



Parameter Correlations in Marine Dose Assessments

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Parameter Correlations in Marine Dose Assessments

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1. Introduction

The Monte Carlo method has been used to develop probabilistic models for assessing radioactive doses in the marine environment (Grzechnik et al., 2002). This method enables the input of distributions of parameter values, which include uncertainty and variability associated with the values. These are propagated by randomly sampling from the distributions to give output doses that incorporate these uncertainties in the form of probability distributions.

It is important for such models to accurately simulate real-world situations and environmental processes. Thus, there may be certain combinations of parameter values that would not be possible if the model is to represent these processes correctly. Because the distributions of parameters are randomly sampled, parameter correlations must be investigated and conditions imposed on possible combinations where necessary.

This note describes the integration and testing of methods to incorporate parameter correlation in the models described by Grzechnik et al. (2002) and Grzechnik (2002).

2. Consideration of Parameters

In the current methodology, dose assessments in the marine environment are conducted in two stages:

- 1) The *dispersal* of radionuclides in seawater and sediment is modelled using either:
 - Advection-Diffusion method (WAT), for open coastlines (Round, 1998a), or
 - Single Compartment method (IDLE), for use in estuaries or enclosed coastal areas (Hunt, 1982).
- 2) Dose calculations are made using the ADO model (Round, 1998b).

These each incorporate a number of parameters that define physical oceanographic flows, sediment interactions and uptake to biota. Parameters will be investigated for correlations and relationships and discussed in turn. Often these have been grouped for discussion, depending upon the likelihood of correlations occurring. For example, transport processes (residual velocity, tidal excursion, diffusion coefficient) have been discussed in a cluster. Similarly, sediment processes are considered as potentially correlated.

2.1 Advection-diffusion model

Mean depth

The parameter that represents the mean depth is measured in the local environment. The distribution incorporates uncertainty in this measurement, as well as variability in depth over the region being considered. Changes in depth do have an effect on the speed of a free wave in ocean environments, but in the coastal situation other factors become involved (e.g. coastline shape, sea-floor materials). Because of this, there is no direct correlation between mean depth and any of the other oceanographic parameters.

Residual velocity & Tidal excursion

Values of residual velocity and tidal excursion are obtained from tidal current meters or tidal diamonds, so it is worthy of investigation as to whether they are correlated parameters. Distributions may be derived from estimates of each parameter's uncertainty and variability in the region. The residual velocity value refers to the 'drift' of a particle in the water over time, and does not depend upon the ebb and flow of the tide. Conversely, the tidal excursion describes the extent that a particle moves along the coast during a single complete tidal cycle. Additionally, it is not uncommon to observe any combination of relatively large or small tidal excursions and residual velocities in different locations. Thus, it can be deduced that the residual velocity and tidal excursion are not correlated parameters.

Diffusion coefficient

In the derivation of the WAT model (Round, 1998a), it is assumed that the advective processes are parallel to the coast, while diffusive processes are perpendicular. Additionally, physically the diffusion (or spreading) of a pollutant plume is expected to increase with higher levels of turbulence and water velocity, but this is independent of the other parameters considered here. Hence, it would be reasonable to suggest that there are no correlations with the diffusion coefficient.

Sediment distribution coefficient (K_d)

There are a number of aspects of this parameter that must be considered. Potentially the K_d value could be influenced by the amount of sediment present (sediment load) or the presence of other radionuclides (other K_d values). Physically it describes the partitioning of each radionuclide into the dissolved (in the water column) or adsorbed (to sediments) phases. As such it would be independent on the amount of sediment present unless a saturation point was reached. Informal expert elicitation suggests that sorption of a radionuclide will only be competitive if either the sorption sites are saturated by other ions and/or the radionuclide levels are excessive, and therefore provide saturation themselves. These would both require extreme conditions, which is extremely unlikely. It was agreed that under normal circumstances it should be assumed that sediments are not saturated (Leonard, 2003; Kershaw, 2003). Because of this, it is reasonable to suggest that K_d is independent of the suspended sediment load and the sediment distribution coefficients of other radionuclides present. Hence there are no correlations for K_d to be considered in the model.

Suspended sediment load & sedimentation rate

The sediment load refers to the amount of sediment in the water column, where sediment rate describes its rate of deposition. One would expect that as the amount of sediment in the water increases, so to does the amount that settles. This implies a dependency, which is confirmed in the report of Round et al. (2002), where the assumption is made that suspended sediment load is proportional to sedimentation rate. This means that the ratio of sediment rate to sediment load is constant, and that there is a correlation that must be taken into account in this case.

