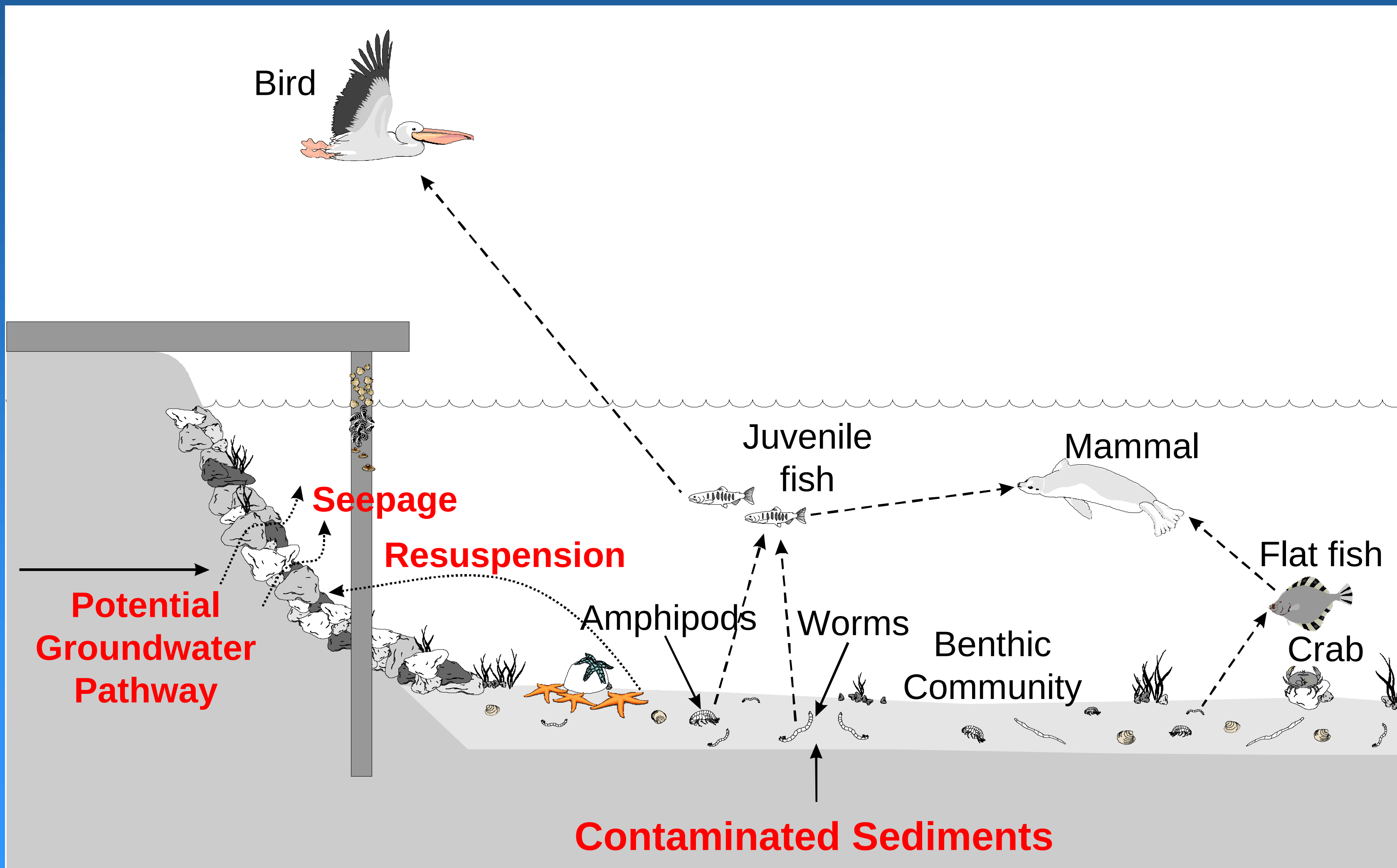
Conceptual Models

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 (Cont’d)

- 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

Example Conceptual Model



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

Erosion Example

- Erosion is a serious environmental issue in the Mekong River Basin but determining the rate and quantity of soil loss for a particular site or ecosystem may be difficult
- The universal soil loss equation is a basic yet functional empirical model that can be used to estimate how much soil loss will occur in a disturbed watershed (e.g., as a result of extensive logging of forests in a hydropower reservoir watershed)

Erosion Example (Cont'd)

- The universal soil loss equation was developed from more than 40 years of data
- The average annual soil loss from a site can be estimated with the following formula:

$$A = RKLSCP$$

Erosion Example (Cont'd)

Where:

- A = average annual soil loss
- R = rainfall and erosivity index by geographic location
- K = the soil erodibility factor

K is influenced by the ability of the soil to absorb water, rather than have water flow over it and remove particles

Soil structure is also important; loose, unstable soil particles are more vulnerable to erosion

Erosion Example (Cont'd)

- L = slope length
- S = slope gradient, or steepness
- C = cover and management, or the amount and type of vegetative cover on the site
- P = erosion control practice, or the type of site management used to protect the land from erosion

