Dose (external, internal) to biota calculation/assessment (ERICA) – PART 2

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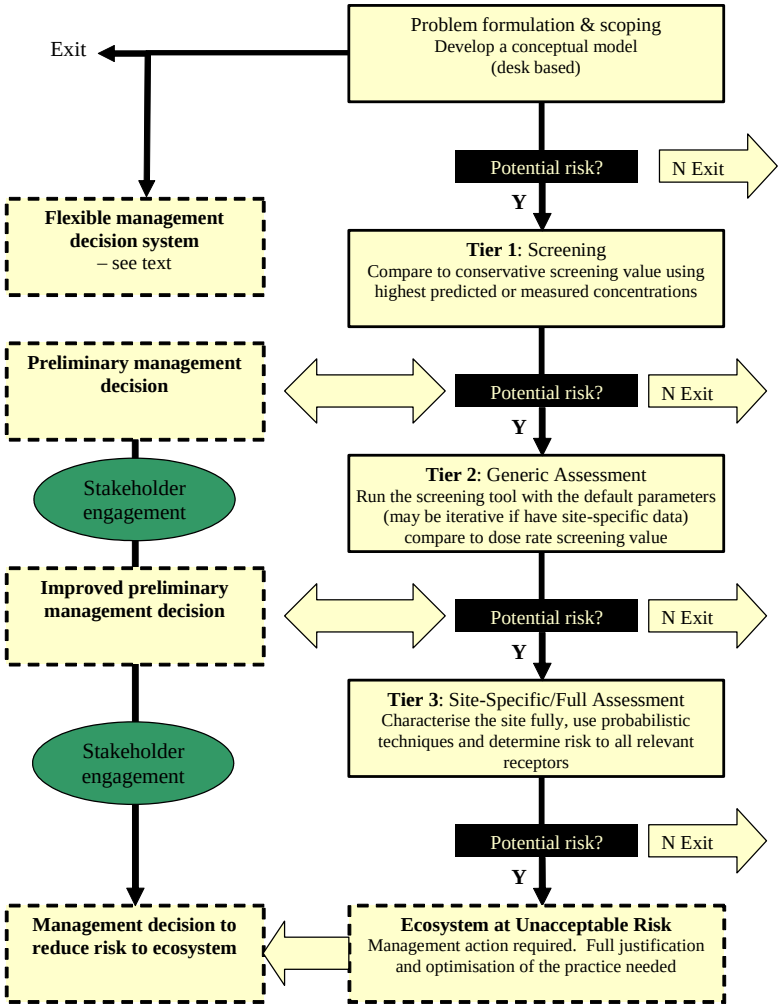
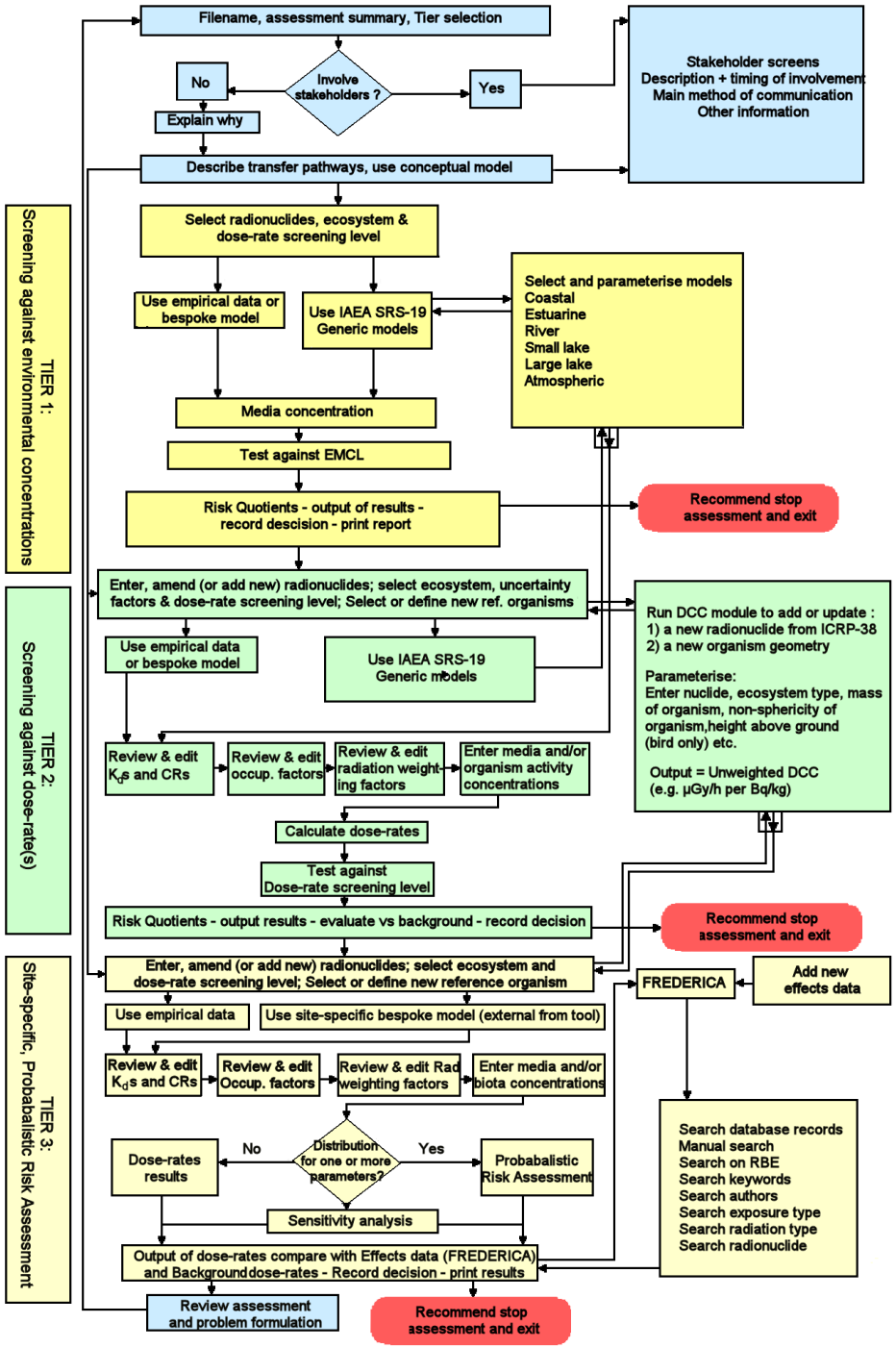
EU COMET course:
"COURSE ON NATURALLY OCCURRING RADIOACTIVE MATERIAL (NORM) IN THE ENVIRONMENT"

The ERICA Integrated approach and supporting Tool.

- Integrate the Tiered approach into a user-friendly computerised system
- Place emphasis on calculation but allow the user to document process/decisions
- Allow flexibility