This dependency has been incorporated into the probabilistic modelling suite. A distribution is input to describe the suspended sediment load (s_L), as previously. Rather than inputting a distribution for the sedimentation rate (s_R), a narrower distribution is input (usually normal, but there is the option of using a single real value). This describes the uncertainty in the *experimentally obtained ratio* s_R/s_L . Hence, the sedimentation rate is defined as the product of suspended sediment load and the distribution that describes s_R/s_L . This will ensure that uncertainties in measurements will be incorporated, while the correlation between sediment load and rate is maintained. The implementation of this system is tested in Section 3.

2.2 Single compartment model

The behaviour of parameters present in the single compartment model that are shared with the advection-diffusion method will be consistent. This means that sediment load and sedimentation rate will be proportional, as discussed in Section 2.1.

Exchange volume and Dispersion factor

The exchange volume is calculated in the model using the formula:

$$V = (\text{Mean depth}) \times (\text{Tidal excursion}) \times (\text{Assumed offshore extent}),$$

where the offshore extent is the expected dispersal of radionuclides offshore due to transverse diffusion and all variables are in metres (or metres per second) for the calculation.

Dispersion factor is calculated in the model using the formula:

$$D = (\text{Residual velocity}) \times (\text{No. seconds per day}) / (\text{Tidal Excursion}).$$

Each parameter that contributes to these two variables is independent of the others, which implies that the dispersion factor and exchange volume are independent of each other. Thus there are no correlations or restrictions between the two.

2.3 Dose Assessment model

Dose assessments are conducted using the ADO probabilistic model, which incorporates the output of radionuclide concentration from either of the models of dispersal, concentration factors, and habits survey data to calculate doses to the critical group. Suspended sediment load, sediment rate and distribution coefficient will be treated as described in Section 2.1.

Habits survey data (consumption/occupancy)

The data obtained from habits surveys can be treated in a number of ways in probabilistic dose assessments, some of which have been investigated in a paper by Grzechnik (2003). There are many correlations and restrictions inherent in these surveys. For example, it is not possible for an individual to be indoors for 7000 hours per year and outdoors for 2000 hours, as there are only 8760 hours in a (non-leap) year. Similar restrictions exist in consumption of foodstuffs, most of which can be based upon maximum amounts of calories that may be consumed. It is because of these restrictions that it is advantageous to use the natural variability inherent in the survey group to define distributions of habits rates. These are applied directly so that no unrealistic combinations are obtained in the dose calculation.

Variability of *dose coefficients*, as investigated by Harrison et al. (2001), may also be included in the model calculation. This is independent of individual intake rates and is treated as a non-correlated parameter distribution.

Concentration factors of environmental media

Concentration factors enable the evaluation of activity concentration in environmental media. These are pathway dependent, and are generally provided by IAEA (1985) in the form of lower bound, best estimate and upper bound. The input distributions can be defined using this information. Each of these factors depends only upon the biota group (e.g. fish, crustaceans, seaweed, etc.), with the concentration calculated in each group depending upon the product with activity concentration in seawater. This ensures the independence of the concentration factors, so it can be assumed that no correlations exist.

Estuarine sedimentation rate

This parameter refers to the depth of sediment deposited along the coast in regions such as creeks or estuaries. The distribution used is derived from measurements within the region being considered. By its nature, it seems that estuarine sedimentation rate is dependent upon the amount of sediment in the water column (sediment load) and the rate of deposition (sediment rate). This is true to an extent, however the volume of water being considered and residual currents also play a role beyond the resolution of these models, which ensures that no direct proportionality exists. Because of this experimental measurements are relied upon for this parameter value and no correlations are assumed to exist.

3. Testing the Upgraded Model

Upon consideration of all model parameters that may have correlations and dependencies it may be concluded that the important interaction is that suspended sediment load is proportional to sedimentation rate. The model has been altered to reflect this proportionality by the incorporation of a distribution to represent s_R/s_L , the mean value of which is obtained through monitoring in the local environment. The Sizewell example used by Grzechnik et al. (2002) will be considered here. In the case of the

deterministic model suspended sediment load has the value 80 mg l^{-1} and sediment rate $1.0 \text{ kg m}^{-2} \text{ y}^{-1}$. To calculate the above ratio measurements of mass should be in kg. Thus, the calculation becomes:

$$s_{R/S_L} = (1.0 \text{ kg m}^{-2} \text{ y}^{-1}) / (80.0\text{E-}6 \text{ kg l}^{-1}) = 12500 \text{ l y}^{-1}.$$

This value can either be presented as a *constant* of proportionality or extended to the form of a *normal distribution* to take into account uncertainty and variability in this measurement. For the test considered here a conservative error of approximately 10% has been considered, with the ratio represented by a normal distribution with 1st percentile at 11250 and 99th percentile 13750 l y^{-1} . This is shown in Figure 1.