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:

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

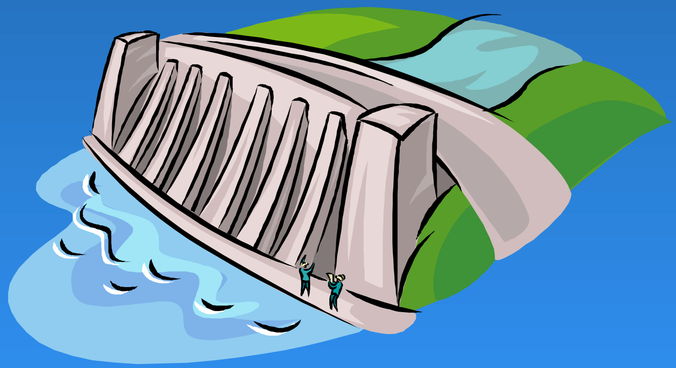
Reservoir Sedimentation Example (Cont'd)

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

Hydrologic Modeling

- Hydrologic modeling is a type of empirical model that is useful in estimating how flow volumes will change as a result of a development activity (e.g., clearing of agricultural land or wetlands for residential and industrial use in an urban setting)
- Modeling can be used to help plan municipal stormwater conveyance and treatment systems

Hydrologic Modeling (Cont'd)

- Practical estimations of rainfall in excess of storm run-off capacity can be modeled with numerical representations that relate run-off to rainfall
- This type of model makes use of available average rain intensity/duration data

Chemical Fate and Transport Models

- This type of empirical modeling can be conducted to determine the fate, residence time and transformation rates of a particular chemical, such as DDT
- In other words, the model helps answer the questions:
  - Where will the chemical go?
  - What species will be affected, and how?
  - How long will the chemical stay in the environment?

Environmental Inputs to Fate and Transport Models

Examples of data requirements of a fate and transport model necessary to characterize an ecosystem include:

- ➔ Total surface area
- ➔ Percent water cover by area
- ➔ Average sediment depth
- ➔ Length of coastline
- ➔ Resident fish species

Chemical Inputs to Fate and Transport Models

Examples of chemical characteristics necessary to model potential contaminants include:

- Water solubility of the chemical
- Reaction half-lives in water, soil, sediment
- Vapour pressure
- Molecular mass

Chemical Fate and Transport Model Outputs

Fate and transport models can produce the following information:

- Chemical residence times
- Concentrations in various environmental media
- Transfer and transformation rates
- Chemical partitioning behavior
- Summary diagram

Pulp Mill Effluent Example

- Potential impacts of an industrial discharge (e.g., pulp mill effluent) to an aquatic receiving environment can be modeled to predict exposure concentrations, identify major transport mechanisms, and estimate persistence of a particular contaminant
- The model requires:
  - a description of the evaluative environment (i.e., how much water, how much air?)
  - information about the properties of the contaminant being modeled

The Evaluative Environment

- For the purposes of modeling, the environment can be thought of as a number of compartments, all interacting with one another, depending on their location and properties
  - air
  - aerosols
  - water
  - sediments
  - suspended particles
  - fish and aquatic life
  - soil

Behavior of Contaminants

Many chemical properties measure the ability of a contaminant to transfer from one compartment to another, and are referred to as partition coefficients

Chemical Properties

- Vapour pressure: the tendency of a chemical to partition into the atmosphere from a liquid form
- Water solubility: the tendency of a chemical to partition into water from a solid form
- Henry’s Law Constant: the tendency for a chemical that is dissolved in water to transfer into the air

Chemical Properties (Cont'd)

- Water-octanol coefficient (K_{ow}): the tendency for a chemical to partition into the lipid (i.e., fat) portion of an organism
  - perhaps the most important property for describing the fate and movement of a chemical in the environment
  - a chemical with a high K_{ow} is referred to as 'hydrophobic', or water hating, and binds readily to lipid tissue in aquatic organisms

Mass-Balance Modeling

- Mass-balance models are commonly used to predict the fate and behavior of contaminants in the environment
  - based on the idea that the entire mass of the contaminant in a discharge must equal the amount of contaminant that eventually ends up in different parts of the environment

Level I Model

- Assumptions of the model
  - contaminant release is a one-time only event
  - chemicals do not react or degrade over time
  - the distribution of the chemical is in equilibrium (i.e., a great deal of time has passed to allow the chemical to fully partition into the various environmental compartments)

Level II Model

- More complex than the Level I Model
- More realistic then the Level I Model
- Assumptions of the model
  - contaminant input and output rates are equal
  - chemical is at equilibrium (i.e., fully partitioned)
  - allows for a chemical to leave through advective transport (large-scale transport of the chemical in a river, or in wind current)

Level III Model

- More representative of site conditions
  - user can specify which compartment is getting the chemical input
  - transport rates are included: sedimentation, water flow, soil run-off
  - model can calculate the chemical’s persistence and residence time
  - provides a more realistic description of the contaminant’s environmental fate

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!