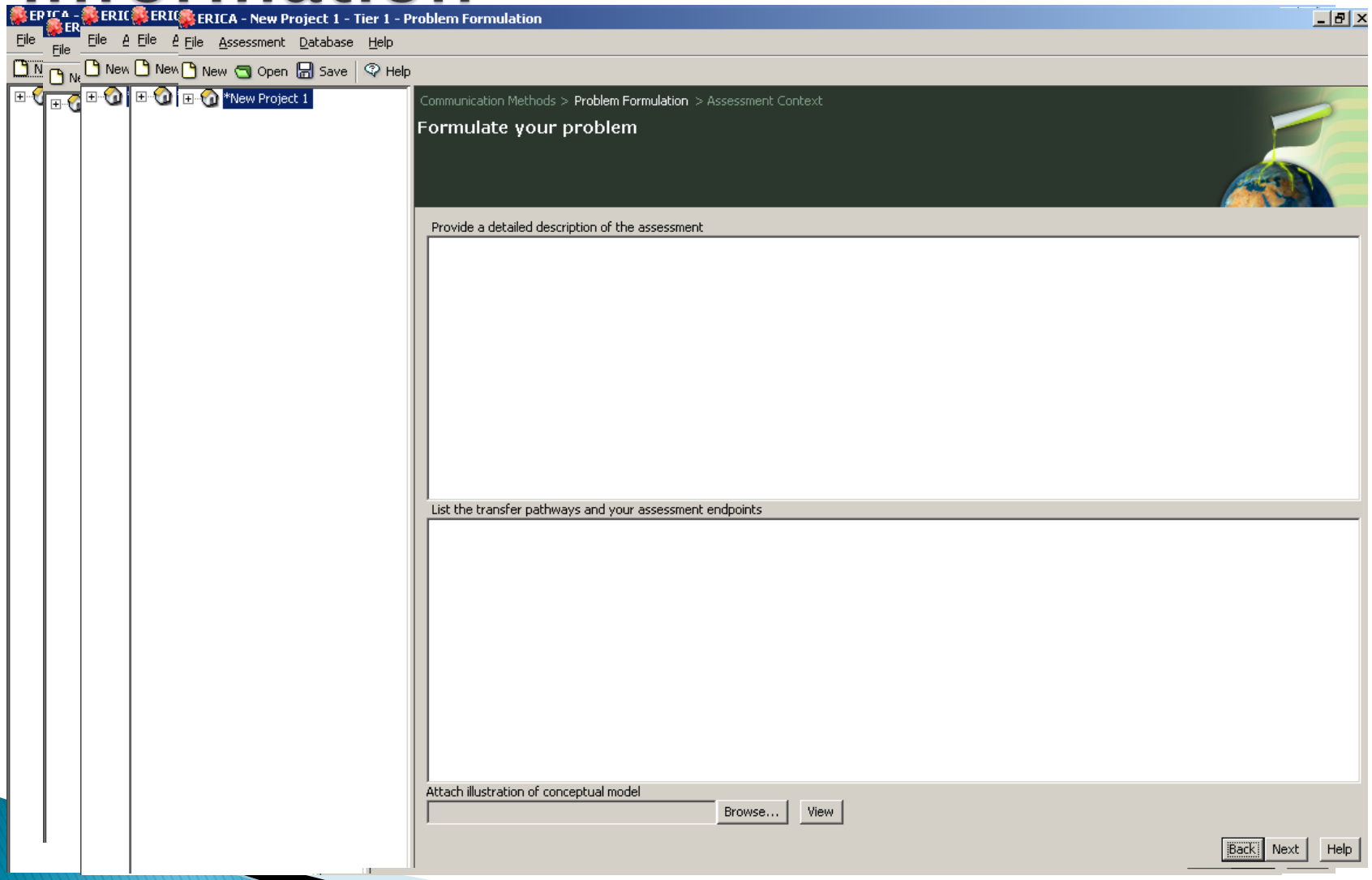



TIER 1:
Screening against environmental concentrations
TIER 2:
Screening against dose-rate(s)
TIER 3:
Site-specific, Probabalistic Risk Assessment
Filename, assessment summary, Tier selection
Involve stakeholders ?
No
Explain why
Yes
Stakeholder screens
Description + timing of involvement
Main method of communication
Other information
Describe transfer pathways, use conceptual model
Select radionuclides, ecosystem & dose-rate screening level
Use empirical data or bespoke model
Use IAEA SRS-19 Generic models
Select and parameterise models
Coastal
Estuarine
River
Small lake
Large lake
Atmospheric
Media concentration
Test against EMCL
Risk Quotients - output of results - record descision - print report
Recommend stop assessment and exit
Enter, amend (or add new) radionuclides; select ecosystem, uncertainty factors & dose-rate screening level; Select or define new ref. organisms
Run DCC module to add or update :
1) a new radionuclide from ICRP-38
2) a new organism geometry
Parameterise:
Enter nuclide, ecosystem type, mass of organism, non-sphericity of organism,height above ground (bird only) etc.
Output = Unweighted DCC (e.g. µGy/h per Bq/kg)
Use empirical data or bespoke model
Use IAEA SRS-19 Generic models
Review & edit K_ds and CRs
Review & edit occup. factors
Review & edit radiation weight-ing factors
Enter media and/or organism activity concentrations
Calculate dose-rates
Test against Dose-rate screening level
Risk Quotients - output results - evaluate vs background - record decision
Recommend stop assessment and exit
Enter, amend (or add new) radionuclides; select ecosystem and dose-rate screening level; Select or define new reference organism
FREDERICA
Add new effects data
Use empirical data
Use site-specific bespoke model (external from tool)
Review & edit K_ds and CRs
Review & edit Occup. factors
Review & edit Rad weighting factors
Enter media and/or biota concentrations
Dose-rates results
No
Distribution for one or more parameters?
Yes
Probabalistic Risk Assessment
Sensitivity analysis
Search database records
Manual search
Search on RBE
Search keywords
Search authors
Search exposure type
Search radiation type
Search radionuclide
Output of dose-rates compare with Effects data (FREDERICA) and Background dose-rates - Record decision - print results
Review assessment and problem formulation
Recommend stop assessment and exit

At all tiers – process documented

- **Assessment details**
  - Assessment name + purpose, author
- **Stakeholder involvement**
  - Type, description, reason for involvement, stage of involvement, influence-interest category, means of engagement
- **Problem formulation**
  - Detailed description (industrial process, discharge regime, receiving medium, ecosystem, regulations)
  - Transfer pathways and assessment endpoints
  - Conceptual model
- **Record decision**
  - Justification
  - check on efficacy of stakeholder involvement

Sequence in the Tool – initial information

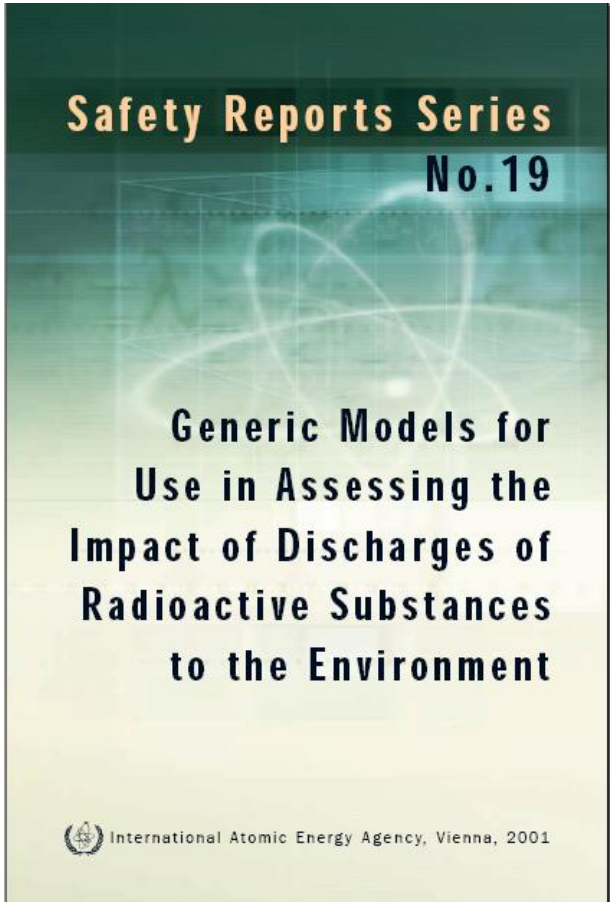


Data entry

- At Tiers 1 & 2, user can either:
  - Enter empirical/bespoke-model data directly
  - Use generic (transport) models (IAEA SRS-19) to generate activity data
- At Tier 3 generic models are unavailable
  - Because they generally provide conservative estimates of activity concentrations
  - more detailed analyses expected at this stage

IAEA SRS-19 Model

- In many cases – empirical data available (monitoring, research studies, bespoke models)
- When this is not the case, the assessor can use generic models – fully implemented in the Tool



http://www-pub.iaea.org/books/IAEABooks/Selected_Book_in_the_series/Safety-Reports-Series/73/19

Note – no dilution vs generic

- No dilution model

$$C_{w,\,tot} = C_0 = \frac{Q_i}{F},$$

$C_{w,\,tot}$ is the total radionuclide concentration (Bq/m^3),
C_0 is the radionuclide concentration in the effluent discharge outfall (Bq/m^3)
Q_i is the annual average discharge rate for radionuclide i (Bq/s),
F is the flow rate of the liquid effluent (m^3/s).

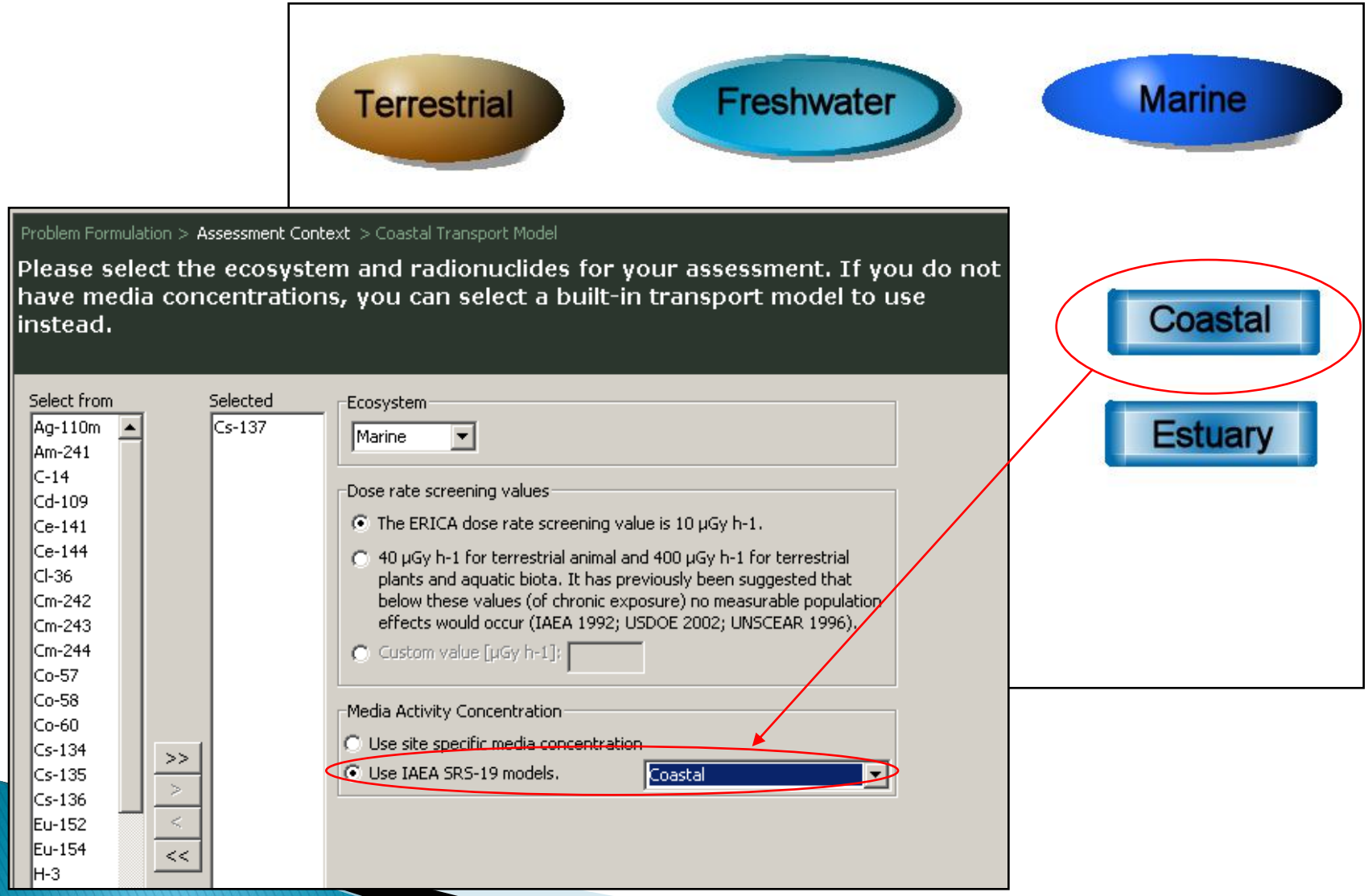
- Calculations can be performed externally and entered directly into the input data screens