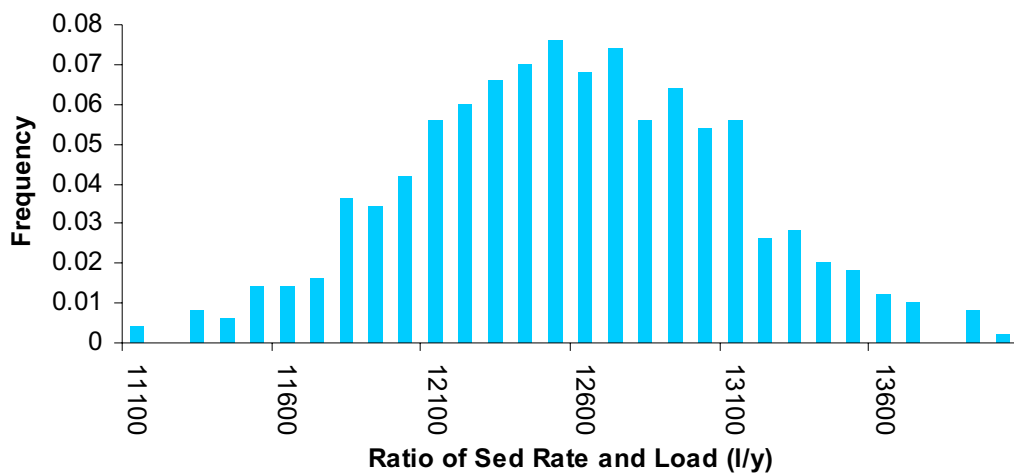


Figure 1 Plot of the distribution ratio of sedimentation rate to suspended sediment load, as calculated by the sampling routine for 500 samples.

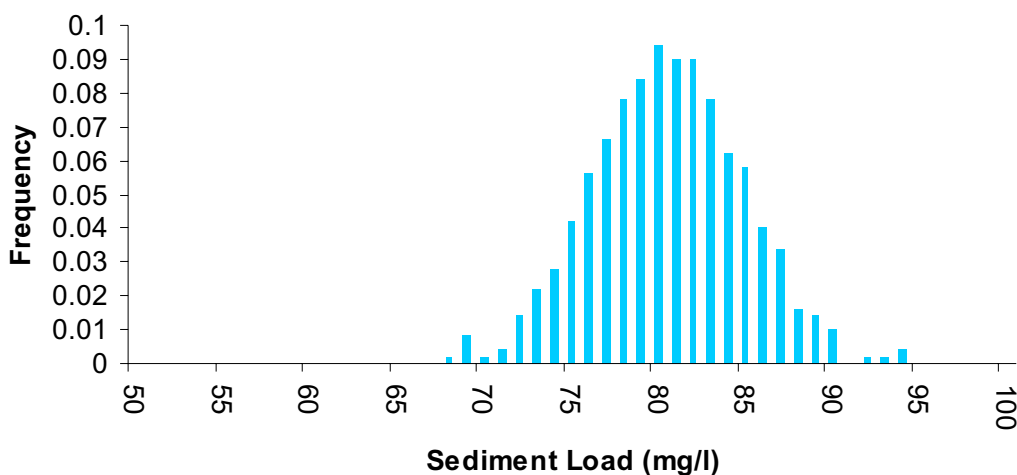


Figure 2 The distribution of suspended sediment load for input in dispersion models as calculated by the sampling routine for 500 samples.

Figure 2 shows the distribution of the suspended sediment load, where a normal distribution between 70 (1st percentile) and 90 mg l⁻¹ (99th percentile) has been applied. When the distributions shown in Figures 1 and 2 are multiplied the sedimentation rate is obtained, as shown in Figure 3.

