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Analysis of Transport of Radionuclides in Surface Waters

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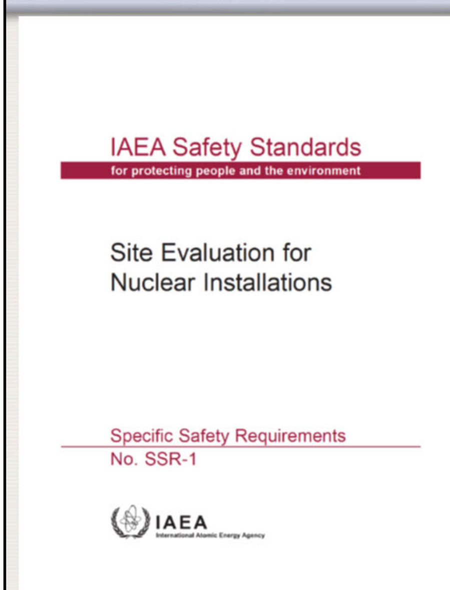
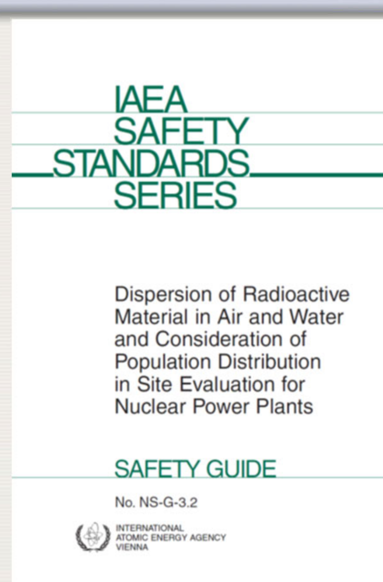
Hydrological & Hydrogeological Studies

Rationale, Approach, Methods, Data, Evaluation and Reporting





GENERAL CONSIDERATIONS

1. Radionuclides entering surface water are dispersed due to general water movements and sedimentation processes. Liquid radioactive releases may be discharged to freshwater, marine, or estuarine environments directly. Radionuclides may also reach surface water bodies through atmospheric release followed by deposition on water or from the ground surface by surface runoff. Based on the safety assessment, the **potential exposure scenarios and source terms** for **each accident scenario** should be examined including the quantities and relevant physical and chemical characteristics of the releases to the surface water .
2. The hydrological dispersion and transfer of radionuclides should be estimated with relevant models, considering the defined hydrological conditions. The output of atmospheric dispersion models may also be used as input in surface water if considered significant; this will probably be necessary for only continuous planned discharges. The relevant exposure pathways and the representative person should then be identified. Finally, the estimated dose, or a measure of the risk of health effects based on the estimated dose, should be derived and compared with the applicable established criteria. As the exposure pathways for a representative person, the surface water should be considered e.g. consumption (drinking water), fisheries, aquatic food, irrigation, and recreation.

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SELECTION OF RELEASE SCENARIOS FOR PLANNED DISCHARGES AND ACCIDENTAL RELEASES

3. **Planned discharges:** There are two discharge sources, directly released into the waterbody as liquid and another one is atmospheric deposition (mainly aerosol) on the surface water. The direct (controlled) release is the major pathway of normal discharges to the surface water. The composition and amount of relevant radionuclides should be determined as the discharge path and the physical properties (gas, aerosol, or liquid) and chemical properties should also be examined for environmental dispersion of radionuclides.
4. **Accidental release:** The most important accidental sources of radionuclides to surface water bodies may be direct release or the indirect atmospheric deposition if large amounts of radionuclides are released into the atmosphere and deposited on surface water; however, the overall radiological impact of the latter is likely to be trivial in comparison with that from the direct atmospheric release. In addition, some of the radionuclides on the ground surface, either due to deposition from atmospheric releases or direct release to the ground may enter the surface water through surface runoff due to precipitation. Such surface runoff should be considered after an accidental release to ground surface.

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SELECTION OF SOURCE PARAMETERS

5. The basic concepts of source parameters are as same as atmosphere. The additional source should be addressed that atmospheric deposition is represented by the scenario-based estimation.

6. The source term should include representative values for all the parameters that would affect the dispersion of radionuclides in surface water;

(a) radionuclides;

– which nuclides could be released from the facilities such as corrosion products, fission products, or activation products is fundamental information to assess dispersion as surface water.

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SELECTION OF SOURCE PARAMETERS

(b) chemical properties, those parameters control the behaviour of radionuclides in surface water such as adsorption affinity, biological uptake, chemical form of radionuclides whether dissolved or particulate form;

- major anion and cation concentrations, which control adsorption of radionuclides;
- organic content, which is important for biological uptake of radionuclides by aquaculture;
- pH, which control behaviour of radionuclides in surface water (dissolution affinity of nuclides);
- and DO, conductivity, suspended substance;

(c) physical properties, determine the distribution, dispersion pattern, and the concentration of nuclides in the surface water;

- temperature at multiple depths which could define the thermocline, and vertical distribution pattern of radionuclides in the water;

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SELECTION OF SOURCE PARAMETERS

- salinity is important for the marine environment and estuarine area where the fresh water and sea water mix. The water mass characteristics which control the distribution patterns of radionuclides are determined mainly salinity and temperature;
- density is determined with temperature, salinity and water depth, which control the mixture of water parcels each other. The water parcels with different density values never exchangeable, the distribution of radionuclides in surface water elongate its distribution within the isopycnal water parcel;
- water flow characteristics control the dispersion pattern of radionuclides in the surface water;
- sediment load parameters control the removal process of radionuclides from surface water to the bottom sediment;

(d) sedimentation properties;

- distribution coefficient (Kd) which determines the removal of radionuclides from surface water to the bottom sediment;
- particle size distribution of sediment (or surface area of sediment as indices for adsorption of radionuclides);

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TYPES OF MODELS FOR LABORATORY OR FIELDS

7. There are three basic types of models to estimate radionuclide transports through surface water:

- Numerical models usually transform the basic equations describing radionuclide dispersion into finite difference or finite element forms.
- Box type models treat the entire water body or sections of a water body as homogeneous compartments. These models often include some sediment–radionuclide interactions.
- Analytical models solve the basic radionuclide transport equations. Simplifying assumptions are made regarding water body geometry, flow conditions, and dispersion processes to obtain analytical solutions to the governing equations.

8. Other types of models can be used for assessing the radionuclide dispersion in the surface water systems (rivers, human made impoundments, lakes, estuaries, open shores, and ocean).

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TYPES OF MODELS FOR LABORATORY OR FIELDS

Rivers

9. The modelling approach and required level of accuracy of the source data depend on the purpose of the model and the expected level of accuracy required. Models developed to produce approximate results may be steady or unsteady flow, 1D or 2D models but are not very detailed. On the other hand, detailed planning studies require more specific data and more detailed knowledge of the river system. 1D or 2D, or both models can be developed in steady or unsteady flow mode, using the site-specific data. For more detailed level studies, the 1D, or even 2D model is used to obtain a preliminary idea on the behaviour of the hydraulic system and based on the understanding of the system a 3D model is constructed for predictions.

10. The size or length of the river to be modelled dictates the level of modelling. When the length of the river section for instance is much larger than the width and dept, a 1D model should be developed. If the flow path of the water is unknown for some of the events, or if it changes significantly during the event, then 1D model is not appropriate.