- Simple Generic environmental model
  - Accounts for dilution and dispersion

Considerations

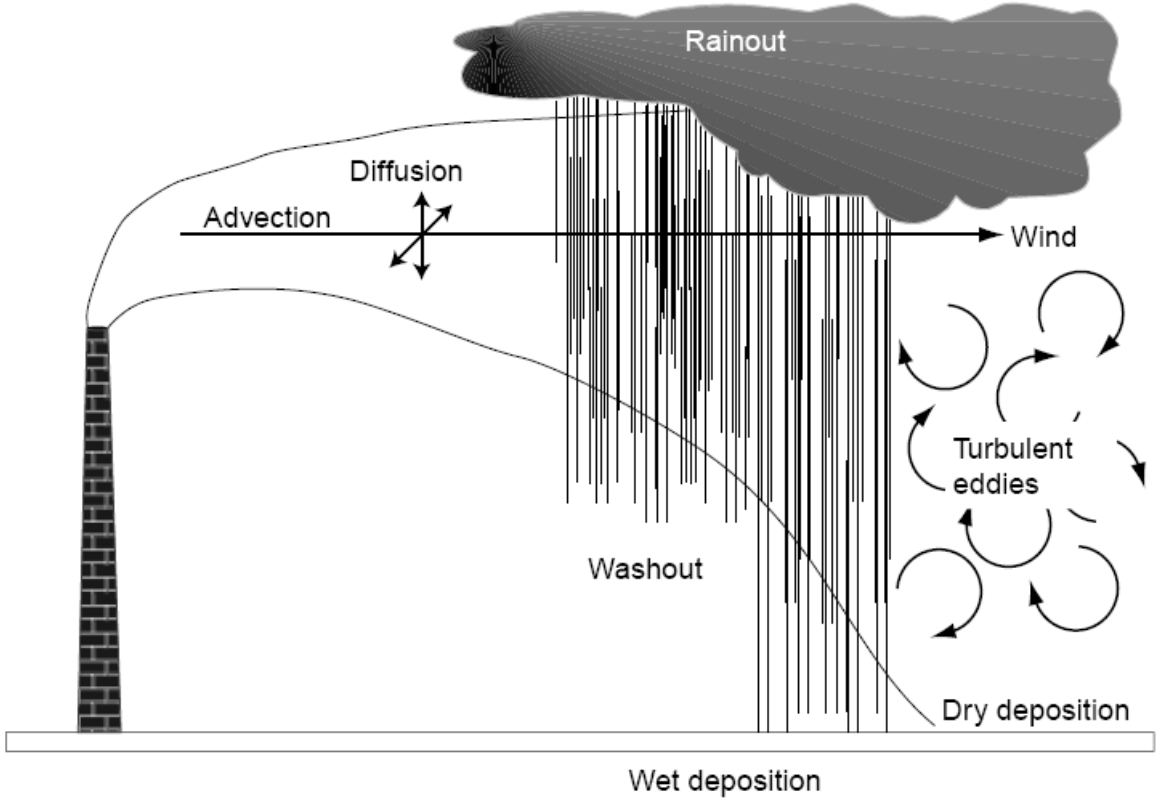
- Model (+ associated parameters) developed such that
  - Hypothetical critical group dose (+ by proxy reference biota doses) likely to be overestimated
  - Under no circumstances will (human) doses be underestimated by more than a factor of 10
- Applicable to prolonged or continuous releases into the environment
  - Assumed that equilibrium (or quasi-equilibrium) has been established
- Particularly useful for assessing radiological impact of discharges from small facilities
  - Low level discharges, less likely to have detailed information for conducting impact assessment, conservatism not an issue.

Available models



Atmospheric dispersion

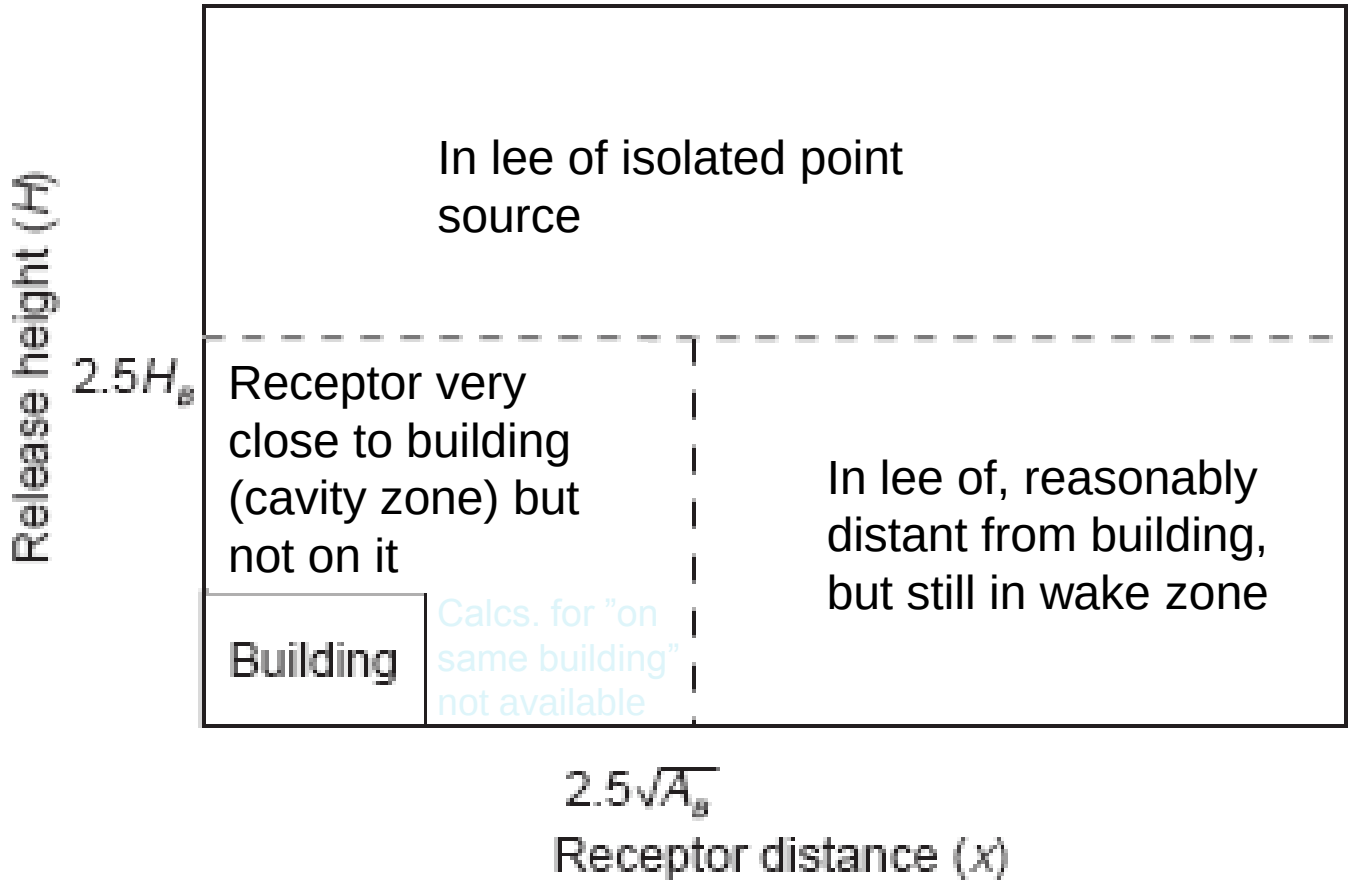
Gaussian plume model – advection + turbulent diffusion



- Model is not generally applicable at $x > 20$ km
- Air conc. prediction within a factor of 4 for flat and 10 for complex terrain

Radionuclide concentrations

- In air:



- In soil:

wet and dry depositions rates, rate constants for loss from soil, surface density

”Air” model – Input data

Isotopes	Discharge Rate [Bq s-1]
Cs-137	1E0

Scenario Characteristics

Release Height [m]	30
Distance to Receptor [m]	10
Wind Speed [m/s]	2.0
Fraction of Time [unitless]	0.25
Dry Deposition Coefficient[m/d]	500.0
Wet Deposition Coefficient[m/d]	500.0
Surface Soil Density [kg/m²]	260
Duration of Discharge [year]	1