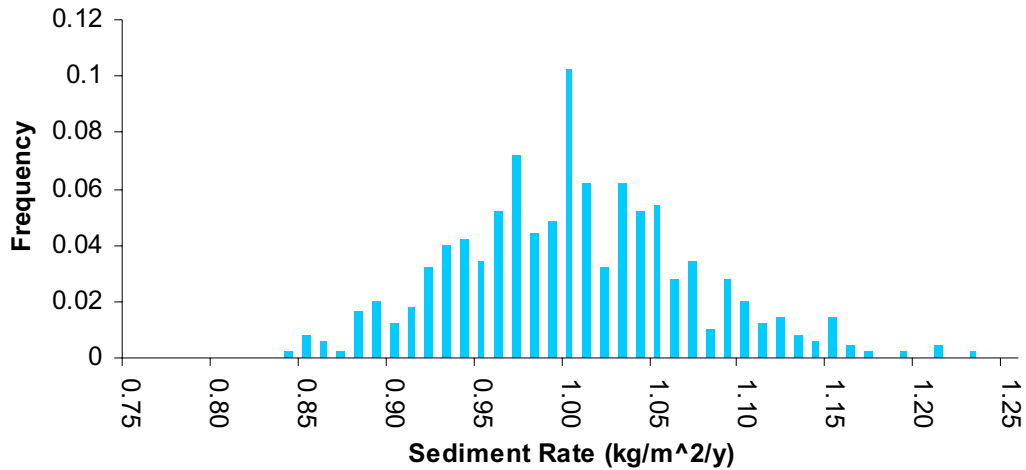


Figure 3 The sedimentation rate calculated by a product of the distributions of Figures 1 & 2. This ensures that it is correlated with sediment load while taking into account uncertainties.

The distributions input to the models behave as expected. In each case the mean values appear to be accurate and the sediment rate distribution incorporates a measure of uncertainty. In order to determine the extent of the correlation, a plot of sediment load against sedimentation rate has been produced and is shown in Figure 4.

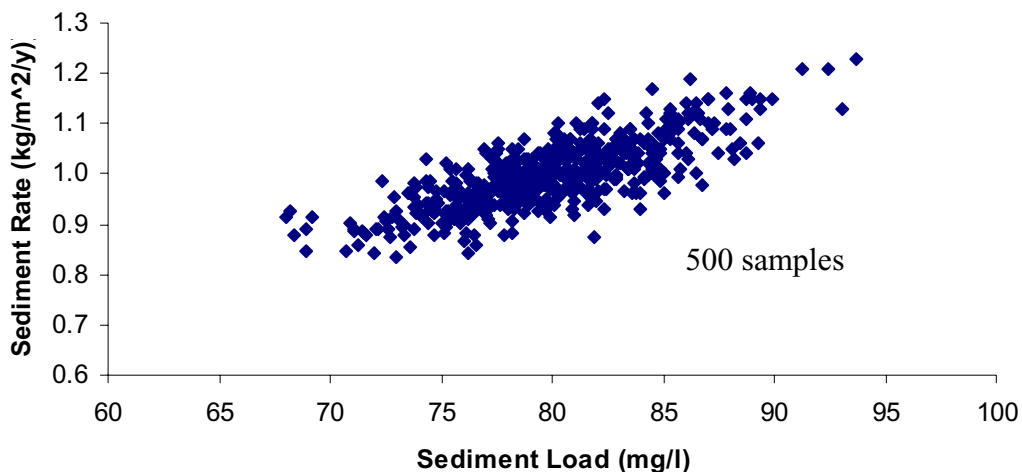


Figure 4 Illustration of correlation between suspended sediment load and sedimentation rate as input into the probabilistic model to calculate radionuclide concentrations in aquatic environments.

This shows that the correlation between these two parameters is reproduced by this technique, with a random variation that can be altered by the user.

This is applicable for both advection-diffusion (WAT) and single compartment (IDLE) modules of the probabilistic models, and can be used in conjunction with either of these.

4. Conclusions

Parameter correlations have been investigated for the probabilistic models described by Grzechnik et al. (2002) and Grzechnik (2002). It has been found that sediment interactions involve a proportionality that must be taken into account between suspended sediment load and sedimentation rate. This parameter correlation has been incorporated into the probabilistic model with allowances for field measurement uncertainty and variability, and its implementation has been tested in this technical note.

In addition, to avoid unrealistic combinations in the final assessment of dose, the raw habits survey data should be applied as collected for each individual.

5. Future Work

Further testing and validation of all modules of the dose assessments model will be conducted in the near future. This includes the validation of the model at various sites to determine performance in a variety of situations, as well as a sensitivity analysis.

In addition to this technical note, an updated addendum for the user guide of Grzechnik (2002) will be produced. This will give the user instructions on how to construct input files for taking correlations into account.

6. Acknowledgements

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7. References

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