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TYPES OF MODELS FOR LABORATORY OR FIELDS

11. The objective (expected type and accuracy of results) may dictate the selection of the appropriate model. Consequently, the source and level of accuracy of the data should be compatible with the selected model. The availability, source and the level of accuracy of data should not be taken as a basis for developing a model, but on the contrary, an appropriate model should be selected to achieve the expected results, and the data should be acquired accordingly.

12. Mathematical models, either analytical or numerical, require knowledge of representative values of the parameters and the boundary conditions. Source of data, either literature or site-specific studies, depends on the purpose and the type of the selected model.

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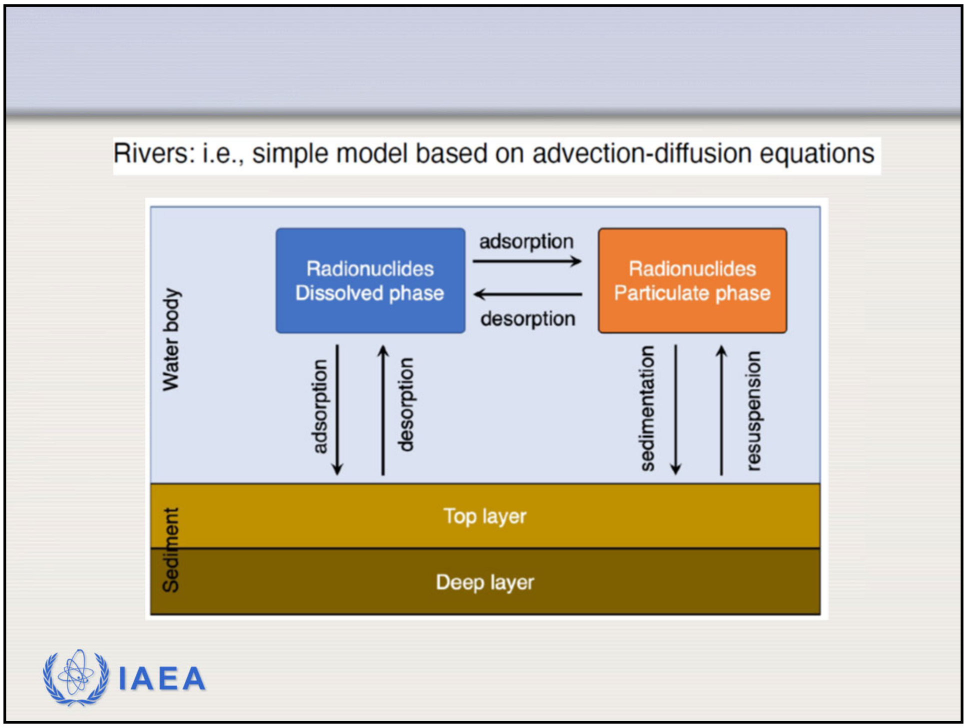
Rivers: i.e., simple model based on advection-diffusion equations
Water body
Radionuclides Dissolved phase
adsorption
desorption
Radionuclides Particulate phase
adsorption
desorption
sedimentation
resuspension
Sediment
Top layer
Deep layer
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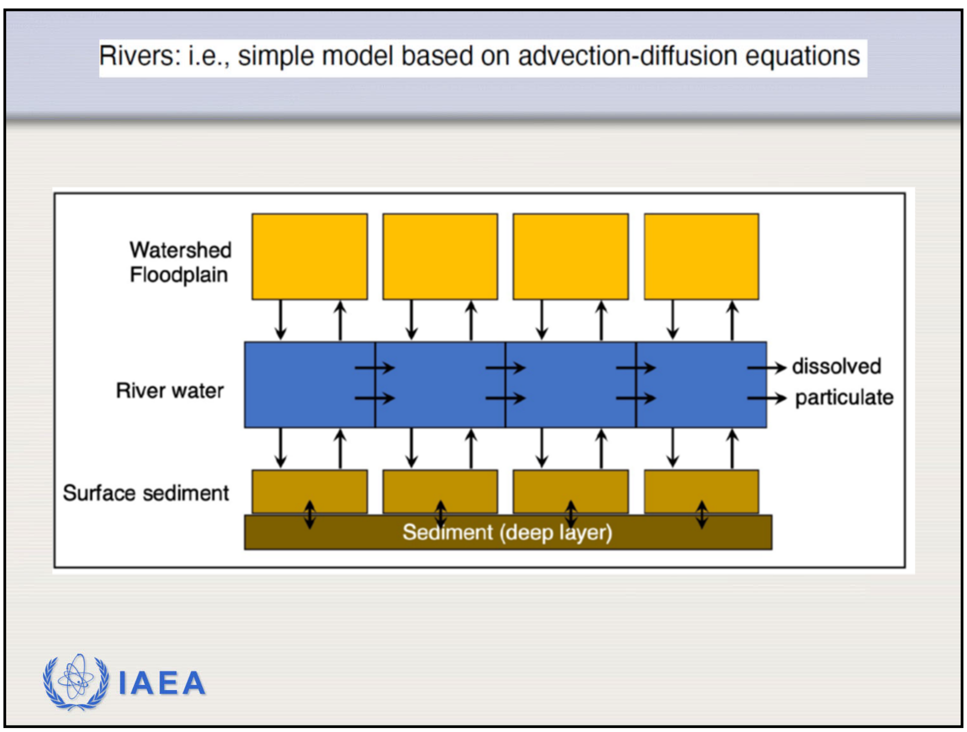
Rivers: i.e., simple model based on advection-diffusion equations
Watershed Floodplain
River water
dissolved
particulate
Surface sediment
Sediment (deep layer)
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TYPES OF MODELS FOR LABORATORY OR FIELDS

Human made impoundments and lakes

13. The typical models suitable for the lakes are as follows:

- Box model: The water body is divided into multiple boxes in the longitudinal direction and the water quality changes associated with the inflow and outflow within each box are calculated. Hydraulic quantities are for income and expenditure only. Water quality is the average of the boxes;
  - **Advantages:** Calculation time is short, long term prediction is possible;
  - **Disadvantage:** not suitable for stratified lakes, cannot represent the heterogeneity within a box, cannot represent the effects of flow changes;
- Vertical 1D model: The water body is divided into layers and the vertical distribution of hydrology and water quantity is calculated. Hydrology and water quantity are stratigraphic averages.
  - **Advantages:** Calculation time is short, long term prediction is possible.
  - **Disadvantage:** cannot represent the distribution within a box, difficult to take into account the effects of flow changes (horizontal variation)

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TYPES OF MODELS FOR LABORATORY OR FIELDS

Human made impoundments and lakes

- Horizontal 2D model: The distribution of hydrological and water quantity is calculated by dividing the water area into horizontal meshes. The amount of hydrology and water quality is determined for each mesh, but the vertical distribution is assumed to be uniform.
  - **Advantages:** Calculation time is shorter than 3-D models, Mid-term (1-10years) prediction is possible
  - **Disadvantage:** not suitable for stratified lakes
- Vertical 2D model: Calculate vertical distributions of hydrological and water quality parameters by dividing a water body into meshes in the vertical directions. The amount of hydrology and water quality is determined for each mesh, but the distribution in the transverse direction is assumed to be uniform.
  - **Advantages:** Calculation time is shorter than 3-D models, Mid-term (1-10years) prediction is possible, the stratification is represented
  - **Disadvantage:** transverse variation such as horizontal flow is not represented in this model

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TYPES OF MODELS FOR LABORATORY OR FIELDS

– Three-dimensional model: The amount of hydrology and water quality is calculated by dividing a water body into meshes in the longitudinal, transverse, and vertical directions. Three-dimensional distribution of hydraulic and water quantity is required.