Building Considerations

Buildings Nearby? ○ yes ◉ no

Building Height [m]	10
Surface Area of Wall[m²]	100

Radionuclide transport in surface waters

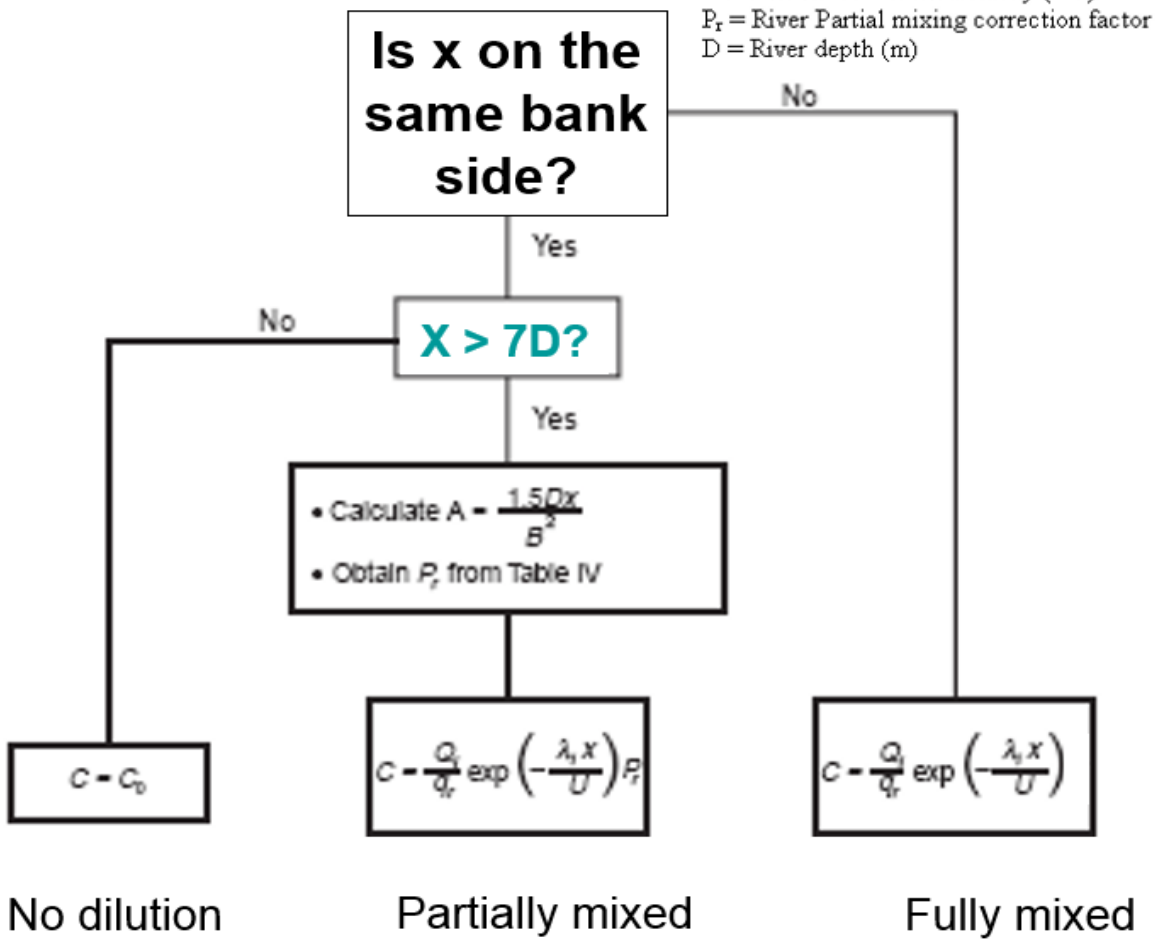
- Based on analytical solutions of advection-diffusion equations

  Assuming steady state uniform flow conditions

- Types of surface water considered:
  1. Rivers
  2. Estuaries
  3. Small lakes
  4. Large lakes
  5. Coastal waters

Rivers

$C_{i,tot}$ is the total radionuclide concentration in water (Bq/m³),
Q_i is the average discharge rate for radionuclide i (Bq/s),
q_r is the mean river flow rate (m³/s),
λ_i is the radioactive decay constant (s⁻¹),
x is the distance between the discharge point and the receptor (m),
U is the net freshwater velocity (m/s).
P_r = River Partial mixing correction factor
D = River depth (m)

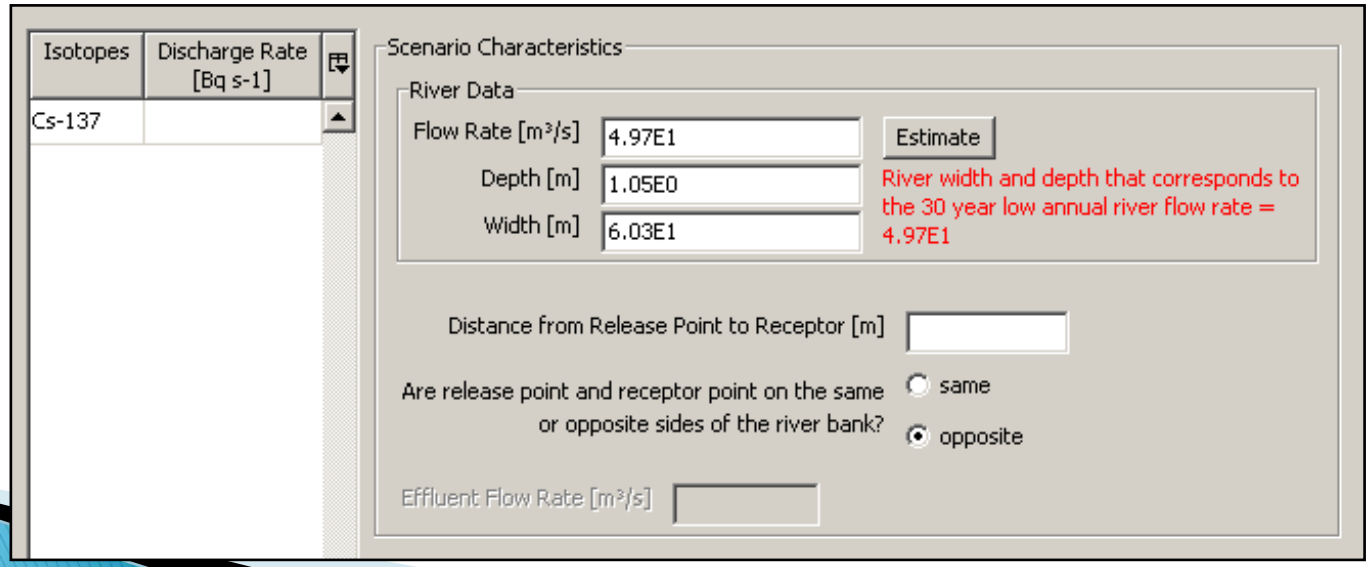


Rivers – input data

Three parameters are required:

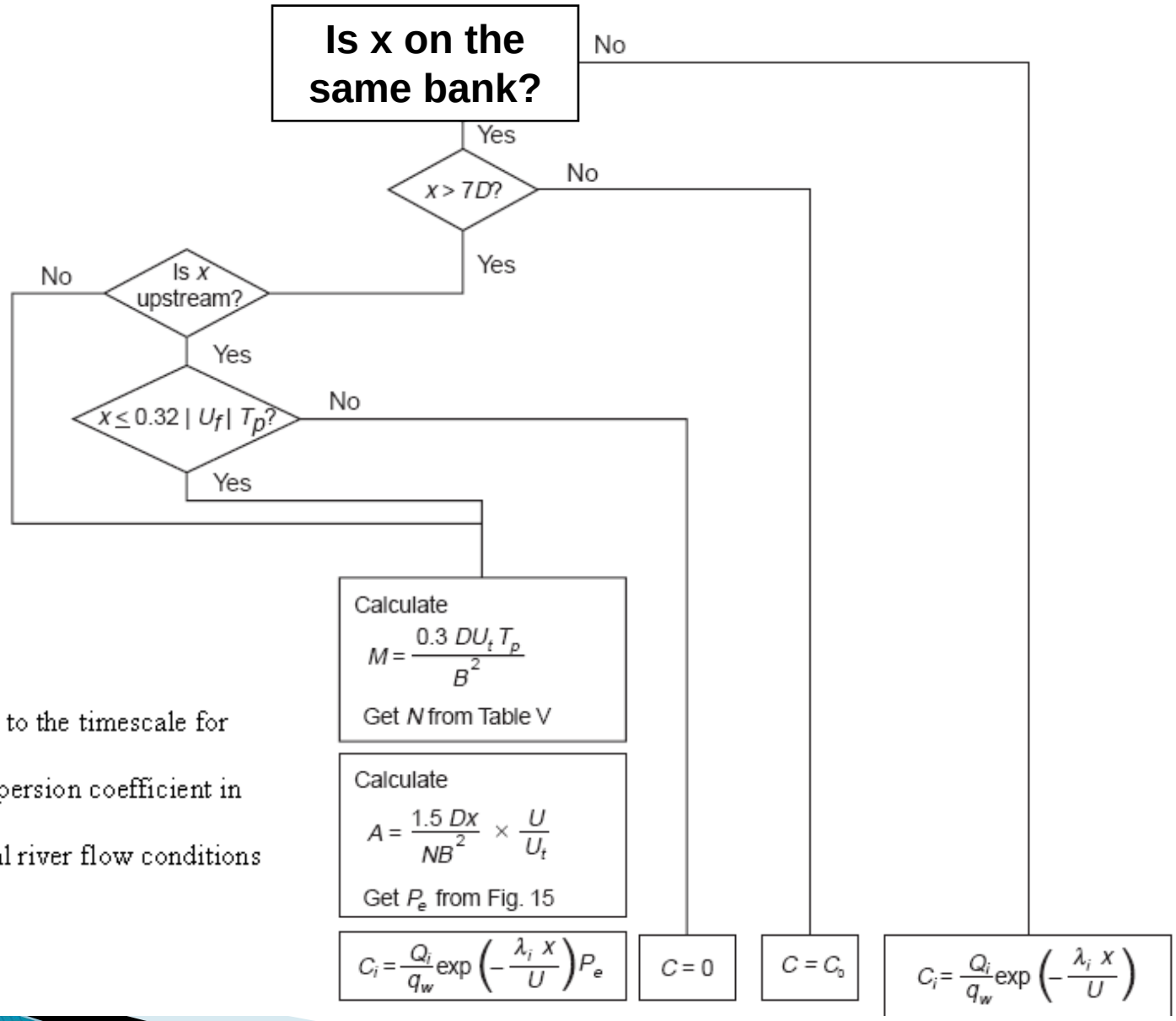
- 30 year low annual river flow (q_r)
- Corresponding Depth (D)
- Corresponding river velocity (U).

Can be approximated from width using tables if no data available



Estuaries

Very similar approach to rivers but with adjustments to account for tidal effects



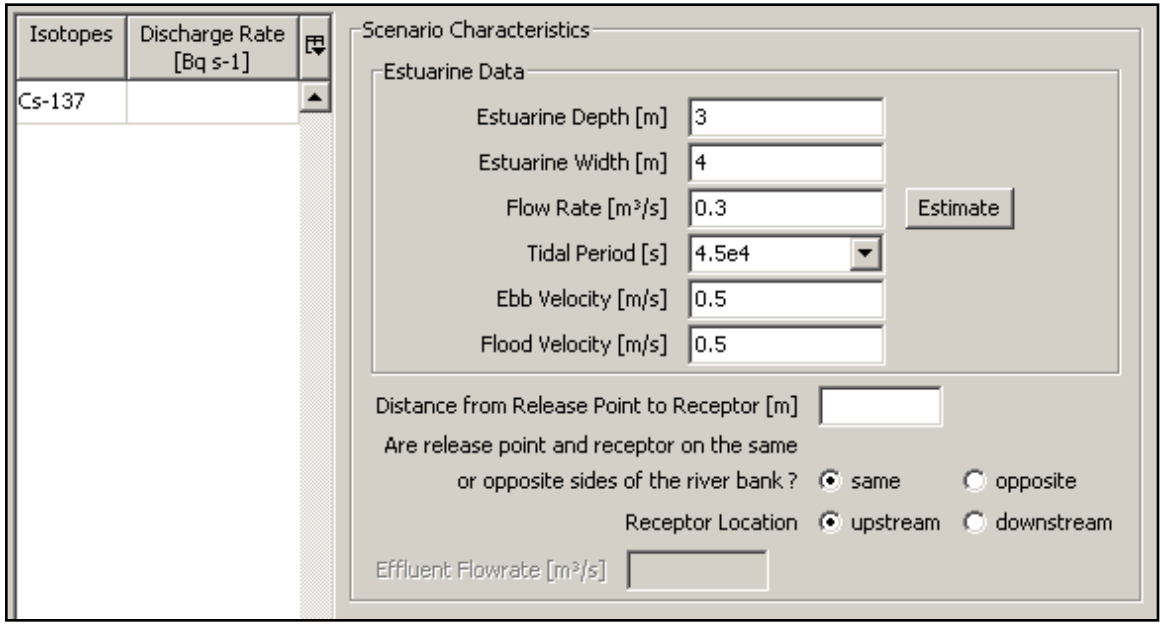
M = ratio of the tidal period (T_p) to the timescale for cross-sectional mixing

N = ratio of the longitudinal dispersion coefficient in the estuary to that in a river

B (m) = river width under normal river flow conditions upstream of the estuary,

A = Partial mixing index

Estuaries – Input data

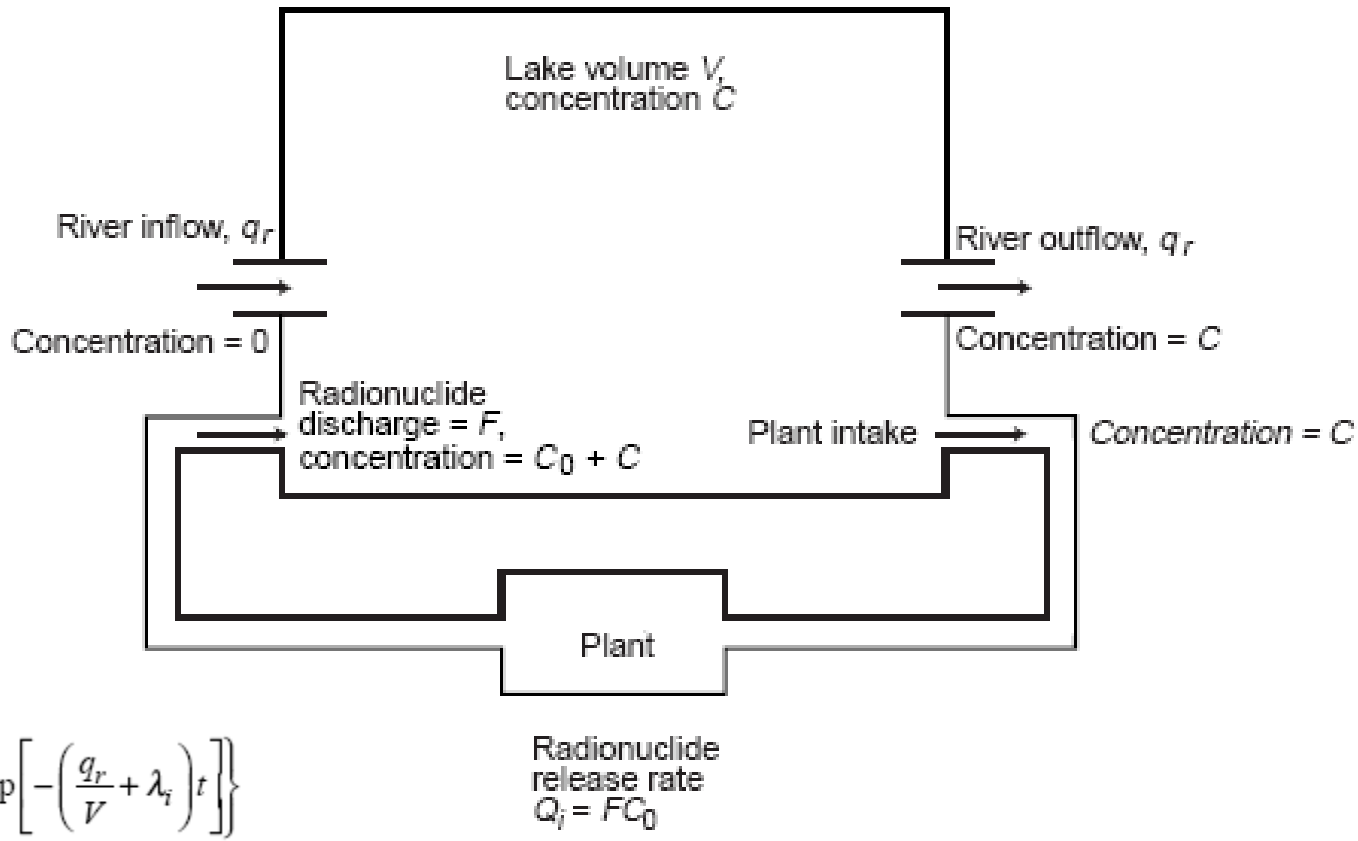


In addition to Depth, Width and Flow rate (as in the case of rivers),

Data is required on ebb and flow velocities + tidal period (defaults available)

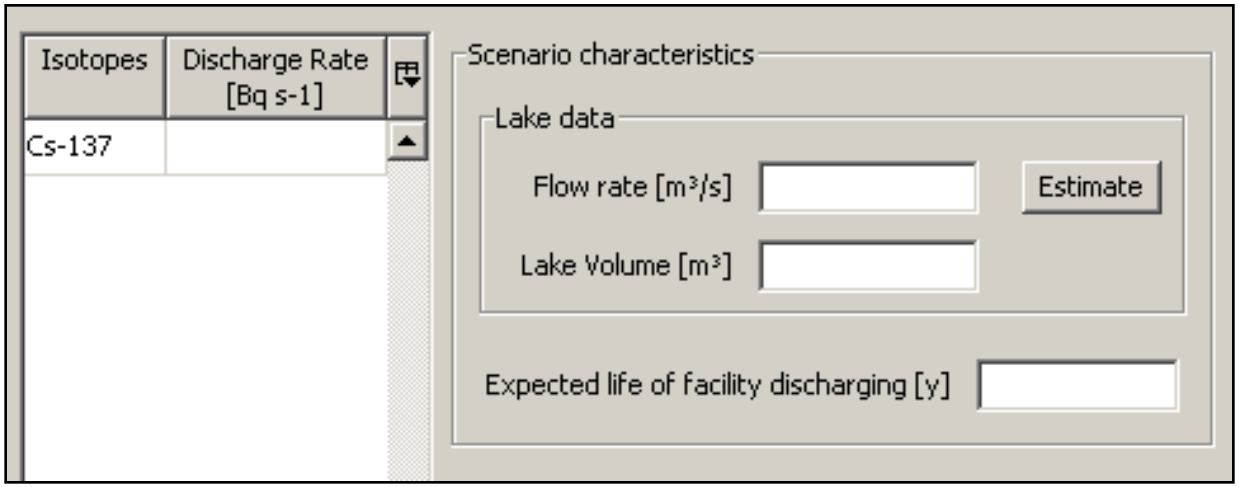
Small Lake <400 km²

- Assuming uniform concentration throughc



$$C_{w,\,\mathrm{tot}} = \frac{Q'_i}{q_r + \lambda_i V}\left\{1 - \exp\left[-\left(\frac{q_r}{V} + \lambda_i\right)t\right]\right\}$$

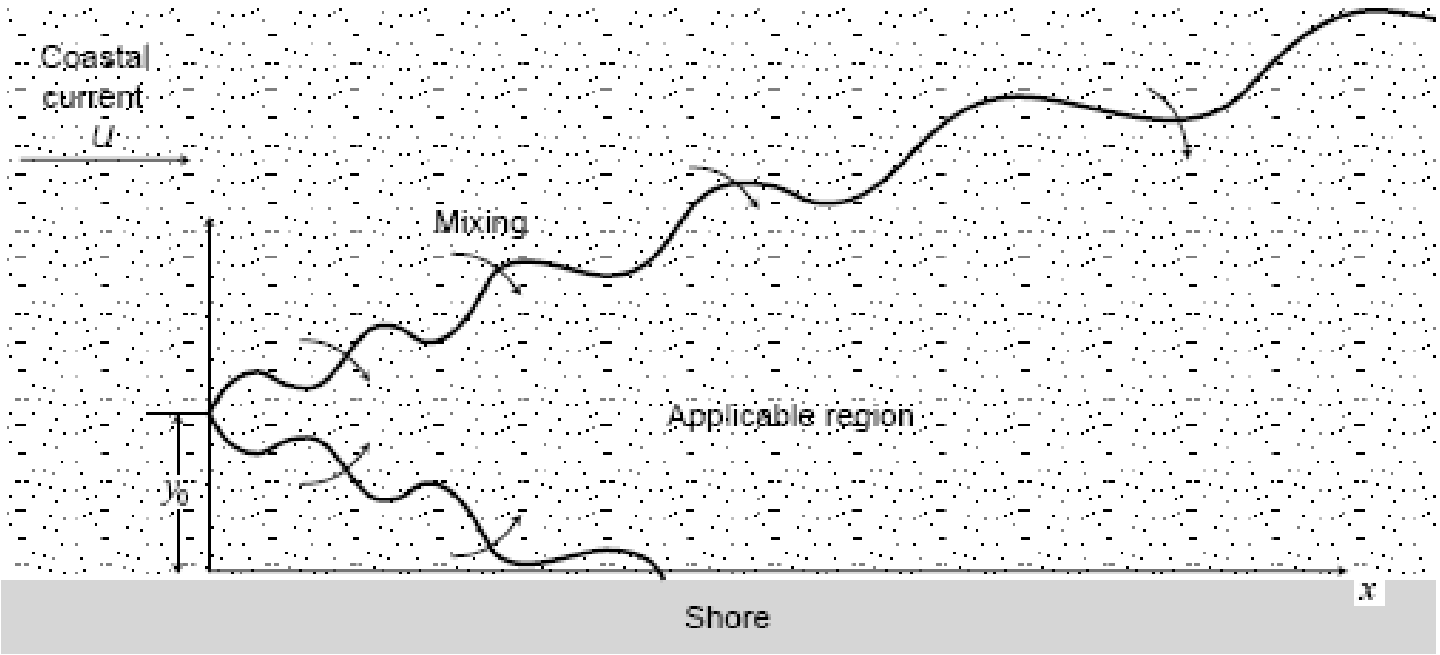
Small lakes – Input data



- 30 year annual river flow
  Can be approximated from width if no data available
- Lake volume
- Expected life of the facility discharging into the lake