  - **Advantages:** can describe local hydrology and water quality characteristics, can take into account density flow, drift current, can reproducible more complex phenomena in the lake
  - **Disadvantage:** Long calculation time is required, not suitable for long-term calculations (> 10 years).

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TYPES OF MODELS FOR LABORATORY OR FIELDS

Estuaries

14. Estuarine regions are connected at one end to a river and the other end to the sea. An estuary velocity reverses with the tide, and an estuary can contain fresh or saline water, although it is generally less saline than that of the sea. For this generic methodology, a radioactive discharge is assumed to occur from one of the estuarine banks. The radionuclide concentration at the banks may be assessed using a methodology that is very similar to that for rivers, but with some adjustments to account for tidal effects, salt wedge, and estuarine circulation.

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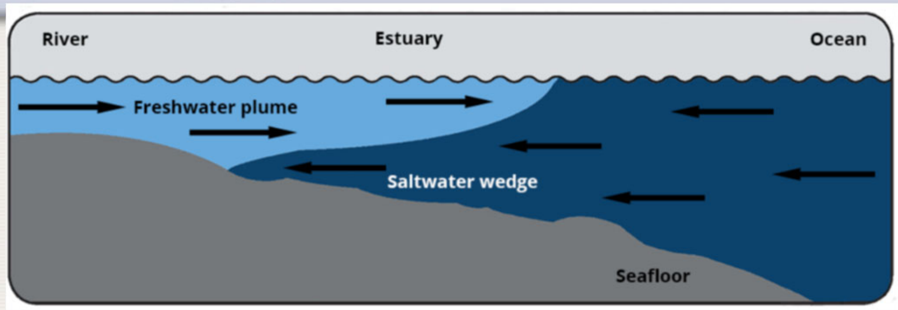
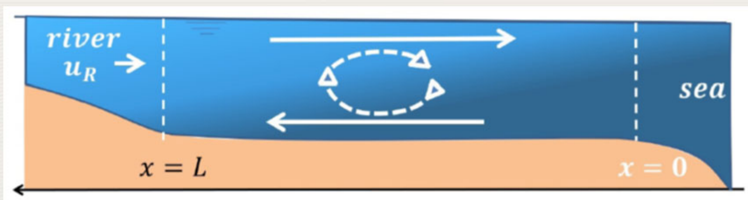
Schematic of salt wedge



Estuarine circulation



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(http://www.coastalwiki.org/wiki/Main_Page)

TYPES OF MODELS FOR LABORATORY OR FIELDS

Open shores of seas and ocean

15. There are three main types of ocean general circulation models which come to be a base of dispersion models for radionuclides, depending on how the vertical coordinate system is taken:
    - (a) Z-coordinate model: Oceanic general circulation model with vertical coordinates perpendicular to gravity. Excellent conservation of calculation variables and suitable for long term calculations. The z-models utilize the character of the ocean that the local pressure is expressed as a function of depth by zero-order approximation, which makes implementing the equation of state straightforward. Implementation of bottom topography and drawing of results are also straightforward. The models of this class are most widely used in the community because of their versatility. The major disadvantages of this class models are: The vertical resolution in shallow seas and near the seafloor tends to be low and the processes that arise near the coast and the seafloor tend to be poorly reproduced.

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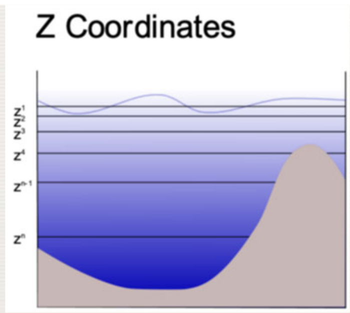
Z-coordinate model (surface, widely used, long-term calculation)

- The layers are often of varying depth with the layers near the top of the ocean being thinner than the deeper layers.
- The processes near the coast and seafloor area poorly reproduced due to the low resolution



From wikipedia

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TYPES OF MODELS FOR LABORATORY OR FIELDS

Open shores of seas and ocean

(b) Sigma-coordinate System Model: A model of oceanic general circulation in which the vertical coordinates are the planes along the seafloor. The number of vertical layers to be calculated in shallow and deep waters is the same. Since the number of vertical grid points is invariable throughout the model domain, sigma-models are widely used for coastal ocean simulations. The major disadvantages of this class models are as follows: An accurate representation of the horizontal pressure gradient is difficult near steeply sloping bottom topography. The lateral mixing along the same vertical layer near the continental slope region might lead to the mixing of the shoreward light water and the seaward dense water.

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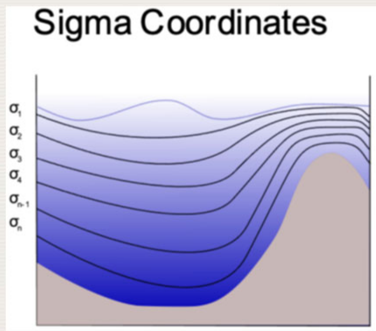
Sigma-coordinate System model (bottom boundary, coastal ocean)

- The bottom topography determines the thickness of the vertical layer at each horizontal grid point
- The horizontal pressure gradient is difficult near steeply sloping bottom topography



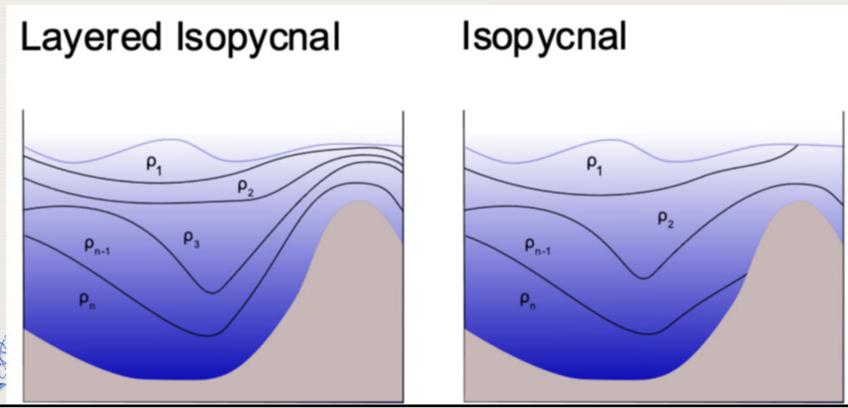
From wikipedia

TYPES OF MODELS FOR LABORATORY OR FIELDS

(c) Isopycnal-coordinate model: Oceanic general circulation model with vertical coordinates of the surfaces along the isopycnal plane. The development of this class of model is based on the fact that seawater moves along isopycnal surfaces in the interior. Thus, the character of a water mass is well maintained in the ocean interior. Since many theoretical studies of physical oceanography use an isopycnal-coordinate framework, the isopycnal-models have the great advantage of providing good correspondence between theory and numerical models. The major disadvantages of this class models are as follows: Implementation of surface mixed layer models into an isopycnal-model is in itself inappropriate.

Isopycnal-coordinate model (ocean interior, theoretical studies)

- This models model the potential density at a given pressure level as the vertical coordinate.
- The processes in surface mixed layer are inappropriate



- Z-coordinate model

Surface mixed layer

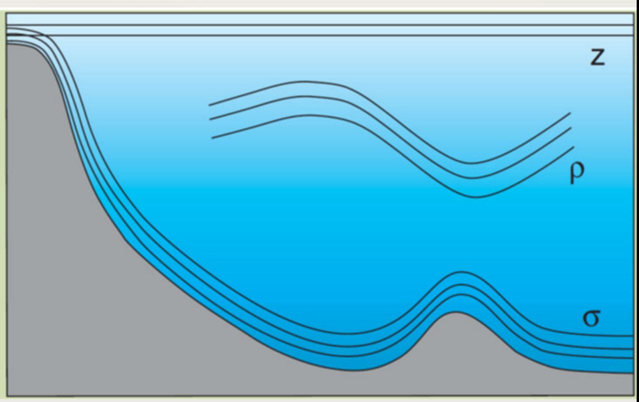
- Sigma-coordinate System model

Bottom boundary

- Isopycnal-coordinate model

Ocean general circulation models describe physical and thermodynamical processes in oceans.

Schematic of an ocean basin illustrating the three regimes of the ocean germane to the considerations of an appropriate vertical coordinate. The surface mixed layer is naturally represented using fixed-depth z (or pressure p) coordinates, the interior is naturally represented using isopycnic ρ (density tracking) coordinates; and the bottom boundary is naturally represented using terrain-following σ coordinates (after Griffies et al., 2000).



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Chassignet et al., 2006

IDENTIFICATION OF EXPOSURE PATHWAYS

16. According to GSG-10 para 5.27 [7], possible exposure pathways for releases of radionuclides to the surface waters in normal operation (typically, for nuclear installations such as nuclear power plants) are:

– Ingestion of drinking water
– Ingestion of aquatic food (freshwater or seawater fish, crustaceans, molluscs)
– External exposure from radionuclides in water and sediments (i.e. from activities on shores, swimming, and fishing).

17. Direct release from the nuclear facility and atmospheric deposition are the major pathways. The most important path is atmospheric deposition onto surface water and its watershed. The model output of atmosphere would be representative result of the exposure pathway via atmosphere. The direct discharge routes should be identified.

Figure V. Exposure pathways from releases of radioactive material to the environment

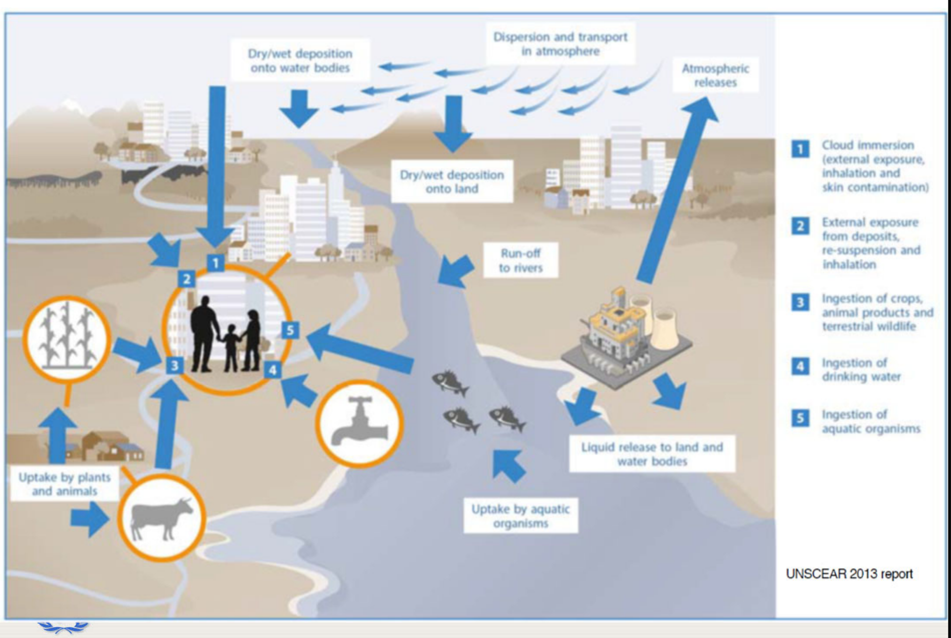
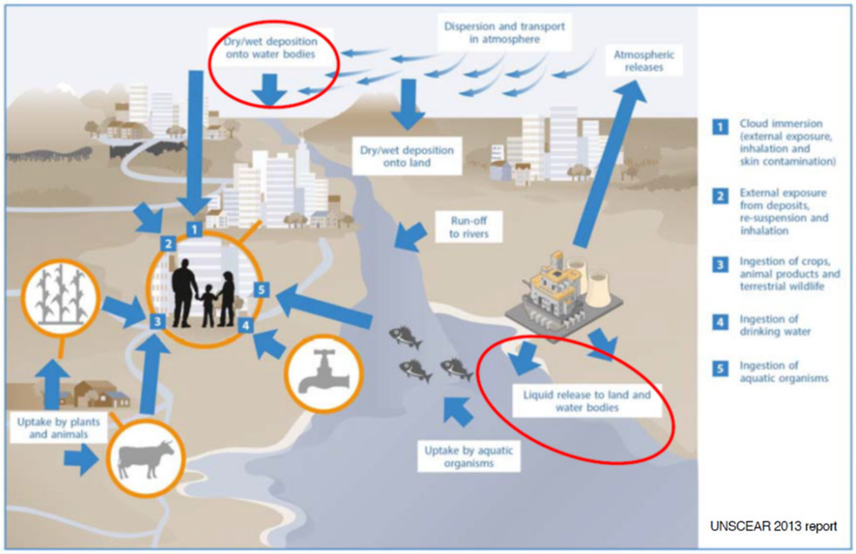


Figure V. Exposure pathways from releases of radioactive material to the environment



IDENTIFICATION OF EXPOSURE PATHWAYS

18. Most potential exposure situations will involve releases to atmosphere with only indirect releases to surface water. In these situations, assessing only the radiological consequences of the atmospheric releases is usually sufficient as these will be dominant and any additional impact from indirect releases to surface water will be trivial in comparison. Given that the computational effect required to assess the impacts of indirect inputs to surfaces waters – many hundreds of meteorological sequences may need to be considered taking account of wet and dry deposition in different locations – is likely to be significant, consideration should be given to whether such calculations would be worthwhile in terms of the endpoints being determined. Uncertainties in the atmospheric source term may be far more significant. Situations where assessment might be worthwhile include atmospheric deposition on reservoirs used for drinking water.

19. Potential exposure situations involving a direct release to surface waters should be considered if their likelihood is such that they could make a significant contribution to the overall risk.

DEFINITION AND COLLECTION OF DATA NECESSARY FOR MODELLING

20. The data necessary for the surface hydrological analysis for a nuclear power plant site come from different sources. The existing hydrometeorological network usually provides sufficient data. These, however, should be verified before being used, since these data are quietly variable and depending on each location.