Simplification: *Additional input from atmospheric sources NOT accounted for in the Tool*

Coastal model and large Lake (>=400 km²)



- Conditions:

$$7D < x$$

$$\left|\frac{y - y_0}{x}\right| \ll 3.7$$

x = longitudinal distance source to receptor

y = latitudinal distance source to receptor

Coastal model and large Lake (>=400 km²) required inputs and applied equations

Isotopes	Discharge Rate [Bq s-1]
Cs-137	

Scenario Characteristics

Water Depth [m]

Distance between Release Point and Shore [m]

Distance between Release Point and Receptor[m]

Coastal Current [m/s] 0.1

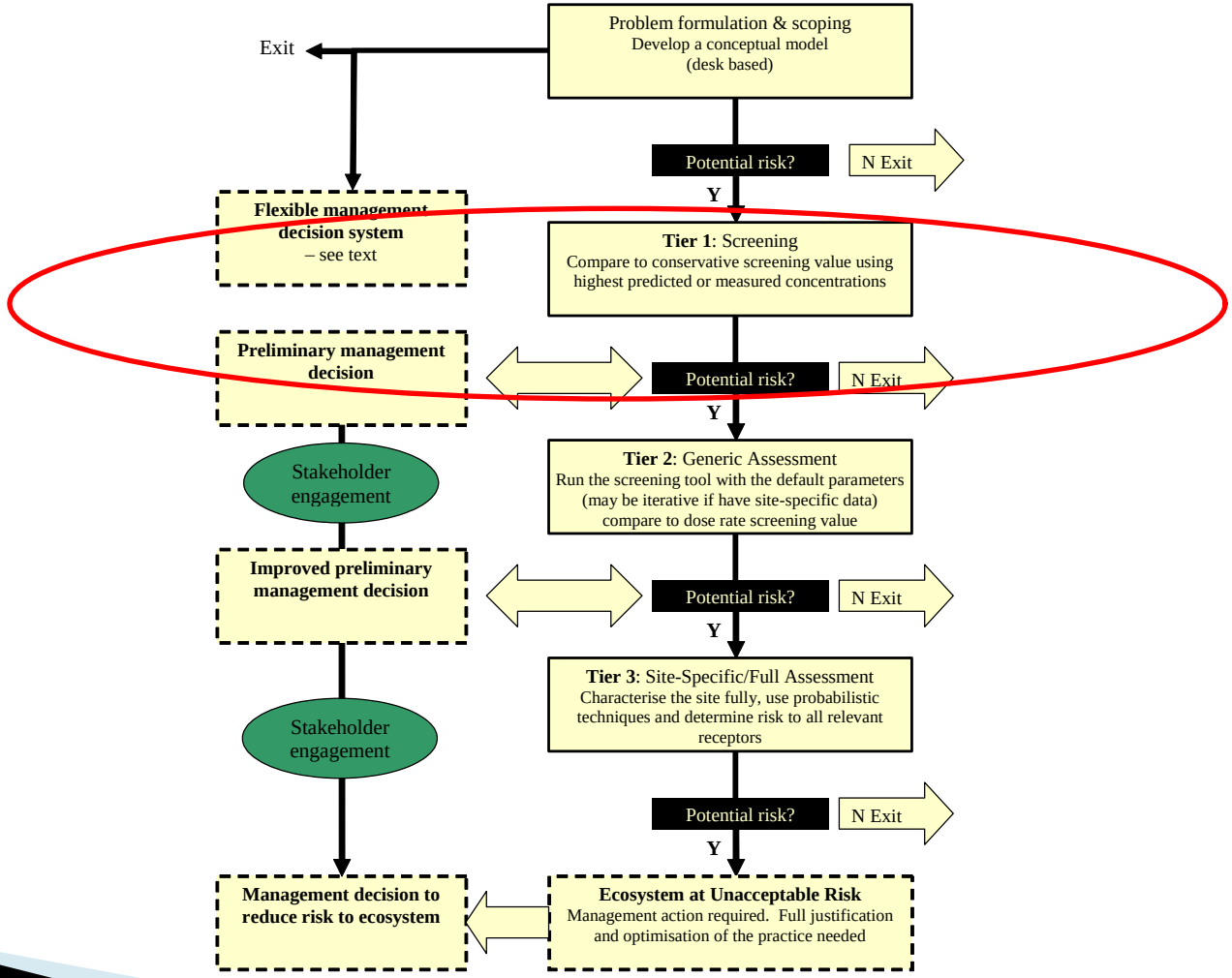
Where is the Receptor Point: on shoreline in sea

Shoreline:

$$C = \frac{962 U^{0.17} Q_i}{D x^{1.17}} \times \exp \frac{(-7.28 \times 10^{5})\, U^{2.34}\, y_0^{2}}{x^{2.34}} \times \exp\left(-\frac{\lambda_i x}{U}\right)$$

Sea:

$$C = \frac{962 U^{0.17} Q_i}{D x^{1.17}} \exp\left(-\frac{\lambda_i x}{U}\right)$$


Exit
Problem formulation & scoping
Develop a conceptual model
(desk based)
Potential risk?
N Exit
Y
Flexible management decision system
– see text
Tier 1: Screening
Compare to conservative screening value using highest predicted or measured concentrations
Preliminary management decision
Potential risk?
N Exit
Y
Stakeholder engagement
Tier 2: Generic Assessment
Run the screening tool with the default parameters (may be iterative if have site-specific data) compare to dose rate screening value
Improved preliminary management decision
Potential risk?
N Exit
Y
Tier 3: Site-Specific/Full Assessment
Characterise the site fully, use probabilistic techniques and determine risk to all relevant receptors
Stakeholder engagement
Potential risk?
N Exit
Y
Management decision to reduce risk to ecosystem
Ecosystem at Unacceptable Risk
Management action required. Full justification and optimisation of the practice needed

Tier 1 – derivation of EMCL

- Essentially this is the activity concentration of a given radionuclide in media (soil, sediment water) that will result in a dose-rate to the most exposed reference organism equal to the screening dose-rate.

$$EMCL = \frac{D_{lim}}{F}$$

Where:

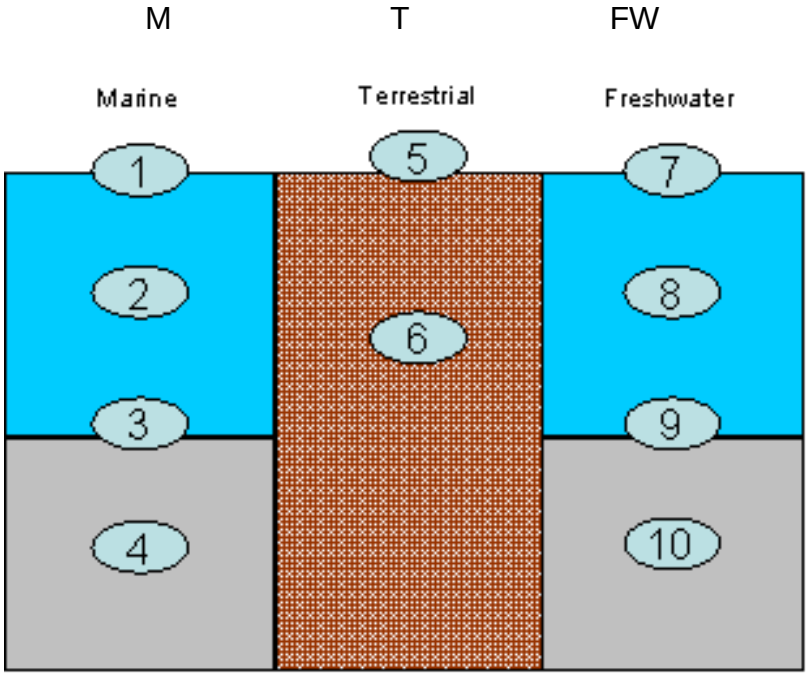
F is the dose rate that an organism will receive for the case of a unit concentration in environmental media (in µGy/h per Bq/L or kg of medium).

D_{lim} is the screening dose-rate or PNEDR (default = 10 µGy/h (ERICA D5); tool allows 40; 400 µGy/h (IAEA conclusions) or custom to be selected)

- 'F' depends upon
  - reference organism type (affects the DCC values, CRs and position within habitat)
  - radionuclide (affects the DCC values, CRs and K_ds).