21. The data needs presented herein relate to standard calculational methods. For advanced models, the data needs depend on the model being used to satisfy the relevant regulatory objectives. Typical water bodies in the vicinity of a nuclear power plant range from rivers, estuaries, open shores of large lakes, seas, and oceans to human-made impoundments. Specific parameters necessary in the models for assessing the aquatic environmental transfer of radionuclides will be discussed as follows.

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DEFINITION AND COLLECTION OF DATA NECESSARY FOR MODELLING

Rivers

22. The parameters required to calculate radionuclide concentrations in a river are; river width and depth, annual river flow rate, longitudinal distance from the release point to a potential receptor location, radionuclide decay constant.

Human made impoundments and lakes

23. Parameters required to calculate radionuclide concentrations in human-made impoundments and lakes are; the geology of impoundments and lakes such as the volume-area-elevation curve, seasonal variation of hydrological parameters, longitudinal distance from the release point to a potential receptor location, and radionuclide decay constant.

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DEFINITION AND COLLECTION OF DATA NECESSARY FOR MODELLING

Estuaries

24. Parameters required to calculate radionuclide concentrations in an estuary are; the estuarine width, estuarine flow depth, river width under a mean annual river flow rate upstream of the tidal flow area tidal period, longitudinal distance from the release point to a potential receptor location , and radionuclide decay constant.

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DEFINITION AND COLLECTION OF DATA NECESSARY FOR MODELLING

Open shores of seas and ocean

25. Various oceanic phenomena that should be considered. The representative physical factors for developing the oceanic models are as below in terms of their space and time scales are in parenthesis:
    - Wind Waves (1-10 s, 1-10 m);
    - Microstructure turbulence (1 s-1 min, 1 cm-1 m);
    - Boundary layer turbulence (1 min - 1 day, 10 cm - 100 m);
    - Swell (1 s - 1 min, 100 m);
    - Internal gravity waves (1 h - 1 day, 100 m-10 km);
    - Sub-mesoscale currents (1 h - 1 m, 100 m-10 km);
    - Mesoscale eddies (1 day - 1 y, 1 km - 100 km);
    - Tides (1 hour - 1 day, 1000 km - 10,000 km);
    - Wind-driven circulation (1 month-100 years, 100 km-1000 km);
    - Thermohaline Circulation (100-1000 years, 1000-10,000 km).

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DEFINITION AND COLLECTION OF DATA NECESSARY FOR MODELLING

26. The ocean general circulation model should consider wind-driven circulation and thermohaline circulation to represent the global scale. The existing global model is used as a boundary condition for the regional model that represents the target ocean. Then, the model is scaled down to a regional model that represents the relevant physical oceanographic phenomena, such as tides, mesoscale eddies, swells, and wind waves, in order to represent the topography and ocean currents specific to the target area. A high-resolution model with a grid size of a few kilometres is used near the coast, for some cases, and a low-resolution model with a grid size of 10 to 100 kilometres is used in the open ocean.

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CALIBRATION OF MODEL AND SENSITIVITY ANALYSIS

27. The results from a calculational model should be compared with laboratory data or field data for a specific site. Such validation usually has a limited range of applicability, which should be determined with a full understanding of the model. The calibration of the model should be done by comparing it with the actual monitoring data set. It should be verified, for example, that the errors and uncertainties in the model output values are within the error range of the actual observed values.

28. As with the atmospheric dispersion model, the above assessment involves many assumptions and uncertainties, so a sensitivity analysis should be performed to assess the sensitivity of the overall results to the assumptions and parameter values. A typical analysis might include the following:
   - — Hydrological data to be used;
   - — Source term assumptions including radionuclide activity released, potential water depth of release, and surface deposition associated with atmospheric fallout;
   - — Representative assumptions (age group, residence, food consumption, drinking water);
   - — Assumptions about parameter values such as deposition rates;
   - — Assumptions about the measures to be applied.

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SCENARIO BASED SIMULATION

29. The scenario for planned release should assume that radionuclides are released to surface water at a constant release rate and that the release continues for the lifetime of the plant. In addition, surface water deposition associated with short-term planned releases to the atmosphere, such as those that occur during maintenance, can also be simulated.

30. In addition, a series of radiological effects can be obtained by reproducing the diffusion of radionuclides as surface water through calculations based on the release of radionuclides (types and amounts of radionuclides) based on multiple accidental releases and the corresponding sample times of hydrological data sets.

31. The level of complexity of a surface water dispersion model for radionuclides should be chosen primarily according to the installation's hazard category and the hydrological environment's complexity. In particular, before developing a detailed model, it is useful to simplify the site's characteristics and consider conservative transport mechanisms.

32. When considering rivers as a target, the size and length of the river to be modelled will determine the level of modelling. If the length of the river cross-section is much larger than the width or depth, a 1D model may be used. When the water flow path is unknown for some events or changes significantly during the event, a 1D model is not appropriate and a more sophisticated model should be used.

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GRADED APPROCH

33. The basic flow phenomena in human-made impoundments and lakes are the flow due to the inflow and outflow of rivers and the wind-driven flow, which can be simplified according to their complexity. In addition, the presence or absence of vertical stratification associated with seasonal changes in air and water temperatures is also a criterion for determining whether the model can be simplified. As for the spatial scale, a low-dimensional model may be selected when a rough scale such as the average water quality in the lake is sufficient. As for the time scale, if the long-term variation over a year or more is to be determined, it may be necessary to select a low-dimensional model because a high-dimensional model may not be practical. On the other hand, if a short-term phenomenon such as runoff or storm surge is determined, a high-dimensional model would be more appropriate to achieve sufficient accuracy

34. In the flow field in the ocean, it is necessary to consider various processes such as three-dimensional mixing of water associate with temperature, salinity, density, tidal fluctuations, freshwater supply from rivers, the influence of strong currents due to thermohaline circulation in the open ocean, and the presence or absence of eddies. In coastal areas, various processes can be applied to simplify the model depending on the region, such as the presence or absence of large rivers, the seasonal development of the vertical stratification, and the influence of tidal currents.

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Thank You

(Surface Water System)

—A descriptive representation of a hydrologic system that incorporates an interpretation of the basin characteristics and basin scale hydrological cycle elements, including information about the interactions with adjacent basins.

- What **processes** are important to model?
- What are the **boundaries**? (Physical/Model)
- What **parameter** values are available/must be collected?

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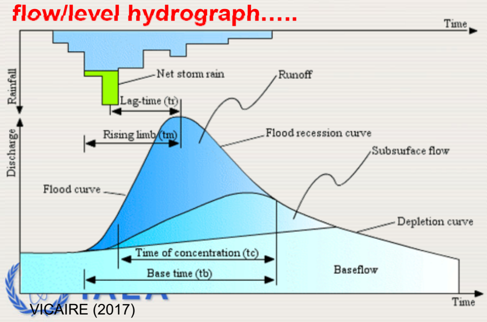
Surface Water (Watershed Characteristics)

- Size
- Slope
- Shape
- Soil type
- Storage capacity
- Landuse
- Drainage network
  - Pattern
  - Density
  - Bifurcation

Characteristics that affect the shape of the *flow/level hydrograph…..*



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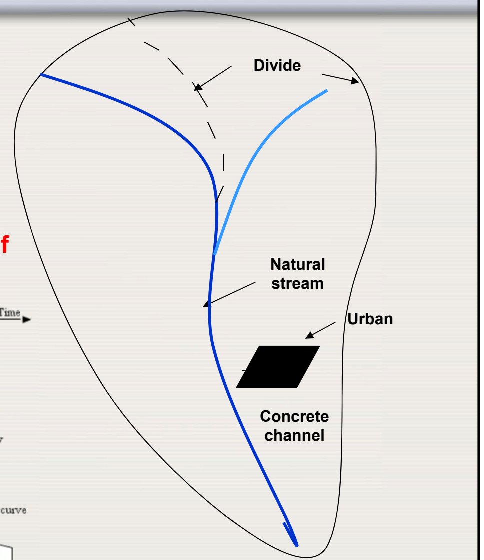
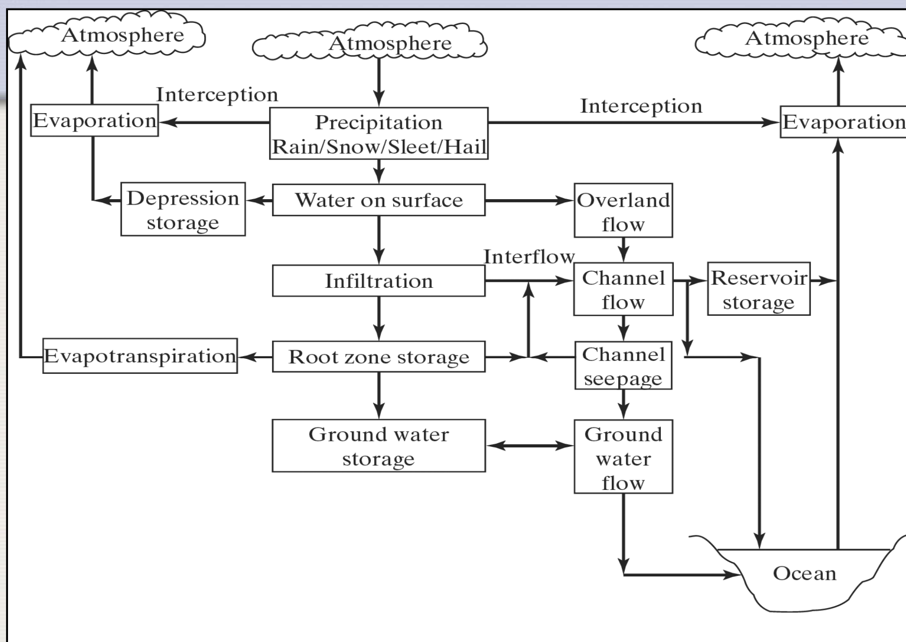


Scale is a big issue for analysis



(Bedient, 2005)

Components of the hydrologic cycle.

PROCESSES CONSIDERED IN CONTAMINANT TRANSPORT IN SURFACE WATERS

- Water and sediment movement,
- Adsorption and desorption,
- Precipitation and dissolution,
- Degradation and decay processes,
- Transformations, and
- Contaminant transfer between surface water and other environmental media

As examples of computer codes, the unsteady one-dimensional

- **Transport One-Dimensional Degradation and Migration Model (TODAM) and**
- **Bencala's models**

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Advective-Dispersive Transport

$$\frac{\partial C}{\partial t} = -U\frac{\partial C}{\partial x} + D_L\frac{\partial^2 C}{\partial x^2}\,.$$

Analytical Solution

$$C(x,t) = \frac{M}{2A\sqrt{\pi D_L t}}\exp\left[\frac{-(x-Ut)^2}{4D_L t}\right]$$

Spill

$$C(x,t) = \frac{C_0}{2}\left[\text{erfc}\left(\frac{x-Ut}{2\sqrt{D_L t}}\right) + \exp\left(\frac{Ux}{D_L}\right)\text{erfc}\left(\frac{x+Ut}{2\sqrt{D_L t}}\right)\right] \quad \text{for } t < \tau$$

Continuous Rectengular source

Advective-Dispersive-Sorptive Transport

$$\frac{\partial C}{\partial t} = -U\frac{\partial C}{\partial x} + D_L\frac{\partial^2 C}{\partial x^2} - \rho\frac{\partial S}{\partial t} \qquad \frac{\partial S}{\partial t} = K_d\frac{\partial C}{\partial t}$$

Advective-Dispersive-Reactive Transport

$$\frac{\partial C}{\partial t} = -U\frac{\partial C}{\partial x} + D_L\frac{\partial^2 C}{\partial x^2} - \rho\lambda(K_d C - S)$$

Models

F-TRAC 3 PROJECT

- River basin models
  - SACT model (originally developed by JAEA)
    - Soil and radioactive cesium transport mainly on the land surface using USLE
  - GETFLOWS (Developed by GETC)
    - Alternative watershed model
- River/reservoir models
  - TODAM model (developed by PNNL)
  - Nays2D (developed by Hokkaido Univ.)
- Reservoir/coast/ocean models
  - FLESCOT model (developed by PNNL)
  - ROMS (openly developed)
- Radiation transport model
  - PHITS (developed by JAEA)

➔ By combining/modifying these originally developed and various existing models in a flexible way, we can solve various issues.

SACT model: Soil And Cs Transport model
GETFLOWS: GEneral purpose Terrestrial fluid-FLOW Simulator
GETC: Geosphere Environmental Technology Corp.
TODAM model: Time-dependent, One-dimensional Degradation And Migration model
PNNL: Pacific Northwest National Laboratory
FLESCOT model: Flow, Energy, Salinity, Sediment Contaminant Transport model
ROMS: Regional Ocean Modeling System
PHITS: Particle and Heavy Ion Transport code System

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GENERIC EQUATION FOR CONTAMINANT TRANSPORT IN SURFACE WATERS

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x_i}(U_i C) = \frac{\partial}{\partial x_i}\left(\varepsilon_i \frac{\partial C}{\partial x_i}\right) + \Sigma_{j=1}^{m} K_j C + \Sigma_{j=1}^{n} S_j$$

where:

C= concentration of the contaminant

t= time

U_i= velocity term

x_i= Cartesian coordinates

ε_i= diffusion/dispersion coefficient

Σk_j= sum of decay rates for a contaminant

ΣS_j= sum of sink and/or source terms

RIVTOX - one dimensional model for the simulation of the transport of radionuclides in a network of river channels

RODOS REPORT
DECISION SUPPORT FOR NUCLEAR EMERGENCIES

RODOS-WG4-TN(97)05

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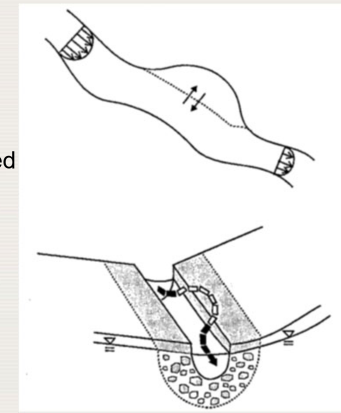
Bencala Model

$$\frac{\partial C}{\partial t} = -U\frac{\partial C}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}\left(AD_L\frac{\partial C}{\partial x}\right) + \frac{q_L}{A}(C_L - C) + \alpha(C_S - C)$$