Habitats defined for all 3 ecosystems

Location within habitats selected as those causing maximum exposure



Organism	Habitat	Equation
Zooplankton	2 (M)	$F = \left[DCC_{int} \cdot CR + DCC_{ext}^{M}\right]$
Polychaete worm	4 (M)	$F = \left[DCC_{int} \cdot CR + DCC_{ext}^{M} \cdot K_{d}^{M}\right]$
Bivalve mollusc	3 (M)	$F = \left[DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^{M}\left(1 + K_{d}^{M}\right)\right]$
Benthic fish	3 (M)	$F = \left[DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^{M}\left(1 + K_{d}^{M}\right)\right]$
Mammal	1 & **2** (M)	$F = \left[DCC_{int} \cdot CR + DCC_{ext}^{M}\right]$
Soil Invertebrate (worm)	6 (T)	$F = \left[DCC_{int} \cdot CR + DCC_{6,vol}^{T}\right]$
Flying insects	5 (T)	$F = \left[DCC_{int} \cdot CR + DCC_{5,vol}^{T}\right]$
Lichen & bryophytes	5 (T)	$F = \left[DCC_{int} \cdot CR + DCC_{5,vol}^{T}\right]$
Tree	5 (T)	$F = \left[DCC_{int} \cdot CR + DCC_{5,vol}^{T}\right]$
Mammal-rat	6 (T)	$F = \left[DCC_{int} \cdot CR + DCC_{6,vol}^{T}\right]$
Mammal-deer	5 (T)	$F = \left[DCC_{int} \cdot CR + DCC_{5,vol}^{T}\right]$

Where :

CR = Concentration ratio (Bq/kg f.w. per Bq/l or Bq/kg) and

K_d = distribution coefficient (l kg^{-1})

DCCs = dose conversion coefficients (μGy hr^{-1} per Bq kg^{-1})

Defining the EMCL

- For each radionuclide, Dose per unit concentrations, ‘F’, calculated for all reference organisms
- Probabilistic methods employed (*described later*)
- Lowest concentration limit value (but highest ”F” value) define the EMCL and Limiting organism

Organism	F [µGy/h]
(Wading) bird	0,08768
Benthic fish	0,61477
Benthic mollusc	0,65006
Crustacean	0,587525
Macroalgae	0,69577
Mammal	0,06944
Pelagic fish	0,01577
Phytoplankton	0,00047057
Polychaete worr	1,3452
Reptile	0,14735
Sea anemones	0,62854
Vascular plant	0,64346
Zooplankton	0,01355

^{137}Cs ”F” ; Limiting organism = Polychaete worm. EMCL = 10/F = 7.4 Bq/kg

Tier 1 Risk Quotients

$$RQ_n = \frac{M_n}{EMCL_n}$$

Where

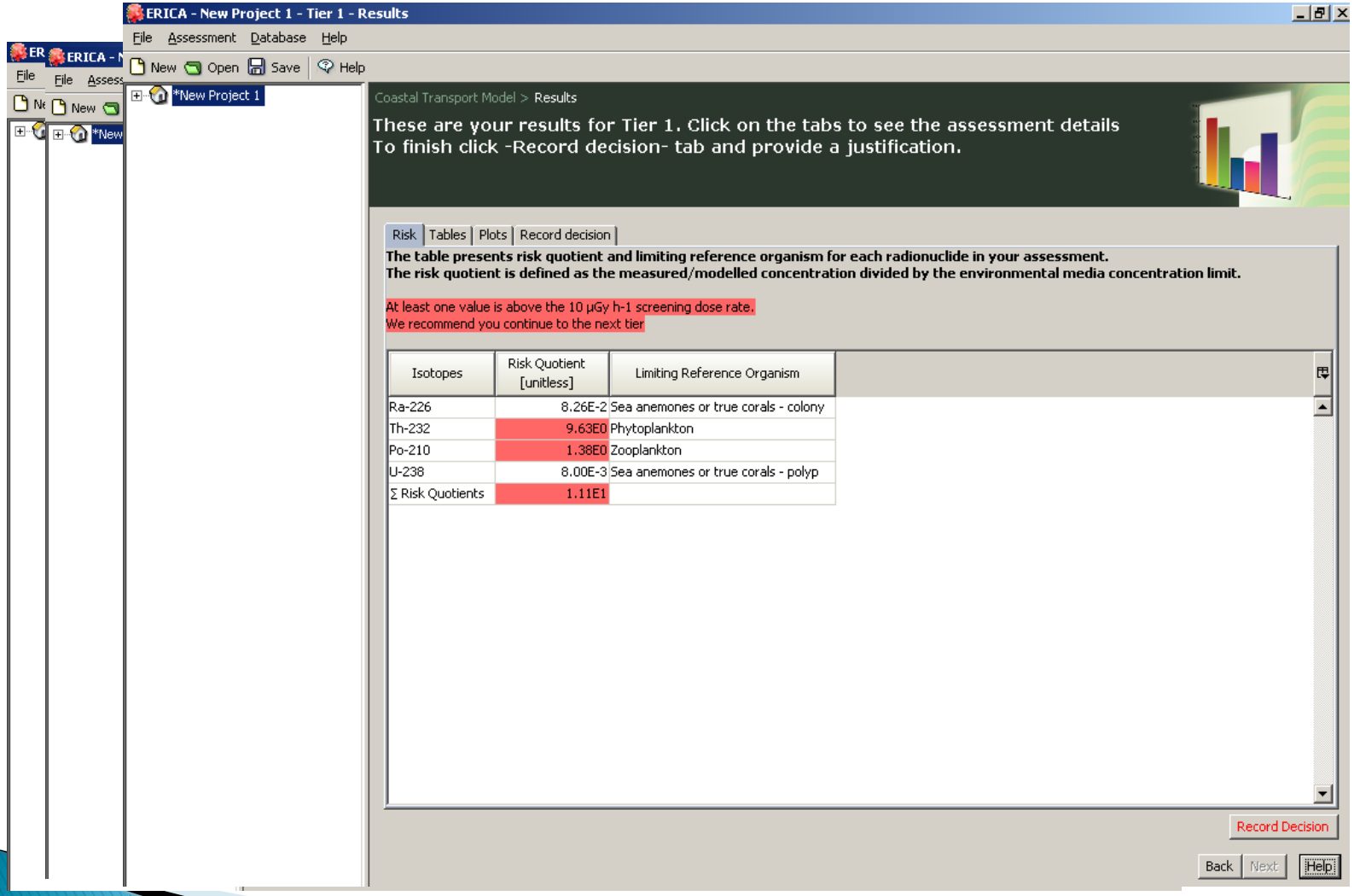
RQ_n = Risk quotient for radionuclide "n"

M_n = measured activity concentration for radionuclide "n" in medium M in Bq per L for water or Bq per kg of soil/sed

$EMCL_n$ = Environmental Media Concentration Limit for radionuclide "n" (same unit)

- User prompted to enter (**maximum**) activity concentrations in environmental media only.
- Results :
  - If RQ < 1 the probability of exceeding the benchmark is acceptably low (> 5%) – justification for terminating risk calculation at this stage
  - If RQ >= 1 unacceptable probability (>5 %) that benchmark exceeded – further assessment recommended ➔ Tier 2

Tier 1 : Sequence in the Tool



Isotopes	Risk Quotient [unitless]	Limiting Reference Organism
Ra-226	8.26E-2	Sea anemones or true corals - colony
Th-232	9.63E0	Phytoplankton
Po-210	1.38E0	Zooplankton
U-238	8.00E-3	Sea anemones or true corals - polyp
Σ Risk Quotients	1.11E1	

Tier 2

- Measurement endpoint = dose-rates in reference organisms
- Assessment context
  - Radionuclide and reference organisms selected by user
  - As for Tier 1 different dose-rate benchmarks can be selected : default ERICA 10µGy/h; 40;400 µGy/h IAEA conclusions; Custom

Tier 2 – risk quotients

$$\Sigma RQ = \frac{D_{TOT}}{D_{LIM}}$$

Where RQ_i = Risk quotient for reference organism "i"

D_{TOT} = Total dose rate - calculated (µGy/h)

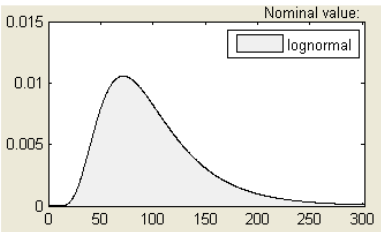
D_{LIM} = Screening dose rate or PNEDR (10µGy/h)

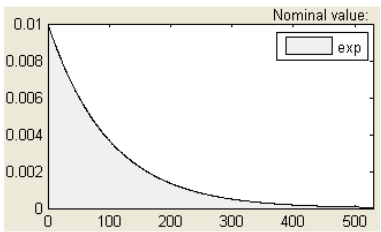
	Σ RQ
Zooplankton	0.65 ☑
Bivalve mollusc	0.50 ☑
Polychaete worm	0.44 ☑
Vascular plant	0.22 ☑

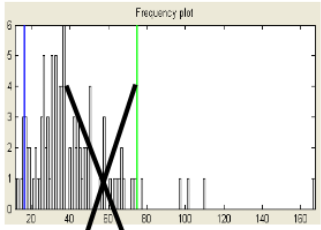
- Uncertainty Factors applied to ensure conservatism (assume exponential distribution for RQ)

Application of Uncertainty factors

- These are applied to ensure an equal degree of conservatism at Tier 2 compared to Tier 1 for a default setting
- The uncertainty factors are defined as the ratio between a conservative value of the calculated dose rate (or RQ), for example the 95 percentile, and the calculated expected value of the dose-rate (or RQ).
- UFs can be pre-calculated using probabalistic methods, e.g.







$$\left[DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^{M}\left(1 + K_{d}^{M}\right)\right] = \dot{D}$$

A_w

$$UF = {}^{95^{th}\text{ percentile}}\!/_{\text{Expected value}}$$

- Default at Tier 2 assumes that <u>RQs follow exponential distributions</u> with means equal to the estimated expected values

Tier 2 it is possible to…

- See how CRs have been derived and edit if necessary (k_ds can also be edited)
- Inspect and edit occupancy factors and radiation weighting factors
- Input data (empirical/bespoke model) for environmental media and/or reference organism (rules to ”back-calculate” depend on data entry) – Note ”expected”values should be entered.
- Inspect and edit % dry weight soil or sediment

Results at Tier 2

$RQ_{exp.} >= 1$

Screening dose-rate is exceeded
Assessment should continue (Tier 3, further investigation, characterisation, analyses)

$RQ_{cons.} >= 1$

$RQ_{exp.} < 1$

Substantial probability that Screening dose-rate is exceeded
Assessment should be reviewed (e.g. at Tier 2 drawing on other lines of information - background, effects data etc.)

$RQ_{cons.} < 1$

Low probability that screening dose-rate is exceeded.
Environmental risk is arguably negligible.
Justification in terminating calculation of risk at this stage.

Tier 2 – Sequence in the Tool

ERICA - New Project 1 - Tier 2 - Results

File Assessment Database Help

New Open Save Help

Inputs > Results

These are your results for Tier 2. Click on the tabs to see the assessment details
To finish click -Record decision- tab and provide a justification.

Risk | Background | Effects | Tables | Plots | Record decision

Total Dose Rate and Risk Quotient

For at least one organism the screening dose rate is exceeded.
We recommend you continue your assessment.

Uncertainty Factor = 3.0; This tests for 5% probabililty of exceeding the dose screening value, assuming that the RQ distribution is exponential

Organism	Total Dose Rate per organism [µGy h-1]	Screening Value [µGy h-1]	Risk Quotient (expected value) [unitless]	Risk Quotient (conservative value) [unitless]
Pelagic fish	1.91E1	1.00E1	1.91E0	5.73E0
Crustacean	1.16E1	1.00E1	1.16E0	3.47E0
Mammal	4.24E0	1.00E1	4.24E-1	1.27E0
Reptile	1.98E1	1.00E1	1.98E0	5.94E0

Record Decision

Back Next Help

For terrestrial ecosystems (change in latest version)

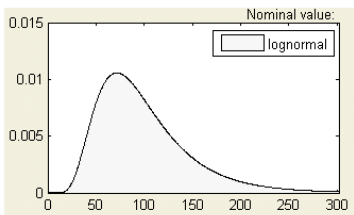
- In all cases where you have a soil (or air) concentration this value will be used to calculate all other missing data via appropriate CRs. The cell showing a radionuclide activity concentration in soil (or air) is highlighted in green and there is no option to select/deselect cells showing activity concentration values for organisms.
- When you have no soil (or air) data but data for biota you can select which values will be used in the calculation of soil concentrations and from that point all other missing data will be generated automatically via appropriate CRs. The selection is activated by clicking within any given cell where you have data.
- The calculation of the radionuclide activity concentration in soil(or air) is performed within the tool by simply dividing the radionuclide activity concentration value for the organism by the corresponding CR value. When multiple values are selected for this calculation, the result is based upon the average of the calculated radionuclide activity concentrations in soil (or air). Furthermore, the missing values are continually updated on the screen as the user selects and deselects the various values to be used in the calculation.

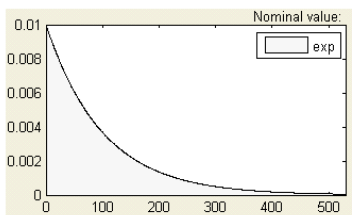
For aquatic system (new version)

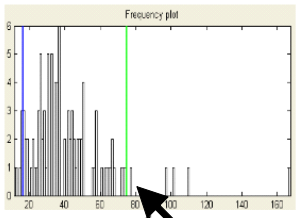
- Uses water values as default
- If no water data but data for biota and sediment, user can select which data are used in the back-calculation.
- Green tick value used in calculation, red cross = not used.

Tier 3 – Risk analysis

- Risk = function (probability, Consequences)
- Probability concerns the uncertainty of results and can be classified
  - Type I – Limited knowledge about the system
  - Type II – Variability
- In ERICA (Tier 3) the assessor can account for the variability in the underlying parameters.







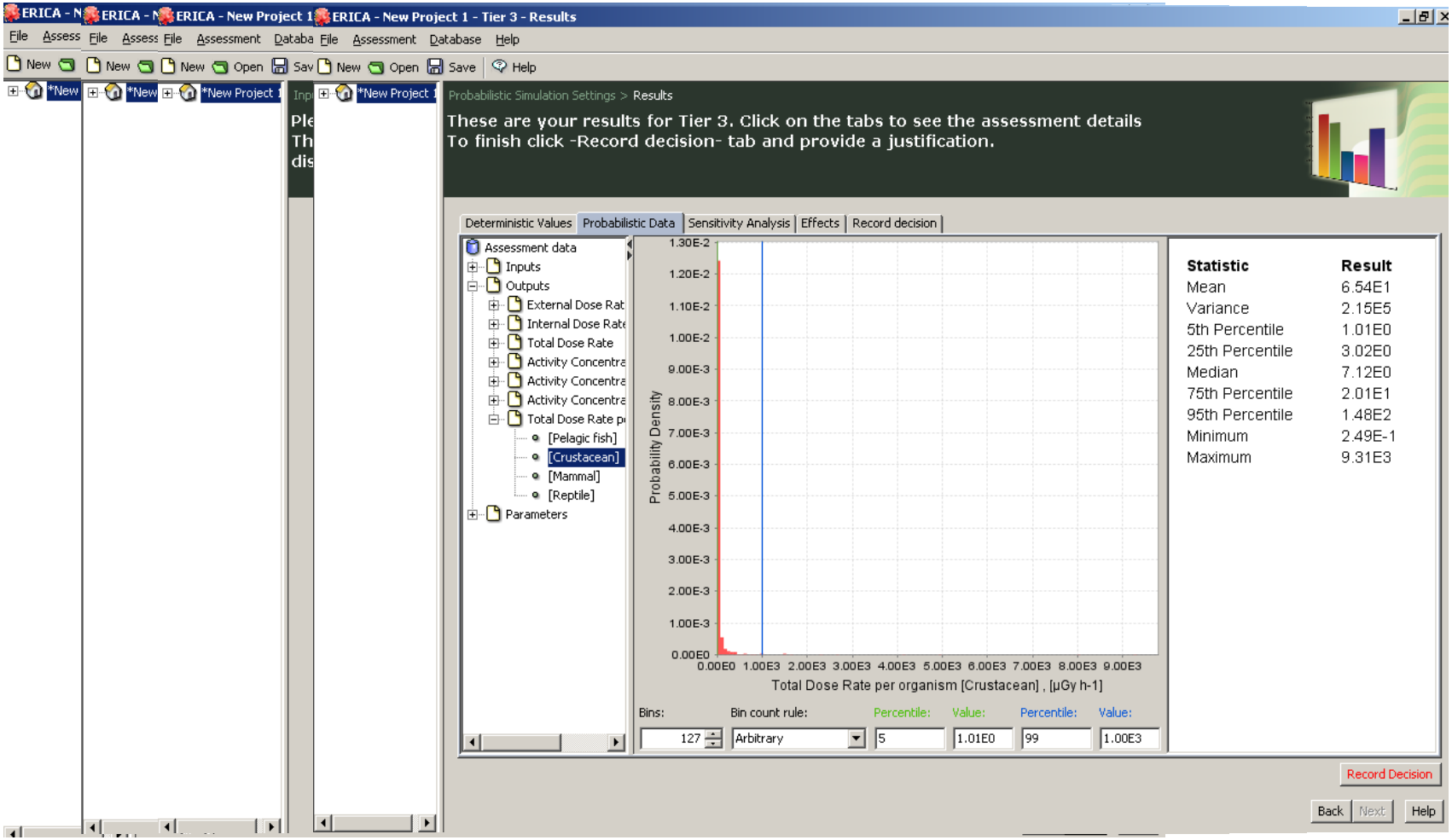
$$\left[DCC_{int} \cdot CR + 0.5 \cdot DCC_{ext}^{M}\left(1 + K_{d}^{M}\right)\right] = F$$

95th percentile

A note on PDFs

- Experience has shown that the uncertainty of radioecological data e.g. CRs, are often well fitted by lognormal distributions. One possible explanation is that the values of radioecological parameters are the result of multiplication of many factors and this should lead to lognormal distributions.
- PDFs have been defined for each entry in the default CR and Kd databases within the ERICA Tool using the following simple rules:
  - where a standard deviation could be determined from the raw data being used to derive a particular parameter (for example for a CR) a lognormal distribution was applied;
  - for all other cases, an exponential distribution was applied using Maximum entropy (a statistical method for assigning a distribution of maximum logical uncertainty with respect to a given parameter, consistent with the amount of statistical information provided)
- Assessors can therefore use the default probability distributions for each parameter in the ERICA Tool or they can define their own pdf for each parameter (or a combination of both) depending upon the availability and quality of the data.

Tier 3 – Sequence in the Tool



Web address + Future plans

- http://www.erica-tool.com/
-
- https://wiki.ceh.ac.uk/display/rpemain/Radiological+Environmental+Protection

- IRSN, Swedish Radiation Safety Authority, CIEMAT, Environment Agency UK, CEH and NRPA.
- Yearly meetings to discuss improvements and suggestions for new functionality

Background literature

Beresford, N.A., Barnett, C.L., Howard, B.J., Scott, W.A., Brown, J.E., D. Copplestone (2008). Derivation of transfer parameters for use within the ERICA Tool and the default concentration ratios for terrestrial biota. Journal of Environmental Radioactivity, Volume 99, Issue 9, Pages 1393-1407.

Brown, J.E., Alfonso, B., Avila, R., Beresford, N.A., Copplestone, D., Pröhl, G., Ulanovsky A. (2008). The ERICA Tool. Journal of Environmental Radioactivity 99, Issue 9, pp.1371-1383.

Oughton, D.H., Agüero, A., Avila, R., Brown, J.E., Copplestone, D., Gilek M. (2008). Addressing uncertainties in the ERICA Integrated Approach. Journal of Environmental Radioactivity, Volume 99, Issue 9, Pages 1384-1392.

Hosseini, A., Thørring, H., Brown, J.E., Saxén, R., Ilus E. (2008).Transfer of radionuclides in aquatic ecosystems – Default concentration ratios for aquatic biota in the Erica ToolJournal of Environmental Radioactivity, Volume 99, Issue 9, Pages 1408-1429.