Lateral inflow, Stoarge concentration included



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Contaminant Model for Streams (CMS)

$$\frac{\partial c_w}{\partial t} + U\frac{\partial c_w}{\partial x} = D_x\frac{\partial^2 c_w}{\partial x^2} - \left(k_{dw} + \frac{k_v}{H}\right)F_{dw}c_w - k_{pw}F_{pw}c_w - \frac{V_s}{H}F_{pw}c_w + \frac{V_r}{H}c_b - \frac{V_d}{H}\left(F_{dw}c_w - F_{db}c_b\right) \quad (1)$$

where,

c_b	=	concentration of the constituent in the sediment bed (M/L^3), total mass on a total volume basis
c_w	=	concentration of the constituent in the water column (M/L^3), total mass on a total volume basis
D_x	=	longitudinal diffusion coefficient (L^2/T)
F_{db}	=	fraction of the constituent dissolved in the sediment bed pore water
F_{dw}	=	fraction of the constituent dissolved in the water column
F_{pw}	=	fraction of the constituent in particulate form in the water column
H	=	hydraulic depth of the stream (L)
k_{dw}	=	decay rate of dissolved constituent in the water column (T^{-1})
k_{pw}	=	decay rate of particulate constituent in the water column (T^{-1})
k_v	=	volatilization rate of the constituent (L/T)
U	=	mean velocity (L/T)
V_d	=	mass transfer rate across the sediment-water interface resulting from diffusion of the dissolved constituent (L/T)
V_r	=	active sediment layer resuspension rate (L/T)
V_s	=	suspended solids settling rate (L/T)
x	=	downstream distance (L)

JAEA

JAEA Modeling of Cs transport within Fukushima aquatic systems

Hiroshi Kurikami
Fukushima Environmental Research Group
Fukushima Environmental Safety Center
Sector of Fukushima Research and Development
Japan Atomic Energy Agency (JAEA)

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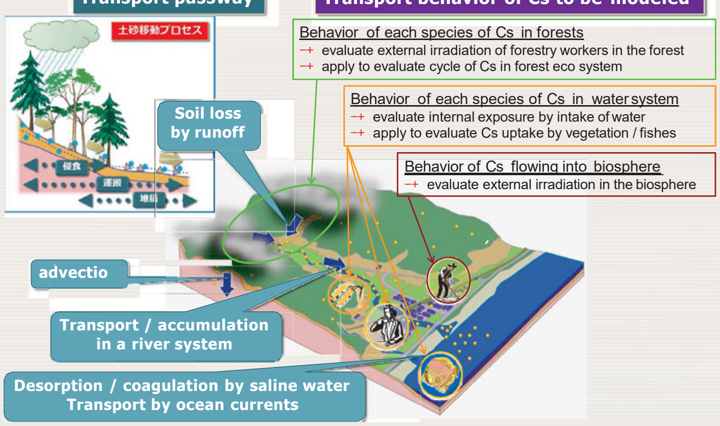
Objectives of the F-TRACE project

2

Develop mechanistic models to predict quantitatively transport of radioisotopes(especially radioactive Cs) along river systems

Transport passway | **Transport behavior of Cs to be modeled**



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1D / 2D river models: TODAM / Nays2D(iRIC)

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Suspended sediment transport C_j (kg·m^-3^)

$$A\frac{dC_j}{dt}+UA\frac{dC_j}{dx}=\frac{d}{dx}\left(E_X A\frac{dC_j}{dx}\right)+Q_{Sj}\ \ Q_l C_j+B(S_{Rj}\ \ S_{Dj})$$

Dispersion — Inflow/outflow — Deposition/resuspension

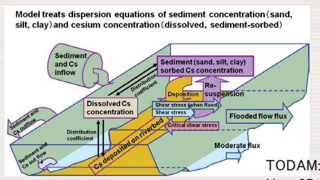
Dissolved cesium G_w (Bq·m^-3^)

$$A\frac{dG_w}{dt}+UA\frac{dG_w}{dx}=\frac{d}{dx}\left(E_X A\frac{dG_w}{dx}\right)\ \ AG_w\ \ Q_l G_w+Q_w\ -\sum_{j=1}^{Nf} AK_j(K_{dj}C_j G_w\ \ G\ )\ \ \sum_{j=1}^{Nf} B\ \ _j(1\ \ n)d_j K_{bj}(K_{dj}G_w\ \ G_{Bj})$$

Dispersion — Decay — Inflow/outflow — Adsorption/desorption to suspended sediment — Adsorption/desorption to bed sediment

Particulate cesium G_j (Bq·m^-3^)

$$A\frac{dG_j}{dt}+UA\frac{dG_j}{dx}=\frac{d}{dx}\left(E_X A\frac{dG_j}{dx}\right)\ \ AG_j\ \ Q_l G_j\ \ +Q_{Pj}+AK_j(K_{dj}C_j G_w\ \ G_j)+B\left(G_{Bj}S_{Rj}\ \ \frac{S_{Dj}G_j}{C_j}\right)$$



TODAM: developed by Pacific Northwest National Laboratory
Nays2D: developed by Hokkaido University

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Applicability of models

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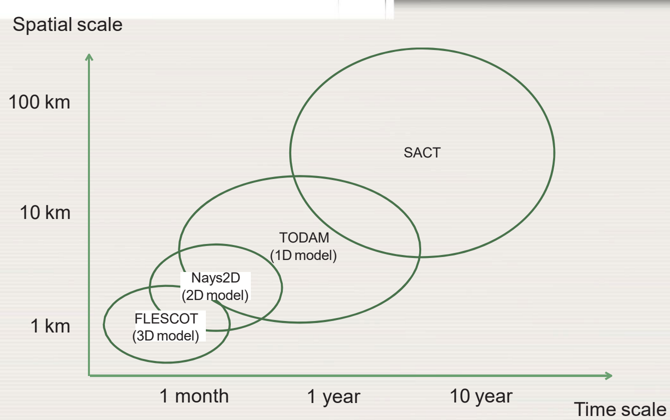

According to time and spatial scales of events, we select models to be applied.

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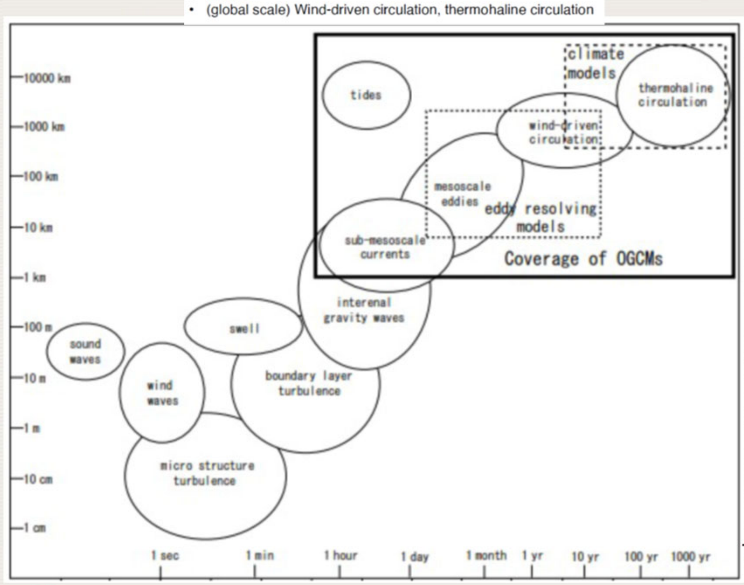
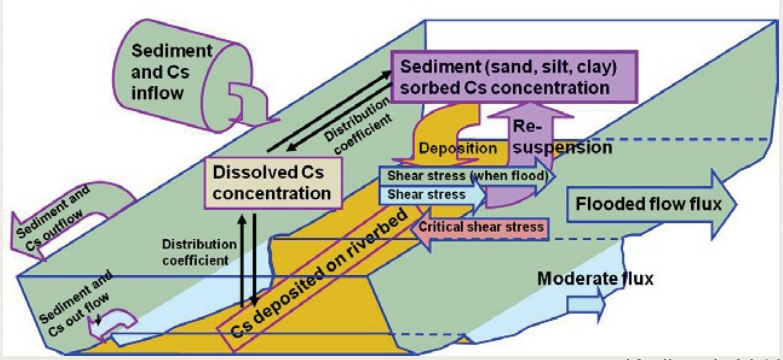
- Wind wave
- Microstructure turbulence
- Swell
- Internal gravity waves
- Sub-mesoscale currents
- Mesoscale eddies
- Tides
- (global scale) Wind-driven circulation, thermohaline circulation



Tsujino et al., 2017

Conceptual Model for Transport One-Dimensional Degradation and Migration Model (TODAM)

Model treats dispersion equations of sediment concentration (sand, silt, clay) and cesium concentration (dissolved, sediment-sorbed)



TODAM: developed by Pacific Northwest National Laboratory
Nays2D: developed by Hokkaido University

Kurikami, 2016

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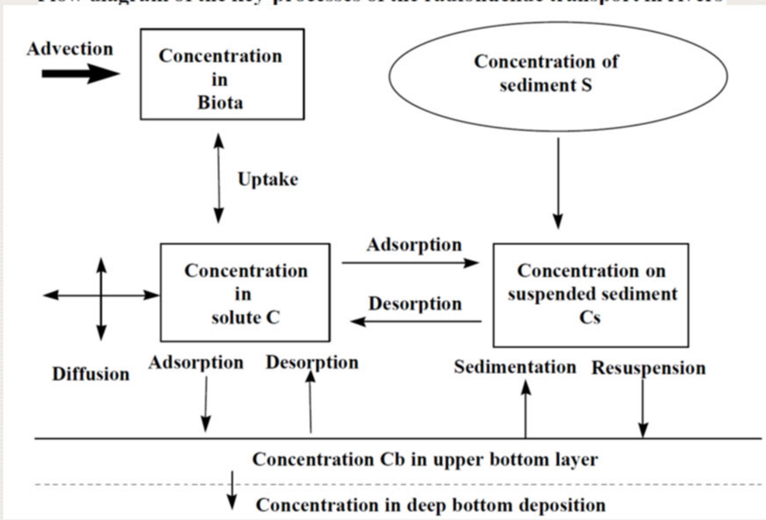
Conceptual Model for Hydrological Dispersion Module - HDM of RODOS

Flow diagram of the key-processes of the radionuclide transport in rivers



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Heling et al., 1999

Conceptual Model for Hydrological Dispersion Module - HDM of RODOS

Key processes with respect to the radionuclide behaviour in lakes and reservoirs

Process	Importance
Aquatic processes	
Residence time of water in lake	High
Turbulent mixing including stratification	High
Sedimentation / resuspension	Moderate
Adsorption and desorption	Moderate
Sediment processes	
Bioturbation	Low
Resuspension	High
Diffusion	Low
Burial	Low
Biological Processes (dynamical modelling)	
Biological half-life	High
Foodweb composition	Moderate
Consumption rate organisms	High

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Heling et al., 1999

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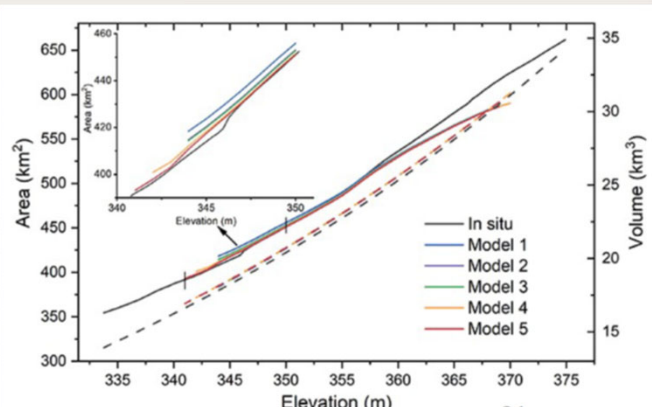

VEA curve for Lake Mead (Li et al., 2021)

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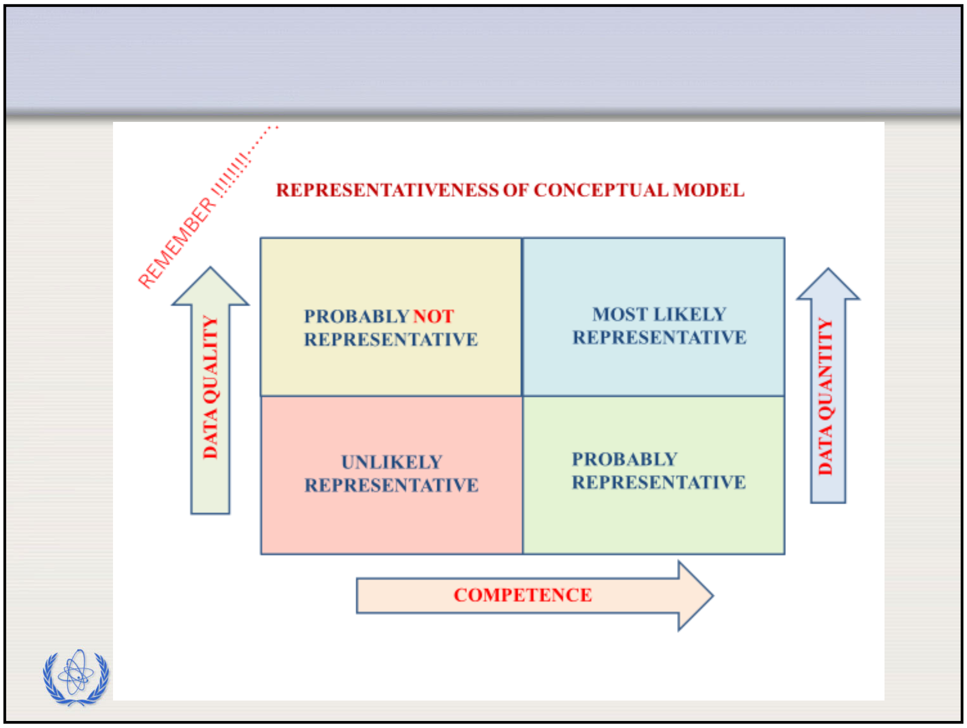
REMEMBER !!!!!!!!.......
REPRESENTATIVENESS OF CONCEPTUAL MODEL
PROBABLY NOT REPRESENTATIVE
MOST LIKELY REPRESENTATIVE
UNLIKELY REPRESENTATIVE
PROBABLY REPRESENTATIVE
DATA QUALITY
DATA QUANTITY
COMPETENCE